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Personal

Born 7.7.70, Philadelphia, PA; raised in Morgantown, WV

Professional Positions

- 2016— , Professor, Department of Psychological and Brain Sciences, Boston University
- 2017— , Professor, Department of Physics, Boston University
- 2011—2016, Associate Professor, Department of Psychological and Brain Sciences, Boston University
- 2008—2011, Associate Professor, Department of Psychology, Syracuse University
- 2004—2011, Courtesy appointment, Biomedical and Chemical Engineering, Syracuse University
- 2002—2008, Assistant Professor, Department of Psychology, Syracuse University

Education

- 2001-2002 Postdoctoral Fellow, Department of Psychology, Boston University, Michael Hasselmo, advisor, Computational neuroscience.
- 1999-2001 Postdoctoral Fellow, Department of Psychology, Brandeis University, Michael Kahana, advisor, Cognitive neuroscience.
- 1999 Ph.D., Brandeis University, Neuroscience; Thesis: *Temporal context in human memory*, Michael Kahana, chair.
- 1993 B.A., Rutgers University, Physics, Magna Cum Laude.
- Also attended: West Virginia University, Raritan Valley Community College, New School for Social Research.

Publications [Google Scholar Citation Report]

- Daniels, B.C., and Howard, M.W. (2025). Continuous attractor networks for Laplace Neural Manifolds. *Computational Brain & Behavior*. **8**, 392–409. doi://10.1007/s42113-024-00234-4
- Affan, R.O., Bright, I.M., Pemberton, L.N., Cruzado, N.A., Scott, B.B., and Howard, M.W. (2025). Ramping dynamics in the frontal cortex unfold over multiple timescales during motor planning. *Journal of Neurophysiology*, **133**, 625-637. doi://10.1152/jn.00234.2024
- Sarkar, A., Wang, C., Zuo, S., and Howard, M.W. (2024). "What" × "When" working memory representations using Laplace Neural Manifolds. arXiv://2409.20484
- Howard, M.W., Esfahani, Z.G., Le, B., and Sederberg, P.B. (2025). Learning temporal relationships between symbols with Laplace Neural Manifolds. *Computational Brain & Behavior*, **8**, 211-232. arXiv://2302.10163 doi://10.1007/s42113-024-00230-8
- Senne*, R.A.,Suthard*, R.L., Cao, R., Monasterio, A.H., Reusch, E.A., Buzharsky, M.D., Howard, M.W., and Ramirez, S. (2024). A hippocampal astrocytic sequence emerges during learning and memory. bioRxiv://2024.09.06.611660v1 arXiv://2406.04545
- Cao, R., Bright, I.M., and Howard, M.W. (2024). Ramping cells in rodent mPFC encode time to past and future events via real Laplace transform. *Proceedings of the National Academy of Sciences*, **121**, e2404169121. doi://10.1073/pnas.2404169121
- Lohnas, L. J. and Howard, M. W. (2024). The influence of emotion on temporal context models, *Cognition and Emotion,* **39**, 18-46. doi://10.1090/02699931.2024
- Howard, M.W. (2024). Memory for time. *Oxford Handbook of Human Memory*, A.D. Wagner and M.J. Kahana, Eds. Oxford University Press. (pdf)
- Mikkelsen, C., Charczynski, S.J., Warden, M.R., Miller, E.K., and Howard, M.W. (2023). Coding of time with non-linear mixed selectivity in prefrontal cortex ensembles. bioRxiv://2023.04.07.535754v1.
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- Howard, M.W. (2023). Formal models of memory based on temporally-varying representations. In F. G. Ashby, H. Colonius, & E. Dzhafarov (Eds.), *The new handbook of mathematical psychology*, Volume 3. Cambridge University Press.
- Cao, R., Bladon, J.H., Charczynski, S.J., Hasselmo, M.E., and Howard, M.W. (2022). Internally generated time in the rodent hippocampus is logarithmically compressed. *eLife*, **11**, e75353. doi://10.7554/eLife.75353
- Jacques, B.G, Tiganj, Z., Sarkar, A., Howard, M.W., and Sederberg, P.B. (2022). A deep convolutional neural network that is invariant to time rescaling. *Proceedings of the 39th International Conference on Machine Learning*, **162**, 9729-9738. pdf, arXiv://2107.04616
- Maini, S.S., Mochizuki-Freeman, J., Indi, C.S., Jacques, B.G., Sederberg, P.B., Howard, M.W., and Tiganj, Z. (2022). Constructing compressed number lines of latent variables using a cognitive model of memory and deep neural networks. NeurIPS MemARI workshop.

