Chapter 2
Systems Principles in the Real World: Understanding Drug-Resistant TB

If a problematic situation is to be resolved, the variety available to the designer of a means of resolving the situation must have controlling access to the same variety as that found in the situation.

John N. Warfield, 2006

In complex situations, decision makers are not presented with problems and alternative solutions. Decision makers must search for problems, as well as solutions…

Kaye Remington and Julien Pollack, 2012

Abstract An example of how a complex modern problem for humankind can be considered in terms of systems science should help in understanding how the principles introduced in Chap. 1 can be applied. Drug-resistant tuberculosis has become a threat brought on by our very use of antibiotics and the power of evolution to select more fit bacteria strain—fit that is to not be affected adversely by antibiotics originally developed by humans to kill them and prevent disease. This chapter lays out the complexity of the problem and examines its facets through the lenses of the principles.

2.1 Introduction

Both of the above statements are interpretations of what is known as Ashby's Law of Requisite Variety. Ross Ashby, a seminal thinker in the then emergent field of cybernetics, came up with his mathematically formulated variety thesis in the late 1950s (see Ashby 1958). His thesis brings the control theory of cybernetics to bear on the world of complex problems. As Warfield's paraphrase brings out, the basic idea is that a complex, multi-faceted problem can be controlled only by means that have as much complexity (variety) as the problem being addressed. Sometimes referred to as "the first law of cybernetics," Ashby's variety law is the antithesis of the always attractive search for a "silver bullet" that will somehow make a complex problem go away. Although the notion that a control must be complex enough to address all the dimensions requiring control seems almost self-evident, we have all

G.E. Mobus, M.C. Kalton, *Principles of Systems Science*, Understanding Complex Systems, DOI 10.1007/978-1-4939-1920-8_2

too many high-profile cases where it is ignored—with sad consequences. One has only to think of our erstwhile "war on drugs" or the once popular "three strikes and you're out" approach to control crime in order to see the appeal and damage wrought by simple solutions to complex problems.

Remington and Pollack, specialists in the management of complex projects, draw the corollary for real-life situations: the first order of business is to get the complex, interconnected dimensions of the problem in view. What sounds at first like a single problem often turns out to be a multi-level interactive web of problems (Chaps. 4 and 5). Simple solutions often snarl the web further in the effort to address a single element as if it could be isolated. The systems challenge and then extends beyond identifying the many aspects of a complex situation as if they are self-enclosed components, each a solvable problem: rather they must also be seen in their dynamic interaction, for that intertwining is often enough the most critical and challenging dimension of a complex problem.

This chapter will give an extended example that will further elucidate the meaning of each of the 12 principles of systems science introduced in the first chapter. But in addition, it is intended to illustrate how these common features of complex systems can serve as windows through which we may see and address the web of interdependent issues that must be identified if we are to make headway as we address complex questions.

Analytic thinking in science and the social sciences typically defines the border of a problem or question to be considered and then proceeds by inspecting the internal structures and dynamics within those borders. We follow a somewhat similar approach when we decompose a complex system by analyzing component subsystems. But the distinctive mark of a whole systems approach is that it can then follow relational lines across would-be topical and disciplinary boundaries to see how the whole fabric of the problematic situation hangs together. These approaches are complementary. We need analysis to identify the many parts or aspects of a problem (Chap. 12). But without seeing the interrelated dependencies and dynamics, we risk dealing with facets of the problem in a counterproductive way. The requisite cognitive variety for dealing with complex problems requires both the manyness arrived at by analysis and the integral understanding of the whole that must inform action on any facet of the problem. We have chosen drug-resistant TB as our example, for it typifies the levels of interwoven clarity and disagreement, solubility and intractability, which are common to many of the problems that confront society.

2.2 Drug-Resistant TB

It is now a well-known and alarming fact that the protective walls of antibiotic drugs we have come to take for granted are crumbling, their defenses circumvented by the evolution of "super bugs." Of course there is nothing unique or "super" about these new strains of bacteria except that they are no longer vulnerable to elements in their environments that in earlier generations were lethal. As we shall see when we discuss evolution (Chap. 11), this is a characteristic of evolution in action. Among the new drug-resistant bugs, the TB bacterium has attracted a lot of attention, and for a good reason, TB was once one of the deadliest scourges faced by humans, especially those living in dense urban populations. TB is most often a lung infection, and because it is easily transmitted by air, a cough could put all the people in a room, a market place, a workshop, or a factory at risk of infection. In the 1800s TB was responsible for almost 25 % of deaths in Europe. Over the next 150 years, improvements in public health based on better understanding of transmission (e.g., warnings against spitting in public and pasteurizing to prevent the transmission of TB through infected cow's milk) did much to improve the situation by the mid-twentieth century. The real corner was turned with the development of the antibiotic, streptomycin, in 1946, the first really effective treatment and cure. Since that time TB has largely receded from public consciousness among the more affluent, antibiotic protected communities of the developed world, but has remained a killer among impoverished populations.[1]

Drug-resistant TB is a many-sided issue, as is evident in the wide array of experts who address the subject. Of course there are medical researchers arrayed in their numerous subdisciplines and public health agencies, epidemiologists, the media, governments, the UN, sociologists, and economists to study its spread. In fact, systemic sectors from the microscopic to global organizations all are involved. Each has a piece of the action, but what do the pieces look like as a whole?

2.2.1 **Systemness***: Bounded Networks of Relations Among Parts Constitute a Holistic Unit. Systems* **Interact** *with Other Systems. The Universe Is Composed of Systems of Systems*

Our first principle, systemness, tells us that any of these aspects may be considered as a system but that each of these systems can also be considered as a component of a larger system. The component view invites crossing boundaries to inquire about relations and dynamics among the components vis-à-vis a larger whole. Growing scales of scope, size, and complexity often signal a "nested" systemic structure, a system of systems in which each successive level enfolds the previous level as an environment. TB bacilli typically are housed in the lungs, the lungs that belong to persons, who are members of families, social groups, the wider community, regions, nations, and the whole globally organized human race. We move from the organization of metabolisms to interpersonal relations, thence to social, political, and economic organization on incremental scales from the local environment to the entire globe (Chaps. 10 and 11). This brief outline of the systemness of the subject at hand furnishes a useful and workable map of relevant questions to be asked as we investigate the relational network that is the matrix for the emergence and spread of drug-resistant TB.

[1] See Tuberculosis: Society and Culture. wikipedia.org/wiki/Tuberculosis#Society_and_culture.

2.2.2 Systems Are Processes Organized in Structural and Functional Hierarchies

System as process (Chap. 6) invites us to look at the dynamic interaction among components of the system. We might start at the level of bacteria and metabolic processes. Bacteria are not necessarily the enemy. The body hosts from 500 to 1,000 species of bacteria internally and about the same on the surface of the skin. Most of these are either expected cooperators in our health maintenance processes or neutral; only a small subset is problematic. Without the bacteria in our digestive tracts, for example, we cannot break down the food we eat into the nutrients we actually absorb. As a result digestive problems are often side effects as antibiotics take out these bacteria essential to our digestive co-op along with the enemies that were targeted. Our life processes are flows combining the input of many streams, some of which, like the bacteria in our intestines, originate somewhere else but nonetheless are expected members of the structured metabolic system. For every cell in our body that "belongs" to us, there are about ten resident visiting microbes (Wenner 2007). The common focus on bacteria as agents of disease, such as TB, needs to be reframed.

