

An Autonomous Molecule Communication System Using DNA Hybridization and Biomolecular Linear Motors

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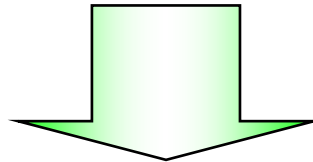
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Overview of Molecular Communication (1)

Molecular Communication is...

A nano-scale, autonomous communication system mimicking the biological communication mechanisms in living organisms. Senders use molecules as the communication carrier and receivers react biochemically to the incoming molecules.



Would work toward the actual design and control of nano-scale communication systems.

Would potentially enable many new applications in the bionanotechnology.



Overview of Molecular Communication (2)

Traditional Communication

Communication carrier:

Electromagnetic wave

Signal type:

Electronic and optical signal

Propagation speed:

Light speed (3×10^8 Km/s)

Propagation environment:

Airborne and cable medium

Encoded information:

Voice, text, and video

Behavior of receiver:

A receiver interprets encoded information

Other features:

Accurate communication and high energy consumption

Molecular Communication

Communication carrier:

Molecule

Signal type:

Chemical signal

Propagation speed:

Extremely slow speed

Propagation environment:

Aqueous medium

Encoded information:

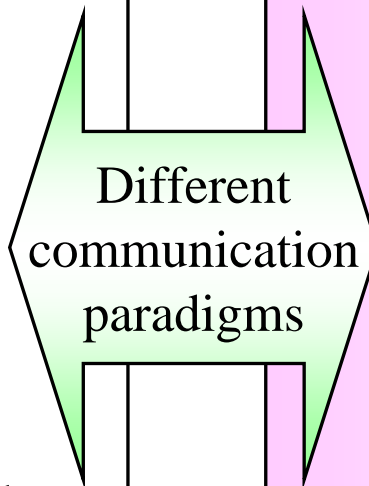
Phenomena and chemical states

Behavior of receiver:

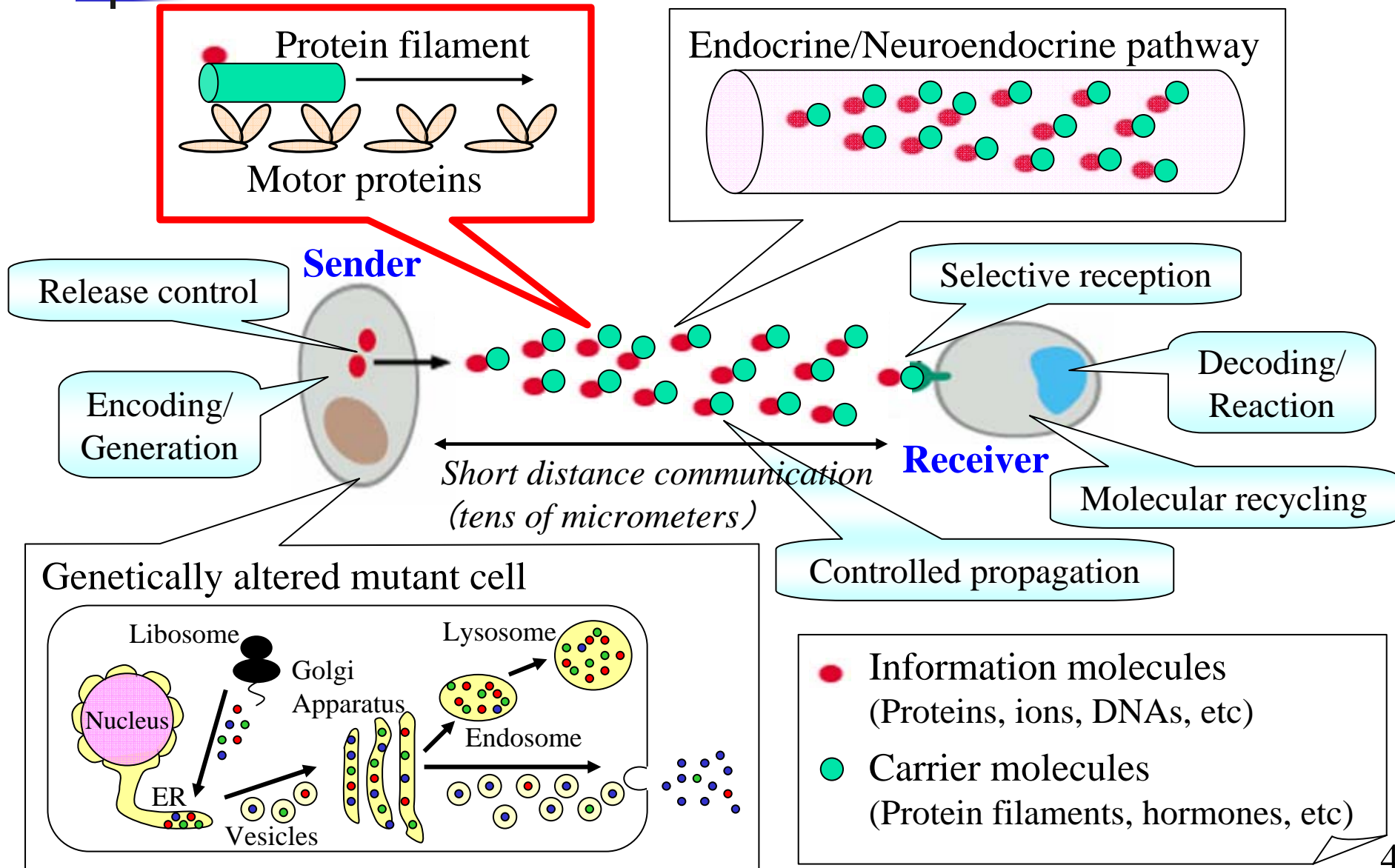
Information molecules cause chemical reactions at a receiver

