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Instructions: Update this file (or recreate a similar one, e.g. in Word) to prepare your answers to the questions. Feel free to add text, equations and figures as needed. Hand-written notes, e.g. for the development of equations, can also be included e.g. as pictures (from your cell phone or from a scanner). ***This lab is graded.*** *and needs to be submitted before the* ***Deadline : Wednesday 27-05-2020 23:59.*** ***You only need to submit one final report for all of the following exercises combined henceforth.*** *Please submit both the source file (*.doc/*.tex) and a pdf of your document, as well as all the used and updated Python functions in a single zipped file called final_report_name1_name2_name3.zip where name# are the team member's last names. Please submit only one report per team!*

Swimming with Salamandra robotica – CPG Model

In this project you will control a salamander-like robot Salamandra robotica II for which you will use Python and the PyBullet physics engine. Now you have an opportunity to use what you've learned until now to make the robot swim and eventually walk. In order to do this, you should implement a CPG based swimming controller, similarly to the architecture shown in Figure 1.

The project is based on the research of [1], [2] and [3]. It is strongly recommended to review [3] and its supplementary material provided on the Moodle. You will be tasked with replicating and studying the Central Pattern Generator (CPG).

NOTE : The session this week will be an introduction to the final project. You will be installing the PyBullet physics engine will and get to familiarise with it. You will start implementing the CPG network which will eventually control the robot.

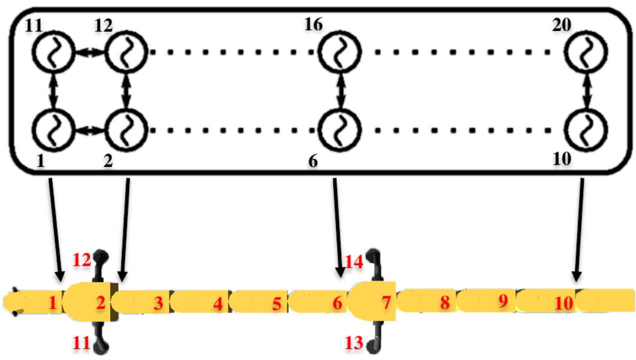

Figure 1: A double chain of oscillators controlling the robot's spine.

Code organization

- **exercise_all.py** - A convenient file for running all exercises. Note you can also run the simulations in parallel by activating `parallel=True`. *You do not need to modify this file.*
- **network.py** - This file contains the different classes and functions for the CPG network and the Ordinary Differential Equations (ODEs). You can implement the network parameters and the ODEs here. Note that some parameters can be obtained from pythonController.py to help you control the values.
- **robot_parameters.py** - This file contains the different classes and functions for the parameters of the robot, including the CPG network parameters. You can implement the network parameters here. Note that some parameters can be obtained from SimulationParameters class

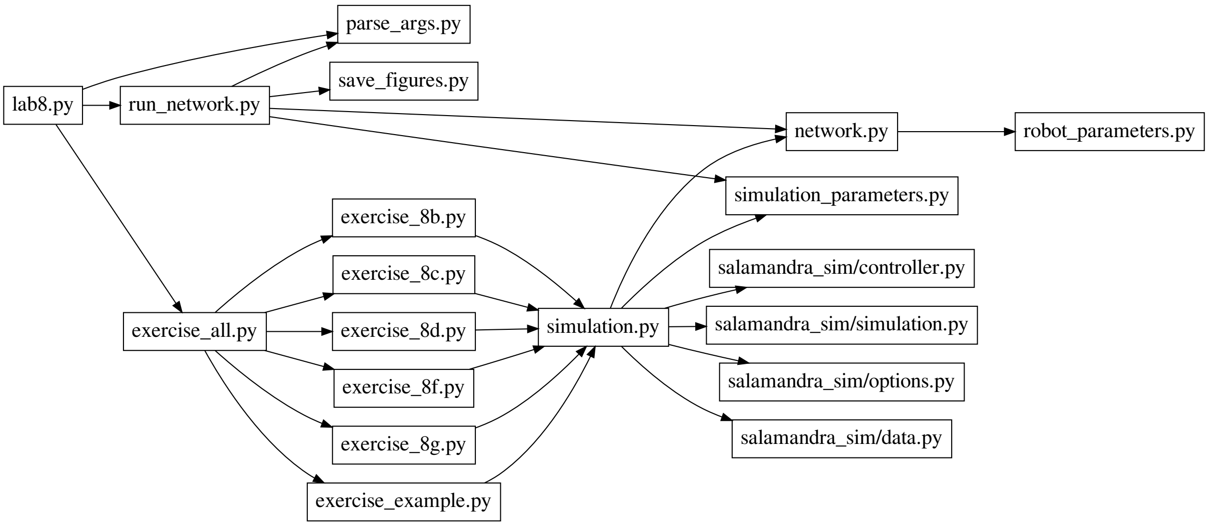

Figure 2: Exercise files dependencies. In this lab, you will be modifying `run_network.py`, `network.py`, `robot_parameters.py` and `simulation_parameters.py`

in simulation_parameters.py and sent by exercise_#.py to help you control the values (refer to example).

- **simulation_parameters.py** - This file contains the SimulationParameters class and is provided for convenience to send parameters to the setup of the network parameters in robot_parameters.py. All the values provided in SimulationParameters are actually logged in cmc_robot.py, so you can also reload these parameters when analyzing the results of a simulation.
- **run_network.py** - By running the script from Python, PyBullet will be bypassed and you will run the network without a physics simulation. Make sure to use this file for question 8a to help you with setting up the CPG network equations and parameters and to analyze its behavior. This is useful for debugging purposes and rapid controller development since running the Pybullet simulation takes more time.
- **parse_args.py** - Used to parse command line arguments for run_network.py and plot_results.py and determine if plots should be shown or saved directly. *You do not need to modify this file.*
- **save_figures.py** - Contains the functions to automatically detect and save figures. *You do not need to modify this file.*
- **test_sr2.py** - This is a file to verify that Pybullet was installed correctly. It is important to make sure that this file works as it will be necessary for the project. *You do not need to modify this file.*
- **exercise_example.py** - Contains the example code structure to help you familiarize with the other exercises. *You do not need to modify this file.*
- **exercise_#.py** - To be used to implement and answer the respective exercise questions. Note that exercise_example.py is provided as an example to show how to run a parameter sweep. Note that network parameters can be provided here.
- **exercise_all.py** - A convenient file for running different exercises depending on arguments. See **lab8.py** for an example on how to call it. *You do not need to modify this file.*
- **simulation.py** A simulation function is provided for convenience to easily run simulations with different parameters. You are free to implement other functions to run simulations as necessary.

- **plot_results.py** - Use this file to load and plot the results from the simulation. This code runs with the original pythonController provided.

Prerequisites

To have all the necessary python packages necessary to complete the final project, do the following.

Clone the latest version of the exercise repository. Navigate to the location of your repository in the terminal and execute the following,

```
>> pip install -r requirements.txt
```

Running the simulation

You can run a simulation example with **exercise_example.py**. You should see the Salamandra robotica model floating on the water. At this point you can now start to work on implementing your exercises.

Questions

The exercises are organized such that you will have to first implement the oscillator network model in run_network.py code and analyze it before connecting it to the body in the physics simulation. Exercise 8a describes the questions needed to implement the oscillator models. After completing exercise 8a you should have an oscillator network including both the spinal CPG and limb CPG. Using the network implemented in exercise 8a you can explore the swimming, walking and transition behaviors in the Salamandra robotica II model using the pybullet simulation and complete exercises 8b to 8g.

8a. Implement a double chain of oscillators along with limb CPG's

Salamandra robotica has 10 joints along its spine and 1 joint for each limb. The controller is defined as

$$\dot{\theta}_i = 2\pi f + \sum_j r_j w_{ij} sin(\theta_j - \theta_i - \phi_{ij}) \tag{1}$$

$$\dot{r}_i = a(R_i - r_i) \tag{2}$$

$$q_i = r_i(1 + cos(\theta_i)) - r_{i+10}(1 + cos(\theta_{i+10})) \text{ if body joint} \tag{3}$$

with θ_i the oscillator phase, f the frequency, w_{ij} the coupling weights, ϕ_{ij} the nominal phase lag (phase bias), r_i the oscillator amplitude, R_i the nominal amplitude, a the convergence factor and q_i the spinal joint angles. For more information, please refer to [3]. Also note how these are the same equations, although Equation (2) has been simplified into a first order ODE in order to simplify the implementation in this project.

