Brownian molecular motors

Bionanotechnology Seminar

Alicja Nowakowska

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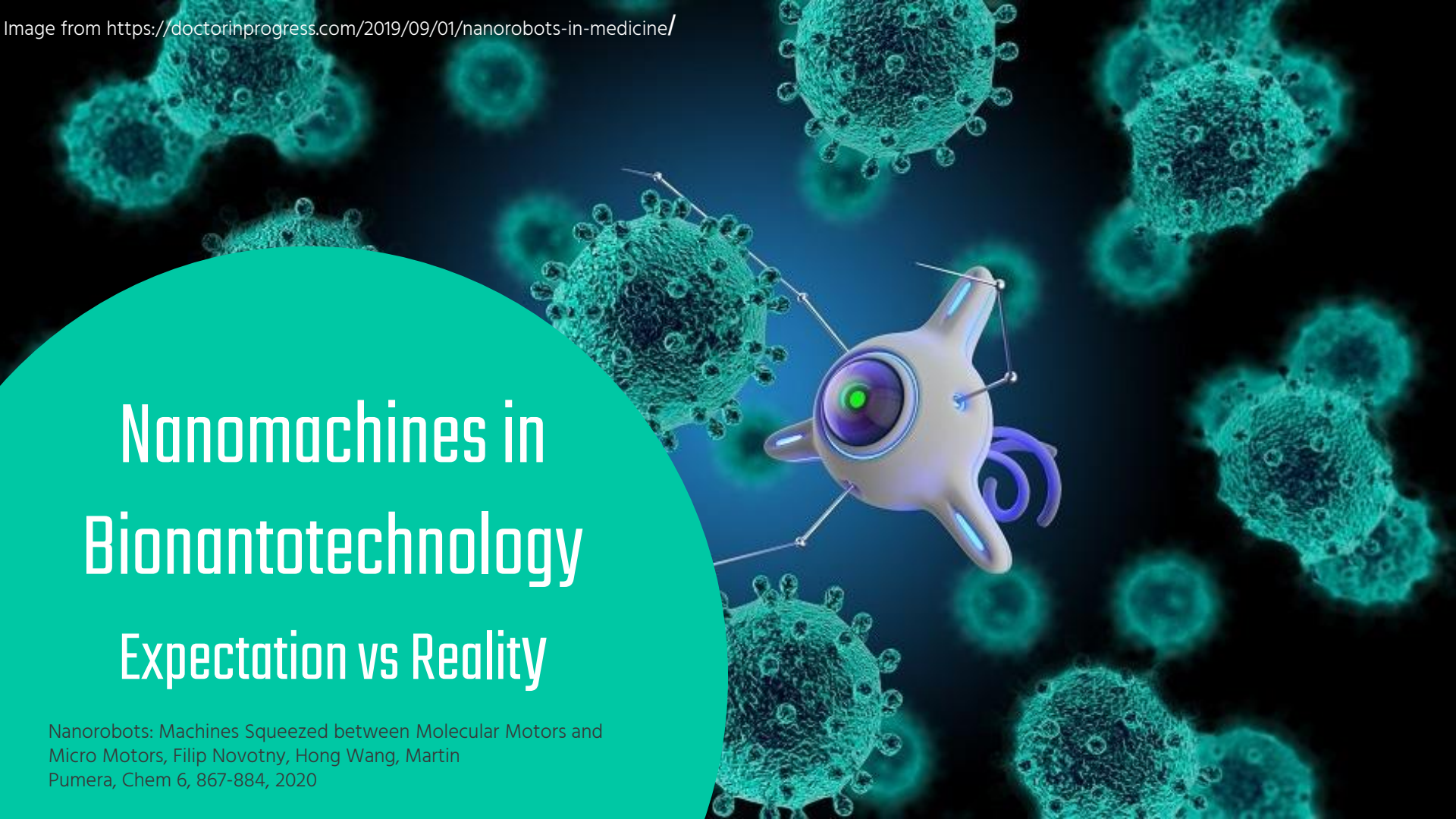
Introduction

