**Fog lifting:** The 24th global climate summit (COP24) will take place in Katowice, Poland, in December. The city has historic importance in the steel industry and was transformed by modernist architecture in the 1970s. (Photo: Midnight Believer, Flickr.)

US president Donald Trump announced in August 2018 that his administration intends to pull out of the Paris agreement as soon as it is legally possible to do so. This will be the case in November 2019, three years after the agreement came into force in the US.

Later in August, the then Australian prime minister Malcolm Turnbull backtracked from a green energy plan that would have helped Australia to meet its commitments under the Paris agreement. This U-turn was forced by his predecessor, Tony Abbot, who, ironically, had been the prime minister signing the Paris agreement for Australia. It failed to save Turnbull's position, however. He was replaced by Scott Morrison, who is known as a defender of Australia's coal exports and hasn't presented any discernible climate policy yet.

Meanwhile, Germany hasn't quite got round to abandoning the open-cast mining of brown coal (lignite), which is regarded as an especially polluting type of fossil fuel and devastates entire landscapes. Protesters motivated by climate change concerns have occupied the forest of Hambacher Forst near Cologne for years now in a bid to stop its destruction. The legal and physical battle continues. Similar fights are also likely to reignite in England, as the production of shale gas by fracking resumes.

Quite possibly the biggest impact on climate and environmental policy could arise from the presidential election in Brazil, however, which goes into its decisive round on October 28th, as this article is in press. The far-right candidate Jair Bolsonaro, who was ahead in the first round with 46% of the votes, has already announced he will withdraw from the Paris agreement, weaken environmental regulations, close the ministries for science and the environment, and cut the federal science budget. Considering the size and global importance of the remaining Amazon rainforest, Bolsonaro's election could herald a global environmental disaster of unimaginable extent.

Democracies are said to be more successful than autocratic regimes because the checks and balances and frequent changes of leadership ward off the dangers of extreme decisions. That remained true until the combination of populism and turbo-charged communications technology produced a situation where pied pipers can lead entire nations over a cliff and the truths of science are no longer heard. Which is why, even after a quarter of a century of discussions, the Katowice summit does not have much of a chance to stop climate change.

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## Book review

# Profound rumblings from the bowels of the lobster

John C. Tuthill[1]

*Lessons from the Lobster: Eve Marder's Work in Neuroscience*
Charlotte Nassim
(The MIT Press, Cambridge, MA; 2018)
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In his essay 'Consider the Lobster', David Foster Wallace summed up the tepid state of human–lobster relations: "for practical purposes, everyone knows what a lobster is. As usual, though, there's much more to know than most of us care about — it's all a matter of what your interests are."

For the last 40 years, the part of the lobster that has most interested Eve Marder is its stomach, specifically a cluster of approximately 30 neurons known as the stomatogastric ganglion, or STG. Neurons in the STG are organized into two interconnected circuits: one controls a set of internal teeth that break down food particles, while the other dilates and constricts a tube that forces food into the animal's gut. In the Marder lab at Brandeis, electrophysiological studies of the neurons that control crustacean munching have transformed how we think about the flexibility, variability, and outright sloppiness of brains.

What would compel someone to study the neural circuits that control lobster mastication and swallowing? The reasons are too many to list exhaustively here, but here are just a few good ones. First, the STG is easy to work with because it produces rhythmic patterns of activity even when removed from the animal and pinned in a dish (as shown in the figure below). STG neurons are humongous: 50–100 μm in diameter (compare this with the measly 3–5 μm neurons in my own critter of choice, the fruit fly). They are also uniquely identifiable in each individual lobster, and even across crustacean species, so you can record from the same cell type day after day. Finally, if you study the STG, you may get the chance to work with Eve Marder, an undisputed sage and genie of neuroscience.

