A LIFE IN SYSTEMS

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ABSTRACT

The author's career in systems began in 1971 at General Motors Research Laboratories, where he was told to replicate the Club of Rome model, and continues now as he edits the Elsevier journal *Technological Forecasting & Social Change*. Highlights included years working with Ilya Prigogine; graduating from Abe Charnes' Center for Cybernetic Studies at Texas; visits to the Santa Fé Institute; and introducing information-theoretic methods to the management field (while arguing with Bayesians). The paper offers lessons learned and perspectives drawn over this span, with regard to computation, big data, and sustainability, as they pertain to the study and management of complex systems.

BOOKENDS: ROLE OF THE TECHNOCRATIC "SOLUTION"

I have been and remain thrilled that mathematics can fruitfully be brought to bear on social and economic problems. I have a degree in mathematics, and an engineer's mind. Still, circumstances made it clear to me, early and often, that technical solutions may not be solutions at all.

As a high school student, I worked with industrial engineers at the University of Iowa to find an "optimal" legislative redistricting plan for the state (Phillips, 1967). No doubt our plan was close to optimal from the citizens' point of view (voter partisanship was not so vicious then), but the legislature would not accept it. Legislators base decisions on vote-trading and the doling of favors and influence. Especially in Texas, my adopted State, this is still true in 2013: Legislators show little interest in optimality.

A mentor at Iowa recommended that I immediately look up Professor Abraham Charnes at Northwestern University, near my home. Abe Charnes had been a founder and president of both the major operations research / management science societies, and had pioneered the mathematics of those fields. Charnes generously employed me to do computer programming for his graduate students.[1] Ironically, one of Charnes' PhD students, Stephen Littlechild, was modeling optimal vote-trading in legislatures (Cartwright, Littlechild, and Sawyer, 1971). I suppose a second lesson is that even the institutional barriers to embracing a mathematical model... can be mathematically modeled! At least, some of them.

[1] Computer literacy was not yet widespread in that era, even among grad students. Charnes' biographical information is found in Phillips and Rousseau (1992); Phillips and Seiford (2006); Seiford and Phillips (2010).

CCS AND ITS RUSSIAN ANTECEDENT

About that time, techno-entrepreneur and polymath George Kozmetsky became Dean of Business at the University of Texas at Austin, determined to lure his old friend Abe Charnes to Texas. (Along with Bill Cooper and Herb Simon, both Charnes and Kozmetsky had been founding faculty members at Carnegie Tech's Graduate School of Industrial Administration, GSIA.) In this George succeeded, and I was an unwitting part of the negotiation. Charnes phoned my home and offered me a scholarship if I would enroll as a freshman at UT. Charnes set up the Center for Cybernetic Studies at Texas, the name of the center inspired by Charnes' admiration for the work of Sergey Yablonsky[2] at Moscow's Institute of Applied Mathematics.

GM LABS

Three years later I'd earned a Bachelor of Arts in Mathematics, and went to work at General Motors Research Laboratories in Warren, Michigan. The Club of Rome had just published *The Limits to Growth* (Meadows, 1971), and the head of the Labs' math department asked me to replicate the model. Computer power, especially at GM, had advanced to the point where calculation of nonlinear system dynamics models was somewhat feasible. Widely misperceived as a technical solution – i.e., a serious prediction about world economic growth and environmental decline – the Club of Rome model's predictive power was easily shot down: It assumed values for unmeasurable data, its approximate functional relationships were clunky, and aside from a few scenario runs, no sensitivity analysis had been performed. This model was not a prediction of the future; it was a tool for designing a future.[3]

GM, however, cared little about a promising tool. It was the title of Meadows' book that frightened GM executives. What was then the US' biggest company could not afford to believe there were limits to growth! Their first hope was to discredit the model.

