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Consequences of Continuity: The Hunt for Intrinsic Properties within Parameters of Dynamics in Psychological Processes

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A little over three hundred years ago Sir Isaac Newton wrote of a simple set of relations that could be used to predict the motions of objects relative to one another. The main advantage of this insight was that the relationship between the movements of the planets and stars could be predicted much more simply than with the accurate, but cumbersome Ptolemaic calculations. But perhaps the most important consequence of the acceptance of Newton's insight was that *intrinsic properties* such as mass could be distinguished from *measurements* such as weight. The success of Newtonian mechanics led directly to the widespread use of parameters such as force, relative speed, and momentum as a way of understanding the dynamics of moving objects. A similar revolution in thinking appears to be underway in the behavioral sciences. It is likely that intensive longitudinal measurement coupled with dynamical systems analyses will lead to simplified but powerful models of the evolution of psychological processes. In this case, it is reasonable to expect that a set of intrinsic psychological properties may be able to be extracted from the parameters of successful dynamical systems models. The purpose of this article is to issue an invitation to the hunt, to provide a tentative map as to where the game might likely be found, and blow a call on the hunting horn.

Introduction

Human behavior is marvelously complicated. The aim of multivariate experimental psychology is to gain understanding of human behavior through observed correspondences between quantitative measurement and theories expressed as mathematical models. In order for this aim to be fulfilled, regularities must exist in the structure of the behavior, quantitative measurement must reliably capture these regularities, and theories must lead

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to models that correspond to the structural regularities in the behavior. Much progress has been made within the framework of multivariate measurement and modeling, but much remains to be done. It is important to recall that spending time developing measurement and modeling methods is rational only if one considers the hypothesis of regularities in the structure of behavior as reasonably likely to be confirmed.

I will be focusing on the logical consequences of three general hypotheses about the structure of behavior over time. These are hypotheses that I consider to be reasonably likely to be confirmed by experimental evidence from many domains. If so, there are interesting implications for extending multivariate measurement and modeling to hunt for and capture regularities in human behavior that have thus far eluded detection in the structure of: personality, social interaction, development, cognition and abilities. This article will present these hypotheses, elucidate the implications for structural regularities by the use of argument and physical analogy, discuss and illustrate methods likely to be useful in measuring and modeling behavior exhibiting such regularities, and summarize some potential benefits and pitfalls in the hunt.

Some Hypotheses Concerning Psychological Processes

Let us begin by examining three nested hypotheses concerning the time evolution of a psychological process. For the purposes of this article, a psychological process will be defined as some psychological construct which exhibits change over time in a theoretically interesting way. Thus, the way that a psychological process changes over time may be as interesting as its measured value at any moment in time. A few of the many examples that fit this definition include: decade to decade changes in cognitive abilities (Donaldson & Horn, 1992), year to year changes in adolescent substance abuse (Boker & Graham, 1998), month to month changes in seasonal affective disorder (Sarrias, Artigas, Martínez, & Gelpí, 1989), week to week changes in self-reported mental health in recent widowhood (Bisconti, 2001), day to day changes in mood in rapid cycling bipolar disorder (Gottschalk, Bauer, & Whybrow, 1995), minute to minute changes in anxiety levels of children in to response to perceived marital discord (Cummings & Davies, 2002), second to second changes in interpersonal coordination of gestures during conversation (Rotondo & Boker, 2002), and millisecond to millisecond changes in neurophysiological evoked response (Hari, Rif, Tiihonen, & Sams, 1992). Each of these examples has the property that change in the values of variables designed to measure the construct may be of as much, if not more, interest than an aggregated value of the variables at any one time.

One of the main goals of this article is to present an argument that most psychological constructs should be viewed as psychological processes. This is certainly not a new idea. For instance, Cattell (1959) argued in favor of a dynamic calculus linking the time evolution of motivation and personality into decisions resulting in behavior. In order to formalize these ideas, I propose three general hypotheses about change in psychological constructs.

