Infant Development: Perspectives from German-Speaking Countries

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3 A Systems Theory Perspective

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Attachment theory may claim three lasting merits: It has freed love from the sexual bias affixed to it by psychoanalysis. It has upgraded bonding behavior from a secondary to a primary motive contrary to the notion of learning theorists. And it was a main step in a due development of ethological motivation theory from energetic and hydraulic models toward a systemic approach.

Bowlby (1971) has defined *attachment* as a form of distance regulation, or more exactly, of seeking and maintaining proximity to caregivers. Surprisingly enough though, neither he nor his followers have ever attempted to seriously apply the formalism of systems theory to analyzing the motivational dynamics of this distance regulation. However, Bischof (1975) pioneered this approach without eliciting much resonance. Some other authors were stimulated to make use of block diagrams (e.g., Bretherton; 1985, Waters & Deane, 1982), but the hypotheses thus visualized remain verbal and nonquantitative in essence. The technique of biocybernetical systems analysis is obviously hard to acquire for psychologists. The present chapter is partly meant as a tool to familiarize readers with this form of theorizing. Moreover, it is supposed to outline some further extensions of the original theory, which are subsequently referred to as the "Zürich model of social motivation."

Speaking generally, *social motivation* refers to the fact that attachment is not an isolated system; it is inseparably intertwined with a larger body of motives controlling intraspecific transactions. Among these motives are social fear and social exploration, that is, behaviors designed to regulate distance and contact with strangers. Moreover, attachment is from early childhood, and markedly in puberty and adolescence, counterbalanced by a propensity to avoid ego-suffocating symbiosis, that is, by a tendency to detach from the caregiver. Last but not least, we find sexuality and a claim for autonomy and competence among the motives intimately interwoven with attachment. It seems obvious that the causal network of all these motives requires a biocybernetic approach to be quantitatively analyzed, including the techniques of simulation and estimation.

The first part of this chapter briefly summarizes the principles of the model developed by Bischof (1975). The second part works out a mathematical realization of the model on the simplest possible level and derives predictions concerning the child's behavior in certain relevant situations. It thereby encounters some counterintuitive, but empirically testable implications of the theory, which would hardly ever become obvious from a purely verbal description. A third part deals with a refined version of the model. Finally, some examples of simulation and estimation based on the refined model are presented.

THE STRUCTURE OF THE MODEL

Basically, the model postulates three interacting motivational subsystems: the *security system*, the *arousal system*, and the *autonomy/sex system* (see Fig. 3.1).

The Security System

The security system controls the behavior toward social objects in as much as they are familiar. Familiarity of a *conspecific*, particularly if dating back to earliest infancy, indicates this conspecific is in all probability a close blood relative and therefore, for sociobiological reasons, inclined to supply prosocial support. The emotional response to familiarity is therefore assumed to be a feeling of security (s).

The model stipulates the existence of a *detector* capable of sensing the *degree of familiarity* (F) of a given object. In terms of information theory, the output of this detector increases directly with the object's redundancy or, what is the same, inversely to the object's entropy (or "collativity" in the sense of Berlyne, 1960).

A second input variable contributing to the feeling of security is supplied by a detector sensitive for the *relevancy* (R) of the given object. Relevancy is a measure defined to score highest when the object is an adult, high-ranking conspecific. Submissive behavior of the object, replacement of an adult by a baby, or replacement of a human partner by a transitional object like a teddy bear or a security blanket, all reduce the output of the *relevancy detector*.

Apart from qualities like familiarity and relevancy, it is mainly the *distance* (x) between the child and the caregiver that determines how much security the latter engenders. Far away helpers are less capable of providing effective support than helpers nearby, and this simple relations is reflected by the degree of experienced security provided by them.

To summarize, the construct of security refers to a hypothetical emotional

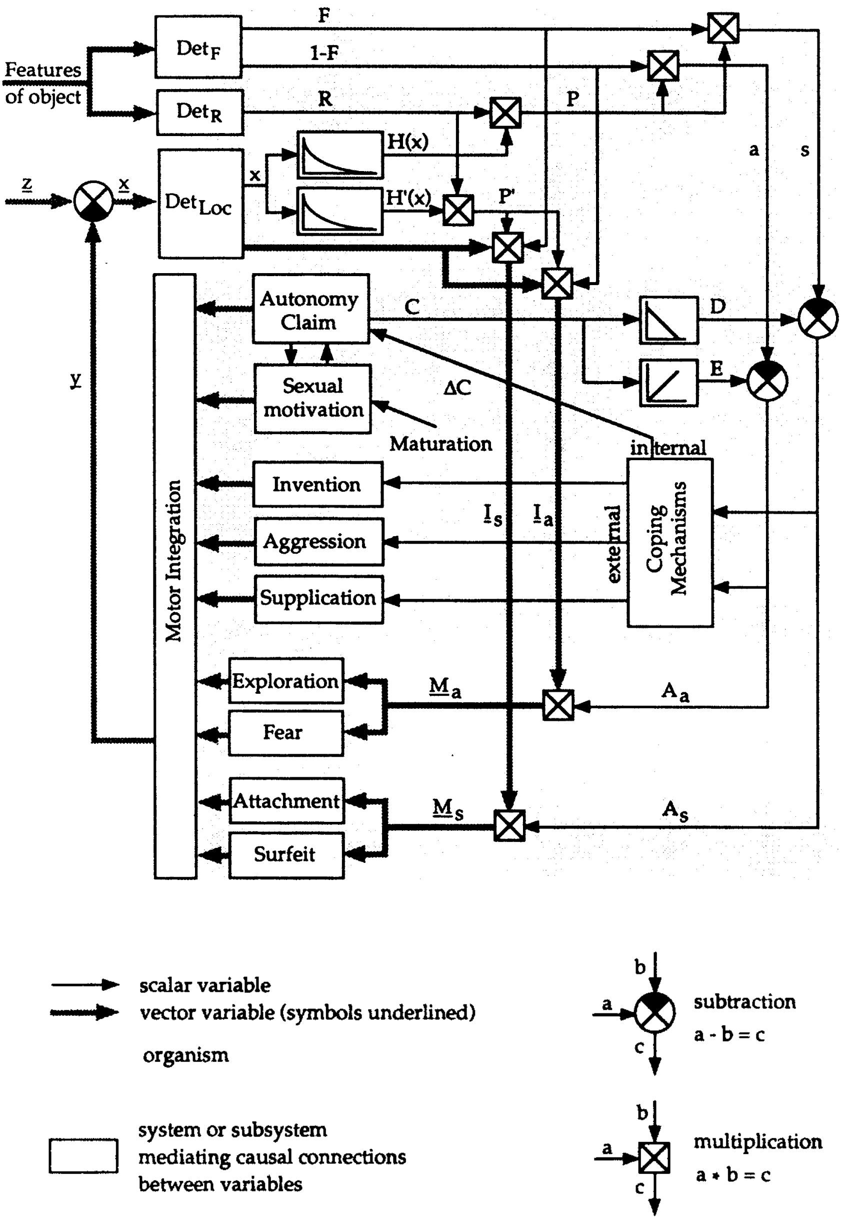

FIG. 3.1. The Zurich model of social motivation. Abbreviations: z = location of object, y = location of subject, x = z − y = vector pointing from subject to object (see Fig. 3), ||| = x = distance, H(x), H'(x) = psychological proximity, Det = detector, R = relevancy, P,P' = potency, F = familiarity, 1-F = novelty, s = security, a = arousal, C = autonomy claim, D = dependency, E = enterprise, A = activation (appetence or aversion), I = incentive, M = momentum, ΔC = acclimatization. For further explanations see text.

variable monotonically increasing with familiarity, relevancy, and proximity of an object. Among those three variables, proximity is the only one that the subject can control, consequently the obvious way to provide a homeostasis of security will result in distance-regulating behavior.

Homeostasis requires a reference value, against which the controlled variable can be matched. In the case of security homeostasis, this reference variable is conceived of as the degree of *dependency* (*D*) felt by the subject.The more dependent subjects feel, the greater their craving for security and hence their propensity to remain in close proximity to a familiar and preferably high-ranking conspecific. It is reasonable to assume that dependency, thus defined, decreases with growing age and maturation.

As long as dependency exceeds security, an *appetence* for security (positive A_s) is maintained, which induces the child to show attachment behavior, that is, to reduce the distance to a caregiver. The opposite situation, frequently encountered in puberty, results in an *aversion* against security (negative A_s) and thus, in an avoidance of the familiar caregivers (*surfeit behavior*). The absolute magnitude of appetence or aversion, regardless of sign, is referred to as the *tension* or *activation* of the security system.

Appetence and aversion vary only in intensity, they are one-dimensional, scalar quantities. But organisms also require information about where to head in order to increase or reduce security. They want information about the location of sources or sinks of security in the social field. The input variable providing this information is obviously vectorial, that is, a two-dimensional variable defined either by Cartesian coordinates or an angular direction (pointing to the familiar object) and a magnitude (having, in the simplest case, only two possible values, 1 or 0, depending on the object's visibility). This vector is called the *incentive component* (I_s; vectors are denoted here and elsewhere by underlined symbols).

Both incentive and appetence/aversion determine the resulting *motivational momentum* (M_s, labeled "impulse" by Bischof 1975). This in turn determines the direction and velocity of security motivated locomotion. In a final common pathway, denoted as the subsystem of motor integration, the momenta of different motives are combined by way of superposition, time-sharing, or other forms of behavior programming.

