

Using state space grids to display, describe, quantify, and analyze synchronized time series or event sequences

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Abstract

The recent increase in observational research has created a demand for methods that can visually display, describe, quantify, and analyze two or more synchronized time series or event sequences. The current paper describes a new methodology based on dynamic systems principles, state space grids, which is well-suited for the kind of data obtained via observational programs such as the Noldus Observer.

State space grids are two-dimensional grids constructed from synchronous sequences of two categorical data streams. Each axis represents mutually-exclusive categories along a single dimension, and the cells on the grid represent joint states of categories along the two dimensions. Behavior is traced as a trajectory across this space: a new point is plotted for each change in state and a line is drawn that connects the old and new state. Examples are presented from the freely available software program GridWare (www.statespacegrids.org).

Keywords

Dynamic Systems; State Space Grids; Developmental Science, Dyadic Interactions; Time Series

1 Introduction

Advances in computing have accelerated the growth in observational methodologies and have allowed researchers to capture complex sequences of events as they unfold in time. This increase in observational data has created a demand for methods that can handle the complexity of these investigations. However, there are few applications that can visually display, describe, quantify, and analyze two or more event sequences. The current paper describes state space grids, a new methodology based on dynamic systems (DS) principles that is well suited for the kinds of data obtained via observational programs such as the Noldus Observer.

1.1 Dynamic Systems

State space grids were inspired by DS principles that describe the processes of change and stability in complex, adaptive, open systems. Most simply, a dynamic system is a “system of elements that change over time” [9]. All dynamic systems have several key properties in common. Although a system may have a wide range of states available, there is a tendency to stabilize in a limited number of these possibilities. In DS terms, these recurrent, stable states are called attractors. These are “absorbing” states that “pull” the behavior of the system from other potential states [1]. The full range of all possible states is called a state space, which is configured by the presence of attractors. This is often represented as a topographical landscape on which valleys are the attractors.

1.2 State Space Grids

Based on these abstractions, Lewis and colleagues [7] recently developed a graphical approach that utilizes

observational data and quantifies these data according to two ordinal variables that define the state space for the system. This technique was first used for analyzing two dimensions for one individual but was adapted to study dyadic behavior, specifically parent-child interactions [3]. With this method, the dyad's behavioral trajectory (i.e., the sequence of behavioral states) is plotted as it proceeds in real time on a grid representing all possible behavioral combinations. Much like a temporal scatter plot, the parent's coded behavior is plotted on the x-axis and the child's behavior is plotted on the y-axis. Any time there is a change in either person's behavior a new point is plotted in the cell representing that behavior and a line is drawn connecting the new point and the previous point. Thus, the grid represents a sequence of dyadic events. For example, a hypothetical trajectory representing 15 seconds of parent-child behavior is presented in Figure 1. The state space is formed by the intersection of an ordinal set of affect categories for both parent and child: High Negative, Low Negative, Neutral, Low Positive, and High Positive. The size of the plot point corresponds to the duration of the dyadic behavior. The sequence depicted begins in the mutually Low Positive cell followed by 3 seconds in the Mother Low Positive/Child Low Negative cell, 4 seconds in the mutually Low Positive cell again, 2 seconds in the Mother Neutral/Child Low Positive cell, 2 seconds in the Mother Neutral/Child High Negative cell, and finally 2 seconds in the mutual High Negative cell.

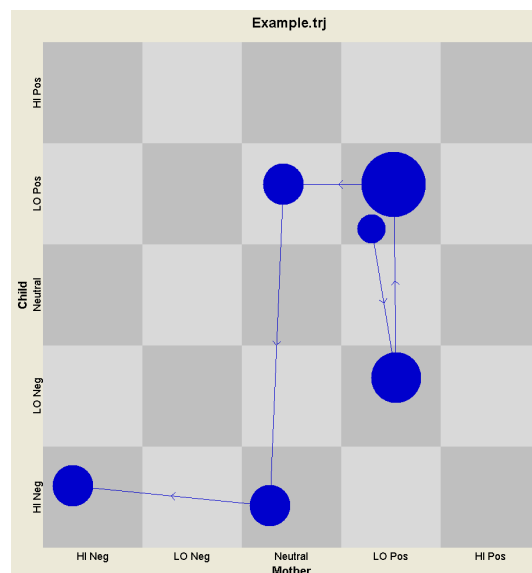


Figure 1. Example state space grid.

