10

A Two-Party Game: Arms Race Escalation

A good deal of theory about social dynamics is concerned with situations that involve limited numbers of self-referencing actors in goal-directed interaction. The "actors" involved may be individuals, groups, organizations, or more extended forms; they may be "self-referencing" in a wide variety of ways; and, they may "interact" by responding directly to other actors or more indirectly by responding to environmental conditions created by other actors.

In principle the dynamics of interaction of any degree of complexity can be captured by coupling together the simple chains we examined in the previous chapter. In the current chapter we will take a couple of short but important steps in the direction of increasing complexity. First, we will have multiple actors (in this case only two, to keep it simple) who directly interact with one another. Second, we will make the actors a bit "smarter" than they have been in previous models in terms of the amounts of information that they take into account in formulating action plans.

The model that we will develop in this chapter is very similar to many others in various social sciences in that it deals with interaction among small numbers of goal-oriented actors. While we will be concerned with the particular two-party game of armed escalation, the current model can also serve as a template for formulating models about interactions in a small group context, among firms in a market, among governments, and many other similar situations in which actors interact in the pursuit of goals.[1]

Arms Races and Other Games

Social scientists have been interested for some time in a problem that contains many of these kinds of dynamics of adjustment to the states of both one's own and others' systems: arms races and escalations of conflict between parties. It takes a certain degree of perversity to group models dealing with arms races into the same category of "games" as "the prisoner's dilemma" or chess. Nonetheless, as theoretical systems, the problems are similar. Escalation models are good examples of "smart" interaction between or among parties in that they are fully dynamic and each party monitors the self, the environment, and other actors. The particular context that we will consider—arms races—is, of course, substantively important. It also differs from many other models in the "game theoretic" tradition in that the interaction is positive sum (or, in the case of arms races, negative sum). This is not a necessary part of such models. For our purposes, it is sufficient that arms races be reasonably thought of as essentially similar to most two or multiactor "games" of this type: Each actor has goals, monitors their own and others' actions, and continuously modifies and updates strategy based on changing conditions.

There are very substantial literatures that present and analyze formalized "games."[2] Formal mathematical models for many relatively simple games have been created, and the problem of escalation and competition between two actors has been subject to particularly close scrutiny. The model of escalation in the interaction between two actors that we develop below as a "systems dynamics" model has also been extensively analyzed by mathematical means and subjected to empirical testing.[3] We will begin by building a simple model of competitive interaction between two actors that is formally identical to these mathematical models. After we explore its properties we will then turn to some of the additional possible specifications that our analysis of the simple model suggests. In particular we shall be concerned with the consequences of informational distortions and delays in complex dynamic systems.

Developing the Baseline Model

Let us suppose that there are two actors (X and Y) and that each possesses a stock of arms. Arms are created by transforming natural resources at some rate over time, and become obsolete or useless after a time and are discarded. Our system then is composed of two "subsystems"—the actors, each of which is characterized by a "state space" composed of a single chain of material feed-forward relations—raw materials are transformed into arms are transformed into scrap. These parts of the model can be diagramed as in Figure 10.1.

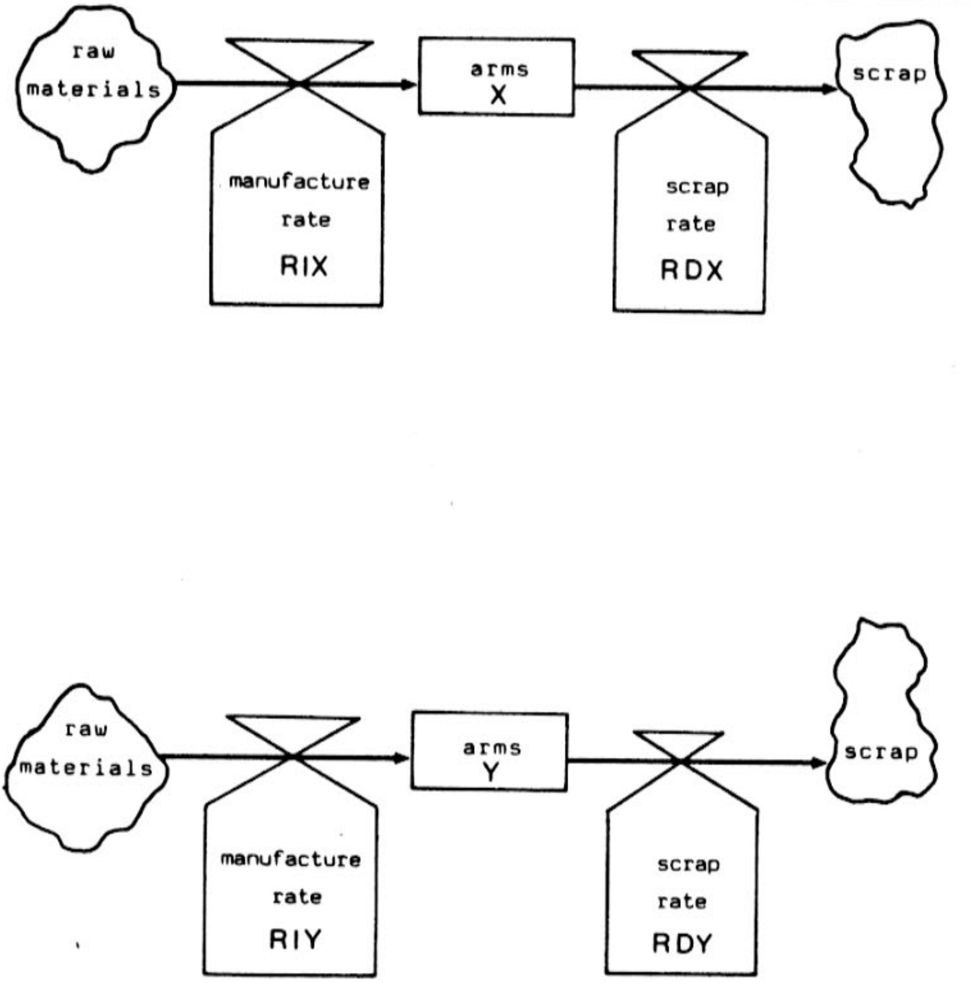

Figure 10.1: Chains for arms race model.

We are deliberately keeping the baseline model quite simple in a number of ways so that we can understand the basic dynamics of this interaction before moving to elaborations. We are assuming that only two actors are involved in the interaction, we are assuming that each actor's resources are unlimited, and we are assuming that "scrap" is a "sink." None of these assumptions are necessary, but they are useful to keep the model to its bare-bones structure.

From looking at Figure 10.1 it is apparent that the system thus far can be represented as two "level" equations, each having two associated rate components (that is, rates of transformation of raw materials into arms, and rates of discard from the stock of arms to scrap). The level equations are:

```
L    X.K = X.J+(DT)(RIX.JK-RDX.JK)
L    Y.K = Y.J + (DT)(RIY.JK-RDY.JK)
```

where X and Y are the current levels of arms of the two competitors.

