STATISTICS

Mr. Bayes Goes to Washington

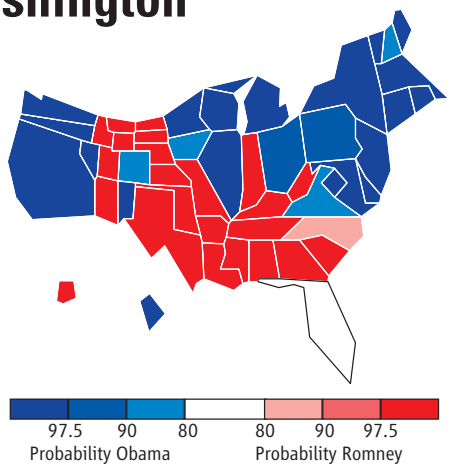
Sam Wang[1] and Benjamin C. Campbell[2]

One day before the 2012 U.S. presidential election, former Reagan speechwriter Peggy Noonan wrote that "nobody knows anything" about who would win, asserting that Republican candidate Mitt Romney's supporters had the greater passion and enthusiasm (*1*). From a similarly data-free remove, columnist George Will predicted a Romney electoral landslide. MSNBC's Joe Scarborough said "it could go either way … anybody that thinks that this race is anything but a tossup right now … should be kept away from typewriters, computers, laptops, and microphones, because they're jokes." (*2*)

In the end, these pundits were the ones whose opinions proved dispensable. They were unable to detect a plain fact: based on public opinion polls with collectively excellent track records, President Obama had an advantage of 3 to 4 percentage points for nearly the entire campaign season. However, the world of political punditry measures success not by accuracy but by readership and viewership. And so it came to pass that legions of commentators expressed total confidence—and were wrong.

Beating the pundits has been possible since at least 2004, when one of us was among the first to statistically aggregate polls (*3*). In 2008, Nate Silver emerged as a poster child for aggregation, armed with a degree in economics, a love of numbers, and a professional track record in analyzing baseball performance and financial data. He enlivened a mostly suspenseless presidential race, providing timely quantitative analysis and color commentary on his website FiveThirtyEight, which became highly popular and was snapped up by the New York Times (*4*). His fame rose further in 2012, when he and other aggregators and modelers used hardnosed analysis (*3*–*6*) to silence skeptics.

Now Silver has written *The Signal and the Noise*, a book that addresses predictions not just in politics but in all aspects of modern life, with the eye of a hobbyist and a sense of fun. Freed from the word limits of blog essays, the book is a meandering, nerd's-eye view of what principles, if any, are common to good forecasting in daily life, leisure activity, and science.



Validated by the outcome. The Princeton Election Consortium's final electoral college predictions for November 2012. (States are sized according to their share of electoral votes.)

The Signal and the Noise
Why So Many Predictions Fail—But Some Don't/ The Art and Science of Prediction
by Nate Silver
Penguin, New York, 2012. 542 pp. $27.95, C$29.50. ISBN 9781594204111. Allen Lane, London. £25. ISBN 9781846147524.

We use predictions to guide our future actions, from planning weekend outings to taking care of our health, but most people have no idea how scientific predictions are made. This book is for them. Silver introduces some of the concepts behind data modeling, including probability, Bayesian inference, and uncertainty. He takes lengthy looks at topics ranging from flu epidemics to the 1996 chess-playing triumphs of Deep Blue.

A reappearing theme in *The Signal and the Noise* is Bayesian reasoning, an approach that has swept the sciences. Probability had been conventionally interpreted as meaning the true likelihood of an event—for instance, how often the total of two rolled dice will add up to seven. Such a "frequentist" point of view has in many cases given way to an approach pioneered by Reverend Thomas Bayes in the 18th century, which emphasizes that probability can only be interpreted in terms of the hypotheses that preceded the measurement.

Although Silver asserts that Bayesian political forecasting has more in common with poker than with hard sciences such as physics and biology, these topics all use the same mathematical toolkit. Large-scale physics collaborations depend on sensitive models to predict the probabilistic decay rates of particles, looking for outliers that might represent signals in the noise and hence discoveries. In our field, many neuroscientists have begun to view the brain as a prediction machine (*7*). We perceive the world around us by making inferences from noisy and incomplete data. To do so, the brain must form a model of its environment—a set of "priors" learned over a lifetime that is used to interpret incoming data. This Bayesian machine continually updates its priors to correspond to its environment. Through this process, our brains spend many years honing appropriate priors for the complex tasks that we perform effortlessly.

Silver gives a well-known equation for how to take into account the Bayesian prior but doesn't show where it comes from. Readers wanting a deeper explanation of Bayes's rule might consult another source such as BetterExplained.com (*8*), which teaches the subject by using e-mail spam filtering as an example. Silver's chosen anecdotes include the classic example of mammogram interpretation—but also how to interpret that unfamiliar underwear that just showed up in your partner's dresser drawer.

At times Silver writes as if the cure for bad modeling can be reduced to "more Bayes." Such a prescription does not do justice to the historic controversies surrounding interpretations of probability. A beginner might come away from this book believing that an earlier generation of frequentists were simply ignorant. In a cartoonish account, Silver lobs a broadside at a monumental figure in statistics, Ronald A. Fisher, who late in life argued against the idea that smoking causes cancer—and who coined "Bayesian" as a derogatory term. Silver suggests that Fisher's aversion to Bayes caused him to err. In fact, the real problem was that Fisher was a smoker (*9*). Fisher's prior beliefs prevented him from accepting epidemiological and biological evidence, an erroneous prior if ever there was one.

