NIH BIOGRAPHICAL SKETCH COMMON FORM

Name: MacIver, Malcolm Angus

Persistent Identifier (PID) of the Senior/Key Person: https://orcid.org/0000-0002-3711-8235

Position Title: Group Leader

Organization and Location: Center for Robotics and Biosystems, Northwestern University, Evanston, Illinois, United States

PROFESSIONAL PREPARATION

INSTITUTION AND LOCATION	DEGREE	Start Date	Completion Date	FIELD OF STUDY
California Institute of Technology, Pasadena, California, United States	Postdoctoral Fellow	07/2001	07/2003	Bio-inspired Robotics and Biofluidynamics
University of Illinois, Champaign, Illinois, United States	Doctor of Philosophy (PHD)	09/1994	06/2001	Neuroscience
Indiana University, Bloomington, Indiana, United States	Graduate Student	09/1992	06/1994	Cognitive Science
University of Toronto, Toronto, Ontario, Canada	Master of Arts (MA)	09/1991	06/1992	Philosophy
University of Toronto, Toronto, Ontario, Canada	Bachelor of Science (BS)	09/1986	06/1991	Computer Science/Philosophy (Double Major)

Appointments and Positions

2025 - present	Group Leader, Center for Robotics and Biosystems, Northwestern University, Evanston, Illinois, United States
2024 - present	Theme Leader, Prediction & Anticipation, National Institute for Theory & Mathematics in Biology, Evanston, Illinois, United States
2022 - present	Professor (Courtesy), Northwestern University, Department of Computer Science , Evanston, Illinois, United States
2016 - present	Professor (Courtesy), Northwestern University, Department of Neurobiology, Evanston, Illinois, United States
2016 - present	Professor, Northwestern University, Department of Biomedical Engineering, Evanston, Illinois, United States
2016 - present	Professor, Department of Mechanical Engineering, Northwestern University, Evanston, Illinois, United States
2010 - 2016	Associate Professor (Courtesy), Northwestern University, Department of Neurobiology, Evanston, Illinois, United States
2010 - 2016	Associate Professor, Northwestern University, Department of Mechanical Engineering, Evanston, Illinois, United States
2010 - 2016	Associate Professor, Northwestern University, Department of Biomedical Engineering, Evanston, Illinois, United States
2005 - 2010	Assistant Professor (Courtesy), Northwestern University, Department of Neurobiology, Evanston, Illinois, United States
2003 - 2010	Assistant Professor, Northwestern University, Department of Mechanical Engineering, Evanston, Illinois, United States
2003 - 2010	Assistant Professor, Northwestern University, Department of Biomedical Engineering, Evanston, Illinois, United States

Products

Products Closely Related to the Proposed Project

1. Han S, Espinosa G, Huang J, Dombeck D, MacIver M, Stadie B. Of Mice and Machines: A Comparison of Learning Between Real World Mice and RL Agents. [revised 2025]. Vancouver, Canada.: Forty-second International Conference on Machine

Learning; 2025 May. DOI: 10.48550/arXiv.2505.12204

2. Lai AT, Espinosa G, Wink GE, Angeloni CF, Dombeck DA, MacIver MA. A robot-rodent interaction arena with adjustable spatial complexity for ethologically relevant behavioral studies. Cell Rep. 2024 Feb 27;43(2):113671. PubMed PMID: 38280195.
3. MacIver MA, Finlay BL. The neuroecology of the water-to-land transition and the evolution of the vertebrate brain. Philos Trans R Soc Lond B Biol Sci. 2022 Feb 14;377(1844):20200523. PubMed Central PMCID: PMC8710882.
4. Hunt LT, Daw ND, Kaanders P, MacIver MA, Mugan U, Procyk E, Redish AD, Russo E, Scholl J, Stachenfeld K, Wilson CRE, Kolling N. Formalizing planning and information search in naturalistic decision-making. Nat Neurosci. 2021 Aug;24(8):1051-1064. PubMed PMID: 34155400.
5. Mugan U, MacIver MA. Spatial planning with long visual range benefits escape from visual predators in complex naturalistic environments. Nat Commun. 2020 Jun 16;11(1):3057. PubMed Central PMCID: PMC7298009.

