A model for personality at three levels

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Abstract

People differ. How and why they differ are the fundamental questions for personality psychologists. In this article we address three levels at which people differ: within individuals, between individuals, and between groups of individuals. A dynamic model of personality is considered where traits are seen as rates of change in states in response to environmental cues. Within individuals, motivational and behavioral states show inertial properties and lead to an analysis of rates of change and latencies of behavior. Between individuals, the analysis is one of frequency and duration of choices. When individuals self select into groups reflecting shared interests and abilities, the structure of these group differences reflects the consequences of the self selection. Examples of the dynamic model are given for each level of analysis.

Keywords: personality traits, dynamics of action, reinforcement sensitivity theory, multi level model, affect, behavior, cognition, desire, motivation, goals

1. Levels of individual differences

People differ. How and why they differ are the fundamental questions for personality psychologists. In this article we address three levels at which people differ: within individuals, between individuals, and between groups of individuals. Although the structure of differences at each level do not necessarily relate to the structure of differences at other levels, analysis of the temporal dynamics of differences suggests some hope for a unified model. The study of temporal dynamics in personality is not new (e.g., Atkinson and Birch, 1970, Carver, 1979, Carver and Scheier, 1982, Kuhl and Blankenship, 1979, Read, Monroe, Brownstein, Yang, Chopra, and Miller, 2010, Revelle and Michaels, 1976, Revelle, 1986) but, with few exceptions (Carver, 1979, Carver and Scheier, 1982, Read et al., 2010), has not had much impact upon personality theory, perhaps because a disproportionate amount of research has focused on the identification of interindividual personality structure rather than dynamics (Read et al., 2010). This is unfortunate, for the study of dynamics integrates aspects of choice, persistence, latency, frequency and time spent into a common framework. As we will show, by understanding temporal dynamics *within* people, we are able to explain patterns of choice *between* people and, by examining the cumulative effect of these choices in terms of time spent, to understand the ways in which individuals tend to *organize into groups* according to personality traits.

Personality is an abstraction used to describe and explain the coherent patterning over time and space of affects, cognitions, desires and the resulting behaviors that an individual experiences and expresses. People differ from themselves on a moment to moment basis in that they do not think, feel or act the same all the time. They change in their feelings, in their thoughts, in their desires and in their actions. To not change in response to a situation is maladaptive. When others evaluate our reputation, they are evaluating our behavior in critical situations and how it changes across situations. When we think of our identity, we interpret our behavior as the result of our affects and our cognitions.

A primary level of analysis of personality examines the patterning of ways in which people change. To observers, the dynamic stream of feelings, thoughts, mo-

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tives and behavior show a unique temporal signature for each individual. To an individual differences theorist, the issues of how and why individuals differ in their patterns are central to the domain of study (Costa and McCrae, 1992a, Eysenck and Himmelweit, 1947, Eysenck, 1981, Digman, 1990, 1997, Goldberg, 1990, Hogan, 1982, Hogan and Kaiser, 2005). To a biologically minded psychologist, these dynamic processes reflect genetic bases of biological sensitivities to the reinforcement contingencies of the environment (Corr, 2008a, Corr, DeYoung, and McNaughton, 2013), (DeYoung, Hirsh, Shane, Papademetris, Rajeevan, and Gray, 2010, Smillie, 2008), (Smillie, Cooper, Wilt, and Revelle, 2012, Smillie, Geaney, Wilt, Cooper, and Revelle, 2013). To a mathematically oriented psychologist, these dynamic processes may be modeled in terms of the differential equations of the Dynamics of Action (Atkinson and Birch, 1970, Atkinson and Raynor, 1974, Revelle, 1986).

Read and Miller and their colleagues (Read, Vanman, and Miller, 1997, Read et al., 2010) have pointed out that most who study the dynamics of personality within individuals tend not to be concerned with between individual structure, and vice versa. They (Read et al., 2010) have presented a neural network model that attempts to integrate dynamics and structure. The "Cybernetic Big Five Theory" proposed by (DeYoung, 2014) is an alternative (although less explicit) dynamic model which attempts to explain personality structure in terms of dynamic processes. Here we present a somewhat different formal model of dynamics that has similar goals to these other researchers.