The Arousal System

The less familiar a relevant object detected, the stronger involved a second homeostatic system becomes, called the arousal system. The paradigmatic case here is the encounter with a high-ranking, adult human stranger. The arousal system releases either a withdrawal (fear behavior) or an approach enabling the subject to explore the source of arousal. Very familiar objects, like the mother, have difficulties activating the arousal system; they can do so to a certain degree, though, by behaving in an unpredictable way such as playing "peek-a-boo" with the child.

Basically, the arousal system can be conceived of a analogous to the security system, and, what is more, it can utilize all three detectors of the latter. *Arousal* (a,) like security, is hypothesized to increase with the object's proximity and relevancy. And because the familiarity detector also provides information about how novel or strange an object is, arousal can be inversely connected to the output of this detector as well ($1 - F$).

It is worth noting that our model regards the arousal system, like the security system, as *homeostatic*. This runs counter to a widespread notion into which exploratory behavior, which is governed by the arousal system, is in some way *antihomeostatic*. This notion stems from a misconception of homeostasis. Homeostasis means a permanent attempt to match the actual amount of a quantity to a standard given by a reference variable. This reference, analogous to dependency in the security system, is labeled *enterprise* (E) in the arousal system. Just as in the security system, we then may distinguish between an aversive and an appetent behavioral response. Aversion against arousal (negative A_a), and hence, fear behavior, results from arousal exceeding the setpoint of enterprise. If, however, arousal falls short of enterprise, an appetence for arousal (positive A_a) develops, which obviously leads not against exploratory behavior but rather directly toward it due to the system's homeostasis. This kind of behavior is to be expected particularly in puberty and adolescence if, as we assume, enterprise increases with age and maturity of the individual.

The Compound System

It goes without saying that the security and the arousal systems do not work independently of each other. Lewis and Michalson (1983, p. 237) failed to comprehend the message of the 1975 paper when feeling invited to remind us of the functional interconnection of both behavioral programs. This is precisely what the systems' approach is all about. Actually, both systems respond to the same stimulus situations, and the quantitative processing of the involved inputs leads automatically to effects such as an intensified attachment behavior toward an available caregiver produced by fear-evoking stimuli, or the caregiver serving as a secure base for exploratory ventures.

If Lewinian barriers prevent tension reduction either in the arousal or in the security system, an auxiliary apparatus responsible for unspecific coping reactions becomes involved. The main strategies of this system are labeled *invention* (i.e., searching for a detour), *aggression* (attempting to destroy the barrier), or *supplication* (begging someone else to remove the barrier). The model does not predict which one of the three coping responses is performed in a given context because it is mainly a result of the individual's learning history. The coping system carries some functional similarities to Freud's *ego apparatus,* which is pursued in the present chapter.

Finally, the security and the arousal systems do not develop independently during ontogeny. The reference variables, *dependency* and *enterprise,* can be assumed to be negatively correlated, and to covary with the individual's age and maturity. Young infants are strongly dependent and only modestly enterprising. They need the presence of a security-providing caregiver in order to start exploring the environment and to acquire competence. Later in development, usually around early adolescence, this pattern changes: Waxing independency and enterprise now demand and allow separation from the familiar partners and the establishment of new relationships. Finally, after adolescence, the two reference values are supposed to level out.

The Autonomy System

The interdependence of the two reference values *D* and *E* suggests that both are causally connected. The model assumes a third variable underlying this connection. It carries the label of *autonomy claim* (*C*) and refers to a need for feeling competent and being respected by others. In the present context, this chapter does not discuss the systems theory of autonomy control to its full extent, because the positive social feedback involved here brings up certain stability problems (for details, see Bischof, 1985). The following are five basic axiomatic assumptions concerning our variable:

1. Autonomy claim is assumed to be the crucial issue at stake in all rank-order altercations; it is therefore functionally connected with reactant display and submissive behaviors.
2. Autonomy claim is a reference variable for the amount of aspired success; it is intimately related to achievement motivation.
3. Autonomy claim correlates positively with sexual motivation.
4. Autonomy claim affects enterprise in a direct, and dependency in an inverse sense.
5. In addition to the three external coping strategies named in the previous section, a state of high activation of either the security or the arousal system can also be reduced internally by way of what McFarland and Houston (1981) referred to as *acclimatization* (ΔC in Fig. 3.1). This mechanism amounts to the strategy of letting the reference variable adapt to the controlled variable, rather than vice versa, as usual. Thus, autonomy claim may be induced to intensify in a state of sustained overarousal or attenuated under conditions of overprotection involving too high a level of security.

Only assumptions 4 and 5 are pursued further in the present chapter.

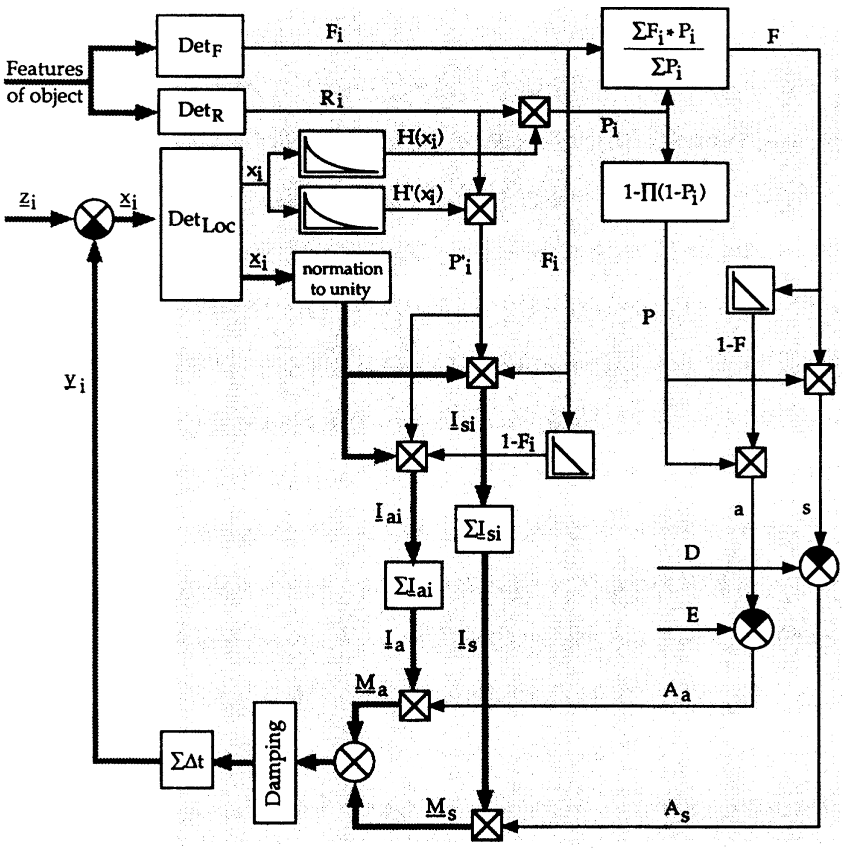

FIG. 3.2. Mathematical realization of the model for the general case of multiple social objects, without inclusion of coping mechanisms. Abbreviations: i = subscript of objects, $\Sigma\Delta\tau$ = integration over time increments $\delta\tau$. All other symbols same as in Figure 3.1. For further explanations see text.

ELEMENTARY MATHEMATICAL REALIZATION

The motives specified and their postulated cross-connections may look quite plausible, but as soon as we really want to test the model's predictions in concrete situations, simulations are unavoidable. For this purpose we have to couch the model in a mathematical form, which is as realistic as necessary and as simple as possible (see Fig. 3.2).

Familiarity

The theory assumes that the degree of an object's familiarity is a central point in social motivation. Thus, we start with the detector responsible for providing this information. Let the detector DetF assign to every perceived object (subscript i) a familiarity coefficient F_i ranging between 0.0 (entire novelty) and 1.0 (utmost familiarity). In the mother's case ($i = 1$), we assume this coefficient to be rather high ($F_1 = 0.9$). Additionally, we introduce a stranger ($i = 2$), who will be understood to be fairly, although not entirely, alien ($F_2 = 0.4$).

It should be noted that the familiarity coefficient is hypothesized to be a fixed perceptual attribute of the object in question, not varying with distance. Loss of familiarity due to difficulties in recognizing remote objects is disregarded. Another simplification concerns the fact that, in real life, the familiarity coefficient of a certain object is liable to change as a function of time spent with this object. In order to avoid this complication, we choose the timespan of our simulation short enough to allow us to neglect familiarizing processes. To summarize, we treat the familiarity coefficients of our simulation objects as constants. In the same vein, we disregard the possibility that one and the same object, say the mother, may apply different behavioral strategies and thereby vary her familiarity.

Relevancy, Proximity, and Potency

In a second step we consider *relevancy*. Similar to familiarity, the output (R_i) of the relevancy detector is understood to be an invariant attribute of the perceived object itself. Again we chose a range from 0.0 (entire irrelevancy) to 1.0 (relevancy of an adult conspecific in uncontested alpha position). Any adult conspecific showing no signs of submission is therefore highly relevant, that is, well capable of engendering security and/or arousal in a child.

Next we turn to spatial behavior. We define the subject's location by a radius vector y ($= [y_1, y_2]$) originating from a fixed reference point arbitrarily chosen somewhere in the two-dimensional field of interaction (cf. Fig. 3.3). Equivalently, the location z of the object is defined. By vectorially subtracting y from z, we arrive at a third spatial vector x, which refers to the object's position in the subject's egocentric perspective. This is the input of the locality detector Det_{Loc} in Figure 3.2. Its magnitude $|x|$ is equivalent to the distance x between subject and object.

