Norman Margolus*

Curriculum Vitae

Education

Ph.D. in Physics, Massachusetts Institute of Technology (1987).
Thesis Title: Physics and Computation (Edward Fredkin supervisor).

Employment

2006–2024 Independent academic researcher (currently affiliated with MIT).

2000–2005 Co-founder (with Tom Knight) and Chief Scientist of Permabit, a storage software startup.

1996–1999 Research Associate Professor at Boston University's Center for Computational Science.

1987–1995 Research Scientist at the MIT Laboratory for Computer Science.

Research

For my Ph.D. research [1–5] I was privileged to work with Ed Fredkin, Tom Toffoli, Charles Bennett, and Gerard Vichniac, who comprised the MIT Information Mechanics Group. We studied "ideal" computers and computations that reflect the structure of microscopic physics (reversibility, locality, quantumness, etc.), and computational models of physics. In this context, I worked to reformulate the computing process to better match fundamental physical constraints, and to elucidate fundamental connections between theoretical physics and finite-state computation. I also had the incredible fortune to spend a year visiting with Richard Feynman, discussing these issues with him and helping him teach a class related to this topic.

During and after my Ph.D I devoted a substantial amount of time and effort to designing, building and programming computers that help us preview, and even begin to make practical, massively parallel applications that can harness the astronomical performance that will ultimately be available in a cellular automaton (CA) format on a very microscopic physical scale. Working closely with Tom Toffoli, who is a hardware and modeling genius, this work dominated my more theoretical physics research, and after I graduated the CAM-8 project took years of time and effort. In that project, stimulated by excitement over realistic lattice-gas models of fluids and the possibilities of virtual-processor CA hardware [2], we built desktop lattice-gas supercomputers [11, 18] and pursued a wide variety of scientific collaborations in large-scale volumetric physical simulations of materials, fluids, fields, digital logic, and also in general 3D image and data processing [19]. The next big leap forward possible in this kind of computation is clear, and I presented a paper on this at the ISCA computer architecture conference in 2000 [37]. Lattice-gas machine development led to several hardware patents on parallel virtual-processor simulation of fine-grained spatial processes and on scalable physical interconnect [14,21,36]. I am also first inventor on 35 issued patents based on ideas I worked on at my software startup [43–45]. These include a new category of erasure-resilient codes, a storage system optimized to store randomly-named (hash-named) blocks of data, and the architecture of a distributed storage system that recovers quickly from large numbers of simultaneous hardware failures.

My early research career is summarized pictorially in slides from a series of lectures I gave in 2002 at Caltech [40]. My best known physics research was done while jointly at Boston University and MIT: it uses quantum mechanics to identify macroscopic classical energy with the maximum rate of distinct microscopic dynamics: the maximum number of physical events per second [32]. I have spent most of my time as an independent researcher extending these ideas, identifying other basic dynamical quantities as counts of distinct states in time and space [51]. This finite distinctness makes classical dynamics effectively discrete, in the same way limited bandwidth makes signaling with a classical wave discrete: the state defined on a discrete set of points carries all of the information, and the rest is interpolation.

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Publications

My five most cited publications have over 10,000 citations: a basic paper on quantum computing [25], the book Tom Toffoli and I wrote about our early work on physical modeling with cellular automata machines [4], the paper identifying energy as operations-per-second for physical dynamics [32], and two early papers on reversible cellular automata [1, 10]. In my opinion, though, my most significant hardware-related paper is the one I presented at ISCA 2000 [37], and I plan to do more to get its ideas out into the world. My most significant physics paper is just now being submitted for publication [51]; it illuminates a lot of basic physics in light of the relationship between dynamical quantities and counting distinct physical states.

[1] Margolus, N., "Physics-like models of computation," *Physica D* **10** (1984), 81–95. `https://doi.org/10.1016/0167-2789(84)90252-5`

[2] Margolus, N., T. Toffoli, and G. Vichniac, "Cellular-automata supercomputers for fluid dynamics modeling," *Phys. Rev. Lett.* **56** (1986), 1694–1696. `https://doi.org/10.1103/PhysRevLett.56.1694`

[3] Margolus, N., "Quantum computation," *New Techniques and Ideas in Quantum Measurement Theory* (Daniel Greenberger ed.), New York Academy of Sciences (1986), 487–497. `https://doi.org/10.1111/j.1749-6632.1986.tb12451.x`

[4] Toffoli, T., and N. Margolus, *Cellular Automata Machines: a new environment for modeling*, MIT Press (1987). `https://people.csail.mit.edu/nhm/cam-book.pdf`

[5] Margolus, N., "Physics and Computation," Massachusetts Institute of Technology Ph.D. Thesis, Department of Physics (1987). `http://hdl.handle.net/1721.1/14862`.