By examining patterns of change *within individuals*, it is possible to organize the study of personality at a second level - that is, the analysis of the structure of differences *between individuals* in the coherent patterning over time and space within individuals. It is at this level that conventional trait theorists describe how people differ from each other in the frequency distribution of their actions (Fleeson, 2004, 2007a). Differences in sensitivity to the rewarding or punishing aspects of the environment are discussed at this level in terms such as *reinforcement sensitivity* (Corr, 2008a, Corr et al., 2013, Gray and McNaughton, 2000, Smillie, 2008, Smillie, Loxton, and Avery, 2011). We model differences at this level in terms of the rates of change in response to situational inputs and how these differences in rates of change result in differences in frequency and duration of various feelings, thoughts, and actions.

People also differ from each other in terms of important life choices; examples include choice of college major and career. As we will show, these choices reflect a dynamic interplay of abilities, interests, and temperament in response to the long term patterns of reinforcements achieved by each individual. These patterns of reinforcement, in combination with original differences in sensitivities to environmental cues can result in group differences that are structured in a completely different manner than the structure of personality normally seen at the interindividual level.

1.1. Different levels can be different

Before elaborating on the three levels introduced above, it is important to acknowledge that each of the levels may differ dramatically in both content and structure. Although it is well known that the structure within one level does not imply anything about the structure at a different level, this distinction is frequently forgotten. Indeed, Cattell (1943, 1946) (see Revelle, 2009) went so far as to suggest that the dimensions within individuals should be the same as those between individuals. That analyses at different levels should not be confused has been labeled the Yule-Simpson paradox (Armistead, 2014, Kievit, Frankenhuis, Waldorp, and Borsboom, 2013, Pearl, 2014, Simpson, 1951, Yule, 1903), the fallacy of ecological correlations (Robinson, 1950) and the within group–between group problem (Pedhazur, 1997). Indeed, to confuse the dynamics within individuals with the averages between individuals is to mistakenly assume ergodicity (Molenaar, 2004). A very clear exposition of the problem is found in Kievit et al. (2013).

This has not been a serious problem until recently, because much of traditional personality research ignored within subject variation and has examined the structure between individuals based upon self report inventories reflecting one's average level of feeling, thoughts, and behavior. But with recent developments in real time data collection (e.g., Electronically Activated Recordings (Mehl, Gosling, and Pennebaker, 2006, Mehl, Vazire, Holleran, and Clark, 2010), paper or electronic diary studies (Green, Rafaeli, Bolger, Shrout, and Reis, 2006, Rafaeli, Rogers, and Revelle, 2007) or cell phone based measures of activity (Wilt, Condon, and Revelle, 2011a), (Wilt, Funkhouser, and Revelle, 2011b)) in combination with improved understanding of multi-level modeling (Bliese, Chan, and Ployhart, 2007, Fleeson, 2007a), (West, Ryu, Kwok, and Cham, 2011) it is now possible to study the individual patterns of dynamics within individuals and relate these patterns to differences between individuals.

In a multilevel structure, observed correlations across individuals (r_{xy}) may be decomposed into within individual correlations ($r_{xy_{wp}}$) and between individual correlations ($r_{xy_{bp}}$). Similarly, the correlations between individuals when individuals are members of different groups reflects this within and between group correlational structure. As a simple example, consider the correlation between cognitive ability and alcohol consumption. Within individuals, the correlation is negative (alcohol consumption reduces cognitive performance) but between individuals, those with higher cognitive ability consume more alcohol (Batty, Deary, Schoon, Emslie, Hunt, and Gale, 2008). At any one occasion, the overall correlation between alcohol consumption and cognitive performance (r_{xy}) will reflect an unknown mixture of these two quite different correlations ($r_{xy_{wp}}$ and $r_{xy_{bp}}$). It is possible to decompose the correlation between two variables such as these into the between and within person correlations using the following, straightforward formula (adapted from Pedhazur, 1997):

$$r_{xy} = \eta_{x_{wp}} * \eta_{y_{wp}} * r_{xy_{wp}} + \eta_{x_{bp}} * \eta_{y_{bp}} * r_{xy_{bp}}$$

where $r_{xy_{wp}}$ is the within person correlation, $r_{xy_{bp}}$ is the between person correlation, $\eta_{x_{wp}}$ is correlation of the data with the within person values, and $\eta_{x_{bp}}$ is correlation of the data with the between person values.

