CODING PROJECT
PH 549: Physics of Biological Systems

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1 Overview

Antal et al. (2007, henceforth referred to as 'the paper') aims to model microtubule growth using a simple kinetic model. The model makes use of the following processes ((1) Attachment, (2) Conversion, and (3) Detachment):

$$\begin{aligned} |\cdots +\rangle &\Rightarrow |\cdots + +\rangle \qquad \text{rate } \lambda \\ |\cdots -\rangle &\Rightarrow |\cdots - +\rangle \qquad \text{rate } p\lambda \end{aligned} \tag{1}$$

$$|\cdots + \cdots\rangle \Rightarrow |\cdots - \cdots\rangle \qquad \text{rate } 1 \tag{2}$$

$$|\cdots -\rangle \Rightarrow |\ldots\rangle \qquad \text{rate } \mu \tag{3}$$

where $+$ and $-$ represent the GTP and GDP monomer units respectively.

The main results that I have replicated are as follows[1]:

1. Microtubule Length as a function of time and the parameters (λ, p, μ). (Figure 1 of the paper)
2. Distribution of the GTP cap length (Figure 4 of the paper)
3. Distribution of GTP islands in the microtubule (Figure 5 of the paper)
4. Phase Diagrams of microtubule growth (Figure 6 of the paper)

I numerically simulated the system using the BKL algorithm (reviewed in, for example, Andersen et al., 2019). However no particular scheme was mentioned in the paper.

Once the numerical simulation is implemented, replicating Figures 1, 4 and 5 is straightforward (with any minor changes made in the calculations mentioned in the respective Figure captions). However, for Figure 6 in the paper, an alternate approximation was employed, which underestimates the actual phase boundary, which is discussed in Section 3

2 Figures

Figures on top on each page is the original and the bottom figure is the replicated version.

[1] Figures 2 and 3 are cartoons to explain the model and have not been reproduced here