Other Significant Products Highlighting Contributions to Science

1. Espinosa G, Wink G, Lai A, Dombeck D, MacIver MA. Achieving mouse-level strategic evasion performance using real-time computational planning. arXiv. 2022. DOI: 10.48550/arXiv.2211.02700
2. MacIver MA, Schmitz L, Mugan U, Murphey TD, Mobley CD. Massive increase in visual range preceded the origin of terrestrial vertebrates. Proc Natl Acad Sci U S A. 2017 Mar 21;114(12):E2375-E2384. PubMed Central PMCID: PMC5373340.
3. MacIver MA, Pichaske K, Gratz R, Nagorka K. Our Short-Sighted Inner Fish (3 min animation available on YouTube). [Video]. Cartuna Animation Studio; 2017.
4. Krakauer JW, Ghazanfar AA, Gomez-Marin A, MacIver MA, Poeppel D. Neuroscience Needs Behavior: Correcting a Reductionist Bias. Neuron. 2017 Feb 8;93(3):480-490. PubMed PMID: 28182904.
5. MacIver MA. The Cambridge Handbook of Situated Cognition. Robins P, Aydede M, editors. Cambridge: Cambridge University Press; 2009. Chapter 26, Neuroethology: From Morphological Computation to Planning; p.480-504. DOI: 10.1017/CBO9780511816826

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to information related to domestic and foreign appointments and positions.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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NIH BIOGRAPHICAL SKETCH SUPPLEMENT

Name: MacIver, Malcolm Angus

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Position Title: Group Leader

Organization and Location: Center for Robotics and Biosystems, Northwestern University, Evanston, Illinois, United States

Personal Statement

The major research goals of my laboratory are 1) the evolution and neural mechanisms of planning in the vertebrate brain and translation into new, energy-efficient artificial intelligence algorithms for planning; and 2) mechanics, neurobiology, and information theory of the control of sensory structures for information harvesting. The unifying theme that spans both domains is search, broadly construed—be it searching inside the skull for a more effective path in light of an organism's reinforcement history and current estimates of an adversary's position, one ethological context for planning, or searching outside the skull to guide the body with respect to sensed cues, as in information harvesting. A characteristic of my work is interweaving theory, computation, robotics, evolutionary/comparative methods, and experiment to address relatively unsimplified natural behaviors from multiple perspectives. I am dedicated to mentoring students to be "full stack" neuroscientists who are as conversant in math and computer science as they are with behavior, evolution, and neurophysiology to be capable of similar synthesis in their own work. I have trained 5 postdocs and 14 graduate students (11 Phds, 3 current trainees). One (a URM) is Associate Professor of Mechanical Engineering (biofluidynamics) at Florida Atlantic University, one is Associate Professor of Applied Math (female, computational biology) at the University of Auckland, one is currently in a "Transition to Independence" postdoctoral fellowship at the Medical University of Vienna (female, computational and experimental neuroscience, Redish lab), another is a postdoc at the RIKEN Center for Computational Science in Japan. Eight graduates and three postdocs are in top technical/managerial positions in AI/machine learning/robotics at Google, Microsoft, Apple, Intuitive Surgical, HDT Robotics, and Murata Vios.

Productivity dip arising from change in science: Up until 2018 my laboratory focused on mechanisms of embodied intelligence, mostly focused on fish (weakly electric and larval zebrafish). Bioinspired robotics, computational neuroethology, biofluidynamics, brain imaging. A sabbatical allowed me to develop a new theory on the origins of advanced cognition, revolving around changes in sensory systems with the emergence onto land in the Late Devonian. To test this hypothesis further, however, required a decisive shift in the lab's infrastructure, from aquatic organisms to mammals. This transition has led to a dip in productivity as we train a new cohort, and (with Dan Dombeck) establish a new paradigm for testing in rodents. The new paradigm, Cellworld, was published in 2024.

