Joshua Lederberg: In Memoriam
Remarks at the Funeral Service, 5 February 2008, New York City
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Marguerite, David, and Annie have asked me to offer some remarks from the perspective of someone who benefitted enormously from Josh's help and friendship in the less chronicled more recent period of his wonderful life.

The person who introduced us was the late William O. Baker, chief of AT&T Bell Laboratories and, in 1984, chairman of the board of Trustees of The Rockefeller University. I was serving as director of programs for the National Academy of Engineering in Washington DC. I had worked for the NAE and National Academy of Sciences since 1977, but Potomac fever never infected me, and I wanted to find a position away from Washington DC. I was caring for a project on research in materials science that Bill Baker invented. It was as if every telephone call in America or the world passed through Bill's head, perhaps even before the calls were made. An exceptionally kind and courteous person, Bill suggested that I visit the Rockefeller to talk with President Joshua Lederberg and Vice President Rodney Nichols about a possible part-time position in New York.

The result was a pair of contrasting interviews in which Rod systematically and successfully searched for tasks around the University on which I might help. I then met with Josh, who elaborated all the dangers I should consider before accepting an offer: Would I have enough time for my own research? What about stress of having two employers in two cities? It was a curious recruiting style and, I would learn, absolutely characteristic of Josh's objectivity. Josh did do a bit of marketing & sales but he also offered the health and safety warnings that most vendors try to hide. I would learn that openness and transparency about risk, whether in space exploration or investment management, was one of his deepest and most valuable commitments. And, like Bill Baker, Josh was omniscient or about as close as possible in the late 20th century.

We began to talk quite regularly, somehow fitted into Josh's crazy schedule by his caring and discerning assistant Mary Jane Zimmerman, and the conversations continued until a little more than a week ago. I think the most fitting tribute I can offer to Josh is a description of a few of the subjects, representing a generous life of the mind of which Josh was the apex.

In the late 1980s and early 1990s, when Josh co-chaired with William T. Golden the Carnegie Commission on Science, Technology, and Government, a consistent theme was the relations of *science and democracy*. In this period I came to accept the essential definition of science as a system of communication for the control of complexity. Control of complexity happens to be the central parameter of evolution. Extremely long, error-free messages are needed for control. DNA and RNA are life's famously long messengers with minimal errors. They dominated evolution for a couple of billion years, a domination a couple of million times longer than the Roman Empire.

More recently, humanity has nourished a competitor, or supplement, to DNA, namely science. Scientific papers as well as engineering creations of various kinds may be considered attempts to create long, error-free, operational messages, transcending generations. Operational means

predictive. The model or the machine works, just like the wing of a bird or the gene making a protein.

The bottom line is that the goal of science is power, and science becomes more powerful over time. A by-product of the power of science is the power of its practitioners. Realistically, the practitioners of science, scientists, retain little of the power they create. Josh knew first-hand that generals, politicians, and business managers seize most of it. Still, scientists retain some, and hence acquire responsibilities and opportunities. Josh and I had many fascinating conversations about these matters, and we promised to write a book for his close friend David Hamburg about them. We did write some essays, but never a book. Josh never did author a book. His compositional taste was for the threaded discussions that Josh foresaw and that the Internet has now made possible.

During the Carnegie years, Joshua made another great gift, an introduction to his fellow microbiologist, Alexander Keynan. Josh described Alex as a kind of genius, having perfect pitch in scientific matters. Alex and his wife Malka are also two of the kindest people I have ever known. Anyway, Josh thus served as father to a series of projects on science, technology, and diplomacy that Alex, Rod Nichols, and I and others have carried out over the past 20 years and that continue to flourish. The theme is cooperation among scientists whose nations are in conflict. Josh's fine appreciation of the invisible colleges of the scientific disciplines that network the world made him sure that science could bridge America and Iran or Israel and Palestine.