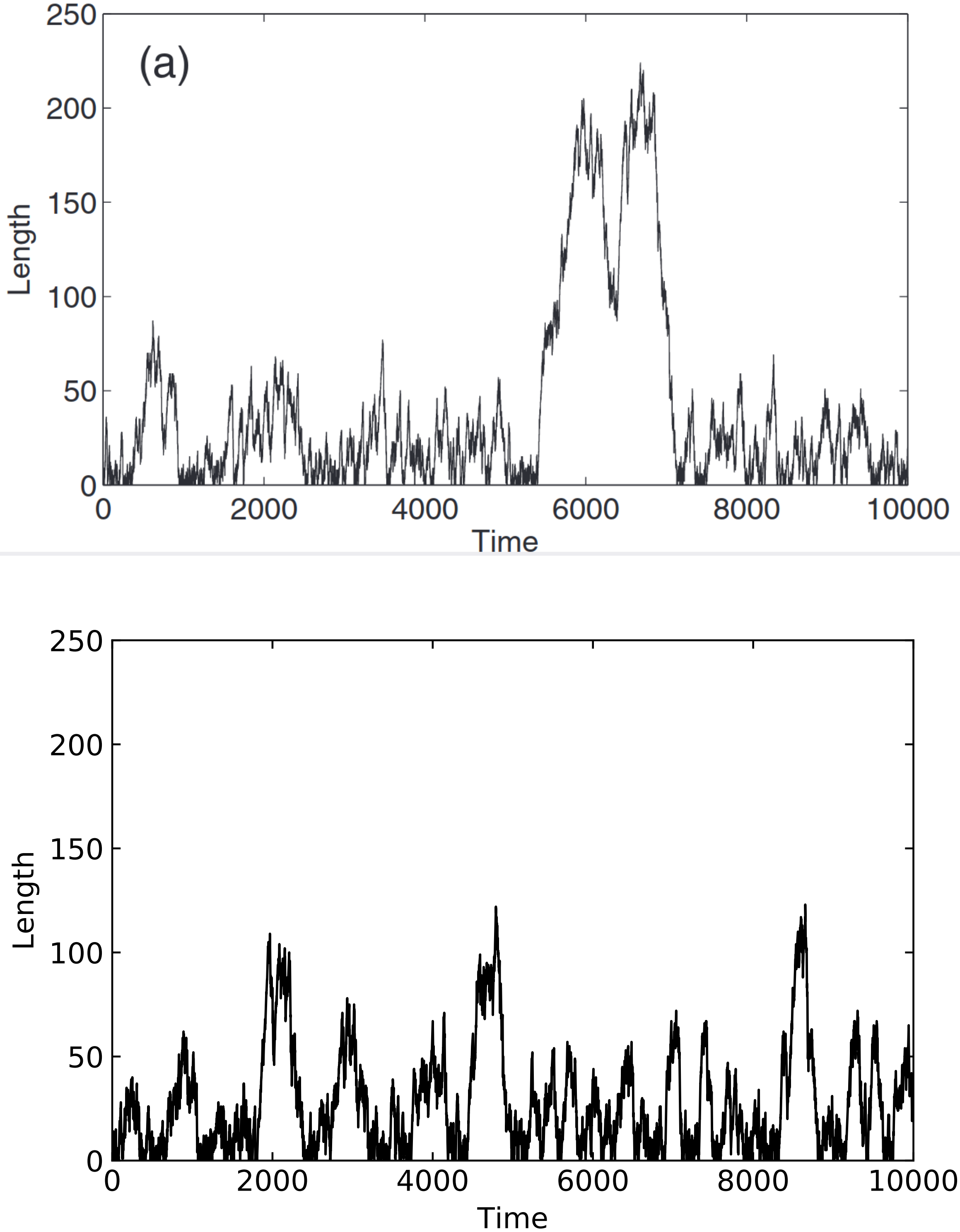


Figure 1
Microtubule growth for $\lambda = 1.4$, $p = 1$, $\mu = 5$

