Scientists of the International Solanaceae Genome Initiative (SOL) Rethink Biodiversity, Food Security and Scientific Collaboration.

by Derek A. Cabrera[1]

International, Interdisciplinary Intergenomics: A grassroots network of international scientists and industry leaders will attempt to answer the oldest and biggest question in biology: what causes biodiversity? In turn, they hope to apply what they learn to one of the toughest problems in agriculture: how to provide global food security?

United by a common organization, The International Solanaceae Genome Initiative (SOL), these scientists propose that the first step toward a solution to biodiversity and food security is to encode a complete "inter-genomic" model, a model family that contains a high degree of biodiversity within its genome. SOL designates its namesake, the *Solanaceae* Nightshade Family, as the ideal candidate for inter-genomic diversity. Steve Tanksley, professor of Plant Breeding at Cornell University, explains: "With the discovery of DNA, we now have the blueprint for life. So we have new tools and understanding with which to explore the questions of biodiversity. Diversity requires looking at a whole group so we need a model that has intergenomic biodiversity. The Nightshade Family is an ideal intergenomic model. It is a relatively simple genome, has been extensively studied and is agriculturally and economically important."

A Model Genome, A Model Organization: In personal and email interviews with members of SOL's Steering Committee—some fifty scientists and industry leaders responsible for the leadership of SOL—it became clear that the large-scale goals and long-term vision of this organization apply to biology, industry, society and the scientific enterprise. From a biological perspective, the SOL Initiative will encode the genomically diverse Solanaceae Family, which will provide a model for encoding biodiversity in other intergenomic groups. From a social and industry perspective, SOL is committed to solving the problem of global food security. And from the perspective of the scientific enterprise, SOL is an organizational model of how scientists can work together to solve interdisciplinary problems that are globally relevant.

Solanaceae Intergenomics: A Model for Biodiversity: The tomato, just one of the venerable Solanaceae, will guide scientists to better understand the entire Solanaceae genome. In turn, the biodiversity and agricultural centrality of Solanaceae makes it uniquely qualified to fill the role of intergenomic model.

A Brief History of SOL

On November 3, 2003, researchers from more than 10 countries met in Washington, D.C. in a forum that united around "a common set of tools, populations and concepts with a firm commitment to work together to elevate our level of understanding of the network of interactions that lead to population diversity and adaptation"[1]. The researchers committed to three, first-phase goals of the project: 1) to facilitate and coordinate research and funding for International Solanaceae projects, 2) to obtain a high quality sequence of the tomato genome that could be used as a model for Solanaceae plants and related taxa, and, 3) to create a "one-stop-shop" on the internet in order to make their data accessible to a growing network of researchers. SOL is organized around larger biological questions:

> "[SOL is] a coordinated network of knowledge about the Solanaceae family aimed at answering two of the most important questions about life and agriculture: How can a common set of genes/proteins give rise to such a wide range of morphologically and ecologically distinct organisms that occupy our planet? The corollary question of agricultural importance is: How can a deeper understanding of the genetic basis of plant diversity be harnessed to better meet the needs of society in an environmentally-friendly and sustainable manner?" [1]

SOL is directed by an International Steering Committee composed of some 50 scientists representing 14 countries. More so than any single individual, SOL is an extension of the Steering Committee's leadership. The first International Solanaceae Workshop, with over 300 scientists expected to attend, will be held on September 19-21, 2004 in Wageningen, Netherlands. This is a good place to start, as the Netherlands was the first country to start sequencing on Solanaceae.

The plant family Solanaceae—the nightshade or potato family—is one of the most familiar, intriguing and economically important flowering plant groups. Encompassing some 90 genera and 3000 to 4000 species, the family is distributed worldwide on all continents except Antarctica. It includes many species cultivated for their edible fruits or tubers, such as the tomato, potato, aubergine/eggplant and chilli pepper. Common ornamental plants such as *Petunia*, *Schizanthus*, *Salpiglossis*, and *Browallia* are members of this family, as well as model experimental organisms like tobacco, petunia, tomato and potato that are used in examining fundamental biological questions in cell, molecular and genetic studies. Paradoxically, while we usually think of members of the family as essential and familiar foods, many other members of the Solanaceae are famed for their alkaloid content and have been used

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throughout history for their medicinal, poisonous, or psychotropic effects; examples include tobacco, jimson weed, henbane, and belladonna. The incredible morphological and chemical diversity, fundamental economic importance and worldwide distribution make the Solanaceae one of the most fascinating groups of flowering plants.[2]