Around the millennial year 2000 we were having a gloomy conversation about the environmental fate of Earth, and I wondered with Josh, Alex, and Josh's endlessly imaginative associate David Thaler whether understanding of other forms of life besides humans might offer humans some hope for avoiding environmental catastrophe. They said, well, of course, you must learning about quorum sensing factors. Quorum sensing factors are chemical compounds that form communications networks in bacteria. The consequence of quorum sensing is the coordination of certain behavior or actions between bacteria, based on the local density of the bacterial population. In short, bacteria may know how to avoid the famous Tragedy of the Commons, in which humans try to graze so many sheep on a field that no forage remains and the herd collapses. Quorum sensing was one of many examples that Josh offered over the years of wisdom from below, from early forms of life, which after all had billions of years to work out very sophisticated solutions.

In even more recent years our conversations often revolved around informatics applied to biodiversity. In February 2002 at an icy workshop in Nova Scotia a Canadian geneticist proposed that a very short segment of mitochondrial DNA would suffice to provide reliable identification of almost all animals, and that such DNA barcodes could also be developed for plants, fungi, and microbes. Returning to New York, I immediately vetted the idea with Josh and with RU Professor Norton Zinder (Josh's first and greatest student), both of whom loved the idea of DNA forensics for nature and declared the DNA barcodes possible, even inevitable. We then plotted a 2003 Cold Spring Harbor Banbury conference supported by the Sloan Foundation that incubated the Consortium for the Barcode of Life, which now has barcodes for over 36,000 species and

plans for the worldwide barcoding movement to reach barcodes for half a million species in 5 years.

With the DNA barcode database and also the emerging on-line Encyclopedia of Life, which is creating a web page for all 1.8 million species of animals, plants, and fungi, Josh immediately appreciated the power to use informatics as a macroscope to discover amazing patterns. Longevity research offers an example. Longevity researchers have wanted to study lifespan across many species and along many branches of the evolutionary tree but have not been able to structure or afford a database to allow large-scale investigations. When Josh realized that the Encyclopedia of Life would offer a structure that could include information on lifespan of every species, he helped arrange in the summer of 2007 for the Ellison Medical Foundation, which Josh launched, to provide generous funding to make the Encyclopedia of Life a powerful tool for longevity research.

In the last few months our conversations, continued with undiminished scope. We continued wondering about microbial cannibalism, on which Josh worked with David Thaler, Zeena Nackerdian, and Noel Goddard. How much of an organism's diet, and ability to be cultured, might come from its own lightly cooked brethren? In a lighter vein, we speculated about how microbiology might differ if it had developed using chicken or vegetable soup instead of beef broth.

We speculated about the historical personages whose DNA sequences we would like to examine. We agreed on Leonardo, who had the ability to see birds in flight. The Neanderthals were great hunters with presumed exceptional visual acuity as further evidenced in their cave paintings. Most geneticists doubt intermarriage between ancestors of *homo sapiens* and Neanderthals but could Leonardo harbor Neanderthal genes for vision? I will try to organize a workshop on sequencing of historical personages and dedicate the meeting to Josh. I think Josh might have slightly envied Craig Venter and Jim Watson for writing their DNA autobiographies first, and maybe Marguerite, David, and Annie would be willing to allow Josh's sequence to become part of the scientific heritage.

Our final conversation, about ten days ago, covered questions of consciousness and intelligence in bacteria. An August 2007 paper in Physical Review Letters by Nakagaki and co-authors addressed Minimum-Risk Path Finding by an Adaptive Amoebal Network. The paper reports how a slime mold presented with two food sources systematically connects to the food sources through the shortest route. We may define intelligence as the capacity to solve problems in a changing context, which requires memory and computing power. Both are essential, and single cell organisms seem to have them. Josh was delighted by the brilliance of early life forms.

In the end, this appreciation of microbiology suffused all Josh's attitudes and behavior. He understood the dependence of the large on the small, in the political system, in the scientific enterprise itself, and in life generally. He could be close to power but not corrupted by it. He appreciated that innovations, sources of mutation, might fly in the window, and the source could well be an unknown student or correspondent. Accordingly, he respected everyone, he respected the consciousness of a single-cell organism, and life repaid him with honors and affection.