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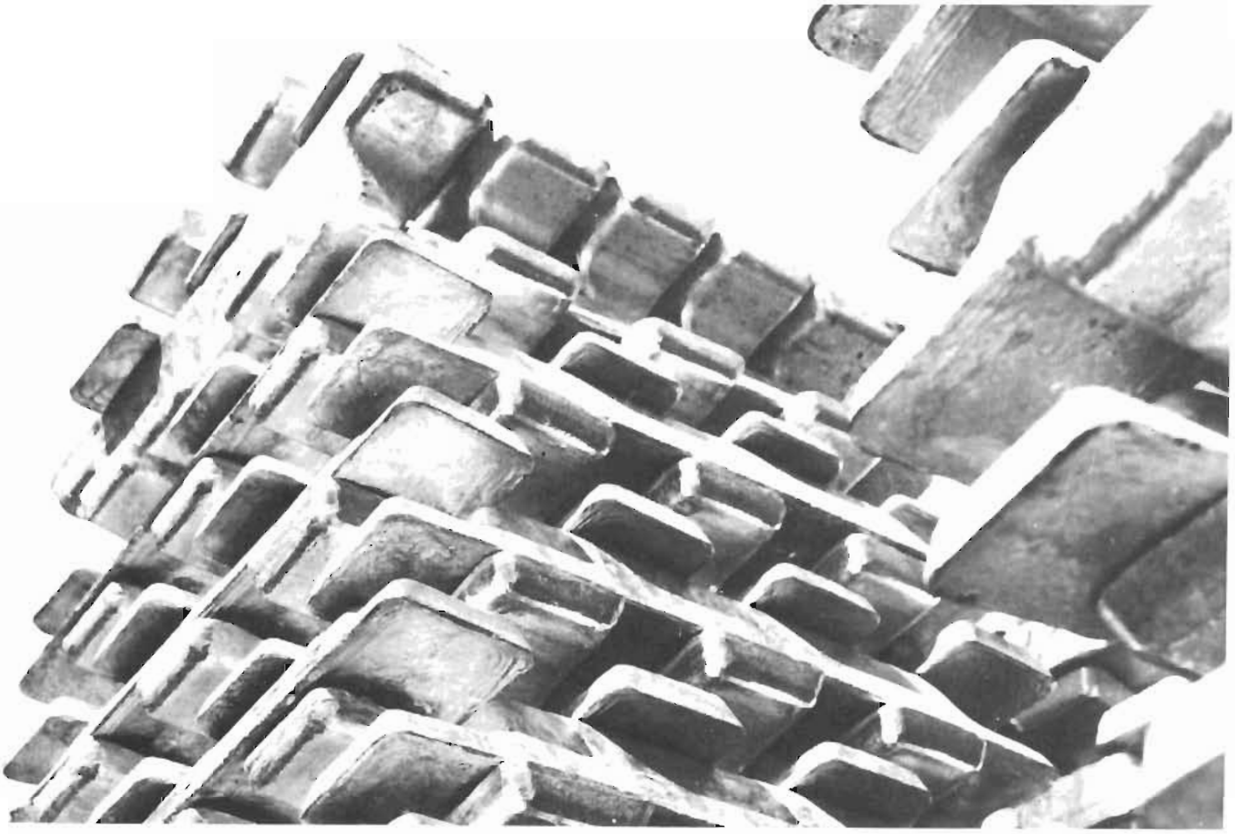

courtesy of Vereinigte Metallwerke Ranshofen-Berndorf AG, Austria

Bauxite ores are refined to provide alumina (aluminum oxide) which is then smelted to produce aluminum, shown here cast into ingots.

# Structural Change in the Aluminum Industry

Responses by governments and firms to dramatic changes in this industry offer insights for coping with both the benefits and dislocations in other sectors of industrialized countries undergoing structural change.

The consumption of all major metals grew rapidly between 1950 and 1980. Aluminum, which has had the shortest commercial life, showed the fastest increase: an average 7.9 percent annually over the three decades. However, 1982 was the third consecutive year in which world primary aluminum consumption declined.

In 1980 Japan was the third largest producer of aluminum in the world, following the United States and the Soviet Union, having jumped from a weak ninth place in 1950. In 1977 Japan produced 1,188,000 tons of aluminum. In 1982, Japan produced 295,000 tons, half its smelters had closed, the work force had dropped from 15,000 in 1980 to 6,000 in 1982, and aluminum imports had nearly tripled over a five-year period.

While some of these changes can be attributed to recession and business cycle fluctuations, it is now widely recognized that more basic structural changes are also taking place. "Comparative advantage, it appears, is a fickle friend," comments Professor John Tilton, leader of IIASA's Mineral Trade and Markets Project. "As the smelting of alumina into aluminum is energy intensive, the sharp rise in world energy prices during the 1970s considerably altered the underlying economics of this industrial activity. The comparative advantage of Japan, the United States, and a number of European countries that traditionally have been

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major aluminum producers declined, while in certain other countries, particularly Australia and Brazil, it appears to have increased."

The IIASA—Resources for the Future study of the aluminum smelting industry emphasizes the policy responses and reactions by governments and firms to facilitate the adjustments required for economic efficiency and minimize the hardships and dislocations resulting from the structural changes in this sector. While the hike in energy prices is a major factor, other causes of changes in consumption patterns include the shifts in the mix of products and services comprising gross domestic product, new technology, lower birth rates and aging populations in most industrialized countries, slower GDP growth rates, financial and debt-servicing problems, and shifts in consumer preferences.

## The Past

The use of some metals can be traced for thousands of years in history, back to the Bronze and Iron Ages. The commercial use of aluminum is less than a hundred years old. It is the youngest, and the largest, of the major nonferrous metal industries. While aluminum is the third most plentiful element and the most commonly found metallic element in the Earth's crust, aluminum in its natural state exists only in combination with other elements. It took until the 19th century to separate the metal from its clay, and some of the earliest aluminum bars were set out with the crown jewels at the Paris Exhibition of 1855. France had the first aluminum plants, using a chemical process developed by Sainte-Claire Deville, following work by France's Antoine Lavoisier, Britain's Sir Humphry Davy, Danish physicist Hans Christian Oersted, and German chemist Friedrich Wohler. Research was supported by the French Academy and Napoleon III. In 1886, two scientists — Paul T. Héroult of France and Charles Martin Hall of the USA — independently found an electrolytic process. The Hall—Héroult process is still used today. Hall started a plant producing aluminum ingots in Pittsburgh, Pennsylvania in 1888, a fabricating plant in 1891, and a smelting facility using hydroelectric power at Niagara Falls, New York in 1895, using bauxite from Arkansas. Smelters were opened in 1898 at Lend, Salzburg, Austria and Rheinfelden, Germany: both are still operating.

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- to promote international cooperation in addressing problems arising from social, economic, technological, and environmental change
- to develop and formalize systems analysis and the sciences contributing to it, and to promote the use of the analytical techniques needed to address complex problems
- to create a network of institutions in the countries with National Member Organizations and elsewhere for joint scientific research
- to inform policy advisors and decision makers about the applicability of IIASA's work to such problems

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From the beginning of the industry, the mining and processing of ores and metal production were geographically separate. Pre-World War I aluminum production centers were in the United States and Canada, Austria, France, Germany, Italy, Norway, Switzerland, and the United Kingdom. Only the United States and France had significant domestic bauxite deposits.

Aluminum's light weight, strength, durability, and ease of handling, plus its properties of conducting electricity and heat, were used in the early 1900s to replace copper in electrical conductors and steel in household appliances and for kitchen utensils. Construction and transportation now account for half of the aluminum consumed each year. The 1984 Corvette uses a new high 170 kilograms (375 pounds) of aluminum, while the average American car in 1979 contained 54 kilos (118 lbs). Electrical and telecommunications (including aerospace) equipment, packaging, and home and office appliances are also major uses of aluminum.

Demand for aluminum soared during World War II and, after a minor dip, continued rising as postwar economies rebuilt and then boomed, other countries industrialized, and technological and social changes opened up new uses and opportunities (civilian airlines, aluminum cans and foil, recycling aluminum).

