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Dynamics from Communications Data

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To create a complex dynamical model for a complex system, it is normally necessary to have a directed graph of the network, a dynamical model for each node, and a coupling function for each directed edge. But in many applications, the only observable data consists of communications from one node to another. In this situation, the modeler may infer a complex dynamical model for the network without any explicit knowledge of the independent dynamical behavior of the component systems (nodes). Here we present one procedure for this type of modeling problem, inspired by the attractor reconstruction procedure of chaos theory. Part of this proposal consists of a strategy for computer graphic presentation of the interactive dynamics of the complex system (or social network of dynamical schemes) called a *netscope*. We can imagine applications to diverse situations, such as decision groups, management, forecasting, international relations, classroom monitoring, therapy (personal, family, group, etc.) and distributed processors, to name a few.

Dedicated to: Gregory Bateson (1904-1980)

Introduction

In the summer of 1986, Bob Langs asked my advice for the application of dynamical systems theory to the therapeutic sessions of psychoanalysis. Since then, Bob and I, along with Marsha Fox, have been working together on this project. The first step has been the creation of a data base. Our approach in this step was guided by my long range goal to develop a strategy applicable to arbitrary networks of agents interacting primarily by communications.

In this paper, I will describe some of our joint work in this first step, and some proposals for the following steps. These will be described in the simplest context, in which there are only two participants. We begin in Section 2 with the first step: the observation of the target system, or creation of a data base from the working network. Then we go on to describe the proposed analysis of the data and construction of a model according to the concepts of complex dynamical systems theory [1]. In Section 3 we show how to reconstruct the response diagram for a dynamical scheme for the participant at each node. The attractor reconstruction method is the model for this analysis [2]. We go on to show how to construct the coupling functions for each directed edge, and the whole complex dynamical model. Our approach to this problem in the psychotherapeutic context will be used as a basis for discussion.

In Section 4, we give some hints for the computer simulation of the model. The nodal models must be expressed in symbolic form, as dynamical schemes: autonomous systems of ordinary differential equations of first order, depending upon control parameters. There are several strategies, all require real mathematical work [3] [4]. In the conclusion, we discuss our hopes and fears concerning the further applications of these methods. This paper is based on a talk presented at a conference on *Mathematical Models for Psychoanalysis and Psychotherapy,* New York, 3-5 June, 1988.

Netscope: observation, scoring and viewing the data

In a general network, communications between the participants might be written, verbal, nonverbal, video, code, and so on. We consider here only one of these possibilities: verbal communication. Other cases might be handled similarly. Further, to simplify the description we consider only the smallest network: two participants. Remarks on the general case are inserted from time-to-time in italics. Due to the original context (psychotherapy) we call the communicants P (patient) and T (therapist). We now describe the first step in four parts: observation, scoring, superscores, and viewing.

Observation. There are two communication channels to monitor: P-to-T and T-to-P. Due to the face-to-face spoken language context of the communication, the two channels are overlapped, and are recorded on a single tape. In future, the whole process might be managed, like simultaneous translation, without recording. But at present, the observation process is based upon audio or video tape recordings.

In case of more communicants, each spoken message might be intended for one or more recipients. We might then assume that the sender (speaker) can be identified by voice, but the intended recipients (or the actual recipients) may not be identifiable from the tape recording. With written communications or electronic mail, however, we would have an explicit target list for each communication. We may deal with this by regarding each transmission as a broadcast, for public reception by all participants. In the general context, each message would be identified with one sender and a set of receivers.

Our current context (two people in conversation) is of this type, so we regard each transmission as belonging primarily to the sender. This is compatible with the viewpoint of complex dynamical system theory, in which couplings are expressed in terms of a function from the internal state of the source (sending) node to the control parameters of the target (recieving) nodes. Hence we will label each transmission by P (rather than P-to-T) or T (rather than T-to-P) to identify the sender.

As we will want to analyse the dynamics of the interactions, we should have a clock in view (in case of video recording) or a pre-recorded clock track (in case of audio recording only.) This will allow time data to be included in the transcription.

After recording a session of the working network in this way, the recording is transcribed by a typist to a text file on a computer disk or diskette. The communications are broken into *lines* of a more-or-less fixed length. For example, Langs and Fox use a long line length, roughly equivalent to 20 seconds of normal speech. Each line is labelled with a line number, the clock-time recorded next to its first word, and the identification of the sender (the speaker, P or T). A fictitious example is presented in Table 1.