In addition, because the center of Solanaceae diversity is near the equator, species were undisturbed by the ice ages and have therefore had time to "accumulate adaptive genetic variation for extreme ecological niches. Solanaceae is the third most important plant taxon economically and is the most valuable in terms of vegetable crops. It encompasses the most variable of crop species in terms of their agricultural utility."[1] Graham Seymour, of the University of Warwick, states, "One of the major challenges faced by plant scientists is to connect information from model systems, such as Arabidopsis, with crops. Once the tomato genome sequence is finished, the availability of this, along with the Medicago and rice sequence, will allow transfer of biological knowledge across all major groups of flowering plants. The Solanaceae are an excellent target because of their genome size, relevance to human health, agricultural importance, diversity, and vigorous well coordinated user groups worldwide."

You Say Tomato, I Say Eggplant:The venerable tomato will help scientists to better understand the entire Solanaceae genome by acting as a reference sequence for peppers, coffee, potato, eggplant, petunia, and other Solanaceae. How did the tomato get the lead role in the On-Broadway production of food security? Tanksley explains, "The tomato as a reference for Solanaceae is just the beginning; it is just a model. This model can be reapplied in other Families." Such a model may also help to answer much more general questions about biological biodiversity. Sandy Knapp, of the Natural History Museum of London, states, "SOL comes at an opportune moment for linking up genomics with biodiversity. The US National Science Foundation has selected the genus *Solanum*—to which tomato, potato and eggplant all belong—as one of four Planetary Biodiversity Inventory (PBI) projects." Led by Lynn Bohs of the University of Utah (and co-PIs Knapp, Michael Nee of the New York Botanical Garden, and David Spooner of the USDA), the PBI *Solanum* team is developing a web-based taxonomic treatment of the approximately 1500 species. Knapp explains, "This rich online resource will allow scientists from unrelated fields to really get a handle on the amazing diversity that exists in the genus in a way never before possible."

And so, the tomato may not hold center stage for very long. Daniel Zamir, SOL's current Co-chair (with Marc Zabeau of Gent University in Belgium) and professor at the Hebrew University of Jerusalem, states, "SOL is not a project to sequence the tomato genome, it's a project to understand diversity and adaptation and how to do better plant breeding. In order to do that, we need to sequence the tomato genome, but it's not an end in itself. It's something we need to do."

SOL: A Model for Interdisciplinary Science of Global Importance: The scientists of SOL are adapting to a changing research environment. As societies become more interconnected and more globally interdependent, so too do the sciences, requiring increased collaboration and interdisciplinarity to make scientific discoveries. Some scientific fields are changing more rapidly than others, abating scientific nationalism in favor of scientific globalism. Tanksley states, "It used to be that scientists were funded by grants from their respective governments and it was presumed that the science they did would contribute to the strength and security of that government. While this is still the case, in many areas, the funding and the security is globally based rather than nationalistic. So we are moving from nationalistic science to global science."

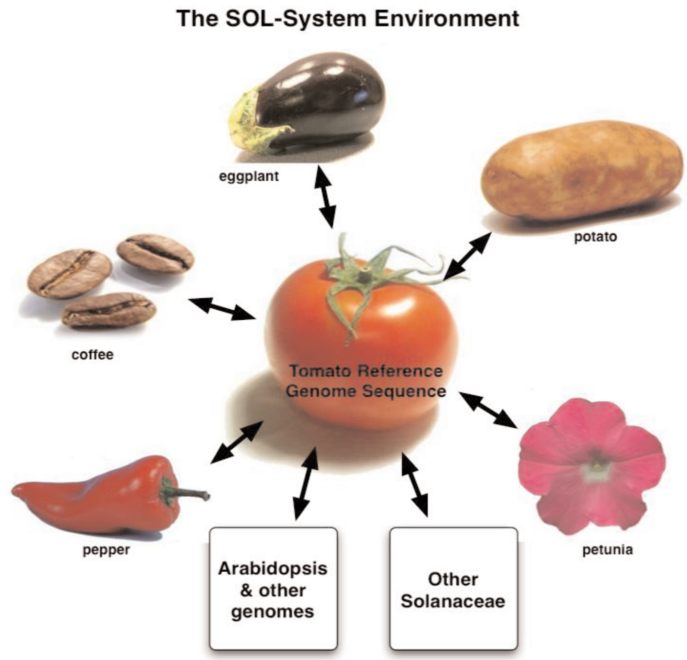

Figure 1.0. Adapted from[1]