To meet the continually rising demand, there was rapid expansion of exploration for new sources of ore, development of mines, construction of refineries, smelters, and plants for various fabrications (sheets, tubes, etc.). Countries that had not been previously involved with aluminum and new firms joined the market, to meet domestic demand, to ensure self-sufficiency of supply, to earn foreign exchange through exports, to satisfy "resource nationalism". American companies went abroad in the 1950s to supply domestic markets and, in the 1960s, European firms constructed smelters in the USA and vice versa. Aluminum production sites were more closely aligned with consumption and proximity to cheap sources of energy than with the location of bauxite mines. Improvements in transportation economics aided new bauxite producers who were further from traditional markets. For example, Australia and Brazil increased their output of bauxite as the cost per ton-mile of transporting bulk ore was more than halved with the introduction in the 1960s of large carrier ships, enabling Japan to become a major aluminum producer. Surinam, Guyana, and the United States in 1950 accounted for some 60 percent of total world mining of bauxite. In 1980, Australia was mining far more bauxite than any other country; Guinea had just overtaken Jamaica in second place; and Brazil was poised to become a major producer. Only 20 percent of the aluminum produced in 1980 was smelted in the same country in which the bauxite was mined. "Resources such as capital and technical and managerial know-how, like mineral deposits, vary greatly among countries," notes Professor Tilton. Comparative advantage at one stage does not guarantee comparative advantage at another stage.

## The Present

The current troubled situation first became apparent in the early 1970s with the energy price rises. Although many societies and industries had difficult adjustments to make, the aluminum industry was particularly hard hit in countries with market economies.

"Bauxite represents only 6 percent value-added for aluminum, while US smelters in the mid-1970s had an average electricity consumption of 9 kilowatt-hours per pound of aluminum produced," explains Professor J. Merton Peck of Yale University, USA. The production of one aluminum can required 4,990 Btu of energy in 1978. Electricity can be generated by many different sources, of course, but the aftermath of the oil price hikes and increased competition for access to energy and electricity supplies raised the price of almost all energy sources. While many smelters depended on electricity from their own sources, others relied primarily on power purchased on long-term contracts. Many of these had to be renegotiated during the 1970s and early 1980s. The long lead time required to construct new smelters also affected the situation. Several smelters started up in the 1970s, adding to general capacity for production just as world demand was falling because of the recession.

Comparative advantage changed swiftly. Reactions varied from country to country and from firm to firm, depending primarily on the source and price of available electricity and whether governments would provide subsidies.

Japan was the hardest hit, as it has few native fuel resources and 99 percent of its oil is imported. "From the beginning of the aluminum smelting industry in Japan in the 1930s, the high cost of domestic smelting due to high electricity rates and the resulting weak cost competitiveness vis-à-vis imports had been the most serious problem, persistently threatening the very existence of the industry," notes Professor Akira Goto of Seikei University in Tokyo. A desire to reduce dependence on imported aluminum and extremely high growth rates in domestic demand during the 1960s led to a rapid expansion of the smelting industry in Japan and abroad. Tariff cuts under the Kennedy round and the introduction of a floating yen in 1971 upset the previous advantage of domestic smelting and the oil crises destroyed the delicate balance as Japanese power companies were 63 percent oil-based in 1976. "The industry lost its fragile edge of cost competitiveness and imports flooded Japanese markets," reports Professor Goto. Imports reached 44 percent of domestic demand in 1978, while domestic production was cut back 40 percent from September 1978 to March 1979. Seven of the fourteen smelters operating in Japan had been closed by 1982, and imported ingots exceeded domestically smelted ingots for the first time. Over 900 thousand tons of capacity was disposed of or frozen between 1978 and 1983.

Professor Goto says that government efforts did not emphasize keeping a certain amount of capacity artificially. Policy measures were aimed at giving the industry "breathing space and time to adjust to the rapidly changing conditions." For example, while the government encouraged power plants and industries to switch from oil to coal, no special rates for electricity for smelters was discussed. The Ministry of Trade and Industry (MITI) designated the aluminum smelting industry as an "especially depressed industry" and devised, with the smelting firms, a stabilization plan. A tariff quota system was set up in 1978–9 and tariff exemptions in 1982–83 so smelters could finance the disposition of excess capacity.

Capacity was also cut in the United States. "The major adjustment to the downturn in demand was in the US production of primary aluminum, which declined by 28 percent between 1979 and 1982," reports Professor Peck. "Of the 32 US smelters in operation in 1981, 16 were operating at less than full capacity and 6 had been closed. Capacity utilization for US smelters was about 60 percent by the end of 1982." The six plants closed used coal and natural gas, but the cost of hydropower was affected as well. Hotly-contested legislation overturned the long-term electricity contracts held by ten smelters in the Pacific Northwest using electricity generated by hydropower by the government-owned Bonneville Power Administration. One major US company disclosed that the cost of purchased power for their seven domestic smelters rose over 600 percent during the past ten years. While Bonneville announced a discount on power rates in early 1983 to encourage smelters to keep operating in a depressed region, this was a temporary situation. There has been no effort by the government to subsidize or protect the industry. Professor Peck believes that "it is unlikely that public policy will attempt to make the United States once again the center of the worldwide aluminum industry. The US primary producers are international companies and the shift to increasing reliance on their smelters abroad to supply their US fabricating operations with low-cost ingot would be only a modest adjustment, and a continuation of the trend already well established in bauxite and

Professor of Mineral Economics John E. Tilton, leader of the Mineral Trade and Markets Project, is returning to Pennsylvania State University, USA. He is co-director of the Mineral Economics and Policy Program sponsored jointly by Resources for the Future and Pennsylvania State University, and has served with the Commodities Division of the United Nations Conference on Trade and Development.

alumina."

"The crisis in western Europe seems to be relatively mild in comparison with the US and Japan. On the other hand, the future of the industry looks gloomy," according to Dr. Christian Kirchner of the University of Frankfurt/Main, Federal Republic of Germany (FRG). "Restructuring programs for the industry are underway in several European countries and public subsidies play an important role in some countries in keeping the industry alive." Italy, for example, has assumed losses incurred by the state company MCS, while France has subsidized electricity rates and, in 1983, nationalized the aluminum industry as it had earlier taken over Electricité de France. The FRG requires the use of its black coal, leading to very high electricity rates, and also insists on equally costly tight environmental protection controls. The regional government of Baden–Württemberg has intervened to establish low electricity rates to help a smelter there, and the federal and regional governments are subsidizing the smelter at Ludwigshaven. Much of the expansion of smelting capacity in the early 1970s in the FRG was based on the expectation of local nuclear power, but delays in constructing the nuclear plants led-eventually to a high cost for the electricity generated. In Austria, the state-managed smelter at Ranshofen bore heavy losses during the 1970s but kept production at full capacity and stockpiled ingots during downturns in demand. In the Netherlands, production was nearly constant between 1974 and 1982 from the two Dutch smelters, one running on natural gas and one on nuclear energy. Holland is a major aluminum exporter, primarily to other countries in Europe, as is Norway, using its abundant hydropower.

While aluminum production is being cut back in Japan and the US and maintained in Western Europe only with public subsidies, smelting capacity is expanding in Australia, Brazil, and Canada to take advantage of their cheaper and more abundant energy

**Bauxite Mine Production** (rounded figures)

| | 1950 | | 1980 | |
|---|---|---|---|---|
| Country and group | Thousands of tons of contained metal | Percent of world total | Thousands of tons of contained metal | Percent of world total |
| Market Economies | 464 | 28 | 7344 | 37 |
| Australia | 1 | 0 | 5979 | 30 |
| Greece | 15 | 1 | 657 | 3 |
| USA | 271 | 16 | 359 | 2 |
| France | 145 | 9 | 341 | 2 |
| Other | 32 | 2 | 8 | 0 |
| Developing Economies | 947 | 56 | 10376 | 52 |
| Guinea | 3 | 0 | 3061 | 15 |
| Jamaica | 0 | 0 | 2775 | 14 |
| Surinam | 409 | 24 | 980 | 5 |
| Brazil | 4 | 0 | 830 | 4 |
| Yugoslavia | 47 | 3 | 722 | 4 |
| Guyana | 334 | 20 | 702 | 3 |
| India | 14 | 1 | 348 | 2 |
| Indonesia | 106 | 6 | 250 | 1 |
| Malaysia | 0 | 0 | 184 | 1 |
| Haiti | 0 | 0 | 110 | 1 |
| Ghana | 3 | 0 | 52 | 0 |
| Other | 27 | 2 | 362 | 2 |
| Planned Economies | 267 | 16 | 2350 | 12 |
| USSR | 150 | 9 | 1280 | 6 |
| Hungary | 116 | 7 | 590 | 3 |
| China | 0 | 0 | 340 | 2 |
| Romania | 1 | 0 | 140 | 1 |
| TOTAL | 1678 | 100 | 20070 | 100 |

Sources for Tables: *Metal Statistics* Annuals and UNCTAD: *The World Market for Bauxite*, United Nations Conference on Trade and Development, 1982.