A mature analyst needs to recognize human nature, and quite aside from their psychological denial, GM's board had a responsibility to shareholders to grow the value of the company. Of course, if GM had been truly devoted to shareholder value, they could have fixed the egregious inefficiencies that I saw in 1972, and which caused them to go bankrupt 30 years later. I was truly surprised it took 30 years. In that era, though, a gigantic company could survive for decades on pure inertia.

I understand there are now dozens of people doing system dynamics at GM Labs. I'm proud to have been the first. I also had the pleasure that year of meeting Ilya Prigogine and Bob Herman for the first time, as they were consultants to the Labs on traffic analysis.

INFORMATION THEORETIC EXCURSIONS

I returned to Texas and completed a PhD in management science under Charnes, combining nonlinear programming with entropic (Shannon and Weaver, 1949) and statistical (Kullback, 1959) information theory for applications in transportation and marketing.

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[2] Successor to Lyapunov as Editor-in-Chief of *Problems of Cybernetics*. en.wikipedia.org/wiki/Sergey_Yablonsky . I became Associate Director of CCS in the late 1980s and served until 1995.

[3] Frederick Betz later made this distinction clearer to me.

As part of the graduate study, I spent six months as *kenkyusei* (research student) in the Systems Science department at Tokyo Kogyo Daigaku (Tokyo Institute of Technology) under Prof. Takehiko "Bill" Matsuda. Matsuda was the first PhD grad of the GSIA (Feigenbaum, 1988) and founder of the Japanese operations research society. Competent in mathematics, he too never let math trump "social technology," the ethical and constituent-based approach to systems. Müller-Merbach held Matsuda in the same regard as Stafford Beer and Russell Ackoff (Müller-Merbach, 2007) in this respect.

The Tokyo sojourn allowed me to advance an ongoing extracurricular – but still well aligned with the systems orientation – interest in Japanese Zen martial art, a practice I have continued for forty years. It led to the publication of *The Conscious Manager: Zen for Decision Makers* (Phillips, 2003) and "Zen and Management Education" (Phillips, 2009a).

In 1980, Kozmetsky brought Charnes' longtime co-author Bill Cooper[4] to Texas from Harvard. He also brought Igor Ansoff's former research assistant Tim Ruefli down from Carnegie-Mellon.[5] With David Learner, Charnes, Cooper and I co-authored several marketing applications of information theory and data envelopment analysis, about which more later.

Our work in information theory,[6] though its basic form depended on Bayes' Theorem, somehow irritated Bayesians. The information-theoretic forms provide more powerful inferences than conventional Bayesian analysis. Charnes and Cooper had been personally acquainted with, and greatly admired, Claude Shannon and Solomon Kullback and were prepared to defend our choice of tools. Nonetheless, outnumbered by Bayesians and having other fish to fry, we retreated from the battle.

PRIGOGINE AND THE HARPER'S LETTER

Tim Ruefli's PhD class in systems theory was an inspiration. We read George Miller's famous paper[7] on metaphors in systems thinking. Five years later, *Harper's* magazine carried an article that struck me as dangerously ignorant of Miller's warning. *Harper's* printed my letter-to-the-editor rejoinder. The unexpected result was a call from an entrepreneur, Barry Hirschowitz: Would I consult for his company on the systems aspects of his early-detection device for breast cancer, and would I recruit Ilya Prigogine to the project?

To my surprise, Prigogine agreed. He and I started a project to see whether the changing (fractal) dimensionality of skin surface differences in electrical potentials could lead to a non-

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[4] The combined OR/MS societies, now called INFORMS, awarded Charnes and Cooper the Von Neumann Prize in 1982 for their contributions that had shaped the fields.

[5] I was later Vice Provost for Research at Alliant International University, where Ansoff spent his final 17 working years. Alliant was the last US bastion of Ansoffian strategy studies, though its influence is now sadly dwindling even there.

[6] Representative articles are Haynes and Phillips (1981), Brockett et al. (1995), and the award-winning Brocket et al. (1996). When the Society of Actuaries named the latter paper the best published in any of the Society's journals that year, it was a sign that system science was getting wider recognition.