Maps, in general, are uniquely suited to provide a big picture and the fine detail at the same time. As school children, the pull down Map of the World at the front of the classroom expanded our perspective on a world much larger than where we lived. In the colored polygons, black dots, and contoured relief, we could imagine diverse peoples and cultures living detailed lives within geographic and political boundaries, countries, capital cities and small towns. Our perspective was expanded again when the first team of international scientists began mapping the human genome in the late 1980's. SOL has produced a new kind of map (See

Figure 2.0); one in which scientists and countries are mapped onto chromosome boundaries rather than geopolitical ones. This "new world" orbits the terrestrial SOL, rather than the celestial Sun. Korean scientists work and live on Chromosome No. 2. Meanwhile, over in Chromosome No. 4, Gerard Bishop, of Imperial College and Graham Seymour, along with Glenn Bryan, of Scottish Crop Research Council (SCRI), are spearheading the involvement of the UK Biotechnology and Biological Sciences Research Council. Four chromosomes away, Japanese scientists work on Chromosome No. 8 while China is mapping Chromosome No. 3. Italian scientists occupy Chromosome No. 12, Spain No. 9, The Netherlands No. 6, and France No. 7. These are just a few examples of the more than 20 countries* and 300 scientists of the SOL Initiative with more countries and scientists joining.

As the map in Figure 2.0 suggests, SOL's scientific goals and its organizational structure are symbiotic. Simply put, it is unlikely that a lone scientist will be the one to solve the kind of scientific problems SOL wants to solve. These problems require coordinated effort. More and more, scientists are mining the interstitial zones between disciplines. More and more, scientific discoveries are the result of teamwork rather than the lonesome work of a stereotypical hermit scientist in his lab.

Antonio Granell Richart, Senior Scientist at the Universidad Politécnica de Valencia in Spain, states that SOL is, "important because such a large endeavor can not be conducted in isolation by a single group or institute but it requires an international effort. Several different groups in Spain are interested in having their research activities under the SOL umbrella." Genoma España, for example, has already allocated resources for the sequencing and will launch an imminent open call to conduct Functional Genomics that will contribute to Solanaceae sequencing. In addition, a number of other projects on Solanaceae are currently being funded by different domestic agencies in Spain. A Trilateral Program between France, Germany and Spain is currently funding several Solanaceae projects. SOL, it seems, is not merely a network of scientists but a network of networks of scientists.

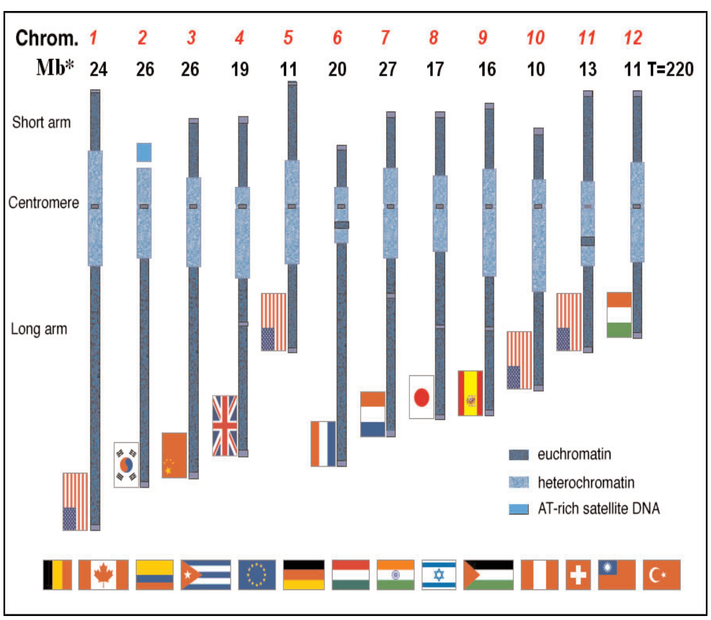

Figure 2.0. Adapted from[1]

It Takes One to Know One: In an article entitled, *The Institute Different*, Bunk[3] describes the Santa Fe Institute (SFI), a research center for the study of complex systems. He writes, "The Institute itself is a complex system." Likewise, SOL's social network of scientists is as complex and diverse a system as the biological systems they study, giving new meaning to the old adage, "it takes one to know one."