This distinction between correlations at different levels is a fundamental part of multilevel modeling and will be important as we consider models of coherency and differences within-individuals, between-individuals, and between groups of individuals. That correlations may differ across levels does not imply that they always will, but the assumption that they do not vary (that they are ergodic) is one that should be tested rather than merely assumed.

2. Dynamics within individuals

Dynamic models imply more than the mere observation that people differ over time for this could just be random fluctuations around a mean level. Rather, the basic concept of individual dynamics is that time is a variable which needs to be modeled. One way to distinguish patterning over time from random variation around a mean level is to examine the *mean square successive difference* (mssd, von Neumann, Kent, Bellinson, and Hart, 1941) which effectively is a (negative) index of the trial to trial autocorrelation. A small mssd in comparison to the variance implies that although behavior may vary across trials, it does not vary much from one trial to the next.

Inspired by the work of Lewin, Adams, and Zener (1935), Zeigarnik (1927/1967), Feather (1961), and Atkinson and Cartwright (1964), the proposition that motivation and action have inertial properties was added by Atkinson and Birch (1970). That is, they proposed that a wish persists until satisfied and a wish does not increase unless instigated. (This is, of course, analogous to Newton's 1st law of motion that a body at rest will remain at rest, a body in motion will remain in motion.) By considering motivations and actions to have inertial properties, it became possible to model the onset, duration, and offset of activities in terms of a simple set of differential equations.

Unfortunately, the theory of the Dynamics of Action (DOA, Atkinson and Birch, 1970) was a theory before its time. Few psychologists of the 1970s were prepared to understand differential equations or develop computer models of difference equations. The exception seems to be those animal behaviorists studying control processes (Houston and Sumida, 1985, Toates, 1983). However, with a simple reparameterization (Revelle, 1986) and modern software and computational power, the model is much easier to simulate and examine. This article describes that reparameterization (the Cues-Tendency-Action or **cta** model) of the original theory and explores the power of including temporal dynamics in a theory of personality at three levels of analysis.

It is important to point out that the DOA-**cta** models are models of control in that they have feedback, but differ from some other models of control (e.g., Carver, 1979, Carver and Scheier, 1982, Miller, Galanter, and Pribram, 1960) in that they do not have a set point or comparator. That is, the the typical example of a control or cybernetic system is that of a thermostat controlling the temperature in a house, or of a ponderostat for controlling body weight, or a preferred arousal level to explain behavioral differences associated with the stimulation seeking of extraverts (Eysenck, 1967). In contrast, the DOA-**cta** models are open control models in the sense used by Bolles (1980). This distinction will be discussed in more detail when the models are reviewed.

Recent discussions of the **cta** model include Revelle (2012), which applied the model to the dynamics of emotion (e.g., Frijda, 2012), and Fua, Revelle, and Ortony (2010), who analyzed social behavior in terms of the **cta** model. To allow the reader to explore the applications of this model, computer code simulating the revised model is written in the open source language R, (R Core Team, 2014) and is included as the `cta` function in the *psych* package (Revelle, 2014) which is available for download from the Comprehensive R Archive Network (CRAN) at `http://cran.r-project.org`.

2.1. The original dynamics of action

The dynamics of action was a model of how *instigating forces* elicited *action tendencies* which in turn elicited *actions* (Atkinson and Birch, 1970). The basic concept was that action tendencies had *inertia*. That is, a wish (action tendency) would persist until satisfied and would not change without an instigating force. The consummatory strength of doing an action was thought in turn to reduce the action tendency. Forces could either be instigating or inhibitory (leading to *negaction*).