**Aluminum Production** (rounded figures)

| Country and group | 1950<br>Thousands of tons of contained metal | 1950<br>Percent of world total | 1980<br>Thousands of tons of contained metal | 1980<br>Percent of world total |
|---|---|---|---|---|
| Market Economies | 1281 | 85 | 10964 | 68 |
| USA | 652 | 43 | 4654 | 29 |
| Japan | 25 | 2 | 1092 | 7 |
| Canada | 360 | 24 | 1075 | 7 |
| FRG | 28 | 2 | 731 | 5 |
| Norway | 45 | 3 | 662 | 4 |
| France | 61 | 4 | 432 | 3 |
| Spain | 2 | — | 387 | 2 |
| UK | 30 | 2 | 374 | 2 |
| Australia | 0 | 0 | 304 | 2 |
| Italy | 37 | 2 | 271 | 2 |
| Netherlands | 0 | 0 | 258 | 2 |
| Austria | 18 | 1 | 94 | 1 |
| Switzerland | 19 | 1 | 86 | 1 |
| Other | 4 | — | 544 | 3 |
| Developing Economies | 7 | — | 1796 | 11 |
| Venezuela | 0 | 0 | 317 | 2 |
| Brazil | 0 | 0 | 261 | 2 |
| Ghana | 0 | 0 | 188 | 1 |
| India | 4 | — | 185 | 1 |
| Yugoslavia | 2 | — | 161 | 1 |
| Other | 1 | — | 684 | 4 |
| Planned Economies | 219 | 15 | 3286 | 20 |
| USSR | 209 | 14 | 2420 | 15 |
| China | 0 | 0 | 350 | 2 |
| Romania | 0 | 0 | 241 | 2 |
| Hungary | 7 | — | 74 | — |
| Other | 3 | — | 201 | 1 |
| TOTAL | 1507 | 100 | 16045 | 100 |

sources. Australia is an example of a country moving from exporting bauxite ore and alumina to producing aluminum. Brazilian production is shifting location within the country, "decisively reinforced by the priority given by the government to the aluminum industry in its strategy to develop the Amazon region," notes Professor Eliezer Braz-Pereira of the Federal University of Paraiba. He sees a two-sector industry arising, one to supply the domestic market based in the previously-developed southeast and a new export-oriented sector in the north. All new projects will be located in the north.

"The healthy state of the Canadian aluminum industry is based on the availability and low cost of energy based on a renewable resource, water," reports Professor Carmine Nappi of the Ecole des Hautes Etudes Commerciales in Quebec. It also has easy access to the US market, still the largest consumer. The Soviet Union, whose industry is based on the hydropower and bauxite and nepheline deposits of Siberia, has also begun to export some aluminum. Generally, however, increasing production in the USSR and the People's Republic of China is for increasing domestic consumption, as is true for the developing countries.

The shocks of higher energy prices, recession, and technological change have altered aluminum demand and sources of supply. Shifting comparative advantage has created opportunities, as well as hardships, and continues to do so as the restructuring of the aluminum industry goes on.

**Roberta Yared**

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Further information on metal trade patterns, mineral exploration, East–West trade, and state enterprises in the mineral sector are available from IIASA. The study of the aluminum smelting industry is being prepared for publication.

# System Complexity

**John Casti** contends that complexity is a contingent rather than intrinsic property of a system, and offers a speculative framework for its identification and regulation.

The science fiction writer Poul Anderson once said that he has "yet to see any problem, however complicated, which, when you look at it the right way, did not become still more complicated." This remark captures exactly the essence of complexity as a system concept: the common notion of a complex system as constituting a large number of variables interacting through many feedback-feedforward loops producing surprising counterintuitive behavior tacitly assumes that the system is viewed in a uniformly agreed-upon fashion, with various measures of complexity following as consequences of the manner in which the system is "seen". But what you see depends upon how you look, and in this essay I argue for a view of *system complexity as a property arising from the interactions of the system with its observer/regulator, rather than as an intrinsic property of the system itself.* Complexity, like beauty, is as much a property of the beholder as of the object being observed.

Despite its currently fashionable status in certain corners of the applied and theoretical systems world, complexity as a concept is certainly far from a new idea. For at least as long as there have been tax laws, government, university and corporate bureaucracies, and economic forecasters, each intellectual era has pitted its theories and technology against the problem of coping with the burgeoning complexity of its social, political, economic, and technological systems; the intellectual and philosophical graveyards are littered with the corpses of these failed efforts. My contention is that these failures are attributable to the *fallacy of regarding complexity as an observer-independent system property*, itself an attitude originating in the Cartesian mind/matter duality and its consequent philosophy of reductionism. Quantum theory demolished the Cartesian view once and for all, and one of the reverberations of this death of reductionism is the need to re-examine a plethora of system concepts from a non-reductionistic point of view.

In what follows, I present an unabashedly speculative non-reductionistic framework for the identification of system complexity and its management. The ideas presented here form the germ of a vastly more ambitious research effort that one might most appropriately term a "theory of models", a theory which, by and large, does not yet exist. A more complete characterization of complexity along the lines sketched here offers the promise of filling in at least one of the stars in the almost limitless constellation we call systems analysis.

## The Simple and the Complex

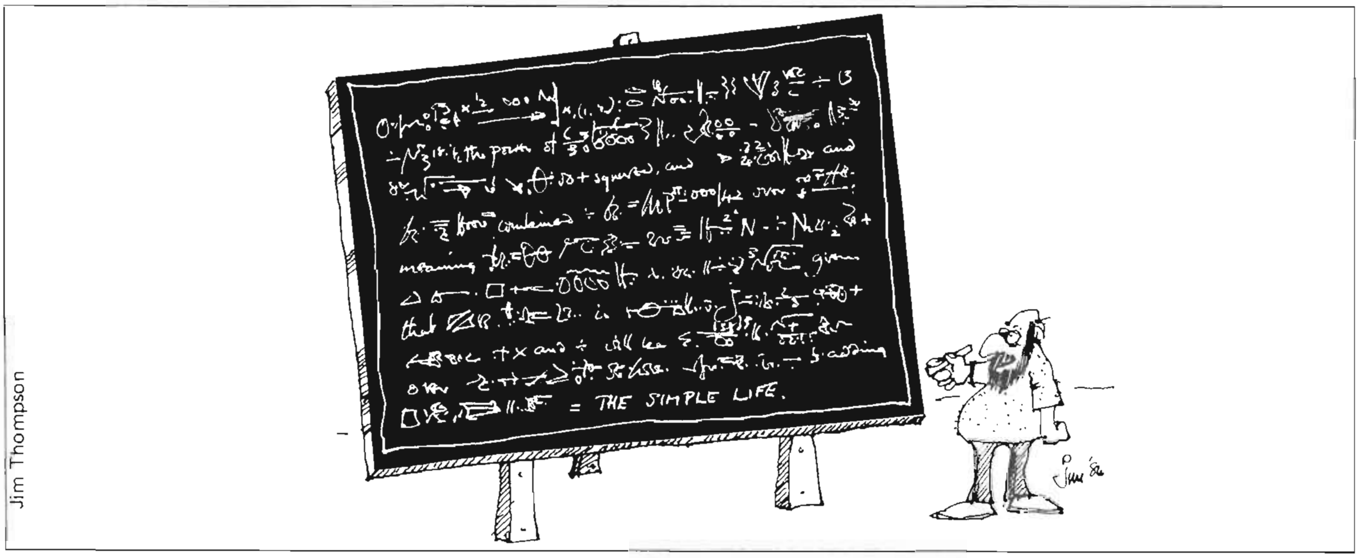
To characterize the complexity of a natural system S, it is necessary to reflect in a mathematical representation that we call a *mathematical model* M, the features of S that are of interest and then to associate the complexity of S with appropriate mathematical properties of M. Since the guiding principle is that the complexity of S can only be spoken of in relation to the system's observer 0, let us call this the *design complexity* of S and denote it by $C_0(S)$. Of course, from the point of view of the system, the observer 0 is also a system with its own complexity $C_S(0)$, which I'll term the *control complexity* of S. It is important to note that these two complexity measures exist not only jointly but on an equal footing. What we have here are two systems S and 0 in interaction, each seeing the other through certain observables and generating a measure of the other's complexity depicted schematically as:

$$\begin{tikzcd}\boxed{S} \arrow[r, shift left] & \boxed{0} \arrow[l, shift left]\end{tikzcd}$$