Hypothesis 1: Continuity

Suppose that the theoretical true score of a psychological process can be represented as a vector **X**. A psychological process will be considered to be *continuous* over an interval of time from t to $t + \tau$ if **X** meets the following two criteria.

First, **X** must take on some value at every moment during the interval t to $t + \tau$. Thus, if two theoretical true scores of the construct were observed at times t and $t + \tau$, the construct can be assumed to have existed and had some value for all times during the interval between t and $t + \tau$. Observations of the theoretical true score of the construct during this intervening interval are missing, but could have been made.

Second, suppose two theoretical true scores $\mathbf{X}(t)$ and $\mathbf{X}(t + \tau)$ were observed at times t and $t + \tau$. Then for each element index i in the vector **X** the construct must have taken on each value between $x_i(t)$ and $x_i(t + \tau)$ during some time during the interval between t and $t + \tau$.

In practical terms, one may consider continuity in the context of a two dimensional map. Suppose you take a continuous journey from a city at latitude 40 north to a city at latitude 50 north, then no matter what your route, you must have at some time traveled through or flown over all of the latitude values between 40 and 50. Even if you take the long way around the globe. The only alternative is a discontinuous journey using some fantastic device like a "transporter" from Star Trek to instantaneously jump from place to place.

The remainder of this talk presupposes that psychological constructs do not jump instantaneously from value to value, but instead exhibit continuous change. While it is not impossible that some constructs change instantaneously, I propose that it is reasonably likely that many if not most psychological constructs do change in a continuous manner (see e.g. Kagan, 1979, for a discussion of continuity and discontinuity in development).

Hypothesis 2: Differentiability

A psychological process will be considered to be *differentiable* over an interval of time from t to $t + \tau$ if the theoretical true score $\mathbf{X}$ for the process is continuous and its derivatives with respect to time are also continuous within that interval. Consider the first derivative of $\mathbf{X}$ with respect to time, essentially the linear slope tangential to the trajectory of $\mathbf{X}$ at one moment in time. If the psychological process is differentiable, then the slope of $\mathbf{X}$ must exist for all times between t and $t + \tau$ and there must be no instantaneous jumps in the value of that slope. Similarly, the curvature of the trajectory of $\mathbf{X}$ over time must be continuous if the psychological process is to be differentiable.

There are a number of interesting systems that are continuous but not differentiable, among them many forms of fractals (Bak & Chen, 1989; Mandelbrot, 1983). It may be that some important psychological processes will turn out to have a time evolution that is fractal in nature (e.g. Collins & De Luca, 1994; Paulus, Geyer, & Braff, 1996). However, I propose that it is reasonably likely that many, if not most, psychological processes are differentiable; that is to say that they change in a relatively smooth way. I also submit that it is rational to test a simple and reasonable alternative prior to testing more complex alternatives. I will therefore hypothesize differentiability of psychological processes in order to explore the consequences that may result.

Hypothesis 3: Structure in Relationships between Derivatives

If a psychological process is continuous and differentiable, then one may consider the relationship between the theoretical true score $\mathbf{X}$ and the derivatives of $\mathbf{X}$ at any moment in time. This relationship may exhibit a pattern that is either constant, or is predictably changing over time. If so, the psychological process exhibits an *intrinsic dynamic* that can be expressed as a differential equation.

Suppose now that there are two continuous, differentiable psychological processes with true scores $\mathbf{X}$ and $\mathbf{Y}$. If the relationship between $\mathbf{X}$ and $\mathbf{Y}$ and the derivatives of $\mathbf{X}$ and $\mathbf{Y}$ exhibit a predictable pattern, then these two processes have *coupled dynamics* that can be expressed as a system of differential equations.

I hypothesize that many, if not most, psychological processes are likely to have continuous, differentiable dynamics such that repeated measurements of those processes will produce data that can be fit using systems of differential equations in such a way that the regularities in the relationships between the derivatives of the respective theoretical true scores will become evident.