This systemic reframing raises new questions, with consequences for practice. If our life system expects and needs so many foreign transients, how does it identify and deal with the bacteria dangerous to our well-being? The immune system, like any defense force confronted with a continual influx of visitors only some of whom are "invaders," has to be pretty sharp to respond with the necessary and proportional discernment (Chap. 9). Is this discernment and resistance totally inborn and automatic, or partially a feature of training? And are there ways of neutralizing invaders in a process less drastic than total destruction? Such questions lead to understanding how we build up "resistance," a natural process that indeed trains the immune system, and one that can be artificially mimicked by the development of vaccines.[2] However, becoming aware of the process of developing resistance also calls into question an overenthusiasm for making household environments as sterile as possible. If some degree of exposure helps train resistance to bacteria, overly sterile environments can create people who, like an isolated community, can lose the knowledge for dealing with outsiders. Indeed, this trained resistance and its absence has had major historical ramifications. A systems thinker such as Jared Diamond can observe how centuries of living at close quarters with their livestock made European explorers, merchants, and missionaries highly resistant to their microbes. At the same time, they became unwitting carriers of invading microbial armies which decimated the residents of the Americas who had not grown up with domestic livestock and so had no resistance to their microbes (Diamond 1999).

At the next level of process, we have not microbes and metabolisms but whole persons and their dynamic interactions with each other. Here reflection turns not just to the disease process of the individual but to the lived experience of being diseased

[2] Katsnelson (2011).

as a member of a family, a wage earner, and a participant in the community. And we must also include the experience of families and communities in dealing with diseased members. A highly communicable disease like TB has very different ramifications from a health problem which is not "catching," for it impacts all the routine forms of close contact which sustain our daily life. Adding to this is the high fear factor that goes with the words drug resistant and feelings of dashed hopes, desperation and despair, that accompany an often prolonged and expensive search for alternatives, and one can see how this disease can pose a special sort of challenge for networks of interpersonal relationships.

Individuals and their families are also enmeshed in an interwoven system with dynamics that span levels from the familial and local to the regional, national, and even global (Chaps. 3 and 4). TB flourishes in crowded conditions and especially among populations where poor nutrition or other factors such as HIV weaken immune systems. It becomes drug resistant due to repeated partial treatments which stop prematurely when symptoms disappear, but the stronger bugs have not yet been wiped out. Patients may stop taking their meds, or low-quality drugs may have been provided; health agencies may not be careful enough with instruction and follow up, or prison inmates may be released before their course of medication has been completed, or some combination of such factors often results in incomplete treatment. Such conditions are especially associated with poverty, so it comes as no surprise that the incidence of TB is highest where the world's poor are crowded together in the rural villages or urban slums of the Third World. Weakened immune systems and crowded, unsanitary conditions work in synergy with low education and inadequate public health and medical facilities, which results in the high incidence of inadequately treated TB that in turn can lead to the emergence of resistant strains.

Since poverty, malnutrition, crowding, lack of education, and weak public health infrastructure empower the TB bacterium, a broad array of systemic processes at every level of local and regional social organization are entangled in the issue. But global dynamics also play a role. Poor rural villages have been a hotbed for TB because of the lack of access to information and treatment services. And now the global market structure is transforming traditional sustenance farming by peasants into commercial agribusiness, displacing peasant farmers and resulting in a wave of migration from the countryside to burgeoning urban slums. Regional infrastructure for sanitation, education, public health, and employment, inadequate to begin with, is overwhelmed by the influx. But cheap labor and unrestricted labor conditions are enticements for foreign investment, so national governments may tolerate conditions, however regrettable, which they regard as a necessary ramp for economic growth and development.[3]

[3] On the intersection of global and national economics on the health of the poor, see especially Kim et al. (2000).

Question Box 2.1
Describe the process of life as a poor person in an urban slum. How does this intersect with processes of the economic and government systems?

2.2.3 Systems Are Themselves and Can Be Represented Abstractly as **Networks of Relations** *Between Components*

Process brings out the complex dynamics of a system, while networks look to the more or less stable relational web within which the process unfolds. With networks, then, our attention focuses on structural linkages. This perspective is useful for considering causality. We often think in terms of chains of causality where A produces B which causes C, etc. But networks call attention to the fact that in complex systems a given effect is commonly the product of multiple causes and a given cause has multiple effects within a system. Or to put it another way, linkages in systems are complex, so real consequences in a network are always more than the single result that is too often our sole focus. Careful consideration of the networked linkage of a system would forewarn us of "side" effects and reduce the frequency of unintended consequences.

The human body is an incredibly complex network. In that interconnected environment, any drug has multiple effects—hence the long list of side effects (actually they are just effects) we hear in drug advertisements. And the list of predicted effects quickly veers to unpredictability for any given patient when the interaction of multiple drugs not only introduces new effects but modifies each other's effects in unexpected ways.

The biological network is complemented by the many-layered social, economic, and political networks we have discussed. Each of these can be analyzed both in terms of their inner systemic linkage and in terms of their linkage to one another, which is the boundary crossing that takes us to the whole system. A system of systems is, in this way, also a network of networks (Chap. 4).

Not only are there many kinds of organizational linkage, there are many degrees of linkage strength as well. Understanding the texture of relative strengths is often critical for understanding both what happens and, equally important, what does not happen in a network. In the network of nations, drug companies and their research facilities tend to be located in wealthy nations, far from the TB-infested rural villages and urban slums of Asia and Africa. Distance weakens the linkage to local problems by the "not my problem" factor. And profit, the guiding link in corporate behavior, is also a weak link when it comes to addressing the diseases associated with poverty. Drug-resistance, however, strengthens the linkage weakened by distance, for global travel now ensures that TB has begun circulating among us in the resistant form that even our most advanced medical facilities cannot cure.

Consequently, it becomes our problem, and so has already received enough media attention to result in public outcry and congressional hearings about the notable lag in antibiotic research.

Between 1945 and 1968, 13 new categories of antibiotics were invented; these for a time saturated the market. Since 1968 just two have been added, even though we have known about growing resistance for decades. After more than two decades of outcry from public health agencies about the emergence of drug resistance, only four of the twelve major pharmaceutical companies are engaged in the research. This research is very expensive and the payoffs are much more modest than for any number of other kinds of drugs such as statin drugs, sleeping pills, or diet pills, to mention a few. Moreover, the FDA has become more reluctant to approve new antibiotics after a scandal in 2007 regarding fraud and safety issues in connection with Ketek (Telithromycin), an antibiotic introduced in 2001. In effect the effort to protect consumers by tighter regulation has contributed to endangering them in new ways, as drug companies become even more reluctant to engage in expensive research with even higher barriers to bringing a new antibiotic to market. The linkage between consumers, drug companies, and the FDA now actively also includes the media, Congress, and the voters. As drug resistance became a high-profile issue, Congress in 2012 enacted provisions in an FDA authorization bill to grant drug companies engaging in antibiotic research an additional 5 years of patent protection (i.e., no generics), thus readjusting the strength of the profit linkage with the reasonable expectation; this will prove motivational for the pharmaceutical companies (Vastag 2012).

Question Box 2.2
Drug companies, the FDA, medical clinics, TB patients, and TB bacteria are all networked components. What are the linkages among them?

2.2.4 Systems Are Dynamic *on Multiple Time Scales*

The time scale difference of most immediate interest for drug-resistant bacteria and antibiotics is that between rapid microbe reproduction rates and the slow pace of human social change. Yet the adaptive dynamics of human societies are lightning fast compared with the adaptive standards of the systems of most larger organisms. The pace at which we are able to conspire and introduce new strategies far exceeds the rate at which most of the larger life forms can adapt. For good reason even in the case of stocks of wildlife, we now use the term "harvest" when managing our fishing and hunting activities.