As I'll point out later, *it is the relationship between the quantities* $C_0(S)$ *and* $C_S(0)$ *that provides the basis for a theory of complexity management.*

What are the mathematical means by which S and 0 interact and form their view of each other? The basic raw materials for such interactions are what we term observables, which are nothing more than rules for associating real numbers with, say, the abstract states X of S. For example, suppose that S constitutes the citizenry of a particular country. Then the abstract states X might be taken to characterize the political mood of the populace, in which case we could have

> **"So then always that knowledge is worthiest . . . which considereth the simple forms or differences of things, which are few in number, and the degrees and coordinations whereof make all this variety."**
>
> ***Francis Bacon***



Jim Thompson

$$X = \{x_1, x_2, x_3, x_4, x_5\} ,$$

where

$x_1$ = very content,
$x_2$ = weakly content,
$x_3$ = divided,
$x_4$ = some dissatisfaction,
$x_5$ = great unrest.

An observer of this system might have the following observables at his disposal:

$f_1$ = fraction of the population disposed to the current ruling party;
$f_2$ = fraction of the population that is neutral or opposed to the ruling party.

It is clear that by surveys, statistical estimates, or guesses, a rule can be developed whereby each of the observables $f_1$ and $f_2$ will associate some real number between 0 and 1 with each of the abstract states of X.

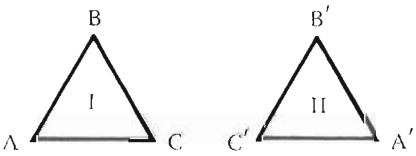
If an observer 0 sees S through a set of observables $F = \{f_1, f_2, \ldots, f_n\}$, how does he describe, or model, the structure of the observations that enable him to distinguish S from another system S′ that may involve exactly the same observables? The distinction between S and S′ is made by means of what I will call the equation of state Φ of S, which is just a set of mathematical relationships linking the observables of the set F. For instance, in the political example discussed earlier, the nature of $f_1$ and $f_2$ insures that we have the equation of state

$$\Phi(f_1, f_2) = f_1 + f_2 - 1 = 0 \ .$$

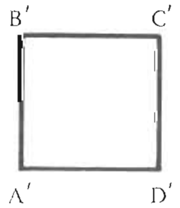
Of course there may be many relations $\Phi_i$ linking the observables of F; the totality of all such relationships that we know or care about constitutes a *description* or *model* of S as formed by 0. It is the mathematical properties of the description Φ that 0 will use to form the design complexity $C_0(S)$. The control complexity $C_S(0)$ is formed by interchanging the roles of S and 0 and using the corresponding equation of state developed by S that describes 0 as a system.

To study complexity it is sometimes best to think about simplicity, so imagine that 0 describes S via a description Φ. Under what circumstances would 0 conclude that S is "simple"? The crux of my argument is that 0 would regard S as simple, i.e., $C_0(S)$ would be small, if and only if almost all other descriptions $\hat{\Phi}$ that 0 could form of S would be *equivalent* to Φ. Here by "equivalent" I adopt the usual technical meaning that Φ and $\hat{\Phi}$ are equivalent if it is possible to transform Φ into $\hat{\Phi}$ by means of reversible relabeling of the observables. In other words, Φ and $\hat{\Phi}$ are abstractly the same object, differing only in their surface appearance through an arbitrary choice of the labeling of the elements $f_1, f_2, \ldots, f_n$. Clearly, any property of S that depends upon such an arbitrary choice of coordinates cannot be an *intrinsic* property of the system, so we conclude that equivalent descriptions Φ and $\hat{\Phi}$ are system-theoretically identical and indistinguishable: there is no information about S contained in Φ that is not also present in $\hat{\Phi}$, and conversely.

To digress for a moment in order to further clarify this pivotal concept of equivalence, consider the two triangles I and II. The simple reversible relabeling A → C′, B → B′, C → A′ transforms I → II. As abstract objects, I and II are indistinguishable other than through the arbitrary labeling of their vertices;



they are equivalent and any property of I can be tranformed into a property of II through the "translation" operations indicated above. On the other hand, no such reversible relabeling exists between the triangle I and the square



John Casti has been a research mathematician with the Rand Corporation and with Systems Control, Inc. as well as having held professorships at New York University, the University of Arizona, and Princeton University. He was at IIASA from 1974 to 1976, rejoining the Institute in 1982 and currently involved in the formulation of a framework for investigating industrial evolution and development. He is also Editor of *Applied Mathematics and Computation*.

so these objects are inequivalent and have properties that are not mutually reducible one to the other.

Returning now to system complexity, I define the design complexity as

$C_0(S)$ = the number of *non-equivalent* descriptions that 0 can form for S.

The control complexity $C_S(0)$ is defined similarly. The underlying motivation for this definition is provided by referring to the circumstances under which 0 would think of S as being simple. Basically, this occurs when 0 can only see S in a very restricted number of ways. As an extreme case, if 0 can form only a single equivalence class of descriptions of S, then any behavior displayed by S that is outside this class can literally not be seen by 0; S can offer no surprises to 0 and 0 sees S as exceedingly simple. *The greater the number of non-equivalent ways that 0 can see S, the greater the number of alternate, possible counterintuitive modes of interaction that S can have with 0 and the greater the perceived complexity of the system.*

So, I conclude that it is the non-equivalent modes of interaction available to 0 that comprise the complexity of S. All of the customary properties associated with system complexity such as surprises, large numbers of interacting variables, irreducibility, many feedback–feedforward decision-making loops and so on are consequences of the existence for 0 of a large number of inequivalent ways to interact with S.

## Managing Complexity

In light of the preceding discussion, it becomes increasingly clear that *the essence of the problem of complexity management lies primarily in the balance between the design complexity $C_0(S)$ and the control complexity $C_S(0)$.* Depending upon what the regulator/observer wants to achieve, it may be necessary to require $C_0(S)$ to be much greater, smaller, or about equal to $C_S(0)$. For instance, in the political example given above where S is the citizenry, while 0 is the ruling governmental body, $C_0(S)$ being much greater than $C_S(0)$ leads to a political dictatorship, while $C_0(S)$ being significantly smaller than $C_S(0)$ would be indicative of a structure approaching a pure democracy. The two quantities being approximately equal suggests a more or less interactive representative political system.

Suppose that a decision maker wishes to modify the complexity of a system in order to push forward some particular objectives. What means does he have at his disposal to bring about changes in the relative level of the control complexity $C_0(S)$? Basically, there are three paths open:

- *change the observables* – by altering the measurement process, observables can be either created or eliminated, opening up the possibility for new equations of state leading to revised levels of complexity.
- *modify the equations of state* – by analysis, observations, ingenuity, or just plain divine inspiration, 0 may create additional descriptions of S admitting the possibility of new modes of interaction. Alternately, existing relations may be eliminated or modified leading to fewer allowable ways for 0 to see S. In either case, $C_0(S)$ may vary.
- *adopt a new notion of equivalence* – 0 may enlarge or contract the set of admissible relabelings of the observables describing S. Changing the dictionary changes the equivalence classes leading to a different level of control complexity.

While I have stated these ideas for complexity management from the perspective of the observer 0, the situation is perfectly symmetric and it is quite conceivable that while 0 is busy making his plans to change $C_0(S)$ by one of the above schemes, S is quite independently engaging in similar actions leading to a modification of $C_S(0)$. In order for 0 to be confident that his decisions will have a therapeutic affect upon the situation, he must be able to insure that S is not foiling his actions by corresponding actions of his own.