Let's now examine the control structure surrounding each of these chains, leaving aside—for the moment—how the chains are coupled together. Take note of the strategy here, for we are following the same approach as we did in the development of simpler models: First divide the problem into subsystems, then identify the chains that couple the states within each subsystem, then examine the control structure of each process. Only after each of the "parts" is assembled are they be coupled together.

The level of arms in each subsystem controlled by two decisions: decisions about rates of arms construction and decisions about rates of scrapping. We will assume that the important and interesting policy decisions are "smart," or "goal oriented and self referencing," and involve how rapidly arms will be built. The process of scrapping arms will be treated as a simple physical process of constant decay of the stock of arms:

```
R    RDX.KL = MAX(A1*X.K,0)
C    A1 = .1
```

That is, the rate of decline in arms for actor X (RDX) will be equal to 10% (A1) of the current level of arms (X), but not less than 0. The same, of course, holds for actor Y.

The "smart" decision making about the building of arms is more complicated, and involves the monitoring of information. In order to make each of these systems "dynamically self-referencing," it is necessary that some mechanisms be specified that describe how actors monitor their own statuses. There are several possibilities: The level of resources available could be monitored; the level of existing armaments could be monitored; the level of scrap could be monitored; the rate of transformation of resources into armaments could be monitored; or, the rate of transformation of armaments into scrap could be monitored. In real world arms races actors probably monitor all of these states and rates and combine the information in complex ways. We will keep the baseline model simple by assuming that each actor monitors their own stock of arms, and does so without distortion or delay.

"Smart" decision making also involves the comparison of the monitored state (in this case, one's level of arms) to some goal. Actions are then based on perceived discrepancies between the actual and desired state of the levels. We will make the assumption that actors goals are constants, and exogeneously determined. The most common such assumption is that each party desires superiority to the other:

```
A    DLAX = KX*YP.K
C    KX = 1.05
```

That is, actor X's desired level of arms (DLAX) is equal to 105% (KX) of the arms it perceives its opponent to possess (YP) at any point in time. Actor Y formulates its goals in the same fashion.

The information that each actor has about its own level of arms (X) is compared to the desired level of arms (DLAX) to produce a perceived arms gap, which serves as the basis for action:

```
A    GAPX.K = DLAX.K-X.K
```

The internal control system for each actor then can be summarized as in Figure 10.2.

There is nothing new in this model so far. Each actor's "subsystem" is a single chain of three states governed by two rates—both of which reference the level of arms, and one of which is "dumb" (scrapping) and the other "smart."

Now we come to the key step. In order for this model to be a true "dynamic interaction," each actor must be paying attention to (monitoring) some aspect of the other's system, and adjusting its behavior to meet its goals in light of the changing behavior of the other. Again there are choices. What aspects of the other's system is monitored? How accurate and speedy is the monitoring? What role does the monitored information play in decision making?

We will begin by assuming, like most of the existing models of escalations, that each actor monitors the level of arms of the other. This is, of course, somewhat unrealistic, for the levels of the opponent's available resources and the rates at which the opponent is building arms are also probably monitored. We will also assume, for our baseline, that each actor has accurate and up-to-date information about the level of the others arms:

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A    YP.K = Y.K
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That is, actor X perceives actor Y's arms (YP) as identical to their true current levels (Y).

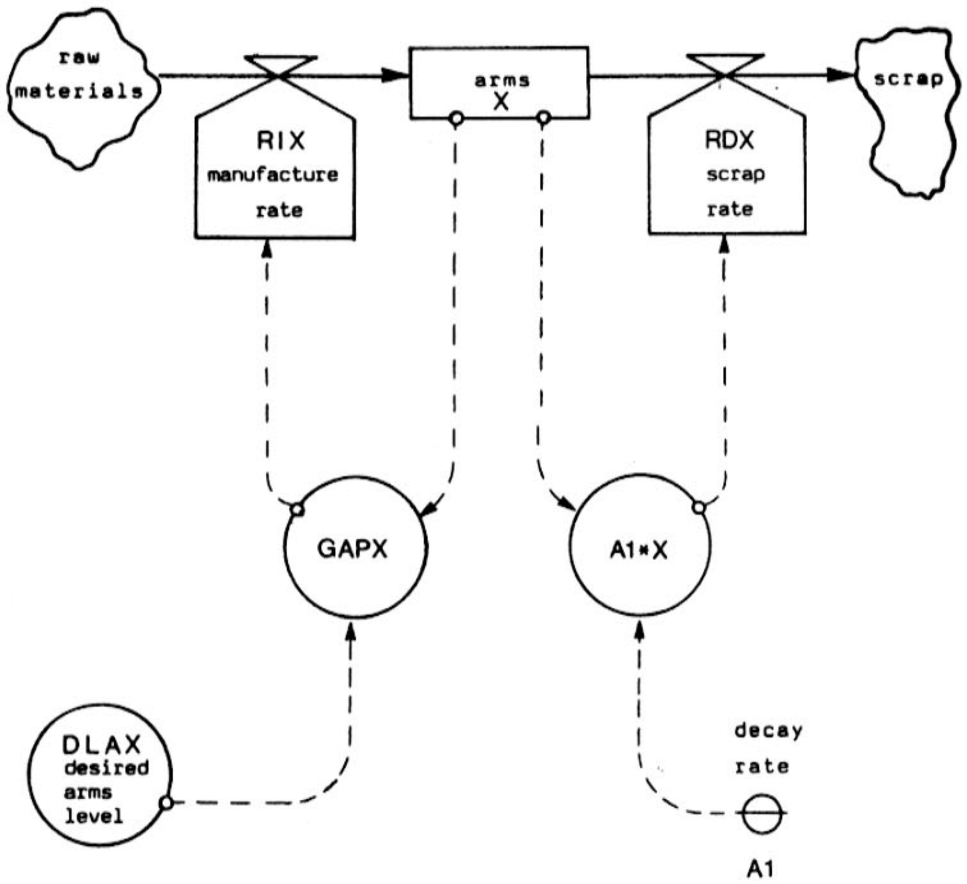

Figure 10.2: Control structure for arms production.

With this simple step in the specification, we have coupled the two actors together into a more complex system. By making the desired level of arms of each actor a result of the goals of the focal actor, the current state of the focal actor's system, and the current state of the other's system (as the focal actor perceives it), the two chains interact. We can represent the full model by elaborating our diagram slightly, as in Figure 10.3.

The general structure of the diagram in Figure 10.3 is now familiar. It, like all of the others to be presented in the remainder of the volume, consists of "subsystems" composed of simple chains that are coupled together by flows of monitored information.