This hypothesis rests on two assumptions in addition to the hypotheses of continuity and differentiability. First, sufficient quality of repeated measurement must exist in order to reliably sample manifestations of the processes involved. Second, modeling procedures must exist that can accurately estimate regularities between derivatives. While much work remains to be done with respect to the methodological complications of measuring and fitting processes with differentiable dynamics, there is increasing evidence that some solutions to these two problems do exist.

I will return to a discussion of some of the methodological problems inherent in the estimation of differentiable dynamics. But first allow me to present an argument from physical analogy in order to elucidate what is meant by regularities in the relationships between derivatives of a process and in order to give an idea of what the discovery of such regularities might gain in terms of understanding that process.

The Motion of the Planets

Prior to the heliocentric view of the solar system, planets were observed to have complex movements in the heavens. From our observation post on Earth, these movements were tracked and recorded. Though complicated retrograde motions were measured, these movements were predictable from season to season, from year to year, and from decade to decade. Clearly such accurate prediction meant that the Ptolemaic view of the solar system as being terracentric was a good model. Copernicus advanced a heliocentric system which simplified the motions and was equally accurate in its predictions. Had William of Occam still been alive, he might have argued in favor of Copernicus on grounds of simplicity, but religious authorities tended to argue in favor of Ptolemy. The choice between models for the solar system might have seemed to many to be a philosophical one.

While this debate continued, Galileo noted that falling objects of differing weights exhibited constant acceleration towards the Earth. Newton used his newly developed Differential Calculus to examine the consequences of this puzzling constant acceleration and eventually succeeded in formulating three simple principles that governed the motions of objects. These “laws of motion” decomposed the observed regularities between the velocity, acceleration and displacement of objects in such a way that a wide variety of earthbound phenomena could be accurately predicted: from the trajectories of projectiles to the regular motions of a pendulum.

The motions of the planets could be brought into this same schema by presupposing a force acting between heavenly bodies separated by a distance: that is, gravity. The motions of the planets could thus be decomposed into orbits which exhibited regularities between their derivatives identical to the regularities observed at a much smaller scale on earth. In order for these regularities to hold across the different planets, a new property of matter was required: mass. An object small enough to hold in the hand had an intrinsic property of mass and so did a planet. By dividing the force due to gravitational acceleration into the weight of an object, one could estimate its mass. By observing the effects of the sun and the planets on each other, one could estimate the mass of each of the objects in the solar system.

The unreasonable success of Newtonian mechanics at predicting such a wide variety of phenomena with such a simple set of rules effectively ended the argument between the Ptolemaic and Copernican views of the solar system. How was it that Newton was able to succeed when so many of genius before him had looked at the same phenomena and had failed to see the unifying principles? Newton focused on the regularities between the derivatives of the systems in question. His application of Differential Calculus made apparent a simple order that had eluded others. More recent views of gravitation are phrased in terms of the second derivative (i.e., curvature) of space, thus reminding us that it is the relationship between the derivatives of systems of objects that are the important regularity here, and not some derived "law of gravity".

Consider once more the difference between weight and mass. Weight is a very useful measurement. One stands on the bathroom scale in the morning and notes with dismay the effects of last night's rich dessert, perhaps reinforcing an inuitive prediction model relating eating behavior and garment size. But more generally, one's weight can be considered to be a measurement of the force due to the curvature of space generated by two objects: oneself and the Earth. This view is helpful to consider if one is expecting to be traveling to other planets. Furthermore, and more germane to the present topic, it is an important distinction to keep in mind prior to drawing analogies between physical and psychological measurement or between physical and psychological change.

Measurement is always relative to some frame of reference. When the frame of reference is unchanging and does not affect the measured object, this relativity of measurement can be ignored. A bathroom scale gives an accurate and linear estimate of your mass for several reasons: your mass is very small in relation to the mass of the Earth, the distance between you and the center of the earth is relatively constant, the mass of the Earth doesn't change much as a proportion of its total mass, and the act of stepping on the scale doesn't change the mass of your body much as a proportion of its total. However, suppose the frame of reference is changing or affects properties of the object to be measured. I submit that regularities in the relationship between the derivatives of the object of interest and the derivatives of several frames of reference may provide the only way to estimate the intrinsic properties of both the object and the frames of reference and thus ultimately derive a stable estimate of the quantity sought to be measured.

