A Goal: Zero Energy Computing

Institute for Molecular Manufacturing

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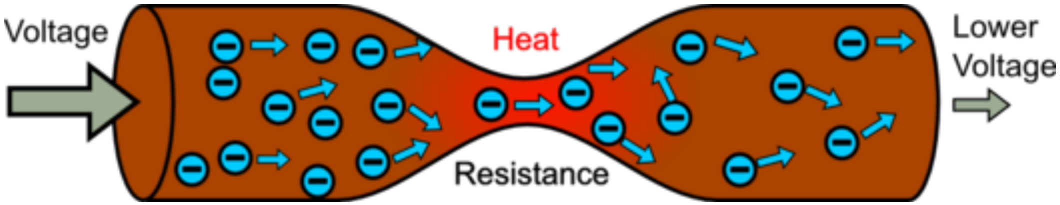
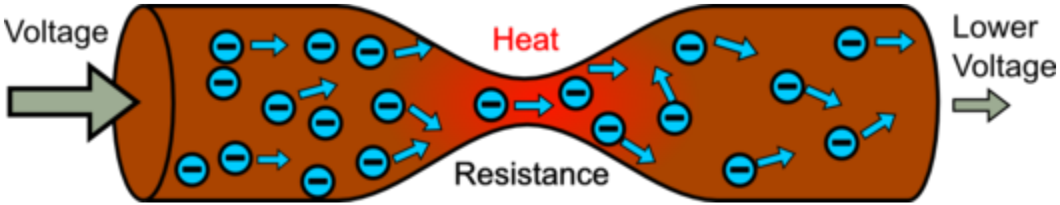
The Problem: I^2R



Typical nanoscale contacts are ~13kΩ*
One electron moving 10 nm in 10 ns dissipates
~3 x 10^{-18} J or ~750 times kT (T=300K)