As we have built it, the model—while highly interactive and dynamic—is still very simple. A great deal of elaboration could be done on each of its parts to make it more realistic. Some of these alternatives

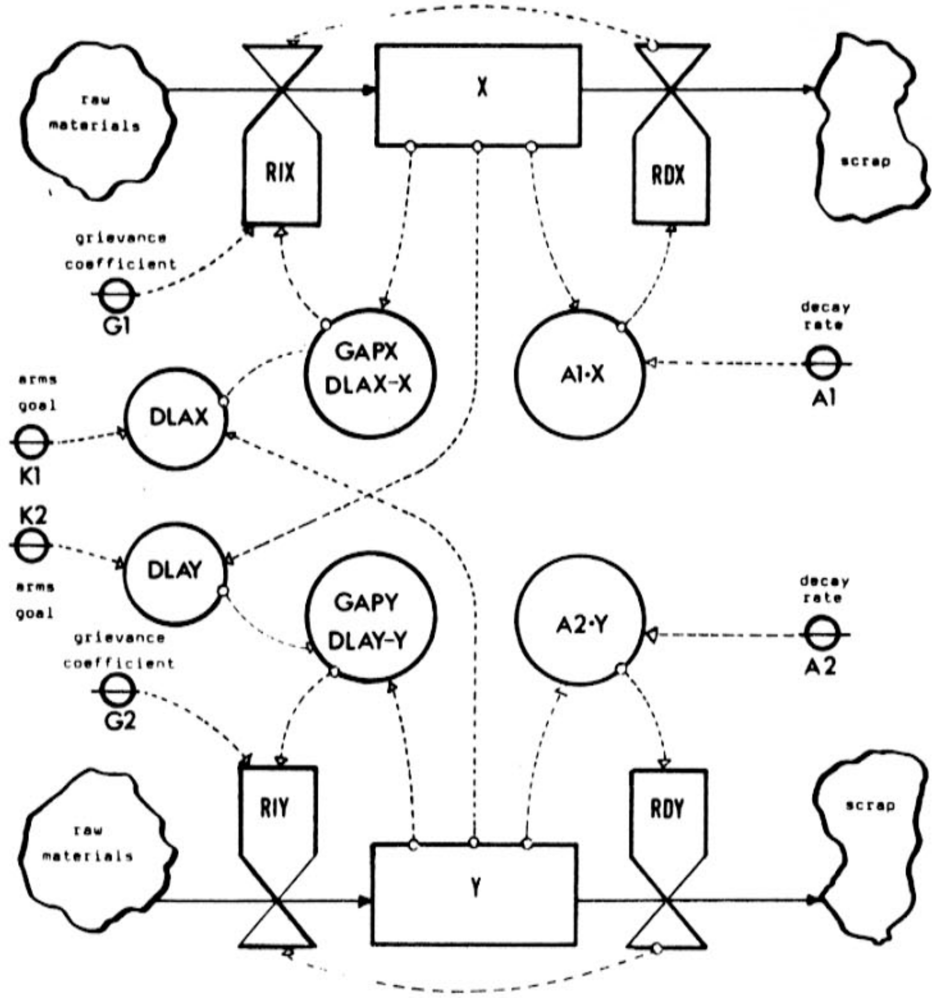

Figure 10.3: Arms race baseline model.

have, in fact, been explored in the theoretical and research literatures on arms races, and we will explore and discuss some of the possible extensions later on. For our current purposes, however, the model that we've specified is sufficient: It shows two actors, each conscious of their own condition and the condition of the other, each with goals (which we have specified as being incompatible), interacting over time. In principle, such a model can serve as a starting point for the formalization of theories having to do with more actors, more complex state spaces for each, and more complexly coupled interactions. Before moving toward such complicated models, however, there are some interesting dynamics to be explored in the baseline model.

Behavior of the Baseline Model

The dynamic behavior of the simplest possible forms of this game are rather easy to anticipate. Answers to questions about equilibria and sensitivity are available by direct solution, but we can also gain an understanding of the behavior produced by our theory by simulating it, as we shall in a moment. But let's think through the problem before looking at the results. What factors might produce different outcomes? What factors and connections are most "central" in the network of variables describing the theory? What are the consequences of modifying these central variables?

By looking at the diagram of the final model (Figure 10.3), it is clear that the behavior of each of the chains is governed primarily by decisions to build arms. The decision to build arms is also the point in the diagram where the two nations "meet" or are connected—their resources, scrap, and levels of arms don't connect, but the level of arms in each is a factor in the decisions to build arms by the other.

The decisions about the rates at which arms are to be built, in turn, depend on several things: the current level of arms in the focal nation, the perceived level of arms in the competitor's nation, and each nation's goals. To anticipate the dynamic behavior of this system then, we must focus our attention on the decisions in each nation to build arms. In turn, this requires us to ask how the current levels of arms in the focal and competing nations and how the nations' goals determine outcomes.

Each actor's rate of arms building is a direct response to the gap between its own level of armament and the level it desires. The rate of change in arms building in each nation, then, is directly proportional to the magnitude of this difference. The magnitude of the difference depends in turn on past levels of arms building and on the goals of that actor. Differences in the goals of the actors, then, would seem to be critical to the dynamic behavior of the system. If each actor desires superiority to the other (KX and KY > 1), escalation results. If each actor should desire inferiority to the other (KX and KY < 1) a "race" downward will result. If the actors have different goals, say one desiring superiority while the other is satisfied with inferiority in arms, or if the two actors desire exact parity, then stability over time would be implied.

According to our logical analysis of the diagram of the theory, the levels of arms in the two nations and the goals of the two parties are the keys to the dynamic behavior of this system. To explore the effects of these factors, let's design a series of experiments that vary the levels of arms, and vary the goals of the actors while holding other factors constant. The levels of arms possessed at any point in time will be set to be equal, favor actor X over actor Y, or vice versa. The goals of the actors can also have several configurations: X and Y may seek superiority, each may seek equality, or each may seek to have fewer arms than the other.

Along one dimension our two actors, X and Y, divide 200 units of arms either equally, or with a 3-to-1 superiority for one side or the other. Along another dimension we vary the goals of the X and Y (labeled KX and KY), which are expressed as their desired levels of arms as a percentage of the arms of their opponent. We create four alternative scenarios of the goals: Both actors desire equality, both actors desire superiority, both actors desire inferiority, or one actor desires superiority while the other desires inferiority. In Table 10.1 below, the levels of arms present in each camp after 25 cycles of the model are reported.

The basic results of these simple interaction games are relatively easy to anticipate and understand: (1) where both actors have the goal of equality with the other, the equilibrium result is equality at a level between the two starting points (here it is 100), (2) initial differences in the levels of arms are rapidly adjusted away by increases in the arms of the initially inferior player and declines in the arms of the initially superior player, (3) where both actors desire superiority to the other, "escalation" or exponential growth occurs, (4) where both actors desire to reduce their arms to be less than those of those of their competitor, the "arms race" leads downward, again regardless of initial levels. In general, whether the characteristic behavior of the model is exponential growth, exponential decline, or stability depends on the sum of the goals of the actors and the ratio of these goals to each other.