Psychology is More Diffcult than Classical Physics

It has been over 300 years since Leibnitz and Newton independently developed differential calculus. If regularities between the derivatives of psychological processes exist, why aren't they well known by now? Dynamic mechanisms have long been hypothesized in psychology (Cattell, 1959). However, only recently have researchers begun to test models that are based on differential equations (e.g. Hamagami, McArdle, & Cohen, 2000). Why has it taken so long? Let us consider some of what Newton had at his disposal and compare that to what is available to quantitative psychologists today.

To begin to tackle the problem of the motions of the planets, Newton needed reliable measurements of quantities such as the acceleration of falling objects near the surface of the Earth, the period of the orbit of the moon, and the distance from the Earth to the moon. Each of the measurements on which Newton's calculations relied was precise and nearly independent of frame of reference problems.

Psychology is more difficult than classical physics due to at least two differences between the fields: differences in the nature of the empirical data and differences in the complexity of the underlying processes. Let us examine these two differences in turn.

Psychological data share little of the convenient aspects of physical data from astronomical observation. The relation of empirical psychological data to unobservable psychological processes presents measurement problems, the frame of reference for measurement is often undergoing change during the interval in which data are collected, and the interaction between the observed process and the frame of reference is frequently non-negligible. In psychology, the problems posed by measurement are many and difficult. Sophisticated techniques have been developed for measuring theoretical constructs that generally cannot be directly observed. Many of these techniques use multiple variables assumed to be observed simultaneously in order to estimate the effects of latent constructs on variables that can be observed.

While it is theoretically possible to estimate the effects of the derivatives of a construct, it is a difficult measurement problem. Observations of multiple variables must be made at multiple time points and from them the effects of latent constructs and their derivatives must be simultaneously estimated. One must also consider the possibility that during the interval of time between the first observation and the last observation the frame of reference may have changed. Thus one must always consider measurement of the frame of reference simultaneously with the psychological process of interest. Finally, one must also consider the possibility that the psychological process has been affected by the act of measurement within the context of the frame of reference. Thus one must consider extending data collection to measurement within several contextual frames of reference.

The second reason psychology is more difficult than classical physics is that psychological processes are likely to be more complicated and have higher numbers of degrees of freedom than physical processes. A system composed of only the earth and the moon has few degrees of freedom and an estimate of how many variables might be involved can be logically derived. However, the logical upper bound on the number of degrees of freedom in the human brain is extremely large. Consider a gross simplification such that at one moment in time each neuron is either firing or not firing: a binary variable. If there were on the order of 100 billion neurons, then the number of possible states which a brain could take on is on the order of 2 to the 100 billionth power (Mead, 1990).

By this logic, the chance that we would, in our lifetimes, ever measure predictable behavior during a psychological experiment is vanishingly small. Since reliable behavior is often observed, the number degrees of freedom for the psychological processes involved must be a reasonably small number in comparison with the theoretical upper bound. Thus, the number of coupled psychological processes that are required to reliably model human behavior can only be determined empirically.

Suppose we were to assume that the measurement issues were solved. Any pattern of regularities between derivatives of psychological processes would still be of an unknown complexity. We would need to find out how many processes were coupled together, how many of their derivatives were involved, and how the pattern might be varying over time or context. In addition, we would need to know the nature of the interactions between the variables and their derivatives. If a system of differential equations includes terms in which variables or their derivatives have been multiplied, then there is the potential for that system to be chaotic under some circumstances (see Ruelle, 1991, for an introduction). The complexity of the behavior of such a nonlinear system is such that empirical observations of a chaotic system with a small number of degrees of freedom may appear as indistinguishable from a linear system with large number of degrees of freedom (Abarbanel, Brown, Sidorowich, & Tsimring, 1993).