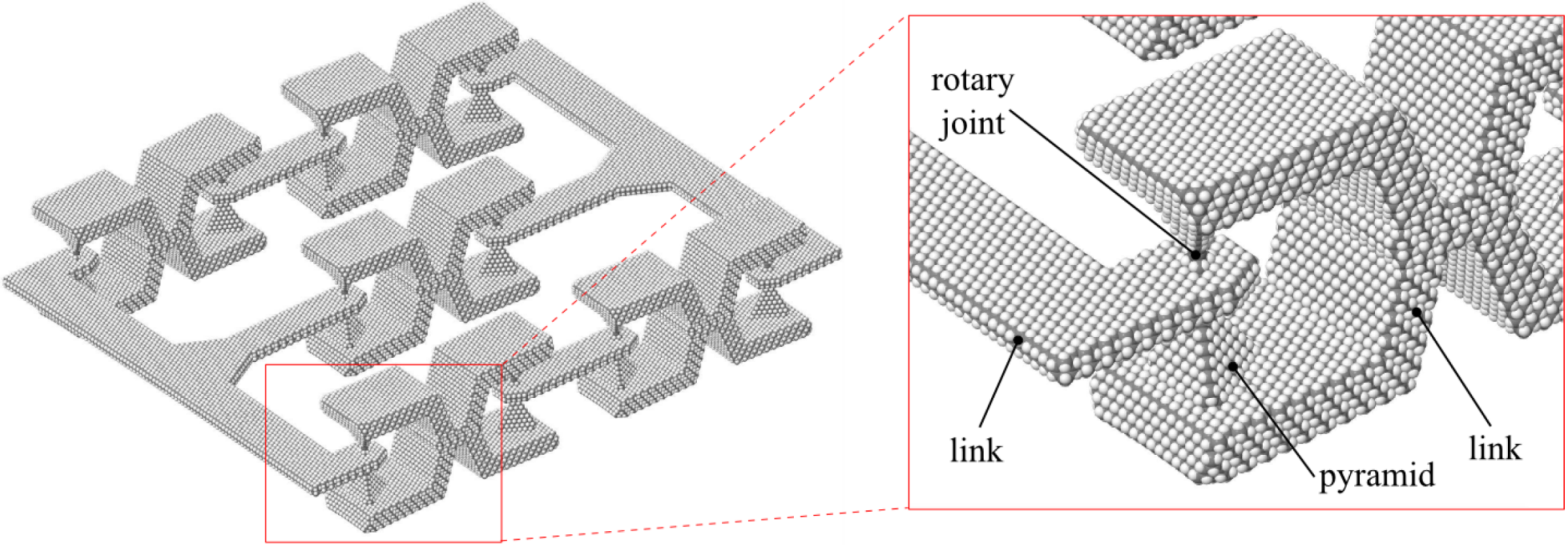


*See the Landauer Formula, https://en.wikipedia.org/wiki/Landauer_formula. Although resistive losses can be avoided by adiabatic switching this raises other issues; see, for example, Helical Logic (http://www.zyvex.com/nanotech/helicalIntro.html).

The Exploding Molecular Computer

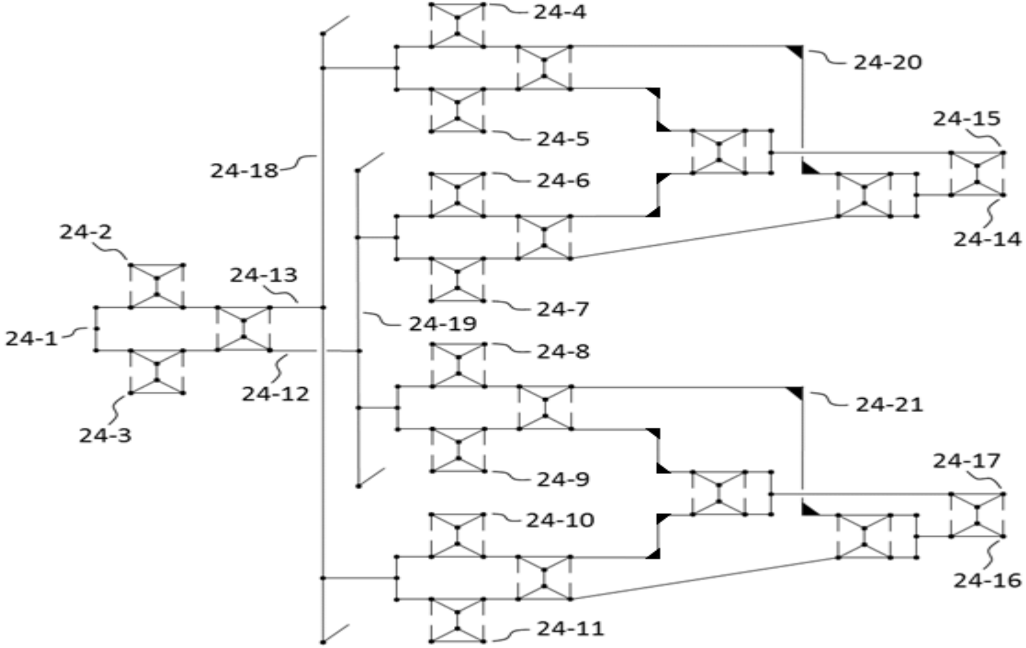
- One-liter computer
- 10^{18} gates (100nm linear size each)
- Each gate dissipating
  3×10^{-18} J per operation
- 100MHz switching speed
- ~300 megawatts