- Tiganj, Z.*, Singh, I.*, Esfahani, Z.G., and Howard, M.W. (2022). Scanning a compressed ordered representation of the future. *Journal of Experimental Psychology: General*. **151**, 3082–3096. bioRxiv://229617 doi://10.1037/xge0001243
- Liu, Y., Levy, S.J., Mau, W., Geva, N., Rubin, A., Ziv, Y., Hasselmo, M.E., and Howard, M.W. (2022). Consistent population activity on the scale of minutes in the mouse hippocampus. *Hippocampus*, **32**, 359-372. bioRxiv://430172
- Goh, W.Z., Ursekar, V., and Howard, M.W. (2022). Predicting the future with a scale-invariant temporal memory for the past. *Neural Computation*. **34**, 642–685. arXiv://2101:10953
- Tiganj, Z., Tang, W., and Howard, M.W. (2021). A computational model for simulating the future using a memory timeline. *Proceedings of the Annual Meeting of the Cognitive Science Society*,**43**, 1173-1179. eScholarship.org://qt7m38h6c9
- Jacques, B., Tiganj, Z., Howard, M.W., and Sederberg, P.B. (2021). DeepSITH: Efficient learning via decomposition of what and when across time scales. *NeurIPS*. arXiv://2104.04646
- Sheehan, D.J., Charczynski, S., Fordyce, B.A., Hasselmo, M.E., and Howard, M.W. (2021). A compressed representation of spatial distance in the rodent hippocampus. bioRxiv://431306
- Sarkar, A., and Howard, M.W. (2021). Scale-dependent relationships in natural language. *Computational Brain & Behavior*. **4**, 164-177. (doi)
- Cruzado, N.A., Tiganj, Z., Brincat, S.L., Miller, E.K., Howard, M.W. (2020). Conjunctive representation of what and when in monkey hippocampus and lateral prefrontal cortex during an associative memory task. *Hippocampus*, **30**, 1332-1346. (doi)
- Howard, M.W. and Hasselmo, M.E. (2020). Cognitive computation using neural representations of time and space in the Laplace domain. arXiv://2003.11668
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- Liu, Y., and Howard M.W. (2020). Generation of scale-invariant sequential activity in linear recurrent networks. *Neural Computation*, **32**, 1379-1407. (doi)
- Babcock, S., Howard, M.W., and McGuire, J. (2020). Time-conjunctive representations of future events. *Memory & Cognition*. **48**, 672-682. (doi)
- Bladon, J.H., Sheehan, D.J. DeFrietas, C., and Howard, M.W. (2019). In a temporally segmented experience hippocampal neurons represent temporally drifting context but not discrete segments. *Journal of Neuroscience*, **39**, 6936-6952. (doi)
- Tiganj, Z., Cruzado, N. and Howard, M.W. (2019). Towards a neural-level cognitive architecture: modeling behavior in working memory tasks with neurons. In A.K. Goel, C.M. Seifert, & C. Freksa (Eds.), Proceedings of the 41st Annual Conference of the Cognitive Science Society (pp. 1118–1123). Montreal, QB: Cognitive Science Society.

