# Thermodynamics in the nanoscale

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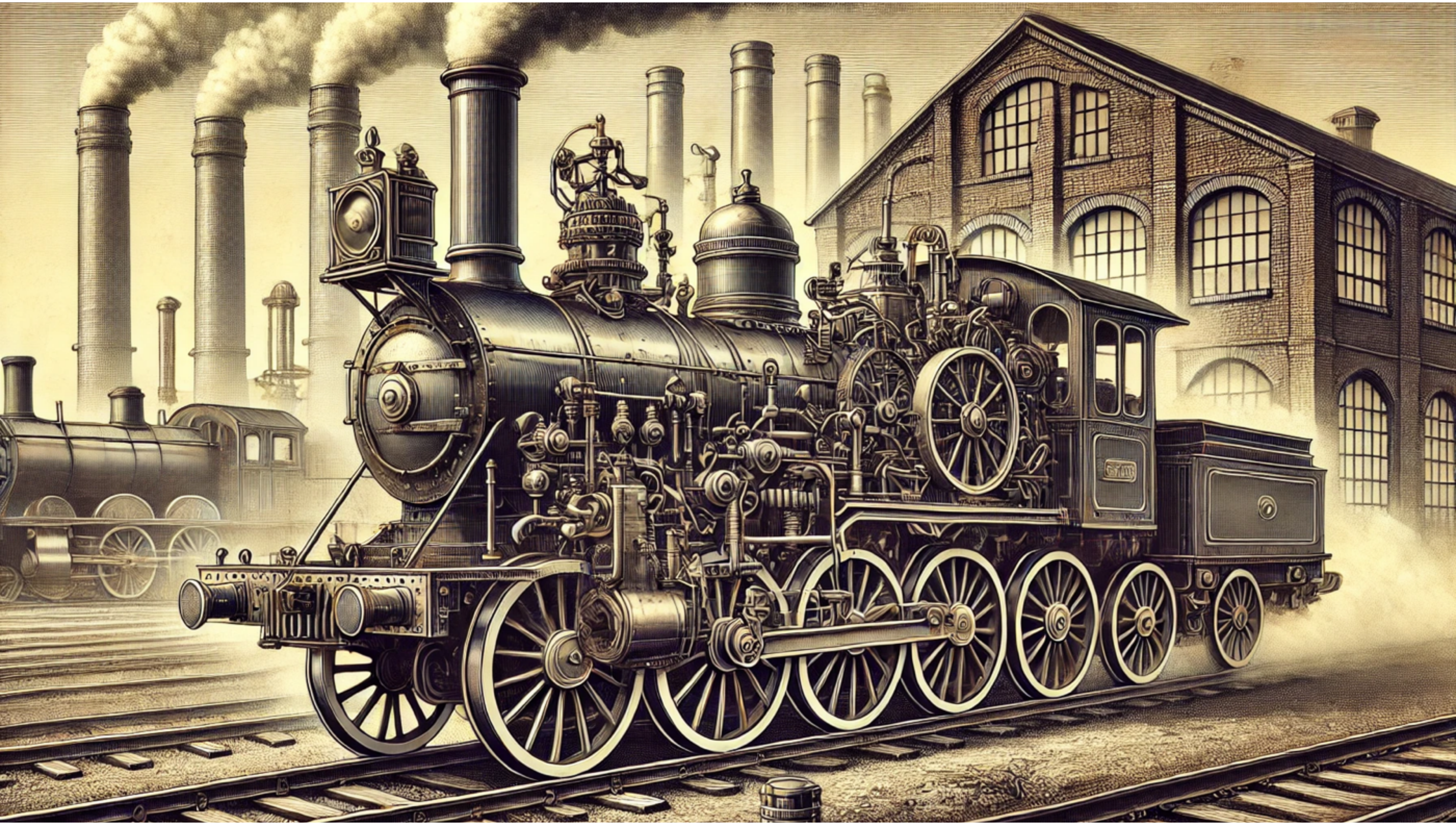
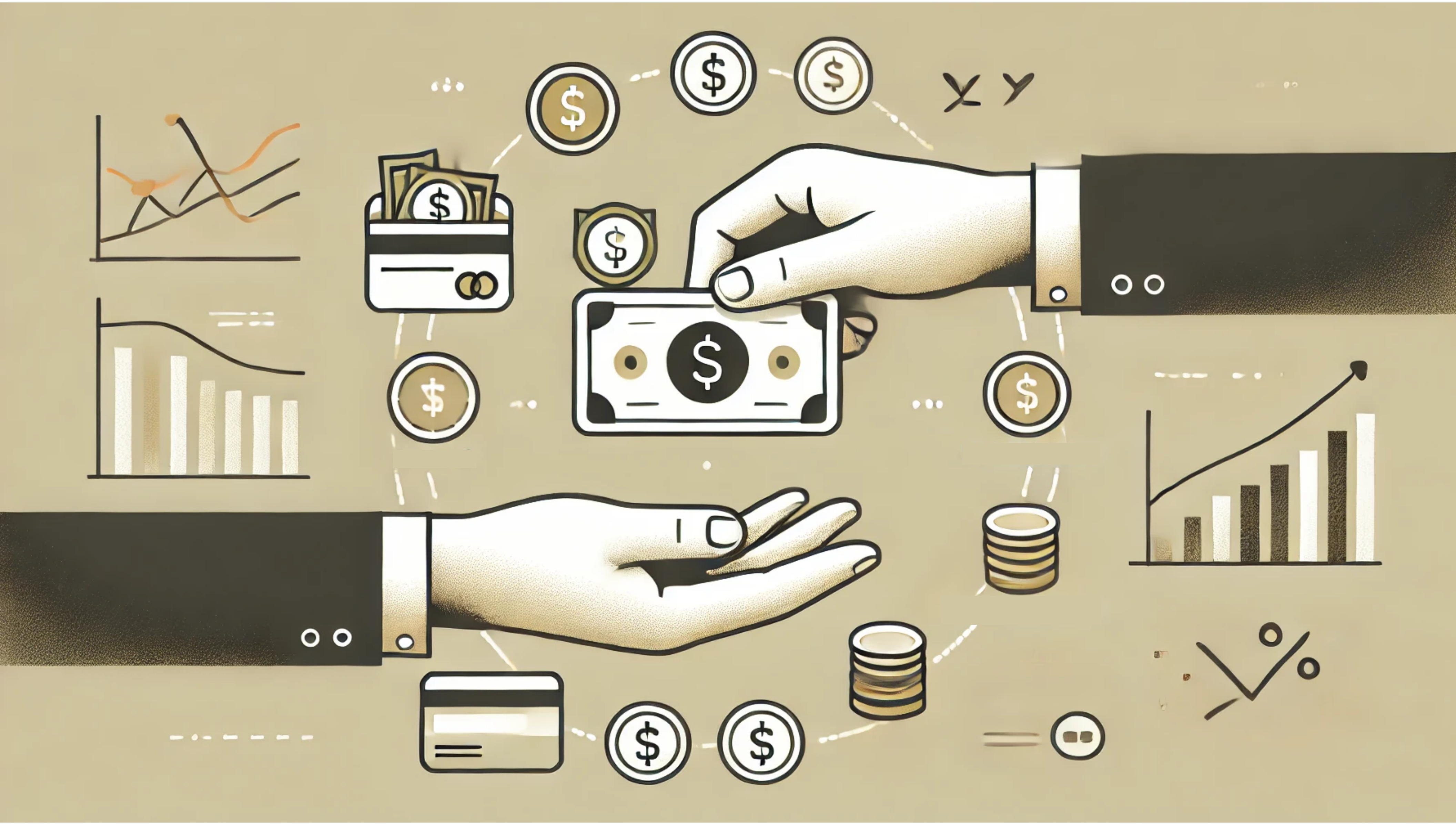


