Communication Among Biological Nanomachines

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Biological Nanomachine Communication

- Goal
  - To achieve communication between biological nanomachines
    - Nanomachines: molecular-cell scale objects that are capable of performing simple tasks

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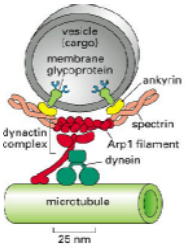
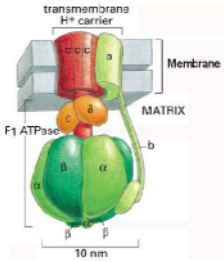
Nanomachines

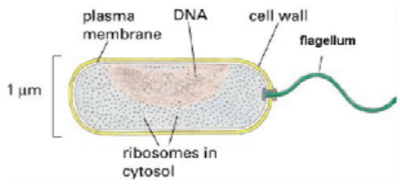
- Biological nanomachines
  - Cells
  - Dynein Molecular Mortor
    - Carries proteins by sliding over the rails (microtubule) in cells.
  - F1ATPase
    - Synthesizes ATP (energy) and rotates using influx of protons
  - Bacterium
    - Swims toward the chemicals (e.g, food) using flagellum



Dynein



F1ATPase



Bacterium

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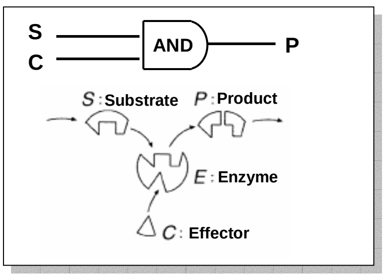
All figures: Alberts, Molecular Biology of the Cell

- Biological nanomachines
  - logic gates made of biological components (e.g, enzymes or bacteria)
    - If both substrate and effector exist, product produced
    - If no effector or no substrate, substrate remains unchanged



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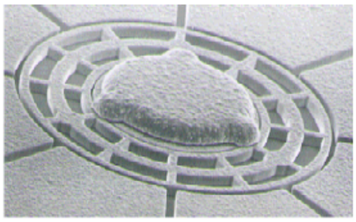
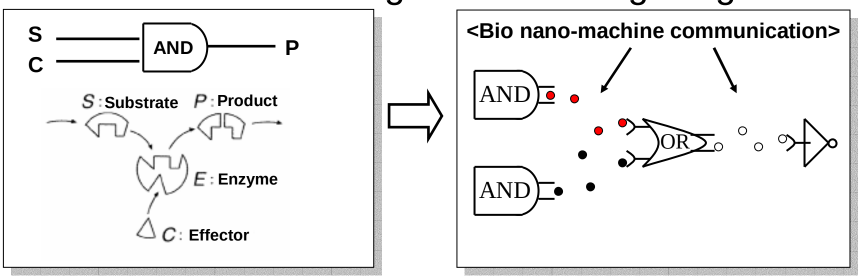
- Artificial nanomachines
  - MEMS/NEMS
  - Micron motor
    - Size: 100 um in diameter
    - Rotates up to 10,000 rpm



MEMS/NEMS: http://www.fujita3.iis.u-tokyo.ac.jp/

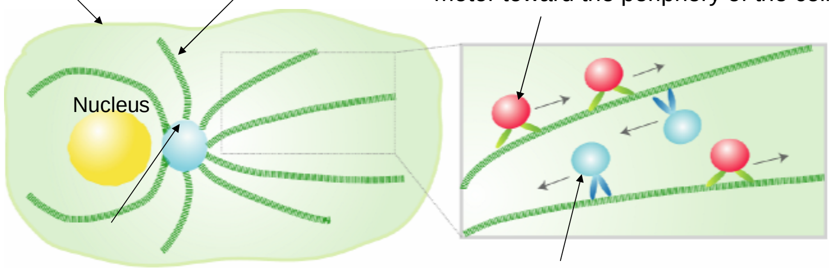
Applications

- Pinpoint drug delivery
  - To deliver drug to (targeted) cancer cells
- Molecular Computing
  - Communication among “logical gates” allows coordination among distributed logical gates



Nano/Micro-Scale Communication in Biological Systems

- Intracellular communication (vesicles transported by molecular motors)