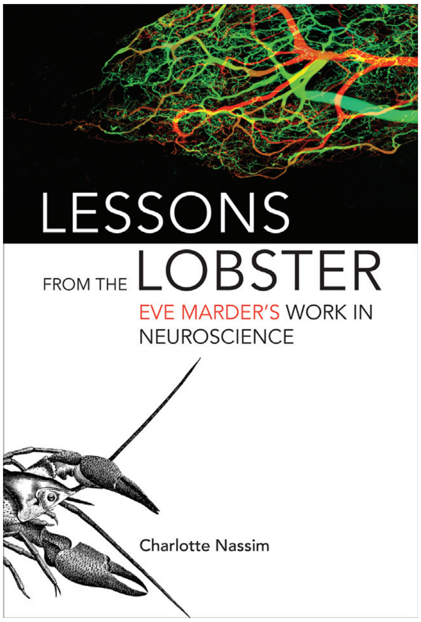
 

In a brave new book, Charlotte Nassim attempts to weave together the insights gleaned from the study of the STG with a biographical account of Eve Marder's life and work. This is a tall order. Ironically, given its numerical simplicity, the STG has a reputation for complexity and arcane terminology. Each STG neuron is known by a 2–3 letter acronym, such as PD (pyloric dilator), AB (anterior burster), and LPG (lateral posterior gastric). Entire PhD theses have been dedicated to studying individual STG neurons. All of this detailed work has revealed how the distinct firing properties of each STG neuron are shaped by the expression of ion channels, as well as the synaptic connections between cells. One of the main contributions of Marder's lab has been to show how STG rhythms can be modified by dozens of diffuse chemical signals, which include amines, amino acids, and peptides, collectively known as neuromodulators. The result is that there are dozens of different ways for the STG to fire, presumably to accommodate all the different types of meals and contexts a lobster will encounter in its lifetime. There are also multiple mechanisms that can give rise to a certain firing pattern, for example, through different combinations of neuromodulators. This has been one of the key insights gleaned from the STG: that even a small circuit of 30 neurons is far more flexible than one might assume.

Things got even more thorny when the Marder lab started to try to understand the variability in their experimental data. Every neuroscientist knows that electrophysiology data are variable, and most of us work to reduce variability by minimizing measurement error (e.g., wearing the same lucky socks for six months). When we plot our data, we often make the mean flamboyantly bold, while the underlying distribution lurks in the background as a muted, unassuming grey. The underlying assumption here is that there exists an ideal result or singular biological solution. Marder's lab was among the first to seriously question this assumption, by showing that many different computational models of the STG network can produce similar, and equally adequate, chewing rhythms. The successful models included startlingly large (2–6-fold) differences in ion channel expression and synaptic strength. By measuring ion channel conductances, mRNA expression, and synaptic connectivity across many different animals, Marder and colleagues found similar levels of variability in real STG circuits. In other words, there are many different ways to build an STG that is 'good enough'. This work not only liberated guilt-ridden lobsters from the unrealistic expectation of chewing perfection, it also revealed the existence of mechanisms that allow a circuit to reach a state of acceptable mediocrity. The molecular implementations of these mechanisms, such as homeostasis, compensation and degeneracy, represent formidable fissures in our understanding of the brain into which the Marder lab and the STG field are just beginning to peak.

Reading an STG paper can be like dropping in on the raucous holiday gathering of a large, close-knit family. You might start off knowing one or two family members, but they quickly introduce you to their grandparents, twelve cousins, and six aunts. It is difficult to tell the cousins apart and keeping track of their names is hopeless. You feel guilty about this because everyone is so *interesting*, spinning zany yarns of extreme situations that the family has collectively endured — starvation, inclement weather, molting. The cocktails don't help — they are slung toward you at a hurtful pace, each one a different flavor and color from the last. Your brain aches. At some point in the night, as you participate in a thunderous drum circle with 27 nearly identical strangers, you think this may be one of the most profound moments of your life.

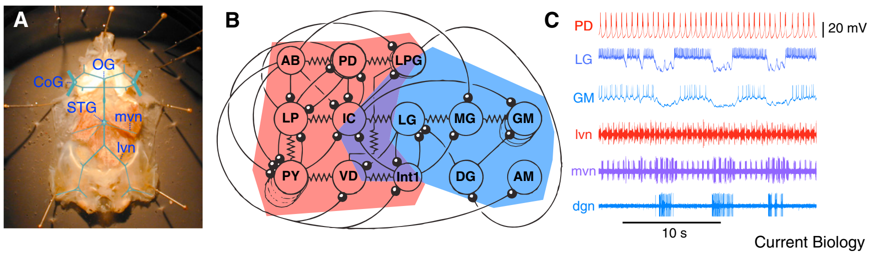
The edges are blurry the next morning. As you drive away through grey flurries, you brace yourself to celebrate the holidays with your own family. That evening, you sip watery beer and play cribbage with your snoozing father. Your mother silently serves you raisin bread from a can, cold. Yes, they raised you and you love them, but the fact is that you learned more from a single evening with the STG than you did from 18 years of living with these silent sphinxes. In spite of its intricacy, you can't help but




yearn for the energy, connectivity, and *depth* of the STG.

Maybe not everybody feels this way about the crustacean stomach. As Nassim describes in her book, it has been an uphill battle for Marder and the STG community to get their results and ideas taken seriously by the broader (read: mousier) neuroscience community. Nassim argues that this was achieved, at least in part, through raw intellect and perseverance. She cites Marder's effectiveness in collaborating with computational and theoretical neuroscientists that not only served to motivate experiments in the STG but also gave rise to general frameworks for thinking about neural circuits that attracted bright people to the field.

