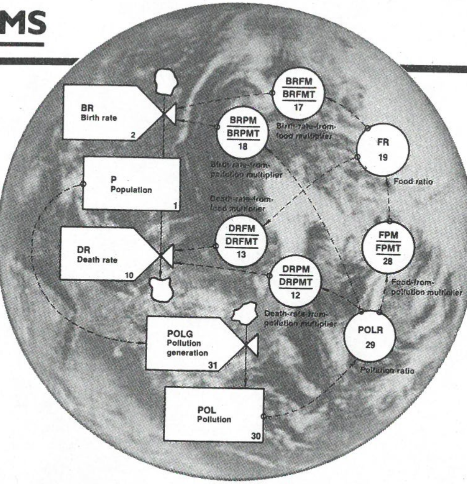
# WHOLE EARTH MODELS & SYSTEMS




*by Donella H. Meadows*

I WANT to describe here just one paradigm or way of looking that reveals just some aspects of reality. I do not believe it is the right or best way, since I cannot settle on any one way as right or best. But it is a perspective that is unfamiliar and thus revealing to most people. And it is, I believe, a useful way of looking at some of humankind's most persistent problems – hunger, poverty, environmental degradation, and war – problems that do not seem to be solvable when looked at from older and more familiar viewpoints.

This paradigm has many names. I will call it the "systems paradigm," knowing that the word *systems* has disparate meanings but intending to clarify what I mean primarily through examples throughout this paper.

I will begin with what might be considered the state of the art – the seven complex computer models of the global system that have been constructed and documented so far. I will describe how the world system looks when it is seen from the comprehensive and sophisticated viewpoint of those models. Then I will backtrack to the very beginning, to what any schoolchild can see and know about complex systems and to the kinds of examples I use to teach systems thinking. Having completed the introductory course, I will progress immediately to more advanced but still computer-free systems insights that any adult can carry in his or her head to deal with the persistent, system-dependent malfunctions of a complicated society. And finally I will come back to an overview of the entire planet and speculate on how it would be different if more of its inhabitants saw it from a systems point of view.

## The Globe as Seen through Computer Models

To most people the word *systems* implies massive computers containing vast arrays of information about everything there is to know. But the first well-known computer simulation on a global, long-term scale was in fact relatively simple. It was published only about ten years ago by M.I.T.'s Jay Forrester.[1] Since then seven other widely recognized "global" models have been completed, with at least 20 more still under development. Some major characteristics of the completed models are summarized in **Figure 1**.

As you can see, global models have been made in many parts of the world, using many different techniques, to answer quite different questions. Even with a computer a modeler is severely limited in the amount of information that he or she can include, and each of these models contains only a fraction of what is known about the world. Most of them focus on

1. Jay W. Forrester, **World Dynamics**, MIT Press, Cambridge, Massachusetts, 1971.

*To my surprise it appears that systems and computer modeling lore is moving rapidly beyond smart toward wise. A coauthor of the famed* ***The Limits to Growth*** *(with Dennis Meadows and Jay Forrester), Dana Meadows gave this paper at an education and environment conference in Budapest, Hungary, in November 1980. She updated the material for CQ and at our request expanded the systems-perversities section at the end. For still further expansion see her new book* ***Groping in the Dark*** *(The First Decade of Global Modeling), coauthored with John Richardson and Gerhart Bruckmann; $29.50 postpaid from John Wiley and Sons, One Wiley Drive, Somerset, NJ 08873. The Meadows family works a small farm near Dartmouth College, New Hampshire, where they also teach. –Stewart Brand*

About one-fifth of the complete diagram of a computer-model of the world. This one, from Forrester's **World Dynamics**, shows negative loops which adjust population levels to the maximum number of people who can survive their own pollution.