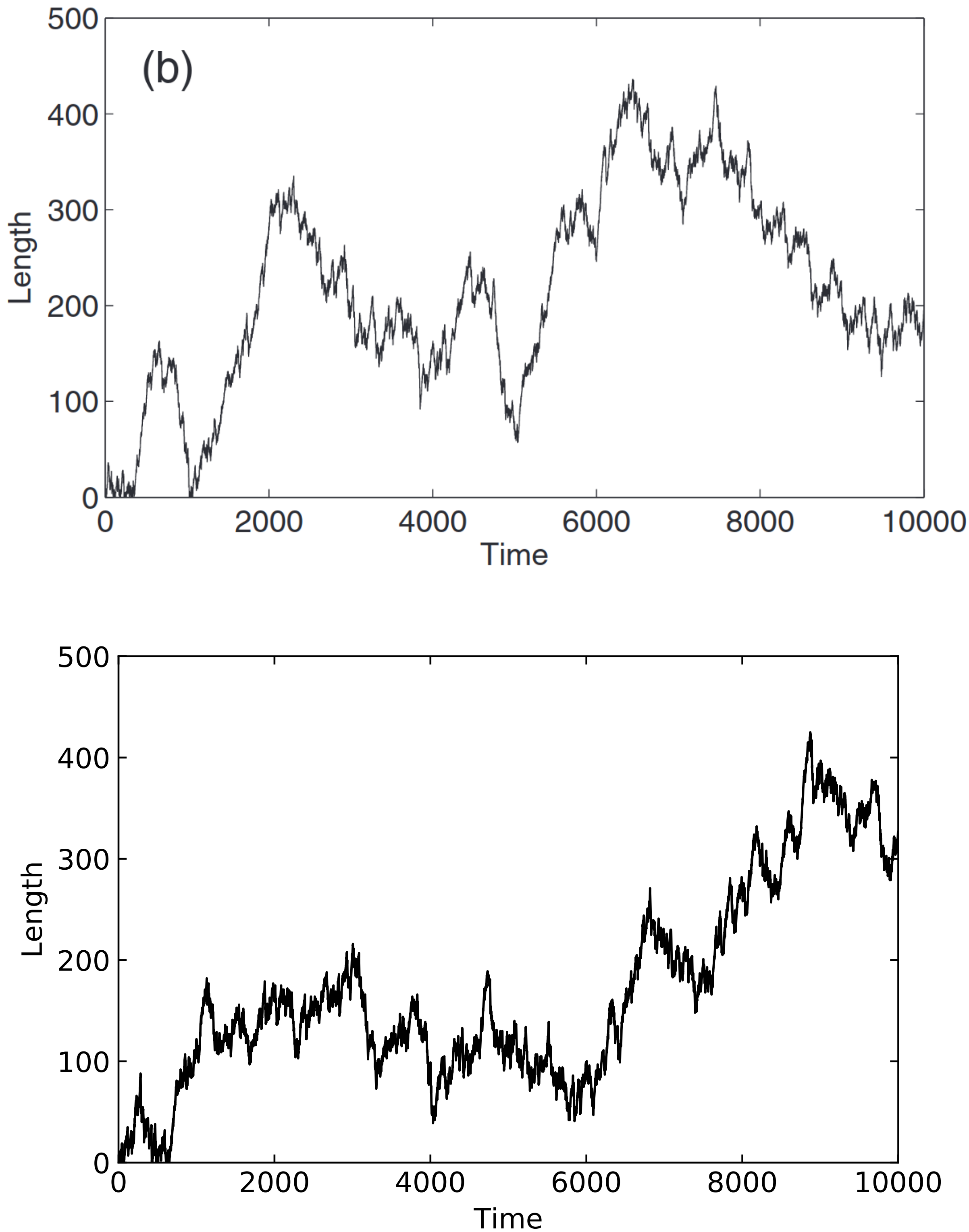
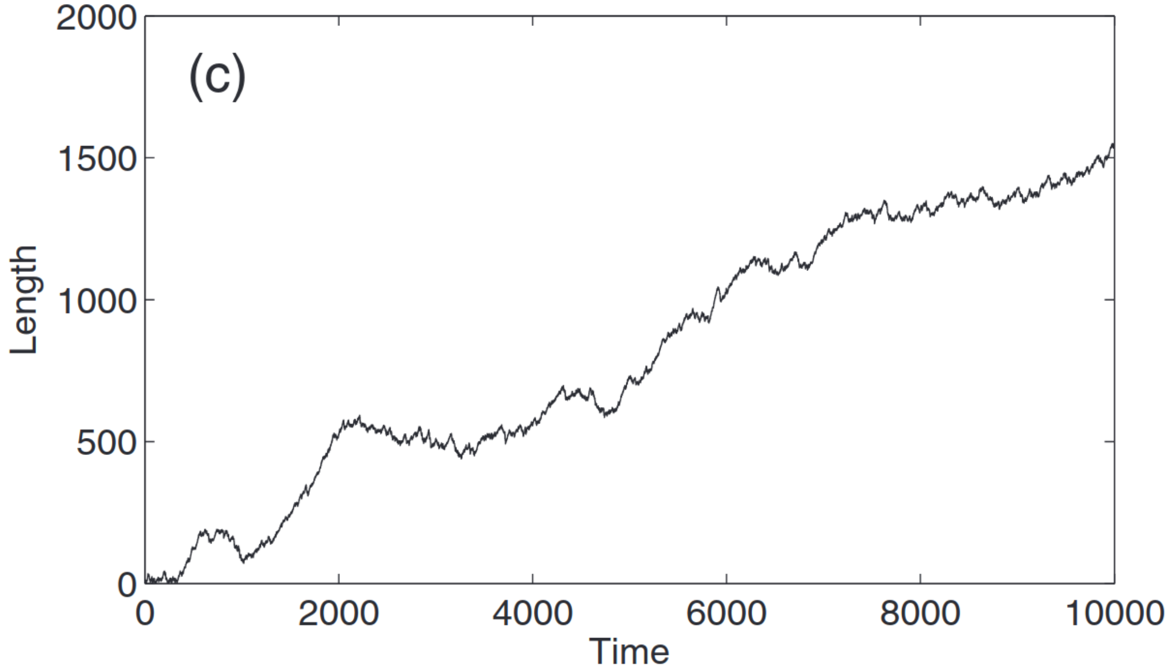