There's Plenty of Room at the Bottom ~ R.Feynman 1959

Image from https://doctorinprogress.com/2019/09/01/nanorobots-in-medicine/



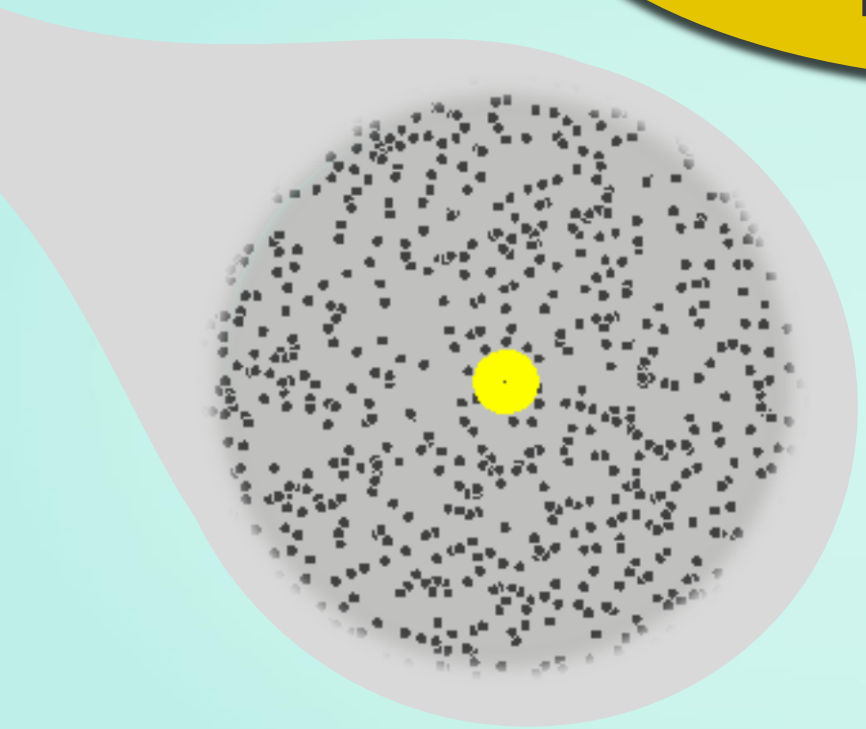
Nanomachines in Bionantotechnology

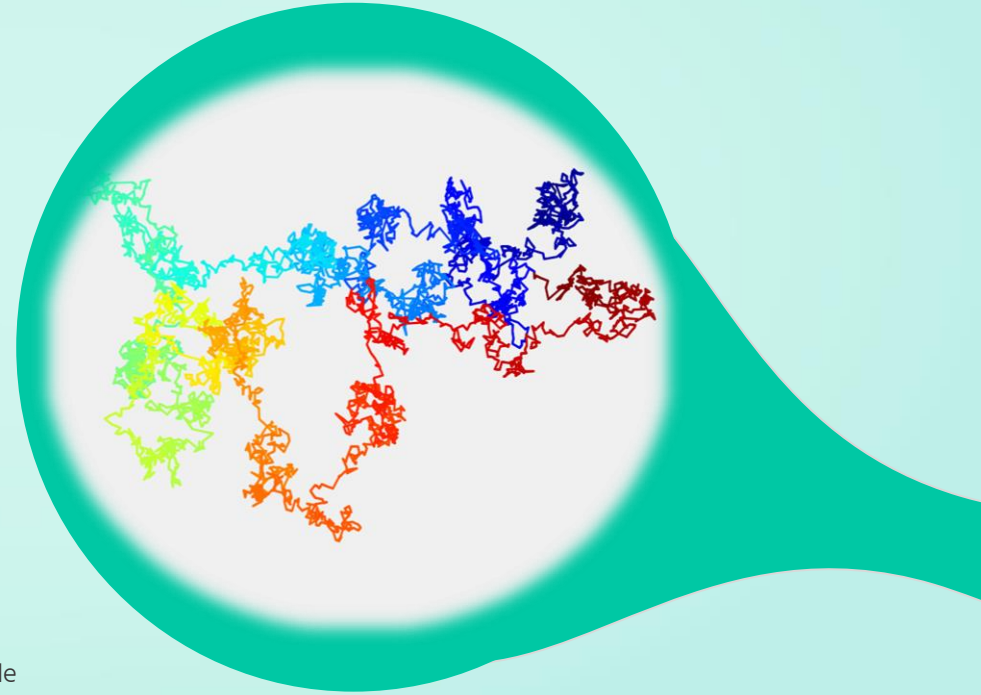
Expectation vs Reality

Nanorobots: Machines Squeezed between Molecular Motors and Micro Motors, Filip Novotny, Hong Wang, Martin Pumera, Chem 6, 867-884, 2020

Microscopic perspective matters

Brownian motion





Adapted from IPython Interactive Computing and Visualization Cookbook by Cyrille Rossant, Ejs Open Source Brownian Motion Gas Model Java Applet by Professor Paco & Hwang

Consequences of Brownian motion

01

Domination of stochastic behaviour

- Randomness and unpredictable trajectories
- Need of statistical perspective

02

Directed motion — as if walking in a hurricane

Fight against it or use it

03

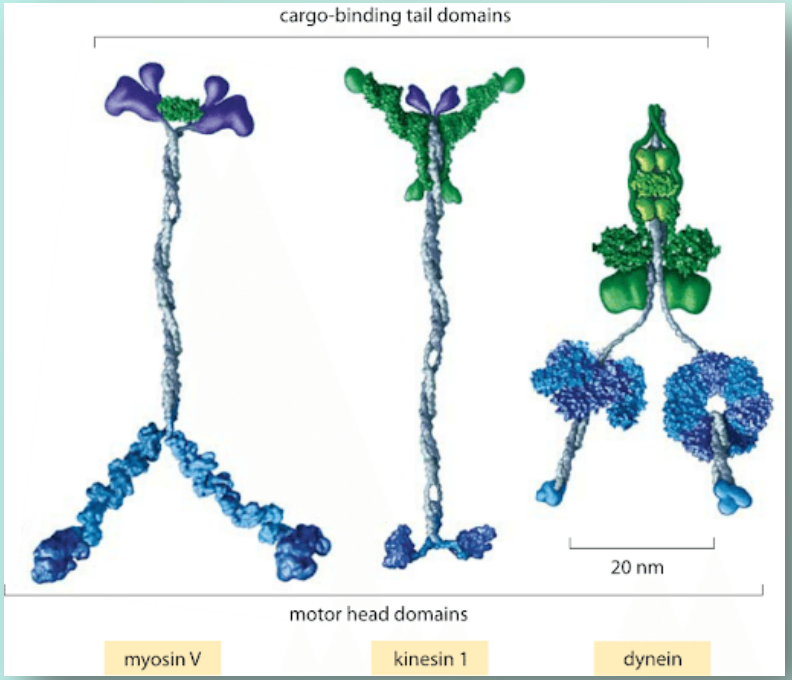
Natural state — diffusion, energy needed to stop moving

How molecular motors extract order from chaos (a key issue review), Reports on Progress in Physics, 79, 2016

Real Molecular Motors

The closer one looks at these performances in living organisms the more impressive the show becomes ~Max Delbrück