If we reduce the reproductive scale to that of insects and even more to microbes, however, their basic adaptive dynamics make our cultural adaptation seem glacial by comparison. By "basic" in this case we mean their rate and quantity of reproduction.

We have for decades been waging all-out chemical and biological warfare against the insects and microbes we define as the enemy. Victory seems rapid and impressive enough to sell a lot of pesticides and antibacterial drugs, but as they are widely used, resistant "super bugs" are bound to emerge. Because of the rapid rate and scale of their reproduction, insects and microbes manage to problem solve by evolution, which can keep pace with and eventually outrun the calculated strategies with which we attack them. If there is any variation in the gene pool that happens to render its carrier more resistant to the current wave of attack, it is likely to survive long enough to produce offspring in numbers, who will in turn produce yet more progeny endowed with fortunate resistance in a geometrically escalating population wave (Chap. 11).

Within the human social system itself, the varying time scales of different systemic levels is a constant source of friction and frustration. Businesses try to be light and lively to take advantage of any opportunity. Bureaucratic agencies need defined rules and procedures to maximize regularity and predictability (Chap. 9). So the regulation of drug companies by the FDA is naturally an area of tension. Predictably, from the point of view of commerce, regulation seems most often to be somewhat out of date and counterproductive, in short "behind the curve," thus hindering rapid response to new opportunities or needs. Consequently the weight of FDA regulation in the area of antibiotics currently seems to make the process of bringing a new antibiotic to market too long and too uncertain to turn a profit on a time scale acceptable to business interests. [4]

Improvements in public health and the availability of antibiotics and other drugs has dramatically reduced mortality rates and extended human life. This advance contributes to another time scale problem. In just 40 years after 1950, the human population doubled from 2.5 billion to 5 billion; by 2050 we expect about 9 billion people to inhabit the Earth. At the time of Christ, world population was only about 300 million. Accelerating growth (a time scale factor) in one segment of a system typically intersects a limit imposed by other interdependent sectors which move at a slower time scale, producing cycles of boom and bust (Chap. 6). In the absence of predation, for example, herbivores such as deer are likely to multiply rapidly until they consume more forage than a growing season can produce, after which they may undergo a population crash of 90 % or more. The acceleration of our population has been matched by technologies that accelerate the extraction processes not only of gas and oil but also of food, and, increasingly, of water upon which we are all dependent. But such acceleration has only been making the pipeline bigger, not increasing the size of the well. Some of our resources, such as oil, replenish only in geological time, a much slower time scale which we cannot manipulate. For trees and plants and the livestock that depends upon them, we can accelerate growth rates to some extent, but the deep processes of fertility have their own timeline that intersects and finally reverses booming populations. Getting the

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[4] For an excellent overview of the situation and suggested measures to encourage renewed efforts in research and development of antibacterials from the point of view of the biomedical industry, see Gollaher and Milner (2012).

time scales of human reproduction and resource consumption in sync with the other systemic time scales is one definition of sustainability, a reality so vital to this world upon which we depend.

2.2.5 Systems Exhibit Various Kinds and Levels of **Complexity**

An easy way to get a start on kinds of complexity is to ask what kind of problem something is. To say drug-resistant TB is a health problem does not narrow the field much. As we have seen, the health problem includes not only the complex metabolisms of biology but also social, psychological, educational, economic, and governmental dimensions, to name only the most evident. Describing any one of these immediately gets us into distinctive types of layered complexity. The TB bacterium is a complex organism which includes many interacting components, each with its own complexity. How it sustains itself and reproduces in the environment of human lungs both relates to its internal organization and to its relation to that environment. And what do TB bacteria do to that environment as they make a living and multiply? The typical course of a disease is a process with its own kind of complexity, and the issue of contagion and transmission intertwines with the complexity of social contacts. All of these considerations belong just to the physiology of the disease, so even this single area harbors diverse kinds of complexity.

We move into a whole different order of complexity when we look at the relationships among humans, who have conscious and subconscious, psychological and social, economic, political, and religious dimensions which are all manifested in the complex systems and subsystems that order their shared lives. Particular kinds of complexity develop in each of these areas, plus a different order and type of complexity unfolds at the holistic level where all these areas interact and shape one another (Chap. 5). This difference is reflected in academic studies: natural and social sciences separate these areas as different kinds of specialization, each delving with special training and jargon into a particular kind of systemic complexity. The humanities, in contrast, typically engage the complex dynamics of the whole, for the mutual interaction of all these areas is quite different from anything that could be understood by studying each of them individually and then attempting to add the results together.

Drug-resistant TB involves all these kinds and levels of complexity. It calls for many specialized kinds of study and intervention, everything from research laboratories to government agencies and UN-sponsored educational outreach. The treatment of patients in the actual practice of medicine stands at a particularly complex intersection. Treatment needs to be informed by all the specializations: the ideal clinic would be up-to-date on medical science and best practices, with good community relations, efficient agency procedures, skilled doctors, etc. But if it is just processing patients as diseased bodies to be tallied as caseload turnaround, something vital will be missing. What every patient wants, in the midst of all that expertise, is to be treated as a human being. Thus, the doctors held in highest esteem, in addition to their specialized skills, will be good at the holistic humanities side of practice, communicating not just expertise but human concern and care. Indeed, part of the complexity of a medical clinic is the motivation of the personnel who undertake such work, and further complexity arises when the clinic is dealing with a highly dangerous communicable disease festering in impoverished areas.

Question Box 2.3
Areas such as medicine, economics, politics, and religion are each so complex that they are often broken into sub-specializations for study by experts. Yet at another level, they all intersect with complex dynamics and linkages as components of a larger system. What are some of the issues you might not see or predict by just becoming expert in one or even several of these areas?

2.2.6 Systems Evolve

Given time, everything changes. But some change is directional over more or less long periods of time. Evolving systems get on a vector that heads somewhere because of some kind of selective pressure that keeps building on a characteristic as it is transmitted over and over again. Drug resistance is a sort of poster child for biological evolutionary process. You take an organism with inheritable variations, put it in an environment where certain variations allow for a good life while alternatives generally perish, and then watch as reproduction increasingly fills subsequent generations with the favorable variation . Partially effective or partially completed courses of antibiotics create exactly such a selective environment, allowing successive generations to become more and more characterized by the recipe that allows the bacteria a good life even in an antibiotic environment.

Society underwent a long evolution to get to the point of producing antibiotics in the first place. Reflecting over decades, centuries, even thousands of years, we can identify the selective pressures that have given our world a social shape in which the conditions are right for the emergence of drug-resistant TB bacteria. From scattered hunting and gathering tribes, we have increased our numbers, invented entirely new ways of making a living, and eventually organized ourselves into a globe-encompassing market economy. The advanced medical research facilities, giant drug companies, and global marketing which produce both conventional and new antibiotics, as well as the conditions of urban poverty in which TB thrives, are themselves the contemporary manifestation of this long and ongoing evolution (Chap. 11).