These experiments give a good understanding of the characteristic behavior of the baseline model. A stable level of armaments is achieved where both actors desire equality, or where both desire inferiority. Where both desire superiority, or the balance between the desire for superiority by one is not exactly balanced by a desired inferiority on the part of the other, unstable situations result. Where both desire superiority, exponential growth ensues; where goals are unequal, either unbounded growth or bounded decline ensue, depending on the ratio of the goals. The levels of arms of the actors at the beginning of the race make little difference in the baseline model: The equilibrium levels of the processes are the same regardless of initial equality or inequality.

An Extension: Delays

There are a number of ways that the baseline model could be extended and made more realistic. In the next section we will briefly

TABLE 10.1
Baseline Escalation Model Results at t = 25
Initial Levels of Arms

Goals	X = 100 Y = 100	X = 150 Y = 50	X = 50 Y = 150
KX = KY = 1.00	X = 100 Y = 100	X = 100 Y = 100	X = 100 Y = 100
KX = KY = 1.05	X = 350 Y = 350	X = 348 Y = 348	X = 348 Y = 348
KX = KY = .95	X = 29 Y = 29	X = 29 Y = 29	X = 29 Y = 29
KX = 1.05 KY = .95	X = 99 Y = 95	X = 98 Y = 93	X = 101 Y = 96

discuss some of the possibilities. One particular modification of the basic game, however, is worth considering in some detail because of the importance it has for understanding the dynamics of most social interactions.

In the interactions among human actors, delays and distortion in perception, communication, and action are usually present and can have substantial consequences. In very simple systems the consequences of delays and distortions are relatively easy to anticipate (as in our discussion in the first part of this volume). In complex systems with feedback, however, the consequences are not always so obvious. Now that we have a firm grasp of the basic dynamics of a two-actor escalation game we can modify our basic model to begin to understand how such imperfections affect outcomes.

There are many kinds of delay and distortion that occur in interactions. Actors may fail to perceive signals being sent, may be slow in decoding them, and may lose part of the message (or add noise to the message). Once a message is received and decoded it takes time for the actor to make decisions. Indeed, the more complex the organization of the actor the more likely it is that there will be a lengthy delay between perception and action. Once a course of action has been decided there are frequently delays (and sometimes errors as well) in implementation. To these "imperfections" in the capacities of each actor we must add another factor. When two actors, each "imperfect," base their actions on the behavior (including signals given off) of the other, the errors, delays, and distortions in interaction are multiplied by the interaction: A incorrectly perceives what B is doing, makes a response that B perceives as inappropriate, which causes A to respond differently, etc. Such cycles of misperception and consequent inappropriate action may make for clever comedy, but may be somewhat less amusing when the interaction in question may lead to a nuclear exchange. What might the consequences be if such delays and distortions were introduced into our escalation-interaction model?

To explore this question, let us first calculate two "baseline" scenarios. We will assume that each actor has perfect information about the other and is able to respond immediately and completely (as we have been assuming thus far). We will further assume that each actor desires a 5% supremacy over the other and has unlimited capacity. When an actor has more arms than he needs at a given point in time he does not get rid of them—except for scrapping obsolete ones—but does not build more. In the first baseline scenario the two actors each begin the game with 100 units of arms. In the second baseline scenario actor X begins with 150 units and actor Y with 50.

As in our analyses in the previous section, starting the actors with equal levels of arms and equal desires to have superiority over the other results in an exponential increase in the levels of arms of each and an exponential increase in the gap between the level of arms that each has and the number that it would deem satisfactory. Starting with 100 units of arms each actor has acquired 331 units by the 25th time period and is acquiring arms at a rate of 50 units per unit time. This is the classic problem of escalation, as we have studied it above.

Initial inequality of arms compounds the problem. Where the actors begin with equal desires to superiority but radically unequal initial levels (X has 150 units initially to Y's 50), both the level of arms accumulation and the rates of accumulation for both actors are accelerated. By the 25th time point both actors have acquired 394 units of arms and are building arms at a rate of 60 units per year at this time under the leader-follower scenario.