Other features:

Stochastic communication and low energy consumption

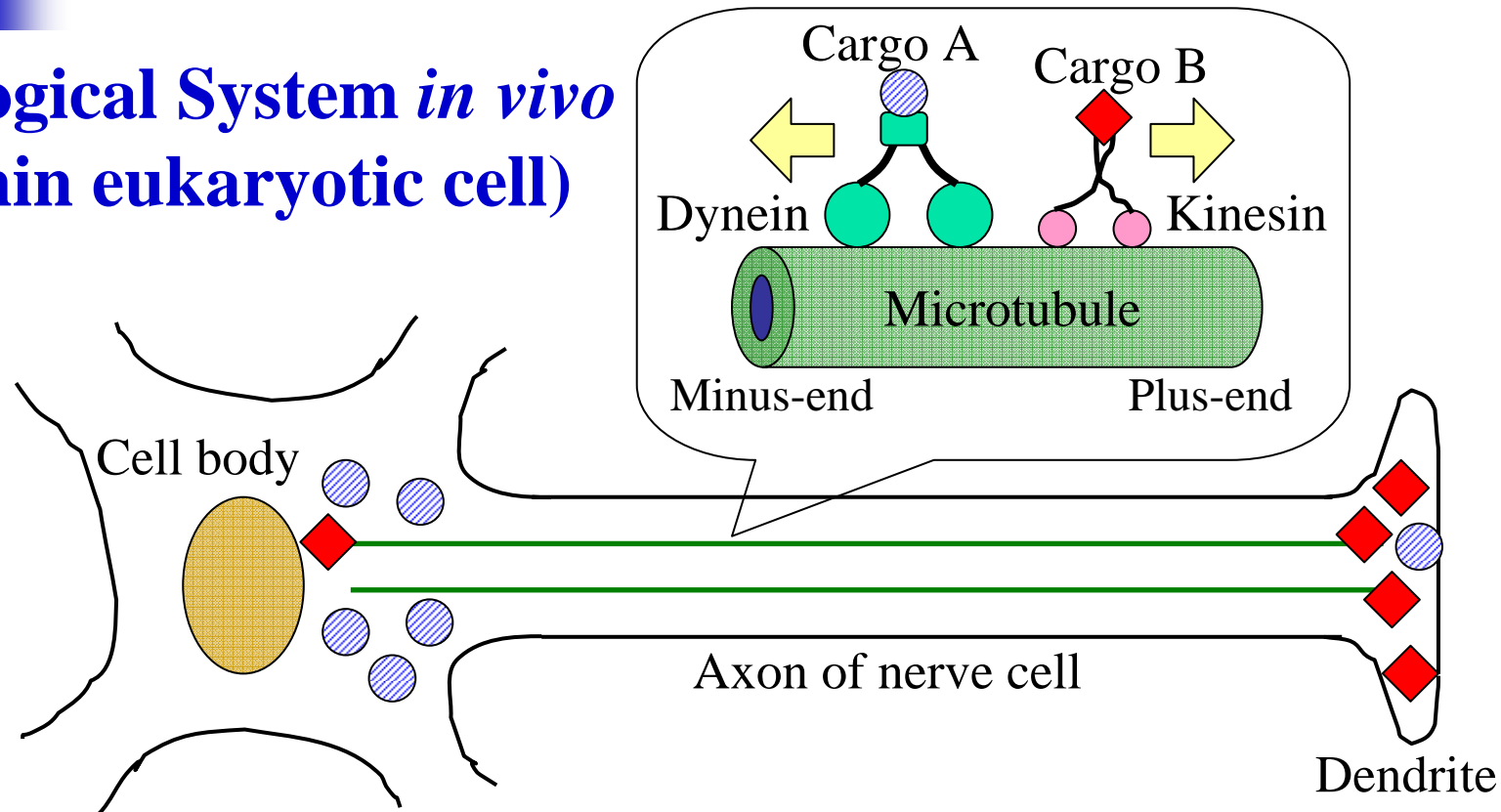


Overview of Molecular Communication (3)



Overview of Molecular Motor Systems (1)

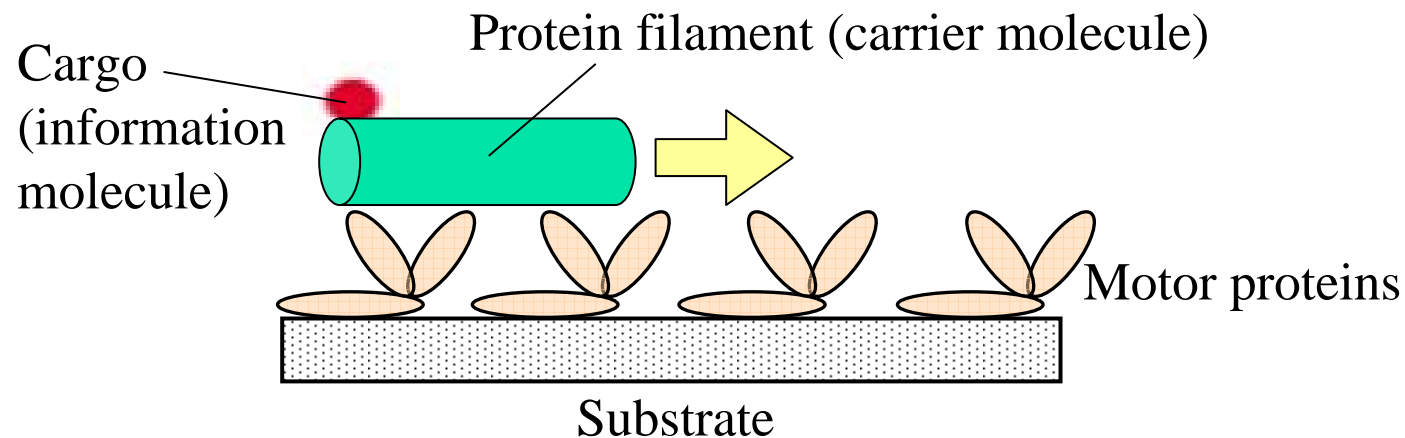
Biological System *in vivo*
(within eukaryotic cell)



Cargoes (vesicles and organelles) are transported by motor proteins (kinesins and dyneins) bidirectionally along an immobilized protein filament (microtubule).