## Laws of Nature and Laws of Human Behavior

The ideal to which much of the quantitative social and behavioral science literature strives is to develop "laws" of human behavior that rival in majesty and scope those laws for the behavior of natural systems bequeathed to us by the physical sciences, especially physics. I have argued elsewhere that this sort of "physics envy" displayed by the social sciences is completely misplaced, and no such laws of human behavior exist, at least as that term is understood in the natural sciences. Nonetheless, it is of interest to see how the concept of system equivalence introduced above enters in an essential way into the arguments supporting my non-existence claim.

In order to qualify as a law of nature rather than as a simple empirical relationship among observables, I claim that an equation of state $\Phi$ must be

i) *independent* – $\Phi$ must be independent of the particular physical situation in which it is observed. We cannot have one law of energy conservation for nuclear reactors and another for the stove in your kitchen;
ii) *analytic* – local space-time information is enough to determine the law and we need not account for what is happening in a distant location or the far distant past in formulation of the law;
iii) *invariance* – the law should not depend upon the scale or language used to describe it, i.e., it should be coordinate-free. Newton's laws of motion remain the same whether they are given in meters or feet or whether they are described in Russian, French, or Swahili.

The first condition is not mathematical, while the second is a technical requirement having to do with the fact that the law ultimately derives from local space-time observations. The last condition is the most interesting and is where the notion of model equivalence comes into play.

Basically, invariance means that a given description $\Phi$ remains invariant under *any* relabeling of the observables. This is a requirement that, in general, is impossible to verify, even in physics. However, in the natural sciences there are certain coordinate changes that can be given a readily identifiable physical interpretation, e.g., rotations, translations, charge reversals and so forth. Technically, such changes form *groups* and it is sufficient in physics for verification of the invariance conditions that a description $\Phi$ be invariant under some sufficiently large such group. In the social and behavioral sciences the problem arises because there are no mathematically interesting such groups that can be readily interpreted in terms understandable in the social or behavioral context. Until such groups are identified, the search for laws in the social sciences will remain a chimera. My contention is that there are no nontrivial groups of this sort.

The point of contact between the existence of laws and the concept of complexity should now be clear: if laws exist, then the invariance requirement basically asserts that there is only one description, i.e., that the system is *simple*. On the other hand, if the system has only a single description to which all others can be reduced, then the description is invariant and is a candidate for a law.

## Modeling Theory and a Theory of Models

As I have noted earlier, a theory of system complexity and complexity management, not to mention the issue of natural laws, is only the tip of an iceberg representing a research program that one might term a *theory of models*. At a rather general level, the type of questions that such a theory should address include:

- what is the relationship between a natural system S and a formal system M (model) that we choose to represent S?
- how do we choose an abstract state set X for S and how do we operationally define an observable on X?
- what types of formal mathematical systems M can be used to model S?
- how can we compare two different formal systems purporting to model the same system S?
- for a given system S, how do we generate new predictions in M from previous predictions?

These are far-reaching questions having no definitive answers. We can only hope to illuminate the issues by further sharpening of the questions through a disciplined and on-going creative research effort. And here the emphasis is on the word *creative*: no pedestrian, put-in-the-numbers-and-turn-the-crank program will shed any useful light on such matters. It seems appropriate to close by listing my own checklist for carrying out the type of creative research I have in mind:

i) avoid the research literature;
ii) avoid routine practitioner's problems;
iii) never put high hopes on any study for any immediately useful information;
iv) never plan – especially not in the long-run;
v) never apply for a research grant;
vi) never give up if everyone thinks you are wrong;
vii) give up immediately if everyone thinks you are right.

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Further explanations and the mathematics of Professor Casti's arguments can be found in papers available from the author.

## Further Reading:

(1) H. Simon, "The Architecture of Complexity" in *Sciences of the Artificial*. Cambridge, USA: MIT Press, 1969.
(2) H. Gottinger, *Coping with Complexity*. Dordrecht, Holland: Reidel, 1983.
(3) R. Rosen, *Fundamentals of Measurement and Representation of Natural Systems*. New York, USA: Elsevier, 1978.
(4) J. Casti, *Connectivity, Complexity and Catastrophe in Large-Scale Systems*. Chichester, UK and New York, USA: Wiley, 1979.
(5) J. Casti and A. Karlqvist, Editors, *Complexity, Language and Life: Mathematical Approaches*, forthcoming.
(6) J. Casti, *System Similarities and Natural Laws*. Laxenburg, Austria: IIASA WP-84-1.

# Evolving Cultural Paradigms

**Andrzej Wierzbicki** depicts the new cultural values being formed as we move to post-industrial societies as a natural process with historic parallels in the development of the Renaissance and the Enlightenment.

Looking ahead, based upon high scientific standards and done on an international basis, has become essential since *the speed of change of human societies now is especially great, and the changes have a global character.* But what do the terms "speed of change" and "global" really mean? When speaking about change, some emphasize its economic aspects, the change of economic structures. Others see even more far-reaching consequences in the change in technological and scientific potential, or point out the danger of ecological and environmental changes. My stay at IIASA has taught me that another aspect is still more fundamental: *the change of basic cultural values in our contemporary societies.*

## Long Cultural Waves

When speaking about changes in various aspects of human development, we often think of waves modulating general growth (or, equivalently, of a spiral); while this model might often be too simple and several others are possible (such as punctuated evolution or self-organization, or chaotic perturbations of any general trend), it will suffice for this exposition. Short business cycles or waves of four-five years' length are well-known in the analysis of market economies; longer waves of fifty to sixty years' length, Kondratieff cycles related to technological change, have been discovered quite a while ago but recently have been studied more intensively. Many historians and philosophers have also shown the occurrence of longer waves; of those, we shall consider here *long cultural waves* of three to four hundred years' length.

The expression "cultural wave" might be misleading, since the changes of basic cultural values are always based on technological, economic, and social changes; on the other hand, cultural changes do also influence in a feedback all other aspects of human development. In fact, when we ask the question whether the technological revolution of the 19th and 20th centuries is a unique historical phenomenon, we find – even in the history of Europe alone – at least two comparable historical periods. One was around the 12th and 13th centuries, with radical modifications of crafts, which resulted in the high arts of the Gothic cathedrals; another was around the 15th and 16th centuries, with the discovery of printing, remarkable developments in shipbuilding and other crafts, and resulted in the growth of a banking system that financed the profound geographical discoveries of this time. Both these periods of technological and economic acceleration prepared the foundations for new cultural platforms – those of the Renaissance and of the Enlightenment, respectively – and both were in turn motivated by previous cultural platforms.

"Cultural wave" is used here because we can relate its length to a possible mechanism, namely, changes in basic cultural beliefs. Cultural anthropologists agree that there is a basic delay in changing cultural beliefs, of three to four generations or seventy to one hundred years – related to the fact that, in a family, our beliefs are also influenced by our grandparents. When we ask a mathematical question: what length of wave is possible in a system with accumulation and delay, possibly oscillating through a feedback mechanism, we can obtain a definite answer:

the typical length is four delay times. Take an equation $\mathring{x}(t) = u(t - T_0)$ to account for accumulation and delay $T_0$ and assume $u(t) = -k.x(t)$ to account for a negative feedback. Consider these equations in frequency domain after the Fourier transformation and apply the Nyquist stability condition. The main transfer function is $G(j\omega) = X(j\omega)/U(j\omega) = e^{-j\omega T_0}/j\omega$, with Arg $G(j\omega) = -\pi/2 - \omega T_0$; this phase shift must be equal to $-\pi$ in order to generate through the negative feedback a wave of the pulsation