SOL researchers refer to the Initiative as a "virtual umbrella" which is reminiscent of Diane Crane's[4] idea of the "invisible college." Crane attributes the growth of scientific knowledge to "invisible colleges", networks of scientists who share similar fields, communicate with one another and monitor the rapidly changing structure of knowledge in their field"[5]. "SOL is like a virtual umbrella" Tanksley says, "it is big enough and flexible enough that people can do the research that interests them and that is important to them, but everyone works under a common vision." Getting a diverse group of people to collaborate, especially scientists, is not as easy as it sounds. Yet, with the promise of new genome sequences and global food security as a carrot, SOL scientists have chosen to set aside their personal goals, egos, and individual agenda in favor to larger collaboration. Each scientist contributes a piece—their specialized expertise and their work in addressing local problems—to the global puzzle of food security. As one example of international involvement, Dr. Byung-Dong Kim of Seoul National University, states, "One of the Solanaceae plants, pepper, is the second most important economic crop in Korea. And the World's largest community on pepper research is working in Korea." Korea will: extend the Pepper EST to 100,000 from at least 25 different cDNA libraries; partially sequence the pepper genome (about 3Mb); engage in comparative genomics between the pepper and the tomato and; pursue functional genomics of pepper pathogen defense-related genes. So, while Dr. Kim and his colleugues work on science that is immediately relevant to Koreans, they also contribute to the larger SOL effort.

Tanksley explains how the scientific problems of biodiversity will be solved by harnessing the power of international cultural diversity, "we are trying to look at biodiversity not through the eyes of scientists from the EU, or from the US, or from developing countries. We will look through the

*Currently, SOL includes the following countries: Belgium, Canada, China, Colombia, Cuba, European Union, France, Germany, Hungary, India, Israel, Italy, Japan, Palestine, Peru, South Korea, Spain, Switzerland, Taiwan, The Netherlands, Turkey, United Kingdom, United States many eyes of each of these scientists. In order to understand nature, you need to encompass as many points of view as possible and then this aggregate perspective will crystallize it into a much clearer vision in the end. So we need the human diversity to study the biological diversity."

Zamir admits that fully utilizing the experience of scientists in developing nations is more easily envisioned than accomplished, "The problem is that there is very little funding for scientists in developing nations. In places like Turkey, Peru, Israel, Colombia, Brazil, Argentina and others, there is important work being done but they lack access to funding. So the most important thing SOL needs to do, today, is to find ways to fund research in developing countries where these plants grow in the wild. Ideally, a far sighted foundation that understands the urgency of this problem and the unique International solution that we are proposing will say, 'we want to contribute to this project.'"

Help Wanted: Peruvian Grad Students: The need for human and International diversity among scientists is not merely the offering of an olive branch—a passing gesture to the "developing world". It is scientifically imperative. Tanksley explains, "If the scientists in the US are sequencing two complete chromosomes for say five million dollars, scientifically speaking, that may be no more or less important than five grad students in Peru that research wild species and how they adapted in their natural habitat for one-hundred thousand dollars; because the sequence itself is not enough to complete the puzzle. Only by combining the genomic and ecological elements will we be able to make a breakthrough in understanding. So we are able to give developing countries an equal role but unfortunately not equal funding. We need to change that. We need a Bill Gates who says, 'this is really important for food security'. And, we need those Peruvian grad students, too."

As a graduate student myself, always searching for research funding, I couldn't resist the temptation to come to the aid of my colleagues in Peru. I asked, "If I'm a graduate student in Peru and I read about SOL, how do I get involved?" Zamir does his best to be accommodating but he knows the realities of funding. Playing the role of Solanaceae Shadchen, he advises, "They could write to me – I do matchmaking. But presently, it's unfortunate because there is so little funding for scientists in developing nations. So that's the major objective—getting them connected into funding streams."

There are other ways to get involved in SOL. In particular, there is a website (http://www.sgn.cornell.edu/) and an online "one-stop-shop". "All of the SOL information, even the sequence, is downloadable from the net," says Zamir, "There is also a country write up for Peru. And you can go to the Solanaceae Genome Network that Lukas Mueller is developing."

Mueller, a bioinformaticist at Cornell University, is managing the biological data for a one-stop-shop where SOL researchers can store, retrieve, and combine data from or to a central database. Mueller believes the one-stop-shop concept provides the technological infrastructure that will be required to serve SOL's organizational and scientific goals, "The SOL project recognizes the importance of bioinformatics to bring data together. Future innovations will happen at the interface of informatics and experimental work. If the information is not available in electronic format, it can't be queried to form new hypotheses. Until now, researchers read papers and their brain was their database. However, with genomics scale experiments, nobody can deal with all the information without the use of sophisticated databases, querying systems and intuitive graphical tools. The one-stop-shop will require researchers to put more emphasis on the computational representation of their data and make it as high a priority as publishing. Biological data that is not stored in databases will be practically lost to other researchers and a waste of time."