Hindsight on evolving systems is 100 %—or at least pretty good—but what the future holds involves considerable unpredictability. Where will the emergence of drug-resistant TB and other antibiotic-resistant infections lead? The outcome of intersecting selective pressures is uncertain, especially in the case of humans who can shift priorities so quickly. There are reputations and careers to be made in advancing medical research, money to be made from drug sales, and lives to be prolonged by defeating infectious diseases. Everything seems to point the same way. But these selective pressures do not at present line up quite so nicely. Researchers now understand that the less an antibiotic is used, the less chance there is that it will encounter and launch some randomly resistant strain which will then undermine its own effectiveness. Thus, in order to preserve their effectiveness, doctors should resort to new antibiotics only as a last resort, when all others have failed (Gill 2008). But such wisdom works against the current in a world shaped by the profit motive. Not much money can be made in drugs that are seldom used. And when it does come time to use them, their rare usage also guarantees the initial price will be sky-high, making them beyond the means of many families. Added to that, the communities in greatest need have the least means to pay. So at this time, society has not evolved much of an effective response to being outflanked by these rapidly evolving TB bacteria.

At some point, however, the drug resistance and contagion base will reach a tipping point which is likely to cause significant social reorganization. But the nature of the reorganization will be highly dependent on timing and circumstances. A celebrity could contract the disease and spur an early response. Or political gridlock about spending could paralyze a government intervention that might otherwise have funded the research activity the market alone cannot. Or fact-finding committees might figure out who to blame, with variable consequences. The Department of Health might grow a new agency to make sure this never happens again. The threat of contagion could reshape housing, workplaces, and schools. In any case, some change or changes will emerge and affect the shape of all the other possibilities and probabilities for evolution as society moves onward into our collective future.

If we focus narrowly and separately on matters such as the evolution of drug resistance in bacteria, likely business response to profit incentives, or human desire to maintain health, their trajectories are all fairly predictable, and such information can be used to anticipate the future. But on a more complex level, the predictable systemic trajectories that evolve under these diverse selective pressures actually intersect *un*predictably, giving us a future that in hindsight always seems as though it should have been foreseeable, although in fact it can never be securely foreseen.

Question Box 2.4

What systemic factors contribute to the selective pressures that drive the evolution of drug-resistant TB bacteria? What sorts of changes might lessen or even remove the pressure?

2.2.7 Systems Encode Knowledge and Receive and Send Information

Knowledge and information are critical and demanding topics that will call for considerable discussion and development. But for the moment, let's take two basic propositions and see where they lead in considering drug-resistant TB. The first is that a system knows how to act. This kind of knowledge does not require a brain; all it demands is structure. System structure itself encodes ways of acting in relation to an array of shifting circumstances of the level and type appropriate to the structure. For example, there's something about mass that draws stuff to it; so it is in the structure of things that our Earth revolves around the Sun, that our Moon is attracted to the Earth, and that if we throw a ball into the air, it falls back to Earth, time after time—the system does know how to act, how to function. Second, insofar as systems exist in a universe of process and change, their structurally encoded knowledge of how to act is modified moment to moment by an information flow, information being the news of difference which arrives as some level of structural modification. This structure-encoded knowledge-behavior linkage, mediated by the continual flow of information, becomes the changing world of process. Process is quite deterministic and predictable at the level of physics, but becomes open in new ways as we move through levels of further systemic organization and complexity (Chap. 6). While physics may be basic, that does not mean sociology is just a complex form of physics!

Viewed through this systemic lens, what can we see about drug-resistant TB? On the level of physics and chemistry, the behavior of every atom or molecule is encoded in its structure and informed by modifications in its relational matrix. On quite a different level from simple physics, the TB bacterium is a complex biological structure that encodes the knowledge of how to keep all those molecules hanging together in a very particular way, and it must likewise manage energy flows to maintain and repair a complex order that would otherwise fall apart. Further, the bacterium exists in a hostile environment where its presence sends information activating the destructive agents of the host's immune system. One component of the immune system includes the macrophages ("big eaters"), which are structurally encoded to react to the information of this sort of bacterial presence by engulfing it, putting it in an environment where the encoded response of critical molecules is to disassemble, i.e., to be digested. Even before evolving drug resistance, TB bacteria evolved defenses against this, restructuring in ways that no longer encoded a disassemble response when ensconced in a macrophage. Rather it substituted the equivalent of "go to sleep," in effect turning the macrophage into a bedroom from which it might awaken and emerge when circumstances were more hospitable.[5] Thus, while as much as one-third of the world population is thought to have dormant (sleeping!),

[5]For a graphic series portraying this process, see Rockefeller University's *TB Infection Timeline*. rockefeller.edu/pubinfo/tbanim.swf.

asymptomatic, and noncommunicable TB, only about 10 % of these cases will ever become active (or about 30 % for those with HIV compromised immune systems).

Knowledge comprises the "how-to" of relational responsiveness within and among systems; such knowledge is encoded in all sorts of organizational structures, from microbes to our most complex social institutions. Just as a social organization can flex and change, so new things can happen in the bacterial world, as when the attacking macrophage is turned into a protective dormitory for the bacterium. Insofar as a given organization endures, a degree of predictability exists: it is the very consistency of the macrophage response to TB that made it a consistent selective pressure toward an evolved reorganization of TB bacteria. Because organization encodes the knowledge that shapes response, we expect personalities, institutions, and organizations to behave certain ways. It is no surprise that drug companies are motivated by profit, that impoverished, densely populated, poorly educated populations are exploited for cheap sweatshop labor, that malnourished bodies are vulnerable to TB, or that some governments are responsive to the needs and well-being of citizens while others are corrupt and ineffective. In each case the knowledge of how to act is built right into the structural organization.

The corollary follows that changing knowledge means changing organization. We process continually changing information from the environment, and as we do so we also engage in a dynamic and restless flow of thought. The knowledge organized into the pattern of our lives is harder to change than the fluctuating stream of our mental life, but some thoughts or new ideas may modify mental models in ways that are literally life-changing (Chap. 13).

If the thought is some insight about significant change, such as combatting the spread of drug resistant TB, one soon encounters the hills and valleys of the relevant kinds of knowledge structured into successive layers of social organization. "How can we help?" "Sorry, it's not our job." "What are your credentials?" "We've always done it this way." "Do you have a permit?" "How much can you pay?" "Let's apply for a grant to fund the research." Because they typify the sort of responsiveness or knowledge structured into the organizations, we can guess likely organizations to match each such response. If we wish to change the status quo, it is critical to understand the way the status quo is programmed into the knowledge encoded into the organizational structure at relevant levels. TB bacteria have the structural knowledge to evolve around antibiotics. But whether or not it does so depends largely on the shape of the knowledge structured into our varied and multilayered social organization.

Knowledge structured into large-scale organization is much more resistant to change than the knowledge of individuals for good reason. A society composed of such organizations results in a relatively stable and predictable world even though in principle everything can change. But it also gives us the all-too-common experience of seeing clearly that such conditions as oppressive poverty, malnutrition, and a high incidence of TB could change and need to change, but somehow nonetheless endure for decade after decade. In our enthusiasms, we often feel "We can change the world," all too commonly followed with frustrating experiences and the observation that things just are as they are and we can't do anything about it.

The former is naïve concerning the structural depth and linkages of knowledge inherent in our socioeconomic system, while the latter mistakes short-term rigidity for a kind of absolute invulnerability to change which in fact is not possible for any complex organization. Understanding the nature of structural knowledge and its power in guiding organizational behavior in a given situation is critical for mounting effective and robust strategies to bring about necessary change. While it gives us reason to hope, it also counsels for a patient- and system-wise strategy.