Both security and arousal provided by a social object decrease with growing distance, and they do so according to an unknown, though presumably monotonically decaying function. For the sake of comfortable simulation, it is useful to introduce a standard function that is monotonically decaying, but allows to adjust the slope of decay. The most simple function coming to mind here is a hyperbola. We thus define the output of the proximity detector as

$$H(X_i) = \frac{r*(x_{\text{max}} - x_i)}{r*(x_{\text{max}} - x_i) + x_i*x_{\text{max}}}, \text{ if } x_i < x_{\text{max}}, \text{ and else } H(x_i) = 0 \quad (1)$$

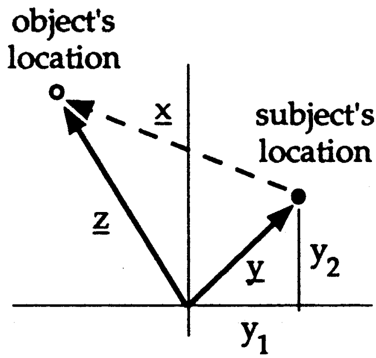

FIG. 3.3 See text for explanation.

$H(x_i)$ may be regarded as a measure of psychological proximity. It decreases with growing distance (x_i) between the ith object and the subject, and has the special properties of becoming unity for zero distance, and vanishing for any distance equal to or greater than a limit given by x_{max}. The parameter r determines the slope of decay of the function. In simulation, x_{max} and r have to be chosen according to empirical plausibility. Figure 3.4 shows the shape of $H(x_i)$ used in the simulation to be described subsequently.

The next construct to be introduced is named *potency* (P_i). It is defined as the product of proximity and relevancy:

$$P_i = R_i - H(x_i) \qquad (2)$$

Potency is a compound measure for those inputs that contribute indiscriminately to security and arousal.

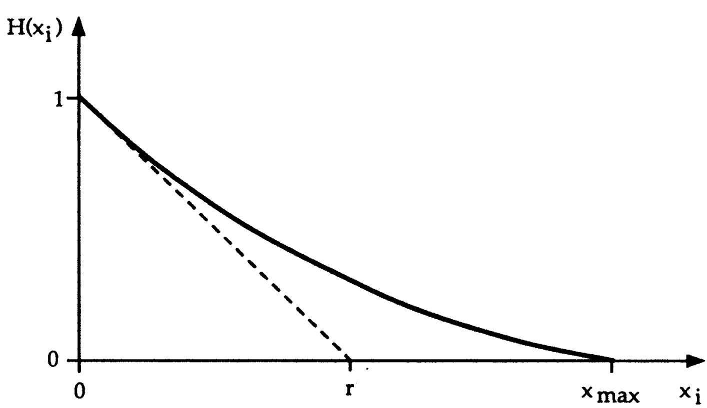

FIG. 3.4. The hyperbolic function used for the simulation of psychological proximity (for symbols see text).

Incentive Vectors

The regulation of social distance requires information about the direction of potent social objects. We have therefore introduced a two-dimensional (i.e., vectorial) construct called *incentive*. For obvious reasons, we need two separate incentive vectors, pointing toward the focus of security in the social field, or toward the focus of arousal, respectively. A question arises regarding the magnitudes of these vectors. Conceivably, an incentive vector might have only two states, that is, for the object being undetectable, and unity otherwise. But there is indication in favor of a more sophisticated relation: The incentive strength seems to correspond to the identifiability of the object. This amounts to the assumption that the magnitude of the incentive vectors is again smoothly decaying with growing distance, like potency, though not necessarily according to the same hyperbolic function. We therefore state, in analogy to (1)

$$H(X_i) = \frac{r*(x_{max} - x_i)}{r*(x_{max} - x_i) + x_i*x_{max}}, \text{ if } x_i < x_{max}, \text{ and else } H(x_i) = 0 \quad (3)$$

For the sake of simplicity, we regard the range of visibility (x_{max}) as equal to the value chosen in (1), but we provide for a separate slope parameter (r') not necessarily equal to r.

The security and arousal incentives exerted by a certain object i (I_{si} and I_{ai}, respectively) are then defined as vectors pointing toward this object and having the magnitudes

$$|I_{si}| = P'_i - F_i \text{ and } |I_{ai}| = P'_i - (1 - F_i) \quad (4a,b)$$

$$\text{with } P'_i = R_i - H'(x_i) \quad (4c)$$

Let us assume that the encounter between the subject and two social objects of different familiarity ($F_1 = .9$, $F_2 = .4$) occurs in a rectangular room, with each object, if present, resting at a fixed place. Equation (4a) will then assign to any given point y in this room a set of n security incentive vectors I_{si} ($1 \leq i \leq n$; n = number of objects present), whose resultant I_s is computed according to

$$I_s(y) = \sum_{i=1}^{n} I_{sI}(y) \quad (5)$$

Vector I_s represents the total incentive force acting on the security system, if the subject happens to dwell at location y. Figure 3.5 shows the field of security incentive vectors I_s when the mother alone is present, and when the mother and a stranger are simultaneously exposed to the subject. Quite analogously, equation (4b) will yield n different arousal vector fields I_{ai}, whose superposition I_a, defined analogous to (5), specifies the arousal incentive situation at any given point in the room.

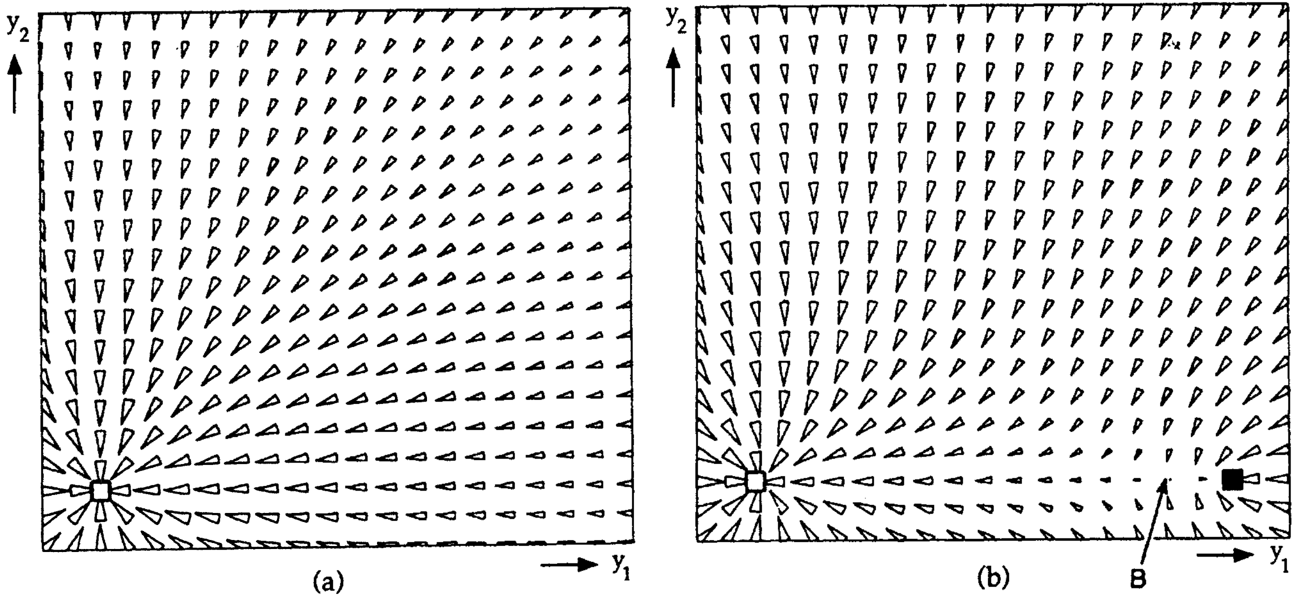

FIG. 3.5. Vector field showing the spatial distribution of security incentive forces (I_s). y_1 and y_2 = space coordinates. (a) Mother (empty square) alone. (b) Mother and stranger (solid square) combined. Arrowheads denote direction of I_s – vectors. The magnitude of a vector is symbolized by the areal size of the arrowhead. B = Buridan's point (see text).

As Figure 3.5b indicates, the incentives exerted by mother and stranger may cancel each other if the components happen to point in opposite directions. This is exactly the case at point B. We propose to call it *Buridan's point* (in honor of Buridan's donkey, who starved to death being trapped halfway between two equally attractive hay heaps), although it is actually a point of labile equilibrium unlikely to be occupied for a protracted time interval.

Joint Familiarity Atmosphere

The next question to be answered is how secure, or aroused, respectively, a subject feels at a given point in space, provided again that more than a single social object is present. A plausible hypothesis is to define a scalar field called *joint familiarity atmosphere*, according to the following statement

$$F = \frac{\sum_{i=1}^{n} P_i * F_i}{\sum_{i=1}^{n} P_i} \qquad (6)$$

The joint familiarity atmosphere F produced by n objects, that is, will be taken to be the arithmetic mean of the single-object familiarity coefficients weighted by their respective potencies. Contrary to the F_i's, then, which are fixed attributes of the objects i regardless of their position in space, the quantity F is contingent on the distances x_i between the subject and its social objects: The farther away an object is, the less is its contribution to the total atmosphere of familiarity present at the subject's location.

It may be noted that by being based on the mean of the given familiarities, the joint familiarity atmosphere remains bounded within the limits of 0 and 1. If, say, a child and the mother are alone in a room, the atmosphere will be more or less satiated with familiarity, and will remain so if the father joins the dyad. However, a stranger entering would, according to (6), reduce the joint familiarity markedly.