$$\omega_w = \frac{2\pi}{T_w} \quad ,$$

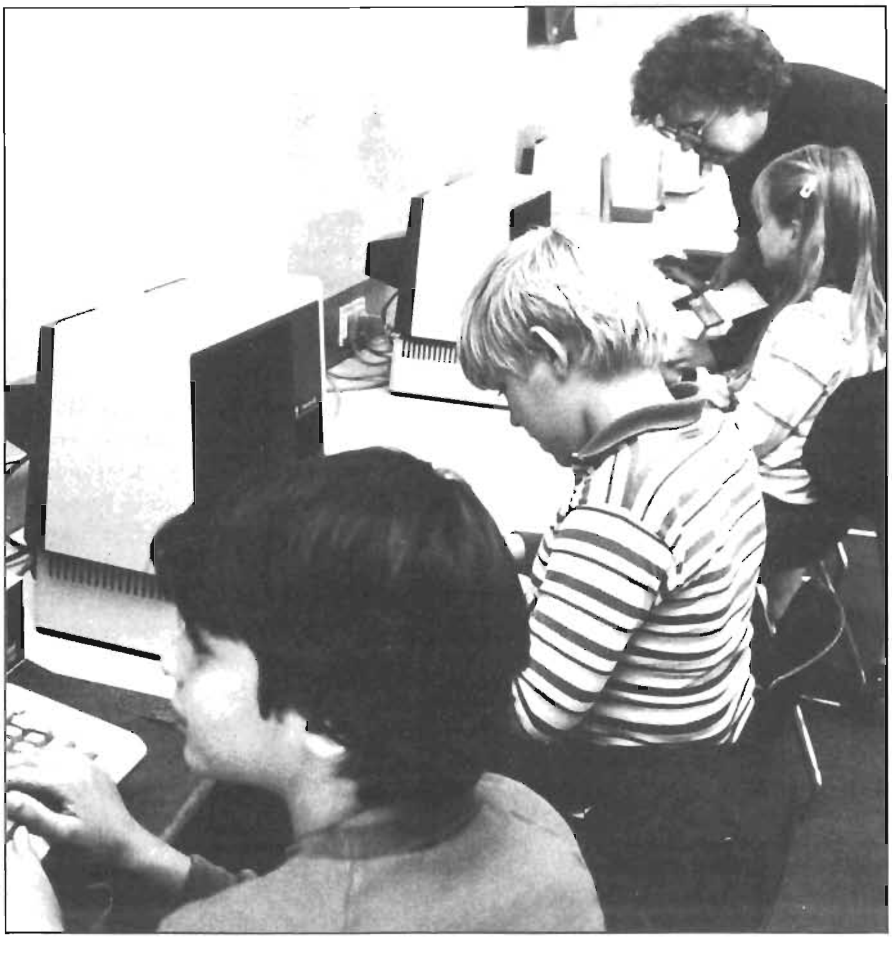
where $T_w$ is the wave length. Hence $\omega_w T_0 = \pi/2$ and

$$T_w = \frac{2\pi}{\omega_w} = 4T_0 \quad .$$

Thus, waves of the length of three to four hundred years, four times seventy-five to one hundred years, are the shortest that can be related to the changes of basic cultural beliefs (at least historically; the pattern might be shortened in the future, because of the impact of global communication and mass media systems).

There are many direct indications of this long cultural wave. Historians of culture agree on three main cultural periods in Europe. One is the culture of the late Middle Ages, starting around the year 1000 with the formulation of the idea of *Pax Dei* in southern France, forbidding warfare between Christians and resulting in the export of warfare through the Crusades, which in turn extended horizons and prepared for the next period. The second is the culture of the Renaissance, starting around the end of the 14th century in Italy with the rediscovery of the banking system along with many basic cultural achievements of ancient Rome and Greece, and spreading through Europe in the 15th and 16th centuries. The third is the culture of the Enlightenment, started by philosophers and scientists towards the end of the 17th century and spreading through Europe and beyond in the 18th century. All of these changes were followed or accompanied by major educational reforms. The first wave of European universities in Spain, Italy, and France starts around the 11th century, coming later to England. The second wave – in Czechoslovakia, Germany, and Poland – starts in the late 14th and 15th centuries. The Enlightenment was accompanied by major educational reforms in England, Germany, Poland, France, Russia, and by the development of North American universities. There is no doubt that these educational reforms contributed significantly to the Industrial Revolution and the acceleration of economic growth in the 19th century. What we realize less consciously is that many of our basic cultural beliefs – the ideas of religious tolerance, of natural morality and natural rights, of human brotherhood and equity – are products of the Enlightenment. In spite of the tremendous development of science and technology, of economic and social systems during the last two hundred years, we are still living, in a sense, in a prolongment of the Enlightenment era; only quite recent changes indicate that this era might be coming to an end.

The acceleration of economic growth in the 15th century led to an accumulation of wealth and subsequent social inequities. The Wittenberg Theses of Martin Luther in the year 1517 were, to a large extent, an intellectual protest against the inequities and the accumulation of wealth by the Church hierarchy. The Reformation soon led to the social uprisings, religious wars, and harsh reprisals of the Counter-Reformation that plagued the late 16th and most of the 17th century. At the same time, geographical discoveries opened new horizons. However, the prevalent social attitudes were obscurantist and antiscientific: scientists were held responsible for the development of modern means of warfare that tormented Europe. Plagued by this obscurantism, by the religious-ideological strife, and motivated by the visions of newly discovered primitive societies that maintained some natural order and were often peaceful though not knowing Christian religion, philosophers and scientists of the late 17th and early 18th centuries formulated a new cultural platform. Nearly a century was needed before the platform of



Professor Andrzej Wierzbicki has led System and Decision Sciences research at IIASA since June 1979, working himself on optimization theory and applications and interactive decision making. The former Dean of the Faculty of Electronics of the Technical University of Warsaw is returning to Poland as Professor at the Institute of Automatic Control, Technical University of Warsaw.

Enlightenment was firmly established, influenced educational reforms, and provided the basis for the American and French revolutions and the resulting development of modern history. On this example, we must stress again that the cultural changes of the Enlightenment platform resulted from previous economic and technological developments — but they also contributed to the next stage of the economic and technological development, to the Industrial Revolution.

When the Industrial Revolution in the 19th century in turn led to accumulation of wealth and the growth of social inequities, a new intellectual protest was pronounced by Karl Marx and Friedrich Engels: the Communist Manifesto was published 341 years after Luther's Wittenberg Theses. This has led to the formation of two opposing social systems that now increase their ideological confrontation; although this confrontation has assumed a global scale and has quite different dimensions than that between Catholics and Protestants in the 17th century, it is no less intense. The late 20th century is plagued by the danger of global nuclear holocaust, by numerous local wars, by environmental degradations. New horizons are being opened through space exploration, global communication systems, automatics, robotics, and computerization. Yet the prevalent social attitudes are again often obscurantist and antiscientific: not only are scientists being blamed for the development of modern means of warfare, but societies also distrust new technologies that bring about rapid economic and social structural change as we move to a new, post-industrial society.

With all the above indications of cyclical phenomena in history, of repeating periods of a certain character, we must, however, be cautious. History never repeats itself; even if certain mechanisms might work similarly, human behavior and culture is too rich to be fully predictable. Qualitatively new phenomena, such as the global character of industrial development, trade, communications, the arms race, educational transition, determine the course of the future. Moreover, the understanding of economic, social, or historical mechanisms is always not only the prerequisite, but also often a sufficient reason for human attempts to influence the future: many predictions can be rendered invalid by our actions based on these predictions. Therefore, the pattern of the long cultural wave may not be necessarily repeated in the future. However, the above discussion has been presented not in order to make predictions, but more as a background for analyzing the formation of new cultural values.

## Forming New Cultural Values

We are now living through a period in which new cultural values are being formed. This process is still in a turbulent stage, but diverse indications of this process — such as the activities of the Club of Rome, or various "Green" movements, or even the phenomenon of a specific IIASA cultural spirit — are more or less visible. The outcome of this process might be a profoundly new system of cultural values, a cultural platform comparable with, and replacing, that of the Enlightenment. Although this new cultural platform might still take some generations to be formed completely, some of its planks can be specified now.

The first plank is *global perspective*: while the Enlightenment platform stressed the universality of natural laws and rationality, it did not stress the *unity of global destiny and responsibility of the human race*. The idea of the unity of humanity is not new. It is stressed by several universal religions, and it was a strong element in Romanticism, for example, *"Alle Menschen werden Brüder."* Social movements in the 19th and 20th centuries have also stressed this idea. However, the idea has not developed until now into a sense of joint human responsibility for the Earth. Yet, wittingly or unwittingly, every man on Earth must now share some of this global perspective. It was brought home to us first by our excursions into the cosmic outskirts of the Earth and to the moon: our globe is beautiful, precious, but small. It was also brought home to us by the development of modern mass communication and transportation systems. It is being brought home to us even more forcefully by the danger of nuclear war. The danger of global deterioration of the environment and climate through human activities, though less acute than the threat of nuclear war, exists and burdens us with similar responsibilities.