Figure 2
Microtubule growth for $\lambda = 1.5$, $p = 1$, $\mu = 5$



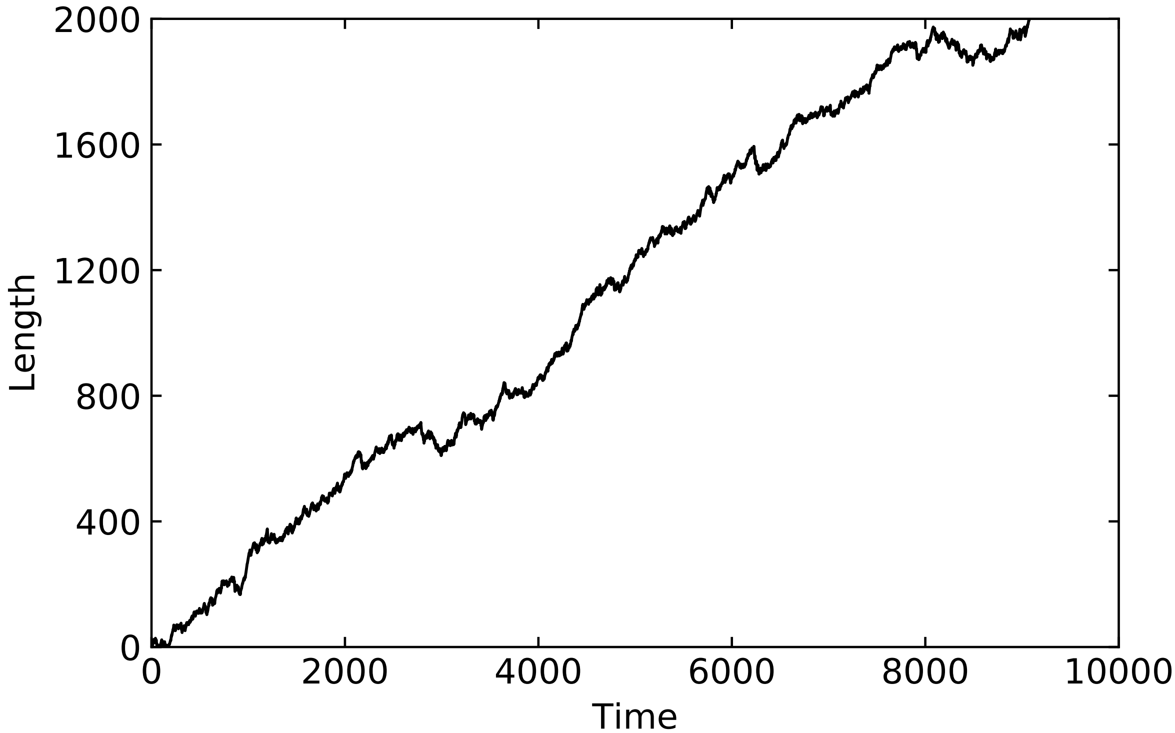


Figure 3