Now let us suppose that there are no delays or errors in each actor's perceptions of their opponent's level of arms, but that it is not possible to immediately respond to perceived gaps. That is, let us suppose that it takes some time to actually build the arms after it has been decided that they are necessary. For current purposes we will use a simple first-order exponential delay with a period of three time units (roughly, the actor responds in such a way as to close the gap over a period of three units):

```
R     RIX.KL = DELAY1(MAX(G1+GAPX.K+RDX.JK,0),3)
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That is, X's rate of arms building (RIX) is a first-order exponential delay of average length of three units (DELAY1,3) of the larger of two quantities. X builds arms at a rate sufficient to satisfy its feelings of grievance or bellicosity (G1), to replace arms that have depreciated (RDX), and to close the gap it perceives between its current arms and its goal (GAP). Arms, once created, are not destroyed even if they are not "needed" (note the use of the MAX function to represent this effect).

When the actors begin the game with equal levels of arms, the effect of a delay in producing new arms is to reduce the final levels of arms. The exponential pattern of growth and growing gaps, however, persists. When the actors begin the game with unequal arms, however, the pattern of dynamic behavior is dramatically affected by a delay in arms production. The actor who is far behind initially undertakes a massive building program to attempt to close the gap. However, since the arms are not immediately delivered, the opponent does not immediately perceive the threat, and initially takes no action to maintain his superiority. As the program of building on the part of the initially inferior actor begins to reach its full realization, the initially superior actor finally perceives the threat and begins his own building response. However, since it takes time for these arms to be delivered, the first actor—who was initially inferior—reaches his goal of superiority and stops building. The resultant pattern is one of dampening cycles in perceived gaps on the part of both actors and an unstable upward arms race—as is shown in Figure 10.4.

It is also notable that the instability introduced by the delays in building not only distorts the dynamic pattern but also the final realization of the series. By the 25th time point in this scenario the total arms possessed by each actor are much greater (570 units) and the rate of building of new arms is somewhat greater (77 units per unit time) than in the equal initial-arms scenario. Thus we are led to an interesting result: In the presence of initial equality, delays in response lead to a lower final accumulation and no change in time pattern; in the presence of initial disequilibrium, delays in building lead to an acceleration of the arms race, and to cyclical instability in the time trace.

It also seems likely in an interaction of the type that we are modeling that actors may not have access to perfect information about the status of the other. Indeed, in arms races (and other forms of competition), actors may find it in their interest to disguise their true strength (or weakness), and hence gain an advantage over the other. Let us suppose that each of the actors in our game is able to hide information, so that the true levels of arms in each system become apparent to the other actor only with delay. This delay can be modeled with the statement:

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A    YP.K = DELAY1(Y.K,3)
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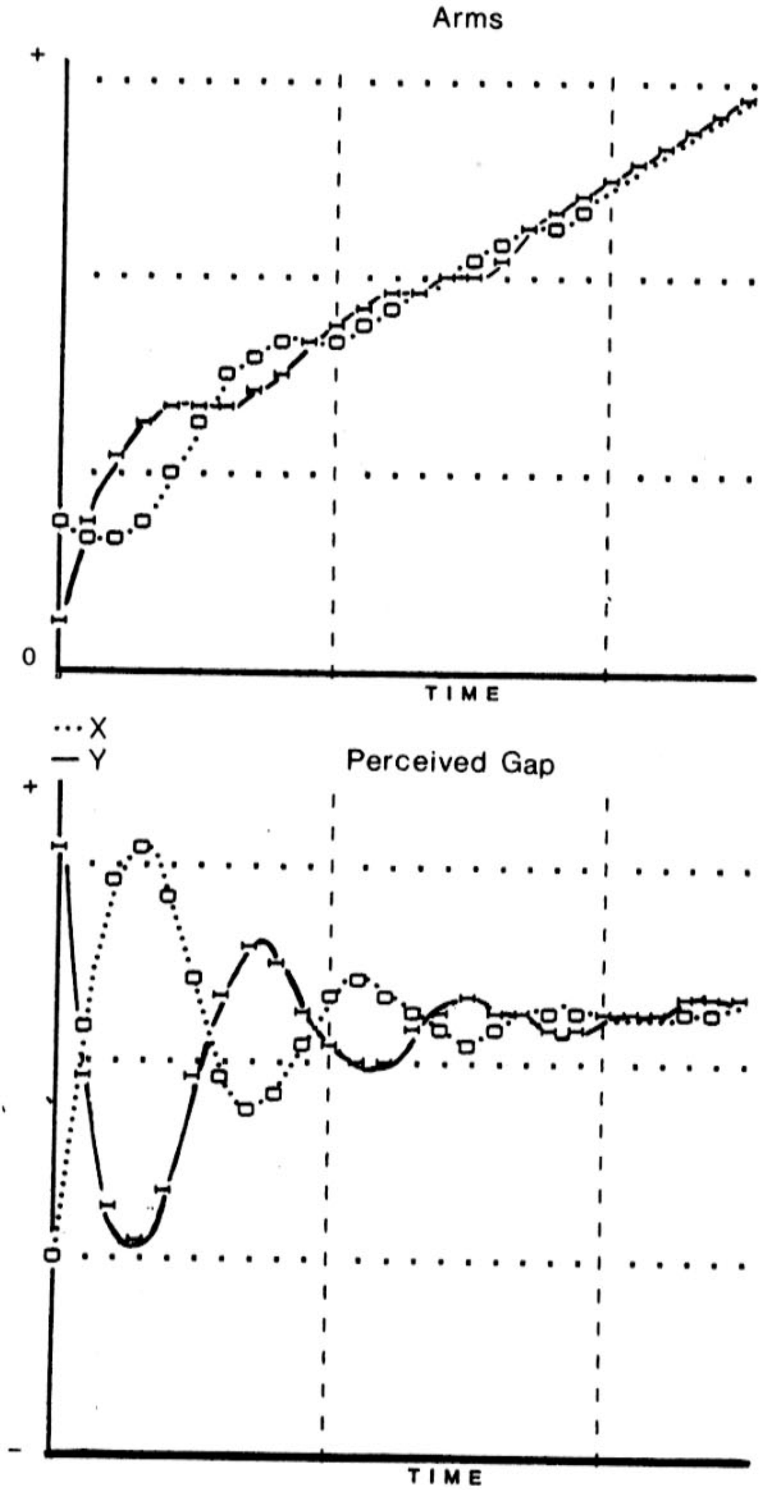

Figure 10.4: Delay in response in leader-follower model.

That is, actor X perceives the level of Y's arms with a first-order exponential delay of three time periods. So that we can see the effect of this kind of "perceptual" delay, we shall, for the moment, allow no manufacturing delay.

In the scenario in which our two competitors begin with equal resources, the major effect of a delay in perceiving changes in the arms level of the other is to slow the general process of escalation. Because each actor sees only a portion of the increase in the other's arms in a given time period, the (false) impression is formed that the other is building arms more slowly than is the case. Each actor formulates their own building program on the basis of this incorrect information and hence creates less ambitious building plans than they would with a correct perception. Since the level of arms actually built is less, the perceived gap is cumulatively reduced. While arms escalation still occurs, it occurs linearly, and the rate of increase in arms building is greatly reduced. In this scenario the level of arms acquired by time point 25 is only 138 by each actor, and arms are increasing at only 16 units per year.

The effects of a "perception" delay are similar where the actors are initially unequal. These results are displayed as Figure 10.5. The degree of inequality in the initial positions of the actors is not fully perceived by either, dampening their responses and dramatically slowing down (but not eliminating) the tendency of each to "overshoot" in adjusting to the other. As a result, the levels of arms acquired by the 25th time point are much smaller (160) than those in the leader-follower scenario where the delays were located in the "response" rather than the "perception."

In real systems both perceptual and response types of delays operate simultaneously. In the case where both forms of delay—perceptual and response—are operating and the actors were initially equal, a complex time trace is produced. The arms race is generally quite retarded by the presence of the perception delay, but retains some of the cyclical character due to the response delay. In the case where both delays are present and the actors are initially unequal, another complex response occurs. These results are shown in Figure 10.6.