1. Implement the double chain oscillator model using the functions `network.py::network_ode`. Test your implementation by running the network using `run_network.py`. For the network parameters check lecture slides (pay attention to different number of segments). You can also find more information in [3] (especially in the supplementary material). You can set all the network parameters in the `robot_parameters.py::RobotParameters`. To facilitate your work, you could start by only implementing the network for the body oscillators ($i = [0, ..., 19]$) and ignoring the leg oscillators ($i = [20, ..., 23]$). Refer to network::RobotState and robot_parameters.py::RobotParameters for the dimensions of the state and the network parameters respectively.

2. Implement the output of your CPG network to generate the spinal joint angles according to equation 3. Implement this in the function `network.py::motor_output`. Verify your implementation in by running the Python file `run_network.py`.

3. Implement a drive and show that your network can generate swimming and walking patterns similarly to [3]. Try to reproduce the plots in 3 and 4

   Hint: The state for the network ODE is of size 48 where the first 24 elements correspond to the oscillator phases θ_i of the oscillators and the last 24 elements correspond to the amplitude r_i. The initial state is set in the init of network.py::SalamanderNetwork.

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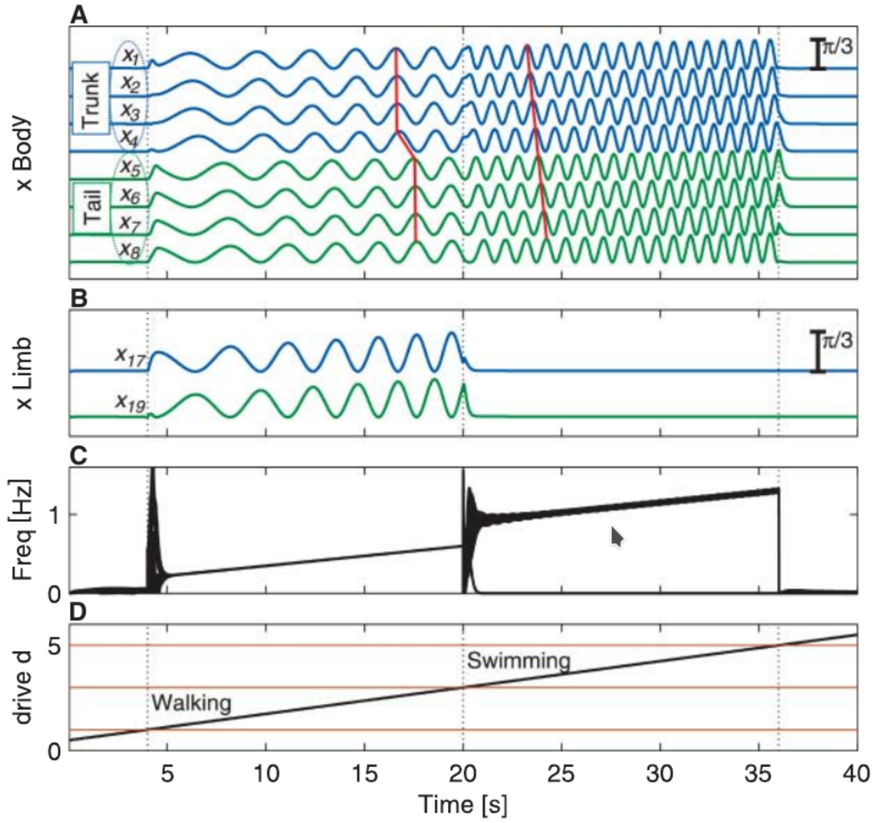

Figure 3: Oscillator patterns from [3], see [3] for details

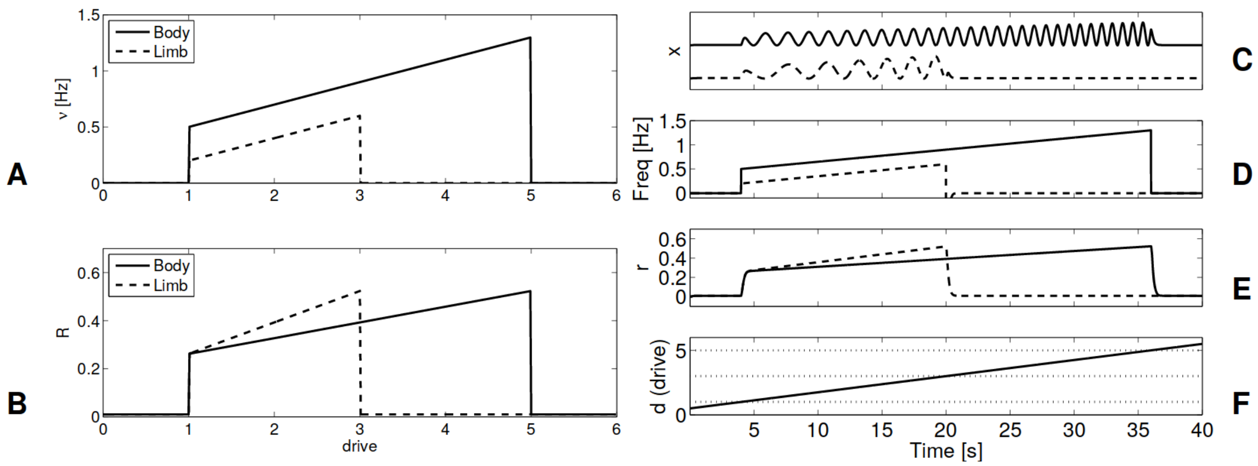

Figure 4: Oscillator properties from [3] supplementary material, see [3] for details