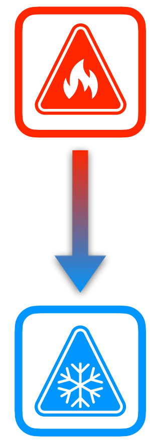


## Budget
Energy = currency

## Transduction (€ ↔ $)
Energy conservation

## Shopping
Useful tasks

## Limitations
$2^{nd}$ law



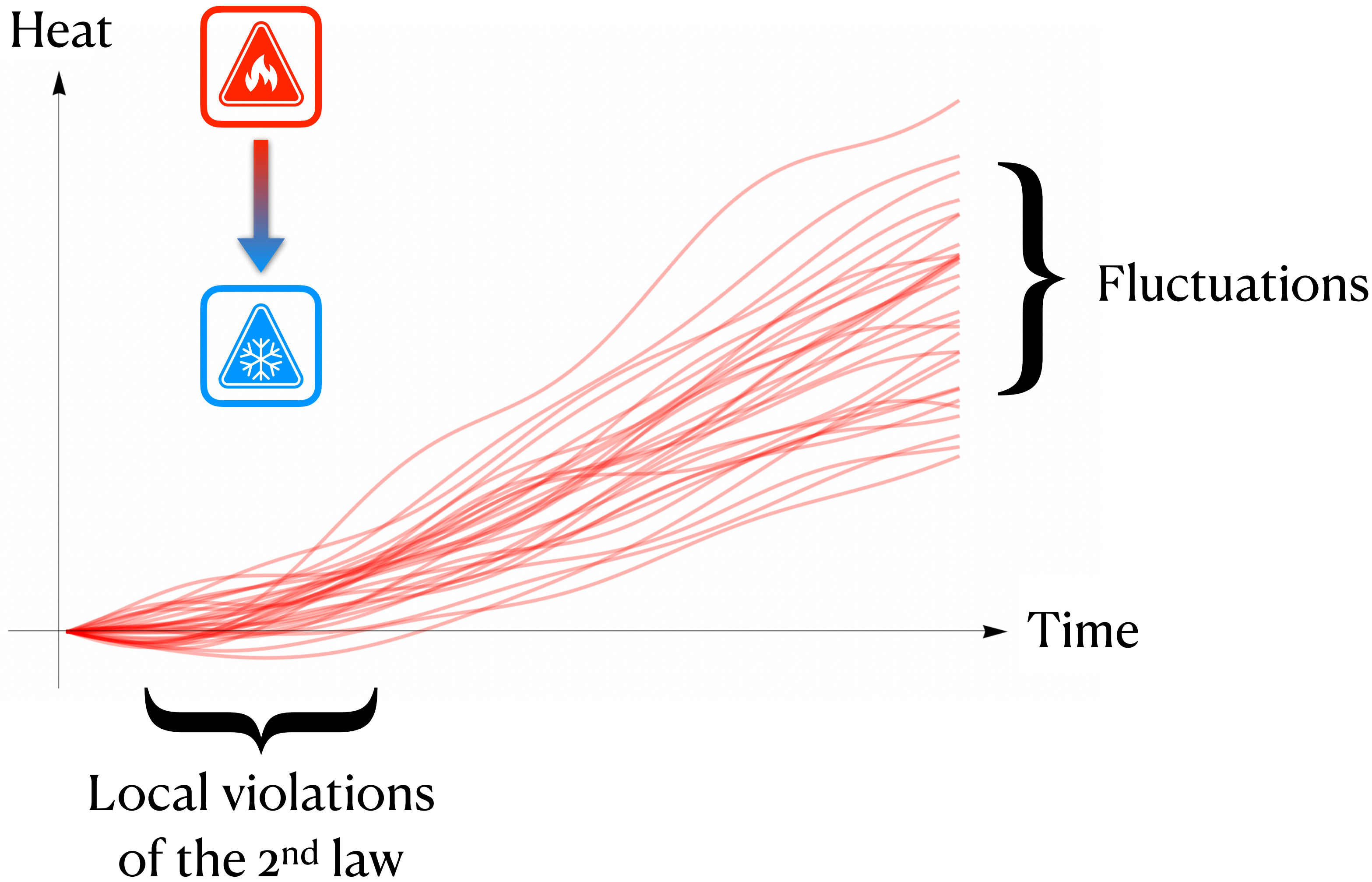
## Trade-offs
Power vs. efficiency

Slow pedaling is energy efficient, but it takes a long time to reach the top.

Pedaling fast gets you there quickly. But consumes more energy.

# What changes at the nanoscale?

Fluctuations.


Heat
Fluctuations
Time
Local violations of the 2nd law

**Thermodynamic processes become probabilistic**

When we try to cool, one of 3 things might happen:

🤩 Success!