Joint Potency

The question of limitation is more tricky in the case of the joint potency. An algebraic summation of all given potencies would imply a counterintuitive linearity. Low potencies may summate, but two highly potent objects (e.g., two parents within reaching distance) can scarcely be assumed to be exactly twice as potent and thus providing twice as much security as one of them alone. We therefore require a formula that yields quasi-linear addition only for low potencies, but a satiation effect when the total approaches an upper limit. The statement

$$P = -1\prod_{i=1}^{n}(1 - P^i) \tag{7}$$

fulfills this requirement. When computed according to this formula, the joint potency P of n objects will never exceed an upper limit of $P_{max} = 1.0$. It will asymptotically approach this limit with increasing n, or with P_i-values approaching P_{max}, and it will equal P_{max} as soon as any one of the components equals P_{max}. All these properties make quite good sense and render equation (7) an appropriate model assumption. The choice of the special value P_{max} equalling unity, thus equalling the maximum possible potency that a single social object may attain according to equation (2), is arbitrary but does not engender any qualitative peculiarities in the model's behavior.

Security and Arousal

Equations (6) and (7) immediately allow us to compute the net values of security (s) and arousal (a):

$$x = P - F \text{ and } a = P - (1 - F) \tag{8}$$

These equations assign scalar quantities of security and arousal to any given point in space, thus defining scalar fields that can be represented graphically by a set of contour lines. Figure 3.6 shows the s-field under the condition of mother alone and mother with stranger.

Figure 3.7 illustrates the same situation as Figure 3.6b, with the spatial manifold being reduced to a one-dimensional cut through the s-field along the shortest connection between mother and stranger. The components of security engendered by mother or stranger alone are inserted for comparison. As the reader may remember, the stranger is moderately familiar ($F_2 = .4$), such as the lady from the house over the street. When this stranger appears on the scene of the mother–child dyad, security as the product of joint familiarity and joint potency decreases in the vicinity of mother, as the figure reveals. Next to the stranger, however, his appearance causes security to rise above the values evoked by mother alone. The exact shape of the curves depends on the parameters chosen in equation (1), and also on the distance between mother and stranger. But qualitatively, we can now see why, in a highly dependent infant clinging to the mother's apron strings, objects of low familiarity are likely to reduce security and thus to even further intensify clinging behavior. In a state of higher independency, where a greater distance to mother is preferred, the same condition raises the security level above the one provided by mother alone, and thus renders the subject even more audacious to contact the stranger.

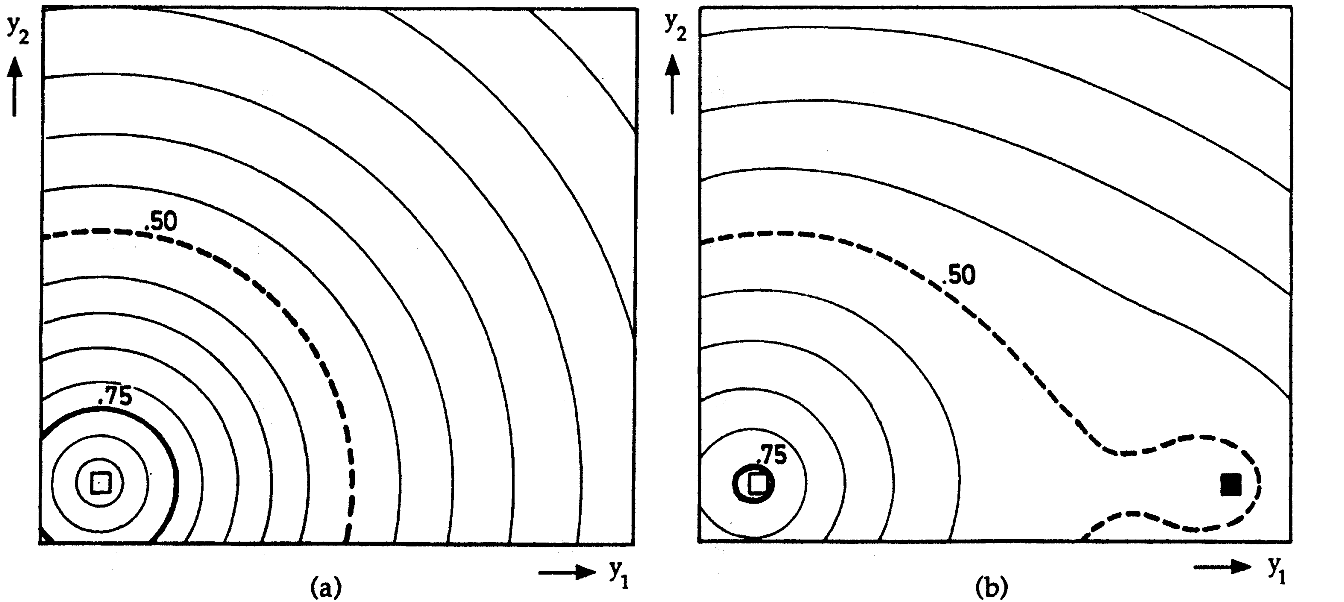

FIG. 3.6. Scalar field showing the spatial distribution of security (same situations as in Fig. 3.5). Contour lines denoting amount of s in 0.05-unit steps. Two particular contours for s = 0.5 and 0.75 are marked by heavy lines (broken or solid, respectively). For further explanation see text.

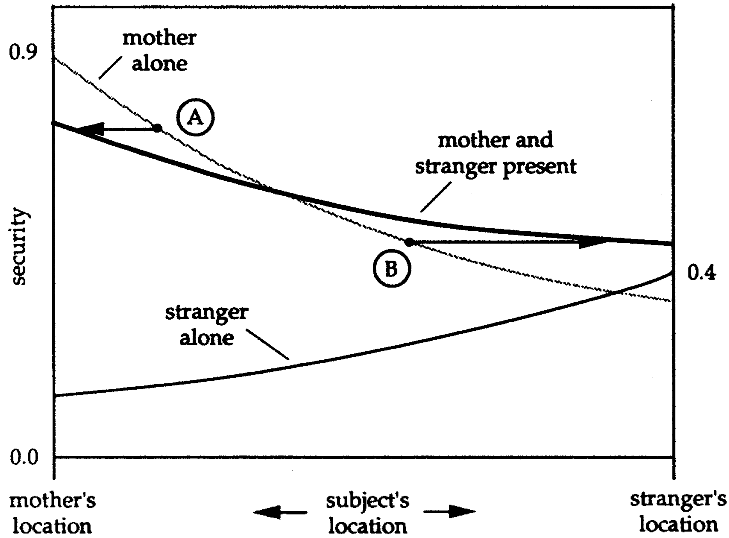

FIG. 3.7. One-dimensional cut through s-field (Fig. 3.6b) along the shortest connection between mother and stranger. A: position of highly dependent subject (D = 0.75), B: position of less dependent subject (D = 0.5), both with mother alone present. Horizontal arrows indicate change of location when the stranger joins the dyad.

Appetences and Aversions

The next step is to compute the activation components of the security and the arousal systems. These are denoted as A_s and A_a, respectively. Their equations follows follow immediately from Figure 3.2:

$$A_s = D - s \text{ and } A_a = E - a \quad (9)$$

As can be seen, the A-values are positive whenever the actual amount of security or arousal falls short of the corresponding reference variable. Positive A values, then, mean appetence while negative A values denote aversion.

In the previous expressions, dependency (D) and enterprise (E) can be chosen arbitrarily, because the model does not imply any assumptions regarding their intensity, except that they are confined to the range of 0.0 to 1.0, which are also the limits of s and a. For example, a rather highly dependent infant ($D = 0.75$) will be liable to dwell on the heavy unbroken contour line in Figure 3.6 because this locus alone would specify zero activation in the security system ($A_s = 0$). The region enclosed by this line, where security is higher than 0.75, is a field of (mild) surfeit of security, whereas in the area outside, the infant is subject to different degrees of separation anxiety. As a comparison of Figs. 3.6a and 3.6b reveals, introducing a stranger contracts the 0.75 contour line, thus entailing a closer association with mother. That this effect vanishes with lower degrees of dependency is indicated by the heavy broken line in Figs. 3.6a,b, which depicts the locus for $A_s = 0$ under the condition of reduced dependency ($D = 0.5$). When the subject has reached this stage of development, the introduction of a stranger will no longer prompt approach to the mother (cf. also Fig. 3.7).

Momentum Vectors

According to Figure 3.2, the momenta (M_s and M_a, respectively) exerted onto the subject's locomotor mechanisms by the security and arousal systems follow from a multiplication of A_s or A_a, respectively, with the corresponding incentive vectors at the Subject's location:

$$M_s = A_s - I_s \text{ and } M_a = A_a - I_a. \tag{10}$$

Computed for all points in space, the motivational momentum again defines a vector field. Figure 3.8 presents an example of the M_s-field under the condition of $D = 0.5$. In this figure, the solid vectors indicate surfeit of security, whereas the empty vectors tend to increase security and are therefore attachment-motivated. At the thin broken line in both figures (locus for absence of activation; $A_s = 0$), and at the asterisk in Figure 3.8b (Buridan's point), no locomotor momentum acts on the child, as far as the security system is concerned.

Motor Integration

All procedures carried out up to this point for the security system must be repeated accordingly for the arousal system. Thus, after choosing a particular value for enterprise, we may compute a vector field analogous to Figure 3.8, with solid centrifugal arrows (centered mainly around the stranger) denoting fear, and the empty centripetal arrows (in more or less respectful distance from the stranger) denoting curiosity.