Molecular motors



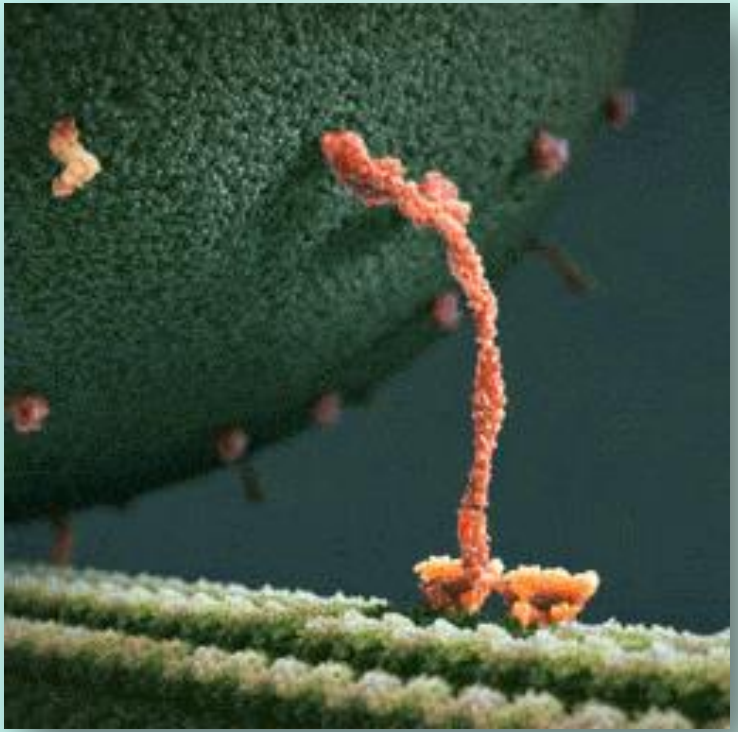
Adapted from R. D. Vale, Cell 112:467, 2013

Main features

- **Definition:** machines that convert chemical energy into directed mechanical work
- **Structure:** proteins – heads (2 binding sites) and tails domains
- **Function**: muscle contraction, cargo transport, cell division, cellular traffic
- **Use cytoskeleton** – filaments and microtubules **(polar and periodic)**

An introduction to ratchets in chemistry and biology, Materials Horizons 4:310-318, 2017

Molecular motors



Adapted from *The Inner Life of the Cell movie, Harvard University, 2006*

Basics of the mechanism of motion

- **Fuel:** ATP
- Conformational changes
- **Step:** Bind – deattach – bind furtherly
- One direction movement – **Hand over hand mechanism**

An introduction to ratchets in chemistry and biology, Materials Horizons 4:310-318, 2017

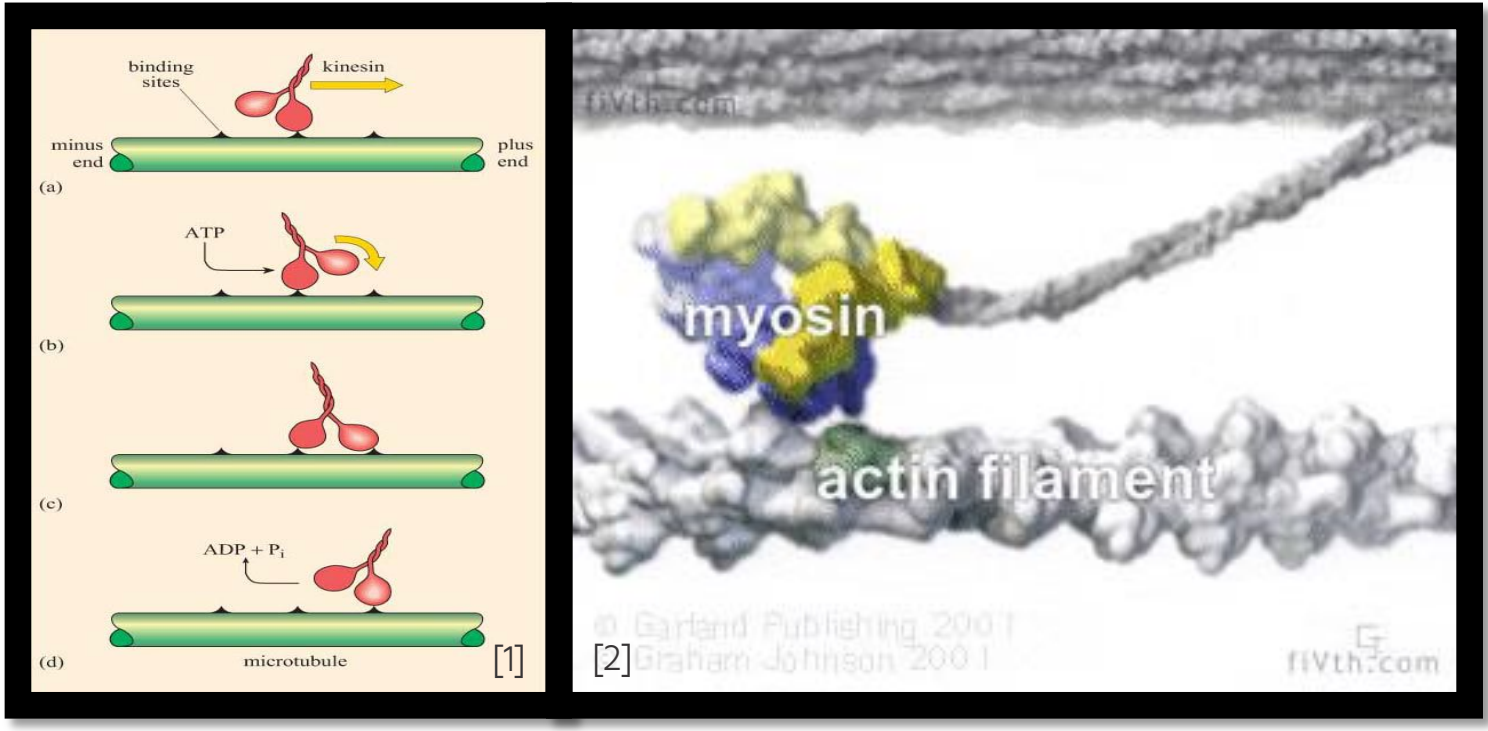
Kinesin I and Myosin II

Notes [3]:

- High efficiency: 40-60%
- 1 step ≈ 1 ATP
- Rare backward steps
- Velocity: 700 nm/s
- Complicated models of motion

<u>Thermal noise:</u>
10^{-9}W
<u>Mean power from 1 ATP hydrolisis</u>
10^{-18}W

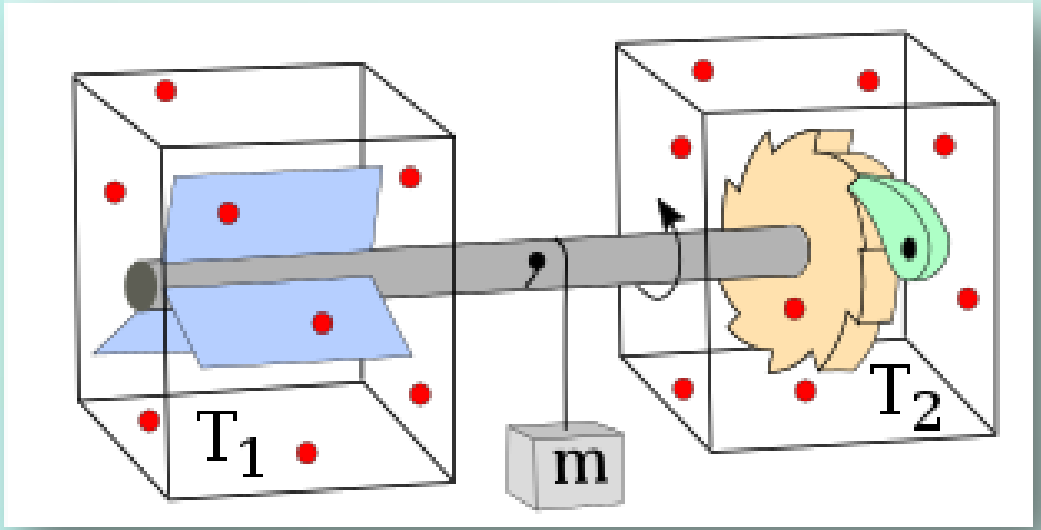
Diffusion matters

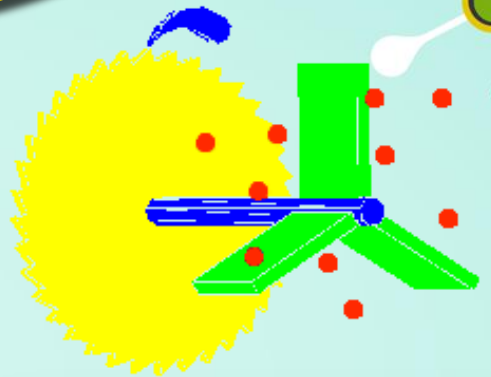


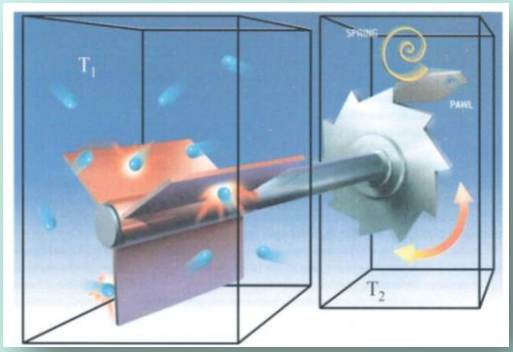
[1] https://www.open.edu/openlearn/science-maths-technology/science/biology/intracellular-transport/content-section-5.2
[2] The Way Things Move: Looking Under the Hood of Molecular Motor Proteins Ronald D. Vale1,*, Ronald A. Milligan2 Science 07 Apr 2000:
[3] An introduction to ratchets in chemistry and biology, B. Lau, O.. Kedem, J. Schwabacher, D. Kwasniewski, E. A. Weiss, Mater. Horiz. 2017,4, 310-318

Order from disorder?