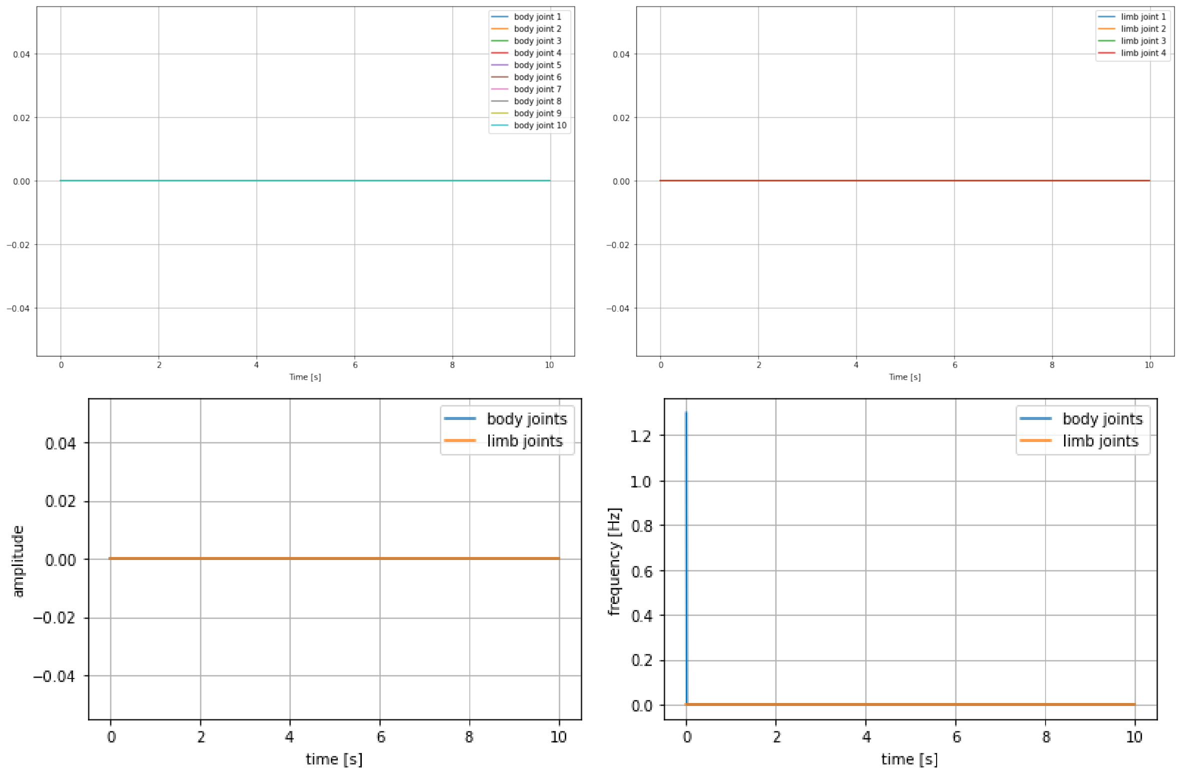

Figure 5: Oscillation properties of walking with drive=0.5 in our simulation

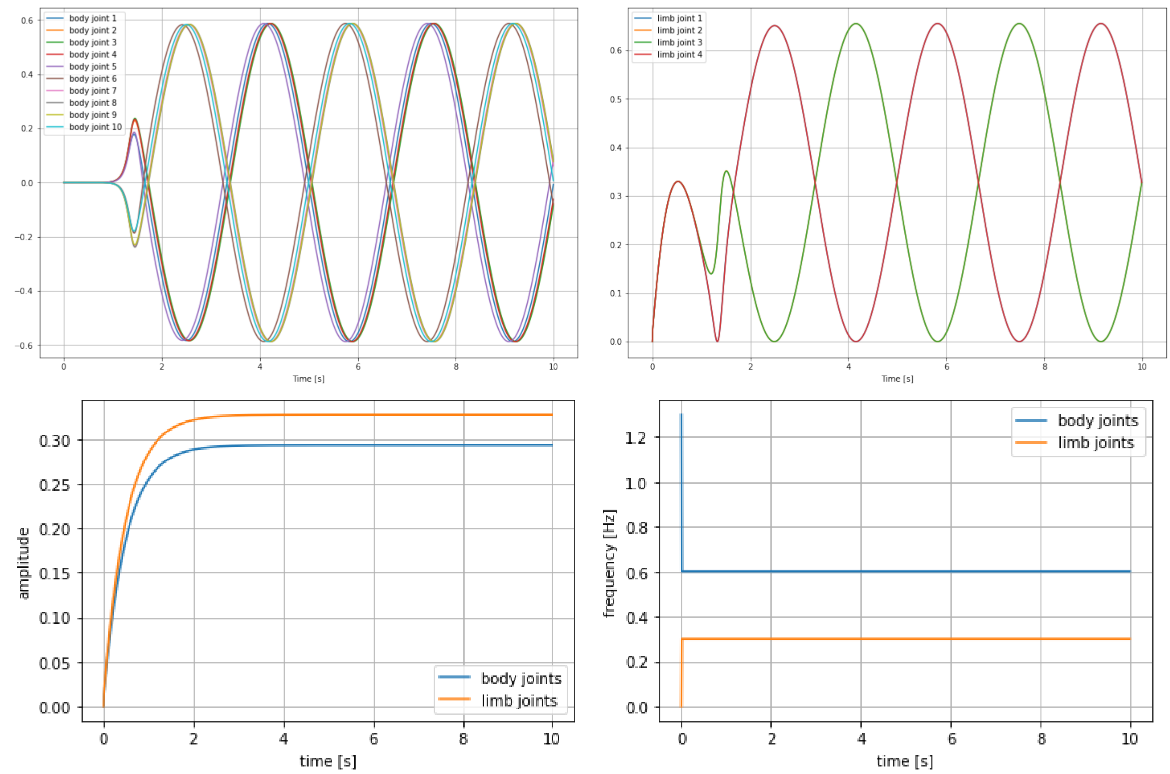

Figure 6: Oscillation properties of swimming with drive=1.5 in our simulation

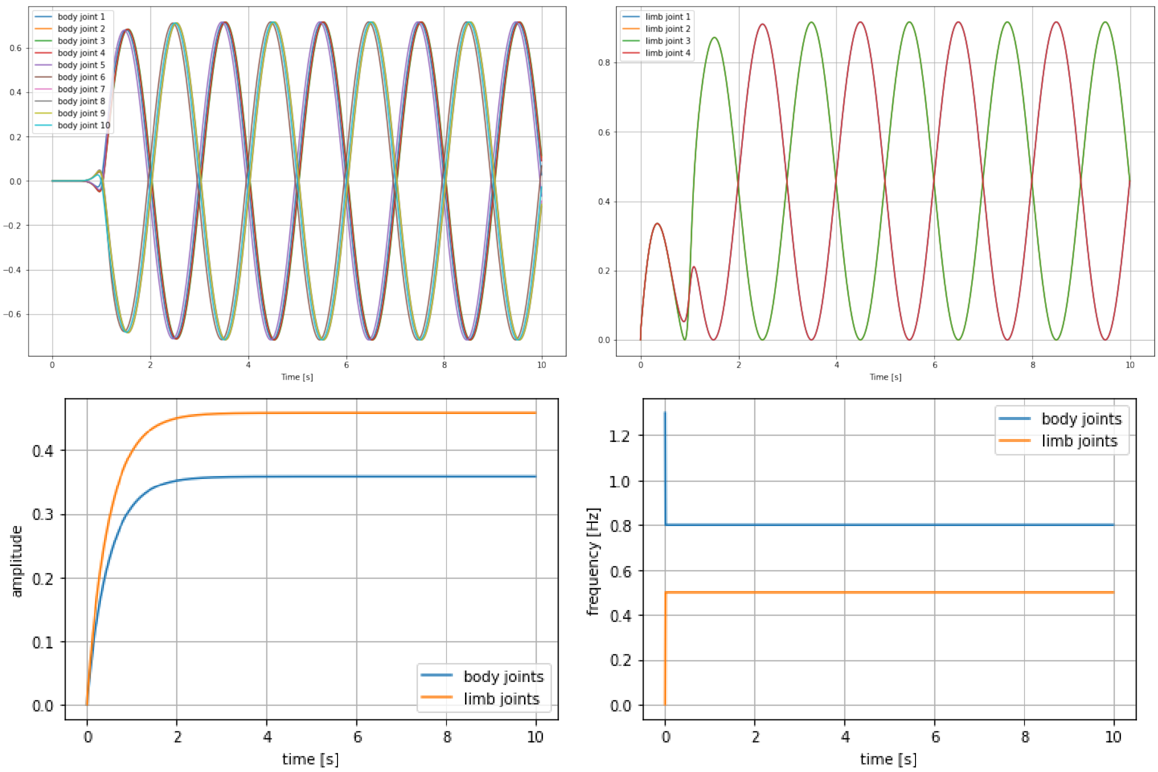

Figure 7: Oscillation properties of swimming with drive=2.5 in our simulation

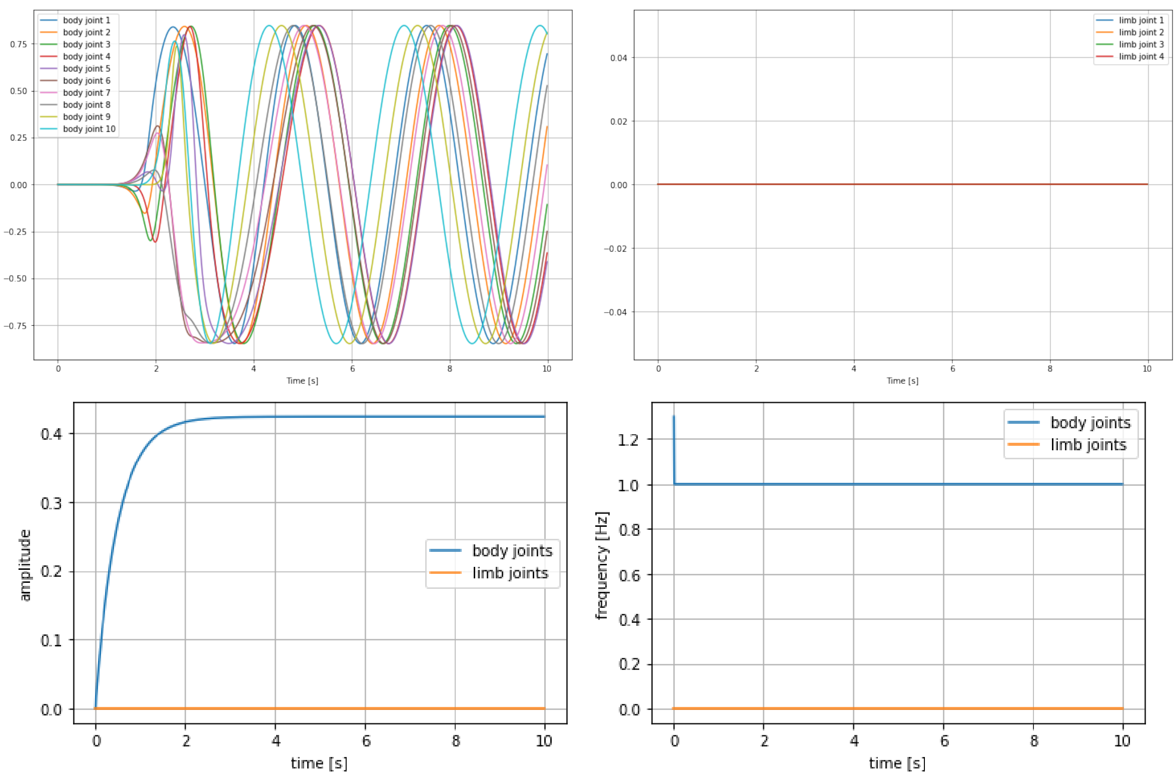

