Population Dynamics and the Arms Race

Reprinted from: **Work in Progress of the United Nations University**, Volume 14, Number 1, June 1992

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The new thinking about chaotic behaviour has led to the notion of "life at the edge of chaos " - expressing the principle that a delicate balance of chaos and order is optimal to life and growth on this planet.

Perhaps nowhere does this balance matter more to our continued survival than in the tangle of competing forces and values that fuel the arms race. Here chaos has traditionally been associated with unpredictability.

History is replete with "what ifs" that lead down or away from the road to war. But a new interpretation, growing out of fresh ideas on chaotic behaviour, sees small-scale chaos as something that rival societies might be able to live with, without resort to wholesale violence and bloodshed.

The role that chaos theory might play in our mutual security was discussed by David Campbell and Gottfried Mayer-Kress in their report to the symposium on nonlinear arms race models. The authors are mathematicians at the Center for Nonlinear Studies at the Los Alamos National Laboratory, New Mexico, and Dr. Mayer-Kress is also with the University of California at Santa Cruz, USA. **- Editor**

The mathematical model, we believe, has great potential contributions to make to efforts to enhance global stability and cooperation. On a number of issues of overwhelming international concern - like the "greenhouse" effect, ozone depletion, or nuclear winter - better understanding of the causal relationships between specific local actions and global consequences might be obtained from studies of highly sophisticated mathematical models containing many subtle and counterbalancing effects.

The situation becomes even more complex when socio-political issues are introduced - such as population dynamics, third-world debt, or combatting the AIDS epidemic. Here, in addition to the complex technical issues, one must also try to account for the vagaries of human psychology. And obviously, both technical and human issues are very bound up in efforts to pinpoint the possible flash points of the arms race.

Beyond the problem-specific technical concerns, moreover, are challenges and limitations that arise from the very nature of the systems in which these many elements are interacting. Such systems often behave in ways that seem to defy everyday experience. For instance, the inherently nonlinear nature of these systems means that they can exhibit sudden and dramatic changes in behaviour when small changes are made in the parameters describing the interactions within the system. Further, "emergent properties" can frequently arise - that is, characteristics whose existence is not at all apparent in the initial formulation of the system.

Developing "Nonlinear Intuition"

It is crucial that those responsible for making decisions on possible courses of action be aware of this second category of general constraints and characteristics that affect the applicability and reliability of the models. To achieve this awareness, it is essential to go beyond our conventional "linear" intuition and to develop an appreciation of what can - as well as what cannot - occur in complex adaptive systems. The development of what we would call appropriate "nonlinear intuition" is extremely important. It is clear that mathematical models not only tell us what is likely to occur but also can limit our perception of what can occur.

Our perspective is based on the considerable recent progress that has been made in understanding nonlinear dynamical systems in the natural sciences. Two of the most important concepts in these systems are (1) bifurcations and (2) deterministic chaos.

Bifurcations are sudden, sometimes dramatic, qualitative changes in the behaviour of a system in response to small changes in the control parameters. The relevance to the modeling of complex environmental issues is immediate: the primary concern of the greenhouse effect, for example, is that slight changes in the average global temperature could lead to catastrophic changes in the climate (due to nonlinear feedback mechanisms).

Deterministic chaos embodies the notion that even in those systems following precisely deterministic laws, the behaviour over long times can be essentially unpredictable, as random as a coin toss. The concept of deterministic chaos has already clarified a number of previously inaccessible phenomena, including, for instance, aspects of the transition to turbulence in fluids or the essential limits to the predictability of the weather.

Malthusian Dynamics

One of the first studied, and still most important, environmental issues is that of population dynamics. Clearly the nature and rate of growth of the human population is of central interest, both to environmental planners and security strategists. So also are a number of questions concerning the population dynamics of competing species, involving, for example, the relationships between predator and prey, parasite and host or exploiter and victim.

At the end of the 18th century, in his Essay on the Principle of Population, Malthus formulated the conclusion that "population, when unchecked, increases in a geometrical ratio." This model, now inextricably linked to his name, describes the growth of an isolated system evolving continuously in time in a constant environment and facing no limits to growth. The idea that population growth was inexorable and eventually had to lead to crisis had profound influence on both the evolutionary theories of Darwin and the economic theories of Ricardo.