A Complement and an Alternative: The SOL literature explains that its approach is "both a complement and an alternative to the GMO strategy for improving the quality and quantity of food"[1]. GMO (genetically modified organisms) is a predecessor paradigm to SOL's genomic approach. Zamir explains the basic premise of the GMO paradigm, "GMO is where you take the gene from, say, a human and you put it into a bacteria. But, there is no naturally occurring avenue of direct transfer of genes from humans to bacteria. What's more, scientists do not completely understand the complexities of these systems so by taking x and sticking it in y, a lot of unexpected things happen. " Dr. Erik Posta, Director for Breeding and research at DeRuiter Seeds, offers an industry perspective, where many of the impending scientific advances will be implemented, "The public at large should be aware that the technologies developed (and hopefully used in industry) are in principle an extension of the knowledge gained from over 4000 years of crop improvement. It is essential that the public accept the usage of these tools and protocols as a refinement of tools already long used in crop development. We are assisting nature not changing it." Posta continues, "[SOL] brings together specific research disciplines on a major and important area: bringing the best vegetable products to the market place. The involvement of the industry is therefore essential to make it a success. The knowledge generated in the public domain is vast but for the major part, it is unstructured. Working on a solid base that also has strong footholds in a commercial sense would be my driving force in involvement in SOL."

SOL's thinking is different than traditional GMO thinking in that it uses the existing biodiversity of nature as a guide. Zamir explains: "The new idea is that existing biodiversity contains a lot of genetic variation that was selected over millions of years. We reuse genetic changes that are already available in nature. Changes that were selected over millions of years, so they have an element of viability." Barry Flinn, who with Sharon Regan, is Co-Lead Investigator for the Canadian Potato Genome Project, describes this new style of genome research, "Many people may believe that the generation of genome sequences somehow means 'transgenic products'. What the public needs to know is that scientists involved in the genome initiatives are not specifically interested in the generation and use of transgenics. The production of genome sequences and ESTs from tomato and the other Solanaceae will make it easier for us to identify the associated genes and their function in the determination of specific traits of interest. This information can then by used for traditional breeding purposes, without the necessity of transgenics. All of the sequence information and genome sequence information will also allow us to understand how the different members of the Solanaceae have evolved to provide the types of fruit, tuber, leaf and other economically important SOL products."

Education: Another area that SOL hopes to develop is education. Sandy Knapp is spearheading these educational efforts. "Solanaceae are ideal for helping people to think about where their food comes from—geographically, physically and taxonomically. Potatoes, tomatoes and eggplants may not look like they are at all related, but through SOL and the PBI *Solanum* initiative we have a golden opportunity to link issues of biodiversity, sustainability and human societies," Knapp says, "The fact that our food comes from far away— even though we think of it as native to our own lands— and that interdependence and cooperation are essential for not only science but also for the continuation of our own species are concepts perhaps more associated with philosophy than hard-core genomic science, but SOL has the unique ability to be an initiative that can make these links."

One example educational project is to create a curriculum module, developed by scientists specializing in education. Elementary and high school classrooms would be given a "Mendelian Module" including seed envelopes and curriculum on CD-ROM that could be used by students to perform the same experiments that Mendel did and to see for themselves the segregation of Mendelian traits. Other Modules would guide students through experiential research into the nature of genetics and biodiversity. SOL has learned from the GMO experience that public understanding and education is not only a core social responsibility of scientists but is also important to the long-term success of the project. "We will demonstrate how, for example, in natural biodiversity, there are natural tomato varieties, that produce 100 times or 50 times the amount of beta-carotene or Vitamin A," which, says Zamir, "is tremendously important for human health."

A Model for Interdisciplinary Science of Global Importance: Initiatives like SOL have great potential as a model for other initiatives hoping to apply interdisciplinary science to problems of global importance. In both its scientific and organizational thinking, SOL seems to follow some basic tenets:

—Use complex social diversity to study complex biodiversity
—Assist scientists working on local problems to contribute their knowledge to a common global problem
—Develop reusable models
—Share resources, information and credit

Biodiversity, Food Security, and Global Scientific Collaboration: SOL may be an innovative model for Solanaceae, research into other genomes, or even scientific initiatives as a whole, but every scientific endeavor, no matter how technically elegant, should eventually be subjected to the social and ethical question: *So What?*

First and foremost, SOL attempts to marshal scientific know-how to solve the problems of global food security. "Food security is a major issue on this planet. It's one of those things that we take for granted—that we will have food for as long as we are here...but don't be fooled," Zamir warns, "what's the probability of a major drought in India or China and how much rice do they have stored in this event? What happens when that is gone?"