Due to the initial inequality and the "acceleration" due to the delay in the production of arms, a substantial stockpile of arms has been acquired by the twenty-fifth time point (285). In addition, the presence of both delays has markedly destabilized the interaction, leading to continuing (though dampening) cycles of building and perceptions of "gaps."

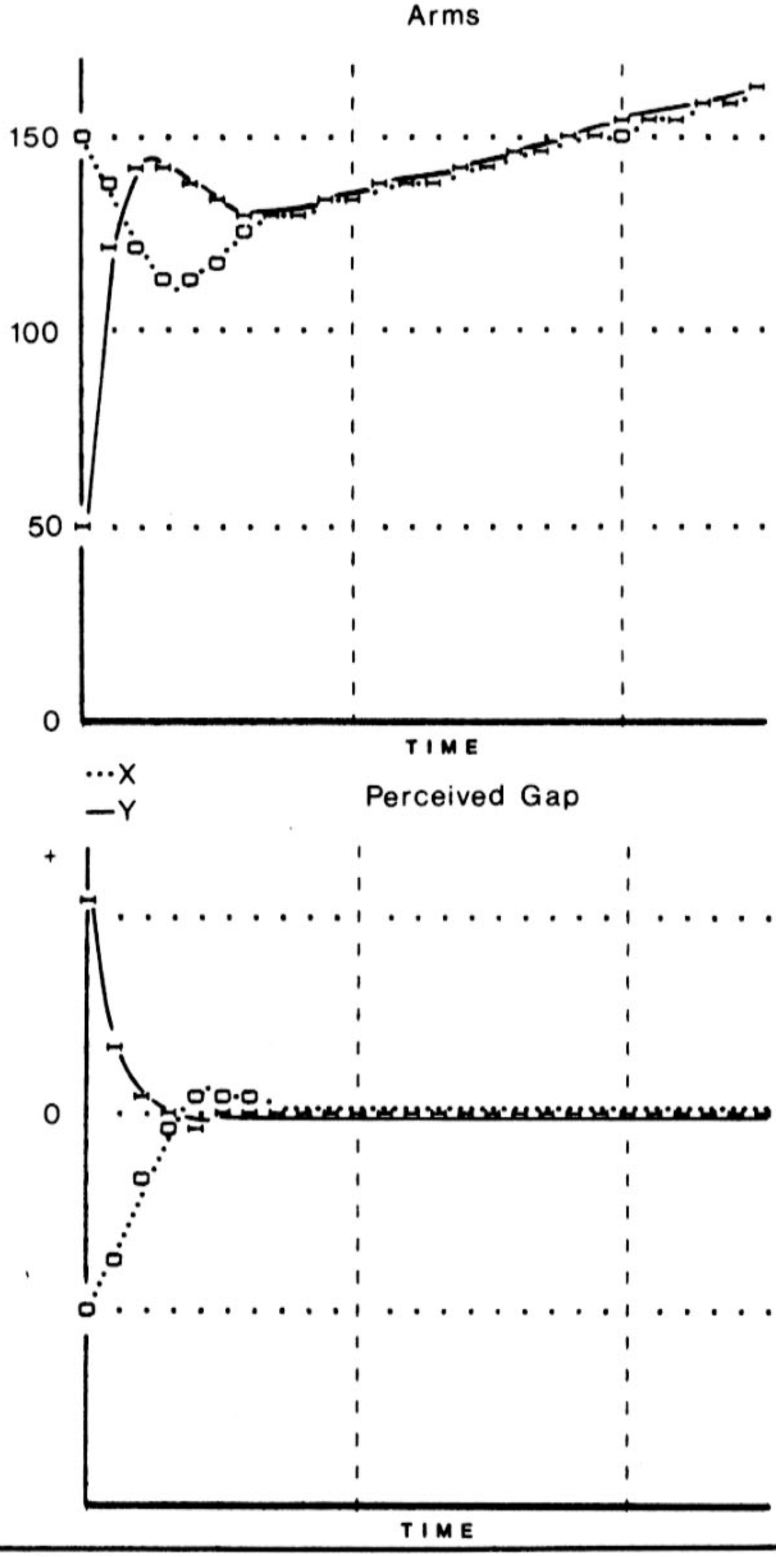

Figure 10.5: Perception delay in leader-follower model.

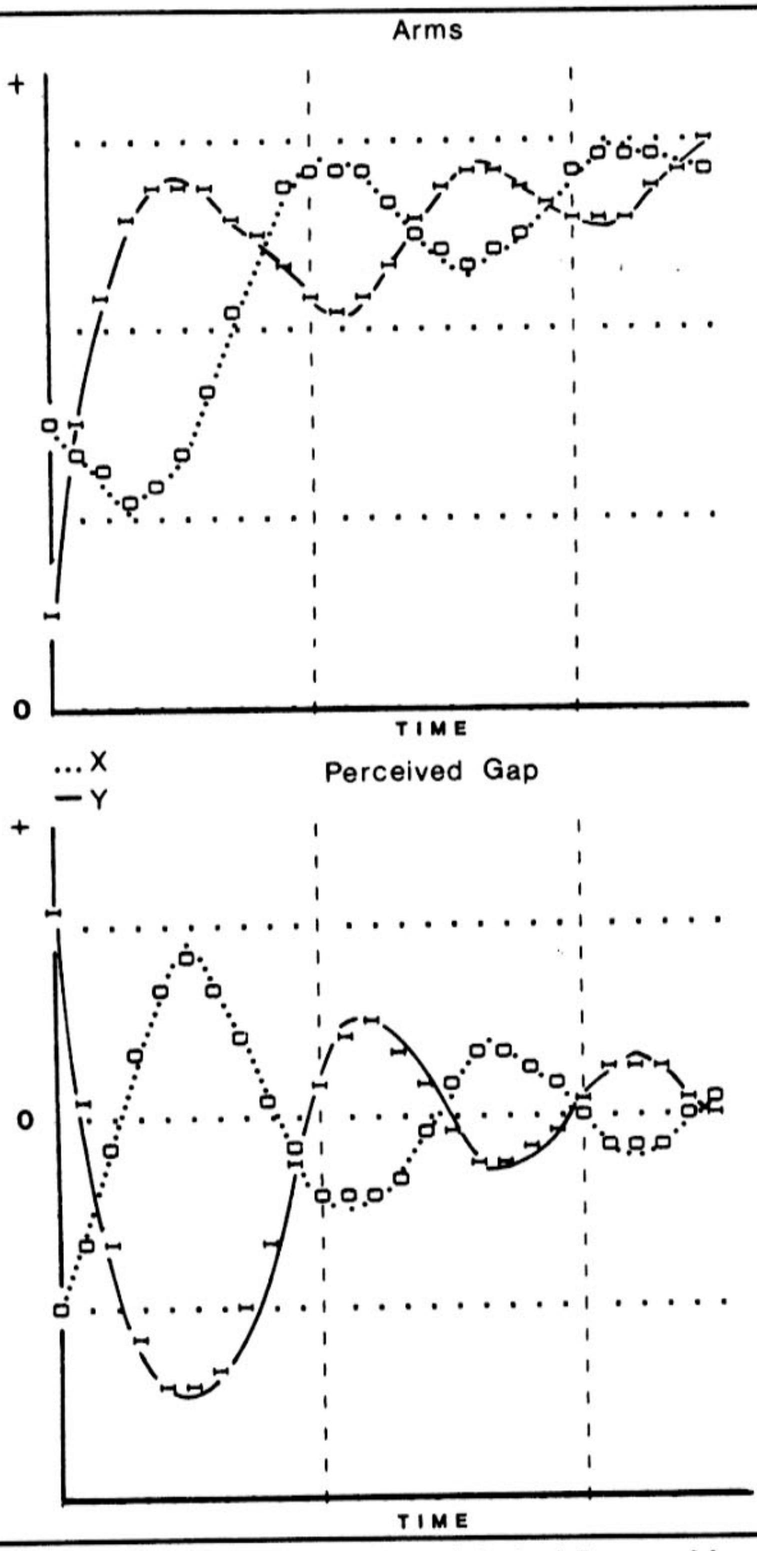

Figure 10.6: Response and perception delays in leader-follower model.

A summary of the results of these experiments with perceptual and response delays is shown as Table 10.2.

We can reach a number of conclusions about the effects of delays on the dynamics of competitive interaction from these results. In the case of a system in which the actors are initially equal, delays in perception and response always result in lowering the rate of growth. Where the actors are initially unequal, however, the effects of delays are not so predictable. Response delays in this circumstance actually accelerate the process of escalation. Under the particular rules of this game, competition between actors who are initially unequal generates more heated races than does competition between equals. The presence of any delay in a system not in "balance" tends to produce the general pattern of overcompensation and cyclical behavior in the time paths of both actors. In this game, the cycles dampen with time in all cases. Where the presence of both delays in the system, however, dramatically slows the rate at which the cycles dampen—that is, misperception and slowed responses tend to reenforce one another in creating problems of adjustment.

We are obviously still very far from an empirically adequate theory of competitive interaction with this model. The results of even such a simple game, however, are interesting—and not entirely obvious. The primary lesson to be taken from this simple extension of the basic model, for our current purposes, is that the delays, misperceptions, and errors and slowness of response by actors in interaction can be highly consequential for both the final realizations and time paths of interactions. Such problems of communication and action are extremely common in human action systems, and should therefore be part of the list of things that theorists of social dynamics must specify in the process of theory building.

Some Directions for Dynamic Theories of Competition

The primary purpose of constructing and analyzing the particular theories of two-actor competition that we examined in this chapter is as an illustration and exploration of the dynamics of social interaction. As a theory of arms races specifically, one can readily imagine a number of important ways in which the current model could be extended and made more realistic. We will not pursue these elaborations here (the reader may wish to, using the model provided in the Appendix as a starting point), but some of the major possible directions are worth noting.

Let's first consider the mechanics of arms production. A number of

TABLE 10.2
Outcomes of Competitions with Delays

	Levels at t = 25	*Rates at t = 25*
Scenario: Actors Initially Equal (X = Y = 100)		
No delays	331	50
Response delay	241	33
Perception delay	139	16
Both delays	139	15
Scenario: Actors Initially Unequal (X = 150, Y = 50)		
No delays	394	60
Response delay	569	77
Perception delay	285	32
Both delays	160	18

simplifying assumptions have been made that might be relaxed. We have assumed, for example, that all arms are identical. More complex models (like those used by nuclear strategic defense planners) might prefer to model the levels of several types of arms, perhaps having relationships of substitutability (more ICBMs and less bombers, etc.). The differing types of arms might have differing delays, differing efficacy, and be subject to differing mechanisms of goal setting. The decision-making process then becomes quite complex, as different mixes of arms can be selected—resulting in an optimization problem.

In the same vein, we have assumed that the stock of arms becomes obsolete at a constant rate and that obsolete arms are automatically replaced. We might instead suppose that arms have a useful "half-life," so that the rate of obsolescence depends on the rate of building at prior time points. The scrap rate might be regarded as manipulable as a result of policy—accelerated to slow the accumulation of arms, or slowed to achieve higher levels of current force. If multiple types of arms were considered, differential obsolescence of different weapons types would have to enter the decision-making matrix.

We have also not considered the problem of resource constraints and resource competition. The rate of possible increase in arms and the total amounts of arms that can be built may well be limited by the resources available. The possibilities here are quite interesting. In addition to absolute limitations imposed by resource availability, the costs and delays of production may differ between actors due to these factors. The competition for scarce resources between armaments and alternative products calls for a more realistic picture of the political processes of our actors. There may be some levels or rates of arms production that are not politically feasible, just as some levels and rates are not physically feasible within natural resource constraints.

Our simple game also makes a series of highly simplified assumptions about the informational aspects of the system, as well as about the material. One can easily imagine alternative specifications about what is monitored, how the information is processed, and how decisions are made.

In the current model, each actor monitors only their own current level of arms and the current level of arms of their opponent. We might suppose that real decision makers have access to more information than this. They might also pay attention to the rates of building of themselves and their opponent and the rates of obsolescence, so that they make decisions on the basis of their projections about the behavior of the other—not merely on the basis of the observed behavior. Our decision makers might also take into account their perceptions of the resource limitations and limitations on the rates of arms building possible for themselves and their opponents in making projections.