Overview of Molecular Motor Systems (2)

Artificial System *in vitro* (in an artificially created aqueous environment)



- Cargo-protein filament conjugates glide over immobilized motor proteins.
- Protein filaments are carrier molecules of cargoes (information molecules).
- Use this approach as a molecular propagation system.

Key Issues in Molecular Propagation System

■ Molecular Loading

- How to load information molecules onto carrier molecules through chemical bonding.

■ Destination Control

- How to control the destination of information molecules using carrier molecules.

■ Molecular Unloading

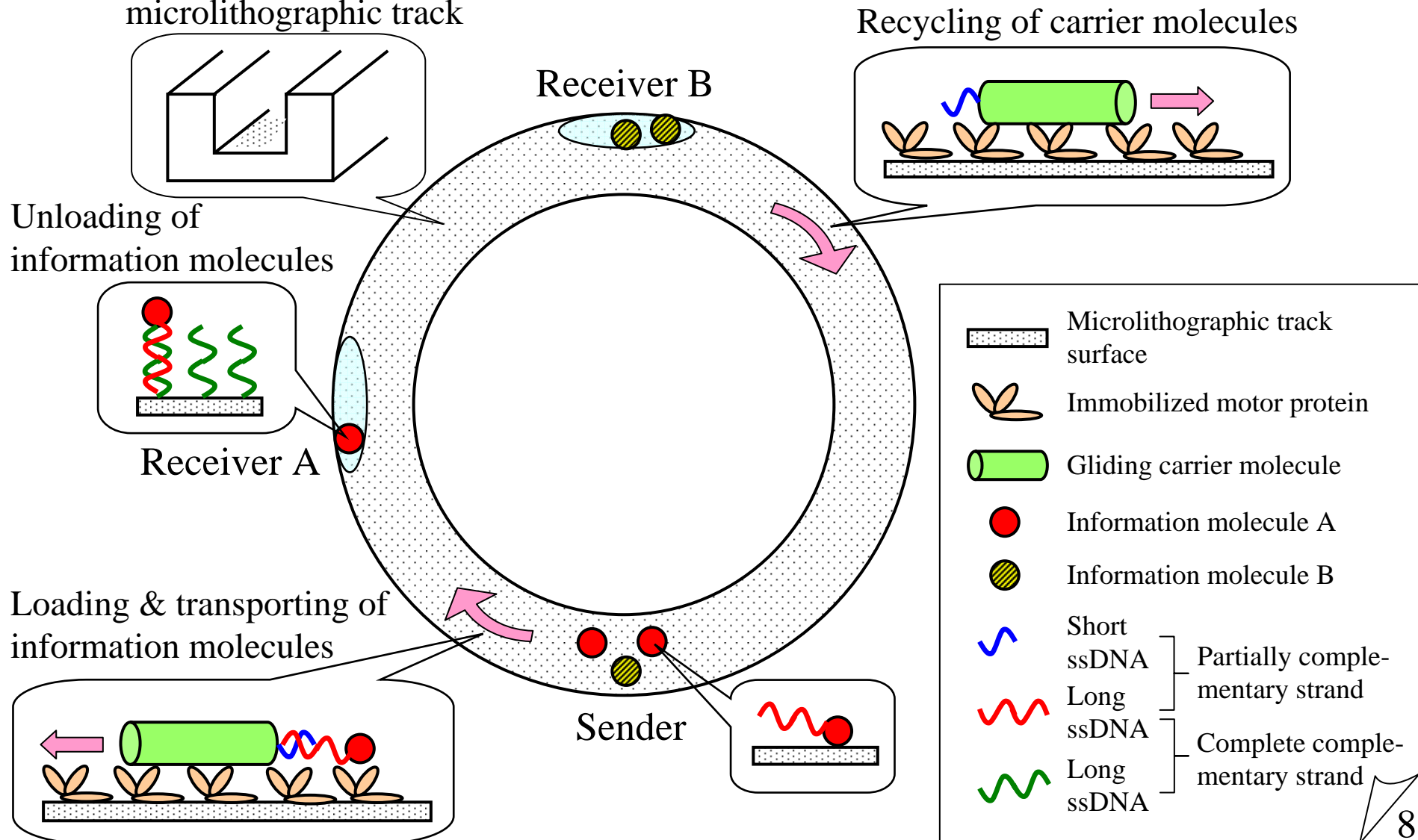
- How to unload information molecules from carrier molecules using chemical interactions of molecules near the receiver.