Perhaps the simplest example is the action tendency (T) to eat a pizza. The instigating forces (F) to eat the pizza include the smell and look of the pizza, and once eating it, the flavor and texture. However, if eating the pizza, there is also a consummatory force (C) which was thought to reflect both the strength (gusto) of eating the pizza as well as some constant consummatory value of the activity (c) (Equations 1, 2). If not eating the pizza, but in a pizza parlor, the smells and visual cues combine to increase the tendency to eat the pizza (Equation 3). Once eating it, however, the consummatory effect is no longer zero, and the change in action tendency will be a function of both the instigating forces and the consummatory forces. These will achieve a balance when instigating forces are equal to the consummatory forces (Equation 4). The asymptotic strength of eating the pizza reflects this balance and does not require a "set point" or "comparator". (See Table 1 and Equations 1 and 2 for a more formal description of this behavior.)

Table 1

Table 1: The basic elements of the dynamics of action. Adapted from Atkinson and Birch (1970). Action and Negaction Tendencies (T and N, respectively) are instigated by external forces (F and I) and reduced if the action is ongoing. See Equations 1 and 2).

Approach		Avoidance	
Action Tendencies	T	Negaction Tendency	N
Instigating Forces	F	Inhibitory Forces	I
Consummatory Value	c	Resistance Value	r
Consummatory Forces	C	Force of Resistance	R

The relationship between instigating forces, changes in action tendencies over time, and actions was described by a simple differential equation (reminiscent of Newton's second law)

$$dT = F - C \tag{1}$$

where

$$C = cT \tag{2}$$

and c = 0 if an action is not being done, otherwise c is a function of the type or perceived value of the action (eating peanuts has a smaller c than eating chocolate cake).

That is, for a set of action tendencies, $T_i \dots T_n$, with instigating forces, $F_i \dots F_n$,

$$\begin{cases} dT_i = F_i - c_i T_i & \text{if } T_i \text{ is ongoing} \\ dT_i = F_i & \text{if } T_i \text{ is not ongoing} \end{cases} \tag{3}$$

It is clear from equation 3 that an unexpressed but instigated action tendency will grow linearly, but once initiated will achieve an asymptotic value when the rate of growth is zero. This occurs when $F_i = c_i T_i$ and thus

$$T_{i_\infty} = F_i / c_i \tag{4}$$

The strength of a single action tendency – say, the tendency to eat a pizza – will increase when instigated by the smell of the pizza but will then (begin to) diminish once the first bite of pizza is consumed. A steady state will be achieved as the effect of the instigating force is balanced out by the successful consummation. These differential equations can be simulated as difference equations with graphical output for the strength of the action tendencies (see Figure 1).

Similar to action tendencies are *negaction tendencies* – tendencies to not want to do something. These grow in response to *inhibitory forces*, I, and are diminished by the force of *resistance*, R, which is, in turn, a function of the cost of resistance, r, and the strength of the negaction, N.

$$dN = I - R = I - rN. \tag{5}$$

In contrast to Equation 3, where action tendencies are reduced only if the action is happening, Equation 5 suggests that negaction always achieves an asymptote, even if the action is not occurring. This is because effort is required to not do a task, that is to resist doing a task, thus the force of resistance is always present and negaction will achieve an asymptotic level of

$$N_{i_\infty} = I_i / r_i, \tag{6}$$

A negaction example, analogous to the pizza example, is the common tendency to avoid unpleasant chores like cleaning. The inhibitory forces (I) related to cleaning one's toilet are clear – it is an unpleasant experience relative to other pasttimes. The force of resistance (R) of toilet-cleaning reflects the intensity with which the experience is unpleasant and a constant value at which the tendency to engage in the behavior is resisted.