The problems posed in the attempt to measure and model psychological processes are much more difficult than those posed by classical physics. Are we then to despair of ever understanding psychological processes? There are several reasons why I believe we should have a more optimistic estimate of our chances. First I will discuss some likely consequences of the three hypotheses presented earlier and then I will discuss a successful empirical application of this logic.

Consequences of Continuity and Differentiability

Consider the consequences of the hypotheses of continuity and differentiability of a psychological process. If these hypotheses hold for a particular psychological process, then according to the definitions above, it exhibits smooth change in its true score. What sorts of mechanisms might be at work that would result in smooth change in a theoretical true score? One possibility is that such a true score might have an intrinsic quality similar to mass that would damp or smooth out abrupt changes in its derivatives, resulting in a continuously differentiable system even in the presence of discontinuous exogenous effects. Among candidate psychological examples of such a quality are the buffering effects of social support. A second possibility is that the psychological process in question is closely coupled to another process that is continuous and differentiable, for instance diurnal or seasonal cycles. Both of these possibilities seem plausible and they are not mutually exclusive of each other. Let us consider them each separately and then in combination.

Mass and Force

Suppose a psychological process possessed an intrinsic property analogous to mass. How would such a property manifest itself so that it could be detected and measured? If the analogy to mass holds and if the process were changing at a known rate, in other words if its first and second derivatives were known, then mass could be measured by applying a known force to the process and finding how much change this intervention induced in the first and second derivatives of the process within some given interval of time. This method assumes that a property analogous to the force due to the intervention exists and can be measured.

Let us assume the existence of a property of an intervention akin to force. How could it be detected and measured? If an intervention with an unknown force were applied to a psychological process with known derivatives and known mass, one could calculate the force that would have been required to effect the observed change in the derivatives of the process.

It seems that we are no further along than we were before: mass and force appear to be completely confounded. How did Newton solve this problem? If all he had were a single object with an unknown mass and a single method of exerting an unknown force, he would be in the same situation in which we find ourselves. However, suppose we are given several objects of differing mass at several distances from each other. From observations of changes in the derivatives of these objects, it is possible to derive the function relating the force to the square of the distance between the objects and the product of their masses.

The functional form for gravity may tell us little, if anything, about psychological processes. However, I do believe that this thought exercise has much to tell us about the search for intrinsic properties of psychological processes. Consider what will be required in order to disentangle these hypothetical qualities of force and mass. We will need multiple measures exhibiting variance in both force and mass across several processes. Also, depending on the functional form of the relation between the derivatives of the psychological processes, we may need some other independently measured variables. To me, this sounds very much like multitrait-multimethod measurement (Campbell & Fiske, 1959) applied to test functional relationships between derivatives; that is, applied to systems of differential equations.

Coupling to External Processes

A second possible reason why a psychological process might exhibit smooth change is that it might be coupled to some other continuous differentiable process. There are many candidates for such processes: the seasonal fluctuations in length of daylight, the daily diurnal-nocturnal cycle, cycles in blood sugar driven by food consumption, the temporal course of a variety of hormone fluctuations. Each of these processes are continuous and differentiable due to the physical systems from which they arise. Any psychological process coupled to such a physical system would exhibit a smoothness to its derivatives that would result in continuous and differentiable change over time.

The strength of the coupling between two processes can be estimated from the relationship between their derivatives. One may therefore test the hypothesis that a psychological process is significantly coupled to a physical process from longitudinal observations of both processes. As long as the coupling is reliable over time, this test can be made either using one of several available methods (Boker & Nesselroade, 2002; Jennrich & Bright, 1976; Singer, 1998) for fitting systems of differential equations to longitudinal data.