**Figure 1**
**CHARACTERISTICS OF GLOBAL COMPUTER MODELS**

| Model | Institution Where Constructed | Major Modeling Technique | Basic Problem Focus | Principal References |
|---|---|---|---|---|
| World 2<br>World 3 | Massachusetts Institute of Technology (USA) | System dynamics | The pattern of approach of the growing population and economy to the limited physical carrying capacity of the planet | Forrester, **World Dynamics**, MIT Press, 1971. Meadows et al., **The Limits to Growth**, Universe Books, 1972. Meadows et al., **The Dynamics of Growth in a Finite World**, MIT Press, 1974. |
| WIM (World Integrated Model) | Case Western University (USA) and Technical University, Hannover (Federal Republic of Germany) | Multilevel hierarchical systems theory, components include simulation, input-output, econometrics | Global interdependence, population and economic growth, resource depletion | Mesarovic & Pestel, **Mankind at the Turning Point**, Dutton, 1974. |
| Latin American World Model | Fundacion Bariloche (Argentina) | Optimization | Maximization of basic human needs, improvement of quality of life of the poor | Herrera et al., **Catastrophe or New Society?**, International Development Research Centre, 1976. |
| MOIRA (Model of International Relations in Agriculture) | Free University of Amsterdam and Agricultural University of Wageningen (Netherlands) | Econometrics, optimization | World food trade patterns, policies to eliminate hunger | Buringh et al., **Computation of the Absolute Maximum Food Production of the World**, Wageningen, 1975. Linnemann et al., **MOIRA — Model of International Relations in Agriculture**, North-Holland, 1979. |
| SARUM (Systems Analysis Research Unit Model) | Department of the Environment (U.K.) | Simulation, system dynamics, econometrics | Consequences of and stresses on economic development | Roberts et al., **SARUM 76 — Global Modelling Project**, UK Departments of Environment and Transport, 1977. |
| FUGI (Future of Global Interdependence) | Tokyo University, Soka University (Japan) | Input/output, econometrics | Co-development of industrial and industrializing economies | Kaya et al., **Future of Global Interdependence**, IIASA, 1977. |
| United Nations World Model | New York University Brandeis University (USA) | Input/output | Effect of development policies on equity and the environment. | Leontief et al., **The Future of the World Economy**, Oxford, 1977. |
| | All-Union Institute for System Studies (USSR) | | Effect of social and political factors on global development | (still in progress) |
| GLOBUS | Wissenschaftszentrum Berlin (Federal Republic of Germany) | | International relations, trade, and conflict | (still in progress) |

economic factors, population, and agricultural production. Only two of the seven contain any mention of resources or the environment. None say anything about war, politics, new ideas, or natural disasters. Most assume either that technology does not change or that it changes automatically, exponentially, and without cost, to allow more and more to be produced from less and less. Some of the models represent the world as a single unit, others divide it into 10 to 15 regions or as many as 106 separate nations. Some run into the future as far as the year 2100, others only to 1985. Several, especially the first ones, have been highly controversial, and some of the later models were made expressly to refute or improve upon earlier ones.

**The modelers themselves, who generally started out hostile and critical of one another, have been surprised at the extent to which their conclusions overlapped.**

I am introducing you to these models to make several basic points that are often misunderstood by a public that is either too easily awed or too easily cynical about computer technologies.

1 The models are highly diverse. They were made by people with different political and cultural persuasions and all are extremely biased, but in very different ways. There is no such thing as an "objective" socioeconomic model.

2 Simultaneously, the models are tremendously complicated in what they represent (detailed population age structures, multiple economic sectors, complex trade patterns, various income classes) and surprisingly simplistic in what they omit (armaments, capital age structures, nearly all values, motivations, social norms, political structures, the sources and sinks of most material flows).

3 No model is (or is claimed to be) a predictive tool. At best each one is a very explicit mathematical rendering of someone's view of the world, tied down as much as possible with statistical data, logically consistent, and able to produce statements of this sort: "*If* all these assumptions are correct, complete, and extended into the future, *then* the logical consequences will be . . ."

To me these models are instructive not singly but as a set. Although they were made by people of different continents and ideologies, the nature of the exercise forced those people to a similar and not-very-ordinary viewing point. All were looking at the globe as a whole and at the relatively long-term implications of the interconnecting web of population, capital, and economic production that links all nations. All were immersed in the global statistics and had to construct a model that captured the global situation with fullness and consistency – every seller must have a buyer, every birth must eventually be matched by a death, once productive capital is in place it cannot shift its purpose from a tractor factory to a hospital. Despite many differences in emphasis and detail, viewing the closed system somehow produced some basic findings that are common to every one of the models. The modelers themselves, who generally started out hostile and critical of one another, have been surprised at the extent to which their conclusions overlapped. The following statements would be agreed upon, I believe, by everyone involved in global modeling so far:[2]

1 There is no known physical or technical reason why basic needs cannot be supplied for all the world's people into the foreseeable future. These needs are not being met now because of social and political structures, values, norms, and world views, not because of physical scarcities.

2 Population and physical (material) capital cannot grow forever on a finite planet.

3 There is, quite simply, no reliable and complete information about the degree to which the earth's physical environment can absorb and meet the needs of further growth in population, capital, and the things that this population will generate. There is a great deal of partial information, which optimists read optimistically and pessimists read pessimistically.

4 Continuing "business-as-usual" policies through the next few decades will not lead to a desirable future – or even to meeting basic human needs. It will result in an increasing gap between the rich and the poor, problems with resource availability and environmental destruction, and worsening economic conditions.

5 Because of these difficulties, continuing current trends is not a likely future course. Over the next three decades the world socioeconomic system will be in a period of transition to some state that will be not only quantitatively but also qualitatively different from the present.

6 The exact nature of this future state, and whether it will be better or worse than the present, is not predetermined, but is a function of

2. The list is taken from **Groping in the Dark: The First Decade of Global Modeling**, Donella Meadows et al., Editors (1982; $26.95 postpaid from John Wiley and Sons, 1 Wiley Drive, Somerset, NJ 08873).

**Some problems consistently resist solution in many cultures and over long periods of time. These are the problems for which a new way of looking is required.**

decisions and changes being made now.