Microtubule growth for $\lambda = 1.6$, $p = 1$, $\mu = 5$

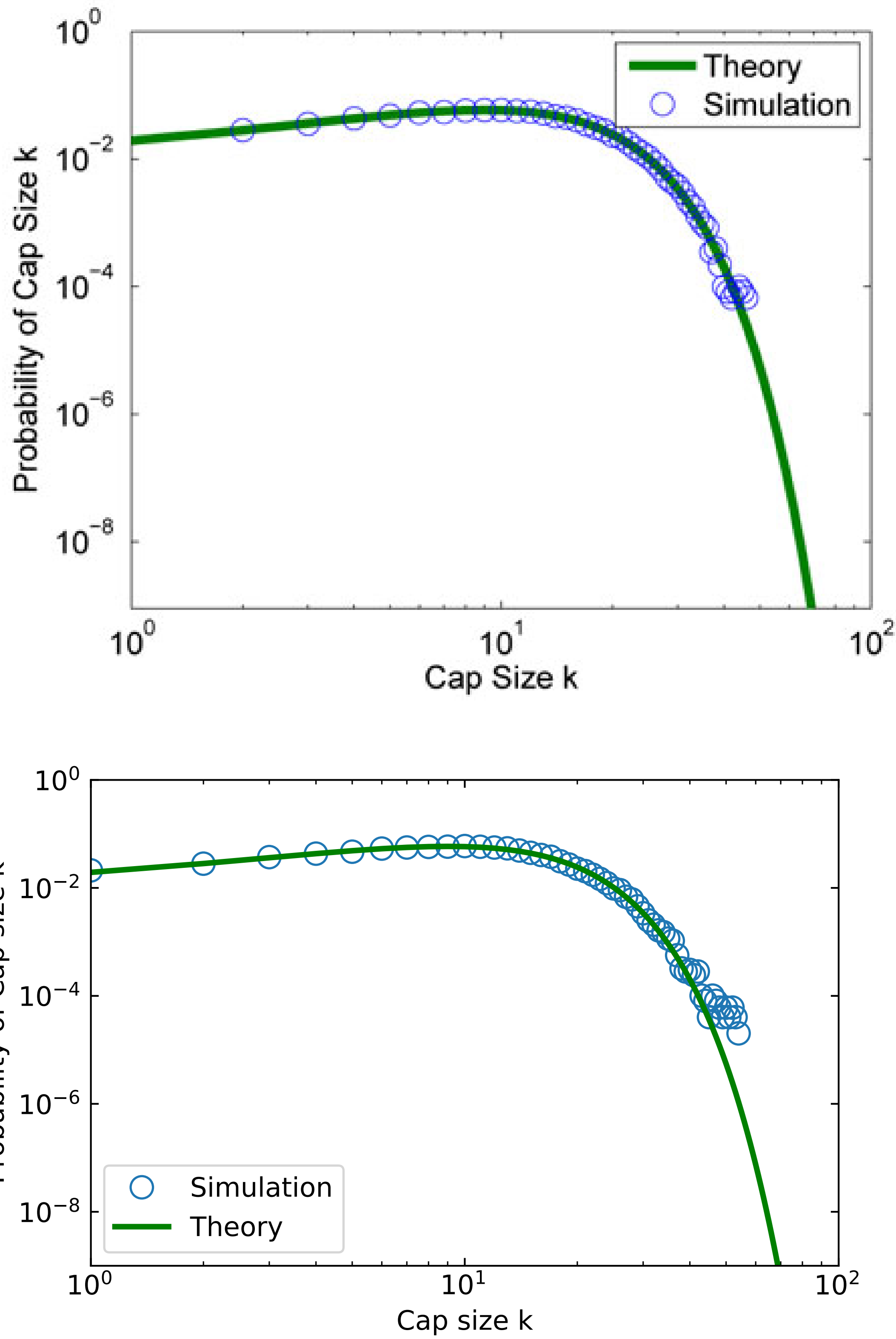
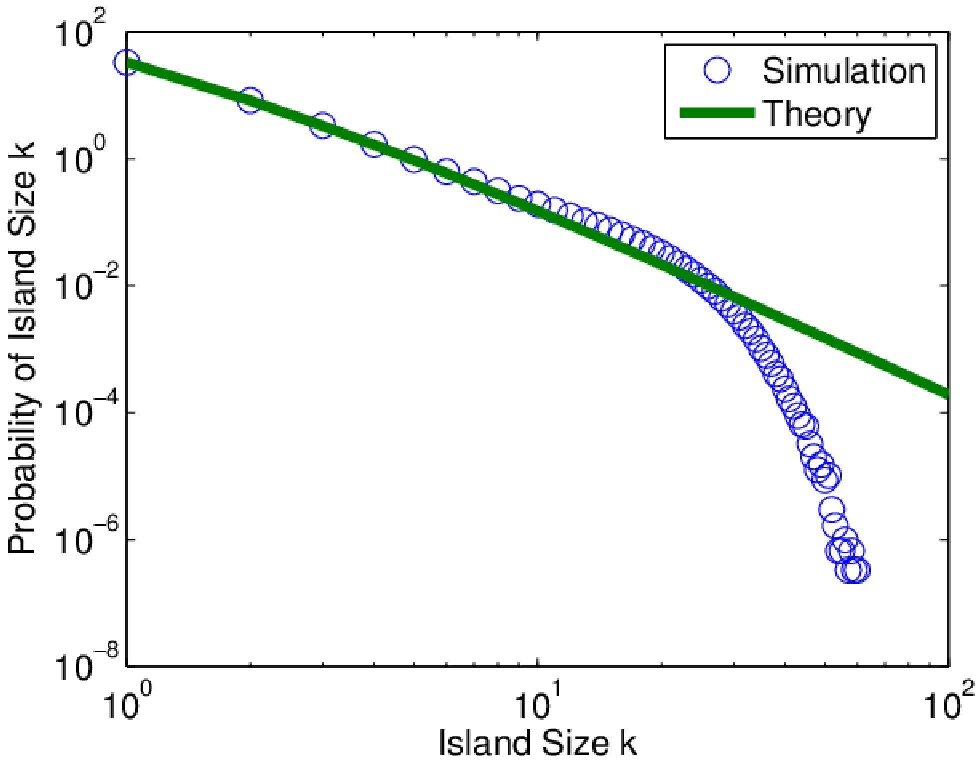