Question Box 2.5

Systemic knowledge keeps organizations performing in a similar way even as the personnel change. The larger and more complex the organization, the more knowledge is embedded in the structure, so it is very difficult, for example, to change a government bureaucracy. The knowledge in a one-person business, in contrast, exists mainly in the mind of the one-person, or at least that is likely to outweigh what is embedded in the structure of the business. At what size do you think organizations start to become "impersonal," where structurally embedded knowledge is the main thing governing responses?

2.2.8 Systems Have Regulation Subsystems to Achieve Stability

Stability means maintaining system integrity and function over time. Simple systems take care of themselves. But in proportion as a system becomes complex, there are also more ways it can breakdown or malfunction. In fact, a narrow range exists of ways of everything going right, compared with the very wide range of ways things can go wrong. Consequently as systems evolve to greater complexity, they also spawn subsystems for the kind of monitoring and correcting needed to keep things on track.

Regulation necessarily involves some kind of expectation and some kind of feedback of information that registers deviation from the expected state of affairs (Chap. 9). Living organisms do this with metabolisms that regulate maintenance and repair through myriads of intertwined feedback subsystems that monitor and shape flows of energy and nutrition.

The question of drug-resistant TB takes us to the heart of a particularly complex area of regulatory feedback subsystems, the problem of maintaining and controlling defense systems. Much as social systems, at the bacterial level the information feedback challenge for appropriate regulation revolves around a dynamic game of detection and eluding detection. Immune systems must be triggered by real invaders, yet remain calm in reacting to the unavoidable host of casual visitors. Allergies represent a familiar failure of the appropriate regulatory response, resulting in one's own defense system becoming a threat as it mounts a violent response to the presence of ordinarily benign agents. Symptoms from seasonal allergies can be indistinguishable from an upper respiratory infection for many people allergic to tree pollen. Even our next level of defense, the medical community, can inadvertently do grave harm by wrong discernment. Thus, the practice of medicine is heavily layered with subsystems of rules and regulations that cover every aspect of training, practice, and the array of technologies used to supplement our onboard defense system. The stability of the medical system depends upon the predictability and reliability conferred by this complex regulatory infrastructure, even though the weight of regulation has the side effect of sometimes slowing the speed and flexibility of response.

Public health agencies are governmental subsystems for regulating the community conditions and habits that concern threats to the health of the general public. The role of these agencies is especially important for a highly contagious airborne disease such as TB. Stable, healthy governments commonly have good, effective public health agencies, much as stable, healthy bodies have sound immune systems. And the converse is also true: governments in turmoil commonly have impaired public health defenses that are ineffectual in regulating and remedying the conditions that promote the spread of TB or the emergence of drug-resistant strains.

Because complex systems rarely can regulate for just one thing, a further complication arises. Governments function at a high level of systemic complexity; consequently they regulate for multiple outcomes which may work together or at cross purposes. Setting priorities is thus a major function of high-level social regulation. In developed nations, public health most often takes priority, though not without economic tensions. Regulatory agencies such as OSHA may be unpopular with business interests, or the FDA with the pharmaceutical companies, and yet they are essential for worker safety and consumer protection. Impoverished nations often feel economic development is the necessary priority, perhaps even the chief method to attain good public health. But the health and well-being of the workers is often in tension with strategies for rapid economic gain. In countries like India and China, when public policy opts to maximize economic growth, masses of farm workers move to urban slums and into the unhealthy and crowded conditions that often characterize concentrations of cheap labor. Wealth and poverty may work in an unhealthy synergy. The governments of wealthier nations rarely prioritize the health of workers in other countries, certainly not to the point of preventing the exploitation of cheap labor in foreign countries. And cheap labor, health issues notwithstanding, can serve as a major advantage for have-not economies to bootstrap themselves up the development ladder.[6] As for the health of the workers, the main way that priority is reasserted and given regulatory teeth is through the corrective force of consumer public outcry in wealthier countries stoked by a sense of common humanity. This constitutes a transnational kind of regulatory system which is facilitated by the global information feedback through the Internet and other media sources.

[6] For an example of these dynamics close to home, see the case discussion of NAFTA and the factory system established on the US-Mexico border in Brenner et al. (2000).

Question Box 2.6
Even criminal systems of any complexity such as gangs or drug cartels have regulatory subsystems to stabilize their operations. What in fact does "regulate" mean in a system context?

2.2.9 *Systems Contain* Models *of Other Systems (e.g., Protocols for Interaction up to Anticipatory Models)*

Systems interact with an appropriate degree of consistency. That is, reactions are not random but are to some extent prefigured in the structure of the systems. The protocol that guides this interaction amounts to a model of the other system—not a complete model-->, but one that specifies what is relevant for the interaction (Chap. 13). The array of signals that set immune systems into action, for example, amounts to a model of the enemy that must be defended against. In the interaction of living systems, such models are often critical strategic factors. An insect, such as a walking stick that looks like a twig, can often elude a bird's model of what lunch looks like; a fisherman can exploit this situation but in reverse, by fashioning cork, paint, and feathers into a lure that fulfills a fish's model of lunch, even though to our eyes the similarity may be far-fetched. Since models guide systemic interaction, every living organism has a structural model of the environment in which it survives and makes a living. For example, our lungs model an atmosphere rich in oxygen.

The creation of an antibiotic is in some ways similar. It begins with a model of the life maintenance system of the target bacteria and then seeks strategies to disrupt some necessary condition. Evolution selectively remodels the offspring of a species to fit changed conditions. When an antibiotic becomes a sufficiently frequent disruptive factor in the environment of a bacterium, the evolutionary process will select any available alternatives which are not disrupted, i.e., those bacteria which survive to reproduce. So the antibiotic-resistant TB in effect has evolved into a form that structurally models an environment in which the presence of the antibiotic is expected but no longer disruptive (Chap. 11). And researchers, in turn, have a new model of the bacterial life maintenance system to figure out and strive to disrupt anew.

The TB bacterium has a model of its world that is continually shaped and reshaped by the selective hand of evolution. But as we move to social, political, economic, and cultural levels, we find that they too each enshrine multiple models, and these models guide all sorts of interactions from our personal daily routines all the way up to the dynamics of global markets. As in the case of predator–prey relationships, or the TB bacterium modeling its environment and the researchers in turn modeling TB's survival in its environment, the organized world is full of fluctuating, cross-referenced models carried by different but related systems and used in all sorts of strategic competitions and cooperations. In this living dance of models, the bottom line for any model is what works for the aims of the system. In the shifting circumstances of life, almost nothing works permanently, so as the world changes, systemic models either change in response to the new conditions, or they become dysfunctional.

We build models from common or repeated experiences, but often need to tweak them with education. A common model for the use of medication is to feel that when you feel better, you can stop taking it, because you think its job is done. This intuitive but misinformed model of effective drug use gives a big boost to bacterial resistance to antibiotics. Unfortunately the more resistant bacteria are still hanging on even when the symptoms seem to have disappeared. Stopping the medication or missing scheduled doses allows resistant bacteria to survive and pass their resistance along to a next generation. When the patient is educated in this new model of what is happening, it shows them the necessity of completing the full course of medication even after they begin to feel better.

The model is not in fact the reality, but a simplified version of reality that typically focuses on one or a few elements designed to address the question immediately at hand. Because of this selective simplification, no model can be pursued single-mindedly without producing unexpected and problematic "side effects." Pharmaceutical companies, for example, "just doing business" in line with a the common profit-maximizing model, have given rise to a conundrum: there's an overabundance of vigorous research on diet pills, statin drugs, and sleep aids for which there is a massive market in wealthier nations, and paralysis when it comes to meeting a growing but not particularly lucrative health challenge posed by increasing resistance to presently available antibiotics.