7 Owing to the momentum inherent in the world's physical and social processes, policy changes made soon are likely to have more impact with less effort than the same set of changes made later. By the time a problem is obvious to everyone, it is often too late to solve it.

8 Although technical changes are expected and needed, no set of purely technical changes tested in any of the models was sufficient in itself to bring about a desirable future. Restructuring social, economic, and political systems was much more effective.

9 The interdependencies among peoples and nations across time and space are greater than commonly imagined. Actions taken at one time and on one part of the globe have far-reaching consequences that are impossible to predict intuitively, and probably impossible to predict (totally, precisely, maybe at all) with computer models.

10 Because of these interdependencies, single, simple measures intended to reach narrowly defined goals are likely to be counterproductive. Decisions should be made within the broadest possible context, across space, time, and areas of knowledge.

11 Cooperative approaches to achieving individual or national goals often turn out to be more beneficial in the long run to all parties than competitive approaches.

12 Many plans, programs, and agreements, particularly complex international ones, are based on assumptions about the world that are either mutually inconsistent or inconsistent with physical reality. Much time and effort is spent designing and debating policies that are, in fact, simply impossible.

To nearly anyone with the education and time to think about the world as a whole, these statements are not surprising. We all have an intuitive feel for how the complex systems in which we are embedded work, and the statements above are about the working of a complex system. Many of them follow directly from general systems theory. They were *bound* to emerge from any systematic look at the global economy.

What is surprising is the lack of congruence between these descriptions of the world and the view of the world reflected in policy – nearly every policy of every nation, enterprise, and individual. Those policies are virtually all based on such implicit assumptions as:

There is not enough of anything to go around.

We know that any physical or environmental limits are far away and can be ignored.

Competition works better than cooperation; if everyone looks out for her or himself, the result will be satisfactory.

Any change in policy should be postponed as long as possible.

The future will be very much like the past, only bigger and better.

The poor will catch up with the rich someday if we pursue business as usual.

The bottom line message of the global models is quite simple: *The world is a complex, interconnected, finite, ecological-social-psychological-economic system. We treat it as if it were not, as if it were divisible, separable, simple, and infinite. Our persistent, intractable, global problems arise directly from this mismatch.* No one wants or works to generate hunger, poverty, pollution, or the elimination of species. Very few people favor arms races or terrorism or alcoholism or inflation. Yet those results are consistently produced by the system-as-a-whole, despite many policies and much effort directed against them. Many social policies work; they solve problems permanently. But some problems consistently resist solution in many cultures and over long periods of time. Those are the problems for which a new way of looking is required.

## A Child's Guide to the Systems Viewpoint

So what is this "systems viewpoint" – what can you see from it that you can't see from anywhere else?

1 **The Concept of a System.** A system is any set of interconnected elements. In our usual reductionist-scientific view of things the emphasis is on the *elements.* To understand things, we take them apart and study the pieces. In the systems view the *interrelationships* are important. A corporation is a corporation even when every person and machine in it changes, as long as the hierarchies, purposes, and punishments remain the same. You can't understand the essence of a symphony orchestra just by looking at the instruments and players – it is also the set of relationships that causes it to produce beautiful music. The human body, the nation of Hungary, the ecosystem of a coral reef are all more than the sum of their parts. As an ancient Sufi sage said, "You think because you understand *one* you must understand *two* because one and one

**When you see whole systems, you start noticing where things come from and where they go. You begin to see that there is no "away" to throw things to.**

make two. But you must also understand *and.*"

To see not only things but also relationships opens your vision immensely. You never confuse hastily constructed government apartment blocks with real communities. You never make an urban policy separate from a rural policy. You begin to lose the distinction between humanity and nature or between economic benefits and environmental ones. You also begin to see new solutions – the traffic problem may be affected by the housing sector, economic growth may be enhanced through increasing capital lifetimes, cancer may be prevented by protecting the integrity of the cell membrane and the whole tissue, not the individual nucleus. It is often easier and more effective to act on system relationships rather than on system elements.

2 **The Limiting Factor.** Growth in a complex system may require hundreds of inputs, but at any given time only one input is important – the one that is most limiting. Bread will not rise without yeast, and adding more flour will not help. Corn will not grow without phosphate no matter how much nitrogen is present. This concept is childishly simple and widely ignored. American economists have claimed that energy cannot be an important factor of production because it accounts for less than 10 percent of the GNP (yeast accounts for much less than 10 percent of the bread – that doesn't make it unimportant). Agronomists assume they know what to put in fertilizer because they have identified the 20 major chemicals in good soil (how many chemicals have they not identified?). Rich countries transfer food or capital or technology to poor ones and wonder why they don't grow. In each case attention may be on every major factor but the crucial one – the limiting one.

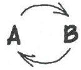
Real insight comes not only from recognizing that the important factor is the limiting one, but from seeing that *growth itself depletes and enhances factors.* The interplay between a growing plant and the soil or a growing economy and its resource base is dynamic, everchanging. Whenever one factor ceases to be limiting, growth occurs and changes the relative scarcity of factors until another becomes limiting. To shift attention from the abundant factors to the *next potential limiting one* is to gain real understanding of and control over the growth process.