Figure 8: Oscillation properties of walking with drive=3.5 in our simulation

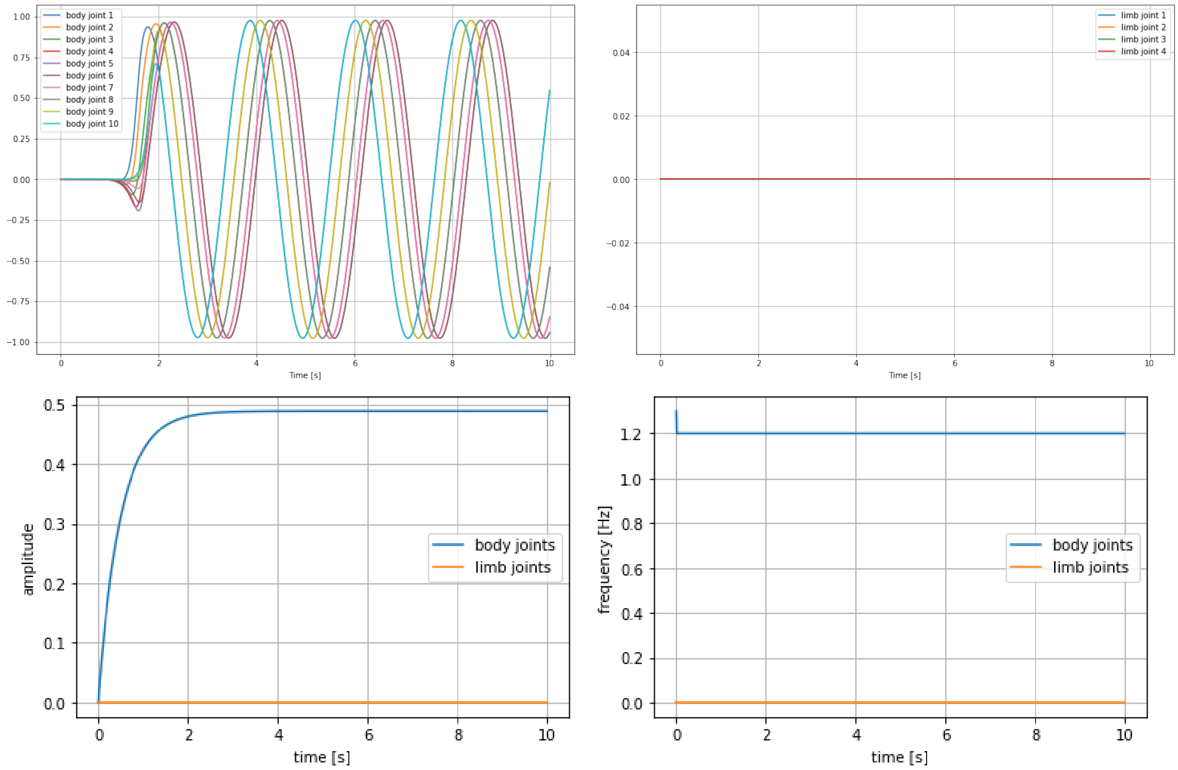

Figure 9: Oscillation properties of walking with drive=4.5 in our simulation

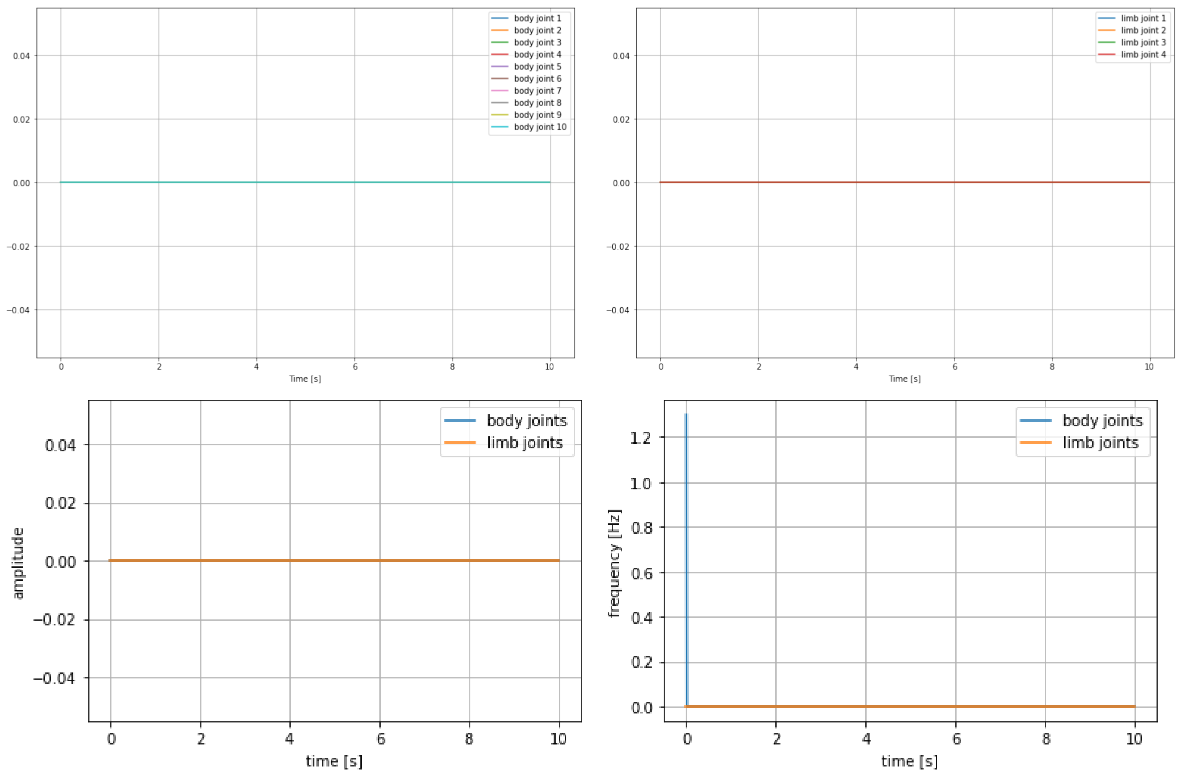

Figure 10: Oscillation properties of walking with drive=5.5 in our simulation

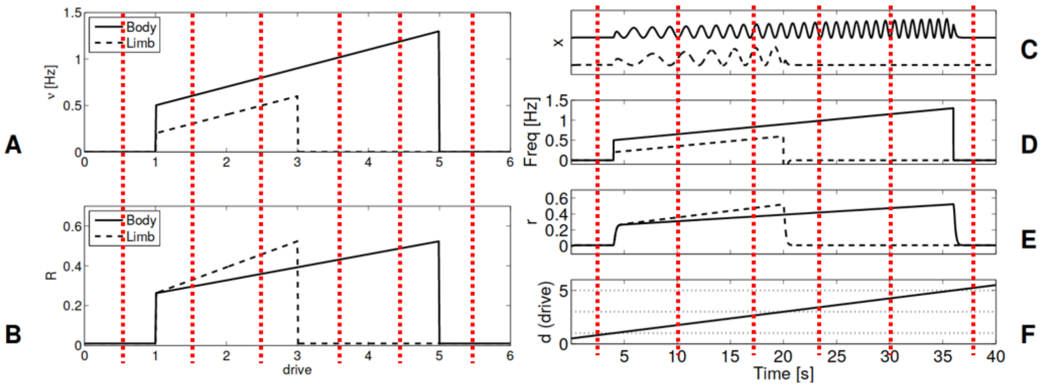

Figure 11: Highlight of oscillation properties with drive=0.5, 1.5 , 2.5 , 3.5 , 4.5, 5.5 in complementary material

