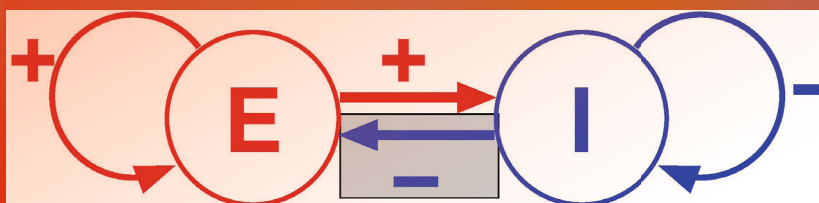Péter Érdi

Feedback

How to Destroy or Save the World

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Foreword

To lead into Péter Érdi's thought-provoking and highly readable *Feedback: How to Destroy or Save the World*, I discuss three feedback systems: the thermostat, the flush toilet—both parts of many readers' lives—and the helmsman.

A thermostat measures the error between a desired temperature and the actual temperature of a room. If the temperature is too low, the thermostat negates the error by a signal to turn on the heating system until the desired temperature is reached. A thermostat connected to both heating and air-conditioning can help negate the error whether the temperature is too high or too low. The thermostat is the classic example of a negative feedback system—it serves to detect some error and provide the control signal to negate, or at least reduce, it.

Now consider a couple who share a double bed and an electric blanket that has separate heating elements for each half with its own controller. Imagine if, by some happenstance, the controls get mixed. Here, when each person thinks they are controlling their half of the blanket they are instead controlling the other. When one person is feeling cold, they use the control on their side of the bed to turn up the heat— but, unfortunately, it is the heat on the other side. Their companion gets too hot and reaches for their control—only to making the bed even colder for the first person, who responds by turning up the heat on the other's side even more. Here we see an unfortunate case of what is called positive feedback, even though it has a negative effect. Rather than negating the error, it serves to increase it. This example can be extended to interpersonal relationships. When someone criticizes you, you may respond with soothing words, possibly calming the situation. In other cases, you get angry, setting off an expanding spiral of bad temper. We see here how feedback can work on a personal scale to destroy or save the relationship.

However, this book demonstrates that the mantra "negative feedback positive, positive feedback negative" is simplistic. At times, we need to encourage growth, and at other times, control it. More to the point, if we wish to avoid destroying the world, we cannot focus on feedback one system at a time. We must instead look at a multitude of interacting systems, where saving key systems may require multiple changes elsewhere.

To move from the interpersonal toward the global, let's start with the flush toilet! Again, we have a basic feedback mechanism which, detecting the low level of water in the cistern after each flush, signals adding water to refill the cistern to a preset level. But to be truly effective, the toilet needed a side invention—the S-shape of the exit pipe from the toilet bowl which ensures that after each flush no smelly material can float up into the bowl. We see here an example of embedding a negative feedback system within a larger system to get its full benefits. However, at their most effective, flush toilets are connected both to a reliable water supply system and a reliable sewage system. Such arrangements helped transform cities from places of fetid living and rampant disease to places that can support healthy lives. Of course, water and sewage are just two of the many interacting systems needed for a large city to support the well-being of its inhabitants, and not just the wealthy. Moreover, the people in the city—and the surrounding countryside and beyond—are crucial subsystems within the overall complexity. We see the increasing importance of feedback in ever-more complex systems as we move up the scale from humans to towns to cities to the whole planet—a level that has become increasingly a focus of the consciousness of many humans at this time of global warming.

Finally, the helmsman. Norbert Wiener had this figure in mind when he chose the title Cybernetics or Control and Communication in the Animal and the Machine for his amazingly influential book that established Cyber- as an almost ubiquitous prefix for the vocabulary of our twenty-first-century information age.

The term cybernetics comes from the Greek word kybernētēs: (helmsman, governor, or pilot). It is cognate with the Latin term gubernator for governor, and those who knew some Latin were amused when Arnold Schwarzenegger became governor of California by the similarity between gubernator and Terminator.

Enough frivolity! The helmsman controls the rudder of a ship as it navigates its way down the river or across the seas. He embodies the principle of negative feedback—if he sees the ship departing from its chosen path, he turns the rudder to move the ship back to its desired direction. However, the larger the ship the slower it will be to respond to the helmsman's feedback corrections. This can lead to many types of system malfunction unless the helmsman plans ahead—whether a collision with another ship or the riverbank, or going into wildly swinging oscillations as the delayed effect of the correction signal yields an over-correction which must then be counteracted to yield an over-over-correction, and so it goes… badly. Thus, if we are to even begin to hope to save the world, we must not only judiciously balance positive and negative feedback in a vast network of interlocking systems, but our interventions must be timely. Will these interventions succeed? Alas, as Wiener knew full well, it is very hard to make predictions, especially about the future.