Intrinsic Dynamics in Addition to Extrinsic Coupling

But the existence of coupling between a psychological process and a particular physical process does not imply that the psychological process has no intrinsic relationship among its derivatives. While hunger and sleep cycles appear to be tightly coupled to the diurnal-nocturnal cycle, when individuals are isolated for long periods in a cave and completely cut off from all clues as to time of day, they still exhibit regular cycles of hunger and sleep. It may be that many psychological processes possess relationships between their derivatives that define intrinsic dynamics independent from their coupling to physical processes.

With possibly many physical and psychological processes coupled together it might be difficult to separate the intrinsic dynamics of a particular process from the many influences due to coupling. One way to increase the chances that we might observe the regularities among derivatives is to make repeated observations shortly after a large perturbation or shock to a system. In such an instance, existing intrinsic dynamics will be most likely to be apparent. Let us take a brief look at an example analysis of an intensive longitudinal study of recent widows.

Example: The Widowhood Study

One of the most stressful events in a lifetime is the death of a spouse (Holmes & Rahe, 1967; McCrae & Costa, 1988). Bisconti (2001) performed a study in which 40 recent widows were contacted within two months of the loss of their husbands and 19 of the widows were asked to fill out a daily Mental Health Inventory (MHI; Veit & Ware, 1983) scale for 90 consecutive days. The MHI is a 36 item instrument that has been reported to be organized as 5 first order factors: Anxiety, Depression, Emotional Ties, General Positive Affect, and Loss of Behavioral Emotional Control; and two negatively correlated higher order factors: Distress and Well-Being. One reason that the MHI was selected for this study is that it has high internal consistency and yet also has low test-retest correlation. If one wishes to measure change it is best to select instruments that are sensitive to any fluctuations in an individual's behavior. Recall that instruments with high test-retest correlation are likely to be insensitive to intraindividual change.

In order to gain an exploratory sense of the pattern of change in this self-reported scale, a naive total score was constructed by reverse coding all items with negative meanings, calculating a sum score, and then plotting these data with respect to time for each individual. Figure 1 contains plots from four representative individuals. A loess nonparametric smoothing of each individual's data was calculated and the result is displayed as the lighter of the two lines in each plot. The individuals' data displayed in Figures 1-A and 1-C appear to have a pattern that is a periodic oscillation, whereas those in Figures 1-B and 1-D appear to have little, if any, periodicity. Recall that a smoothing function such as loess tests no model against the data, but does remove high frequency components.

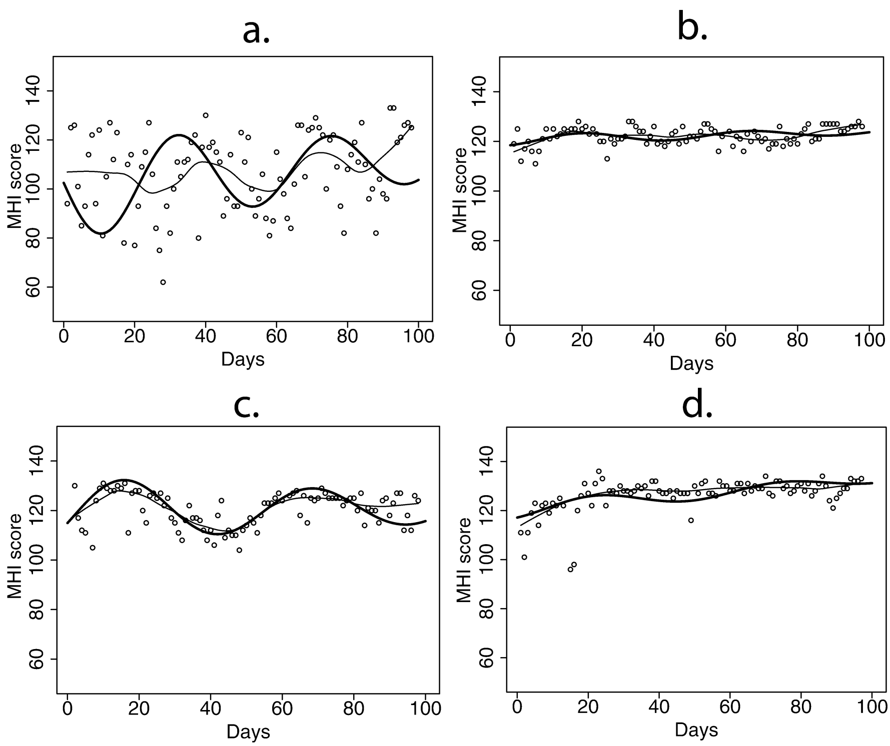

Figure 1
Four Widows' Daily Self-Reported Mental Health Inventory (MHI) Total Scores