Figure 4
Capsize distribution for $\lambda = 100$, $p = 1$, $\mu = 0$



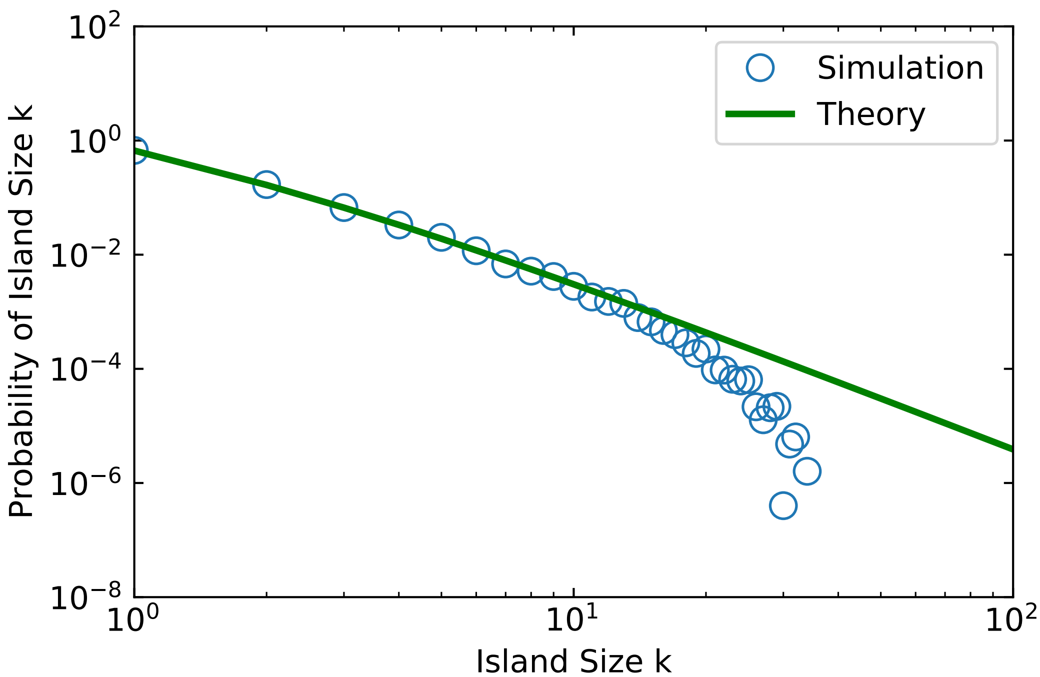


Figure 5
Island size distribution for $\lambda = 100$, $p = 1$, $\mu = 0$. Plots differ by a scaling factor in the definition of Island Size