The work of myself and my colleagues has focused on using this technique to display and quantify patterns of infant emotional development [7,8], and patterns of parent-child interactions [2,3,4,5]. However, this technique is not limited and can be used for a wide range of applications. Some possibilities include eye tracking (horizontal vs. vertical plane), group dynamics, reaction

time and performance combinations, bivariate economic trends, and biological and behavioral combinations. Before describing examples of this technique, I will first describe the software that can be used to create state space grids.

2 GridWare

Recently, my colleagues and I developed GridWare [6], a software program for the creation of state space grids that can be downloaded for free from the web (www.statespacegrids.org). This program allows the user to view and manipulate trajectories based on 2 or more synchronized data streams. Thus, it is quite amenable to any multiple pass coding within the Noldus Observer. In fact, we have created a Perl script for this conversion. The input for this program is a control file, called the GridWare File, and one file for each trajectory (synchronized time series data). The GridWare File provides the parameters of the grid dimensions (names and # of categories, names of dimensions, etc.) and identifies each trajectory file. It is also possible to add variables that uniquely identify characteristics of each directory (i.e., treatment group, gender, session #). The trajectory files themselves have a minimum of three columns each: onset, state variable 1, and state variable 2 (although more than 2 state variables are acceptable). When a project is opened in GridWare, three windows appear. These are described below.

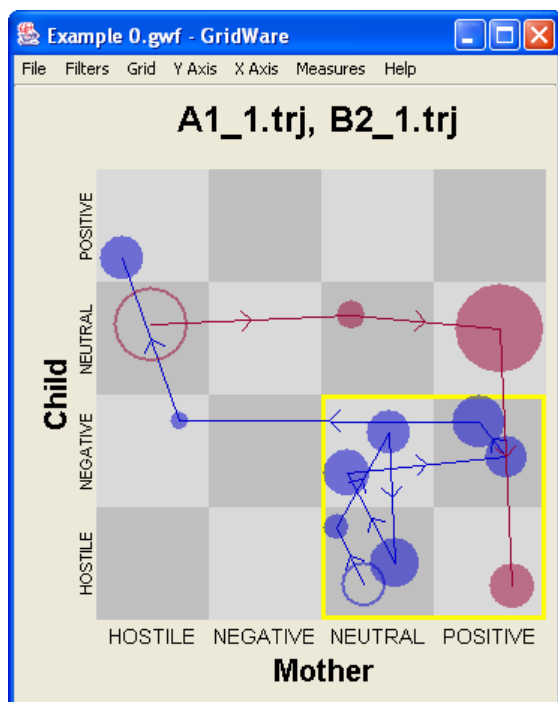


Figure 2. The Grid Window displaying 2 trajectories.

2.1 The Grid Window

Figure 2 shows an example of 2 trajectories displayed in GridWare. GridWare can display none, one, some, or all of the trajectories in a project. If there are more than 2 streams of simultaneous data (state variables), the axis menus allow the user to choose which to display on each axis. Some of the display options include: Arrows to indicate the direction of the trajectory in time, hiding the plot points or transition lines, selecting one or more cells to create a region (the highlighted yellow quadrant), and color can be applied to any selection, as seen here by one trajectory in red and the other in blue.

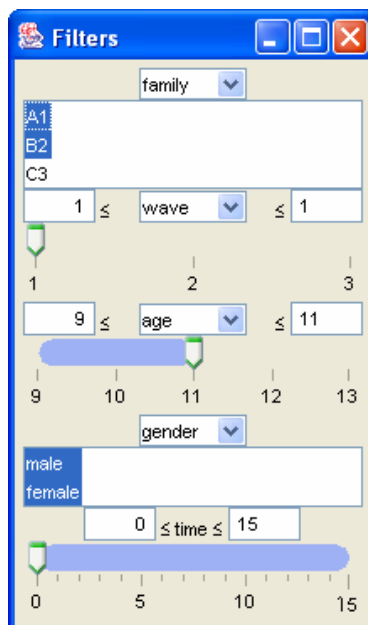


Figure 3. The Filters Window that can be used to select one, some or all of the trajectories.

2.2 The Filters Window

Figure 3 shows the filters window of the example trajectories displayed in Figure 2. In this example, the trajectories selected are from families A1 and B1 at wave 1 of the study and these children were between the ages of 9 and 11 at that time. Any number of filter variables can be included in a project, although only up to 6 can be displayed in the filters window at any one time. Categorical filters (Family and Gender in this example) allow the user to select multiple, non-adjacent values (i.e., A1 and C3) but ordinal filters only allow a continuous selection. The last filter is always time. This slider can be used to select a window of time, or it can be used to scroll through the sequence displayed by selecting a window and then moving the slider. The selection of filters also constrains the measures that are displayed or exported for analysis.