Table 1. Transcribed data

LINE	TIME	NODE	TEXT
1	011500	P	My mother brought me today.
2	011520	T	How nice, I always wanted to meet her.

Scoring. The transcription must now be scored. Each line of text must be transformed into numerical values of the observable parameters according to some theory. The procedure is circular, in practice. A list of observables is proposed, and a scoring range for each. Rules are written for the transformation from text into scores. This is called the *scoring manual.* Then, people are trained in the use of the scoring system from the manual, and the transcribed recording is scored. This produces a data base file on a personal computer disk or diskette, which will be the basis for the next step. An example, based on Table 1 and a fictitious scoring manual with 4 scores, is shown in Table 2. This step is the most important and, in our experience, can profit from several months of iteration. The manual is rewritten, the training is repeated, and the transcribed recording is scored again. With each revision, it seems to grow. The scoring system of Langs and Fox currently records sixty-seven scores for each line of text.

Table 2. Scored data

LINE	TIME	N	S1	S2	S3	S4
1	011500	P	1	-3	2	-5
2	011520	T	0	2	-7	-2

Superscores. To obtain a simple visualization of the session based upon the scores, we must reduce their number. Eventually, the analysis might provide an estimate for the actual dimension of the information, and thus an indication of a good target value for the total number of scores to record for each line. But at the start, we will be restricted primarily by our cognitive strategies. And in this project, we will rely on computer graphics to inspect the data. Thus, we must ask the scoring manual experts to indicate which scores might be totally ignored in a preliminary inspection, which might be largely ignored, which are the most important, and so on. Considering our reliance on inexpensive business software for personal computers, we might try to find a small number of reduced indicators to reveal graphically the significance of the scores. The method we have used is to combine several scores into a weighted average or linear combination which we call a *superscore*. For example, Langsian analysis might make use of two superscores, activity of the conscious (C) and unconscious (U) systems, as we show in Table 3. The data base manager or spread sheet program may be able to add the superscore columns automatically.

Table 3. Superscored data

LINE	TIME	N	S1	S2	S3	S4	U	C
1	011500	P	1	-3	2	-5	0	5
2	011520	T	0	2	-7	-2	5	-2

Viewing. All the scores may be viewed graphically as functions of time (time series) by utilization of the built-in graphing functions of the data base manager. But in the spirit of dynamical systems theory, we want to view trajectories in the state space or response diagram of the various nodes [5]. Here our task is simplified if our network is *symmetric.* By this we mean that the same dynamical scheme appears as the dynamical model for each node. In the present context, this means that we will use the same model (dynamical scheme, i.e., dynamical system depending on control parameters) for the patient (P) and for the therapist (T). And therefore, we may indicate the data for the entire network within a single portrait or response diagram. For example, if we are satisfied with two superscores and no controls, the common portrait is two-dimensional. In case of two superscores and one control parameter, the common response diagram is three-dimensional. The two participants will each have there own trajectory, say a blue one (P) and a red one (T). This is not essential, however. We could view the trajectories on separate screens, each screen devoted to a different nodal response diagram.

The observation of a symmetric communications network with several participants in this manner would show several colored trajectories moving about within a common response diagram. We call this strategy of observation (which could concievably be achieved in real-time with a short delay) a netscope. Each trajectory should advance at the proper time, to represent the true dynamics along the locus of attraction within its own response diagram. For example, we could imagine a two screen replay of a summit conference. On the left screen, we would see (and hear) the actual negotiations for world peace. And on the right, the simultaneous representation by the trajectories winding around the locus of attraction in contrasting colors. In our case, there would be two dots moving on the right-hand screen, each trailing a trajectory behind. When this can be accomplished in real-time with a brief delay, the discussants might be aided in achieving their goals by watching themselves on the netscope!

Construction of the complex model

We give here a concise recipe for the modeling process, in five steps: filtering, smoothing, parsing, interpolating and embedding.

Filtering the data by sender. Eventually we propose to view each participant as a trajectory moving within a response diagram. At this point, we have data, but no response diagram. To develop this model for the dynamics of each participant, we must treat the data for each sender separately. In our present context (conversation) participants generally take turns sending. Thus, there will be long gaps in each trajectory.