Feynman's ratchet and pawl



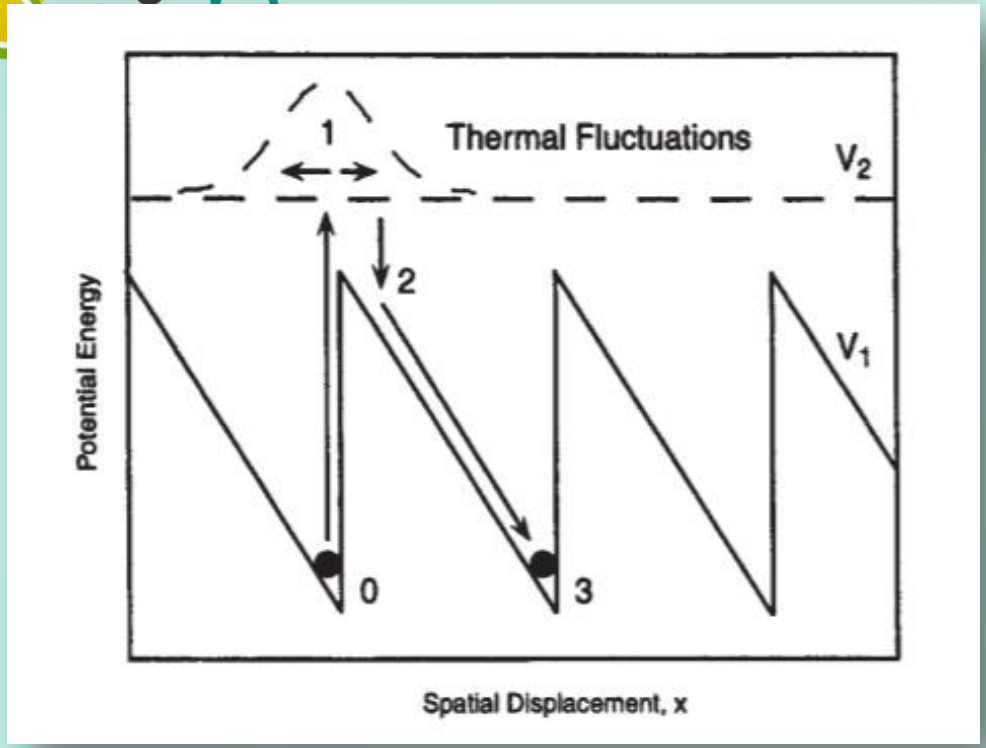




Conclusion: Assymetry makes difference

Adapted from https://www.feynmanlectures.caltech.edu/I_46.html, Astumian, R. D. (2001) Making molecules into motors. Sci. Am. 285, 57–64.

Brownian molecular motor



0
- Localized in a minimum of V_1

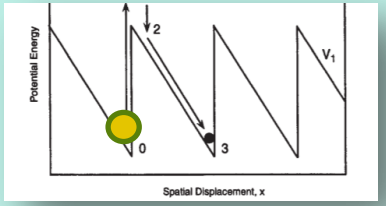
1
- Switch on V_2 - free diffusion

2-3
- Again V_1 relax and go to the minimum

Effect: moving forward with rare backward steps

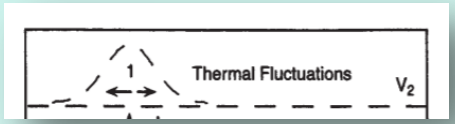
Brownian Ratchet Models of Molecular Motors, Rachid Ait-Haddou, Walter Herzog, Cell Biochemistry and Biophysics, Volume 38 (2003)

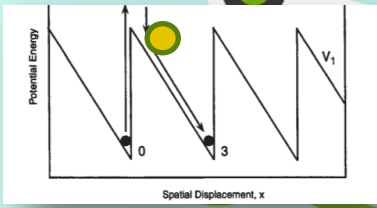
Chemically driven



1. Filament of anisotropic periodic dipoles

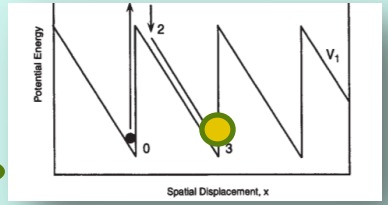
2. Green will deattach





3. White-yellow neutral

4. White deattaches



5. Goes to minimum and a step forward was performed

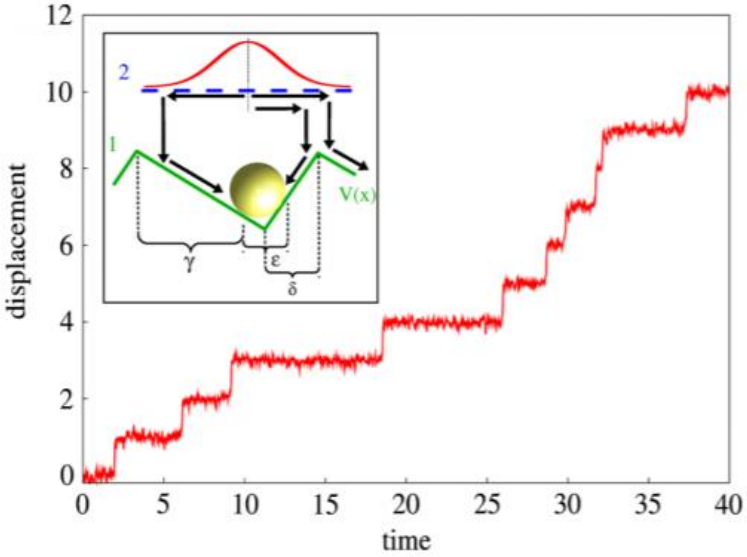
Motor Proteins as Nanomachines: The roles of Thermal fluctuations in Generating Force and Motion, Jonathon Howard, Biological Physics 47-59, 2010
Brownian Ratchet Models of Molecular Motors, Rachid Ait-Haddou, Walter Herzog, Cell Biochemistry and Biophysics, Volume 38 (2003)

Things to consider

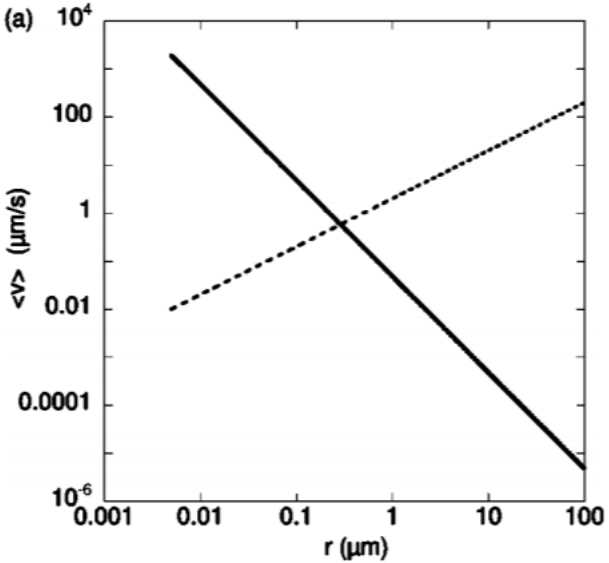
Simulations and plots

Displacement

Speed for kinesin parameters: 150 nm/s



Exemplary trajectory [1]