If we share these responsibilities, we must learn to live together despite cultural, ideological, and social differences, to help each other in alleviating difficulties. We would all have the duty to consider and devise measures for eradicating hunger in the world, to stimulate balanced growth in the poorest countries, to help those affected by natural disasters or by disproportionally high demographic growth, just as neighbors in a village should help the hungry, the poor, or the large family, even if they were of different religions or ideological beliefs. Many would say that this is a very fine but idealistic statement and that people will not voluntarily part with their economic wealth or exert themselves in order to help others, especially when they do not share the same basic values. Yet many nations have eradicated hunger and basic values will continue to change, albeit slowly, towards a more global perspective.

These responsibilities also imply that we must learn to have much more respect for other cultures and more toleration of ideological differences than has previously been the case. *This does not mean convergence nor cosmopolitan separation from national background.* On the contrary, *diversity is of great value when facing uncertainty*, as seen in biological evolution, in scientific, technological, and many economic systems. Many diverse national cultures would contribute towards our global obligation to preserve the Earth for mankind. This means greater tolerance: as we developed religious tolerance on the cultural platform of the Enlightenment, following a long period of wars motivated by religion, so we must now deepen ideological and cultural tolerance to construct a new cultural platform. This means deeper respect towards and willingness to learn about other cultures. Conflicts are often escalated beyond rational limits because of unintentional incompatibility in the aspirations of the various sides; learning about the other side's aspirations requires some understanding of its culture, and culture cannot be understood if it is not respected. Thus, the second plank in the new cultural platform is *tolerance and respect for the cultural and ideological diversity of fellow humans.*

The third plank in the new cultural platform is a *deeper understanding and better use of the value of information.* This does not only imply improvement in mass media systems. On the philosophical level, this also means better understanding of the relative nature of knowledge as shaped by our mental images and the limits of our language.

On the technological level, this has profound implications with respect to the use of data processing, robotics, and automatic systems. We are moving towards what is termed the post-industrial society, in which the provision of basic materials and food will require only a small fraction of the available labor force. In the United States, this percentage is now some 22% including agriculture, and is steadily decreasing. From a purely technological perspective, this new society is not very far off. From an economic and social perspective, this process requires much more time for adjustments.

The new cultural platform may have many other planks. For example, we might foresee (and can observe even now) decreasing emphasis on purely economic values. The desire for self-fulfillment in a given job or social role might become stronger than the financial incentive.

However, the change facing our world is so vast that we cannot foresee all its aspects. This is the meaning of "global speed of change", and that is why it is imperative to intensively look into the future.

The century of Counter-Reformation and religious wars in Europe preceding the Enlightenment should serve as a warning. If we do not foresee and implement the necessary adjustments now, we might face a similar period of fanaticism, obscurantism, and war on a global scale. The signs that such a development is possible may be observed today. The phenomenon of pure consumerism, of *"panem et circenses"* is spreading through some of the more-developed countries; it is accompanied by growing obscurantism, distrust towards and lack of understanding of science and research, resistance to technological change. Its counterpart is provided by young people fed up with "consumerism", disillusioned with old ideologies, groping for new ideas but lacking a comprehensive understanding of what might lie ahead. In developing countries, exasperated by economic ills, maldistribution of wealth, and frozen political systems, revolutionary movements often lead to improvements but sometimes to fanaticism, intolerance, and war. Hence, simply "riding the wave" without looking ahead holds grave dangers for our world.

## The Role of IIASA

The perception of the necessity of intense looking ahead was shared by the founding fathers of IIASA, and is expressed in our Charter: "The Institute shall initiate and support collaborative and individual research in relation to problems of modern societies arising from scientific and technological development.... The Institute's work shall be exclusively for peaceful purposes." And the Institute has been addressing the global issues of energy supply, of food and agriculture, of economic structural change, of population growth and aging, of environmental dangers, as well as working on methodological tools that help us to look ahead, to alleviate conflicts, and to understand how systems adapt to change and uncertainty.

One of the most important functions of the Institute is to provide a meeting ground – a place where various cultural perspectives, various ways of looking into the future are compared, and where respect for other perspectives is cultivated. Therefore, all of the aspects of the new platform of cultural values discussed here – which might be called the platform of an *Informed Cultural Era* – belong to what we usually call the "IIASA spirit". These are the cultural values that most IIASA staff members accept and help to disseminate; they are also the reason why anybody who spends time at IIASA and participates in its work returns home somewhat changed. Let us hope that IIASA will be allowed to continue this important work.

# News from the Institute

## Professor Thomas H. Lee Appointed IIASA Director

Professor Thomas H. Lee will become Director of IIASA on September 1, 1984, as Professor C.S. Holling resumes teaching and research at the University of British Columbia, Canada upon completion of his three-year term as Director.

Energy specialist Professor Lee joins the Institute from the Massachusetts Institute of Technology, USA where he is the Philip Sporn Professor of Energy Processing, Director of the Laboratory for Electromagnetic and Electronic Systems, Associate Director of the Energy Laboratory, and Professor of Electrical Engineering.

The holder of 30 patents, Professor Lee has had a long career with the General Electric Company where he moved from test engineer to manager to Staff Executive and Chief Technologist concerned with engineering, business strategies, manufacturing, and R&D in the Power System Sector. Professor Lee was born in Shanghai, China but went to the United States shortly after World War II and earned his graduate degrees there. Professor Lee is the author of many publications in the technical literature and is an elected member of the US National Academy of Engineering and a fellow of the Institute of Electrical and Electronic Engineers.

Introducing himself to IIASA staff members at an Institute meeting, Professor Lee said that his professional experience and interests will lead him "to emphasize the relevance and applicability of IIASA research to policy advisors and decision makers in government and industry, while maintaining the Institute's technical interactions with the worldwide scientific community."

## Awards

Thirty-three IIASA staff members were honored after having served the Institute for 10 years, marking IIASA's entry into its second decade. Professor Holling presented each with a Maria Theresia silver taler, the ceremony taking place in the IIASA Conference Theater originally designed and used by the Empress. Also honored were three of the signers of the 1972 Charter creating the Institute; Soviet Academician Jermen Gvishiani, Chairman of the IIASA Council, Professor Koichi Miyasawa of Japan, and Professor Tibor Vasko of Czechoslovakia. They each have been closely associated with, and have actively supported, IIASA for over a decade.

IIASA is also initiating a program of awards to young scientists in honor of the late Aurelio Peccei, President of the Club of Rome and a founding father of IIASA. Two Peccei scholars from the IIASA Young Scientists' Summer Program will receive financial support for an additional three months' work at the Institute. Forty predoctoral students were enrolled in 1984 for the 8th year of this work–study summer program.

## Meetings

A simulation game designed to train senior public officials in principles of sustained, high-yield resource use, developed at IIASA for microcomputers, was presented at a meeting at the Institute. Strategem I has been selected for the annual course conducted in Dresden, GDR for officials from developing countries by the United Nations Environment Programme, and will also be used at an Agency for International Development meeting of program managers concerned with investments in energy and environmental projects in Latin America.

The Institute's research and its applications were featured at an IIASA Day during the Systems Engineering '84 Conference at Karlovy Vary, Czechoslovakia. This was organized by the State Committee for Science and Technology, the Union of Scientific and Technical Unions, and the Committee for IIASA of the Czechoslovak Socialist Republic with the Institute.

Structural change in the aluminum smelting industry was analyzed by industry, government, and academic specialists at a meeting at IIASA. The emphasis was on policy responses and reactions by governments and aluminum firms to the sharp rise in energy prices during the 1970s.

Industry and government officials affiliated with the forest sector attended the IIASA Forest Sector Project's first Summit Meeting recently. These policy leaders, who are among the potential users of the global forest sector model under development at IIASA, discussed scenarios which should be analyzed during test runs of the model. High priorities were assigned to the analysis of time supply, changes in production technology, development of substitutes for wood products, and uncertainties in the global economic climate (including the effects of inflation and currency exchange rates).

The proposed IIASA global econometric model to forecast the evolution of the world economy was presented at a conference held at the Institute. Scholars invited to participate in the modeling effort reported the current state of their national or regional models and the analyses undertaken relating to economic structural change.