- Toro-Serey, C., Bright, I.M., Wyble, B.P., and Howard, M.W. (2019). Rapid presentation rate negatively impacts the contiguity effect in free recall. In A.K. Goel, C.M. Seifert, & C. Freksa (Eds.), Proceedings of the 41st Annual Conference of the Cognitive Science Society (pp. 1131–1135). Montreal, QB: Cognitive Science Society. psyArxiv://qb5sx
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- Palombo, D.J.*, DiLascio, J.M.*, Howard, M.W., and Verfaellie, M. (2019). Medial temporal lobe amnesia is associated with a deficit in recovering temporal context. *Journal of Cognitive Neuroscience*. **31**, 236-248.
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- Spears, T.A., Jacques, B.G., Howard, M.W., and Sederberg, P.B. (2018). Scale-invariant temporal history (SITH): optimal slicing of the past in an uncertain world. arXiv://1712.07165
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- Howard, M. W. and Shankar, K. H. (2018). Neural scaling laws for an uncertain world. *Psychological Review*, **125**, 47-58. (doi)
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- Tiganj, Z., Kim, J., Jung, M. W., and Howard, M. W. (2017). Sequential firing codes for time in rodent medial prefrontal cortex. *Cerebral Cortex*, **27**, 5663-5671. (doi)
- Singh, I., Oliva, A., and Howard, M. W. (2017). Visual memories are stored on a logarithmically-compressed representation of the past. bioRxiv://201295
- Shankar, K. H., Singh, I., and Howard, M. W. (2016). Neural mechanism to simulate a scale-invariant future. *Neural Computation*, **28**, 2594–2627, (doi).
- Salz, D. M., Tiganj, Z., Khasnabish, S., Kohley, A, Sheehan, D., Howard, M. W., and Eichenbaum, H. (2016). Time cells in hippocampal area CA3. *Journal of Neuroscience*, **36**, 7476-7484. (doi).
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- Howard, M. W., Shankar, K. H., Aue, W. R., and Criss, A. H. (2015). A distributed representation of internal time, *Psychological Review*. **122**, 24-53. (doi)
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- Howard, M. W., and Eichenbaum, H. (2013). The hippocampus, time and memory across scales, *Journal of Experimental Psychology: General*, **142**, 1211-1230.
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- Shankar, K. H., and Howard, M. W. (2012). A scale-invariant internal representation of time, *Neural Computation*, **24**, 134–193.
- Howard, M. W., Shankar, K. H., and Jagadisan, U. K. K. (2011). Constructing semantic representations from a gradually-changing representation of temporal context. *Topics in Cognitive Science*, **3**, 48-73.
- Shankar, K. H., and Howard, M. W. (2010). Timing using temporal context, *Brain Research*, **1365**, 3-17 (lead article).
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- Onyper, S. V., Zhang, Y., and Howard, M. W. (2010). Some-or-none recollection: Evidence from item and source memory. *Journal of Experimental Psychology: General*, **139**, 341-364.
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- Howard, M. W., Sederberg, P. B., and Kahana, M. J. (2009). Reply to Farrell & Lewandowsky: Recency-contiguity interactions predicted by the temporal context model. *Psychonomic Bulletin & Review*, **16**, 973-984.
- Howard, M. W., Jing, B., Rao, V. A., Provyn, J. P., & Datey, A. V. (2009). Bridging the gap: Transitive associations between items presented in similar temporal contexts. *Journal of Experimental Psychology: Learning, Memory & Cognition*, **35**, 391-407.
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- Howard, M. W., Wingfield, A. and Kahana, M. J. (2006). Aging and contextual binding: Modeling recency and lag-recency effects with the temporal context model, *Psychonomic Bulletin & Review*, **13**, 439-445.
- Howard, M. W., Bessette-Symons, B. A., Zhang, Y., and Hoyer, W. J. (2006). Aging selectively impairs recollection in recognition memory for pictures: Evidence from modeling and ROC curves, *Psychology and Aging*, **21**, 96-106.
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- Schwartz, G., Howard, M. W., Jing, B., and Kahana, M. J. (2005). Shadows of the past: Temporal retrieval effects in recognition memory, *Psychological Science*, **16**, 898-904.
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- Howard, M. W. and Kahana, M. J. (2002). A distributed representation of temporal context. *Journal of Mathematical Psychology*, **46**, 269-299.
- Howard, M. W. and Kahana, M. J. (2002). When does semantic similarity help episodic retrieval? *Journal of Memory and Language*, **46**, 85-98.
- Howard, M. W. and Kahana, M. J. (1999). Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **25**, 923-941.