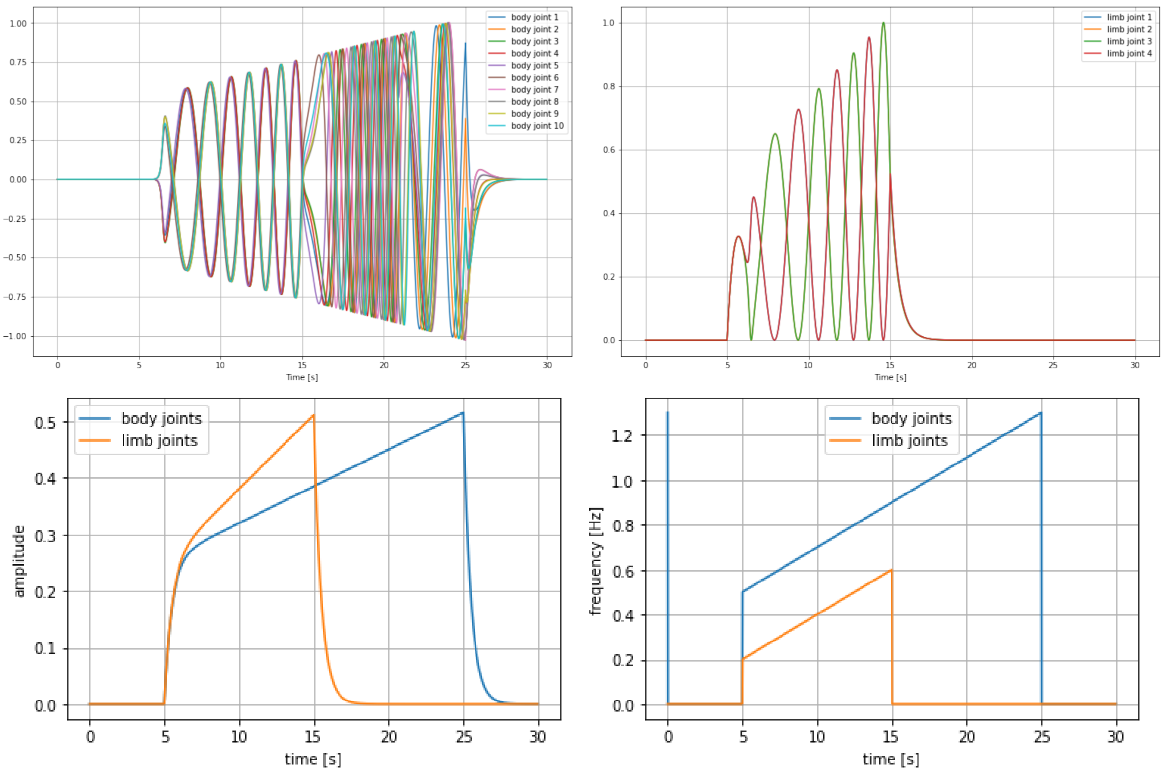

Figure 12: Oscillation properties when drive increases from 0 to 6 linearly within 30 seconds.

Here we visualize the oscillator performance with different constant values (Figure 5-10) for steady observation, and changing drive (Figure 12) similar to reference plot.

Picture 5-10 show the transition from walking to swimming with different drives. When walking, axial produces standing waves. With the same descending signal, the phase of the output of the four body joints in trunk is the same and that in the tail is also the same but the difference between the the phase of body joint in trunk and that in tail is 180 degrees (Figure 3A). When swimming, axial produces traveling waves, body joints remain constant phase lag along the spinal cord and the relative phase lag between head and tail is usually 100 percentage (Figure 3A).

Figure 4 (left) shows that the limb oscillators oscillate with lower frequencies than body oscillators at the same level of tonic drive d and saturate at with lower drive. While the limb oscillators converge to a higher amplitude than body oscillators at the same level descending drive signal. In our plots all oscillators are driven by the same drive d. Figure 4 (right) gives us the information that the movement of body and limb oscillators (uncoupled) when the drive increases with time. When the drive is lower than the threshold (1), there are no oscillations for both limb and body. When the drive is the larger than the thresholds, slow oscillations can be seen. When the drive d increases from 1.5 to 2.5 (Figure 6-7), the amplitude of both body and limb joints increase and the oscillations of both joints eventually converge to a stable state. We can see from the lower right corner of each graph that body and limb joints frequencies are also increasing but the former is always larger.

Further increasing the drive d to 3.5 and it's in a swimming pattern, it surpasses the upper threshold of limb oscillators and they are deactivated and we can see the 0 frequencies and amplitudes. While the amplitude and frequency of the body joints continue to increase, and the phase difference all body joints at the same time also increase with respect to the previous case. If we further increase the drive to 4.5, it maintains the same trend of variation as in the case of drive d is 3.5.

When the drive d is lower than the lowest threshold of of the body joints (same of the threshold of the limb joints), the body joints and limb joints do not activate(Figure 5). When the drive d is greater than the highest threshold of of the body joints (and, of course,d has already surpassed the highest threshold of the limb joints now), the body joints and limb joints are all at still(Figure 10).

All the above cases of different drive d are marked in Figure 11. And a smooth continuous variation trend of the amplitude and frequency of both body and limb joints with respect to the variation of drive d are shown in Figure 12. Please note that the body and limb oscillators are decoupled. Just by changing the magnitude of the descending signal d (one dimensional signal), we realized the modulation of the amplitude and frequency of all limb and body joints, that is, the modulation of the gaits, speed etc (very large dimension).

8b. Effects of amplitude and phase lags on swimming performance

Now that you have implemented the controller, it is time to run experiments to study its behaviour. How does phase lag and oscillation amplitude influence the speed and energy? Use the provided exercise_8b.py to run a grid search to explore the robot behavior for different combinations of amplitudes and phase lags. Use plot_results.py to load and plot the logged data from the simulation. Include 2D/3D plots showing your grid search results and discuss them. How do your findings compare to the wavelengths observed in the salamander?

- **Hint 1:** To use the grid search, check out the example provided in exercise_example.py. This function takes the desired parameters as a list of SimulationParameters objects (found in simulation_parameters.py) and runs the simulation. Note that the results are logged as simulation_#.h5 in a specified log folder. After the grid search finishes, the simulation will close.
- **Hint 2:** An example how to load and visualise grid search results is already implemented in plot_results.py::main(). Pay attention to the name of the folder and the log files you are loading. Before starting a new grid search, change the name of the logs destination folder where the results will be stored. In case a grid search failed, it may be safer to delete the previous logs to avoid influencing new results by mistake.
- **Hint 3:** Estimate how long it will take to finish the grid search. Our suggestion is to choose wisely lower and upper limits of parameter vectors and choose a reasonable number of samples. To speed-up a simulation, make sure to run the simulation in fast mode and without GUI as shown in exercise_example.py or using `-fast` and `-headless` in the Python command line (Use `-help` for more information).
- **Hint 4:** Energy can be estimated by integrating the product of instantaneous joint velocities and torques. Feel free to propose your own energy metrics, just make sure to include the justification.

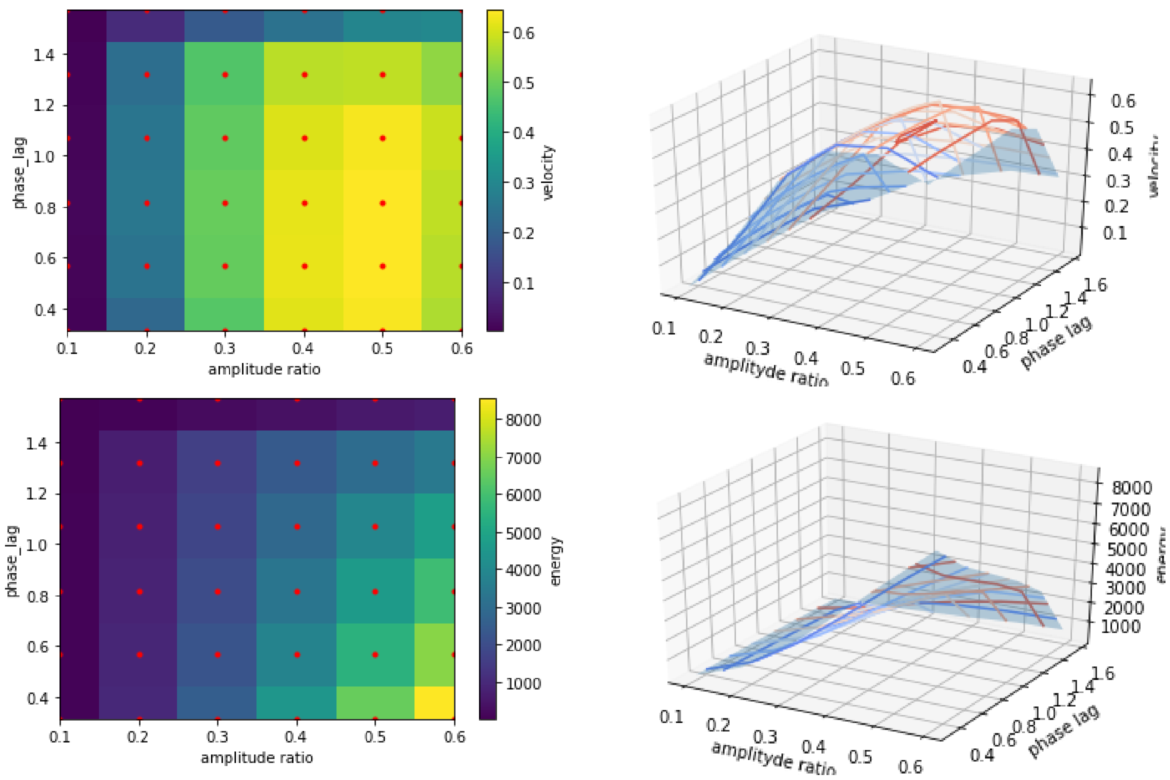

Figure 13: Grid search of phase lag and oscillation amplitude, and their influence on speed (up) and energy (down)