Recent research published in PNAS[6] shows that increased temperatures, caused by global warming, have led to a decline in rice yields; the plant cannot adapt quickly enough to its rapidly changing environment. Zamir concludes, "We need a new engine to provide food for the next millennium." Dr. Kim thinks that SOL might be an important driver of such an engine, "SOL is an important international cooperation in plant science for improving sustainable agriculture."

Richart explains the important role Solanaceae plays in food security, "SOL addresses crops as important as potato, tomato, pepper, eggplant, and also related species such as coffee. Natural variability within Solanaceae is huge but is probably a small fraction of what can be obtained. The scientific challenge is to understand how relatively similar genomes result in such a wide variation and how this can result in even better crops. Solanaceae are widely distributed and are part of almost everybody diet, therefore it is an initiative that would have an almost worldwide interest."

Where is SOL?: I asked Zamir what excited him most about the SOL Initiative, "It's the international collaboration. At the beginning, the most exciting thing was the Solanaceae. But as the Initiative has developed, the most exciting challenge is to create a consortium of scientists from different countries. I am Israeli and I have colleagues in Palestine—and we work together. Still there are the conflicts between our peoples, but still we work together, because scientists are—sure we have our politics—but for real scientists, science stands much higher than anything else. The concept of science is something that has historically united diverse people from different cultures or even antagonistic cultures, because it stands above the cultures or the politics." Dr. Ayed Mohammad, of Hebron University, states, "Scientific work cannot be contained within geographical borders. Palestinians and Israelis have the same environmental conditions and in many cases similar problems and most of the time we have shared scientific interest, and by collaborating with each other on the basis of respecting each other, we exchange our experience and use our resources more efficiently and in many cases have more integrated research work and wider scope for the results of the research, and as Palestinians build our scientific infrastructure." Zamir concludes, "So what's most exciting to me is that this project integrates as many countries as possible, as many people as possible, as many cultures as possible. So only by combining the diversity that is present in the human race, we will be able to explore the diversity that is present in nature. That is the most exciting thing to me."

I began my inquiry into the SOL Initiative with the question, *what is SOL?* But I soon learned that the more perplexing question was, *where is SOL?* I learned that SOL sets out to find answers to some of the oldest, biggest and hardest problems and questions; questions pertaining to biodiversity, global food security and interdisciplinary scientific collaboration. However, each time I attempted to put SOL in a tightly wrapped organizational box, it eluded me. SOL *is* a formal organization with a proper noun for a name. SOL *has* a website and a whitepaper, among other things. Yet, I could find little central control of the organization, its messages or its boundaries. In fact, it is difficult to know, *where SOL is,* as it seems to be in so many places. In the end, I decided that SOL is more like a scientific movement than an organization—an idea distributed across a global network of networks. Lynn Margulis and Dorion Sagan write, "the view of evolution as chronic bloody competition, a popular distortion of Darwin's notion of 'survival of the fittest,' dissolves before a new view of continual cooperation, strong interaction, and mutual dependence among life forms. Life did not take over the globe by combat, but by networking."[7] Maybe the old saying is true; maybe it does take one to know one. □

1. Committee, S.S. The International Solanaceae Genome Project (SOL): Systems Approach to Diversity and Adaptation, A Whitepaper. (2004).
2. SolanaceaeSource Website. Vol. 2004 (The Natural History Museum, 2004).
3. Bunk, S. The Institute Different. Researchers at the Santa Fe Institute study what they are: complex adaptive systems. *The Scientist* **15**, 1 (2001).
4. Crane, D. *Invisible Colleges: Diffusion of Knowledge in Scientific Communities*, (The University of Chicago press, Chicago, 1972).
5. Chen, C. *Mapping scientific frontiers: the quest for knowledge visualization*, xii, 240 p. (Springer, London ; New York, 2003).
6. Peng, S. et al. Rice yields decline with higher night temperature from global warming. *PNAS* **101**, 9971-9975 (2004).
7. Margulis, L. & Sagan, D. *Microcosmos: Four billion years of microbial evolution*, (University of California Press, Berkeley, 1986).