In the previous section we examined the effects of simple first-order delays in the perception of and response to the opponent's actions. The results were rather dramatic and, in a few cases, somewhat unexpected. The kinds of delays and distortions we considered above however, are only a very small part of the range of possible informational imperfections that occur in such systems. In addition to simple delay, organizational systems often contain delays that vary randomly or systematically with levels of the system (e.g., the more highly developed the technology, the shorter the average perceptual delay). Informational systems are often "noisy," as well as filled with delay. Such noise can be quite destabilizing in the dynamics of interaction—as it is sometimes amplified, as well as dampened. Real bureaucratic decision makers also may take considerable periods of time in making decisions—quite independently of delays in perception and delays in response. As we have seen in the example above, multiple delays in a system can have the consequence of amplifying distortion and slowing the realizations of equilibrium tendencies.

To all of this complexity about how information is really handled in competitions between actors, we should add an additional very troublesome possibility—that the actors are "intelligent" in how they deal with information problems (research on organizational decision making, however, does not always support the view that bureaucratic actors deal intelligently with such problems).

Consider a problem that currently exists in the arms race between the United States and the Soviet Union. Given the speed and accuracy of certain new missile types, deployment near the national boundaries of the other actor reduces the available response time in the event of a first strike. Being aware of the limited response time (that is, correctly perceiving the degree of information processing delay in their own system) each actor must adopt a more rapid decision-making method than the one currently used (a highly specific and routinized plan with executive veto). Each actor is tempted to program the decision making into a microprocesser to meet the challenge. To make such a change, however, eliminates discretion and judgment from the decision-making process and may result in an "incorrect" response if any "noise" gets into the monitoring and decision-making system. Since both actors are quite aware that their systems for monitoring the behavior of the other (i.e., whether the other has, in fact, begun an attack) are slightly unreliable—that is, they are aware of the existence of noise—each faces a dilemma. Where lies the greater risk: in the new information processing technology that is inflexible and hence subject to error due to noise, or in the old technology, which is flexible and less sensitive to noise errors but is too slow? We have, unfortunately, no answer to offer. The point for those who would theorize about social interaction, however, can be taken: Actors are sometimes aware of, and seek to take into account, informational delays and distortions in designing systems and making decisions. The introduction of such a high level of self-awareness into the models of escalation considered here could produce systems with dramatically different dynamics.

We have only considered the simplest possible ideas about goal formation in the current model. We might first explore the consequences of assuming more complicated goal setting algorithms on the part of our actors. Leaders may not simply desire superiority, but might desire to not see existing gaps narrowed. The goals may also be made a function of other factors—and hence dynamic rather than static. For example, actors may be less interested in superiority, and become willing to settle for equality as the levels of arms of each reach very high levels, or as the strain of building arms becomes too great (either as a function of limitations of physical or of political resources). One can also imagine that goal setting becomes "intelligent." For example, an actor that falls too far behind in the race may capitulate—ending the game. Or, possibly, actors may adjust their goals due to internal political considerations (i.e., nations may become more aggressive if they are suffering from problems of internal order) or the behavior of the other (e.g., being willing to accept a lesser degree of superiority when the opponent is not closing an existing gap).

Lastly, and importantly, our "game" is quite limited in that it takes into account only two actors, and assumes that the two actors are quite similar. Real arms races are often multiparty games, and the different actors usually face quite different configurations of constraints. Expanding the game to include multiple actors and allowing the actors to differ in both their material and informational systems presents no technical problem for constructing theories. The complexity of such models, however, expands by law of combinations, not additively. For each new actor the relations between that actor and all others in the game must be specified: In a two-actor game, there is one such relation; in a three-actor game, three; in a four-actor game, six, etc. The addition of more actors may also realistically be expected to change the nature of the game in fundamental ways. Each actor must now monitor, make sense of, and respond to multiple stimuli—a far more complex and indeterminant task. Where all of the actors in such games are connected, each additional complexity, delay, or distortion also multiplies through the system, producing still greater uncertainty.

The possibilities for elaborating and exploring theories of relatively simple dynamic interactions among even relatively similar and simple actors are numerous. Far from being intimidated by the range of possibilities, however, theorists should see these possibilities as a research agenda. By decomposing scenarios of social interaction into the language of subsystems, states, rates, and coupling, even the most complex forms of interaction are analyzable in formal terms.