3 **Boundaries.** When you see whole systems, you start noticing where things come from and where they go. You begin to see that there is no "away" to throw things to. You can no longer ignore the connectedness between an automobile's exhaust and your nose. You see that the products of a coal-burning electric plant are electricity, fly ash, particulates, $SO_2$, $CO_2$, $NO_x$, and heavy-metal aerosols and that there is no real boundary between the economic product and the "byproducts." You wonder why some effects of a policy are called "side effects" when they are as real and direct as the "main effects." You notice how beautifully designed natural systems are so that the outputs and wastes of one process are always inputs to another process, and you begin to think of new designs for industrial systems.

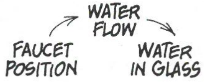
4 **Feedback.** Whenever you postulate that A causes or affects B

A → B

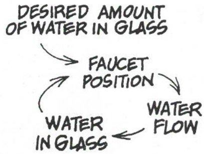
look for all the ways that B in turn affects A.




When you turn a faucet to control the level of water in a glass

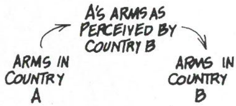



notice how the level of water determines how you turn the faucet, so that the level comes to just where you wanted it.

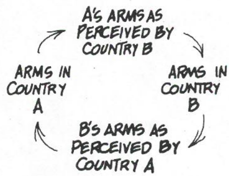



A closed chain of causal relationships that feeds back on itself is called a feedback loop. The water-glass system is a *negative* feedback loop that draws the system to a goal (desired amount of water). Negative loops act to adjust systems toward equilibrium points or goals, just as a thermostat loop adjusts room temperature to a desired setting.

When your country acquires more armaments to catch up with the competition




it effectively generates more armaments for the competition.



This is a *positive* feedback loop, a vicious circle that builds upon itself more and more. Positive loops cause growth, evolution, and also collapse in systems.

Of course most systems, especially socioeconomic ones, are made of hundreds of interconnected positive and negative feedbacks and their behavior becomes very complicated.

The concept of feedback is a powerful one because it allows one to link causal structure to dynamic behavior. If a system persistently oscillates or equilibrates or fails to grow, one can identify the structural reasons for that behavior and learn how to intervene in the feedback loops to alter it. That is what I do for a living, and my colleagues and I have applied these concepts to problems as varied as fluctuating inventory, unstable grain prices, diabetes and cancer, rising oil prices, and economic development.

But the most powerful aspect of the feedback concept, a truly profound and different insight, is the way you begin to see that *the system causes its own behavior.* Country A perceives the arms race as "caused" by country B and vice versa, but one could equally well claim that country A causes its own arms buildup by stimulating the buildup of country B. Or, more accurately, there is no single cause, no credit or blame. The relationships in the system make an arms race inevitable, and A and B are helpless puppets (until they decide to redesign the system). Similarly oil-price rises that are blamed on OPEC could equally be blamed on the heavy consumption of the non-OPEC countries, but more accurately, the price rises are an inevitable result of a growing economic system dependent on a depleting nonrenewable resource base. Similarly, from a systems point of view, businesses make up a system that is structured to generate recessions and depressions, the decisions of farmers make fluctuating commodity prices inevitable, and the flu doesn't invade you – you invite it.

Seeing the source of a problem within the system that suffers the problem is never politically popular. It is much more appealing to find a "cause" for your problems somewhere "out there" than to contemplate changing the relationships between the elements "in here." It is comforting to view something outside the system as the problem, but it isn't very effective. There is real opportunity for action in learning to view every system as the cause of its behavior. First of all, if the entire concept of blame is removed, you can stop arguing about who is at fault and get on with solving the problem. And second, if a system is the source of a problem, it is also the mechanism for a solution. To demonstrate that, I would like to proceed to the advanced-level systems course and talk about multiple-feedback systems.

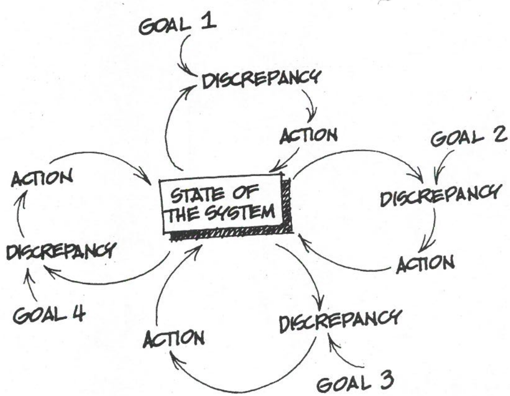
## Advanced Understanding – Making Complex Systems Work

1 **Policy Resistance.** Why do some problems persist in spite of continuous efforts to solve them?