This exemplifies the difficulties that arise when the market model is applied too exclusively to the health-care system. It begs to be complemented by the common ethical model of humans forming communities in which they take care of one another. Frequently this model is invoked as a perspective quite critical of the capitalist dynamics of just doing business in the area of health. Business is quick to respond that if we single-mindedly pursue such health and ethical models, commerce will suffer, prices rise, jobs disappear, and everyone will be the worse off—an anticipatory model from a business point of view of how linkages will work in our society. Socialism is one alternative model that attempts to synthesize markets and an ethics of communal care, and frequently those who criticize the capitalist model are simply labeled as "socialists." In fact, much political controversy pivots around competing (and often poorly understood) models.

Institutions, professionals, and everyday people alike engage the world through models fitted to their particular situations; frequently these partial models are mistakenly thought of by those who constantly use them as "the way the world works." Such simplistic models might suggest seemingly obvious paths to optimization—the wishful "if only" thinking. It might go something like this: the emergence of drug-resistant strains of TB could be curbed if only people stayed on the farm, if only exploitation ceased and poverty and ignorance were alleviated, if only health agencies had good funding and regulatory power, if only governments behaved responsibly, if only we could find the right market mechanisms, if only…

We have seen that models can be effective protocols for areas or types of systemic interaction, but they are partial, so none can be maximized without disruption. Nor can they simply be added together to constitute an adequate model of a whole, for on closer examination they most often involve too many contradictory dynamics and trade-offs for any additive process or formula to work. Being aware of the role of models as protocols for system interactions alerts us to both their inevitability and their unavoidable partiality. Being forewarned about their partial nature does not allow us to somehow magically find non-partial alternatives. It does, however, introduce a very useful measure of caution and prudence as we follow our necessarily partial and limited courses of action in a reality always spilling beyond our models.

Question Box 2.7
One of the common "if only" propositions is, "If only people behaved the way they should!" But there are very different (and importantly different) models of what constitutes proper behavior. What are some of the competing models? Can such a model be dismissed just because few people live up to it? What is the role or function of such ideal models?

2.2.10 Sufficiently Complex, Adaptive Systems Can Contain Models of Themselves (e.g., Brains and Mental Models)

All the humans and human institutions or organizations involved in the drug-resistant TB situation carry models of themselves, self-conscious images of who and what they are that inform and guide their activity. Less evident is that the TB bacterium also carries a model of itself—not in consciousness but in its DNA. The DNA, as a model of the whole organism, serves as the critical protocol for subsystem interactions that function to produce another copy of the original, which will in turn be complete with its own onboard model of itself. In the process of evolution, variations of this DNA model are continually sifted, screened for how well the resulting organism fares in comparison with other models in the challenge of fitting the current environment. The evolution of drug resistance in an environment laced with antibiotics exemplifies a search for models of itself that still work even when antibiotics are present.

Models, as we have seen, are essentially functional, serving as protocols that guide system interactions. The example of DNA shows the distinctive functionality of a self-model, functioning both for integral maintenance and for the reproduction of a complex system. Similarly, the self-models carried in consciousness maintain and reproduce personal psychological, social, and institutional identities. While engaged in the continual flux of experience, these self-models give a relatively consistent identity through time to the fluid world of consciousness and the forms of organization created and maintained by consciousness (Chap. 13).

Insofar as it is the source of continuity and identity, this onboard model of self easily becomes a bulwark against change, even when change is needed. The conditions that help spread TB are to some extent produced by external forces, but they also become internalized in the habits which become part of the identities of individuals and communities: "This is just who we are and how we do things." Governments and their agencies may resist changes to their mission or routines, especially if they wish to preserve the appearance of a good self-image. And crusaders for change often take on that crusading self-image and have a hard time knowing when to back off or compromise.

The contents of a system's model of itself include not only relations among its internal components but also its relations with its external environment. DNA lays out an organism, but the way in which it lays it out has been selectively shaped already by the environment in which it must fit. Similarly self-models at the personal level are shaped selectively through family within a culture; cultures are shaped in dynamic interaction with other cultures. Institutions anticipate a fit with other institutions, often across cultures. Thus, self-models are not only a protocol for inner organization but also for interaction with other systems. The dynamics that shape any system's self-model or identity necessarily extend far beyond the perceived confines of that self. Nothing exists in itself alone.

Thus, systems composed of multiple layers of systems which have their own self-model possess, a particular kind of complexity. These layered systems of self-models are continually being shaped in a restless dance of internal-external definition and redefinition which includes influence from self-models up and down the hierarchy. Our families make us what we are even as we make them what they are, and the same goes for all the other layers of organization that emerge. However, models of hierarchical control (Chap. 9) need to make room for the dynamics of self-definition among components, and models of individual freedom need to be complemented with the necessary relational fit into the larger environing system. This causal loop between layers means that at any level, self-maximizing strategies may become short-sighted and eventually counterproductive. While neither family nor company, community or government can totally define who we are, neither can we ourselves. Yet the self-model of every community, company, or government does inform its component units, i.e., family members, employees, citizens, etc., and our own self-models critically include some sort of fit, comfortable or not, within these various and layered contexts.

The mutuality of this many-sided dance of self-modeling ensures that systemic social evolution is open-ended: there is no self-enclosed, self-defining, and unchangeable systemic identity. Thus, a situation such as the emergence of antibiotic-resistant TB and the conditions of poverty and ignorance in which it thrives can be challenged and changed. But an understanding of this dance of self-definition must necessarily underlie any effective strategy for change. Self-models also include individuals' roles in the dance, i.e., to whom one should listen, and who has the authority to change things. Such understanding helps identify points of leverage for intervention and constructive change.

In the corporate world, the guiding role of the profit motive can be difficult to change (Chap. 11). Except in extreme cases such as war or economic collapse, democratic governments do not ordinarily legislate what should be manufactured. In light of this, the self-models of capitalism and democracy may trap their cultures into a short-term profit-oriented status quo which may need to be modified or replaced by more far-sighted systems in order to address problems not immediately resolved with profit-oriented thinking. Thus, in order to solve perceived problems, revolutionary thinking may challenge the basic self-model of capitalism with a line of argument at odds with its core beliefs. Frustration with the way in which capitalism can ignore glaring problems sometimes leads to extreme proposals: if the capitalist system were overturned, we could do away with poverty and ignorance along with the urban slums which lay populations open to TB and other epidemics.

In our democratic model, we attempt to use less drastic approaches to systemic change while trying to respect existing self-models. Taxes and tax breaks, surcharges and subsidies, consumer protection and patent rights, etc. are routine tools to enable government to shape the terrain of profit for the greater good. In the world of drug development, a carrot of profitability can be extended by these means to drug companies by governments, and business can be expected to react to the opportunity with research on new antibiotics. Congress, for its part, keeps a self-interested ear open for voter sentiment, which in turn is often shaped by the media, which may quote experts, some spinning facts to further a political agenda. This dance of ideas, alternatives, and compromises often results in watered-down baby steps in the right direction, but steps nonetheless. Our intertwined self-models at every level suggest ways of acting, sometimes in mutually reinforcing synergies, sometimes in corrective tensions. Understanding the layers and interrelation of these self-models becomes a map of points for strategic intervention and leverage in a complex system in which we are both components of the system and agents for change.