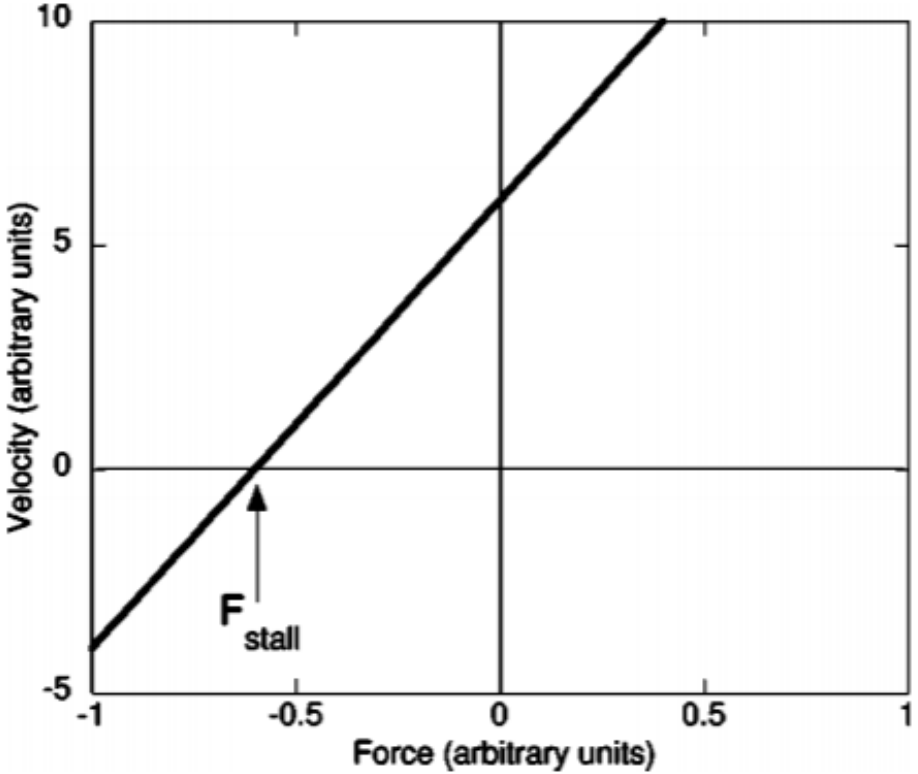


Speed as a function of size (solid line) [2]

Adapted from: [1] Performance characteristics of Brownian motors, Heiner Linke, Matthew T. Downton and Martin J. Zuckermann, : Chaos 15, 026111 (2005) [2] Running Faster Together: Huge Speed up of Thermal Ratchets due to Hydrodynamic Couplin, Paolo Malgaretti,1,* Ignacio Pagonabarraga,1 and Daan Frenkel2, PRL 109, 168101 (2012)

Cargo

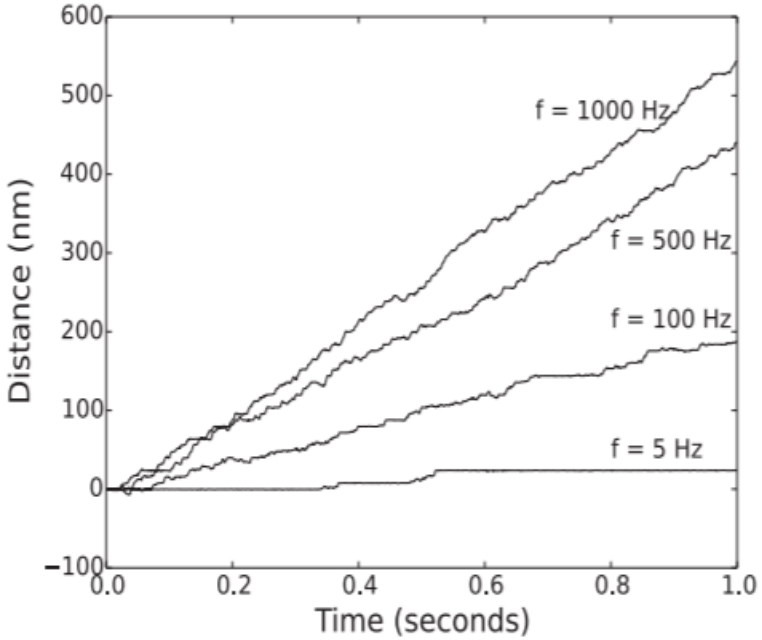
Phemonena: Too big force will make a motor to move in the opposite direction

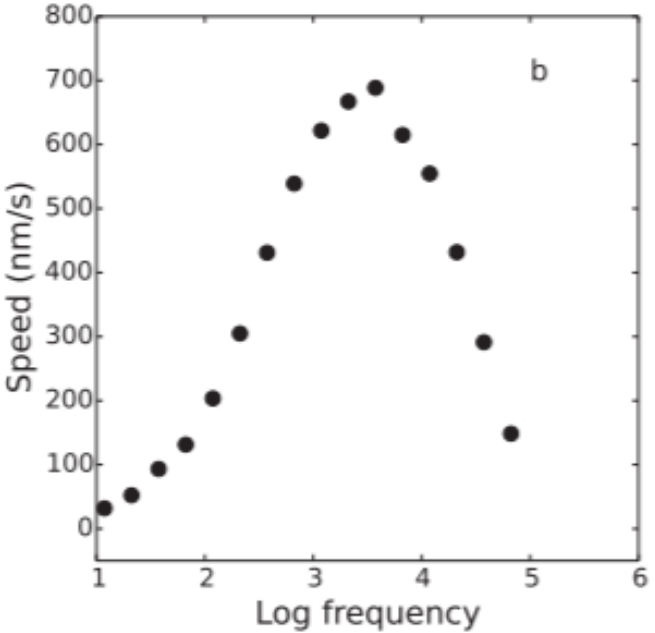


Adapted from: Performance characteristics of Brownian motors, Heiner Linke, Matthew T. Downton and Martin J. Zuckermann, : Chaos 15, 026111 (2005)