■ Carrier Molecule Recycling

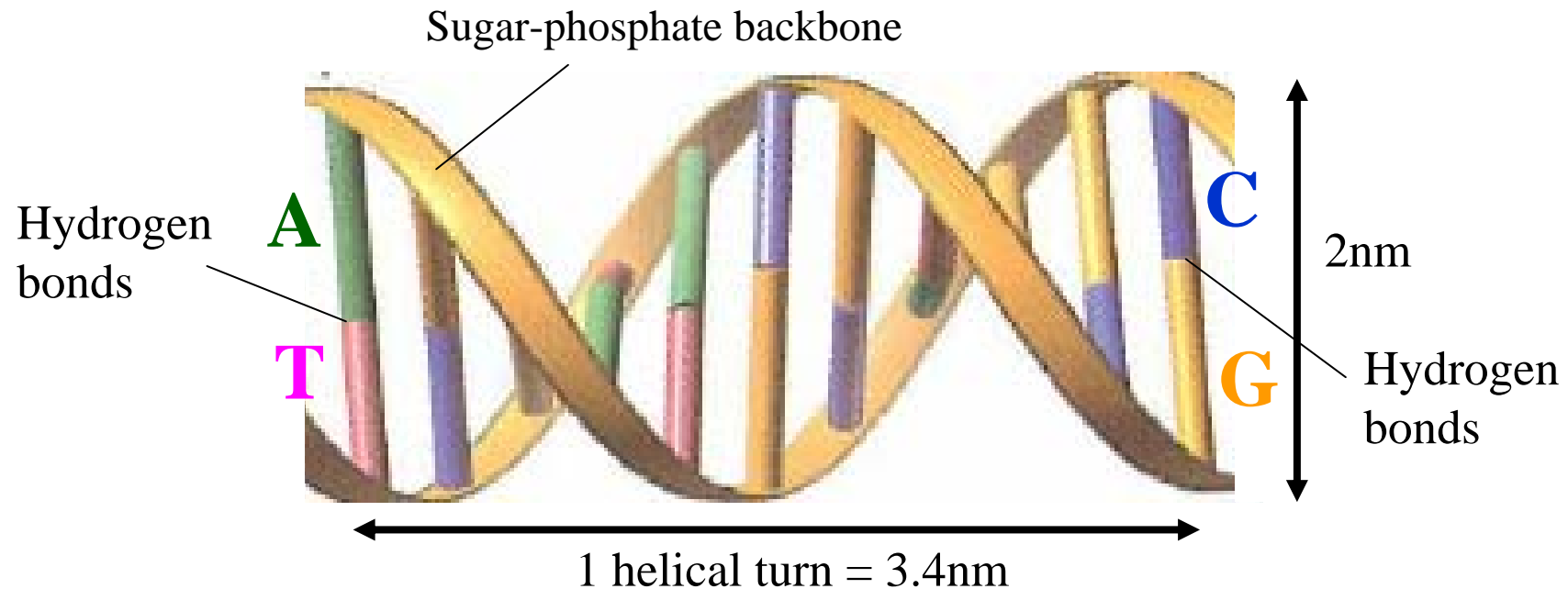
- How to return carrier molecules to the sender side after unloading information molecules.