A systems analyst would explain it this way (see **Figure 2**). Any social system is made up of hundreds of actors, each with his or her (or its in the case of an institution) own goals. Each actor monitors the state of the system with regard to any important variable, income or prices or housing or whatever, and compares that state with his, her, or its goal. If there is a discrepancy, if the system is not meeting the goal, each actor does something concrete to correct the situation. Usually the greater the discrepancy between the goal and the actual situation for any actor, the more emphatic will be the action taken on the system. The combination of all actors trying to adjust the system to achieve all the different goals produces a system state that is often not what anybody wants. And yet everyone is putting great effort into keeping it there, because if any single actor lets up the effort, the others will drag the system closer to their goals and farther from his/hers.

Examples of such system configurations come to mind far too readily. Farmers, consumers, and farm suppliers pursue various income goals and produce economic conditions unfavorable for production and also unfavorable for protection of the soils and

**Figure 2 Policy Resistance**



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waters. Government, laborers, and producers act together to produce inflation that damages everyone. Rich and poor nations trade basic commodities, each nation pursuing overriding domestic political and economic goals, with a resultant instability on the world market that systematically penalizes the poor. Or, closer to home, individual members of a family or of a working group, each concentrating on personal goals, can produce an uncoordinated or disconnected entity that furthers the goals of no one.

Suppose a government intervenes in such a system with a strong policy that actually moves the state of the system toward the government's goal. That will open up greater discrepancies for other actors with different goals, which will cause them to redouble their efforts. If they are successful, the system is likely to equilibrate very near its previous state, but with everyone working harder to keep it there. Think, for example, of efforts to improve traffic flow (by widening streets or adding control lights or building mass transit systems) that eventually result in the same traffic densities as before. Or look at the results of one country's attempt to raise its birth rate by prohibiting abortions **(Figure 3)**. Abortions were legal until 1967, when they became unavailable. The birth rate rapidly tripled, but then came slowly back down nearly to its previous level. The individual families, pursuing their own family-size goals, found some other way to achieve them, perhaps through dangerous illegal abortions.

This systems view of policy resistance suggests some interesting new approaches to previously intractable problems. At the very least, it suggests letting up on an ineffective policy, so that all the resources and energy spent on enforcing and resisting the policy could be released for some more constructive purpose. One might also look more closely at the goals and actions within the system, to understand them and to look for a way they could be used instead of being combatted or subjugated. The principle is similar to that of karate: use the force and energy of your opponent instead of resisting it. For example, a nation wishing to increase its birth rate might study the reasons for families to want few children, discover that cramped housing conditions may be a prime motivating factor, and devise a housing policy that allows young couples to achieve their goals for peace and privacy while also achieving the national goal of more births. This policy has been followed in Hungary, with much better results than those of Romania's policy of abortion restrictions.

The most effective way of dealing with policy resistance is to find an alignment of the goals in the system, so that all actors are working harmoniously and naturally toward the same outcome. If this can be done, the results can be amazing. The most familiar examples of this are mobilization of economies during wartime or recovery after war or natural disaster. Another example was Sweden's population policy during the 1930s, when the Swedish birth rate dropped below replacement. The government assessed its goals and those of its population carefully and decided that the real basis of goal-agreement was not the size of the population but its *quality*.[3] Every child should be wanted and cared for, preferably in a strong, stable family, with access to excellent education and health care. The government and the Swedish people could align on that goal. The resulting policies included free contraceptives and abortions, sex and family education, easier divorce laws, free obstetrical care, support for families with children not in cash but in kind (toys, clothing, etc.), and increased investment in education and medical facilities. Some of these policies looked strange in a time when birth rates were thought to be too low, but they were implemented anyway, and since then birth rates have risen, fallen, and risen again.

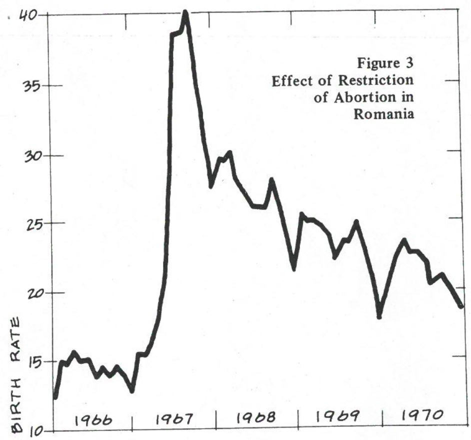



**Figure 3**
**Effect of Restriction of Abortion in Romania**

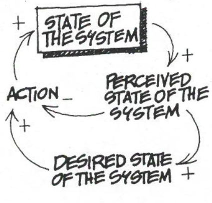
2 **Drift to Low Performance.** Some systems not only resist policy and stay in their normal state, they actually worsen gradually over time, despite efforts at improvement. Examples could be falling productivity or market share of a business enterprise, reduced quality of service at a repair shop or hospital, continuously dirtier rivers or air, or increased fat on a person in spite of periodic diets.

[3] See Alva Myrdal, **Nation and Family**, MIT Press, 1968 (reprint).