For example, the P trajectory of data has a long gap while the T trajectory moves. During this gap, we assume that the P trajectory continues to move, but we have no data to reveal its motion. When T quits, there may be a pause, then the P trajectory may resume from a new location. Furthermore, it is *only* during this gap, or invisible segment in the P trajectory, that the control parameters of the P model scheme are being changed by the message from T. Thus, what we are missing is the most vital information about the P model, its bifurcation behavior. As we will probably never obtain enough data to fill in the full response diagram, we may eventually have to guess it.

This step is reflected in the tabular data by a separation (filtration) into two tables, as shown in Tables 4A and 4B.

Table 4A. Filtered data, node P

LINE	TIME	N	S1	S2	S3	S4	U	C
1	011500	P	1	-3	2	-5	0	5
2	011520	T	?	?	?	?	?	?

Table 4B. Filtered data, node T

LINE	TIME	N	S1	S2	S3	S4	U	C
1	011500	P	?	?	?	?	?	?
2	011520	T	0	2	-7	-2	5	-2

Smoothing the data. In our experience, the data obtained by this method are rough. They do not graph well. This is inherent in our discrete scoring method, and the more different scores utilized in the method, the rougher the resulting data. But our dynamical models assume continuous state and control parameters. So, smoothing the data may help in the development of the nodal models. As the gaps are significant, and catastrophic bifurcations (ie, discontinuites) are expected to occur during these invisible portions, we do not want to smooth the gaps. Our strategy, then, is to smooth the data within each message or speech (ie, between gaps.) This can be done by averaging, splines, least squares, or by any other means.

Parsing the data by control parameters. If we now plot some superscore trajectories (for example, U versus C for P only, smoothed as described above) we may expect to see trajectories crossing themselves in a jumble. This is discouraging, as it should not occur in dynamical systems. One of the usual remedies is embedding the data in higher dimensions. We regard this as a last resort, and will discuss it presently. Now, however, we describe a more fundamental strategy.

We have not yet devoted much discussion to control parameters. Yet state and control parameters are equally basic to a dynamical scheme. Recall that the phase portrait is a visual representation of a dynamical system emphasizing its attractors, basins and separatrices. In contrast, the response diagram of a scheme is a visual representation of its locus of attraction, drawn in the response space of both state and control parameters [5]. For each value of the control parameters, we have a different dynamical system in the state space, with its own portrait, attractors, basins, separatrices and trajectories. Thus, each trajectory data point must be located in the portrait corresponding to its own control parameter values. But what are the controls, in the data obtained by our scoring method, for node P for example?

In general, the controls of one nodal model are to be determined by the state of other nodal models by coupling functions. Thus, the control parameters for P may be added to our model by hypotheses. We must decide what factors change the dynamics of P, and how these factors depend upon the state (that is, the scores or superscores) of T. These choices are quite arbitrary, depend upon the prevailing theory of the modelers, and may be modified many times before a useful model results. In fact, many different models may fit the data equally well (or badly) and may be used interchangeably.

We are going to suggest now the addition to our data base of additional columns for control parameters. These may be defined, like superscores, as functions, the *coupling functions.* Superscores are functions of scores, and controls may be functions of superscores. The coupling functions are maps from the state parameters of one node to the control parameters of another. *In general, different control parameters and coupling functions are required for each directed edge* (eg, separate control columns for P and T in our current example). But for the present, we may assume the control parameter superscore columns are shared by the P-to-T and T-to-P edges (another aspect of our symmetry assumption). The control values for node T must be entered in the table of filtered data for node T, during the gaps occupied by the message from node P, and *vice versa.*

To begin with the simplest possible case, we will try to model these nodes with schemes having two superscores (U and C) and one control parameter (A). We may assume that the coupling function defines A as a superscore obtained from U and C only, for example,

$$A = 0.2 * (U + C)$$

which we may call *activation.* This is now added to the database, as shown in Tables 5A and 5B.

In general, the strength of these couplings may be changed to alter the behavior of the model. This is the connectionist approach of neural net theory. In the asymmetric case, we could have different coupling functions for each directed edge.

