Report: Modeling Chromosomes During Meiosis in Fission Yeast

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1 Introduction

During meiosis I in Fission Yeast (S. pombe), there is a dramatic chromosome movement named nuclear oscillation. A centrosome like organelle Spindle Pole Body (SPB), which is embedded in the nucleus membrane, is bonded to the Microtube. Collective force generated by the motors in the cell drives the nucleus moves back and forth, forms an oscillation behavior. Chromosomes in the nucleus, which are of course moving together, are arranged and recombined during this period.

The nuclear oscillation is believed to play an important role for chromosome paring and recombination, which are crucial for the following separating procedure. The exact process how these movements facilitate or suppress paring and recombination is not clearly understood. Here, we propose an realistic physical model and try to describe the chromosome movements during nuclear oscillation quantitatively, aiming to understand the biological functionalities of these chromosome movements.

2 Chromosome modeled by polymer

During nuclear oscillation, chromosomes are compacted and sister chromatins are adhered together form a much thicker rod like structure comparing to single DNA strand. Moreover, both ends of the chromosomes are bonded to the SPB, so that it drives the whole nucleus. Thus the topology of chromosomes is ring like loop if including the driving SPB.

Chromosomes in the nucleus during nuclear oscillation are modeled by polymers. More specifically, the model that bead connected by massless rod is employed. A sketch is shown in figure 1. The red bead representing SPB

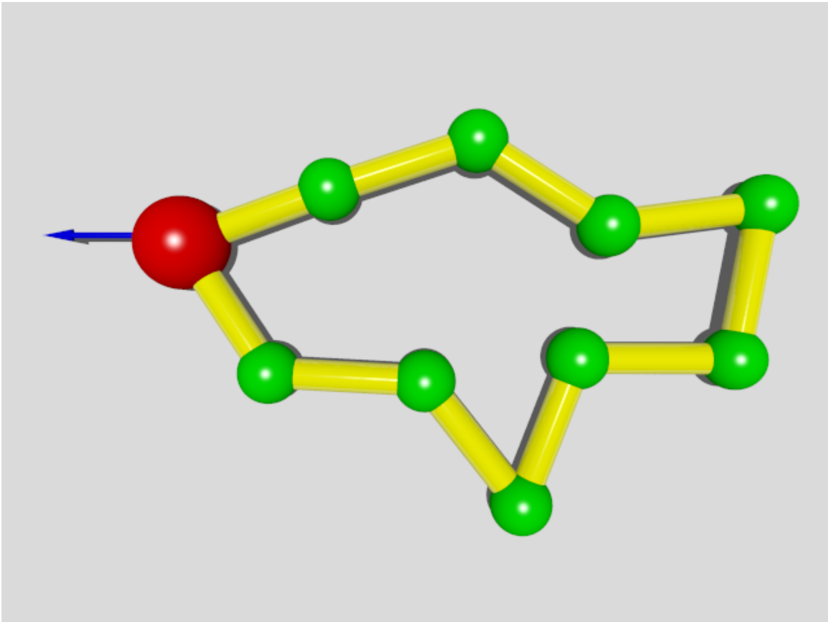

Figure 1: A sketch for bead-rod model representing one chromosome, red bead represents SPB.

is driven by a force and other beads are connected through rigid rod, which means the length of each rod is unchangeable.

It would be a good approximation that the SPB is driven by a periodic force during nuclear oscillation. However, we start from the simplest scenario that the driven force is constant. Experimentally, it is shown that the speed of SPB is almost constant when moving in one direction [1]. So it is nontrivial to consider the constant driven force case. In this case, we can change to a co-moving frame, i.e., sitting on the SPB, then it is equivalent to the scenario that SPB is pinned, and a constant force is imposed on all other beads. See in another sketch figure 2.

Let us consider pinned polymer ring in external force field described above. Denote the position of every bead using $\mathbf{r}_i$ where $i = 0, 1, \cdots N$.

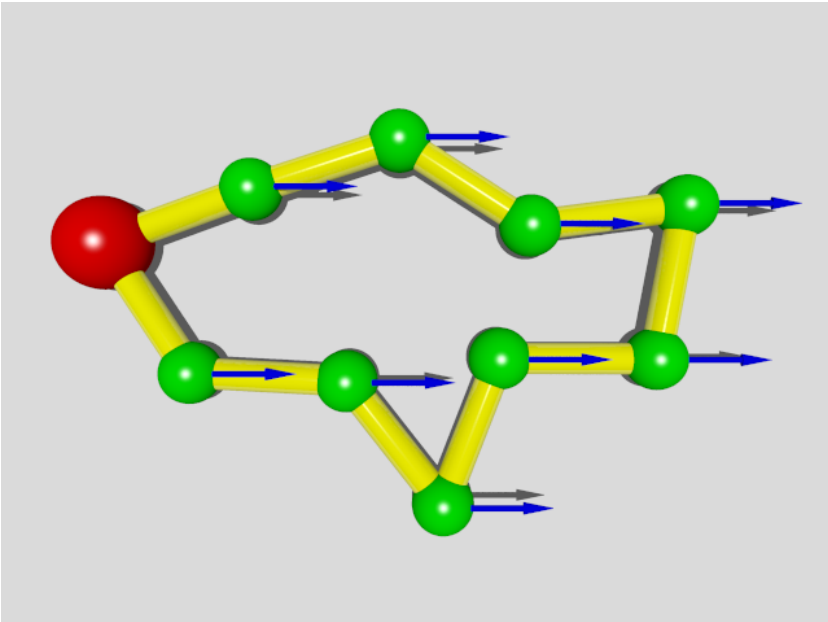

Figure 2: Sketch of pinned bead-rod ring in co-moving frame.

3 Simulation

3.1 Monte Carlo Simulation

3.2 Brownian Dynamics Simulation

4 Theory

The square mean position of every bead writes

$$\langle \mathbf{r}_i \rangle^2 = T^2 \left(\log \left(\frac{\mu}{T \sinh\left(\frac{\mu}{T}\right)} \right) - \log \left(\frac{i-\mu}{T \sinh\left(\frac{1}{T}(i-\mu)\right)} \right) \right)^2 \tag{1}$$

where T is the dimensionless temperature and μ is chemical potential, i.e. $\mu = (N+1)/2$ in our case.

5 Outlook

References

[1] Sven K Vogel, Nenad Pavin, Nicola Maghelli, Frank Jülicher, and Iva M Tolić-Nø rrelykke. Self-organization of dynein motors generates meiotic nuclear oscillations. *PLoS biology*, 7(4):e1000087, April 2009.