[7] Psychologist and system theorist George Miller, in an anthologized essay first published in the 50s or 60s, predicted that it would become widely popular, after the work of Shannon and Wiener, to see the whole universe as an information processor. Miller noted that after Newton, people loved to see the universe as a mechanical clockworks, and in the age of Carnot to see it as a gigantic heat engine. Each view, Miller said, is only part of the truth, and he urged that we not put all our eggs in the one basket of the information processing analogy.

invasive and effective early warning for breast cancer. However, the company lost its funding before we were to launch the experiments.[8]

DEA/RVA

With Cooper's student Rhodes, Charnes and Cooper devised Data Envelopment Analysis (DEA) as a way to measure and diagnose the relative efficiency of not-for-profit programs (Charnes, Cooper and Rhodes, 1978). It allowed multiple "dependent variables" (incommensurate outputs, in an input-output black-box process) and involved solving a linear programming problem for (in the example of Rhodes' dissertation) each location participating in a pre-school "Head-Start" program. DEA has since been used in well over a thousand applications in public, private, and for-profit spheres, and its links to economic theory have been well established.

Efficiency is a thermodynamic concept, and statistical entropy also has a (formal but not scientific) link to a parallel concept in thermodynamics. Both DEA and Minimum Discrimination Information have appeal in that they make absolutely minimal assumptions. In Phillips (2005) I chronicled Charnes' and Cooper's transition from research in statistical information theory to research in DEA, citing these two common factors as formative factors in the invention of DEA.

Efficiency tells only part of the story of organizational performance – as anyone who remembers Lucy and Ethel in the chocolate factory is well aware. Organizations must also be flexible, to meet new imperatives of the business environment.

Where Charnes, Cooper, and Rhodes took the thermodynamic efficiency constraint (outputs/inputs $\leq$ 1) and appended an extremal principle,[9] Tuladhar and I (Phillips and Tuladhar, 2000) laid an extremal principle over the constraints implied by Ashby's law of requisite variety, yielding a measure of relative variety behavior, or flexibility. Bill Cooper wrote a note expressing appreciation for this advance, which we called Relative Variety Analysis (RVA).

However, efficiency is a short-term concept, easily measured by this week's outputs divided by last week's inputs. RVA's data requirements are much more difficult[10] than DEA's, and it takes a baseline of ten years of data to determine whether a firm is nimble or just lucky. Though academically interesting, RVA therefore does not contribute much to an organization's decision-making power, and RVA has not gained the currency achieved by DEA. My students and I are now pursuing more useful variants of the RVA idea.

KOZMETSKY AND THE HONORS COMPLEXITY COURSE

George Kozmetsky (1917-2003) quit the radical, new management school at Carnegie Tech, determined to forge an even more radical academic venture – after first making a lot of money.[11] George worked a while for Howard Hughes, and then founded Teledyne Corp, winning large defense contracts with the consulting help of Charnes and Cooper. He went to

[8] 25 years later, another company realized Hirschowitz' vision, using thermocouples rather than electrodes: http://techcrunch.com/2012/10/11/breast-cancer-sensing-bra-detects-tumors-years-before-some-mammograms/

[9] Articles representative of our joint work in DEA are Golany et al (1990, 1993); Thore et al (1995).

[10] Inter alia, RVA requires estimating the entropy of an empirical data set.

[11] http://www.ic2.utexas.edu/about-ic-/dr.-george-kozmetsky-memorial-page.html

Texas as Dean in 1967. In his design of curricula and businesses, Kozmetsky emphasized (much like Gregory Bateson) connections and alliances, serving each constituent's motives and incentives, and understanding each constituent's culture.

In anticipation of stepping down as Dean (which he did in 1981), Kozmetsky launched the IC^2 Institute in 1976. He hired me as the Institute's first research assistant. After graduating and working in industry for twelve years, I returned to UT and succeeded Tim Ruefli as Research Director at IC^2.

