1 A Physical System that Has Been Realized: Thermodynamic computing

1.1 Overview

In classical computing errors need to be corrected. Thermodynamic computing takes an alternative view: natural thermal fluctuations (heat and electrical noise) can be used to process information. Instead of spending massive energy to *suppress* noise like standard processors, these probabilistic systems *harness* noise for energy-effi and AI acceleration.

Here is a catchphrase: *Thermodynamic computing isn't simuulating Physics. It is Physics.*

We will omit the technial details of thermodynamic computing except to say that it uses the randomness of thermodynamics as an advantage, and not as noise you need to get rid of. Conte et al. [3] from 2019, and Ball [2] are good overviews of the field.

1.2 Potential Advantages

The advantages below are *potential*.
Noise-Powered Efficiency: Traditional computers spend massive amounts of energy to clear out "noise" so distinct 0s and 1s remain recognizable. Thermodynamic computers utilize this natural wobble to process and sample from probability distributions natively.
Power Savings: Probabilistic machine learning models are emulated inefficiently on standard digital hardware. Specialized thermodynamic hardware may yield practical computing gains for specific workloads.
Room Temperature Operation: Unlike many quantum computers that require extreme sub-zero cooling, thermodynamic systems can naturally operate at ambient room temperatures.

1.3 What Problems can it solve?

Because these systems utilize physical heat fluctuations rather than deterministic logic gates, they have the potential to excel at tasks where uncertainty or randomness is an inherent part of the problem. We give some examples where there is potential, and also the obstacles.

- **Generative AI Sampling:** Digital GPUs are excellent at deterministic math (like matrix multiplication) but highly inefficient at sampling from probability distributions, which is what generative models (like ChatGPT or Midjourney) do to generate new data. Thermodynamic hardware handles this by harnessing physical noise. There has been much work on this application: (1) Wellings-Lu-Holdijk [7] have written a book on it, (2) Whitelam [8] have a recent article on it, (3) Melanson et al [5] present a small-scale thermodyamic computer and uses it to do Gaussian sampling. This is good as a proof of concept but a long way from being practical.

- **Combinatorial Optimization:** A thermodynamic computer might be able to solve NP-complete problems. The hardware treats the constraints as an energy landscape and uses thermal noise to naturally settle into the optimal solution. See Neukart [6] for a good overview. There are issues with using thermodynamic computing for NP-complete problems:

  1. The number of possible solutions to explore is still exponential.
  2. A thermodynamic computation is likely to get stuck in a local minimum.
  3. There are problems with input and output.

- **High-Dimensional Linear Algebra:** Fundamental operations like matrix inversion (flipping vast tables of numbers). By manipulating the physics of the circuits, the system solves complex linear algebra equations natively through electrical equilibrium.Molecular

  Aifer et al. [1] give thermodynamic algorithms for problems in linear algebra. Melanson et al. [4] used a thermodynamic computer to invert 4×4 and 8×8 matrices. (see

  `https://www.normalcomputing.com/blog/a-first-demonstration-of-thermodynami`

  You can click on this link even though it goes off the page. It was impossible to put the link into the bibliography entry.)

  The matrices were of floating point numbers and there was some error. This is not important if the application is AI. This is a good proof of concept but a long way from being practical.

1.4 Thermodyanmic Computers Have Been Built

1.5 Commercial Hardware & Prototypes

- **Normal Computing:** Normal Computing announced that it build a thermodynamic computer in 2025. The press release for it claims that it can do

    1. Linear and Matrix operations.
    2. Stochastic Sampling with Lattice Random Walk

    The press releas is here:

    `https://www.normalcomputing.com/blog/normal-computing-announces-tape-out-c`

    A paper by the people at Normal Computing on what it can do is here:

    `https://arxiv.org/abs/2507.10463`

    A paper in IEEE Specturm about what it can do is here:

    `http://spectrum.ieee.org/thermodynamic-computing-normal-computing`

- **Extropic (X0ero):** In 2025 Extropic announced that they have build a small thermodynamic computer. The main application seems to be sampling.

    See their press release:

    `http://extropic.ai/writing/inside-x0-and-xtr-0`

1.6 Academic & Laboratory Systems

Berkeley Lab Frameworks: Scientists at the Lawrence Berkeley National Laboratory implementing non-linear circuit frameworks. The press release claims that it can solve non-linear problems; however, at this time, this is speculation.

See their press release.
`http://newscenter.lbl.gov/2026/03/05/thermodynamic-computing-advances-with-c`

References

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[7] M. Welling, S. Lu, and L. Holdijk. *Generative AI and Stochastic Thermodynamics: A Tale of Free Energies*. Cambridge University Press, Cambridge, United Kingdom, 2026.

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