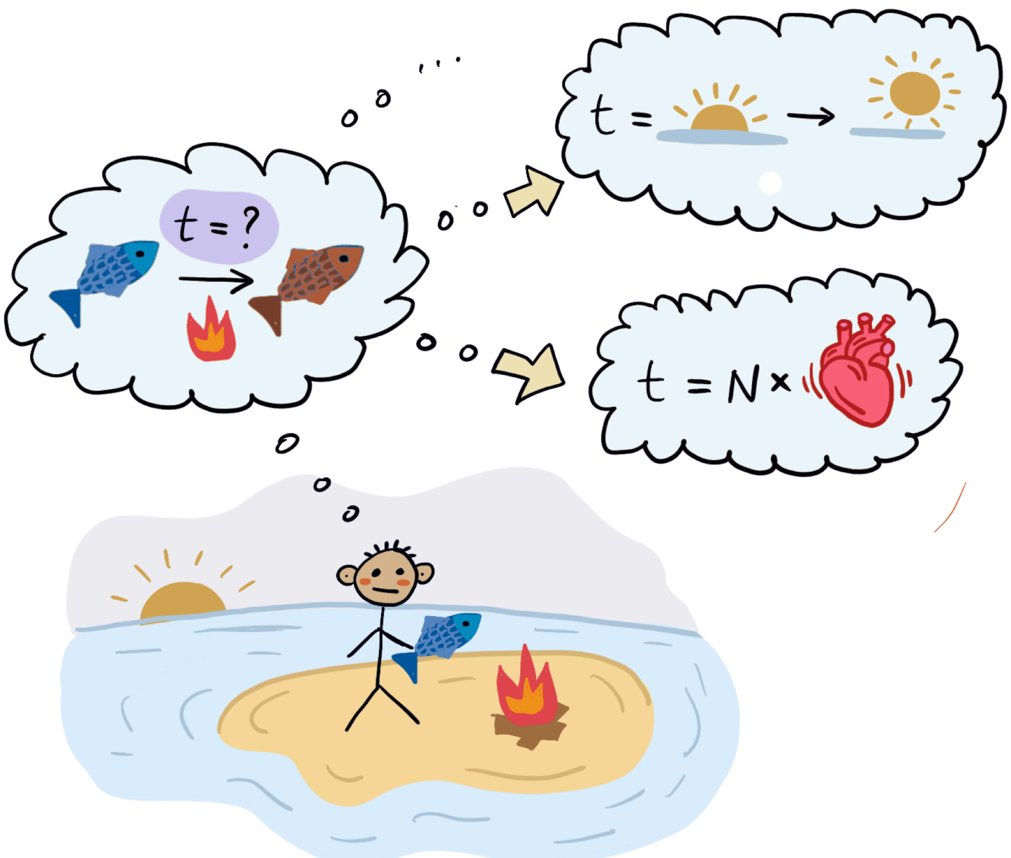
🤦 Failure.

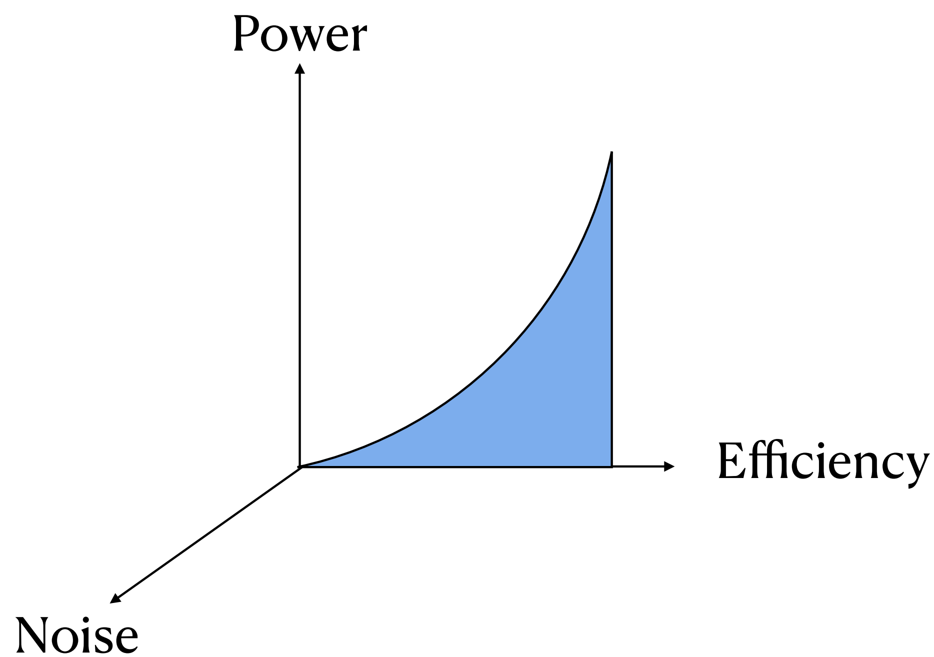
😱 Disaster! (freezer actually heat up)

Events are probabilistic: $p_S + p_F + p_D = 1$

| | |
|---|---|
| Thermodynamics imposes constraints that stop us from having $p_S = 1$ | $p_D = p_S e^{-\sigma}$ |