The paradigm was designed to work in close synergy with artificial intelligence computational infrastructure. For example, we have ported the task to OpenAI Gym and have it interoperable with StableBaselines2 for rapid testing of the leading AI algorithms, key to a recent ICML paper where we show that a digital version of PTSD applied to the replay buffer is key to more animal-like trajectories. Large amounts of ethological and neurophysiological data are now being turned into submissions for publication; two slated for early 2026, the third (neurophysiology) for late 2026 or 2027.

Honors

2018	Science Ambassador, US Consulate, New Zealand
2009	Presidential Early Career Award for Scientists and Engineers, The White House
2009	CAREER Award, National Science Foundation

Contributions to Science

1. **A new hypothesis about the origin of planning in terrestrial vertebrates.**

   Background: While aquatic and terrestrial vertebrates have had equal time to evolve advanced cognition, sophisticated planning appears largely restricted to terrestrial mammals and birds. In 2009, I published the *Buena Vista Hypothesis*: that expansion of visual range during the water-to-land transition (~380 Mya) was key to the selective benefit of planning and underlies this disparity.

   Central findings: This hypothesis has gained converging support. In 2017, we provided paleontological evidence that increased visual range preceded terrestrialization in crocodile-like taxa that used aerial vision while living in water. In 2020, AI-based modeling of planning indicated that planning confers survival advantages only in certain terrestrial environments. In 2024, we introduced Cellworld, a robot–rodent paradigm with tunable spatial complexity, showing strong behavioral effects from this tuning. Ongoing results indicate that obstacle density and spatial patchiness shape planning. We show that simple predator dynamics promote automaticity, whereas complex dynamics suppress it. Large-scale recordings (>30 TB Neuropixels2 data) in freely behaving mice are now revealing neural correlates of planning.

Influence: A commentary in *Current Biology* on the 2017 study stated that, if further corroborated, the findings “would rewrite the story of how vertebrates conquered land.” Subsequent fossil discoveries (e.g., *Parmastega*, 2019) support the proposed sequence. The hypothesis has informed theories of visual consciousness (Fleming & Michel) and programs on the origins of cognition (Lund University). Cellworld provides the first automated system for studying planning in naturalistic predator–prey contexts.

Role: I originated the hypothesis, led the paleontological, and computational programs, and co-directed development of Cellworld and experimental data collection in close collaboration with Dan Dombeck.

2. **Artificial active electrolocation and the bioinspired robotics of undulatory swimming.**

   Background: Gymnotid weakly-electric fish are a leading model system in sensory neuroscience. These animals emit a short-range electric field to detect prey and obstacles, and are highly maneuverable due to a median undulatory propulsor.

   Central findings: *Artificial electrosense:* We developed an algorithm using movement sequences to detect size and shape of simple objects. We showed that capacitive electrosense improves signal-to-noise over amplitude-based methods, and demonstrated operation in marine conditions where biological electrolocation is absent. We achieved autonomous following

   and clutter navigation in a large gantry-controlled *SensorPod* system. *Undulatory propulsion:* Using experiments and computational fluid dynamics, we characterized fin-generated flows and thrust. We showed that combining counter-propagating waves cancels fore--aft thrust to generate heave or enable precise positioning.

   Influence: In 2012 I brought together researchers from around the world that had begun work on artificial electrosense, largely originating from our 2001 and 2008 studies. Since then one of those groups, the Boyer group in France, started the company ELWAVE that commercializes artificial electrosense. Similarly, the robotics work has disclosed core mechanical principles for undulatory swimming and those results are being used at Pliant Energy Systems, New York, for new underwater vehicles and energy harvesting. I received the 2009 Presidential Early Career Award from Obama at the White House for this work.