Now consider fitting a model to these four data sets in which the derivatives of this MHI total score are related to one another. If the MHI score for individual i at time t is $x_i(t)$ then let

$$\ddot{x}_i(t) = b_{i1}\dot{x}_i(t) + b_{i2}x_i(t) + e_i(t). \tag{1}$$

When this model was fit to the detrended data from the 19 recent widows, two main conclusions were drawn. First, the null hypothesis that the intraindividual variability was normally distributed measurement error was rejected: this differential model explained more variance than would be expected by chance. Second, the b_{i1} parameter associated with how quickly the individuals reduced their periodic oscillation in MHI could be predicted from two other variables in the study. Greater amounts of emotion focused coping tended to be associated with quicker damping to equilibrium and greater amounts of problem focused coping tended to be associated with slower damping to equilibrium.

Each of the darker lines in Figure 1 plots an example trajectory generated from a system exhibiting the coeffcients estimated from the respective individuals' data. Each trajectory was generated by assuming two initial conditions estimated from the data. While there is evidence of significant individual differences in the coeffcients of the model, these differences are small in comparison with the differences in the example trajectories. The majority of variation between the example trajectories is due to individual differences in the initial conditions.

My intent in presenting this example is twofold. First, these data represent a successful example of the application of differential equation models as a tool for understanding behavior that may constitute a self-regulatory process. A self-regulatory process implies intrinsic dynamics, although these dynamics need not necessarily take the form of regularities between the derivatives of variables measuring the process. This example is thus a demonstration that the three hypotheses set out at the beginning of this article are not unreasonable in at least one instance.

The second reason for introducing this example is to present some possible implications of the particular differential equation model used in this experiment (Equation 1). This model can also be used to describe the behavior of a pendulum with friction. A pendulum composed of an object on the end of a rod swings at a frequency that is dependent on a length of the rod and not on the mass of the object at the end of the rod. The acceleration due to gravity is constant on the object and the more the object is displaced from equilibrium, the closer is the alignment between the direction of the force due to gravity and the direction of movement of the object. Thus the displacement of the pendulum is linearly related to the acceleration due to gravity.

Imagine two pendula with the same resistance due to friction at the pivot and with the same length of rod. One pendulum has a small mass at the end of the rod while the other pendulum has a large mass. The pendulum with the small mass would come to rest sooner than the pendulum with the large mass. The rate of damping of the pendulum is related to the mass of the object at the end of the rod.

Now imagine two pendula with the same length rod, the same amount of friction and the same mass at the end of the rod. One pendulum is on the moon and the other is on the Earth. The pendulum on the moon would swing more slowly than the pendulum on the Earth but both would come to rest at the same time.

How should we interpret the results of fitting Equation 1 to the data from the widows? One possible explanation is that there is some special purpose self-regulation mechanism that the Mental Health Inventory total score was tapping into. This explanation would posit adaptive changes in behavior resulting from some mechanism that detected and adjusted the underlying construct until it once again came into equilibrium.

A second possible interpretation of these results is that the regularities in the relationships between the derivatives of the MHI total score provided indirect evidence of a general field that might affect many psychological constructs. This hypothetical field would exhibit curvature so that constructs whose values deviated from being perpendicular to that field would be accelerated proportional to their deviation from perpendicular. Given the data and the models used, these two explanations cannot dissociated from one another. However, multivariate measurement and latent variable differential equation modeling of several constructs returning to equilibrium in several frames of reference may allow us to distinguish between these two interpretations.