Proposed Molecular Propagation System (1)

A cross section of a preconfigured microlithographic track



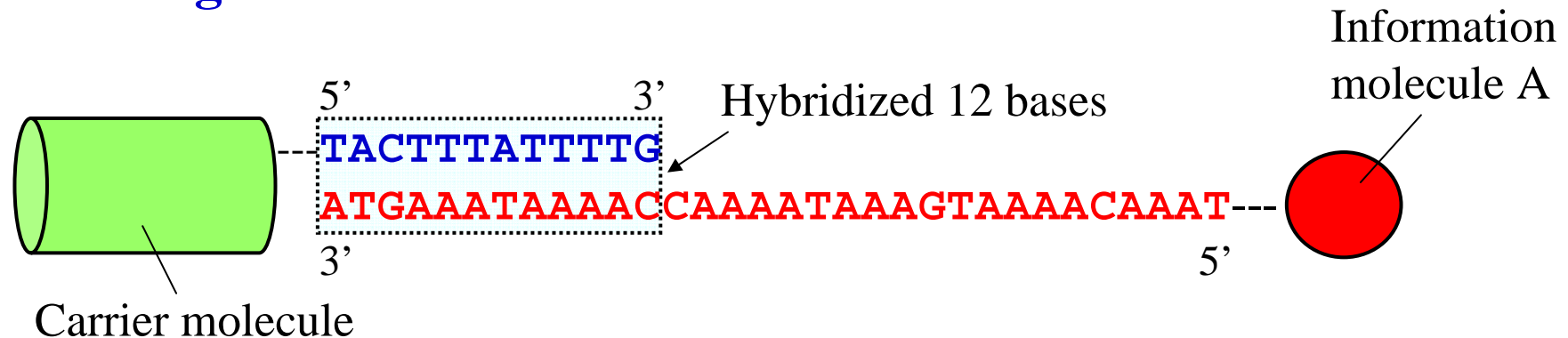
Basics of DNA (DeoxyriboNucleic Acid)



- DNA uses 4 bases: **A** (adenine), **T** (thymine), **C** (cytosine), and **G** (guanine).
- **A** and **T**, **C** and **G** are complementary bases to bind to each other and form a double strand (called hybridization).
- Any base sequences can be artificially synthesized.

Proposed Molecular Propagation System (2)

