emerging: thought leaders

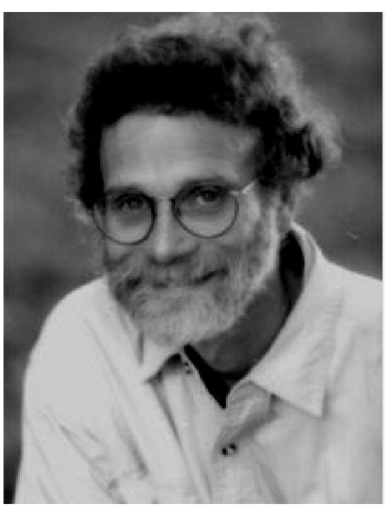
The Networked Universe

From fluid dynamics in astronomy, to the human eye, to disease control and beyond, one scientist is finding important commonalities in a universe of networks.

Larry Liebovitch has the sort of intellectual inclinations that demand challenge and experimentation. Astronomy was challenging, but astronomers can't move stars and planets around and they can't examine them at close range. So he turned his attention to a subject that is infinitely smaller but still imbued with compelling universal interest: the human eye.

"My special area in astronomy was fluid dynamics. I had studied how the stars and hydrogen gas moved in galaxies, and I was looking for jobs where my knowledge of fluids would be useful," he recalls. "I connected with a group studying fluids in the eye. I studied how fluids in the center of the eye wind up in the cornea, and how the cornea moves sodium and potassium. That creates an osmotic flow of water to keep the cornea dry and transparent.

"I wound up in one lab, then another, and then I began doing mathematical measurements of water movements through corneas. Those movements are driven by the movement of ions like sodium and potassium and chloride, and they are similar to what happens in other parts of the body, such as the kidney."



Dr. Larry Liebovitch

Dr. Lebovitch studied how sodium, potassium and chloride ions move through proteins called ion channels in the cell membranes, and he realized he was seeing fractals. That new vision would lead him to new discoveries and a new direction in scholarship.

Dr. Liebovitch earned a bachelor's degree in physics at City College of New

York, a doctorate in astronomy from Harvard. He was a Postdoctoral Fellow at Mt. Sinai School of Medicine in New York, and then served as assistant professor at the College of Physicians and Surgeons of Columbia University.

When he saw fractals in cells in his laboratory, he recalls, he immediately bought himself a new copy of the book by Benoit Mandelbrot, the famous inventor of fractal geometry. Mandelbrot had described the coast of England as a fractal, because on closer and closer examination, he kept seeing the same kind of irregularities. Fractal structures self-replicate across different scales. The structure of tree branches, for instance, is fractal because the successively smaller branches at the top of tree successfully replicate the patterns of larger low branches.

"I realized I could apply Mandelbrot's mathematical ideas to study ion channels, and then I began applying them to more complex ideas in biology," Dr. Liebovitch says. "Others heard about what I was doing, and they would come to me about other problems they had in biology, usually about systems that had separate pieces. They asked help analyzing questions related to a number of things, things like breathing, for instance."

For several years, Dr. Liebovitch has used complex systems, including fractals, chaos, and neural networks to study molecular, cellular, physiological and psychological systems.

People always looked at the brain in terms of anatomy. Scott's Kelso's central theme was to look at the brain in terms of dynamical *patterns.*

"I specialize in systems that have a lot of pieces that interact with each other," he explains. Dr. Liebovitch is now the interim director of the Center for Complex Systems and Brain Sciences at Florida Atlantic University, where he also has appointments in the Departments of Psychology and Biomedical Science and the Center for Molecular Biology and Biotechnology. At the moment he is working on three projects that involve networks.

One is an investigation of how genes regulate other genes, and how that network of interactions manifests itself in the changes that happen when people have heart disease. He is doing that study in conjunction with former students and colleagues at FAU and the University of Miami. Another project is a study with people at the US Naval Laboratory and others on how diseases such as measles spread from one geographic area to another, and how population densities in urban, suburban and rural settings influence the spread.

In addition, he is working with a group of researchers in Syracuse who are investigating the properties of a single celled organism. "This cell has two cilia, or oars, that it can't swim without, " he says. "They are trying to reverse engineer this little bug. They can set up measurements and try to understand when light comes in, what are the biochemical pathways that change. We want to understand all the ways this little thing works."

Connections to Scott Kelso

At FAU, Dr. Lebovitch just finished working on the Center's courses for next spring. He is trying to craft closer cooperation among scholars and researchers in medical science, psychology, and engineering, and get the Center to interact more fully with people at other research institutions who are investigating things related to how the brain works.

The Center celebrates its 20th anniversary this year. It was founded in 1985 by neuroscientist Dr. J.A. Scott Kelso, whose background originally was in sports and physiology, motor control and motor coordination. Dr. Kelso was influenced by the ideas of Dr. Hermann Haken, who had profound insights about self-organization in complex systems. Dr. Kelso realized those ideas could be applied to biological systems. He began the Center with the idea of gathering a group of scientists who could work together using sophisticated concepts in physics, engineering, math, biology and psychology to look at self-organizing systems. "People had looked at the brain in terms of anatomy, in terms of electrical signals," Dr. Lebovitch observes, "and Scott's central theme was to look at the brain in terms of dynamical patterns." That was a major contribution, he says, because it emphasized the concept that the dynamics of a system, in the brain or anything else, is something that can be studied and that it is vital to understanding how a system works.