   Role: I was first author on the original artificial electrolocation paper from 2001, part of my PhD thesis. I was first author on the original artificial ribbon fin undulator from 2004, built during my postdoctoral fellowship in robotics at Caltech. Subsequent efforts have involved numerous collaborators in circuits, robotics, and computational fluid dynamics.

3. **Computational ethology and neuroscience of predator-prey interactions**

   Background: Understanding the nervous system is increasingly advanced by studying natural behaviors, particularly predator--prey interactions, rather than simplified laboratory tasks.

   Findings: Across weakly electric fish, larval zebrafish, and dragonfly nymphs, we revealed how sensing and action are tightly coupled in natural contexts. In electric fish, we showed that signals during prey capture differed from those used in prior studies; correcting this led to discovery of distinct neural pathways for hunting versus communication. We demonstrated how the body functions as a sensory antenna and that prey capture relies on closed-loop adaptive tracking rather than ballistic strikes, with sensing volumes matched to biomechanical reach. In larval zebrafish, we provided a full kinematic description of hunting and characterized looming-triggered escapes, including threshold visual angles. We identified distinct kinematic and neural signatures for Mauthner versus non-Mauthner escapes using light-field imaging. Across systems, we introduced the concept of "motor volumes" to predict outcomes of predator--prey interactions, including ambush strikes by dragonfly nymphs.

   Influence: This work helped establish computational ethology approaches grounded in natural behavior. A coauthored perspective (*Neuroscience Needs Behavior*) contributed to a broader shift toward studying neural function in ecologically relevant contexts. The electric fish studies reshaped experimental paradigms in that field, while the zebrafish work has been widely used as the model system has expanded to more complex behaviors.

   Role: I led the electric fish work as first author (PhD with Mark Nelson) and continued it as a postdoc and independent investigator. The zebrafish studies were conducted in close collaboration with David McLean.

4. **A new theory of active sensing**

   Background: Active sensing is at once a way to harvest information and a way to move the body. Yet metrics for these domains are incommensurable: bit rate for information, and joules for movement. How can these be conjointly optimized? We proposed Ergodic Information Harvesting (EIH) as a new quantitative method for understanding active sensing. It is essentially proportional betting on the expected gain of information.

   Central findings: We were able to show---across a data set of multiple vertebrates and vertebrate active sensing movements---that EIH was able to predict previously obscure patterns in active sensing kinematics. For example, how the position, amplitude, and frequency of side-to-side movements has to alter as the signal-to-noise ratio varies.

   Influence: This work established a new normative framework for active sensing that unifies information acquisition and energetic cost. EIH has been taken up in robotics and control as a general strategy for exploration, search, and target localization under uncertainty. In neuroscience, it has provided a quantitative account of sensorimotor patterns across species, influencing experimental design and interpretation. More broadly, it has contributed to a shift from heuristic descriptions of active sensing to formal, optimization-based theories.

   Role: This theory was co-developed with Todd Murphey and members of his lab. It was a close interaction from robotics work with my artificial electrosense facilities to numerical simulations using methods for computing ergodicity from his lab.

5. **Showing that participation in prediction markets elevates concern about long-horizon outcomes**

   Background: Like all animals in which it has been quantified, humans are characterized as discounting future payoffs and harms. Temporal discounting phenomena are a barrier to motivating change to avoid future existential threats such as climate change. We investigated whether placing monetary bets on the outcome of climate-related events changed the participants view of the threat level of climate change.

   Central findings: We found a significant increase in concern about global climate change in the climate prediction market compared to participants in a non-climate prediction market (N=600).

   Influence: This study is being used by a variety of private sector interests for designing new markets around climate phenomena.

   Role: This work was conceived in close collaboration with Moran Cerf and Sandra Matz. It emerged over discussion of sociotechnical solutions to deficiencies in the planning system with Moran Cerf in 2013.

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