The resultant action tendencies are the difference between Action and Negaction $T_{i_r} = T_i - N_i$. That negaction achieved an asymptote even if the action was not

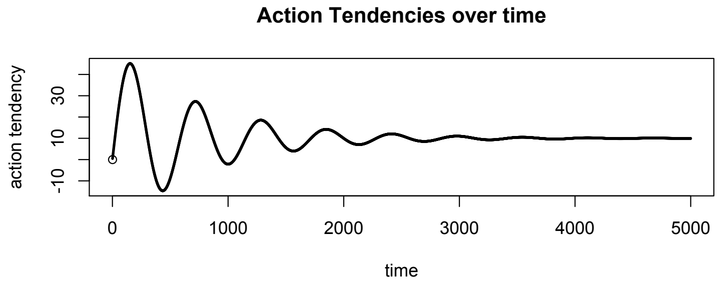

Figure 1: A single action tendency will achieve an asymptotic value of the ratio of instigating force to consummatory value as corresponding action is expressed and leads to consummation. Time is expressed in arbitrary units.

being done led to the prediction that negaction would delay rather than stop behavior (Atkinson and Birch, 1970, Humphreys and Revelle, 1984). It also led to the concept of "bottled up action tendencies". That is that the intensity of the unexpressed action could grow higher than it would normally if there were threatening (inhibitory) cues present. A classic example of this phenomenon is the case of the fierce elementary school teacher enforcing absolute silence in a classroom. This works as long as the teacher is present, but results in chaos if he or she leaves the room. In contrast, a less fierce teacher, whose classroom might be a little noisier normally, does not bottle up the desires to talk, and when he/she leaves the room, little change occurs.

Although a general theory of action, the dynamics of action was typically considered in an achievement setting. Based upon the theory of achievement motivation (Atkinson, 1957, Atkinson and Raynor, 1974), in a setting where the outcome was associated with effort rather than luck, the instigating force was thought to be a quadratic function of the subjective expectation of success (p_s), the value of that success which varied according to task difficulty ($1 - p_s$), and the need for achievement (N_{ach}):

$$F = (p_s)(1 - p_s)N_{ach}. \quad (7)$$

But an achievement setting is also an opportunity for failure and the change in negaction induced by the task was a function of the inhibitory forces which were in turn a quadratic function of the likelihood of failing, and the pain experienced in failing, and the need to avoid failure (N_{af}). The likelihood of failure is of course just task difficulty, and the pain of failing is greater the easier the task. Thus:

$$I = (1 - p_s)(p_s)N_{af}. \quad (8)$$

Early suggestions for inertial properties of motivations were found in the studies by Zeigarnik (1927/1967) as well as by Feather (1961). An application of the inertial properties of motivation in an achievement setting was found in an analysis of the effect of task difficulty on performance as a function of the number of repeated trials (Revelle and Michaels, 1976). This application demonstrated how two seemingly contradictory models of on-task effort (Atkinson, 1957, Locke, 1968) could be reconciled with the addition of inertial properties. Assuming that success quenches action tendencies but that failure does not, resultant motivation should grow over successive failures. As task difficulty increases, the likelihood of failure increases and thus there should be more carryover and growth of motivation as tasks become harder. The effect of carryover may be expressed in colloquial terms as "If at first you don't succeed, try, try again".

By separating action tendencies from negaction tendencies, the dynamic theory had the advantage over earlier work that the measurement of approach and avoidance motivation did not have to be on the same ratio scale of measurement (Kuhl and Blankenship, 1979). That is, what determined the growth of action tendencies (N_{ach}) could be measured on a different scale from what determined negaction (N_{af}). This was a marked improvement over prior work (Atkinson, 1957) suggesting that resultant action tendencies were a function of the difference between achievement strivings and fear of failure as well as any extrinsic needs (T_{ext}) to do the task:

$$T_r = T_{ach} - T_{af} + T_{ext} = (N_{ach} - N_{af})p_s(1 - p_s) + T_{ext}. \quad (9)$$

To simulate more than one behavior, Atkinson and Birch (1970) assumed that action choice between competing action tendencies simply followed the maximum (resultant) action tendency. Even with one behavior being modeled, it was always necessary to consider the other, alternative behaviors. Unfortunately, although easy to specify, the DOA model needed a number of extra parameters to work: it was necessary to include a decision mechanism that would automatically express the greatest action tendency in action. Complicating this addition, the rule of always doing the action with the greatest action tendency led to "chatter" in that an action would start and then immediately stop as the action it had supplanted had a rapidly growing action tendency. To avoid this problem it was necessary to introduce instigating and consummatory *lags*, where switching to a new activity would not immediately lead to complete consummation of that need (eating the first bite of a piece of pizza does not immediately satisfy the desire to consume pizza). An similar solution to avoid "dithering" (or chatter) in another dynamic model was proposed by Houston and Sumida (1985) who suggested positive feedback upon initiating an activity.

