DNA-Based Nano-Engineering: DNA and its Enzymes as the Engines of Creation at the Molecular Scale (Invited Talk)

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Abstract. This talk surveys various emerging "autonomous kinetic engineering and programming" techniques in recombinant DNA, nano-engineering, and molecular computing that make sophisticated use of kinetic properties of DNA nanostructures and DNA enzymes to perform tasks in an autonomous fashion, without outside intervention. Techniques that make use of sophisticated engineered kinetic design include the use of strand displacement techniques and/or irreversible enzymic reactions. We first discuss the prior use of these techniques for a variety of applications, including DNA robotics, isothermal DNA amplification, and logical control of gene expression. We overview our recent use of irreversible enzymic reactions to design and experimentally demonstrate a nanomechanical DNA device that achieves unidirectional motion and operates in an autonomous fashion. We detail the extension of these techniques to design an autonomous nanomechanical DNA device capable of universal computation and programmed translational motion. We describe two levels of design of these nanomechanical DNA devices: first using conceptual enzymes to illustrate the general design principles, and next a refined design making use of commercially available enzymes determined by use of our design software. We discuss our initial development of simulation software to refine and verify the kinetic engineering of these devices. We discuss possible extensions of this work to allow for programmable autonomous bi-directional rotation as well as contraction/extension and open/close motions. We consider various methods by which these autonomous nanomechanical DNA devices can receive inputs and outputs by molecular signals and/or external environmental changes. There has been recently considerable progress in construction of patterned nanostructures by use of synthetic DNA strands that first self-assemble into DNA tile nanostructures and then further self-assemble to patterned DNA lattices, using various techniques such as programmed tiling self-assembly and scaffold strands. We discuss the integration of our autonomous nanomechanical DNA devices into such self-assembled patterned DNA nanostructures. Possible applications of such autonomous nanomechanical DNA devices developed by "kinetic engineering and programming" techniques include: (1) Autonomous robotic methods for transportation, sorting and manipulation of nanostructures such as carbon nanotubes. (3) Improved protocols for exquisitely sensitive detection of DNA and RNA and other biomolecules using isothermal amplification. (3) Autonomous nanomechanical DNA devices within the cell that sense levels of molecular signals and provide molecular responses.

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