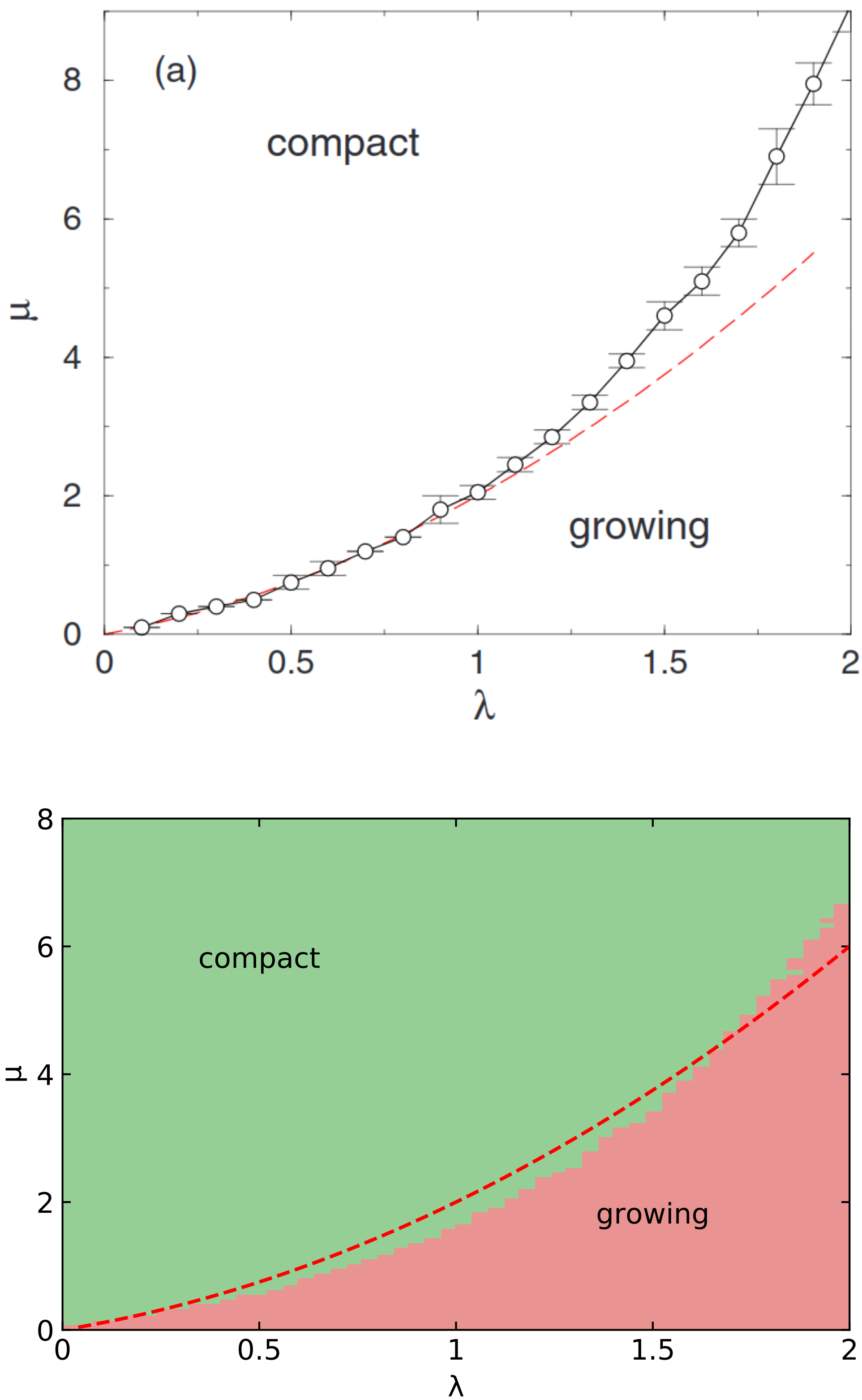


Figure 6
Phase Diagram for $p = 1$

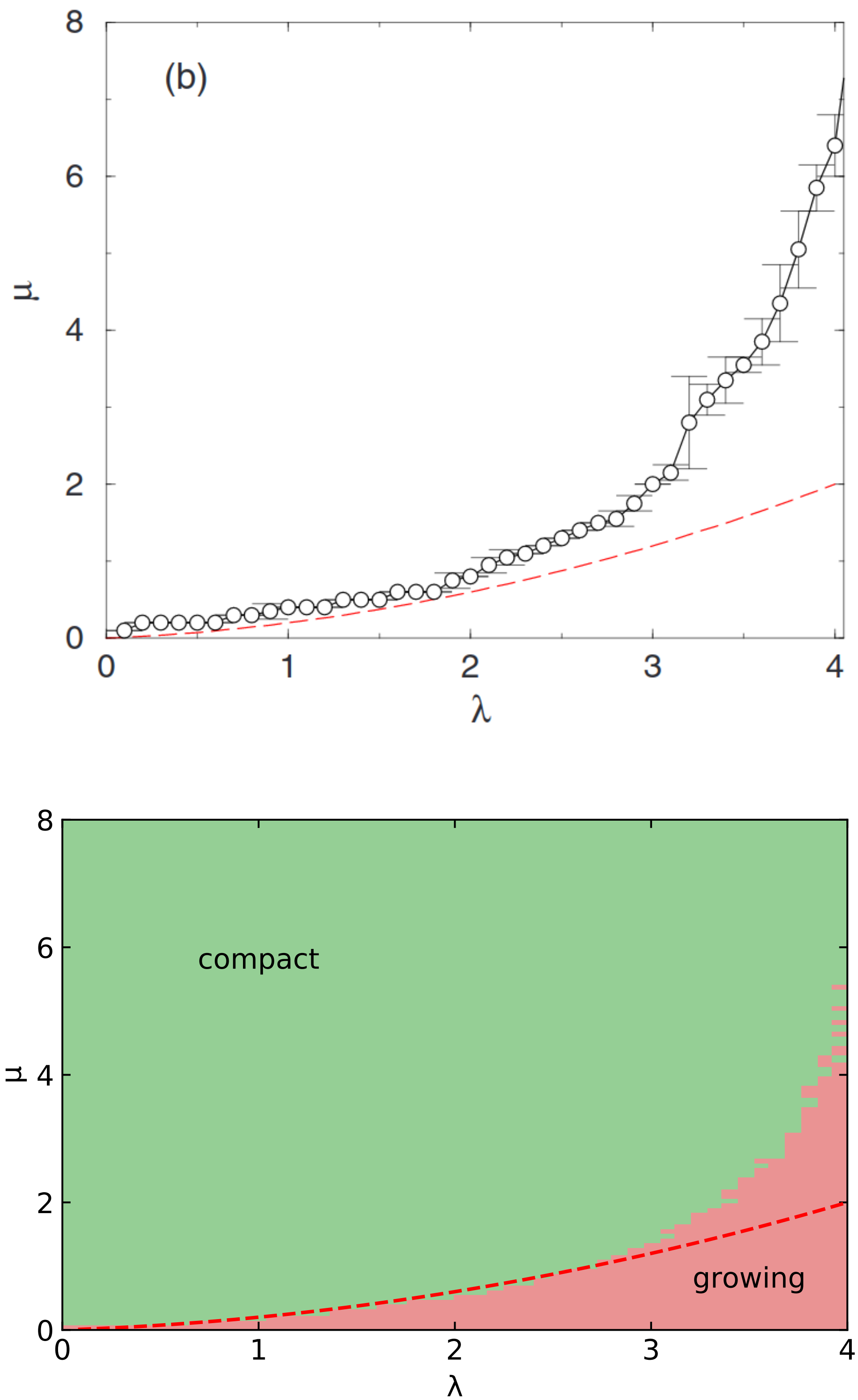


Figure 7
Phase Diagram for p = 0.1

3 Discussion

The replicated versions of Figure 1 show similar behaviour to the original versions.

In Figure 5, it is clear that the probabilities in the replicated version is scaled by some value compared to the original. The replicated version is scaled so that the total probability is 1 (it is unclear why the authors of the original paper chose to apply this scaling). In addition to this, I do not observe the increase in simulated values before decreasing with respect to the theoretical prediction that the original paper had claimed.

Figure 6 deviates the most from the original paper. Instead of using the velocity of growth of the microtubule, I have used a simple threshold to determine whether the growth of a microtubule is bounded or not (microtubules that grow beyond a length of 5000 units after 100 000 steps is deemed to be 'growing'). Such a method will underestimate the threshold value $\mu_\star$ given a λ since slowly growing microtubules are deemed to be compact. However, this is a good first order approximation as the Figures above show.

4 Acknowledgements

This work has made use of Python (Van Rossum and Drake, 2009), and several Python packages: NumPy (Harris et al., 2020), Matplotlib (Hunter, 2007) and Numba (Lam et al., 2015); as well as the IPython web application Jupyter (Pérez and Granger, 2007).

References

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