Current Support

- Co-Investigator, "The Role of Medial Prefrontal Cortex in Context-Dependent Valuation and Decision Processes," R01MH130374 (Joseph McGuire, PI; Chantal Stern, co-I), 5/15/23–4/30/28, $2,993,531 (total).
- Principal Investigator, CRCNS: Neural Representations of Time Across Scales in Natural and Artificial Networks," R01MH132171 (Elizabeth Buffalo, U. Washington, PI). 9/1/2022–8/31/2025, $1,287,540 (total).
- Principal Investigator, "Spectral methods for remembering the past and predicting the future." Google Faculty Research Award. $72,457.

Completed Support

- Co-Investigator, Electronic-photonic neuromorphic integrated circuits with brain-inspired scale-invariant perception, BU College of Engineering Dean's Catalyst award (with Milos Popovic and Michael Hasselmo), 5/1/2023–4/30/2025, $100,000.
- co-Investigator, "Neural Circuits Underlying Symbolic Processing in Primate Cortex and Basal Ganglia", ONR MURI N00014-16-1-2832 (M. Hasselmo, PI). 9/1/2016–8/31/2021, $4,464,349 (total, BU award).
- Principal Investigator (H. Eichenbaum original PI, M. Hasselmo co-PI), "Temporal Organization of Memory in the Hippocampus", NIMH R01MH095297, 5/1/2017–4/30/2021, $1,648,541 (total)

- Principal Investigator, "Collaborative Research: NCS-FO: Learning Efficient Visual Representations From Realistic Environments Across Time Scales", NSF IIS 1631460 (P. Sederberg PI on linked proposal, M. Rucci and M. Belkin co-Is). 9/1/2016–8/31/2020, $479,015 (total, BU award)
- Principal Investigator, "Toward a Theory for Macroscopic Neural Computation Based on Laplace Transform", NIBIB R01EB022864 (M. Hasselmo co-I). 9/27/2016–8/31/2019, $988,166 (total).
- Principal Investigator, "CRCNS:Navigation Through A Memory Space in the Rodent Hippocampus", NIMH R01MH112169 (H. Eichenbaum, A. Johnson co-Is), 7/15/2016–4/30/2019, $1,021,506 (total).
- co-Investigator, Initiative for Physics and Mathematics of Neural Systems, NSF PHY1444389 (M. Hasselmo, PI).
- Subcontract Principal Investigator, Memory Enhancement with Modeling, Electrophysiology, and Stimulation (MEMES), DARPA Restore Active Memory (RAM) program, 7/1/2014–6/02/2016, (M. Kahana project P.I.).
- Principal Investigator, Sequential learning from a scale-invariant representation of remembered time, NSF award BCS-1058937, 1/15/2012–12/31/2015, $366,567 total costs.
- Principal Investigator, A distributed representation of space and time, AFOSR FA9550-12-1-0369, 7/1/2012–6/30/2015, $390,754 total costs.
- Principal Investigator, A distributed representation of remembered time, AFOSR FA9550-10-1-0149, 5/1/2010–4/30/2012, $264,907 total costs.
- Principal Investigator, Retrieved Context in Episodic and Semantic Memory, 1-R01 MH069938-01, 2/1/2004–1/31/2010. $770,000 in direct costs (initial budget).
- Principal Investigator, Toward the neural basis of episodic memory. 1F32 MH65841-01 (Individual NRSA). Michael Hasselmo, sponsor. 01/02—01/05. $145,000 (terminated early to accept faculty position).