Working as George's right-hand man was like getting a second PhD. He exemplified not only systems thinking but systems practice, showing an early and complete understanding of what are now called business ecosystems. He created a superior new business incubator, and pushed me to lead the public, cross-sectoral discussions leading to the creation of the Austin Technology Council. Both organizations are still thriving and highly influential.

George Kozmetsky was mentor to Michael Dell and was a board member of Dell Computer. He was also on the board of the Santa Fé Institute. He appointed Ilya Prigogine as a Fellow of the IC^2 Institute.[12]

Though comfortable with quantitative reasoning, George preferred to leave the math to others. He was also aware of the trouble his old acquaintance Robert McNamara[13] had got into by leaning excessively on technocratic reasoning during the Vietnam war. As in Capra's *Mindwalk* (1998), George saw systems thinking as an interplay among politician, poet, and scientist mindsets. He would not let me remain a quant jock, and I'm grateful for his influence in rounding my personality.

UT has an honors undergraduate program[14] called Plan II, in which full professors teach selected freshmen and sophomores. George thought it was high time these youngsters were exposed to complexity science. He called a meeting of Ilya Prigogine, Bob Herman, Walt Rostow, Linda Reichl, Betty Sue Flowers, Paul Woodruff, and myself. We designed a course that was taught for several years.[15]

LINSTONE AND *TFSC*

I first met Hal Linstone[16] at a PICMET conference[17] in 1991. I picked up a sample copy of *Technological Forecasting & Social Change,* of which Hal was Founding Editor, and fell in love with the journal immediately. Hal (a past president of the International Society for Systems Sciences) is well known for his work advancing the Delphi method, and for advocating multiple perspectives (again, no sole reliance on technocratic solutions) in problem solving. He also co-pioneered the idea of discounting – that people's reactions to an

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[12] I basked in reflected glory as Ilya's photo neighbored mine in the alphabetical-order IC^2 Fellows' Directory, and as I helped him organize two conferences at the Institute.

[13] McNamara was Secretary of Defense (1961-68) under US Presidents Kennedy and Johnson.

[14] of which both my daughters are graduates.

[15] Bob Herman, whom I'd met years before at General Motors, had been a co-discoverer of the cosmic background radiation. Inexplicably, he spent the remainder of his career studying traffic dynamics. Betty Sue Flowers (who later supervised the thesis of my younger daughter) was well known *inter alia* for her work with Royal Dutch Shell's futures scenario projects, and with Joseph Campbell and Bill Moyers on *The Power of Myth.*

[16] wikipedia.org/wiki/Harold_A._Linstone

[17] Portland International Conferences on Management of Engineering and Technology

event taper off with the event's distance in time and space – and developed many of its consequences.

Hal invited me to the editorial board of *TFSC;* I later became Associate Editor, then Senior Editor, and in 2011 Editor-in-Chief. Hal is now Editor-in-Chief Emeritus, having served at the helm of the journal for more than forty years.

Our latest collaboration (Linstone and Phillips 2013) looks at the role of information technology in the increased internal complexity of our social/political system, and attempts guidelines for avoiding particularly vicious types of complexity. Systems pioneer Ross Ashby (1957) had focused on organizations' need to generate internal variety to meet the demands of external variety. Though he noted that metabolic energy is expended maintaining an inventory of internal variety, he did not pursue the implied, detailed questions of managing the resulting internal complexity. Linstone and I hold that this is a challenge equal to that of navigating the external environment, especially for our polity as a whole.

During my years at Oregon Graduate Institute of Science and Technology (OGI), I collaborated with David Drake of the American Society for Training and Development to organize Portland's first conference on complex organizations. Christopher Laszlo, then at Lafarge, was keynote speaker.[18]

VALUE OF THE SYSTEMS APPROACH

Horgan's (1995) disparagement of system science garnered wide attention. He held that complex systems studies are unlikely to yield any useful general principles, and moreover that complexity is a "fact-free science."[19]

This moves me to defend complexity and systems studies. My grad course in systems science[20] was inspiring. It captured my imagination, and that's value proposition ("VP") #1. If a new view of any scientific area (or, in this case, many areas) gets youngsters excited, so much the better.