## A system that takes its goal from its own performance is very likely to drift downhill.

The structure that produces such a behavior is shown in **Figure 4**. The actor in this system (enterprise, repair station, environmental agency, fat person) has a performance goal (desired state) that is compared to the actual state. If there is a discrepancy, action is taken to restore the system state to the goal. So far that is a simple negative feedback loop that should keep performance at a constant, high level.

**Fig. 4 Drift to Low Performance**




The problem comes in the connection between the actor's perception of the system state and his or her desired state. If for some reason performance falters, and *if the lower performance becomes the standard,* then less corrective action is taken for any given discrepancy and the system state is permanently lowered. Another shortfall can produce another drop in standards, and so on until performance is nearly totally degraded. A system that takes its goals from its own performance is very likely to drift downhill.

Some examples: In the U.S. 4 percent inflation used to be considered unacceptable and would generate strong corrective action. That standard has slowly changed so that now inflation below 10 percent looks good, 12 percent is almost normal, and it takes rates of 20 percent or more to raise great public concern (and we're beginning to get used to those). Also, in the U.S. air quality standards are set at different levels for different areas; places with dirty air have far less stringent standards. Another example: I live in a beautiful rural area where the streets of the small village are kept quite clean and unlittered. I find myself bothered when I go to big cities and see all the trash littering the streets. My friends who live there are almost unconscious of the trash – and after a few days there I am too.

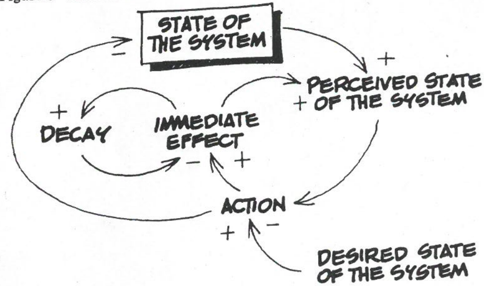
An obvious antidote to the drift to low performance is to keep standards absolute – never let past performance become a guide to present goals. Another is to make goals sensitive to *over*performance as well as underperformance. The same set of feedback loops could actually pull the system state to better and better levels, if *good* performance were taken as reason to reset standards but bad performance were considered only bad luck, not to be taken seriously.

3 **Addiction.** The structure of a system that produces addiction is shown in **Figure 5**. Again the actor has a goal and compares the goal with a perception of the actual state to determine what action to take. But here the action chosen has the effect of making the system appear better to the actor, while actually over the long term it is making it worse. As the effect of this action wears off, the problem reappears, probably more insistently, so the actor applies even more of the "solution," thereby worsening the problem and making it necessary to use more "solution" in the future.

Consumption of alcohol, nicotine, heroin, caffeine, and sugar are obvious examples of addictive actions. A less obvious example is the use of pesticides (removing the immediate pest, but also eliminating natural control mechanisms, so that the pest is likely to surge back in the future). Another is the pricing of a depleting resource such as oil at average rather than replacement costs (thereby keeping price artificially low and postponing the pain but also encouraging further use and more rapid depletion and discouraging the shift to other resources that will eventually be necessary).

Policy choices with addictive effects are insidious because they look good in the short term, but once chosen they are very difficult to reverse. Obviously, the best procedure is to be alert for options that improve the symptoms but worsen the problem and to avoid them, whatever their political appeal. Once caught in the addictive cycle, one must

**Figure 5 Addiction**



almost inevitably prepare to suffer short-term difficulties in order to get out, whether that means the physical pain of heroin withdrawal, a sudden sharp price rise to reduce oil consumption, or an invasion of pests while natural predator populations are being restored. Sometimes the reversal can be done gradually, or an alternative nonaddictive policy can be put in place first to restore the system state with a minimum of turbulence (psychiatric help to restore the self-image of the addict, home insulation to reduce oil expense, crop rotation and multiculture to reduce vulnerability to pests). But it is always less expensive to avoid the addiction in the first place than to get out of it once it has started – as anyone with a long-term systems viewpoint can see.

4 **Official Addiction – Shifting the Burden to the Intervener.** As I grew older and spent most of my time reading, I slowly became more and more near-sighted. Finally I couldn't read writing on a blackboard or slides on a screen anymore. So I got contact lenses. Within a year my uncorrected vision deteriorated far more than it had in the previous 30 years. Now the lenses are necessary not only for reading distant fine print but for everyday navigation. Apparently the muscles around my eyes had been doing a fair job of compensating for an increasingly misshaped natural lens. But when they no longer had to do that job, they lost their tone, their ability to do it. Soon I needed a newer, stronger prescription.

That is a classic case of shifting the burden to the intervener– a benevolent form of addiction **(Figure 6).** In this sort of system a natural corrective force is doing only a so-so job of maintaining the system state. A well-meaning, benevolent, and very efficient intervener decides to help out by taking on some of the load. A new mechanism is established to bring the system to the state everybody wants it to be in. This new mechanism works beautifully.