Nassim also credits Marder's rhetorical flair and traces her development as a writer throughout the years. Early papers from the Marder lab are straightforward, long-winded tomes. They bring to mind the music of the Eagles: the mechanics are all there, but the *élan vital* is lacking. The abstracts of these early papers often kick off with a byzantine, declarative statement, possibly intended to ward off readers unprepared to enter the labyrinth. Examples of this include "the cardiac sac motor pattern consists of slow and irregular impulse bursts in the motor neurons that innervate the dilator muscles of the cardiac sac region




**The crustacean stomatogastric nervous system:** (A) Gross preparation of the crab stomach, removed from the animal and pinned in a dish. The stomatogastric ganglion (STG) is located at the center. It receives descending input from the oesophageal (OG) and commissural (CoG) ganglia. The output of the STG is through the lateral ventricular (lvn) and medial ventricular (mvn) nerves. (B) Circuit wiring diagram of the STG. Balls represent inhibitory synapses and resistor symbols represent electrical coupling via gap junctions. Red shading outlines the pyloric circuit and blue shading outlines the gastric circuit; the purple region represents overlap between the two circuits. (C) Simultaneous electrophysiological recordings from STG neurons showing the pyloric (red) and gastric (blue) rhythms. The top three traces are intracellular recordings from single neurons, while the bottom three are multiunit extracellular recordings from the nerves leaving the ganglion. Thanks to Gabrielle Gutierrez for images and help with figure preparation and Adriane Otopalik for helpful discussions.

of the crustacean foregut” and “the modulation of the pyloric network of the stomatogastric ganglion of the lobster *Panulirus interruptus* by the neuropeptide proctolin is described.”

It’s not all perdition; there are wellsprings of insight. Nassim effectively curates some of the earliest moments when Marder flexed her speculative muscles, starting with her PhD thesis. These passages presage the purposeful style that makes post-millenial papers from the Marder lab so persuasive. One characteristic flourish is that they often pose a big, concise question at the outset, such as “when does neuromodulation of a single neuron influence the output of the entire network?”, “how different are the neuronal circuits for a given behavior across individual animals?”, and “to what extent do identified neurons from different animals vary in their expression of ion channel genes?”

These are lofty questions that are clearly impossible to solve in a single paper. However, the point is not to solve them outright but to outline *one solution* that indicates a general way forward. This is the strategy used by lyrical songwriters like Leonard Cohen: he can be singing about a bird on the wire but be talking about the human condition. This has been the Marder lab’s contribution on a number of fronts, including the two discussed above: neuromodulation and circuit variability. In each case, the ability to go deep and measure many variables in the STG has provided an example or framework for thinking about circuits in which we currently lack the tools to directly study these questions. Whether the same parameters apply literally to other brains is beside the point, in the same way that not every human always feels like a tethered bird. It’s the *principle* that matters and inspires further investigation. As Nassim quotes Marder, “I get told it’s a circuit controlling a stomach, therefore the rules are different from circuits of cognition. And I just say, ‘Huh?’”

(One could argue that all scientific writing has moved in the direction of generalization, as glam journals have pressured authors to exaggerate the earthshaking nature of their work. But, maybe because they were already working on big questions, it rings true in papers from the Marder lab.)

A strength of Nassim’s book is her careful analysis of the classic STG papers. However, the book neglects Marder’s non-technical writing. For years, Marder has written personal essays about scientific and academic life, first in the pages of *Current Biology*, and more recently in *eLife*, the latter of which she also serves as deputy editor. Many of these essays cover the same personal history as Nassim’s book, but others are straight-up polemics or laments, such as her introspective, two-part series about the ‘depressing’ process of grad student recruitment. Nearly every piece contains an apt and detailed sports metaphor, most often relating to football. As a reader and a fan, I was eager to learn what compels a busy and successful scientist like Marder to dedicate valuable time to writing contemplative prose. Also, is she a Patriots fan, and if so what’s her take on Deflategate?

*Lessons from the Lobster* is not a book that I would recommend to a layperson interested in learning about brains or lobsters. But I would recommend it to a young neuroscience PhD student, particularly for the stories about Marder’s experiences as a student and postdoc. Nassim has unearthed some fascinating letters from this period, such as one in which Marder digresses from an update on her thesis writing to gripe about how some of the men on her intramural soccer team won’t pass the ball to the women. Nassim’s account of Marder’s difficulties as a postdoc in Paris will resonate with anyone who has struggled at the rig and engender respect for individuals who practice science abroad, in a non-native language. Credit is justly given to the students and postdocs who passed through the Marder Lab, by both the author and Marder herself. Learning the humble origin stories of these personalities, many of whom now have their own independent labs and esteemed reputations, is especially gratifying.

This is Charlotte Nassim’s first writing project. Apart from some hagiographic lapses (“so how does she think? Like a detective, but a detective without bias”), and the distracting overuse of qualifiers (“that makes some sort of sense”), she has written a highly enjoyable book about an abstruse topic. Its importance is only elevated by the unfortunate lack of biographies about other female scientists. By comparison, there exist a good number about men — many of them autobiographical. We need more books like this one, and I hope that Charlotte Nassim continues to mine this vein.

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