The course predated modern complexity studies. It was all Bertalanffy, Rapoport, George Miller, Ross Ashby, etc. – classical general systems theory. I've since tried to read as much of the new stuff as I can – I had to, as Research Director at the IC^2 Institute in the mid 90s, "managing" Institute Fellows like Ilya Prigogine, economists Bill Barnett and Sten Thore (teacher of Nobel Laureate Finn Kydland), and the great Bill Cooper[21] (teacher of Nobel Laureate John Nash).

Value proposition #2: We whine about silos, but as we all know, interdisciplinary studies' reception at the university or the corporate/government lab varies from outright hostility at worst, to tepid moral support and no funding at best. Creativity happens when a team with expertise in more than one discipline uses insights from one of them to illuminate a problem in another. Complexity is a "branded" interdisciplinary study that attracted philanthropy, via

[18] Gifford Pinchot , a longtime admirer of OGI, maintained that he borrowed OGI's name for new academy, the Bainbridge Graduate Institute.

[19] Melanie Mitchell (my colleague at Oregon Graduate Institute early in the century, who came to OGI from the Santa Fé Institute) mentioned it in the closing chapter of her book (2009), and my fellow blogger at Science 2.0, Michael White, addressed it in his blog (2010).

[20] under a terrific teacher, Tim Ruefli, who, sad to say, succumbed to a brain tumor in 2010: http://today.mccombs.utexas.edu/2010/07/in-memoriam-tim-ruefli-an-inspiring-teacher-and-academic

[21] http://utexas.edu/know/2012/06/20/cooper-william/

the Santa Fé Institute. More power to them. Creative things have happened there already, and more are likely.

I hear two additional objections to systems and complexity science: That proponents claim it will cure everything from cancer to hangnails; and that no real advances in have resulted, in terms of specific new knowledge in physics or biology. These points are well-founded. Still, I think I can offer significant counter-examples.

Because IC^2 Director Kozmetsky was a board member at the Santa Fé Institute, I was able to cadge fly-on-the-wall privileges at the SFI summer school, and attend the symposium that preceded one of the board meetings in those years.[22] An SFI immunologist gave a brilliant talk about how complexity studies enabled researchers to completely reconceptualize immunology. If you believe, as many do, that science's role is help us see the world in new ways, as well as to generate new specific theories, facts, and data, then we have VP#3: Complexity studies bring great new perspectives. Fact-free? Perhaps – so far. But promising new perspectives aplenty.

Ilya Prigogine did bring new facts and specifics in chemistry, based on the complexity perspective. Was it worth a Nobel Prize? To my embarrassment, Abe Charnes challenged Ilya on this point, loudly and none too politely. (Charnes maintained that the greats, back through Riemann all the way to Newton, knew that iterating a quadratic or a system of differential equations could lead to instability – they just couldn't explore the knowledge fully because they didn't have computers.) Though Prigogine did sometimes succumb to the "complexity and emergent order answers every question in the universe" syndrome, he knew how to turn it off and he didn't confuse it with facts. He replied to my advisor with gentle graciousness, specifying exactly what he (Ilya) had contributed to the state of knowledge.

In the same way but much more politely, I pushed back against something John Holland said at SFI. You're right, he replied courteously and precisely, the genetic algorithm can't do that, but here's exactly what it can and does do. His manner as much as his knowledge impressed me deeply.

Charnes was much more attentive and deferential to Benoit Mandelbrot, who had clearly contributed to applied mathematics and whose work had already affected areas from geography to cardiology to finance. I think it was Mandelbrot's work that showed chaotic fluctuations in heart rhythms are a sign of good health rather than the opposite, and the regular beats doctors had approved of prior were in fact a sign of illness.