For the sake of simplicity, we assume that in the block "motor integration" of Figure 3.1 the arousal momentum is superimposed with the security momentum of Figure 3.8 or, in other words, that the final distribution of motivational forces directing the infant's locomotion is a result of simple vectorial summation. Nevertheless we have to keep in mind that, in order to reconcile divergent momenta of different motives, other and more complex forms of behavioral programming are very likely to occur, particularly *competition* and *time sharing* as investigated by McFarland (1974, 1976). Theorizing in these more advanced fields, however, should be guided by empirical research that, in our problem area, still remains to be carried out.

Finally, the resulting momentum is mildly dampened by adding some friction, in order to improve stability, and then integrated over time to yield the subject's

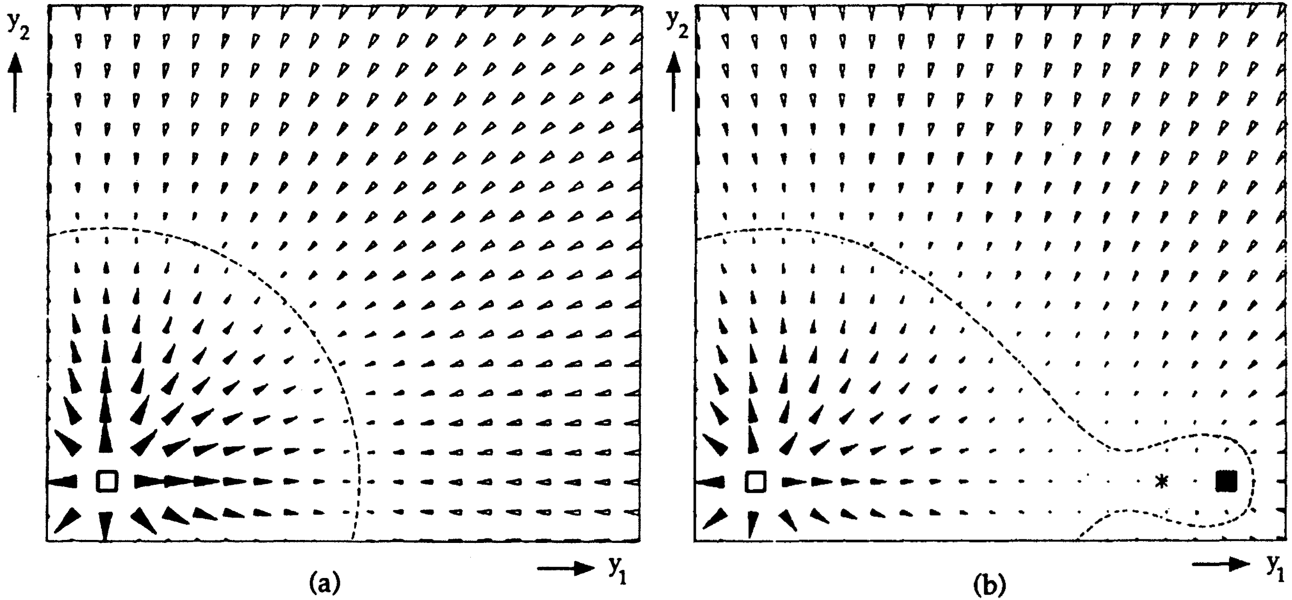

FIG. 3.8. Vector field showing the spatial distribution of locomotor momenta, as exerted by the security system (M_s). Situations (a) and (b) same as in Fig. 3.5. For further explanation see text.

new location y. As indicated in Figure 3.3, y is then subtracted from z, thus closing the feedback loop of proxemic homeostasis.

EXTENSIONS OF THE MODEL

The "Pool" Hypothesis

Homeostatic systems are normally devised to be stable. That is to say, when all disturbing inputs remain constant, the system is supposed to reach a steady state. It may oscillate for a while around this state, but these oscillations are expected to be dampened and should sooner or later come to rest. Translated into our case we would expect that, provided there exists a locus for zero activation of both the security and the arousal system, the subject, once having arrived there, should relax, as long as the social objects do not change their position either.

This expectation is valid as far as long-term simulation of general ontogenetic trends, or of time-invariant social organization is concerned. But it is not suitable when it comes to predicting the dynamics of real-time behavior. Children's actual distance control is characterized by a significant instability: The child keeps oscillating in an undampened fashion around its hypothetical steady state without ever resting in it. Mahler, Pine, and Bergmann (1975) referred to this phenomenon as *emotional refueling,* thereby unintentionally hinting at a possible systemic explanation of the instability mentioned. Suppose the constructs of security and arousal, as defined in the previous version of our model, would not refer to quantities that enter into motivational activation in a proportional way, but rather would determine the rate in which this activation changes. Security, for instance, would then behave like a kind of "fluid" feeding into a leaking "pool," with dependency determining the aperture of the drain. The fluid level in the pool would be behaviorally controlled such as to remain close to a neutral mark. Any deviation above or below this mark is experienced as security aversion or appetence, respectively (see Fig. 3.9a). For arousal, an analogous pool would be postulated with enterprise as the variable controlling the drain.

Mathematically, the process described is called a (temporal) *integration* (cf. Fig. 3.9b). Another integration occurs at the site where momentum is transformed into location y, thus the feedback loop postulated contains a double integral that, for systemic reasons, is essentially unstable and would therefore account for the locomotor oscillations actually observed.

In order to allow for the proposed refinement, we have to modify equation (9) in the following way:

$$A_s(T) = \sum_{t=0}^{T} (D - s)t \text{ and } A_a(\mathrm{T}) = \sum_{t=0}^{T} (E - a)t \qquad (11)$$

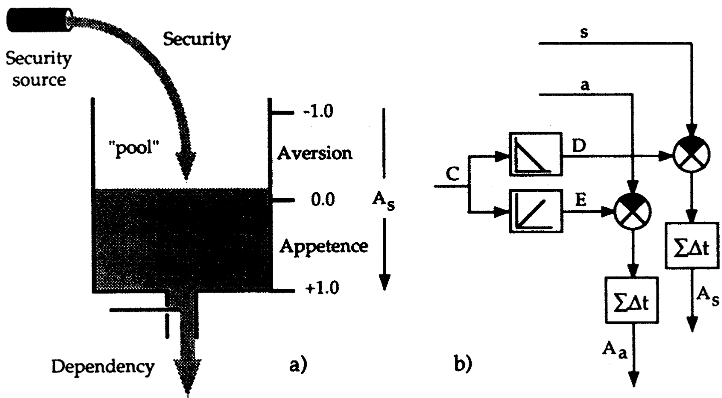

FIG. 3.9. The pool model. (a) graphic illustration, (b) cybernetical formalism (symbols same as in Fig. 3.1 and 3.2). Note that the scale of A_s is upside down because increasing level of security leads to aversion.

where t = running index of (appropriately calibrated) time steps and T = present moment.

It seems reasonable that motivational activation cannot increase beyond limits to either direction, so we restrict A_s and A_a arbitrarily to a range from -1 to $+1$.

Except for the modification specified in equation (11), all computations remain the same as in the original model. Again, vector fields for the security and arousal momenta can be computed that are no longer contingent on space coordinates only, but on time as well, because they continuously change according to the current security and arousal levels in the respective pools, thus producing the child's "refueling" behavior.

Coping

A brief comment should be made with respect to the handling of external coping in the model. We subsequently confine coping to its inventive variant (see section on the compound system), and here again to its most elementary form usually appearing in lower animals, namely, motor unrest. We thus superimpose a *random locomotor activity* onto the subject's momenta with a standard deviation u computed according to the formula

$$u = \mathrm{k} - (|A_s| + |A_a|) - |M_s + M_a|), \text{ if } u > 0, \text{ and } s = 0 \text{ otherwise} \qquad (12)$$

k = calibration factor.

Random movement, that is, will occur whenever the magnitude of the resultant locomotor momentum is small as compared to the combined activations of arousal and security.

Autonomy Claim and Acclimation

In a last step we want to deal with the mechanism of acclimatization. As already stated, the reference variables, enterprise and dependency, are assumed to be controlled by a third variable labeled autonomy claim (C). High autonomy claim, according to this hypothesis, increases the need for arousal and renders the individual more independent of familiar caregivers. Low autonomy claim has the inverse effect. We incorporate this basic relation into the model by the two simple statements

$$D = 1 - C \text{ and } E = C \text{ with } 0 \leq C \leq 1 \tag{13}$$

which, for the time being, is just as well as any other more sophisticated assumption. The degree of autonomy claim itself is supposedly influenced by (sexual) maturation, by the amount of experienced success, and by acclimation.

As mentioned previously (see section on the autonomy system), acclimatization should be understood as an internal coping process that is capable of reducing sustained activation by (in Piagetian terms) "accomodating" the reference variable to the controlled variable. In order to ensure that accomodation does not entirely override outward-directed assimilation, we have to preclude that every short-term disturbance of the motivational balance releases a quick adaption of autonomy claim before a locomotor response provided that an agreeable proxemic situation, or an external coping reaction, had a chance to occur in the first place. The mechanism of acclimatization, then, should only become involved if activation definitely persists for a prolonged time interval.

In order to fulfill this requirement, we have to allow for a temporal accumulation of activations to occur. We thus define a *stress coefficient* q at time T by the statement

$$q(T) = \sum_{t=t0}^{T} (A_s - A_a)t \tag{14}$$

with a lower summation limit $t0$ to be defined later.

