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# Gradient Expectations

## Structure, Origins, and Synthesis of Predictive Neural Networks

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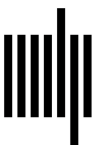
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## Acknowledgments

Back in the early 1980s at the beginning of our afternoon runs for the Bucknell cross-country team, we would occasionally hear the chant, “FUBAR, FUBAR, FUBAR,” from several teammates. At the risk of losing grade-school readership, I will only repeat the final three words of that acronym: beyond all reason. The call for FUBAR was a desire to let our whims lead us in any and all directions for those 70–90 minutes of running, whether across a superstore parking lot, down the rows of a cornfield, or through a carwash. Very little was out of bounds as no-trespassing signs became mere recommendations for our own safety.

My own research in artificial life (ALife) and artificial intelligence (AI) has always had a FUBAR flair. I can change directions whenever some shiny object pops up that exhibits an interesting form of life or intelligence that seems amenable to computer simulation. When one of those attractive baubles turned into a lump of coal back in 2020, a few months into the pandemic, I did a little soul-searching and decided on an abrupt shift and returned to the concept of the predictive brain to see what more I could find in the neuroscientific, and particularly the connectionist, literature. Uncertainty was the only certainty in that pursuit, so I contacted Elizabeth Swayze at MIT Press to try to get some indication of whether a book in that area was a worthwhile goal. Her encouragement was a much-needed and appreciated constant for the ensuing 15 months of research and writing. Matt Valades entered the process a little later and was equally helpful. Now, as my part of the project draws to a close, Theresa Carcaldi stands by to clean up my grammatical messes with her eagle-eyed copyediting. I am very grateful to all three of these patient and supporting individuals.

I once gave a lecture on AI and ALife to a group of engineering professors. One of their questions, apparently meant as an insult, was, “Is this stuff science . . . or art?” Coming from the liberal arts side of mathematics and computing, I found the answer quite obvious: it’s both. A good many researchers in the sciences of the artificial have a creative passion (often bordering on artistic) that drives the field. When that combustible, visionary energy and the untethered explorations that it inspires gives way to so-called epsilon research and citation counting, it’s time to look elsewhere for fulfilment. For me, book writing provides the perfect opportunity to explore fascinating topics and mix a bit of art with the science without fear of repercussions from just-the-facts, competitive-results-only journal reviewers.

Although Wolfgang Banzhaf encouraged me to take a shot at long-form writing over 20 years ago, it took more than a decade for me to summon the gumption to follow through.

I am very grateful to Wolfgang for his continuing support of my research and writing. My former and eternal Bucknell teammate Eric Allgaier originally convinced me that my words were worth reading, and to this day he serves as my unofficial publicist as he flashes copies of my texts during group Zoom calls and jokingly recommends my materials as excellent bedtime reading and Christmas gifts to our friends.

In March 1993, Jim Valvano, one of college basketball's most famous coaches, gave an unbelievably sad yet gripingly inspiring speech just a few months before dying of cancer. The slogan from that evening and for the V Foundation for Cancer Research is simple and poignant: "Don't give up; don't *ever* give up." Although many of life's adversities are trivial in comparison, those words have motivated me in so many instances, including the writing of this book. There were many points at which I saw no easy road forward, but then a second phrase, by one of college football's most famous coaches, Woody Hayes, would start to ring in my ears: "Anything that's easy ain't worth a damn." Finally, my own college coach, Art Gulden, supplied daily injections of motivation that are not encapsulated in a single most-memorable event or quotation, but his effect upon the lives of many was very profound and perfectly in tune with Valvano's message of unwavering perseverance.