Mandelbrot was interested in the dimensionality of the stock market also, as was Ilya Prigogine and Ilya's post-doc Ping Chen. Ilya and Chen showed that a simple system of two differential equations can give rise to a series whose dimensionality is indistinguishable from that of the real stock market. However, in conversation, Ilya told me the market is about your expectations about my expectations about your expectations about… and so on ad infinitum.[23] How this infinite regress's results can be reflected by two simple DEs is mysterious. It is also the function of science to raise new questions, and in this case complexity studies did so: This is VP#4.

Analyzing the complex dynamics of the Lotka-Volterra equations yielded a new explanation for the disappearance of species. Where it was previously thought that either predators had enough prey to eat or they didn't, it was now clear that sometimes the complementary cycles

[22] There was too much partying the night after the symposium. Otherwise I'd remember more details of the following day, when a small group of us joyously bopped around Los Alamos National Laboratories with Murray Gell-Mann.

[23] Assuming you and I are players in the market and form expectations about future price movements.

of predator-prey populations could never recover even when food appears available; the chaotic cycle meant both populations could crash for "no apparent reason." This was a new and specific result in population biology. (See also Phillips and Kim, 1996).

The new interpretation of Lotka-Volterra meant that, e.g., paleontologists trying to explain an extinction by looking decade after decade for crop or climatic explanations might want to stop doing so, because we now understand there is not always a "reason."

At a small conference at Lakeway, Texas, with Mandelbrot, I sat next to the mathematician Marc Kac and interpreted for him the geographic acronyms and jargon Mandelbrot was spouting. (Never having considered problems of urban and regional geography before, Kac was nonetheless interested. Here's another value (#6) of interdisciplinary work: When methods and analyses prove applicable in many fields, it's a suggestion that something profound is going on. We might not know what that something is, but good scientists are alert to it.)

SUSTAINABILITY AND RISK

Now that we have (I hope) agreed on the value of systems and interdisciplinary approaches, we face the question of why they are not more commonly applied to that most systemic of problems, sustainability. We do not, for instance, apply the disciplines that deal with risk.

There are many definitions of sustainability. Perhaps the most familiar one is the Brundtland report's (WCED, 1987): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

A green future depends on innovation. Innovation needs to be financed, and that implies risk. We laud entrepreneurial risk takers from one side of our mouths, while abhorring risk from the other. We open any book of common quotations and find dozens of variants on "nothing ventured, nothing gained."

It is necessary and unavoidable that we lend, invest, and borrow when it seems wise to risk the consequences. The consequences *may* compromise future generations' assets. Like the "precautionary principle," the Brundtland definition is too conservative.

I offer, with apologies to Dr. Brundtland, a modification of her principle: *Let us always do our best for the future, while not compromising (too much) our enjoyment of the present, nor our capacity for taking bold risk.*

In science and engineering we do a lot of yin things like conservation, learning to get along with each other, and so on. But we need yang things also: Exploring outer space and the deep sea, building large hadron colliders, "boldly going where none have gone before." They're risky, but if we don't do them, we lose our souls, as well as our chances at those energy and mineral resources that we'd find.[24]

PlaNet

Former National Science Foundation official Frederick Betz and I believe we can network selected experts and labs across the globe, to make significant progress on global problems.

[24] See an extended version of this section at my blog, http://www.science20.com/machines_organizations_and_us_sociotechnical_systems/sustainability_gladly_pay_you_tuesday_hamburger_today

We turned to the Swiss company TallyFox (tallyfox.com) for its online collaboration tool and as a partner in funding proposals. We've named the project PlaNet, and its first program will be to find a way meet the needs of every country for electric power, with a sustainable mix of generation and transmission methods. Distributed research centers will describe local conditions and propose local solutions that will form part of an aggregated PlaNet strategy.