Acclimatization of autonomy claim is assumed to occur if and only if the absolute magnitude $|q|$ exceeds a given limit q_{lim}. At present T autonomy claim, having been corrected in every previous time step t by an increment $\square C$, will amount to

$$C(T) = \sum_{t=0}^{T} (\square C)t \tag{15}$$

where DC is computed according to the following formulae:

$$\text{if } q < q_{\text{lim}}: \qquad \square C = -p*C \tag{16a}$$

$$\text{if } q < q_{\lim}: \qquad \square C = p*(1 - C) \tag{16b}$$

$$\text{else } \square C = 0. \tag{16c}$$

In these expressions, p is an arbitrary parameter that has to be chosen smaller—in fact, substantially smaller—than unity. Following each quantitative changes of C, the stress coefficient q is reset to zero. In other words, the lower time limit t_0 in equation (14) is defined as the instant following the latest acclimatization step where ΔC was not equal to zero. This precaution ascertains that acclimatization remains an emergency measure that would not unduly take over and render homeostatic control a mere issue of internal accomodation.

By summing, in equation (14), over the *difference* of A_s and A_s, rather than over each of them separately, we allow for an excess of security, even if maintained over some time, to be counterbalanced by a corresponding excess of arousal. It should be noted, though, that the behavior of the system would not change dramatically if acclimatization were released by an imbalance of the security or the arousal system alone.

The limit $q_{\lim}$ determines how sensitively the mechanism of acclimatization reacts to protracted states of motivational stress. For the purpose of simulation, $q_{\lim}$ should be chosen such as to allow children, under normal social conditions, to satisfy their security and arousal needs without having to resort to acclimatization all too frequently. Only under conditions of permanent security deprivation, for example, in children of rejecting parents, the stress coefficient q ought to exceed its limit $q_{\lim}$, and only then should the children reduce the permanent activation of overarousal by "arming their ego" or, in terms of the model, by strengthening their autonomy claim, thus increasing their enterprise and reducing their dependency according to equation (13). Conversely, autonomy claim and enterprise would be attenuated, by acclimatization in the opposite direction, and dependency increased, if the children had to live permanently in an overprotective atmosphere surfeited with familiarity.

MODEL SIMULATION

Defining the Scenario

In principle, every individual acting as a social partner in a given situation ought to be endowed with a motivational system of the kind described earlier. Systemic interactions within the group could thus be simulated. Such group processes being highly complex, however, and hard to analyze, a more transparent way of studying the model's behavior is indicated. It consists of "severing" all social feedback loops, that is to say, of confining the simulation to a single motivated subject, with all other partners performing according to a fixed schedule and refraining from reacting to the subject's behavior. In experimental settings such as Ainsworth's *Strange Situation* (Ainsworth, Blehar, Waters, & Wall, 1978) basically the same strategy is applied.

In order to set the model to work, initial conditions have to be specified. This implies defining location, relevancy, and familiarity of the social objects to be considered, and assigning to subjects coordinates of their initial position, and the strength of their autonomy claim. Given these conditions, the simulation process can be started. The model will, for every given time step, yield a locomotor increment according to the direction and magnitude of the resultant momentum vector.

In keeping with Ainsworth's standard experiment, we choose the case of individuals confronted with their mother and a stranger. We assume the interaction to occur in a narrow corridor virtually confining movements to only one dimension. This condition allows for a simple graphic presentation of the results without qualitatively differing from a two-dimensional simulation. Our first two examples correspond to the simulations presented by Bischof (1975) insofar as, again, infancy and early puberty are chosen as paradigmatic developmental stages. However, we have now replaced the proportional model recapitulated in the section on elementary mathematical realization by the pool model described earlier. A third example illustrates the effects occuring if we allow children to acclimatize their autonomy claim.

Simulation of Infancy

Figure 3.10 shows the model simulation of an infant's behavior at an age around 15 months. We assume autonomy claim and enterprise to be low and the dependency level to be correspondingly high at this stage ($C = E = 0.25$; $D = 0.75$). When exposed to mother alone (phase I), the infant's locomotor activity oscil-

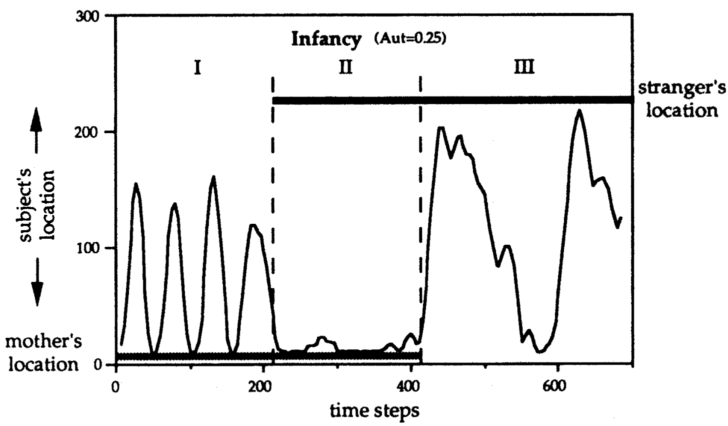

FIG. 3.10. Simulation of infancy with autonomy claim fixed to C = 0.25. (I) subject with mother alone, (II) subject with mother and stranger combined, (III) subject with stranger alone.

lates in a way typical of Mahler's *refueling* (Mahler, Pine, and Bergmann, 1975), as a consequence of the double integration mentioned in the section on the pool hypothesis. With no arousal sources being present in this condition, locomotion is entirely governed by the (unstable) level in the security pool. If mother were to change her position, the children would follow immediately. In the next stage (II), a stranger is introduced in addition to mother. Children immediately retire to their mother's lap (cf. also Fig.3.7, situation A). Their locomotor oscillation vanishes, and only rarely do they venture a few hesitant steps toward the visitor. When finally left alone with the stranger (phase III), infants change their attitude and approach the latter, who is, as may be recalled, not entirely alien and therefore capable of providing at least moderate security. But the strongly increasing arousal component near the stranger keeps repelling the child. Due to this impossibility to satisfy both the security and the arousal needs, a considerable amount of external coping unrest remains, as can be recognized from the minor oscillations superimposed onto the main locomotor trend.

Simulation of Puberty

A quite different behavioral pattern ensues in the same situation when the individual has reached a later stage of development, such as puberty, with a substantial decay of dependency and increase of enterprise. For a quantitative example we choose $C = 0.5$ (entailing $E = 0.5$ and $D = 0.5$). If juveniles in this condition dwell with mother alone (Fig. 3.11, phase I), they keep returning to her from time to time, but the range of their excursions is markedly extended. In terms of real life, this corresponds to the fact that juveniles feel fed up with "home, sweet home" but are not yet quite ready to leave it for good. As soon as we introduce

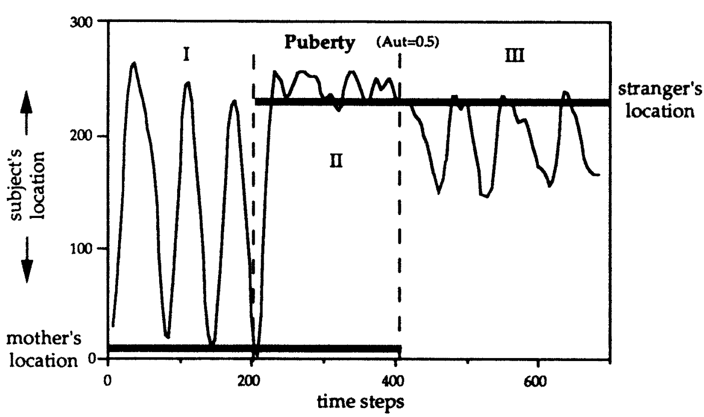

FIG. 3.11. Simulation of puberty with autonomy claim fixed to C = 0.5. Phases I, II and III same as in Fig. 3.10.

the same moderate stranger as in the previous simulation (phase II), the latter is readily contacted (cf. also Fig. 3.7, situation B). Mother's continuing presence provides so much security that juveniles prefer their new acquaintance, who is the only arousal source available. This preference is conspicuously accentuated by the subject's avoidance of the space interval between stranger and mother. When mother finally leaves the scene (phase III) the ensuing reduction of the net security level entails but a moderate effect. Obviously she is no longer of crucial importance. The stranger, nevertheless, is still a trifle too unfamiliar to allow feeling really comfortable in the subject's vicinity, and because the model does not (although it could) provide a gradual familiarization with persons permanently joined, our subject shows signs of uneasiness as evidenced in temporary withdrawal and motor unrest. Incidentally, even a little increase of autonomy claim (say $C = 0.6$) would cause the juvenile to stay with the stranger in a more relaxed fashion.

Simulation of Acclimatization

Thus far, we have worked with a fixed autonomy claim. In a last step we consider the model's behavior if we allow autonomy claim to acclimatize. We use the same three paradigmatic phases as in the previous examples. The results are presented in Figure 3.12.

We start simulation with the lowest possible value of autonomy claim ($C = 0.0$), that is, at a very early age. In a first phase (I), we again expose the infant to mother alone. As usual, we regard her as highly, though not maximally familiar ($F = 0.9$), thus allowing for the fact that she sometimes does emit mildly unfamiliar or surprising signals. The quantity of arousal thereby provoked is small, but would nevertheless be sufficient to slightly overstimulate an infant who, as supposed, has zero enterprise and therefore no arousal tolerance at all. The (negative) activation level A_a thus maintained will, if cumulating over a sufficiently long time interval, release an acclimatization process. Autonomy claim will thereby be intensified, albeit only to a minor degree owing to the entire absence of arousal-evoking stimuli other than those emitted by the mother. Consequently, infants oscillate very close to the mother in a similar way as they did in phase I, Figure 3.10.