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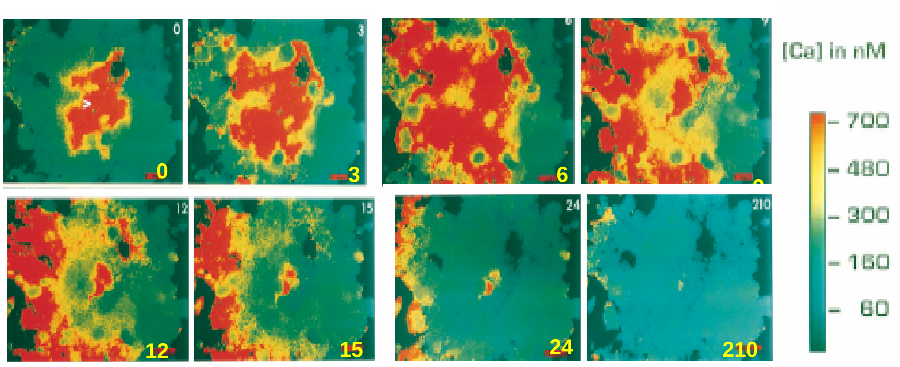
- Intercellular communication
  - Cells coordinate through calcium signaling



J. Cell Biol. Jørgensen et al. 139 (2): 497, 1997

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Molecular Communication

- Make bio nanomachines communicate using communication mechanisms in real world biological entities
  - Senders/receivers = biological nanomachines
  - Communication carrier = molecules (e.g., proteins, ions, DNAs)
  - Communication distance = nano/micro scale
  - A receiver (chemically/physically) reacts to incoming molecules

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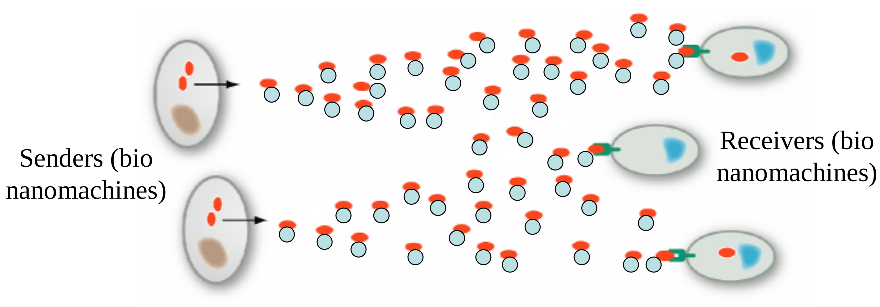
An Example System



Nano/micro-scale communication

Information molecules (Proteins, ions, DNAs, etc)

Carrier molecules (Rail molecules, hormones, etc)

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Key System Components

- A sender
  - Molecule generation
  - Molecule encoding
  - Molecule emission
- Propagation
  - Molecule loading at a sender
  - Direction control
  - Molecule unloading at a receiver
  - Molecule recycling

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- A receiver
  - Molecule reception
  - Molecule decoding
  - Molecule decomposition or recycling

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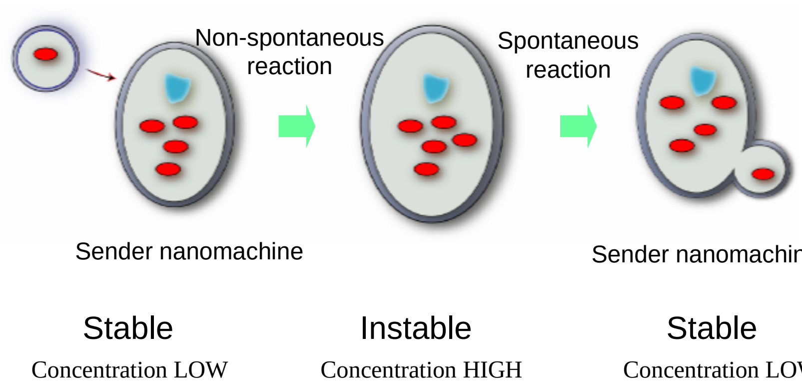
An Example Component: *A Sender*