In swimming state, the limb of the salamander is deactivated, meaning that it will not affect the whole body. The amplitude and the phase lag are referred to the body oscillators (axial).

Figure 13 is the result of grid search. If we look at the diagram in the upper left corner of the Figure 13, we can find that the smaller the phase lag, the greater the velocity in the case of the same amplitude. When the phase lag is constant, the velocity increases with the increase of the amplitude. However,the velocity achieves the maximum when the amplitude reaches 0.5, and it will decrease with the increase of the amplitude after this point.

In the analysis, we estimate the energy by integrating the product of instantaneous joint velocities and torques. In the lower left corner of Figure 13 one can observe how the energy changes with the variation of phase lag and amplitude. The smaller the phase lag, the greater the energy under the same amplitude level. In addition, the larger the amplitude, the greater the energy when the same phase lag appears.

Generally speaking, salamander tends to move in a less energetic manner, where the speed is not necessarily the largest. In our phase lag range, increasing the phase lag can make the energy smaller. When it meets a predator, it moves in the fastest way. There are three lattice corresponding to the parameters leading to the fastest velocity, but the energy corresponding to the parameters of the three lattice is different. This paved a way for us to reduce the energy at the same speed. We can choose the parameter corresponding to the smallest energy which can still keep a good speed.

Traveling wave has constant phase lag along the spinal cord and the relative phase lag between head and tail is usually 100 percent for any frequency, meaning that the body always makes one complete "S" shaped undulation and the wavelength is constant one body length. While the time needed to complete the entire cycle (traveling wave propagates from the head to tail or from the tail to head) will increase with the increase of the phase lags. In faster swimming, bursts have higher amplitude, meaning that the muscles will contract more (higher firing rates). In this condition, the bursts are faster, meaning that the bursting frequency is higher.

8c. Amplitude gradient

1. So far we considered constant undulation amplitudes along the body for swimming. Implement a linear distribution of amplitudes along the spine, parametrized with two parameters: amplitudes of the first (Rhead) and last (Rtail) oscillator in the spine (corresponding to the first and last motor). To do so, you can add a parameter amplitudes=[Rhead, Rtail] in simulation_parameters.py::SimulationParameters. Don't forget to modify robot_parameters.py::RobotParameters::set_nominal_amplitudes() and interpolate the amplitude gradient between values Rhead and Rtail within the function. Note that you can then provide this amplitudes parameter from exercise_8c.py.

2. Run a grid search over different values of parameters Rhead and Rtail (use the same range for both parameters). How does the amplitude gradient influence swimming performance (speed, energy)? Include 3D plots showing your grid search results. Do it once, for frequency 1Hz and total phase lag of 2π along the spine.

3. How is the salamander moving (with respect to different body amplitudes)? How do your findings in 2) compare to body deformations in the salamander? Based on your explorations, what could be possible explanations why the salamander moves the way it does?

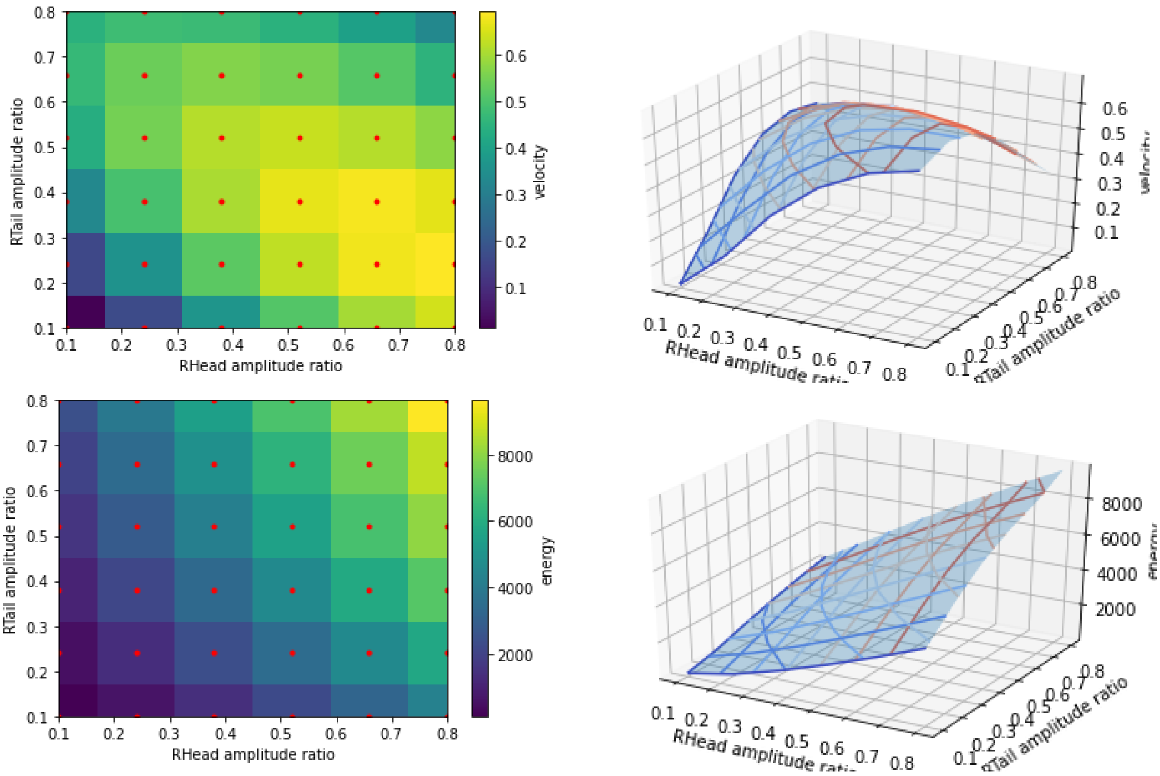

Figure 14: Grid search of amplitudes of the first and last oscillator, and their influence on speed (up) and energy (down)

The results of grid search are shown in Figure 14. From the upper left corner of the Figure 14 we can observe that there is a certain head amplitude corresponding to the maximum velocity at each fixed tail amplitude. Before this point, the velocity increases with the increase of head amplitude. But the inverse trend appears after this point. The same phenomenon is observed when we fix the head amplitude and vary tail amplitude. If we connect the points corresponding to the maximum velocity at different amplitudes, we can find that the two amplitude coordinates of the maximum velocity are highly correlated, almost a straight line. The the velocity is symmetrically arranged on both sides of the line. The upper right corner of Figure 14 also shows that the maximum velocity occurs where the surface gradient is 0.