[6] Margolus, N., and T. Toffoli, "Cellular automata machines," *Complex Systems* **1** (1987), 967–993. `https://content.wolfram.com/uploads/sites/13/2018/02/01-5-5.pdf`. Reprinted in *Lattice Gas Methods of Partial Differential Equations* (Doolen et al. eds.), Addison-Wesley Longman Publishing Group Ltd. (1990), 219–249. `https://doi.org/10.1201/9780429032738`.

[7] Califano, Andrea, N. Margolus and T. Toffoli, *CAM-6 User's Guide*; *and* Kenneth Porter, *CAM-6 Hardware Manual*, Systems Concepts, 55 Francisco St., San Francisco 94133 (1987).

[8] Bennett, Charles, N. Margolus and T. Toffoli, "Bond-energy variables for spin-glass dynamics," *Phys. Rev. B* **37** (1988), 2254. `https://doi.org/10.1103/PhysRevB.37.2254`

[9] Margolus, N., "Parallel quantum computation," in *Complexity, Entropy, and the Physics of Information* (W. Zurek ed.), Addison-Wesley, (1990), 273–278. `https://doi.org/10.1201/9780429502880`

[10] Toffoli, T., and N. Margolus, "Invertible cellular automata: a review," *Physica D* **45**, (1990), 229–253. `https://doi.org/10.1016/0167-2789(90)90185-R`

[11] Toffoli, T., and N. Margolus, "Programmable matter: concepts and realization," *Physica D* **47**, (1990) 263-272. `https://doi.org/10.1016/0167-2789(91)90296-L`

[12] Margolus, N., "Fundamental physical constraints on the computational process," *Nanotechnology: Research and Perspectives* (B.C. Crandall and J. Lewis eds.), MIT Press (1992), 199–213. `https://people.csail.mit.edu/nhm/constraints.pdf`

[13] Smith, Mark, Yaneer Bar-Yam, Y. Rabin, N. Margolus, T. Toffoli, and C. H. Bennett, "Cellular automaton simulation of polymers", *MRS Online Proceedings Library* **248** (1991), 483–488. `https://doi.org/10.1557/PROC-248-483`

[14] Margolus, N. and T. Toffoli, "Multidimensional cellular data array processing system which separately permutes stored data elements and applies transformation rules to permuted elements," United States Patent and Trademark Office Patent No. 5,159,690, filed 09/30/88, Issued 10/27/92. `https://patents.google.com/patent/US5159690/en`

[15] Ostrovsky, Boris, M. A. Smith, M. Biafore, Y. Bar-Yam, Y. Rabin, N. Margolus, and T. Toffoli, "Massively parallel architectures and polymer simulation," *Parallel Processing for Scientific Computing*, (R. Sincovec *et al.* ed.), Society for Industrial and Applied Mathematics (1993), 193–202. https://people.csail.mit.edu/nhm/polymers.pdf

[16] Margolus, Norman, "Cellular automata machines: a new kind of computer," in *Second international conference on computational physics (ICCP-2)*, International Press (Beijing, September 1993). https://people.csail.mit.edu/nhm/china.pdf

[17] Margolus, N., "A bridge of bits," *Workshop on Physics of Computation—PhysComp '92*, IEEE ComputerSociety Press (1993), 253–257. https://people.csail.mit.edu/nhm/bridge.pdf

[18] Margolus, N., T. Toffoli, "STEP: a Space Time Event Processor," *Tech. Rep. MIT/LCS/TR-592*, MIT Lab. for Computer Science (1993). https://people.csail.mit.edu/nhm/cam8/hard-ref.pdf

[19] Agin, R., M. Biafore, R. D'Souza, S. Ganguli, H. Gilliam, N. Margolus, P. Pierini, J. Quick, D. Risacher, M. Smith, T. Toffoli, and J. Yepez, "An early sampler of CAM-8 applications," *Tech. Memo LCS-TM-513*, MIT Lab. for Comp. Sci. (October 1994). https://people.csail.mit.edu/nhm/sampler.pdf

[20] Margolus, N. and T. Toffoli, "MIT CAM-8 project final documentation and source files," (1994), including manuals http://www.ai.mit.edu/projects/im/cam8/ps, design and fabrication files http://www.ai.mit.edu/projects/im/fab, and all software and demonstration experiment files http://www.ai.mit.edu/projects/im/cam8/cam8. The entire website has been preserved from when DARPA canceled all of its parallel processing projects http://www.ai.mit.edu/projects/im/cam8.