- Artificially synthesized cell



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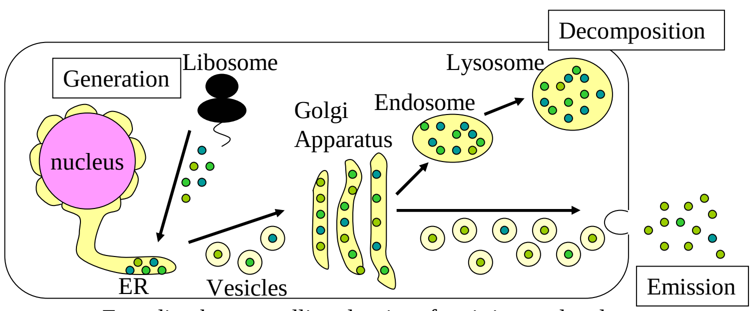
- Genetically altered mutant cell



Encoding by controlling density of emitting molecules

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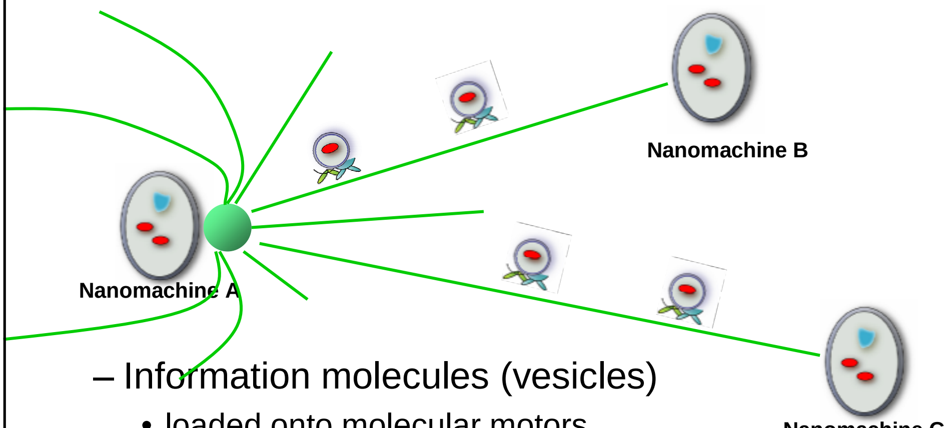
An Example Component:
Propagation Direction Control



– Information molecules (vesicles)
  - loaded onto molecular motors
  - transported by molecular motors

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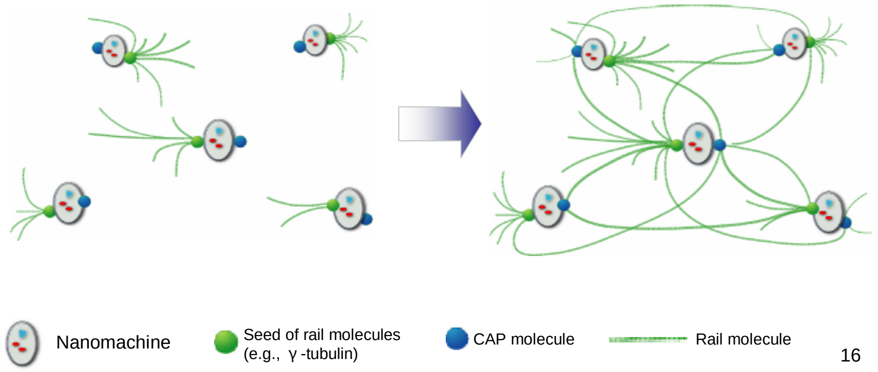
- Rail molecule network
  - Self organizing creation of rail molecule network



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An Example Component: *A Receiver*

- An artificially synthesized cell

A receiver

- Reception
  - Using artificial receptors
  - Liposome-liposome merger
- Decoding
  - A receiver reacts to incoming molecules, or
  - A receiver converts incoming molecules to another type (e.g., using enzymes)

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Other Components

- Intermediate nodes
  - For multihop communication

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System Characteristics

- We want the system to be
  - Autonomous (i.e., no human control)
  - Closed (i.e., no energy supply from outside)
  - Recycling (of carrier molecules and information molecules)
- Other system characteristics
  - Probabilistic behavior
  - Many to many communication
  - Slow delivery of molecules

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Research Issues

- Developing applications that require communication among bio nanomachines
- System designs using biological communication mechanisms
  - Autonomous, closed, recycling system
  - Various system components
- Creating new "information" and "coding" concepts and models
- Various approaches
  - Feasibility test through experiments
  - Theoretical modeling and analysis
  - Simulations

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Conclusions

- Molecular Communication
  - New paradigm
  - Need a lot of research
    - Integrating nano technology, bio technology and computer science

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