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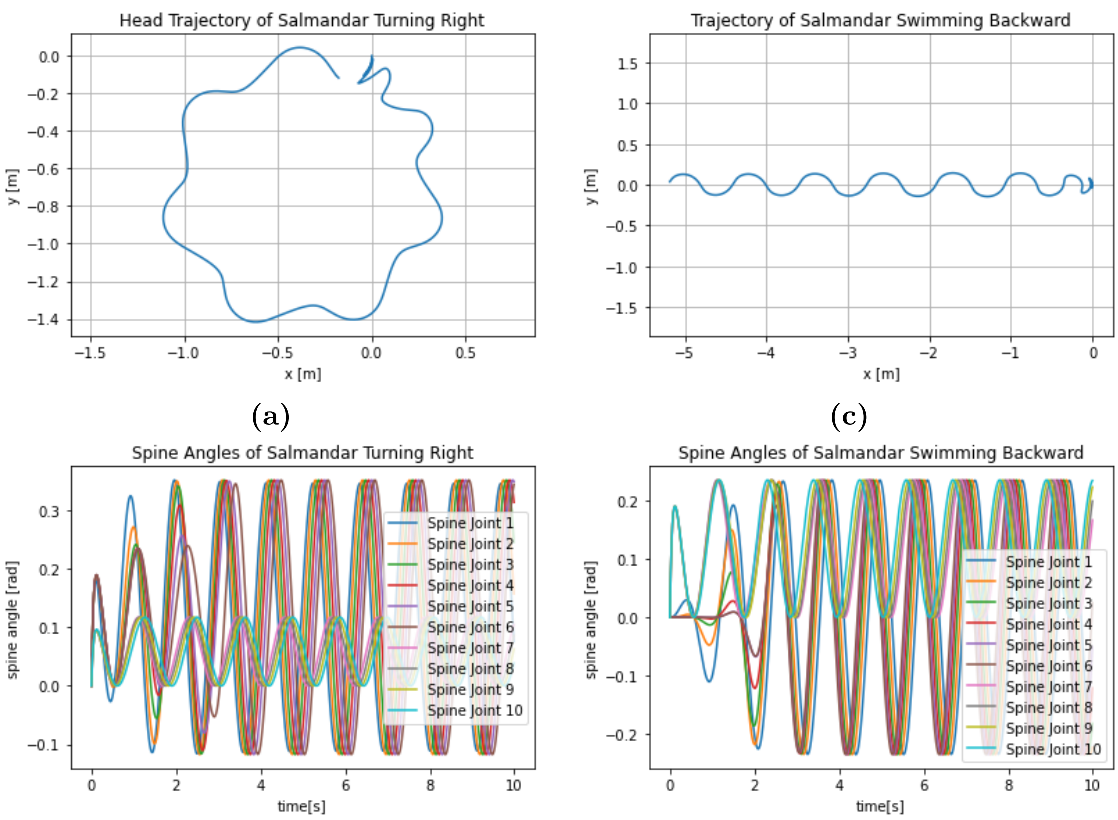
The lower left corner of Figure 14 also shows that the energy increases with the increase of both the amplitude of the head or tail. This paves a way reduce energy by reducing both amplitudes. The upper left corner of the Figure 14 illustrates that the point (parameters of both tail and head amplitudes) of maximum velocity does not necessarily correspond to the point of maximum energy, because the amplitude of tail corresponding to the maximum velocity is relatively small.

In the motion of a true salamander, the amplitude of one side of the whole body is increased from head to tail. This makes the head more stable and helps the visual system to observe and track prey as well as navigate. The tail, especially the part without limbs, can move with a much larger amplitude because there is no coupling with the limbs. Decreasing the head amplitude and increasing the tail amplitude can increase the speed. While reducing the amplitude of the head with high mass and maintaining the high amplitude of the tail with low mass is beneficial to save energy.

8d. Turning and backwards swimming

1. How do you need to modulate the CPG network (network.py) in order to induce turning? Implement this in the model and plot example GPS trajectories and spine angles.
2. How could you let the robot swim backwards? Explain and plot example GPS trajectories and spine angles.



(a) **(c)** **(b)** **(d)**

Figure 15: Spine angles plots with time along with position coordinates evolution for both turning right and swimming backwards.

To achieve turning (in our case, for instance, a right turn), one side of the spine should be triggered more than the other side. This can be easily realized through adding a turning parameter λ to the amplitude of both sides of joints. The amplitudes of the joints can be modified as $r_i \times (1 + \lambda)$ and $r_i \times (1 - \lambda)$ so that we can set the value of λ to have a biased joints amplitudes on 2 sides for a turning motion. In our simulation, we set λ to 0.5 so that the spine movements always have a positive amplitude range. The phenomenon can be seen in Figure 15-(b) where the spine joint angles amplitudes are clearly varying in the positive direction only. This offset will cause the turning to the side receiving the larger amplitude variations.

Changing the intrinsic frequency of some oscillators of axial leads to changes in the phase lags globally. In moving forward, the first spine joint nearest to the head of the salamander has a phase lead over the other ones, and every subsequent joint leads the one after it, until the last joint at the tail of the salamander is reached. When a negative phase lag is applied, the first joint to jump into action would be Joint 10, as seen in Figure 15-(d). Then the previous joint is triggered, followed by the one before it, until reaching Joint 1 near the head. This will cause the salamander to start moving backwards. In simpler terms, simply reversing the directions (phase lag) of the joints for moving forward will cause the backward movement. Also, it can be observed through spine movements (d) that the tail joint leads the waves.

To better show our turning and backward moving trend, we also recorded 2 videos and attached them in the folder.

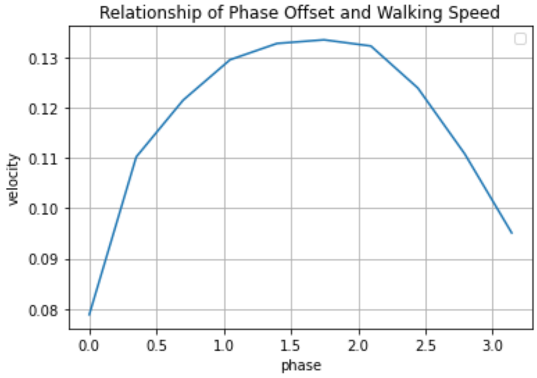
8e. Cancelled

8f. Limb – Spine coordination

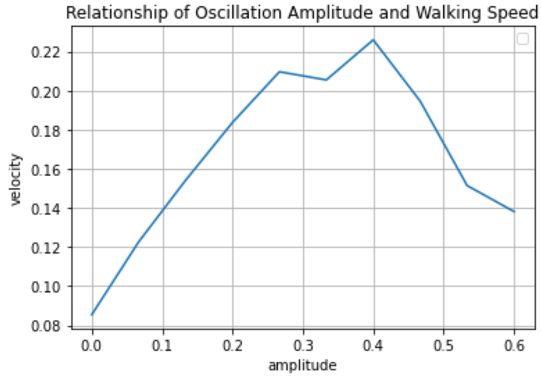
In this next part you will explore the importance of a proper coordination between the spine and the limb movement for walking.

1. Change the drive to a value used for walking and verify that the robot walks
2. Analyze the spine movement: What are your phase lags along the spine during walking? How does the spine movement compare to the one used for swimming?
3. Notice that the phase between limb and spine oscillators affects the robot's walking speed. Run a parameter search on the phase offset between limbs and spine. Set the nominal radius R to 0.3 [rad]. Include plots showing how the phase offset influences walking speed and comment the results. How do your findings compare to body deformations in the salamander while walking?
4. Explore the influence of the oscillation amplitude along the body with respect to the walking speed of the robot. Run a parameter search on the nominal radius R with a fixed phase offset between limbs and the spine. For the phase offset take the optimal value from the previous sub-exercise. While exploring R, start from 0 (no body bending).

Include plots showing how the oscillation radius influences walking speed and comment on the results.



(a)



(b)

Figure 16: Variation of walking speeds as a function of changing phase offsets and oscillation amplitudes.

During walking, a well-established in-sync coordination between the limbs and the spine is very important in achieving an optimal outcome when it comes to moving faster. Therefore, the element of phase lag introduced between the spine and the limbs becomes an important parameter that can be the difference between walking with maximum speed or maybe not walking at all. Here we set phase lag 0.2π between neighbour joints. The expected spine movement should conform to Figure 6 and Figure 7.

In swimming, the limbs are no longer needed while the axial part becomes important in propagating the salamander in water. Having the whole body (from head to tail, i.e. all joints 1 to 10) be in oscillation becomes what is important in this process. Therefore, a phase lag between the spine and limb joints is no longer an important parameter. Rather, the phase lag along all the body spine joints themselves becomes crucial in moving while swimming. To move forward in this case, joint 1 must begin oscillating, followed by joint 2 after a very small delay, and so on until the last joint 10 is reached. This translates into having a propagating wave shape exhibited by the salamander body. This propagating wave allows the salamander to gain mobility in water.

In walking standing wave there is no phase lag in both head part and the tail part of the spine while the head and tail have 2 difference of phase. In this case the phase offset between axial and limb is important. The maximum speed occurs when the body axial bends on the side of which the limbs stench forward (phase of the body). The bending curvature of the axial (amplitude of body oscillators) also influences the speed. While in swimming there is constant phase lags from the head to tail or from the tail to head. The total phase lag for both swimming and walking is 2.

