

## **Method of submission:**

Email your materials as a zip file to [jkishi@g.harvard.edu](mailto:jkishi@g.harvard.edu) and put them in the Dropbox folder for the course as a subfolder.

## **Submission notes:**

- Each project has two dates, the first for slides and the video accompanying the slides, and the second for the remaining project deliverables. These typically include a detailed written report and sequences for the designed systems.
- Between the two due dates, each group will meet with the course instructors to receive feedback on their project and ensure they are on track to complete the final report.

## **Collaboration policy:**

Discussion and the exchange of ideas are essential to academic work. For assignments in this course, you are encouraged to consult with your classmates on the choice of paper topics and to share sources. You may find it useful to discuss your chosen topic with your peers, particularly if you are working on the same topic as a classmate. However, you should ensure that any written work you submit for evaluation is the result of your own research and writing and that it reflects your own approach to the topic. You must also adhere to standard citation practices in this discipline and properly cite any books, articles, websites, lectures, etc. that have helped you with your work. If you received any help with your writing (feedback on drafts, etc), you must also acknowledge this assistance.

# Midterm 1

## Molecular machine design using structural DNA nanotechnology

### Due dates:

- 12pm Monday Oct. 5th (slides, video)
- 12pm Monday Oct. 12th (report, caDNAno file, sequences)

Student teams will present detailed designs for nanostructures implementing one of three molecular machine concepts:

- Flashing ratchet
- Strain-gated bipedal walker
- Electrophoretic ratchet

The goal of this project is to learn how to a) design nanostructures and b) study mechanisms for efficiently extracting mechanical work from a free energy source in an environment dominated by thermal fluctuations. For an introduction to such “Brownian ratchets”, and their uses in molecular Biology, see: Wang, H., and G. Oster. "Ratchets, Power Strokes, and Molecular Motors." *Appl. Phys. A* 75, 315 (2002). Bustamante, C., D. Keller, and G. Oster. "The Physics of Molecular Motors." *Acc. Chem. Res.* 34, 412 (2001).

A *flashing ratchet* is a system in which unidirectional motion is achieved by using an asymmetric potential energy surface which is periodically turned “on” and “off” by an energy source. Students should design a nanostructure track which presents a switchable, asymmetric potential energy surface for a nanostructure vehicle, and should include detailed design of a mechanism for coupling an external free energy source (such as DNA hybridization, photons, temperature gradients, etc.) into the system so as to “flash” the track.

A *strain-gated bipedal walker* is a molecular system with two “feet” which walks along a track. Release of free energy drives attachment and/or release of the feet from the track. Typically, walking is achieved using a “hand over hand” mechanism. In this case, unidirectional motion requires a means for the system to determine which foot is in front at any given time, and to modulate the release of free energy accordingly. An excellent reference may be found here: Yildiz et al., “Kinesin Walks Hand- Over-Hand.” *Science* 30 January 2004: Vol. 303 no. 5658 pp. 676-678

An *electrophoretic ratchet* is a nanostructure which extracts energy from an *alternating* electric field and converts it into unidirectional motion. Because the field is alternating in polarity, it is not sufficient simply to place a net charge on the nanostructure and rely on drift in the applied field. Instead an asymmetry must be introduced to ratchet the alternating field into a constant average drift velocity.

### Project deliverables consist of:

1. a pdf document describing the design and proposed method of construction of the system
2. a pdf slides of a powerpoint or keynote presentation on the design
3. a 10 min narrated youtube video, posted on a password protected URL
3. caDNAno files and DNA sequences for the structures proposed
4. extra credit: a calculation of the maximum force which can be opposed by your molecular motor

# Midterm 2

## Dynamic self-assembly using metastable hairpins

### Due dates:

- 12pm Monday Nov. 2nd (slides, video)
- 12pm Monday Nov. 9th (report, sequences)

Student teams will present detailed designs for metastable hairpin systems building on the work of Yin, 2008:

Yin et al. "Programming biomolecular self-assembly pathways." *Nature* **451**, 318-322 (17 January 2008)

In their focus on control of free-energy transduction, these projects are similar to those of Midterm #1. Here, however, a versatile, programmable molecular motif is used to generate a range of dynamic behaviors by harvesting the free energy of DNA hybridization.

The project choices include:

***hairpin walker***: Design a hairpin based molecular walker with coordinated leg motion, such that the trailing leg is lifted only after the leading leg is attached to the track.

***hairpin dendrimer***: Design a hairpin based systems with  $O(1)$  distinct DNA hairpin species. The introduction of prescribed initiator triggers the initially meta-stable hairpins to self-assemble into a binary dendrimer with unbounded size. The system is expected to demonstrate initial exponential growth kinetics.

***catalytic self-assembly***: Design a self-assembly pathway in which formation of a three-armed branched junction catalyzes the formation of a four-armed branched junction.

Project deliverables consist of:

1. a pdf document describing the design and proposed method of construction of the system
2. a pdf slides of a powerpoint presentation on the design
3. a 10 min narrated youtube video at a password protected URL
4. DNA sequences for the structures proposed

Your designs should be specified in the graphical node-based "programming language" presented in (Yin, 2008), and additionally, should be "compiled" to the DNA sequence level using sequence designers such as nupack.org

# Final project

## Due dates:

- 12pm Monday Nov. 30th (slides, video)
- 12pm Monday Dec. 7th (report, sequences)

The final project is an open-ended design project. You should clearly articulate a design goal for a synthetic molecular or cellular system, propose a concrete implementation and study the theoretical properties of the system. The method of construction and testing of the system should be emphasized.

Alternatively, you may write a software program to facilitate a specific aspect of the design of synthetic molecular systems.

## Project deliverables consist of:

1. a pdf document describing the design and proposed method of construction of the system
2. a pdf slides of a powerpoint presentation on the design
3. a 10 min narrated youtube video
4. In class presentation