Fuel concentration

Saturation of the system



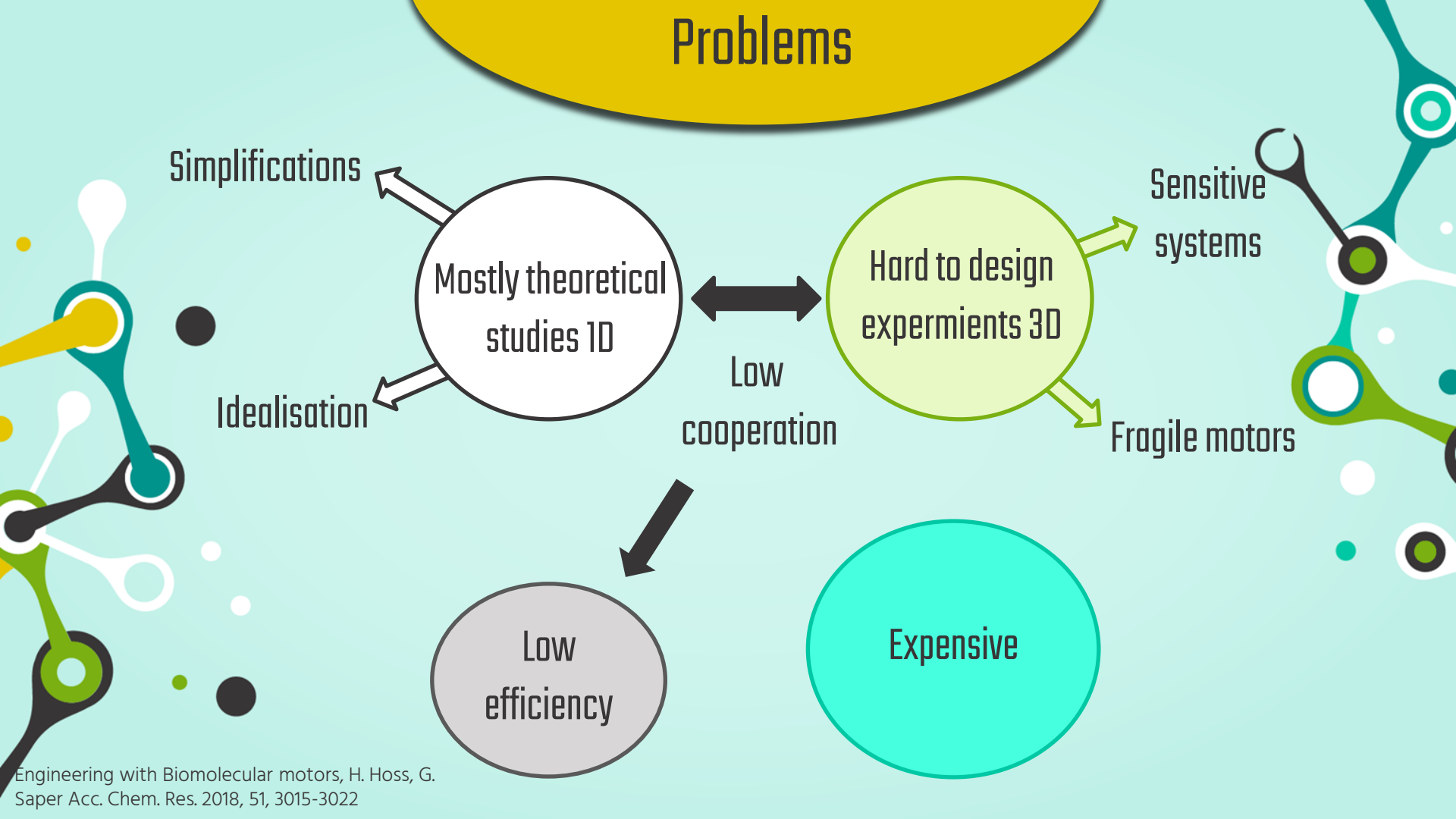


Kinesin parameters were used

Adapted from: How molecular motors extract order from chaos (a key issues review), Peter M Hoffmann 2016 Rep. Prog. Phys. 79 032601