[21] Ward, S., G. Pratt, J. Nguyen, J. Pezaris and N. Margolus, "Three-dimensional interconnect having modules with vertical top and bottom connectors," United States Patent and Trademark Office Patent No. 5,691,885, filed 10/14/94, Issued 11/25/97. https://patents.google.com/patent/US5691885/en

[22] Margolus, N., "CAM-8: a computer architecture based on cellular automata," in *Pattern Formation and Lattice-Gas Automata*, A. Lawniczak and R. Kapral, (eds.), American Mathematical Society (1996). https://arxiv.org/abs/comp-gas/9509001

[23] Margolus, N., "CAM8: a virtual processor cellular automata machine," in the proceedings of the *Eighth International Conference on Parallel and Distributed Computing Systems* (Orlando, Florida, September 1995). https://people.csail.mit.edu/nhm/pdcs95.pdf

[24] Adler, C., B. Boghosian, E. Flekkoy, N. Margolus, and D. Rothman, "Simulating three-dimensional hydrodynamics on a cellular-automata machine," *J. Stat. Phys.* **81** (1995), 105–128. https://doi.org/10.1007/BF02179971

[25] Barenco, A., C. H. Bennett, R. Cleve, D. P. DiVincenzo, N. Margolus, P. Shor, T. Sleator, J. Smolin, H. Weinfurter, "Elementary gates for quantum computation," *Phys. Rev. A.* **52:**5 (1995), 3457–3467. https://doi.org/10.1103/PhysRevA.52.3457

[26] Margolus, N, "Large-scale logic-array computation," in Schewel et. al. (eds.) *SPIE Proceedings, volume 2914*, SPIE (1996), 341–352. https://doi.org/10.1117/12.255832

[27] Boghosian, B., J. Yepez, F. J. Alexander, and N. Margolus, "Integer lattice gases," *Phys. Rev. E* **55**:4 (1997), 4137–4147. https://doi.org/10.1103/PhysRevE.55.4137

[28] Margolus, N.,"An FPGA architecture for DRAM-based systolic computations," in Arnold et. al. (eds.) *Proceedings of the IEEE Workshop on FPGAs for Custom Computing Machines*, IEEE Comp. Soc. Press (1997), 2–11. https://doi.org/10.1109/FPGA.1997.624599

[29] Frank, M., T. Knight, N. Margolus, "Reversibility in optimally scalable computer architectures," in Calude et. al. (eds.) *Unconventional Models of Computation*, Springer-Verlag (1998), 165–182. https://people.csail.mit.edu/nhm/rev-scalable.pdf

[30] FRANK, M., C. VIERI, M. AMMER, N. LOVE, N. MARGOLUS and T. KNIGHT, "A scalable reversible computer in silicon," in CALUDE et. al. (eds.) *Unconventional Models of Computation*, Springer-Verlag (1998), 183–200. https://people.csail.mit.edu/nhm/flattop.pdf

[31] VIERI, C., M. J. AMMER, M. FRANK, N. MARGOLUS, and T. KNIGHT, "A fully reversible asymptotically zero energy microprocessor," in *Proceedings of ISCA Power-Driven Microarchitecture Workshop* (1998), 138–142. https://people.csail.mit.edu/nhm/10.1.1.35.474.pdf

[32] MARGOLUS, N., L. LEVITIN, "The maximum speed of dynamical evolution," *Physica D* **120**, 188–195 (1998). https://doi.org/10.1016/S0167-2789(98)00054-2

[33] MARGOLUS, N., "Crystalline Computation," Chapter 18 in *Feynman and Computation* (A. HEY, ed.), Perseus Books (1999). http://arxiv.org/abs/comp-gas/9811002

[34] D'SOUZA, R., and N. MARGOLUS, "Thermodynamically reversible generalization of diffusion limited aggregation," *Phys. Rev. E* **60**, (1999) 264–274. https://doi.org/10.1103/PhysRevE.60.264

[35] MARGOLUS, N., "SPACERAM: A SIMD-on-DRAM spatial lattice processor," *Proposal to DARPA in response to BAA99-03* (1999). This proposal was withdrawn because of an (incorrectly) perceived conflict with another proposal I was affiliated with. https://people.csail.mit.edu/nhm/darpa.pdf

[36] MARGOLUS, N., "Mechanism for efficient data access and communication in parallel computations on an emulated spatial lattice," United States Patent and Trademark Office Application Number 09/373,394, filed 08/12/99, issued in 2001 as US Patent 6,205,533. https://patents.google.com/patent/US6205533B1/en