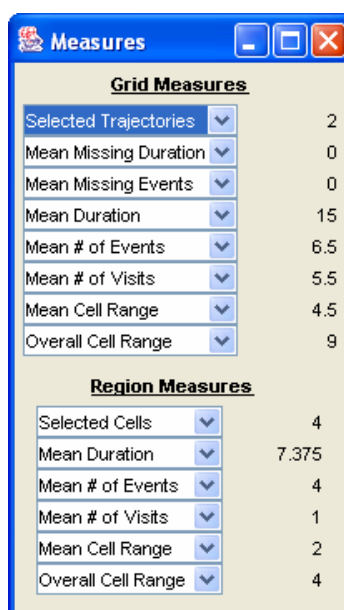


Figure 4. The Measures Window with a few of the many possible measures displayed for the whole grid and the selected region (see Figure 2).

2.3 The Measures Window

Figure 4 shows the measures window of the example trajectories displayed in Figure 2. Measures derived from the grids can either describe patterns across the whole grid or within a cell or region that has been selected. For the whole grid, these include: total and mean duration, number of events, transitions, number of cells occupied, and dispersion (an index based on proportional durations). These are also available for selected regions. There are specific region or cell measures as well. All of these measures, including measures for each individual cell, can be exported as a tab delimited text file for use in other statistical packages.

3 State Space Grid Examples

State space grids open up new possibilities for research designs and analyses. The measures derived from state space grids have been successfully applied to a handful of studies on child and adolescent development and several more are in the works. The examples I have chosen represent how this technique has been applied at different time scales. In each of these examples, parents and children were coded for their emotional displays during several tasks, usually discussions. These emotion codes formed the categories of each grid dimension.

3.1 Rigidity in Parent-child Interactions and the Development of Problem Behaviors in Early Childhood [5]

The continuum from rigidity to flexibility is easily captured by several grid measures. As shown in Figure 5, the grid on the left is more rigid (less flexible) than the grid on the right. In particular, the dyad on the left occupies fewer cells, makes fewer transitions (fewer lines), and has higher mean durations (bigger plot points) than the flexible dyad on the right. Using these measures, we were able to show that higher rigidity in parent-child interactions at the beginning of kindergarten predicted growth in aggressive and antisocial behaviors over the subsequent 18 months.

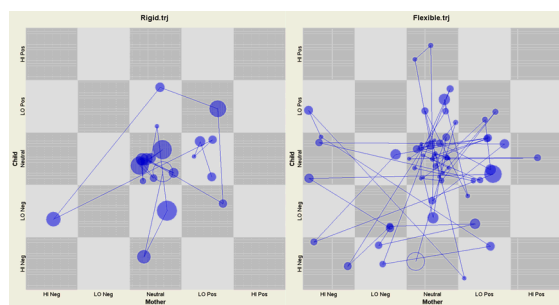


Figure 5. Two example state space grids that differ on the rigidity-flexibility dimension. The grids on the left depicts more rigid behavior, the grid on the right depicts more flexible behavior.

3.2 A Developmental Phase Transition across Early Adolescence [2]

As an adaptive dynamic system changes in structure it goes through a *phase transition*: a period of instability and high variability observed when one stable pattern or structure breaks down and a new structure emerges in its place. The transition through early adolescence has been described in the same way. In this study we examined whether families with boys traversing the transition into adolescence would show a peak in variability

characteristic of a phase transition. Boys and their parents were observed every other year for ten years, beginning when the boys were 9-10 and ending when they were 17-18 years old. The middle of the 5 waves corresponded with early adolescence (age 13-14). Thus, we examined whether the number of cells or transitions derived from the state space grids of their interactions would peak at the transition wave. As shown in Figure 6, both the number of cells and transitions peaked right at the early adolescent transition.

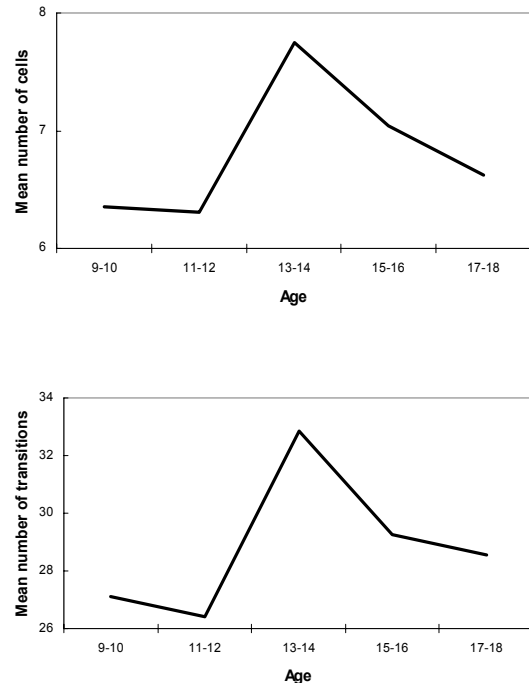


Figure 6. The mean number of cells (top) and transitions (bottom) during parent-boy interactions from late childhood to late adolescence.