This behavioral pattern changes as soon as we introduce a stranger (phase II). The presence of this additional arousal source induces autonomy claim to rise again, for reasons analogous to those in effect in phase I. The subject starts exploring the stranger. Initially, it is true, fear evoked by the stranger is too strong to allow staying with that person. Also, the security inflow next to the stranger is too meagre to balance the drain caused by a still considerable dependency. Therefore, the subject is every now and then liable to return to mother in order to refill his or her security pool.

After an unpredictable number of oscillations, subjects will eventually (still

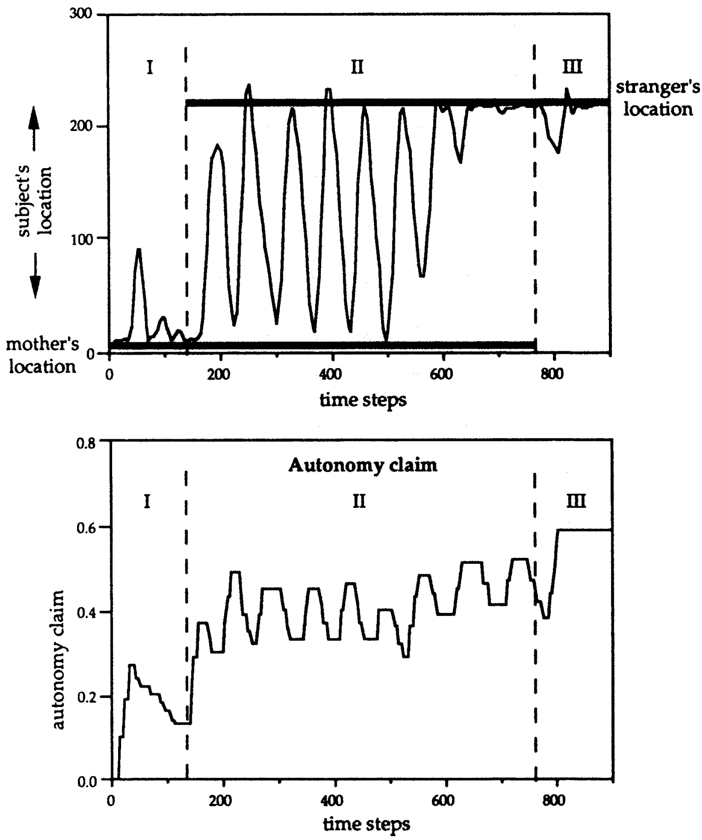

FIG. 3.12. Simulation of acclimatization. (a) Subject's distance regulation and (b) the corresponding development of autonomy claim. Phases I, II, and III same as in Fig. 3.10.

during phase II!) reach an autonomy level allowing them to sustain close contact with the stranger, and this condition will persist even when mother leaves (phase III). Thus a mother who provides security and offers the possibility to cope with an initially strange environment, will at the same time promote her child's competence and autonomy, until she is no longer required for security homeostasis.

This result is quite remarkable, indeed, because at first sight, we would not expect an acclimatization mechanism, that is constructed in perfect symmetry with respect to security and arousal, to produce an irreversible increase in autonomy claim. So where is the source of this conspicuous asymmetry that, after all, dispenses us from introducing special maturational processes gradually boosting autonomy claim during ontogeny? The answer lies in the choice of the familiarity coefficients: We have assumed that the stranger is more familiar than the mother is alien. In real life, this corresponds to the fact that mother remains familiar in spite of separation, whereas strangers lose their strangeness to a certain degree by way of continuous familiarization. As stated earlier, this process was not explicitly incorporated into the model, but would have yielded essentially the same results as the asymmetry of familiarity coefficients used in our simulation.

MODEL ESTIMATION

As indicated by our simulation examples, the model's predictions of the basic patterns of attachment and exploratory behavior in infants make at least some intuitive sense. It seems in order, then, to try applying the theory directly to empirical data. When preparing to do so, certain difficulties come to mind. The model deals essentially with distance regulation. But in adult people as well as in higher animals, social relationships are almost never expressed to the full extent in spatial distance, measurable in meters. For this reason mainly, we have first confirmed the basic usefulness of the model in experiments with lower animals. For example, the model was applied in an investigation of pair bonding and incest avoidance in painted quails. In a series of experiments, Gubler (1989) analyzed the sex-specific contributions to distance regulation and pair formation in quail couples composed either of siblings raised together from hatching, or of individuals devoid of contact prior to the experiments. It can be assumed that both groups differ substantially in the construct familiarity.

As can be seen from Figure 3.13, the style of proxemic behavior differs

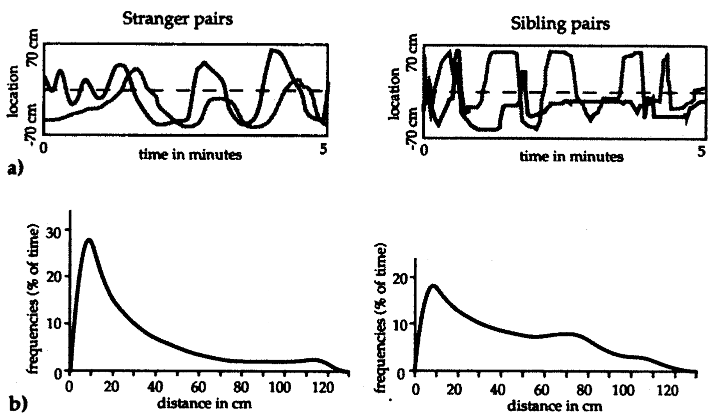

FIG. 3.13. Empirical data for pairs of strangers and siblings of painted quails. a) locomotor behaivor in a nearly one-dimensional cage, black line: male, grey line: female. b) the resulting distance distributions.

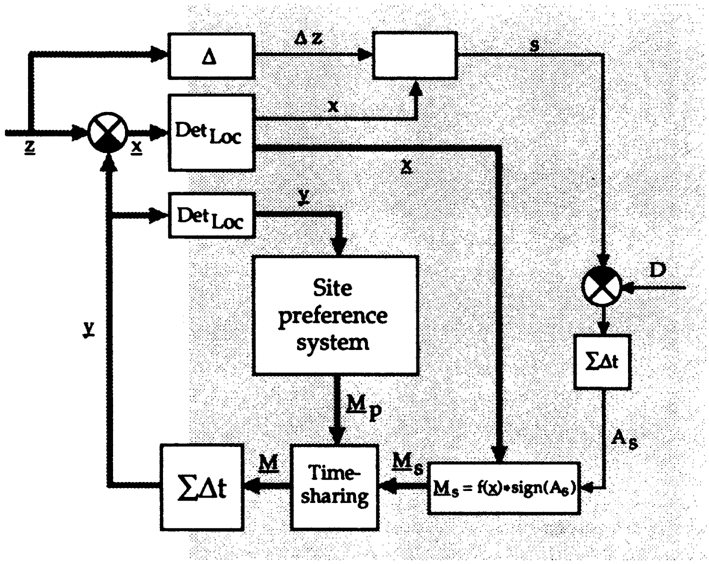

FIG. 3.14. Modified pool model used by Gubler (1989). Δz = velocity of the partner; approaches or withdrawals, Mp = momentum produced by the site preference system, all other symbols same as in Fig. 3.1 and 3.2.

markedly in the two groups. In order to account for the distance regulations observed, the Zürich model had to be slightly modified (Fig. 3.14).

First, a *site preference system* had to be introduced in addition to the attachment system controlling distance from the partner, that is, a motive to dwell preferentially at particular, empirically assessible sites of the territory, regardless of the partner's momentary location.

Second, it turned out that the attachment system is affected not only by the partner's distance, but also by the velocity ($\Delta z/\Delta t$) of approach or withdrawal. In technical terms, the distance control system is of the proportional–differential type.

Thirdly, in quails, the momentum M_s does not depend on the magnitude, but only on the sign of the security activation (A_s). Therefore the velocity in which social distance x changes, apart from its direction, is determined by the amount of this distance alone.

Last, a *time sharing* mechanism, as proposed by McFarland (1974), was found to determine the resultant momentum M out of the momenta of the attachment system (M_s) and that of the "site preference system" (M_p), with the attachment system playing the dominant part in this competition.

The parameters of the model could be directly assessed from the experimental data and were subsequently used to simulate a typical interaction of two individuals of either pair type. All differences encountered between stranger pairs and sibling pairs could be accounted for by the siblings being just more familiar and therefore providing each other with more security. Consequently, in stranger pairs the need to maintain proximity caused the mates to synchronize their locomotor behavior, whereas siblings moved around much more independently.

Another case where social motivation is still more or less directly expressed in terms of distance regulation, is in early ontogenetic stages in virtually all social animals, including man. Two studies in our group (Diener, 1982; Friedländer, 1987) were especially designed to investigate emotional refueling in human infants, under various levels of arousal. In order to manipulate the latter, Diener used the conventional technique of a suddenly occuring, strange object.

In Friedländer's device, this object was replaced by an unexpected, ominous sound signal, with a frequency too low to permit localization in space. The gist of this setup was to homogenize (actually, to erase) the vector field I_a, and thus to facilitate the quantitative analysis of the results. The experiment was conducted in a long, narrow corridor similar to the one on which our previous simulations were based (see section on defining the scenario). Figure 3.15 shows the modified pool model used by Friedländer to interpret his results.