A Lock
~30nm x ~30nm x ~10nm

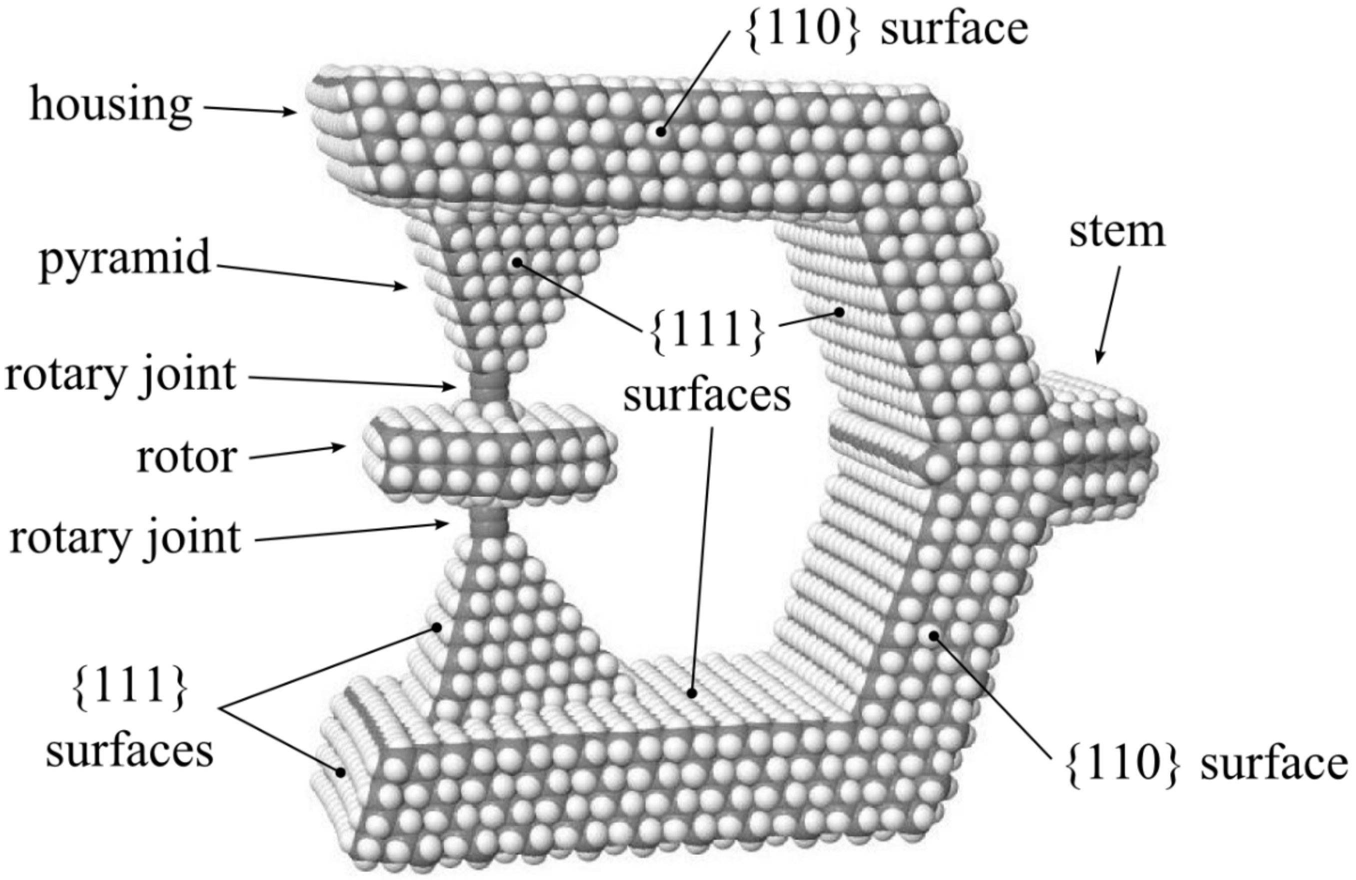


Mechanical Clocked Fredkin Gate

(made from Locks and Balances)



*Mechanical Computing Systems,
http://www.merkle.com/papers/MechanicalComputingSystems.pdf



Model used in measuring rotor drag

Rotor Drag Coefficient

$$K_{rd} \sim 2 \times 10^{-35}\ \mathrm{J\ s}$$

Evaluating the friction of rotary joints in molecular machines

Tad Hogg, Matthew S. Moses and Damian G. Allis

Molecular Systems Design & Engineering, 2017, 2, 235-252

https://doi.org/10.1039/C7ME00021A

What’s the energy dissipation?