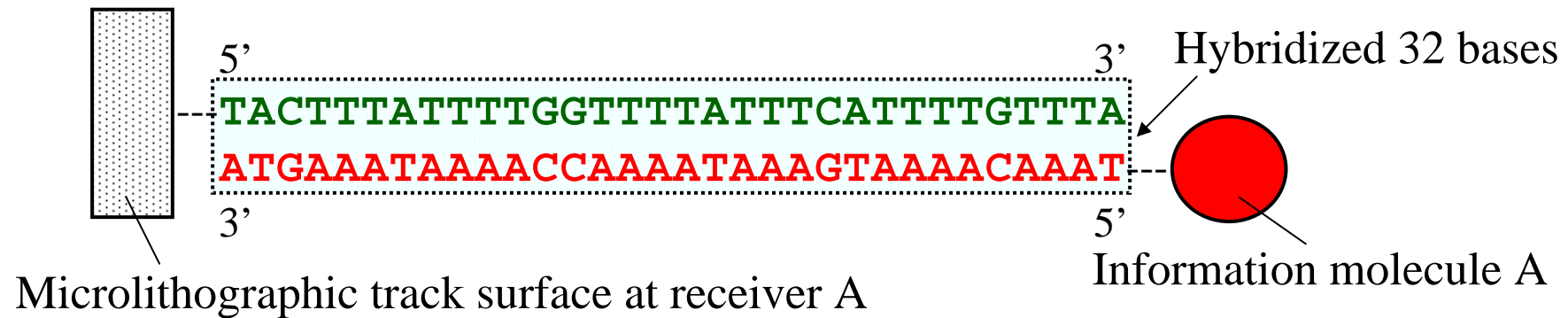
■ Loading of An Information Molecule



- Short (e.g., 12 bases) single stranded DNAs (ssDNAs) are attached to a carrier molecule (i.e., a protein filament).
- Long (e.g., 32 bases) ssDNAs are attached to an information molecule A.
- Parts of the base sequences (i.e., 12 bases of a short ssDNA and 12 bases of a long ssDNA) bind to each other and form a double strand.
- This partial DNA hybridization allows unloading of information molecules.

Proposed Molecular Propagation System (3)

■ Unloading of An Information Molecule



- Long (e.g., 32 bases) ssDNAs are immobilized onto the microlithographic track surface at receiver A.
- All the base sequences bind to each other and form a complete double strand.
- This unloading process may be initiated by the energy state transition from an unstable state (i.e., partial DNA hybridization) to a stable state (i.e., complete DNA hybridization).
- Short-ssDNA-linked carrier molecules continue to glide and may load new information molecules.

Features of Proposed Propagation System

- **Autonomous System Operation (No External Control)**
 - Loading and unloading of information molecules based on the DNA hybridization.
 - Transporting information molecules based on the gliding of carrier molecules over immobilized motor proteins along preconfigured microlithographic tracks.
 - Recycling use of carrier molecules.

- **Extremely Miniaturized System**
 - Utilization of nano-scale biological components such as motor proteins and DNAs.
 - Utilization of chemical power sources such as energy state transition and adenosine triphosphate (ATP).



Research Steps

Currently conducting biochemical experiments and empirically examining the proposed system design

- (1) Explore binding methods of ssDNAs and carrier molecules using a chemical linkage.
- (2) Confirm the gliding of ssDNAs-linked carrier molecules over the immobilized motor proteins.
- (3) Examine the loading of ssDNAs-coated information molecules onto carrier molecules.
- (4) Confirm the gliding of carrier molecule-information molecule conjugates over the immobilized motor proteins.
- (5) Confirm the gliding of carrier molecule-information molecule conjugates over the immobilized motor proteins along preconfigured microlithographic tracks.
- (6) Examine the unloading of information molecules from carrier molecules.

Preliminary Experimental Results

Motility video of ssDNA-linked carrier molecules over the immobilized motor proteins on a non-configured substrate observed by a microscope
(Experimental results of the 2nd phase of research steps)

- Carrier molecules: Microtubules
- Motor proteins: Kinesins
- ssDNAs: oligonucleotides
- Chemical linkage: Succinimide ester-maleimide cross-linker
- Gliding speed: 0.28 $\mu\text{m}/\text{sec}$ (on average)





Conclusions

An Autonomous Molecular Propagation System

- that loads, transports, and unloads information molecules using DNA hybridization and molecular motor systems.
- is currently examined by biochemical experiments.
- is applicable to communication among biological and artificially-created nanomachines using molecules as communication carrier.
- would also potentially enable a number of new applications in the bio-nanotechnology.

A decorative graphic consisting of overlapping colored squares (yellow, red, blue) and a black crosshair.

Acknowledgements

Special thanks to Associate Professor Yoko Y. Toyoshima and Mr. Kenya Fruta of the Department of Life Sciences, the University of Tokyo for helping with biological preparation.

For More Information (Published Works)

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- T. Suda, M. Moore, T. Nakano, R. Egashira, A. Enomoto, S. Hiyama, and Y. Moritani, "Exploratory Research in Molecular Communication between Nanomachines," UCI Technical Report, 05-3, Mar. 2005.
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- T. Suda, A. Enomoto, T. Nakano, R. Egashira, M. Moore, S. Hiyama, and Y. Moritani, "Communication Among Biological Nanomachines," The Second Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services 2005 (Mobiquitous'05), Jul. 2005.
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