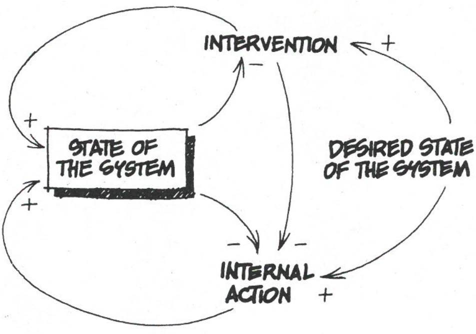
But in the process, whether by active destruction or simple neglect and atrophy, the original corrective forces within the system are weakened. The system slips away from the desired state. So the intervener increases his, her, or its efforts. The natural system weakens or atrophies still more. The intervener picks up the slack. And so forth. Finally, most or all of the original job carried out by the natural system has, gladly or reluctantly, been accepted by the intervening system. The ability of the original system to do the job has been severely and perhaps irreversibly weakened.

Finding examples of burden-shifting systems is easy and fun and sometimes horrifying. Here is a beginning of a list, to which everyone will be able to add.

Shifting a burden to an intervener is not necessarily a bad thing. It is usually done willingly, and the result is often an increased tendency for the system to achieve desired states. But this system characteristic can be problematic, for two reasons. First, the intervener may not realize that the initial urge to help out a bit can start a whole chain of events that leads to ever-heavier loads on the intervening system. The American social security system is now experiencing the strains of that chain of events. Second, the community that is being helped may not think through the long-term loss of control and the increased vulnerability that may go along with the opportunity to shift a burden to a more able and powerful intervener.

| **burden** | **original system** | **intervening system** |
|---|---|---|
| care of the aged | families, communities, accumulation of personal wealth | social security |
| bread-making | households, local millers, small bakeries | multinational corporations |
| smallpox prevention | natural resistance, accidental cowpox infection | vaccination |
| long-distance transportation | railroads | interstate highways, trucks |
| arithmetic | mental training | personal calculators |
| grain storage | households, farmers, local merchants | grain trading companies, international reserve agreements |

**Figure 6 Shifting the Burden to the Intervener**



Rebuilding a decayed system of self-reliance and private enterprise that long ago stopped handling its own burdens is a long, difficult process, something no Republican administration seems to understand. Sudden removal of an intervening system does not necessarily shift the burden back; it may drop the burden because there is little left to shift it back to. Intervening in such a way as to *strengthen the ability of the system to shoulder its own burdens* is very possible and often cheap and easy, something no Democratic administration seems to realize. The secret is to begin not by taking over, but by asking why the natural correction mechanisms are failing to handle the problem, and how the obstacles to handling it could be removed.

5 **High Leverage, Wrong Direction.** Jay Forrester, my systems guru, likes to tell of working with corporations to establish a systems view of management. He has often discovered, in modeling the feedback loop structure of a corporation's decision processes, that:

- Whatever the problem is (falling market share, unstable inventory, inadequate quality control), it is nearly always traceable to the way the *corporation* does things – not to the customers, the competitors, the regulators, or any other convenient scapegoats.
- Often one small change, in one or a few simple policies, will solve the problem easily and completely.
- The high-leverage policy point is usually far removed in time and place from where the problem appears. It is seldom the subject of much attention or discussion, and even when it is identified, no one will believe it is related to the problem.
- If it happens that someone has indeed identified and questioned the high-leverage policy, that person has almost always decided to push the lever in the *wrong direction*, thereby intensifying the problem.

The peculiarity of high-leverage points lurking in unexpected places and inviting counterproductive policies is not one I can illustrate with a simple feedback diagram. It seems to occur in just about any system that contains enough interlocking feedback loops to boggle one's capacity for mental analysis (for me that means more than four feedback loops).

**Policy choices with addictive effects are insidious because they look good in the short term, but once chosen they are very difficult to reverse.**

Here are a few examples of systems with high-leverage points pushed the wrong direction.

A large engine company had a problem with falling market share. Every four years or so, it would lose sales to the competition, and the lost customers rarely returned. The problem was finally traced to the firm's *inventory* policy. The company was reluctant to build large, expensive engines on speculation to accumulate an inventory. It preferred to build only on definite orders. This policy saved a lot of money, but on the upturn of each business cycle, the company was swamped by new orders, which it could deliver only after a long delay. Customers turned to the competition who could supply engines quickly "off the shelf." The firm habitually responded to the loss in sales by cost-cutting measures, including *decreases* in its inventory.

Most people in Vermont are concerned about the "disappearance of the family farm." They propose policies such as cuts in property tax, low-interest loans for farm equipment, and subsidies on milk prices. It turns out that if you really like the idea of lots of small farms, you should oppose all those measures. The major cause of farm loss is farm expansion. Farmers try to increase their incomes by producing more, logically enough. When all the farmers do that, the market is flooded with milk, and the price goes down (the price is not currently subsidized enough to hold constant regardless of supply – if it were, it would shift the burden to an intervener!). Since the profit per unit of milk has gone down, each farmer must produce more *even to keep the same income.* Some do. Others don't, and eventually their incomes drop so low that they quit farming.