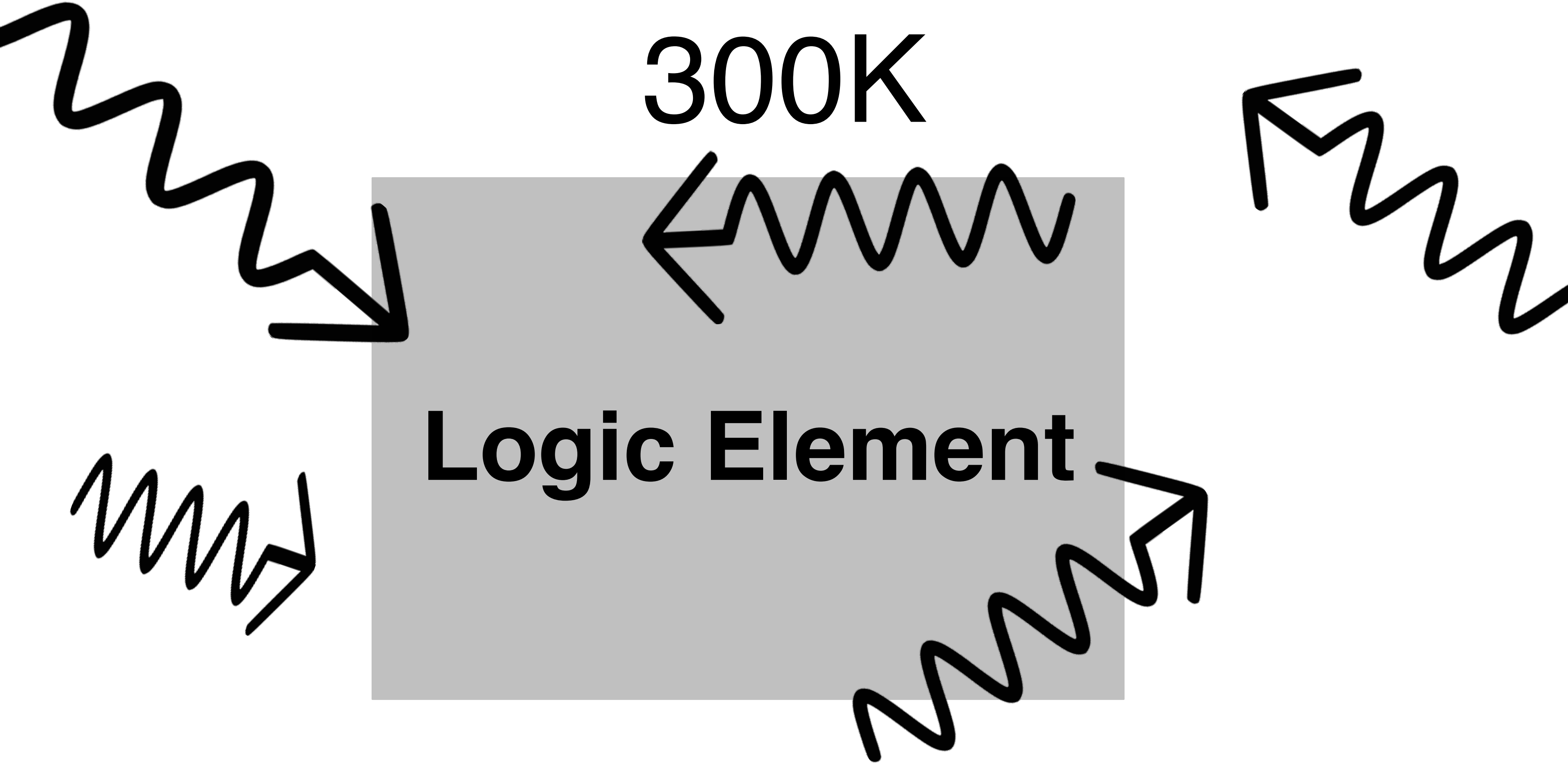
1) Rotary joints have very little drag
2) Other dissipative mechanisms can have less drag

What’s the energy dissipation?

1) Count the rotary joints
2) Determine their rotational speed
3) Apply the equation $P_{rd} = K_{rd} \nu_r^2$
4) Neglect other dissipative mechanisms

That was at 300K
What happens if we drop the temperature?