What follows will be comments on phase offset and oscillation amplitudes effects on the walking speed of the salamander. The velocity here is calculated through the final head joint's distance with respect to overall time.

In Figure 16-(a), generally the same velocity curve behavior is exhibited for a change in the phase offset given a fixed amplitude. An increase in the phase offset between body axial and limb of the salamander aids the walking process and allows for an increase in velocity. This increase reaches its maximum for a phase offset of around 1.4 rad. Afterwards, the velocity decreases with increase in phase.

In Figure 16-(b), it is expected that for a fixed phase offset, as the amplitude of the body oscillations increases, the walking speed also increases. However, this is true up to a certain limit in amplitude (here around 0.4), after which the velocity decreases. This is expected since very big and out of control oscillations start to interfere with the limb movement, rendering it ineffective.

Both figures show the importance of having a wave body motion along with the motion of the limbs to achieve higher speeds while walking. This is all under the condition that the phase offset and the amplitude of the oscillations do not bypass their respective threshold values providing highest efficiency for walking at higher speeds. Passing this threshold will put the body in an out-of-sync state with the limbs and will, in fact, render the walking process less efficient (having much lower speeds).

8g. Land-to-water transitions

1. In this exercise you will explore the gait switching mechanism. The gait switching is generated by a high level drive signal which interacts with the saturation functions that you should have implemented in 8a. Implement a new experiment which uses the x-coordinate of the robot in the world retrieved from the GPS sensor reading (Check simulation.py for an example on how to access the gps data). Based on the GPS reading, you should determine if the robot should walk (it's on land) or swim (it reached water). Depending on the current position of the robot, you should modify the drive such that it switches gait appropriately.
2. Run the Pybullet simulation and report spine and limb angles, together with the x coordinate

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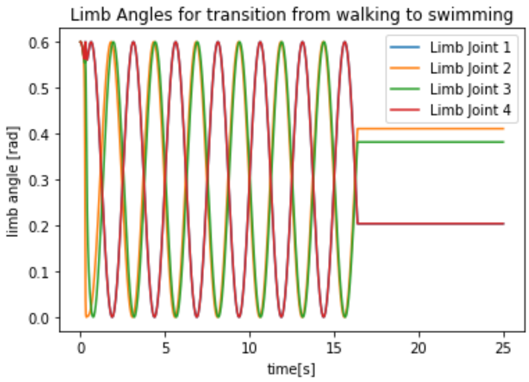
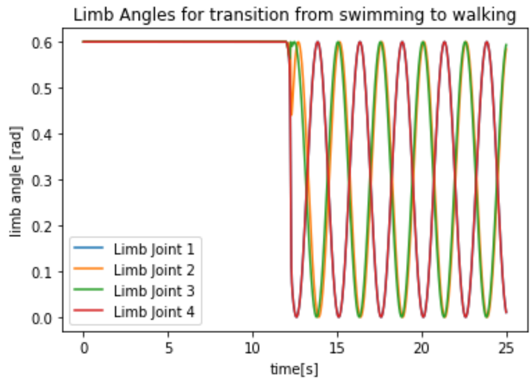
from the GPS signal. Record a video showing the transition from land to water and submit the video together with this report.

3. (BONUS) Achieve water-to-land transition. Report spine and limb angles, the x-coordinate of the GPS and record a video.

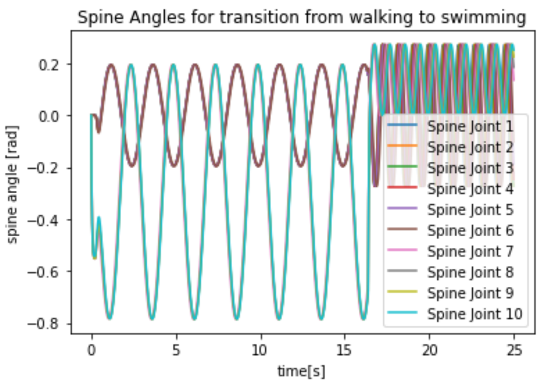
Hint: Use the record options as shown in exercise_example.py to easily record videos.



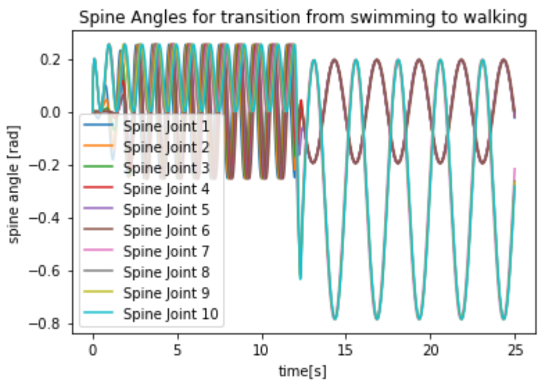
(a)



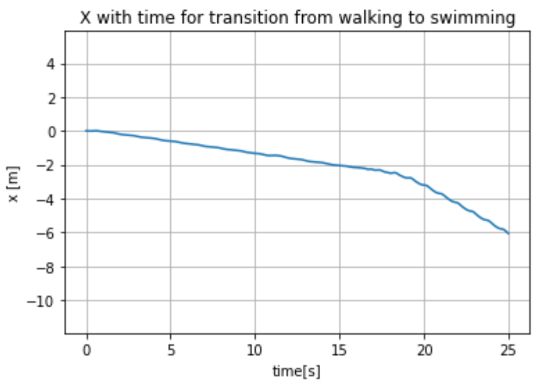
(d)



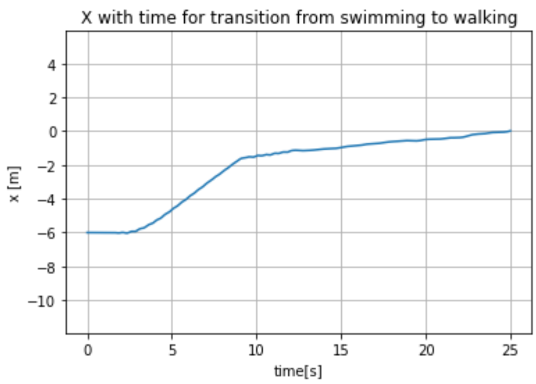
(b)



(e)



(c)



(f)

Figure 17: Plots for limb angles, spine angles, and x-position evolution with time when transitioning from walking to swimming. Same plots are shown also for the transition from swimming to walking.

Increasing the drive the motion of salamander shifted from walking to swimming and there is no overlap between the drive frequency for swimming and walking. The transition can be realized through changing the drive and other parameters that can directly help change the motion pattern. The condition for transition is based on the x-coordinate of the robot's head joint position. In our simulation, the land-to-water transition is realized by changing drive from 2 to 4 when head x position is detected less than -2.2, while water-to-land transition is realized by changing drive from 3.5 to 2 when head x position is detected larger than -1.2.

As expected, in Figure 17-(a), the four limb joints behave in an oscillatory manner in while walking forward. Once the limb joints angles get fixed to a constant value, this is when swimming starts, as swimming does not require the motion of the limbs. In Figure 17-(b), the transition is clear at the same time stamp seen in limb angles figure before. These observations all conform to the analysis of swimming and walking pattern in previous sections.

For a transition from swimming to walking, the exact opposite of what was shown earlier occurs. This can be clearly seen in Figure 17-(d) and Figure 17-(e).

Besides, our group also tried another method for the transition based on the x-coordinate of different joints. Based on more precise location of water-land border, we can assign different motion parameters to different joints. For example, the robot has half the body on land while the other half in water during water-to-land transition. The front joints will have parameters for walking pattern while the tail joints are assigned with parameters for swimming pattern. However, the transition strategy may lead to turning over due to lack of physical coordination. Therefore, the transition by previous simpler method has a more robust performance, and in the report we only visualize the performance of that method.

The videos of land-to-water and water-to-land transition have been recorded and attached in the folder.

References

[1] A. Crespi, K. Karakasiliotis, A. Guignard, and A. J. Ijspeert, "Salamandra robotica ii: An amphibious robot to study salamander-like swimming and walking gaits," _IEEE Transactions on Robotics_, vol. 29, pp. 308–320, April 2013.

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[3] A. J. Ijspeert, A. Crespi, D. Ryczko, and J.-M. Cabelguen, "From swimming to walking with a salamander robot driven by a spinal cord model," _science_, vol. 315, no. 5817, pp. 1416–1420, 2007.