And so I end where Péter Èrdi begins—with the dreams of Norbert Wiener.

La Jolla, California, USA   Michael Arbib
March 2024

Michael Arbib used the word feedback in his first book, *Brains, Machines and Mathematics.* His recent books include *How the Brain Got Language* and *When Brains Meet Buildings: A Conversation Between Neuroscience and Architecture.*

Preface

This book, of course, is about feedback. The concept of feedback is ancient. However, similarly to Moliére's Monsieur Jourdain, who did not know that he had been speaking prose all his life, people who built systems capable of self-regulation did not even give names for their techniques. We call it feedback.

I had two motivations to write this book. I will start with the second one, which is much newer than the first. I realized that many of us are wrestling with the problem of the world's future. (We have already discussed some aspects of the problem in our previous book written with Zsuzsa Szvetelszky: Repair: When and How to Improve Broken Objects, Ourselves, and Our Society. "Many people now agree that something went wrong in the world. Food waste and hunger, cheap clothing for the rich manufactured in conditions close to slavery in another part of the world, climate crisis, and social inequality. More frequent natural and social disasters" [1].

Will humanity survive, and will our grandchildren (including Hanna and Leo) live in prosperity? Or should we worry about the possibility of the extinction of humanity? The book is based on one assumption, hypothesis, on a belief: There is a *narrow border* between destruction and prosperity: to ensure reasonable growth but avoid existential risk, we need to find a fine-tuned balance between positive and negative feedback. My attempt is not to deal with the impossible task, to prove (certainly not in the spirit of formal feedback control theory), but to support the belief.

The second (my initial) motivation is personal: my love for the somewhat ill-fated cybernetics. As it happens in love, we cannot always rationalize our feelings. Norbert Wiener (1894–1964) created the modern field of cybernetics. His book *Cybernetics: Control and Communication in the Animal and the Machine* was a pluralistic theory and an interdisciplinary movement of several leading intellectuals. The term cybernetics goes back to Plato, who explained the principles of political self-governance. (Wiener referred to the ancient Greeks but did not mention Plato by name). Feedback is the fundamental concept of cybernetics. It is a process whereby some proportion of the output signal of a system is passed (fed back) to the input. So, the system itself contains a loop. Feedback mechanisms fundamentally influence the dynamic behavior of a system. Roughly speaking, negative feedback reduces the deviation or

error from a goal state and has stabilizing effects. Positive feedback, which increases the deviation from an initial state, has destabilizing effects. Natural, technological, and social systems are full of feedback mechanisms.

Cyberneticians realized that goal-oriented systems (designed machines and animals) don't operate on the "single cause, single effect" paradigm, but what is called *circular causality*. In essence, it is a sequence of causes and effects whereby the explanation of a pattern leads back to the first cause, and either confirms or changes that first cause. Example: A causes B causes C that causes or modifies A. The concept had a somewhat bad reputation in legitimate scientific circles since it was somehow related to vicious circles in reasoning. It was reintroduced to science by cybernetics emphasizing feedback. In a feedback system, there is no clear discrimination between causes and effects since the output influences the input. The book secretly celebrates the revival of the perspective of cybernetics. I am honored that Michael Arbib, one of the last students of the two Founding Fathers of Cybernetics (Wiener and Warren McCulloch [1898–1969]), accepted writing the Foreword.

The flow of the book. Chapter 1, *Norbert Wiener's Dream: Technology, Life, and Society* starts with his perspective to describe goal-oriented behaviors in machines and animals. Wiener had a deep interest in the future of human society. Initially, no sufficient tools (data, models, computers) existed to make predictions. General System Theory and the development of simulation tools led to the emergence of the celebrated "world models," leading to the report of Limits to Growth [2].

If the Reader accepts that (i) it is worth studying the "narrow border" hypothesis and (ii) the feedback control approach might be a beneficial strategy to avoid catastrophes, then a massive but non-technical summary of the topic "feedback everywhere" in Chaps. 2, 3, 4, and 5 will encourage the Reader to think with me about possible natural and social disasters and strategies to avoid them.

Chapter 2, *Feedback Control: A Modern Concept is (a not so) Invisible Thread in the History of Technology* was strongly motivated by the writings of Dennis Bernstein, a professor of Aerospace Engineering at the University of Michigan. He showed the power of the concept by reviewing studies on mechanical clocks, steam engines, aerodynamics, and electronic devices.

Chapter 3, *Feedback Control in Biology: An Overview* illustrates that the concept is a fundamental tool at every level of the biological hierarchy, from cellular to socio-ecological systems. Feedback control strategies maintain the stable, healthy operation of biological systems. Stability has nothing to do with time-independent, stationary behavior, and stable, self-sustained oscillations with very different parameters have indispensable physiological roles.