300K



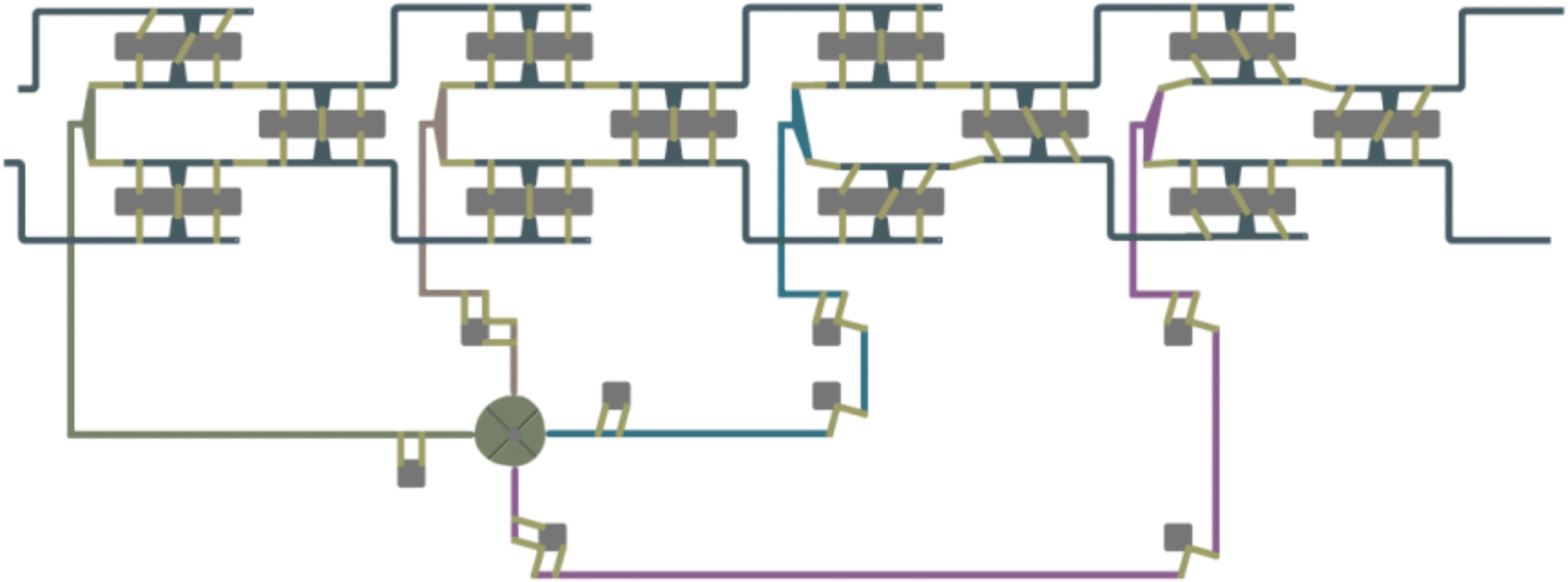
Cryogenic Temperature

If we drop the temperature enough, rotary drag should go away

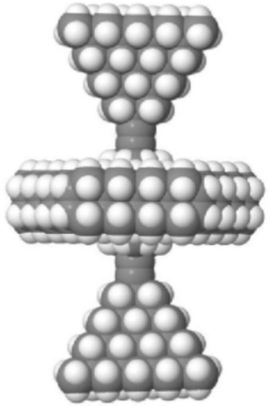
Dissipative Mechanisms Considered

Sliding drag (none)
“Snap to” (none)
EM radiation (none)
Resistive losses (none)
Resonance mechanisms (very small)
Acoustic radiation (very small)
Acoustic radiation (extremely small when canceled)
Entropic losses (extremely small)
Heat flows caused by stress/strain (extremely small)
Thermal equilibration times (under 1 ps)

END OF TALK



Rotary Drag Power Equation



$$P_{rd} = K_{rd}\, \nu_r^{\,2}$$

where:

P_{rd}	is the power dissipated (in watts) by rotary drag
K_{rd}	is the applicable rotary drag coefficient (in J·s or kg m^2/s)
ν_r	is the rotational speed (in radians/second) between the housing and the rotor