The leverage point in this system is the farmers' ability to increase their production. Given the treadmill of the system, they will have to use any break that gives them more cash to expand their output. And that drives prices, profits, and farm numbers down still faster. The best way to stabilize farm numbers would be to restrict total production in some way. If that could be done, all farmers would have higher and more stable incomes (as many industrial sectors have discovered).

One of the leverage points in any growing economy is the lifetime of the capital plant. The easiest way to stimulate economic growth is to increase the useful lifetime of capital (by better design, or better maintenance). Yet the policy of planned obsolescence is promoted and defended for the sake of economic growth.

The way to revitalize the economy of a city and create more upward mobility for the poor is not to build subsidized housing in the inner city. It is to demolish substandard and abandoned housing, creating open space for the establishment of more businesses, so the job/population balance can be restored.

I wish I could provide here some simple rules for finding high-leverage points and for knowing what direction to push them. Some of my professional colleagues would argue that this is the point where I should stop relying on innate systems understanding and start hiring them.

Indeed, all of the examples I have given here came from formal computerized analyses. I do respect and use the computer as a handy tool to help learn about complex systems, but I also think one can go a long way without it.

One's rational, figuring-out ability seems to be a bad guide for finding leverage points. It leads one to look at pieces of systems, and to make judgements based on short-term and incomplete information. It would lead a company to cut back on inventory when sales are down, the state of Vermont to reduce farmers' property taxes, or a nation to invest in new machines instead of repairing old ones. All very *reasonable* policies. And yet there is something in all of us that might lead us to notice the customers' dissatisfaction with long delivery delays, or to wonder why farmers always complain about the pressure to expand, or to feel that replacing a machine that is still productive somehow doesn't make sense.

I think we do have within us the ability to see whole systems and to sense leverage points. What we don't seem to have is the ability to win arguments, even within ourselves, with that "reasonable" side of us. We keep expecting a solution to be near a symptom, a long-term gain to start off with a short-term gain, or a winning strategy to produce instant gratification for all players. We know complex systems don't behave like that. But something within us keeps insisting somehow that they should. And so we pursue difficult policies that can't work, and miss seeing rather simple policies that can. We try to compete instead of cooperating, to push against environmental limits instead of noticing that there is already enough, to hang on to a deteriorating status quo instead of welcoming changes that take us where we really want to go. The results are hunger, weapons, pollution, depletion. And just within our grasp, accessible through our innate systems understanding, are sufficiency, peace, equity, and sustainability.

**We keep expecting a solution to be near a symptom, a long-term gain to start off with a short-term gain, or a winning strategy to produce instant gratification for all players.**

## Back to the Globe

It is impossible to lay out a whole new way of viewing the world in a short paper – it is like trying to describe everything that can be seen through a telescope and comparing it systematically to what can be seen through a microscope. I could go on about the role of delays and nonlinearity in systems, about the structural homologies across systems, about other behavioral properties such as the tragedy of the commons or the worse-before-better syndrome. One could create whole undergraduate and graduate curricula on the subject, and of course I and many other people have done so.

It should be clear that I am excited by what I can see from the new viewpoint of systems. I find my entire sense of what is happening, what is possible, what I identify with, and what is important is shifting. I want to take others by the hand and say "Look at that" – which I do in my teaching. I believe that if more people could learn to see the world as a system, *in addition to, not in place of*, the ways they already see the world, some remarkable things would happen. At the very least, like the global modelers who started from very different positions, they would find a common ground of understanding and would find that many current proposals that are the source of argument and divisiveness simply cannot be effective. They would find themselves losing interest in simple notions of fault or blame. And then they would start seeing whole new kinds of policies.

What would these policies look like? Some people expect that policies arising from systems views and computer analysis should be precise, absolute, certain, and a bit inhuman. In my own experience, however, after ten years of trying to simulate social systems, I find myself becoming more humble, less certain, more experimental, and acutely aware of the unique and wonderful complications human beings add to complex systems. I am finding that policies consistent with the systems view would be:

1 **Respectful of the system** – designed to aid and encourage those forces within the system that help it to run itself, rather than imposing on it from "outside" or "above."

2 **Responsible** for the system's behavior, rather than trying to blame or control outside influences.

3 **Experimental** – recognizing that nature is complex beyond our ability to understand; therefore careful experiment and constant monitoring are more appropriate than certain, undeviating directives.

4 **Attentive to the system as a whole** and to total system properties such as growth, oscillation, equilibrium, or resilience, rather than trying to maximize the performance of parts.

5 **Attentive to the long term**, realizing that in fact there is no long-term short-term distinction; that actions taken now have effects for decades to come and that we experience now the results of actions taken decades ago.

6 **Comprehensive** – above all, the systems view, as demonstrated by the global models, makes clear that no part of the human race is really separate either from other human beings or from the global ecosystem. We all rise or fall together. ■