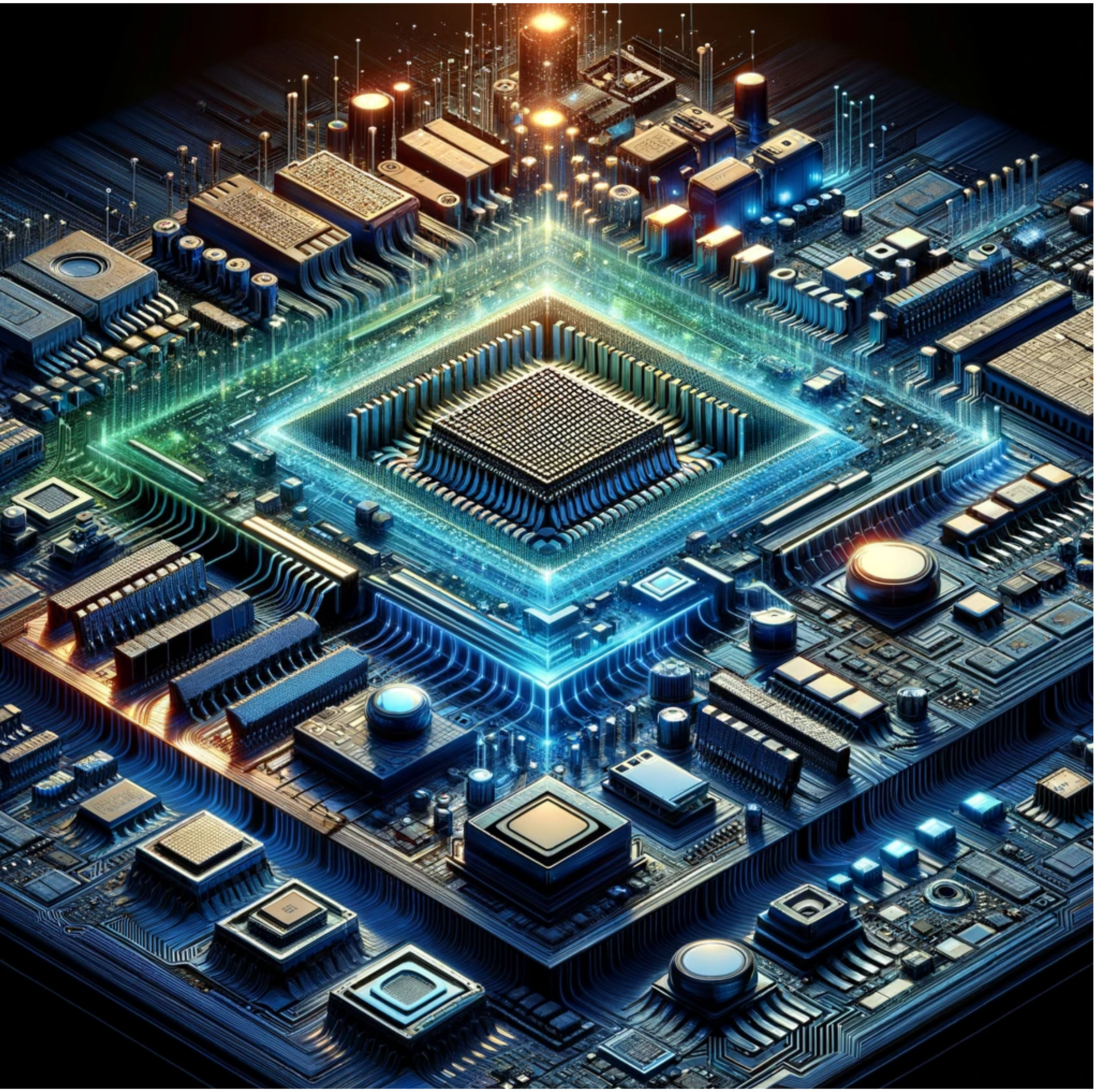
## Precision becomes part of the budget



# Why is thermodynamics at the nanoscale relevant?

**1 turbine:**
3300 tons
1.5 rotations/sec
700 MW
≃ 1% of Brazil's power
≃1.5M people



- Modern devices contain elements that spam a broad range of scales.
- Energy consumption across these scales differ *dramatically*.
- Must be able to move heat around, and across scales.
- Ex: high performance CPUs use thermoelectric plates.
  - Consume power to pump heat out of the core.