[37] MARGOLUS, N., "An embedded DRAM architecture for large-scale spatial-lattice computations," in *The 27th Annual International Symposium on Computer Architecture*. IEEE Computer Society, (2000), 149–160. https://doi.org/10.1145/339647.339672

[38] MARGOLUS, N., "Universal cellular automata based on the collisions of soft spheres," in *Collision Based Computation*, A. ADAMATZKY (Ed.), Springer (2002) 107–134; also in *New Constructions in Cellular Automata*, C. MOORE and D. GRIFFEATH, (Eds.), Oxford (2003) 231–260. https://doi.org/10.1007/978-1-4471-0129-1_5

[39] D'SOUZA, R., N. MARGOLUS and M. A. Smith, "Dimension-splitting for simplifying diffusion in lattice-gas models," *J. Stat. Phys.* **107** (2002), 401–422. https://doi.org/10.1023/A:1014587326991

[40] MARGOLUS, N., "Physics becomes the computer," static version of slides presented in a series of lectures at the *Computing Beyond Silicon Summer School* at Caltech (June 2002):
Emulating Physics https://people.csail.mit.edu/nhm/emulating-physics.pdf
Physical Worlds https://people.csail.mit.edu/nhm/physical-worlds.pdf
Spatial Computers https://people.csail.mit.edu/nhm/spatial-computers.pdf
Nature as Computer https://people.csail.mit.edu/nhm/nature.pdf

[41] Margolus, N., "Looking at nature as a computer," *International Journal of Theoretical Physics* **42**:2, (2003) 309–327. https://doi.org/10.1023/A:1024403618093

[42] D'SOUZA, R., G. HOMSY and N. MARGOLUS, "Simulating digital logic with the reversible aggregation model of crystal growth," in *New Constructions in Cellular Automata*, C. MOORE and D. GRIFFEATH, (Eds.), Oxford (2003) 211–230. https://doi.org/10.1093/oso/9780195137170.001.0001

[43] MARGOLUS, N., T. KNIGHT Jr., B. BOGHOSIAN, J. FLOYD, S. HARTMAN, G. HOMSY II and G. PRATT, "Data repository and method for promoting network storage of data," United States Patent and Trademark Office Application Number 09/785,535, Filed 02/16/01. Split into 12 continuation applications and issued between 2008 and 2015 as utility patents: US7412462, US7457959, US7657931, US7693814, US7587617, US7287030, US7124305, US7356701, US7506173, US7685096, US7398283, US9177175. https://patents.google.com/patent/US7412462/en

[44] Margolus, N., J. Floyd, G. Homsy and J. Keller, "History preservation in a computer storage system," United States Patent and Trademark Office Application Number 10/374,517, filed 02/26/03. Split into 15 continuation applications and issued between 2009 and 2015 as utility patents: US7478096, US7987197, US8055628, US7979397, US9104716, US7912855, US7363326, US7734595, US7496555, US7467144, US7930315, US7318072, US8095516, US7747583, US7293027. https://patents.google.com/patent/US7478096/en

[45] Margolus, N., J. Coburn and T. Jaskiewicz, "Scalable and fault tolerant storage system," United States Patent and Trademark Office Application Number 60/789,016, filed 04/04/2006. Split into two US patent applications issued in 2011 and 2013 as US7979771 and US8364891. Also issued as PCT, European and Japanese patents. https://patents.google.com/patent/US7979771/en https://patents.google.com/patent/US8364891/en

[46] Margolus, N, "Mechanical systems that are both classical and quantum," (2008). https://arxiv.org/abs/0805.3357

[47] Margolus, N., "Quantum emulation of classical dynamics," (2011). https://arxiv.org/abs/1109.4995

[48] Margolus, N., "The ideal energy of classical lattice dynamics," *Lect. Notes Comput. Sc.* **9099** (2015), 169-180. https://doi.org/10.1007/978-3-662-47221-7_13

[49] Shanahan, B., A. Chenu, N. Margolus and A. del Campo, "Quantum speed limits across the quantum-to-classical transition," *Phys. Rev. Lett.* **120** (2018), 070401. https://doi.org/10.1103/PhysRevLett.120.070401

[50] Margolus, N., "Finite-state classical mechanics," *Lect. Notes in Comput. Sc.* **11106** (2018), 47-60. https://doi.org/10.1007/978-3-319-99498-7_3

[51] Margolus, N., "The finite distinctness of physical systems," (May 2024). https://arxiv.org/abs/2111.00297