Question Box 2.8

Self-identities are formed and maintained in a constant negotiation between inner and outer and up and down the systemic layers of identity (individuals, families, communities, businesses, regions, governments, etc.). What happens in systems dynamics when any self-layer behaves as if it is truly self-enclosed, ignoring the claims of other levels/selves (e.g., individuals focused entirely on themselves, totalitarian governments, businesses that exploit their workforce)?

2.2.11 Systems Can Be Understood (A Corollary of #9): Science

The systemness of the universe forms the basis for relational patterning that makes the world comparatively predictable and hence understandable. The relational patterning of the system of current interest enters the realm of one's conscious understanding as a mental model of causal relationships: we understand how it works well enough to have expectations regarding it that can guide our interaction with it. Actual interactions may further fill out the model, either by simply reaffirming it or challenging it as expectations prove wrong. In this ongoing process of modeling and experiential feedback, understanding is never full, perfect, or complete, though continually open to revision (Chap. 13).

Our living world eludes complete understanding not only because of the limited and selective nature of models, but because, unlike some passive object, it becomes different as it is understood differently. Understanding guides the ways we act, and systems are reshaped in response, actively as well as passively. For example, land, soil, and communities in rural societies become different when agriculture is understood as another industrial process, with productivity subject to efficiencies of scale as in any other industry. Similarly microorganisms and immune systems both become different when people mistakenly regard every environment as a health risk to be "improved" by spraying disinfectants around. The discipline of cultural anthropology is replete with examples of cultures becoming virtually different worlds through their radically different understandings and expectations. Sometimes unexpected side effects persuade us to revise previously held understandings in light of bitter experience; for example, water engineers concerned with flood control have spent the last several decades reintroducing twists and turns to the very waterways they spent earlier decades straightening, with the unintended consequences of devastating floods downstream. But often understanding, especially of people and social relationships, creates the very thing they expect, making the phrase "self-fulfilling prophecy" a commonplace. Children expected to do well in school often do so, and vice versa. An economy with low consumer confidence is likely to perform badly.

Cognition, the ability to know as a dynamic function of a system, as opposed to knowledge imbedded in structure, emerged in the course of evolution as a more effective way of guiding an increasingly broad and flexible range of an organism's life-sustaining interactions with its environment. This kind of knowing, of understanding, has a pragmatic base: the models it employ must correlate sufficiently with the relevant aspects of its world to support functional interaction as it pursues its well-being. However, human cognitive faculties have reached such breadth and flexibility that what they expect and look for as functional in interactions can vary widely. And in the absence of a common reference point, the feedback of functionality does not necessarily shape understandings in any one direction. An example most of us experience daily is lunch, most often a light meal taken in the middle of the day. This thing we all call lunch, we actually think of and experience in many ways. Some people focus on nutrition, while those in a hurry settle for a fast and easy snack; some look for the least expensive option, while others insist on a fine dining experience, or what might be uniquely tasty, or just uniquely unique. All of these different ways of approaching lunch concern the function of lunch, and they feedback into different personal understandings. Thus, in matters of lunch, as well as in many areas of life, the really important shared understanding is the one honed by the experience of diversity: we have learned to tolerate a wide variety of understandings.

As we collectively organize, ever more complex technologies and ways of interacting with the world, however, shared understanding becomes critical. Science and its measurement-based methodology, the process by which both observations and expectations are translated into numbers, arose as a method for grounding the all-too-flexible feedback between understanding and experience in a common framework of agreed numerical processing. Such measurement has become an effective way to cut through the myriad personal, organizational, ideological, and cultural differences of understanding and perception. All the different approaches to lunch in our example above, for instance, could be brought together in a comparative statistical review of preparation and consumption time, number of calories, percentages of daily nutrition requirements, etc. With the advent of this kind of understanding, the world of personal preferences can be subjected to an "objective" critique with a claim to general validity, possibly leading some individuals to a better understanding of what is in fact in line or out of line with their well-being.

A particular advantage of the introduction of scientific measurement was that it opened the prospect of an especially powerful way to improve systems. The ability to track by means of measurements what differences various kinds or quantities of intervention make in systemic functions promises insight into strategies to improve those functions. The effectiveness of approaches to coping with disease or improving public health, for example, could be tracked and continually improved. The disunity of an array of personal interests and understandings is replaced with a precise and agreed-upon standard of functionality and an objective way of measuring it. Ideally this approach opens the prospect of continual improvement of both understanding and function.

Such enthusiastic expectations concerning the power of scientific method gave rise in the nineteenth century to hopes for universal human progress. Such a dream persisted among some well into the twentieth century. Experience, however, has shown that only some areas of life submit to the precision of measurement in a way that allows calculated and steady improvement. We have come to take such improvement for granted in technology and industrial systems. But the anticipated convergence of understanding in the arenas of politics, religion, and social mores has not occurred. Measurement as applied to these areas has limited effect; it tends to measure, and therefore emphasize, the differences rather than transcend those differences to converge on some single model of functionality.

With regard to the case of drug-resistant TB, scientific understanding and the technology of intervention have improved greatly. Mistaken ideas about the causes of the disease, such as spirit possession or as divine punishment, could not (in the larger picture) withstand the power of measurable causes and effects; as the world's outlying populations becomes better educated, these ways of understanding the cause of disease are fading. But other causes of the emergence of drug-resistant TB have thus far proved intractable. After years of research, reams of statistics are available on income disparities, levels of education, access to clean water, square feet of household living space per person, daily caloric intake of food, and other measures concerning living conditions on all levels—local, regional, national, and international. By correlating all this information with statistics on the rates of TB and the emergence of resistant TB, we are able to understand the many layers of systemic causality involved and even predict levels of incidence and where antibiotic resistance is likely to emerge and spread. The human community already possesses the wealth, material, and technological resources to address every one of the problem factors statistically correlated with TB.

But social problems are inherently multi-causal, and there is no convergence of understanding and motivation to improve any given function as the key to remedying the situation. While the dynamic interplay of the complex factors involved in the system of impoverished urban slums and the way it feeds into the rise of disease and drug-resistant bacteria can be understood, the multiple causes are assessed differently. Political and social groups, and even whole nations, have different interests, and from their different perspectives, they tend to focus on one or another of the causes, but protect the status quo in other areas. Statistics are often used to support opposing positions: some groups will use them to prove the inevitable inequality and exploitation that feed the market system, while others will use the same statistics to show how poverty follows from the restriction of a fully free market. Corruption is often supported in systemic local practice even as it is bemoaned publicly and outside the local system. Religion may be used both to support the status quo and as its fiercest critic. While understanding abounds, those understandings pull in different directions rather than converge on any one or several solutions.

This should come as no surprise. Cognition, as you may recall, arose to guide activity effectively for maintaining well-being. Insofar as well-being is a many-faceted condition involving tensions and tradeoffs among individual units at any given level and across systemic levels (individual vs. community etc.), we should expect that the understanding proportioned to all these different systemic locations/perspectives likewise will involve tensions and oppositions.

Question Box 2.9
What do you make of the multiple ways of understanding just about anything? Are they all equal? What would constitute a mistaken understanding?

2.2.12 Systems Can Be Improved *(A Corollary of #6): Engineering*

We improve systems all the time, or so we think. However, viewed from a systemic perspective, the notion of improvement is not so simple. Virtually any improvement from one point of view can be found to be problematic from some other point of view. In fact, it is hopeless to disentangle improvement from a particular point of view, representing some individuals or levels, but necessarily in tension with the points of view of other individuals, groups, or levels. Improvement must really be thought of in terms of trade-offs. In the maintenance of human health, for instance, let's consider our case concerning TB, which can be cured with the use of antibiotics. Curing the disease can contribute to both better reproductive success and higher life expectancy. These desirable consequences, good for virtually all individuals and their families, at another level also contribute to the hugely problematic systemic challenge of population growth.