New input/output models of both market and centrally-planned economies were installed at IIASA and reviewed at a meeting of the scientists in the international network collaborating with the Interindustry Forecasting Program – INFORUM – of the University of Maryland, USA.

The software used was demonstrated on an Altos computer. This meeting was preparatory to a further linking of the individual national models during the coming year.

Government officials, regional planners, and scientists from Austria and Hungary investigated how long-term development could be implemented while preserving the binational Fertö–Neusiedlersee Biosphere Reserve at a workshop held in Sopron, Hungary. IIASA scientists used adaptive management methods pioneered at the Institute and computerized simulation models to portray the effects of alternative development strategies at the workshop, jointly sponsored by IIASA and the United Nations Educational, Scientific and Cultural Organization's Programme on Man and the Biosphere.

The development dynamics of metropolitan areas was examined at an IIASA workshop in Rotterdam, Holland as part of the Regional Science World Congress hosted by the Netherlands Economic Institute of Erasmus University. The studies of Amsterdam, Budapest, Chicago, Dortmund, Helsinki, Leeds, Nagoya–Kyoto, Melbourne, Moscow, San Francisco Bay area, Stockholm, Turin, Warsaw, and Vienna will be published.

The IIASA approach to integrated analysis of acid rain in Europe was presented to government officials and scientific experts at a meeting at the Institute. IIASA has developed a computerized decision support system showing the amount and location of sulfur dioxide depositions resulting from alternative control strategies and fuel mixes. Participants included representation from the Economic Commission for Europe, which oversees implementation of the International Convention on Long-Range Transboundary Air Pollution.

The second IIASA task force meeting on applied general equilibrium modeling included discussions on theory, solution algorithms, policy analyses, and presentation of new models. The material is being prepared for publication. General equilibrium modeling was also the subject of a training seminar for young economists and modelers, demonstrated through models developed at IIASA. Both meetings were held in Sopron, Hungary, sponsored by the Institute and the Hungarian Committee for Applied Systems Analysis.

Policy makers, science advisors, and scientists explored concrete ways of moving findings and insights of current and proposed IIASA research into the policy process at a meeting at the Institute. Participants were drawn from the International Forum on Science for Public Policy held at IIASA in January. They reviewed and suggested activities at the Institute and elsewhere to enhance the scientific input to public policy issues with technical components.

## New Titles

### Books

**Modeling Water Demands.** Janusz Kindler and Clifford S. Russell, Editors. In collaboration with Blair T. Bower, Ilya Gouevsky, David R. Maidment and W.R. Derrick Sewell. 248 pp. Published by Academic Press.

**Rethinking the Process of Operational Research and Systems Analysis.** Rolfe Tomlinson and István Kiss, Editors. 227 pp. Frontiers of Operational Research and Applied Systems Analysis series, Volume 2. Published by Pergamon Press.

**Operational Gaming: An International Approach.** Ingolf Ståhl, Editor. 329 pp. Frontiers of Operational Research and Applied Systems Analysis series, Volume 3. Published by Pergamon Press.

**Interactive Decision Analysis.** Manfred Grauer and Andrzej P. Wierzbicki, Editors. Proceedings of the IIASA International Workshop held in September 1983. 268 pp. Lecture Notes in Economics and Mathematical Systems, Volume 229. Published by Springer-Verlag.

### Summary Report

**Assessing the Impact of Climatic Change in Cold Regions.** Martin L. Parry and Timothy R. Carter, Editors. Report of a Workshop held at Villach, Austria, September 1983 as part of the International Study Conference on the Sensitivity of Ecosystems and Society to Climatic Change, cosponsored by the World Meteorological Organization, the United Nations Environment Programme, and the International Council of Scientific Unions, and supported by the Austrian Government, the World Resources Institute, the United Nations Educational, Scientific and Cultural Organization, and IIASA. 42 pp. Summary Report SR-84-1. Published by IIASA.

Summary Reports can be ordered from the Publications Department, IIASA.

# Director's Corner

## *Perceiving and Managing Complexity*

Industry and government find themselves almost overwhelmed by problems of such complexity that their capacity for effective control is sorely stressed. However, the complexity of a system is in the eye of the beholder. It is measured by how well we understand causes, predict behaviors, and achieve purpose.

Complexity is relative to a frame of reference that gives order to understanding, expectation, and action. Science, including my own field of ecology, has evolved a sequence of such frames of reference, each developed to give comprehension to some set of paradoxes, to some mismatch between theory and perceived reality. And as each set of paradoxes was resolved, a stage was established for more observation, deduction, and analogy so as to expose the new limits to understanding from which paradox and complexity once again emerged.

Three viewpoints have dominated perceptions of causation and behavior. Each suggests distinctly different policies and actions. The first is an equilibrium-centered view that emphasized constancy in behavior over time. The second is a dynamic view that emphasized the role of instability in the maintenance of system resilience. The third is an evolutionary view that highlights organizational change and the surprises generated by such change.

The first viewpoint — the equilibrium-centered view — has been rooted in reductionism and the experimental methods of science. Understanding was sought by analyzing parts of the whole. Current during the first half of this century, and still the view of traditional western economics, it was a view dominated by cause/effect determinism, by a quantitative emphasis, and by a paradigm of stability, order, and regulation.

But consider the following typical examples:

- Successful suppression of spruce budworm populations in eastern Canada using insecticides certainly preserved the pulp and paper industry and employment in the short term by partially protecting the forest. But that policy has left the forest and the economy more vulnerable to an outbreak covering an area and with an intensity never experienced before.
- Transient success in malaria eradication has led to human populations with little immunity, and mosquito populations resistant to insecticide. As a consequence, during the past five years some countries report a 30 to 40-fold increase compared to 1969–70, endangering not only the health of the population but also overall socioeconomic development.

In each of these examples, the policy successfully reduced the probability of an event that was perceived as being socially or economically undesirable. Each was successful in its immediate, short-term objective. Each resulted in the system evolving into one with qualitatively different properties. The social and economic environment changed. Pulp mills were built to exploit the protected spruce-balsam forest, and more development was possible in those areas protected from malaria. Management agencies began to emphasize operational efficiency. But evolution also occurred in a third area — the biophysical — whose consequences were not generally foreseen or perceived.

That evolution in the ecological system led to increasing fragility. In essence, parameters — presumed constants — evolved. The spatial distribution of foliage for budworm and of people susceptible to malaria became more homogeneous. The minor and inevitable local flare-up hence has the opportunity to spread and accelerate.

The response, so often, is an attempt to use more money, more efficiently to do what was always done before. Hence, success in achieving constancy produced crises, more difficult and costly management problems, more unexpected events. In short, complexity is the consequence of an equilibrium-centered view. For some 15 years a growing body of work has been motivated by efforts to resolve this paradox. It has been a search for simplified understanding rather than for detailed explanation, efforts to preserve key features of variability and open the flexibility and responsiveness of institutions — in short, to retain resilience. In some cases that is feasible and desirable. In others it is not — because of institutional and political rigidities, polarization among powerful single-interest groups, or simply because the effort to conserve variability can be a kind of naive return to a fantasy of noble nature that freezes opportunity. There is a continuing search for still added levels of understanding.

Three viewpoints, or better, myths, are suggested. One is a myth of fixed and stable organization that is sometimes adopted as an institutional goal where persistence is the dominant value and unexpected events, external or internal, are seen as threats to that existence. That is the equilibrium-centered view. The second is a myth of gradual organizational change — a dominant myth of development and social and institutional growth that recognizes the resilient nature of systems. The third myth is one of punctuated change, a phrase borrowed from the revisionists of evolutionary theory such as Stephen Jay Gould. In that myth, gradual changes can accumulate until a critical point is reached (a bifurcation) where dramatic reorganization occurs as a consequence of an expanded or contracted set of new opportunities. There are many examples of technological, economic, social, and biological change that point in this direction.

The myths of constancy of "nature" concern variables of a system. The myths of resilience contrast the static with the dynamic nature of parameters. And the myths of organization concern changes in the basic equations and relationships of a system, i.e., with structure as well as function. The paradox of constraints and costs experienced at one level is resolved by recognizing that opportunities can be released at the next. Man does not have to return to a past nature. Action is not only possible, it is desirable.

C.S. Holling