Thus in our context, we could have two activation formulas, for example:

$$A = 0.2 * (U + C) \text{ if P-to-T}$$
$$A = 0.4 * (U + C) \text{ if T-to-P}$$

But for the present, we continue to assume symmetry.

Table 5A. Filered data, node P									
LINE	TIME	N	S1	S2	S3	S4	U	C	A
1	011500	P	1	-3	2	-5	0	5	-
2	011520	T	-	-	-	-	-	-	0.6

Table 5B. Filtered data, node T									
LINE	TIME	N	S1	S2	S3	S4	U	C	A
1	011500	P	-	-	-	-	-	-	1.0
2	011520	T	0	2	-7	-2	5	-2	-

Now, the trajectories (smoothed, but retaining gaps) may be drawn in the 3D response space of the variables (A, U, C). *We assume that P's control A changes only during a gap, while T is transmitting, and vice versa.* When U, C, and A are properly chosen, we hope that all self-crossings will disappear. Important information may now be obtained by constructing a *response histogram* (that is, a scatter plot) of all P data points (red) and T data points (blue), plotted within the 3D response space. In case of multiple scorers, we might try plotting all the data without smoothing. The response histogram (also called the *invariant measure)* is a very important aspect of the nodal scheme. The response diagram is obtained by interpolating the response histogram.

Interpolating the response diagrams. Assume that, proceding as described above, we have obtained trajectories without crossings. All that remains to complete the nodal models is to smoothly fill in the locus of attraction, using the histogram as a guide. A knowledge of the atlas of bifurcations will be essential to this task, as data will generally be sparse [5].

On the other hand, if crossings remain, then we must increase the number of state or control variables. One way to accomplish this is to utilize more superscores of the original scores (if there are lots of them) or to embed the data (if there few). In our case, the Langs/Fox scoring system provides a large number (ca 67) of scores, so new superscores may be added to the database. Hopefully, a small number of superscores will suffice to provide useful simple models [6]. Otherwise, we are in trouble.

Embedding the data. In the exceptional case in which only a small number of scores can be obtained from the data (for example, we are processing someone elses scores, and the original data or transcript is unavailable) we may create fictitious supplementary scores by the embedding procedure. We would just add new columns identical to the original columns, but slipped down by one row. See [2] for details.

Simulating the complex model

The complex model now exists. Each node has a model scheme, represented by the interpolated response diagram constructed above, and the control parameters and coupling functions are provided by the superscore and coupling formulas. In order to do computer simulation with the model, we need some mathematical expressions for the dynamical schemes at each node. The experienced dynamicist should be called at this point, to conjure appropriate formula for the schemes. These are generally built from a library of known models, inherited from the early pioneers. Simulation software [7] and chaotic measurement tools [8] are then available to study the model and compare the simulated data to the experimental data, and so on. Sophisticated programs for obtaining equations from the data [4] or economically generating additional data [3] may be called upon if needed.

This completes the construction of the working model for the interactive social network of two participants. Without substantial modification, a model may be constructed for larger networks, even if asymmetric. The evolution of the model may be an accomplishment for the social sciences, but the possession of the model may convey a certain power. For example, crude forecasting becomes possible, and may enable winning bets, as in a roulette game [9].

As we might fairly wish all participants to have equal access to the model, the possibility must be considered to carry out the simulation on a distributed network of computer graphic workstations, one for each node. Concievably, each participant might utilize their own actual self, together with a dynamical model of the other, to rehearse their interactions in advance of an actual interchange, as with ELIZA. Many possibilities suggest themselves, both good (big sister applications) and bad (big brother applications).

Conclusion

The procedure described here for the construction of a complex dynamical model for a social network entirely from communications data may be easily generalized to asymmetric networks with many nodes, with different schemes at each node. The communications need not be restricted to the verbal.

Models made in this way may play the role, in the social sciences, that Newton's laws played in the history of the physical sciences. The applications are numerous, and not entirely benign. Both big brother and big sister applications suggest themselves, and we hope the stability of the world will be increased by the development of this modeling strategy. We have proposed applications to international political relationships, as well as group decision processes. Good models, when and if they eventually become available, might be used for education, amusement, the arts, police work, management, decision making, and in fact, wherever the social sciences are already applied.

In sum, it seems that netscopes may function to make the unconscious visible. This may be hard to get used to, but basically evolutionary.

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