When we try to improve a given function, the question of from what particular points of view it is an improvement cannot be neglected. A particular function that fulfills a particular interest can always be improved. In fact, our conscious life is so filled with arranging and rearranging the contents of our multiple mental models precisely because the systems so modeled are responsive to our interested intervention. However, backed up by ample experience, one caveat here is that in the network of complex systems, any change or "improvement" has not only the intended effect but also side effects which may or may not be an improvement, even from the limited point of view of our own interests. In the wider world, and on a larger scale, this becomes even more obvious. In China, for example, increased subsidies to enable health agencies to treat more poor TB patients not only increased the number of patients helped, but it also became an incentive for clinics to keep patients longer than necessary and to avoid referring them to more accessible dispensaries or care units for follow-up care (Tobe et al. 2011).

As we play with our mental models, systems seem easy to improve: there is hardly any function in life that we cannot think of ratcheting up (Chap. 14). In part that is because we can mentally abstract a function of interest from its real-life embeddedness in the complex matrix of related and competing interests and functions. We can easily think, for instance, of educating and treating more impoverished at-risk slum dwellers; but in real life, such ideal intervention will require facilities, staffs, and supporting agencies, all likely to require funding, often from some government with a limited supply of tax dollars—time, effort, and money—for which fierce competition abounds. And as in the case of the Chinese clinics mentioned above, the desire for expansion of these facilities, and the trajectory of staff careers, etc. may themselves become goals that compete with the implementation of the specified functional improvement they were originally intended to bring about.

Even when resources are in theory available, how they might be used in the process of systemic improvement can be surprising, as illustrated in the following table from a 2004 Worldwatch report (Table 2.1) (Gardiner et al. 2004).

This table reflects how some kinds of improvements (to consumer goods) are inherently easier to make than others (social improvements). It also demonstrates how different systems are better, or worse, at working out a given sort of improvement. Luxury goods are produced and marketed through complex systems involving many component technologies, skills, and techniques; all of these are honed continually for productivity, efficiency, competitive marketability, etc. From the consumer's point of view, greater functionality takes the form of satisfaction of an interest and for the producer, profitability. The market serves to link these two in a feedback loop that in theory generates continual improvements—although we also have found that short-term profit can be a misleading guide for systemic improvement!

Table 2.1 Annual expenditure on luxury items compared with funding needed to meet selected basic needs

Annual expenditure on luxury items	Annual expenditure	Social or economic goal	Additional annual investment needed to achieve goal
Makeup	$18 billion	Reproductive health-care for all women	$12 billion
Pet food in Europe and United States	$17 billion	Elimination of hunger and malnutrition	$19 billion
Perfumes	$15 billion	Universal literacy	$5 billion
Ocean cruises	$14 billion	Clean drinking water for all	$10 billion
Ice cream in Europe	$11 billion	Immunizing every child	$1.3 billion

Luxury goods reflect human desires rather than needs, while social goals are concerned with deep needs inherent in human well-being. Market forces take care of deep needs for populations with enough money, but are less effective where satisfying those needs is not allied with the prospect for profit. Poverty is also often accompanied by weak social agencies and corrupt government (a nonproductive profit motive!). Unfortunately this combination often spawns fertile conditions for situations like epidemic TB morphing into drug-resistant strains because of incomplete treatment. In such conditions, local feedback through voting or even revolutions may easily be infected with the very systemic dysfunction it was meant to improve. The deeper systemic problem here may be the local and global distribution of resources, which is inevitability tied with diverse and competing interests with their disparate views on functionality and improvement. Consequently the negotiation of social change for the improvement of society is perhaps the human community's most complex challenge.

The social and economic philosophies that divide the international community are grand mental models for improvement, and implementing any of them in reality runs into the complexity, the constraints, and the unanticipated consequences we have described above. Yet even at this complex, social level systems clearly can and do improve; the process, however, becomes difficult and uncertain in proportion as multiple interests and intersecting dynamics on various scales make definition of function increasingly contested and arbitrary.

And we can also see why, conversely, technology and all sorts of engineering mediated by science and with agreed-upon definitions of measurable function have shown spectacular improvements. Of course this is the easy framing of the notion of improvement, achieved by limiting consideration to a narrowly defined function. Pursuing the question of new and improved technologies in terms of their functionality in a larger social or environmental system again raises the questions about relative trade-offs among differing interests with differing perspectives on function. But there is also hope for improvement at this more complex level. As the problematic social and environmental consequences of our technology are identified, this understanding can circle in a feedback loop between levels to furnish new definitions of technological functionality. Power plants and automobiles, for example, can be engineered for superior function in terms of carbon emissions if that function is given priority. Or on a more complex systemic level, the regulations governing drug companies can be modified so that companies have an adequate incentive to do research and produce the next generation of antibiotics.

Having spent much time and money undoing the large-scale dysfunctionality brought on by short-sighted or insufficiently informed engineering (such as changing, and re-changing, the courses of water ways), we have learned to intervene in the function of complex systems such as the environment with greater caution. In framing our consideration of functionality, competing interests, priorities, and even the boundaries of the system to be considered are all often contested and negotiated at length. But once such hurdles are overcome, system function itself can be modified and improved. In the case of drug-resistant TB, the technological improvements should be the easy part. As we have seen however, that is, contingent upon complex social, economic, and political systemic factors. Improved function at these complex levels is a formidable challenge, but fortunately improvement is not an all-or-nothing proposition, and these systems are in principle open to improvement.

Question Box 2.10
Building on our technological success, the notion of "social engineering" became popular, though it is now in less favor. Technology relies on accurate measurements applied to implementing and improving functionality. To what extent can we use the statistics of social and political science in a similar manner to improve our social and political systems?

2.3 Conclusion

Running throughout our illustration of these twelve principles of systems has been the very first, the principle of systemness. The systemness of the universe means that a double perspective is constantly in play: at any level we can consider a system and its environment and then at another consider the system and environment as itself a system and inspect its interchanges with a yet wider environment. Thus, every aspect of our discussion is marked by movement through multiple levels of consideration and changing dynamics. We move from bacteria to hosts to families, communities, nations, and the world. We see productive and reproductive processes that intersect and interdepend on micro- and macro-scales of extent and time. We see cooperative networks framed in competitive environments that are in turn cooperative networks on other levels.

The principles we have introduced are tools to explore the modalities and dynamics of systemic organization. Systemness articulates relationship among all these dimensions, so their connectedness is explicit, or at least the implicit subtext of any investigation. As we move from the organization of metabolisms to households, daily routines, social dynamics, or global economics, it is simply exploring the systemic topography of a single topic, and any topic is in fact enmeshed in a similar topography.

Becoming skilled navigators of this interconnected skein of systemness has important advantages. Our conscious lives are bubbles of anticipation, where the awareness of what is enables our adjustment for what will be. In so living, an awareness of this web of multi-leveled systemic relations is critical both for better anticipating the range of consequences from any given action and for understanding points for strategic intervention. On all scales and levels of human life, understanding the fact and functioning of this connectedness enhances the strategies by which we live and minimizes the unintended side effects of our actions.

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Principles of Systems Science
Mobus, G.E.; Kalton, M.C.
2015, XXXVI, 755 p. 199 illus., 163 illus. in color.,
Hardcover
ISBN: 978-1-4939-1919-2