Communication Among Biological Nanomachines

Tatsuya Suda
University of California, Irvine
suda@ics.uci.edu
and
NTT DoCoMo, Inc

Enomoto, Nakano, Egashira, Moore (UCI)
Hiyama, Moritani (Docomo)

Biological Nanomachine Communication

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

• 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
• 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)

A vesicle transported by a kinesin motor toward the periphery of the cell

A vesicle transported by a dynein motor toward the center of the cell

• Intercellular communication
  – Cells coordinate through calcium signaling

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

An Example System

Nano/micro-scale communication

- Information molecules (Proteins, ions, DNAs, etc)
- Carrier molecules (Rail molecules, hormones, etc)
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

• A receiver
  – Molecule reception
  – Molecule decoding
  – Molecule decomposition or recycling
An Example Component: A Sender

- Artificially synthesized cell

![Diagram showing the process of a Sender nanomachine](image)

<table>
<thead>
<tr>
<th>Stable</th>
<th>Instable</th>
<th>Stable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration LOW</td>
<td>Concentration HIGH</td>
<td>Concentration LOW</td>
</tr>
</tbody>
</table>

- Genetically altered mutant cell

![Diagram showing the process of a Sender nanomachine](image)

Encoding by controlling density of emitting molecules
An Example Component: *Propagation Direction Control*

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

- Rail molecule network
  - Self organizing creation of rail molecule network
An Example Component: A Receiver

- An artificially synthesized cell

- 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)

Other Components

- Intermediate nodes
  - For multihop communication
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

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
Conclusions

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