To achieve this on a large scale, we realize that models must be able to talk to each other – to execute and solve each other using transmitted data sets – and that interfaces can be designed to translate between, e.g., environmental models and financial models. This work is just beginning, but will have much impact on ontology design and even scientific publishing (Betz and Phillips, 2013). PlaNet thus involves mathematics, computer science, and linking and valuing the diverse inputs of research teams in many cultures.

NEW COMPUTATIONAL POWER AND BANDWIDTH CHANGE EVERYTHING

The same information and communication technology (ICT) that now makes sensitivity analysis of large system dynamics models a snap, also leads e.g. to climate models that are susceptible to "garbage in, garbage out" criticism. It leads moreover to opportunities for sabotage and fraud, risks always present in complex social-political-technological-financial systems (Linstone and Phillips, 2013). It makes PlaNET possible, and perhaps the knowledge sharing that will save our Earth. The same advanced ICT that allows the computation of DEA models – inconceivable 50 years earlier – and the ubiquitous computing exemplified by Google glasses, tempts us against George Miller's advice to see the universe as an information processor and to hit every problem "nail" with the ICT hammer.

ICT is driving all the changes I've noted above. Its Janus-like capacity to direct us toward benefit or harm, combined with its ubiquity, makes it the responsibility of all of us to become knowledgeable about its use and its ongoing development.

CONCLUSION

I am guilty of much name-dropping in this account, and admit to a childish delight in it. Its serious purpose has been to inform the systems community of some lesser-known activities of those leaders in the field whom it has been my honor to know. These activities continue to influence the field. They offer, via the investigative threads left hanging, research opportunities for younger scholars. They provide fodder for the further defense of the systems view.

It will be additionally helpful to our young scholars to know of mistakes made by those who came before. Let me detail two of my big ones.

My first paper on information theory (Phillips, White and Haynes, 1976) included a section showing how constrained maximum-entropy problems could generate hypotheses automatically from a data set. One of the journal's reviewers was horrified by this notion, and I had to remove it before publication. I shared the reviewer's distaste for the possibility of machine-generated hypotheses, but it was technically correct. Now in 2013, of course, modern data mining uses similar procedures. Lesson: If you have something solid to contribute, argue forcefully for it.

The company I worked for after grad school was innovative, but had no intellectual property policies, nor a patenting mentality. The computer programming department asked me how to compute the pixel coordinates of a proportional Venn diagram, to show how many people buy product A, product B, and both. My assistant Naras Eechambadi and I faxed a solution that used tools of plane geometry, analytic geometry, and trigonometry.[25] The mathematicians at headquarters had tried and failed to do it all analytically; our systems background allowed Naras and me to give no thought to the boundaries of tools and disciplines. Years later, Apple patented a way to draw proportional Venn diagrams on screen. I still have the fax sheet showing our solution, but I had not even put a date on top. Lessons: Even if you are not a laboratory scientist, keep a lab notebook. Borrow tools from all fields as needed.

In this paper I have referred to systems, interdisciplinarity, complexity, and multiple-methodology research. Readers will understand that these terms are overlapping but not synonymous.

There are two lasting dilemmas of system thinking. Some ISSS members have suggested resolutions like the following. I close with them because they have served me well.

Q: In any systems framing of an issue, the question arises: Is it science or is it poetry?

A: If it answers some questions and raises new ones, chances are it's science. If it answers *all* questions (as do "intelligent design," or multiple-universes), it's at best poetry or metaphor. If it carries a principle from one field to another (e.g., physics to business management) without rigorous correspondence rules and re-testing in the new milieu, it is unscientific reasoning-by-analogy.

Q: Where to draw the boundaries of a 'system'?

A: Wherever needed to solve the management problem at hand. No bigger, no smaller.

Make as few assumptions as possible. Keep up on developments in math, data, and IT. Use dialog-based and qualitative methods to temper the technical solution.

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[25] Screen shots are in Phillips (1985).

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