Two generations after Malthus' Essay, the Belgian social statistician Pierre-Francois Verhulst formulated and named the now celebrated "logistic" equation to model the effects of limits to Malthusian growth of the population. Although there are many sources of limits to population growth, a fundamental one is the "carrying capacity" of the environment: namely, that if the population increases beyond a certain size, the environment is unable to support it, and the resulting effective reproduction rate or "fecundity" becomes negative.

It can be demonstrated through modeling that population behaviour, in certain instances, depends critically on the fecundity parameter and exhibits in certain regions "bifurcations"- sudden and dramatic changes in response to small variations in the reproduction rate. As the rate is increased, the model of population growth generates periodicity and begins to exhibit "deterministic chaos."

Arms and Insecurity

Let us turn now to the question of arms race models - and, in particular, those first introduced by L.F. Richardson in the 1920s in his work on applied dynamical systems and population growth. These models exhibit the characteristic features of nonlinearity, including bifurcations from one type of behaviour to another and, for certain ranges of their parameters, deterministic chaos.

Richardson's pioneering efforts, in his work, Arms and Insecurity, set the stage for subsequent attempts to analyse quantitatively many questions of strategic military and economic competition between - and among - nations. We have worked with several variants of the Richardson equations - beginning with a basic two-nation model - to show how chaos may play a role in increasing the risks of conflict. The model introduces such nonlinear variables as limited economic resources and the respective fractions of the available resources which the two nations devote to armaments.

The model shows the appearance of chaotic solutions as the countries X and Y are first in a steady state, then

simultaneously bifurcate to a periodic state before together entering a situation of chaos. The transition to chaos is associated with unpredictable behaviour, crisis, unstable arms races, and therefore with an increased risk for the outbreak of war. While this interpretation can be disputed, it has become clear that the possibility of chaotic behaviour has to be taken into account in arms race models.

A second interpretation of the role of chaos in arms race models is that bounded, small-scale chaos cannot be anticipated in detail (possibly because of internal political problems of one country), but the stability of the attractor itself allows for confidence in the fact that no disastrous surprises will occur. This would be expected, for example, if there exists a basic consensus within one nation about defense policy, but details of the budget are subject to internal discussion. Elsewhere in our work, we have already suggested the effect of couplings between internal opinion formation (between "hawks" and "doves") and interactions between two nations.

The appearance of this type of small scale chaos has to be distinguished from large chaotic fluctuations which would lead to configurations in which certain situations of crises could lead to unbounded arms races, war, or economic collapse.

Chaos in "Star Wars"

In a more specific arms race situation, we analysed the impact of strategic defense systems - SDI, the so-called "Star Wars" - on the superpower arms race.

This model only includes three SDI elements: (a) intercontinental ballistic missiles (ICBMs); (b) anti-ICBM satellites designed to attack and destroy ICBMs in space; and (c) anti-satellite missiles or other weapons launched to destroy anti-ICBM satellites before they can destroy the ICBMs.

The results of this model indicate that for most parameter combinations, the introduction of SDI systems leads to an extension of the offensive arms race rather than a transition to a defense-dominated strategic configuration. In the case of a strongly accelerated arms build up - either offensive or defensive - we observe a loss of stability of the solutions that we interpret as a transition to unpredictable chaos.

The Complications of Allies

When we extended the Richardson equations to model an arms race among three nations, this introduced the additional complication of possible alliances.

With three nations, the natural choice for an alliance is between the two weaker nations - otherwise, the two allies would have dominant superiority over the third nation, and the competition would be reduced to that between the two nations in the alliance.

The model assumes a situation in which the three nations have arms expenditures over a given period, corresponding to a typical decision period. The equations describing armament levels take into account actual spending levels, desired rates, external threats, and economic limitations. External threats are different for nations who have to defend themselves against an alliance and those who are allies. Certain parameters determine how fast each nation tries to achieve its desired armament level, while others describe the rate at which a perceived external threat is countered. We attempted to isolate those regions of the parameters where sensitive, chaotic behaviour was obtained.

While we recognize no one could take the conclusions drawn from this over-simplified model as the sole basis for any political decision, we feel that the attempt to understand and quantify various causal relationships will lead to increasingly sophisticated models. When they are produced, one will certainly need the insight gained from the techniques of modern nonlinear dynamical systems to analyse these models.