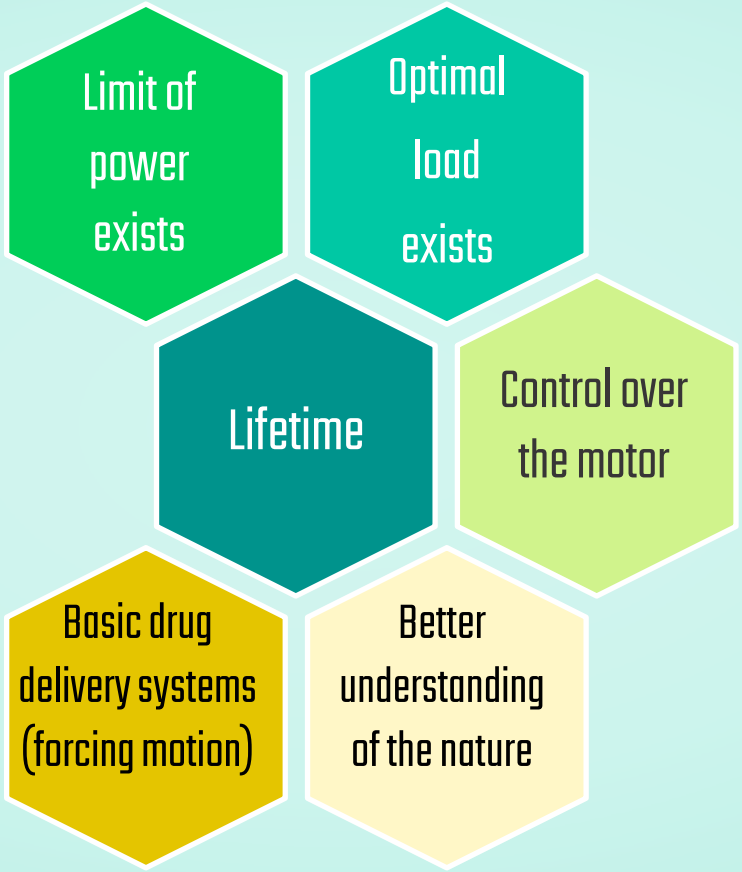
Research

Problems



Engineering with Biomolecular motors, H. Hoss, G. Saper Acc. Chem. Res. 2018, 51, 3015-3022

Sucesses in the field



Synthetic Systems Powered by Biological Motors, G.Saper, H.Hess, Chem.Rev, 120:288-309 (2020)

Future

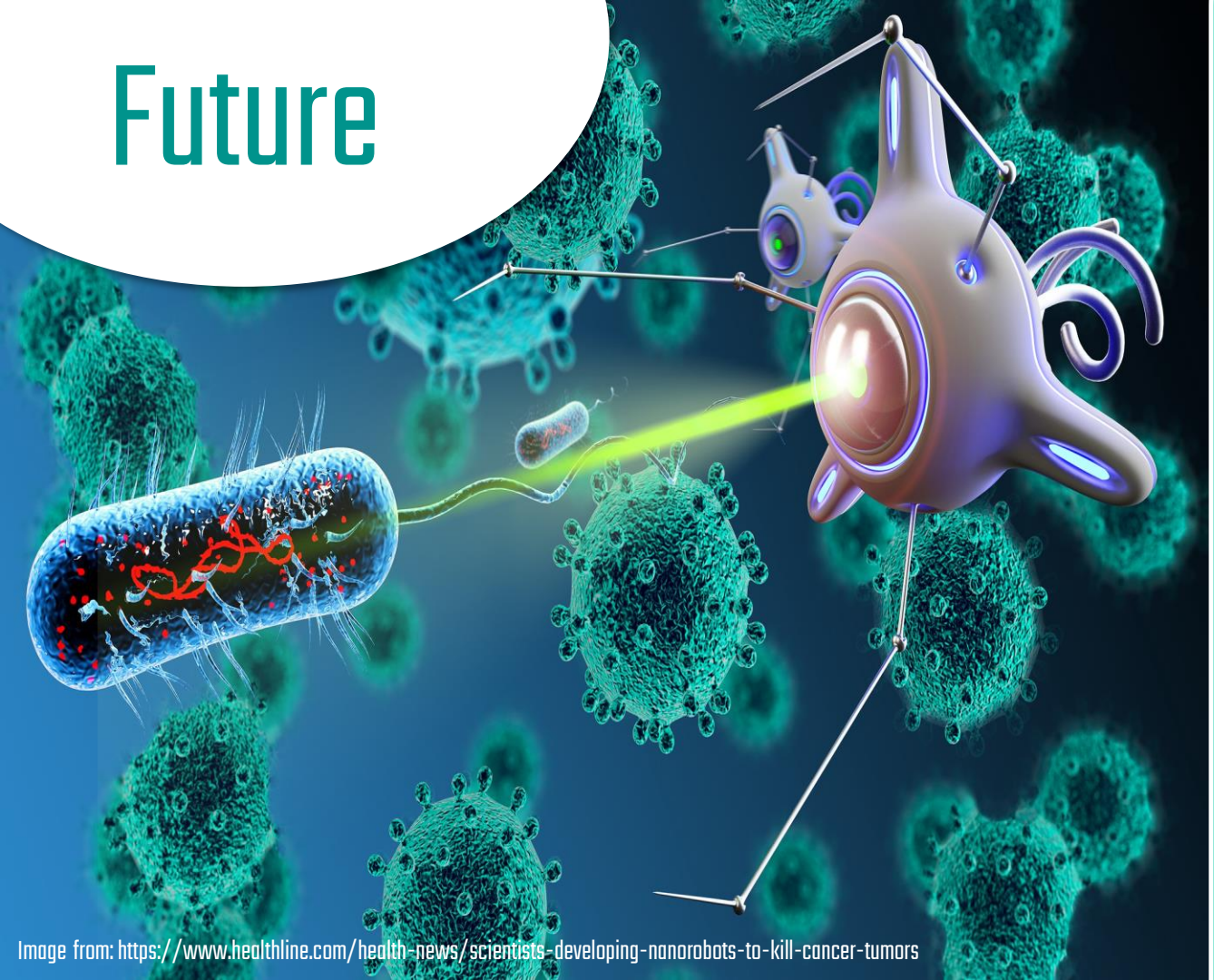


Image from: https://www.healthline.com/health-news/scientists-developing-nanorobots-to-kill-cancer-tumors

- New fabrics
- New therapies
- New tools
- Chance to use Brownian motion
- Working more in-vivo
- Chemically driven?
- Micronization of the world

Summary and personal thoughts


Thank you !