Chapter 4, *Climate Changes, Wildfires, Tsunamis* analyzes the appearance of complicated feedback loops in generations of seemingly natural disasters. Climate predictions have their problems, and because of the presumably chaotic nature of the climate, predictability has severe limitations. At the global level, the future will tell whether social control will be sufficient to stop negative tendencies.

Chapter 5, *From Laissez-Faire to Greenspan: Feedback Control in Economic Systems* summarizes the central possible answers to the age-old question: Is economics a self-regulatory system that works reasonably, leaving everything to the

decision of the individual participants (buyers and sellers), or should the government intervene. Symbolically, it can be labeled as the Keynes versus Friedman debate. Former Fed Chairman Greenspan realized some regulation was missing in the financial system. So far, humanity has not found any better suggestion that democratic institutions should have the power of control. Recent concerns emerged that the financial power of the few can be converted into political and legal power. We leave it for the next generation to stop and reverse this negative spiral.

As we know now how feedback control works in technology, biology, economics, and the global environment in Chap. 6 *From Natural Disasters to Social Riots*, we are ready to discuss the predictability of catastrophic and existential risks and the control mechanisms avoiding them. The complex systems approach to political instabilities combines causal modeling techniques and machine learning methods-based data processing to study the sophisticated problems: How much social unrest do we need? How much migration do we need? Even if we don't have direct answers, we should consider the stabilizing and destabilizing mechanisms to keep the world safe. Chapter 7 *Epilogue: The Narrow Border between Prosperity and Destruction* suggests that first, we need systems for providing early warnings for possible disasters. Second, rapid and local interventions by making decisions and taking actions may (or may not) save the world.

There are several excellent books discussing different aspects of feedback. A very tentative list [3–7]:

- Wiener N: The Human Use of Human Beings. Houghton Mifflin, 1950.
- Arthur, W. B. (1994). Increasing returns and path dependence in the economy. Ann Arbor, MI: University of Michigan Press.
- Diamond J: Collapse: How Societies Choose to Fail or Succeed. Viking Press 2004/2011.
- Tetlock PE and Gardner D: Superforecasting: The Art and Science of Prediction. Crown 2016.
- Cavana RY et al.: Feedback Economics: Economic Modeling with System Dynamics. Springer 2021.

(Last minute note: As I complete the Preface, I learned about the recent publication of a book *Feedback: Uncovering the Hidden Connections Between Life and the Universe* by Nicholas Golledge [8]. In that book, cycles of changes driven by feedback mechanisms are suggested to lead to life and creativity. I am sure the two books will reinforce each other.)

The book is intended to be an academic trade book. While the primary readership is mostly the broadly defined academics, it is not a research monograph. I hope some people outside Academia, say from public policy, might find some message. I see the book in the hands of people from various generations. Who are they? Young people are growing up in a world where everything seems to fall apart. People in their 30s who are thinking about how to live a fulfilling life. As recently written in a Forbes article, "Contrary to popular belief, Millennials read more than older generations do; and more than the last generation did at the same age." The text will also interest people in their 50s and 60s who are thinking back on life and how to repair their

relationships. In 2022, about 70 million baby boomers in the United States will still be reflecting on their past successes and failures. Male Boomers, many of whom have a forever-young mentality, like to read non-fiction, which connects them with the younger generation.

I am grateful for comments, conversations, correspondence, and/or moral support from several colleagues and friends: Patrick Grim, Ágnes Hárs, Bryan D. Jones, József Lázár, Scott Page, András Schubert, András Simonovits, Zsuzsa Szvetelszky, Ferenc Tátrai, and Jan Tobochnik. Two of my excellent former students at Kalamazoo College kindly helped me. Caroline Skalla prepared high-quality and legally transparent figures, and Raoul Wadhwa copy-edited the original Hunglish text. Big thanks, Caroline and Raoul!

I thank the Kalamazoo College community, specifically my close colleagues, who provided a friendly, intellectual atmosphere. I am also indebted to my colleagues at the Department of Computational Sciences at Wigner Research Centre for Physics in Budapest. I also thank the Henry R. Luce Foundation for letting me serve as a Henry R. Luce Professor.

I almost finished the book when I conversed with Dennis Bernstein in Ann Arbor. He tried to explain his perspective, and I hope I understood it. A single sentence can't grasp his whole approach. Still, it is illuminating: "The goal of feedback control is to achieve the best possible performance through closed-loop uncertainty mitigation, recognizing that performance is the objective of *control*, but uncertainty is the *raison d'être* for feedback *control* [9].

I am thankful to Springer Editors Thomas Ditzinger, who worked with me initially, and Leontina di Cecco, for her professional help in completing this book.

My wife, Csuti's support, love, and wisdom greatly benefited me. It isn't easy to express my gratitude.

Kalamazoo, USA   Péter Érdi

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