Figure 3.16 gives an impression of the results obtained in Friedländer's experiments. The child's spatial position oscillates in a way similar to the one obtained in our simulation study. Nevertheless, the two cases ought not to be directly compared. In the empirical case, we have to take time-sharing mechanisms into consideration. An additional flip-flop device is likely to interfere between the tendencies to approach and to avoid the mother, thus superimposing onto the real time course of momentum M_s an extra oscillation that should be gotten rid of before assessing M_s. Therefore, the original curve x was only used on the input side, that is, to compute the security s provided by mother, whereas M_s was derived from a smoothed version of x (broken line x^* in Fig. 3.14). This was also necessary for a technical reason: In order to compute the magnitude of M_s ($= \Delta y^* / \Delta t$), we have a differentiate distance, which requires a sufficiently smooth original curve ($y^* = z - x^*$).

By way of a suitable optimization technique, the parameters affecting the causal connections represented in Figure 3.13 were then estimated such as to yield minimal differences between observed and estimated momenta.

The graphs inserted in the two bold-rimmed blocks S and M of Figure 3.15 visualize the parameters capable of producing an optimal fit for the data presented in Figure 3.16. The technique applied by Friedländer allowed estimations of the temporal decay (the so-called "transient") of acoustically induced insecurity (shown in Block S), the security gain as a function of distance from mother, and the child's dependency level (both presented in Block M). The time course of the security momentum predicted by the model according to this estimation yielded a quite satisfactory correspondence to the empirical data, as indicated by Figure 3.17a. In fact, Friedländer was able to approximate the distance-regulating be-

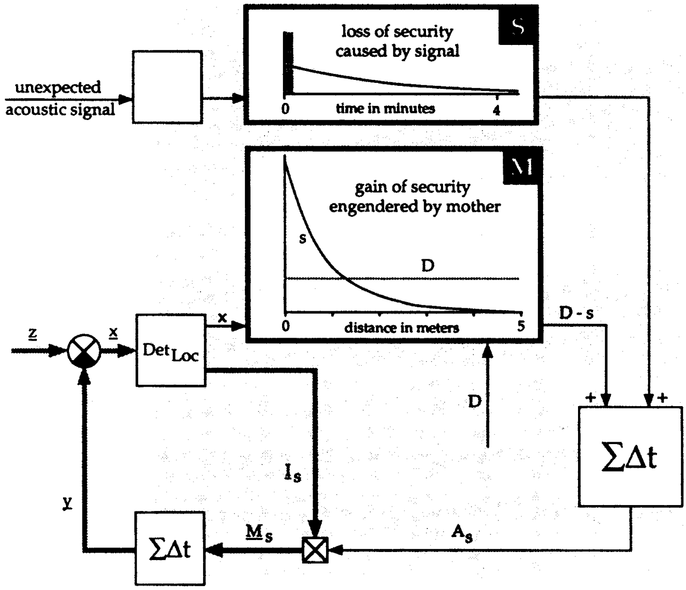

FIG. 3.15. Modified pool model used by Friedländer (1987). Symbols same as in Fig. 3.1 and 3.2 with z = fixed location of mother. The magnitude of Is is assumed to equal unity.

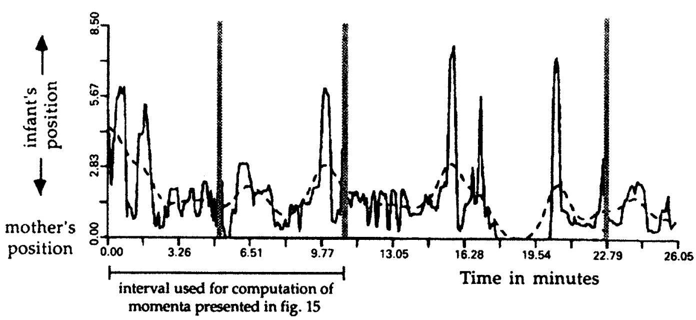

FIG. 3.16. Distance behavior of a 21-month old child (from FRIEDLÄNDER, 1897), Solid line: distances between mother and infant (x), broken line: smothed distances (x*), grey bars: time and duration of the acoustic signal.

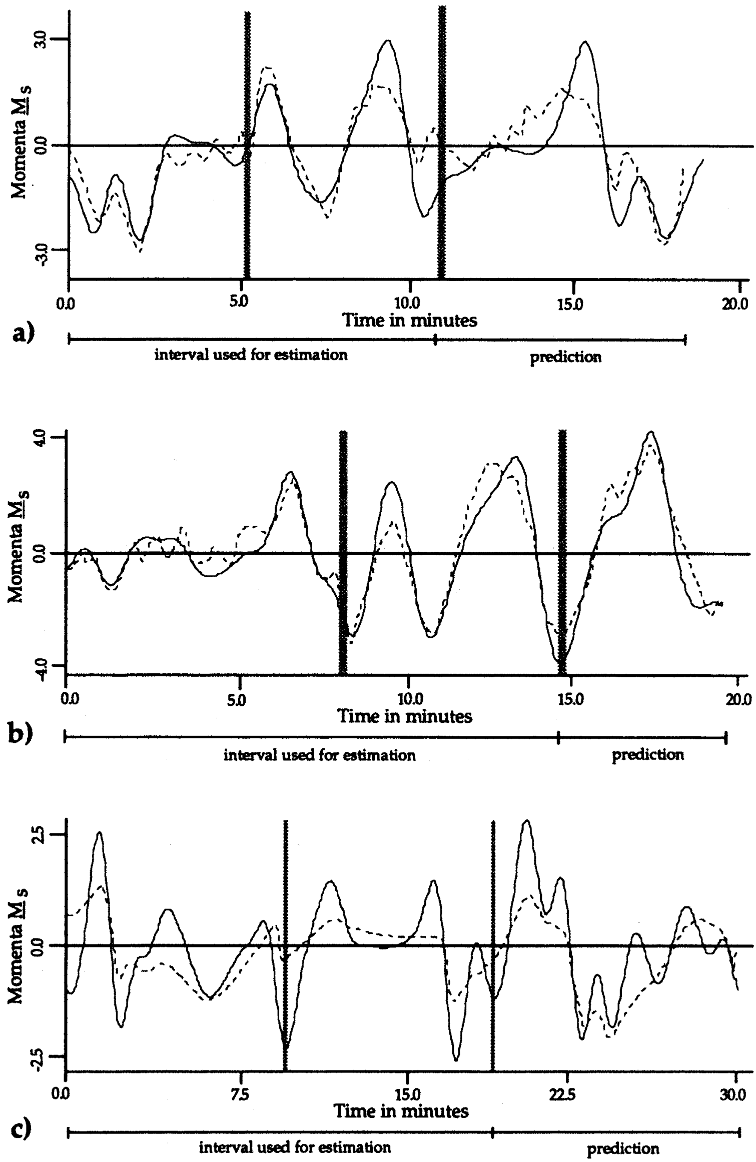

FIG. 3.17. Observed and estimated or predicted momenta of a) the child presented in Fig. 3.16, b) the child with good and c) a child with poor estimation and prediction. Solid line: observed momenta, broken line: estimated or predicted moments, respectively. Grey bars: acoustic signals. Negative momenta indicate approach, positive momenta withdrawal from mother, measured in centimeters per second.

havior with a mean quality of 0.7 (extreme cases in his sample of 15 Subjects: 0.4 worst, and 0.9 best. Fitting quality is defined by the following limits: 1.0 = entire congruence; 0.0 = approximation by a straight line. The examples given in Figure 3.17a-c have qualities of 0.8, 0.*x*. and 0,*x*, respectively).

In the graphs shown, parameter estimation was based solely on the interval from the start until immediately before the onset of the second noise signal. The parameters obtained were then used to predict the child's locomotor behavior during the following interval. Only two additional parameters determining the effect of the second acoustic signal had to be newly calculated. Some examples illustrating the high quality of these predictions over an interval of several minutes are shown in Figure 3.17.

CONCLUSION AND OUTLOOK

This chapter attempted to illustrate a technique of applying systems theory to social behavior by means of simple, but not trivial examples of simulation and estimation. A lot of further interesting and more complex questions can be addressed with a similar approach. Many of these questions would not arise unless one is attempting to transpose a theoretical and, in general, a plausible idea into the realm of simulation.

The model is designed to incorporate only the most basic principles underlying social behavior. Whenever it is applied to a concrete problem, it must be modified and adapted according to the requirements of the case in question. The few examples presented show that, on principle, this is possible.

It goes without saying that several crucial aspects of social motivation are not yet incorporated into the model and should be further elaborated. Some problems have already been discussed, such as the questions of how access to the final motor path is shared by contradicting motivational momenta, or of how to treat the difficulties that arise as soon as the model is applied to higher social animals who regulate social distance by way of expressive or even cognitive activities.

Another deficiency of the current model concerns the behavior of the mother and the stranger. Our simulations pretend that only the child is responsible for distance regulation. But in real life, the mother participates in this regulation to a great extent. She may follow her children or restrict their excursions, and the children expect her to do so. In order to simulate interactions of this kind, it would be necessary to implant into our model the whole complex of altruistic behavior (especially, caregiving) into the model.

Finally, little is known to date about the factors responsible for the choice of particular coping strategies in a given situation. In this and other areas, much further empirical and theoretical effort will be necessary to advance our understanding of the complex mechanisms underlying social behavior.

The Zürich model in its present form may or may not provide a good baseline for extended theorizing in this field. It is hard to see how a breakthrough could ever be attained without availing oneself of the tools offered by systems theory in general. And this implies not only toying around with magic words like *system* or *feedback*, but also entering, hard as it may be, into mathematical analysis proper.

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