In July 2001, I presented two completely different and fully FUBAR papers at the Genetic and Evolutionary Computation Conference in San Francisco. After the second talk, a soft-spoken yet highly energetic man, Julian Miller, greeted me in the hallway and expressed his interest in my work. That encounter started two decades of informal collaboration and spawned many research visits of Julian traveling to Norway, and me and my Norwegian colleagues traveling to England. Julian became very prominent in the fields of ALife and evolutionary computation, so I have always considered it a privilege to share a certain scientific wavelength with him, even with the diverging trajectories of our careers. My continued optimism for the ALife-based methods discussed in chapter 7 of this book, regardless of the onerous challenges, directly stems from watching Julian doggedly attack them for 20 years with no hint of regret nor fear of failure despite the long odds. Julian lost his battle with cancer in 2022. This book is dedicated to his memory.

You will have a hard time finding the FUBAR philosophy promoted by any of the normal research funding agencies, despite the fact that a large percentage of funded research is exploratory and leads to no noteworthy breakthroughs. Hence, for the nearly 40 years of my career in AI and ALife, I have had no significant association with any of these sources. I advise my share of PhD and master's students, but I do my best to shield them from any negative consequences of my wild ideas. The vast majority work on relatively safe and straightforward projects that will lead to a degree. These days, my FUBAR runs tend to be solo. I owe a great deal of debt to the Norwegian university system, which still allows professors enough time and basic resources to pursue creative passions (albeit with constant encouragement to join large international projects), and gives reasonable teaching loads that make it possible to devote oneself to producing a few high-quality courses instead of a bevy of mediocre offerings.

At the local, departmental level, my attempts at book writing have received stout backing as a legitimate form of research and scholarship from a series of talented department heads: Guttorm Sindre, Jon Atle Gulla, Letizia Jaccheri, John Krogstie, and Heri Ramampiaro. I would have never realized my primary professional goals without their generous support and understanding.

I would have never even logged on without the frequent assistance of Erik Houmb, our systems ace who has guided me through the jungle of online tools for the latter half of my academic career. Unlike nearly all my family members, Erik has resisted the (surely gnawing) temptation to sarcastically inquire, “*You* have a PhD in computer science?”

My friends in the neuroscience department at Oberlin College also deserve a round of applause for their assistance. Not only do they give me a place to hang my thick, Norwegian wool hat and connect my laptop during sabbaticals, but they trust in my ability to teach and advise their (very bright) students despite my lack of a formal neuroscience education. I hope to visit you all again soon, Kristi Gibson, Gigi Knight, Mike Loose, Tracie Paine, Pat Simen, and Jan Thornton.

When working in Oberlin, I receive bottomless generosity from my Ohio family in many departments, from transportation and lodging to dining and entertainment. Though I work very hard during those visits, each day still feels like a vacation thanks to them. My brother Steve Downing, my sister-in-law Meg Downing, and my cousins Kathy and Denny Mishler are all vital links back to my primary identity as an American citizen . . . and Cleveland sports fan.

My wife, Målfrid, has repurposed the FUBAR run to the FUBAR hike, with the latter taxing my muscles, joints, and psyche much more than any college cross-country workout. By yanking me from my comfort zones of groomed trails, bike lanes, and swimming pools, she has opened my eyes to a beautiful world off the beaten path, even when the unbeaten path is thinner than its corresponding line on the map, and I stumble along, far behind the group. I wish I could cite Jimmy Buffett and say, “With you I’d walk anywhere,” but she knows that to be true solely in the metaphorical sense.

Our children, Neva, Asta, and Jasem, help keep us young. They inspire us with their diligence and steady stream of hard-earned successes, whether in music, sports, or academics. But no prizes, medals, or scholarships make us prouder than simply observing the kindness that they show to others.

Finally, I owe an immeasurable intellectual debt to my PhD advisor at the University of Oregon, Sarah Douglas, and to two professors in the Department of Mathematics at Bucknell University, Eugene Luks and Michael Ward. Mike awakened me (literally, in 8 am classes) to the intricate patterns and rigorous proofs that make mathematics such a gratifying pursuit, while Gene cultivated my appreciation for computation as an abstract and omnipresent process, whether he intended to or not. Sarah grounded artificial intelligence in cognition, thus magnifying the appeal of both subjects. Their aggregated influence stoked my endless curiosity as to how it all fits together. This book is one of the more personally satisfying by-products of that quest.



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