Recent Invited Talks

- Emerging Directions Workshop, National Institute for Theory and Mathematics in Biology, Uchicago and Northwestern; February 2025.
- Redwood Seminar, Redwood Center for Theoretical Neuroscience, UC Berkeley, December 2024.
- Sensory Prediction: Engineered and Evolved, Santa Fe Institute, July 2023.
- Cognitive brownbag, Ohio State University, April 2023.
- Seminar, Duke Kunshun University (virtual), December 2022.
- UC Irvine Symposium on Big Data Challenges (rescheduled from Jan. '20), September, 2022.
- Brandeis University, Psychology Department Colloquium, September 2022.
- NeuroMONSTER, September 2022, Crete (virtual).

- Reinforcement Learning and Decision Making Workshop, Temporal Representations in Reinforcement Learning, Providence, RI, June 2022.
- Reinforcement Learning and Decision Making Workshop, Maps in reinforcement learning: Efficient representations of structure and time in decision-making, Providence, RI, June 2022.
- George Mason University, Biomedical engineering colloquium, March 2022.
- Timing Research Forum, March 2022.
- BU Hariri Institute "Did you know" series, Feb. 2022 (virtual).
- Vanderbilt University, Cognitive Modeling Symposium, Nov. 2021 (virtual).
- MIT AI Hardware Program, Oct. 2021 (virtual).
- University of Pittsburgh, Electrical and Computer Engineering Departmental Seminar. Oct. 2021 (virtual).
- NeuroMONSTER, Sept. 2021, Rhodes Greece (virtual).
- Keynote Talk, NeuroMatch 3.0, October 2020 youtube
- Cognitive Neuroscience Society May 2020, Symposium on Integrating computational models and neuroscience (virtual).
- UC Irvine Symposium on Big Data Challenges (cancelled due to COVID-19), January 2020.
- Rohr University Bochum, Institute for Computational Neuroscience, January 2020
- BRAIN Investigator's meeting, April 2019.
- Cognitive Neuroscience Annual Meeting, Symposium on time and memory, San Francisco, March 2019.
- Redwood Seminar, Berkeley, March 2019.

Patents

- A METHOD FOR CONSTRUCTING A SCALE-INVARIANT MEMORY BUFFER, U.S. Provisional Patent Application No. 62/048,091 (with Karthik Shankar and Zoran Tiganj).
- Method, System, and Computer Readable Medium for Scale-Invariant Temporal History (SITH) for Optimal Slicing of the Past in Uncertain Conditions U.S. Provisional Patent Application No. 62/596,488 (with Per Sederberg).

Awards

- Member, Memory Disorders Research Society
- Google Faculty Research Award 2018
- 2004 Society for Mathematical Psychology New Investigator Award.
- Knight of the Golden Horseshoe

Professional Activities

- Co-founder, Cognitive Scientific AI, Inc., 2024—
- Program Director, Boston University Brain, Behavior & Cognition PhD program, 2017—2021
- Associate Editor, *Open Mind*, 2022—; *Psychonomic Bulletin & Review*, 2014—2017
- Editorial board, *Psychological Review*, 2015—; *Computational Brain & Behavior*, 2017—2025; *Hippocampus* 2023— *Journal of Mathematical Psychology*, 2010—; *Psychonomic Bulletin & Review*, 2008—2013; *Frontiers in Cognition*, 2010—2013;
- NSF grant review: College of Reviewers Perception, Action & Cognition, Science of Learning Centers Site Visit Team (multiple times), National Research Training (NRT), Collaborative research in computational neuroscience (CRCNS), Physics of Living Systems
- Other grant review: NIH/NINDS, AFOSR, Netherlands Organization for Scientific Research, Israeli Science Foundation, Marsden Fund (New Zealand), NIMH B/Start mechanism, Department of Education Program on Research in Reading Comprehension review panel
- Founding program director, Syracuse University Integrated Learning Major in Neuroscience, 2010–2011
- Area Director, Syracuse University Cognition, Brain & Behavior graduate training program, 2010–2011
- Co-founder (with Laurel Carney) of SNO, the Syracuse Neuroscience Organization.
- Member, Society for Neuroscience, American Psychological Society, Psychonomic Society, Society for Mathematical Psychology