Potential Consequences for Quantitative Methods

If regularities in the relationships between the derivatives of continuous differentiable processes do exist and can be identified and estimated, there may be several potential opportunities for improvements in quantitative methods. I will summarize a few of the possible areas that I consider to be likely to benefit.

If regularities among derivatives exist for groups of manifest variables, it may provide another tool to help develop more accurate and reliable scales.

If regularities among derivatives of theoretical true scores exist, it may provide a tool to improve the identification and correction of measurement issues for the latent variables representing those true scores.

Reliable patterns of relationship between derivatives of latent variables may also help identify missing variables. Consider how the planet Pluto was discovered. Originally, it was not directly observed. Instead, an irregularity in the symmetry of the motions of the known planets allowed the inference of the existence of Pluto and provided a likely orbit which was subsequently targeted optically. Similarly, latent variables for which there are no known indicators may still disturb regularities between the derivatives of latent variables that are identified by observation.

Finally, the symmetry or regularity between derivatives of factors may help with the number of factors problem. Factors that hang together may exhibit more reliable patterns of prediction between derivatives than do factors that might be better split into two.

What Could Go Wrong?

Suppose that one accepts that there is a reasonable likelihood that regularities exist between the derivatives of many psychological processes. To what sort of mistakes might this decision lead? In the brief time remaining, I will discuss a few of the potential hazards in the hunt.

The first and perhaps most serious potential mistake is that one might be tempted to accept analogies based on physical processes as correct in application to psychological processes. While some physical analogies may be useful, it is unknown whether psychological processes bear any more than superficial resemblence to physical processes. It is important to test any physical analogy by fitting models to data. Even when such models seem to fit well, one must be careful to recall that psychological processes may fit the same models as physical processes for different reasons.

In the course of this article I have made extensive use of physical analogies in order to communicate some possible forms that the structure of the relationships between derivatives of psychological processes may take. Please do not take this to mean that psychological constructs have properties such as force, mass, momentum or gravity. While we may find that some of these analogies are apt, it may be that some or all of them are misleading. It is too early to tell which is which.

The second mistake that might be made is that there may not be any pattern to the relationship between derivatives of psychological processes. In this case, the search for such relationships will turn out to be in vain. Occasionally such relationships would still be found, but these would simply be Type I errors. This mistake is not so serious. Although some time would have been lost, disconfirming models is how science advances. If we pursue the hunt for regularities between derivatives, we must also keep in mind what conditions would signal the time to call off the hunt.

A third mistake that could be made is that some simple models might turn out to be unreasonably successful. This would lead to optimism and simple theoretical explanations for the discovered regularities. But the true system might be much deeper and more complicated. This type of local minimum in theory space has often been encountered in a wide variety of disciplines. One must always be alert for this type of mistake.

A final problem, which is a diffculty rather than a mistake, is that the regularities between derivatives may not be invariant over time. In fact, it may be that these regularities are one way of effciently controlling a psychological process without resorting to the direct manipulation of a large number of degrees of freedom. This problem would manifest itself as nonstationarity in the variables used to measure the psychological process. In work in my lab, we have seen some variables that have highly patterned relationships between derivatives over any particular short interval of time and yet have no apparent stable pattern over longer periods of time. One example of this type of system is patterns of coordination between gestures of individuals engaged in conversation. This type of problem will require new analytic methods that can simultaneously extract short term relationships between derivatives and treat the resulting pattern as a process in and of itself.

Conclusion

It is my contention that many, if not most, psychological processes are reasonably likely to be continuous and differentiable. I also contend that the true scores of such processes are reasonably likely to exhibit predictable regularities between their derivatives. If these two hypotheses turn out to be upheld, it is likely that a great deal can be learned about the structure of psychological constructs and the time evolving nature of human behavior by modeling intensive longitudinal measurements using differential equations. I believe that the hunt for regularities between the derivatives of psychological processes is reasonably likely to be successful and that the expected payoffs greatly exceed the risks.

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