Conclusions

Social interaction in general is complex, relative to the simple action models considered in the earlier chapters. In an interaction each of the parties monitors both the status of their own system and the system of the others. The information derived from the mutual monitoring is used by each actor, in conjunction with its own goals to formulate actions—which in turn provide the basis for action on the part of others. Social interactions are necessarily symbolic. Each actor must perceive, interpret, and formulate goals and plans within the constraints of its own system of meanings. But social interactions are also necessarily physical. It is the action of each party that creates the field that is monitored and interpreted by the other. The dynamics of social interactions are, consequently, determined by both the material and informational aspects of the system and its parts.

As the model of the very simple interaction developed in this chapter suggests, there is no basic difficulty in using the language of systems to describe, formalize, and analyze the dynamic behavior of social interaction. Indeed, patterns of social interaction can be seen as being built up of the coupling together of actors through the exchange of information. The actors may be many or few; they may each be characterized by simple or complex state spaces; the connections among the actors may be simple and sporadic or dense and multifaceted. All such systems of interaction are potentially decomposable, and their characteristic dynamics analyzable.

In the specific model developed in this chapter we've paid particular attention to the role played by delays in systems. The reason for this emphasis is that where concern focuses on dynamics rather than statics, such imperfections in perceiving, organizing, and responding to information can have major consequences. We have tried to make several simple but important points about the effects of delays in models of interaction. Depending on their nature and location in the systems, delays can act either to dampen or to amplify. The presence of multiple delays in a system can lead to unanticipated results as the delays may either reenforce distortions or dampen them. The presence of delays in interactions can result in extreme complexity and instability, as the imperfections of information and consequent response are reenforced in the dynamic interaction.

Notes

1. Theories involving the dynamics of smart interaction among relatively small numbers of actors have been highly developed in a number of disciplines. In addition to formal "game theory" (see note 2), the analysis of small-group dynamics and social exchange have extensively developed models that have many similarities to those described in this chapter. The interested reader might want to look at some of this work; some places to start are Bartos (1972), Blau (1964), Camilleri et al. (1972), Caplow (1968), Cohen (1962), Coleman (1972), Davis (1967), Davis and Leinhardt (1972), Fararo (1972), Holland and Leinhardt (1977), Hopkins (1964), Komorita (1974), Malone (1975), and Simpson (1973).

2. "Game Theory" is a set of particularly well-developed formalizations of interactions such as those described in this chapter. For some of the interesting applications of formal game theory models, see Ackoff (1959), Bloomfield and Padelford (1959), Brams (1975), Luce and Raiffa (1957), von Neumann and Morganstern (1947), Raiffa (1970), Rapoport (1966), Rapoport and Chammah (1965), Thrall et al. (1954), and Shubik (1964 and particularly 1984).

3. The arms race model in this chapter is based on the work of Lewis B. Richardson (1960), and the extensive literature that has developed surrounding his original model. For an introduction to the rather extensive theoretical, mathematical, and statistical literature on escalations, see Abelson (1963), Alker and Brunner (1969), Boulding (1962), Brody (1963), Brody and Benham (1969), Cappello (1972), Coe (1964), Hollist (ed., 1978), Pruitt (1962), Rapoport (1957, 1960), Saaty (1968), Schelling (1963), Schrodt (1978), Shubik and Hansford (1965), Singer (1958), Smoker (1965), and Waltz (1967).

APPENDIX 10.1. Arms Race Model With Delays

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*           ARMS RACE MODEL, BASED ON RICHARDSON'S THEORY
NOTE
NOTE                    ***** ACTOR X *****
NOTE
L           X.K = X.J+(DT)(RIX.JK-RDX.JK)
N           X = XI
C           XI = 100
NOTE                    Arms increase at RIX and depreciate at RDX.
A           DLAX.K = KX*YP.K
NOTE                    Desired arms are equal to KX of Y's perceived arms
A           YP.K = DELAY1(Y.K,3)
NOTE                    X perceives Y's arms with 1st order delay.
A           GAPX.K = DLAX.K-X.K
NOTE                    The gap between desired and current arms.
R           RIX.KL = DELAY1(MAX(G1+GAPX.K+RDX.JK,0),3)
NOTE                    X's rate of arms building is equal to the whole
NOTE                    of the gap between desired and actual arms
NOTE                    plus an amount due to "grievance" (G1).
NOTE                    Building, however, takes an average of 3 units of
NOTE                    time to accomplish.
R           RDX.KL = MAX(A1*X.K,0)
NOTE                    The rate of exhaustion of arms is A1.
NOTE                    PARAMETERS FOR ACTOR X ARE SET:
C           A1 = .1
C           KX = 1.05
C           G1 = 0
NOTE
NOTE                    **ACTOR Y'S SYSTEM IS SIMILARLY DEFINED**
L           Y.K = Y.J+(DT)(RIY.JK-RDY.JK)
N           Y = YI
C           YI = 100
A           DLAY.K = KY*XP.K
A           GAPY.K = DLAY.K-Y.K
A           XP.K = DELAY1(X.K,3)
R           RDY.KL = MAX(A2*Y.K,0)
R           RIY.KL = DELAY1(MAX(G2+GAPY.K+RDY.JK,0),3)
NOTE                    PARAMETERS FOR ACTOR Y
C           A2 = .1
C           G2 = 0
C           KY = 1.05
NOTE
NOTE                    OUTPUT SPECIFICATIONS
SPEC            DT = .1/LENGTH = 25/PRTPER = 2/PLTPER = 1
PRINT           Y,X,RIY,RIX,GAPY,GAPX
PLOT            Y,X
PLOT            GAPY,GAPX
RUN
```