Our biggest criticism of the book is that although statistics and Bayesian inference are powerful ideas, they are not a cure-all. In his enthusiasm for the good Reverend, Silver has stuffed a fair bit into the same Procrustean bed. Silver uses the old fox-hedgehog analogy, saying that foxes (including himself) use many ideas, whereas hedgehogs focus on one subject only. But here he is a hedgehog with one big idea: statistics.

However, Bayesian reasoning works only if the prior is adapted for the task. According to Silver, many of today's "half-baked

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policy ideas" could be rectified by Bayesian thinking, but that is only part of the story. The more difficult task is determining good priors. Silver rejects bad priors effectively in his own field of electoral forecasting by dismissing much of the noise of political punditry. In other fields, he does not always bring the same critical attitude.

Scientific research is often confronted by political and economic forces that are not always appreciated by nontechnical outsiders. For example, Silver somewhat perversely takes climate scientists to task for bringing politics into their work (*10*). If anything, climate scientists have been dragged unwillingly into a dispute with political interest groups such as the Heartland Institute. At this point in history, human-induced global warming is a fact and no longer a matter of disputing probabilities. The book's extended treatment of scientific fringe figures has the inadvertent effect of giving credence to antiscientific views that fly in the face of experimentation and hypothesis-testing on the greenhouse effect dating back to Arrhenius over a century ago. When Silver, now himself a prominent pundit, depicts a "controversy," he highlights the challenge scientists face in convincing people that carbon dioxide is a pollutant. Not all priors are equally defensible.

Silver's quirky personality and eclectic interests come through in his writing. *The Signal and the Noise* is strongest when Silver sticks with subjects he has pursued for a living: political forecasting, baseball, and poker. Poker is a game of clear probabilities, but he points out that understanding the math is not enough. A key step is to identify at least one doomed "fish" at the table. As the joke goes, if you can't identify the fish, it's you. In political prediction, Peggy Noonan and other traditional pundits are the fish.

On the central topic of how to make a good prediction, Silver is right that there is no magic formula. Heuristics are no substitute for careful and rigorous study—in other words, expertise. In political prognostication, Silver found the barrier to entry to be "invitingly low." For areas that require more scientific rigor, his enthusiasm and fame have blazed a trail for other data enthusiasts to follow.

References

1. P. Noonan, http://blogs.wsj.com/peggynoonan/2012/11/05/monday-morning/, 5 November 2012.
2. D. Byers, "Nate Silver: One-term celebrity?" www.politico.com/blogs/media/2012/10/nate-silver-romney-clearly-could-still-win-147618.html, 29 October 2012.
3. S. Wang, Princeton Election Consortium, http://election.princeton.edu.
4. N. Silver, http://fivethirtyeight.blogs.nytimes.com.
5. D. Linzer, http://votamatic.org.
6. S. Jackman, www.huffingtonpost.com/simon-jackman/pollster-predictive-perfo_b_2087862.html, 7 November 2012.
7. K. Doya, S. Ishii, A. Pouget, R. P. N. Rao, Eds., *Bayesian Brain: Probabilistic Approaches to Neural Coding* (MIT Press, Cambridge, MA, 2011).
8. K. Azad, "An intuitive and short explanation of Bayes' theorem," http://betterexplained.com.
9. P. D. Stolley, *Am. J. Epidemiol.* **133**, 416, discussion 426 (1991).
10. M. E. Mann, "FiveThirtyEight: The number of things Nate Silver gets wrong about climate change," www.huffingtonpost.com/michael-e-mann/nate-silver-climate-change_b_1909482.html, 24 September 2012.

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NEUROBIOLOGY

The End of the Beginning for the Brain

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How to Create a Mind
The Secret of Human Thought Revealed
by Ray Kurzweil
Viking, New York, 2012. 352 pp. $27.95, C$29.50. ISBN 9780670025299. Duckworth, London. £20. ISBN 9780715645376

Science-fiction novels and films have long popularized the notion that machines will, sooner or later, match and ultimately exceed human-level intelligence. On the way they will acquire feelings and consciousness. In the most famous such movie, *Blade Runner*, a replicant exclaims in the face of its imminent demise, "I've seen things you people wouldn't believe. Attack ships on fire off the shoulder of Orion. I watched c-beams glitter in the dark near the Tannhäuser Gate. All those moments will be lost in time, like tears in rain. Time to die."—revealing in its eloquence and poignancy its (simulated) humanity.

A strand of Anglo-American thought fervently believes in the infinite betterment of the human condition through cultural and technological means. The more extreme version is known as transhumanism (h+ for short). Transhumanists argue that biological limitations, including aging and insufficient memory and intelligence, should, and will, be transcended by nanotechnology and artificial intelligence (AI). Their prophet is the engineer, inventor, and futurist Ray Kurzweil, who has just been made a head of engineering at Google. He is best known for his advocacy of the singularity, the point in time when computers—designing and redesigning themselves in a continuously accelerating feedback loop—will become smarter than people, thereby bringing human history to an end. Kurzweil believes that this momentous, eschatological event is a mere decade or two away and will usher in an earthly paradise. Rapture for techies!

In his latest book, Kurzweil takes a romp through the history of AI. He is one of the field's pioneers, having developed and successfully commercialized optical character recognition, advanced music synthesizers, and speech recognition. Kurzweil highlights some notable successes: Deep Blue (the IBM program that beat the reigning chess master in 1997), self-driving Google cars, smart phones that can access the entire repertoire of human knowledge within seconds, the answer engine Wolfram Alpha, and Watson. Another IBM creation, Watson publicly bested humans in the TV quiz show Jeopardy! in 2011. It represents a milestone on the way to true AI, as the program had to learn to parse and understand highly ambiguous sentences by repre-

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Replicant's end. Publicity still from Ridley Scott's *Blade Runner* (1982).

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