Teaching and Mentoring

- Undergraduate courses: Human Memory, Cognitive Psychology, Cognitive Neuroscience, Honor's course "Towards a Physics of the Mind," Cognitive Psychology Lab.
- Graduate courses: Computational Methods for Experimental Psychology; Cognitive Neuroscience of Memory; Memory and Attention; Memory Systems of the Brain; Time and Memory; Human Memory: Theory and Data; Theoretical Cognitive Neuroscience
- Postdoctoral advisees (first position)
  - Rui Cao (Psychology PhD), 2018—2025 (Asst Professor, University of Tennessee)
  - Zahra Esfahani (Theoretical Physics PhD), 2018—2022
  - Andre Luzardo (Mathematical Psychology PhD), 2018—2021, Lecturer Boston University
  - Konstantin Tiurev (Computational Physics PhD), 2018—2019, Postdoc, Department of Physics, University of Copenhagen
  - Zoran Tiganj (Neural engineering PhD), 2013—2019, Assistant Professor, Department of Computer Science, Indiana University.

  - Karthik Shankar (Theoretical Physics PhD), 2007—2017, Independent researcher.

- Current Ph.D. students:
  - Chenyu (Six) Wang (BBC, BS Applied Math)
- Past PhD Students:
  - Aakash Sarkar (BBC, BS Physics), Post-doc UCSF
  - Ian Bright (BBC, BS Psych & Math), Post-doc NINDS
  - Wei Zhong Goh (BU GPN 2022), Wayfair.com
  - Catherine Mikkelsen (BU GPN 2022), Postdoc teaching fellow, Smith College
  - Nathanael Cruzado (BU GPN 2021), Postdoc Georgia Tech
  - Daniel Sheehan (BU BBC 2020), Postdoc BU
  - Yue Liu (BU Physics 2020), Postdoc NYU
  - John Bladon (BU GPN 2019), Postdoc Brandeis
  - Inder Singh (BU BBC 2017), Data scientist Wayfair.com
  - Jennifer Provyn, (Syracuse, 2013), Children's Mercy Hospital, Kansas City
  - Asli Kılıç (Syracuse, 2012, Dissertation advisor Amy Criss), Assistant Professor (tenure-track), Mid-East Technical University
  - Brandy Bessette-Symons (Syracuse 2008), Assistant Professor, Ithaca College
  - Serge Onyper (Syracuse 2007), Associate Professor, St. Lawrence University
- M.S. students
  - Vinayak Rao (Syracuse EE), Computational Neuroscience PhD, Gatsby, University College London; Assistant Professor, Department of Statistics, Purdue
  - Vaidehi Natu (Syracuse EE), Psychology PhD UT-Dallas, Post-doc Stanford
  - Stuart Babcock, (BU GPN), Yale Law student
  - Joe DiLascio (BU GPN)
  - Yaofei Zhang (Syracuse Psych), AVP at JPMorgan Chase
  - Aditya Datey (Syracuse CE), VP at JPMorgan Chase
  - Mrigankka Fotedar (Syracuse CS), Microsoft
  - Udaya Jagadisan (Syracuse BME), PhD BME Pitt, Post-doc Cal Berkeley
  - Sridhar Iyer (Syracuse CS), Cisco Systems.
- Undergraduate RAs (selected)
  - Donna Bridge, PhD UX
  - Seth Elkin-Frankston, PhD; Research position at Charles River Analytics
  - Clarion Mendes, MA, Clinical Instructor/Speech-Language Pathologist at UIUC
  - Michelle Wiciak, Clinical Research Coordinator, University of Vermont
  - Jodi-Ann Manning, Clinical Research Coordinator, Massachusetts General Hospital.