> Dr. Liebovitch and colleagues have come up with unexpected findings in their study of the timing of heart attacks: The pattern was fractal.

The Center's accomplishments have been innovative and substantial. "We helped train a generation of scientists who are comfortable with biology and math, and who can link the two together," Dr. Liebovitch says. "We hope that as they filter through the scientific community they will set new approaches to many areas. The idea is to gather people who not only work in teams with their separate skills, but people who have multiple skills themselves, which in itself brings a new way of looking at the world."

Surprising Applications

The concept of dynamical patterns has already had important ramifications in several areas of research into complex systems. Dr. Liebovitch and colleagues in collaboration with Dr. Mark Wood at the Medical College of Virginia have come up with unexpected findings in their study of the timing of heart attacks. They looked at a group of patients with heart disease who had implanted defibrillators, which are tiny computers placed under their skin in their chest with wires snaked to their hearts. When the heart began to beat in an unhealthy way, the normal rhythm could be restored by a shock to the heart. With two years of data, they analyzed the time between the episodes of irregularity that triggered the shocks. The length of time between the triggers might be minutes or months, but surprisingly, the pattern was fractal—that is, as events became more frequent, the times between them became increasingly and successively shorter.

"We are doing a follow up study to see if we can use that information in a different way to monitor the success of therapies," he explains. "We don't have a definitive answer yet. But what is important is that you don't have an average time between events. The single most used statistic in science is the mean, and fractals don't have a mean value. There is no average for time between these events just as there is no average for the size of the branches of a tree. With the tree, you can only ask how many new branches there will be in smaller and smaller sizes, which is described by the fractal dimension. The fractal dimension has deep importance for how we handle all kinds of data."

The single most used statistic in science is the mean, and fractals don't have a mean value. There is no average for time between these events just as there is no average for the size of the branches of a tree.

Income is a good example of data where the real distribution is fractal and an arithmetic average is misleading: Averaging the income of Bill Gates and a sales clerk doesn't produce a meaningful figure. An economist using the fractal dimension, Dr. Liebovitch says, could ask different questions, going down the income scale by factors of 10, and identifying in each group how many people have each income and how fast the income rate is changing. Dr. Liebovitch says there is even research to suggest that people's emotions, tracked over time, have fractal properties. In one experiment, research subjects watched a video and were asked to record their feelings with a stylus on a digitizing pad, where the top represented happy, and the bottom sad. When subjects are asked to rate their feelings numerically, say from 1 to 5, dynamic qualities are eliminated. When they used the stylus on the pad, the up and down movements were fractal.

Dr. Liebovitch discovered another mathematical surprise during a study of e-mail viruses.

The Internet has grown so big that it is basically more biological than electronic, he observes. "It's like a living thing put together from different pieces," he says. "People don't even have a map of what it is out there, and there are studies, called Internet tomography to find out."

One way of probing the structure of the Internet, he says, was to look at arrival times of Internet viruses at an Internet Provider node in the UK.

"We thought these viruses were coming from different computers, so we did not think they would come together. In fact, we found a fractal correlation in arrival times," Dr. Liebovitch says. He and colleagues created a mathematical model of the structure of the Internet, and the pattern of e-mail virus arrival times showed a correlation between the fractal structure of the Internet and the fractal timing of arrival of messages along its pathways.

He found that project engaging, he says, “because you had to sit down with a blank piece of paper and figure out what the model was going to be. It’s a lot harder and more fun than having a complicated model and adding bells and whistles at the end.”

A Shift in Thinking

Despite the enjoyment he derives from applying his own skill and creativity to difficult and esoteric challenges, Dr. Liebovitch believes the most exciting expectation for complexity science is not specific research results, but changes in attitudes. “We have to deal with many complicated systems, and it may take a multidisciplinary approach to do it,” he says. “In biology, we have torn things apart and tried to study the dead parts. Using the methods of complexity we have to understand interactions. And we have to study things in their working environment, and we have to understand context. That’s the philosophical background.”

In biology, we have torn things apart and tried to study the dead parts. Using the methods of complexity we have to understand interactions. And we have to study things in their working environment, and we have to understand context.

The National Institutes of Health Roadmap, which is designed to look at complicated medical systems from a multidisciplinary view, is one example of the philosophical change at work. The new approach involves evaluation of the social, psychological, environmental and economic context in which a medical condition arises and is treated. That will lead to new understandings. But perhaps, Dr. Liebovitch suggests, the biggest success for complexity would be if people begin to understand it so well that it no longer needs to be viewed as a separate entity.

“People say there are no good examples of artificial intelligence any more, because as soon as some example works, it becomes part of the engineering culture and doesn’t count as AI any more,” he says by way of example. “Artificial neural nets are connected to phone systems, menus move you to somewhere else, it’s all become so common place it doesn’t seem like first line science any more. Once complexity becomes really well understood, it won’t seem so unusual any more.” ■

By: Prucia Buscell, Plexus Institute