3.3 Measuring Behavioral Change through Comparisons of State Space Grids Over Time [8]

This study took a novel approach to examine changes in state space grid patterns for evidence of a phase transition. These grids were constructed from ordinal data on one toddler along 2 dimensions during a frustrating toy task: attention to the toy and attention to mother. Thus, repeated activity in one cell or region was considered a child's behavioral attractor. The toddlers were observed once a month for 12 months and grids were constructed for each time point. In order to test for the degree of stability or change from month to month, 2 novel methods were used. First, the durations in the cells of all of the grids across all of the months were entered into a cluster analysis. Each grid was identified as a member of one cluster. Then, each child received a month to month cluster change score (1 if the cluster changed, 0 if it didn't). The average cluster change score peaked at the hypothesized phase transition age of 18-20 months. The second method to compare grids was an inter-grid distance score. With this method, each cell in grid A was subtracted from the same cell in grid B using a Euclidian distance algorithm. The sum of the squared differences between monthly grids also peaked at the hypothesized transition age.

3.4 The Effect of Negative Emotions on Flexibility [4].

Flexibility is known to increase under conditions of positive emotions and decrease in the presence of negative emotions. Until the advent of state space grids, socioemotional flexibility has been difficult to measure. One of the goals of this study was to use state space grids to look at changes in mother-daughter flexibility as they went from discussing a positive topic to a self-identified unresolved conflict and then back to a positive topic again. State space grids can be used to look at specific content or attractors as well as overall patterns of behavior. In this study, negative emotion was measured as the number of visits to and the duration in the negative emotion region of the state space. Flexibility included cells and transitions, as in the previous study, but also mean duration and dispersion (a new devised measure that combines duration information with the number of cells). Negative emotion, as expected, was highest during the conflict and dropped off again during the last, more positive interaction. Flexibility changed in the opposite way, as expected – the dyads were most flexible during the positive discussions. Two other interesting results emerged. The dyads were less flexible (but not more negative) during the last positive discussion. Thus, the conflict had a lingering effect. The girls were grouped according to the amount of current stress (high vs. low). The low stress group responded to the changing contexts in the way just described for the whole sample. The high stress group, however, were less flexible in the positive tasks and showed little change across the different contexts.

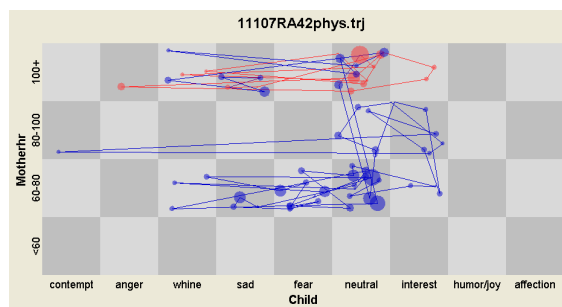


Figure 7. Child's affect with mother's heart rate. Red indicates when child's heart rate was high.

3.5 Combining Psychophysiological Data with Coded Observations

With the release of the next version of the Noldus Observer, researchers will be able to easily record video and psychophysiological data simultaneously. This opens up a whole world of possibilities for the application of state space grids. My colleagues and I have just started analyzing some pilot data that combines these two measurement types and an example grid is shown in Figure 7. This is a grid of mother's heart rate (y-axis) and child's affect (x-axis) and the child's highest heart rate is colored red. In this example, you can see that both the mother's and the child's heart rate was in their highest category at the same time. Of course, many issues of collapsing the continuous heart rate data emerge (the next version of GridWare will allow for continuous and categorical data), but as this is the very first image of behavior and biology on a state space grid, the possibilities are exciting. With better measurement techniques this can only improve.

4 Conclusions and Future Directions

Although state space grids have so far been used primarily for developmental research on social and emotional processes, there are clearly many more research areas that could benefit from this technique. I am currently working on various projects that use hourly and daily sampling methods, eye-tracking data, and group interactions. One of the tricks with this research is how to construct the state space, which informs the coding process as well. As with coding, the construction of the state space is an integral part of the research design [1]. My hope is that more researchers from varied disciplines will find this technique useful and informative for their inquiries.

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