Although successful computer simulations of the model were implemented (Atkinson, Bongort, and Price, 1977), few researchers were interested in testing the implications of computer simulations with studies of human behavior. An important exception was Blankenship (1987) who directly tested the implications for a study of achievement. A modification of the DOA model which maintained specification of the dynamic properties of behavior has been developed by Sorrentino (1993) and his colleagues (Sorrentino, Smithson, Hodson, Roney, and Walker, 2003) who have applied it to a variety of social contexts.

2.2. *A simple reparameterization: the CTA model*

To avoid the problems of instigating and consummatory lags and the need for a decision mechanism, it is possible to reparameterize the original model in terms of action tendencies and actions (Revelle, 1986). Rather than specifying inertia for action tendencies and a choice rule of always expressing the dominant action tendency, it is useful to distinguish between action tendencies (**t**) and the actions (**a**) themselves and to have actions as well as tendencies having inertial properties. By separating tendencies from actions, and giving them both inertial properties, we avoid the necessity of a lag parameter, and by making the decision rule one of mutual inhibition, the process is perhaps easier to understand. In an environment which affords cues for action (**c**), cues enhance action tendencies (**t**) which in turn strengthen actions (**a**). This leads to two differential equations, one describing the growth and decay of action tendencies (**t**), the other of the actions themselves (**a**).

$$d\mathbf{t} = \mathbf{Sc} - \mathbf{Ca} \tag{10}$$

$$d\mathbf{a} = \mathbf{Et} - \mathbf{Ia} \tag{11}$$

To continue our pizza example, the smell and appearance of the pizza is a cue **c** which increases the desire or tendency (**t**) to eat the pizza. This desire increases the strength of the eating action **a** which, when large enough will overcome the inhibition of other actions (e.g., drinking, talking, etc.). **c**, **t** and **a** are vectors (perhaps of different dimensionality), one of which (**c**) is a function of the environment, and two of which (**t** and **a**) change dynamically. The parameters **S**, **C**, **E**, and **I** are matrices representing the connection strengths between cues and action tendencies (**S**), action tendencies and actions (**E**), the consummatory strength of actions upon action tendencies (**C**), and the inhibition of one action over another (**I**). They are specified as initial inputs but could themselves change with learning and reinforcement (Corr, 2008b, Revelle, 2008). That is, while successfully completing an action reduces the immediate tendency to do the action, the connection strengths between the cue and the tendency as well as between the action and the tendency and the tendency and the action are presumably increased. The model, although expressed in equations 10 and 11 may best be understood as a box diagram of the flow of control (Figure 2). Not shown in Figure 2, but implied by the use of matrices for **S**, **E**, **C** and **I** are the connections between cues and different action tendencies, and between action tendencies and different actions. Thus, cue_1 can excite $tendency_2$, and $action_3$ can reduce the desire for another action $tendency_1$.

If just a single action tendency and the resulting action are cued, the result is an action tendency and resulting action similar to that predicted by the dynamics of action and shown in Figure 1 as modeled by the `cta` function in the *psych* package (Revelle, 2014). Actions that are not mutually inhibitory both rise and fall independently of each other (Figure 3 upper panel represents three different action tendencies in response to cue strengths of 4 (black/solid), 2 (blue/dashed), and 1 (red/dotted), with the diagonal of the consummation matrix set to .05, .02, and .03 and the self inhibition values of .09, .05, and .02). Cue strength (**c**) is reflected in the initial growth rate of action tendencies and of actions as well as the asymptotic level. The consummation parameter, **C**, affects the asymptotic level as well as the frequency and speed of dampening of the action tendencies and thus of the actions. The self inhibition param-

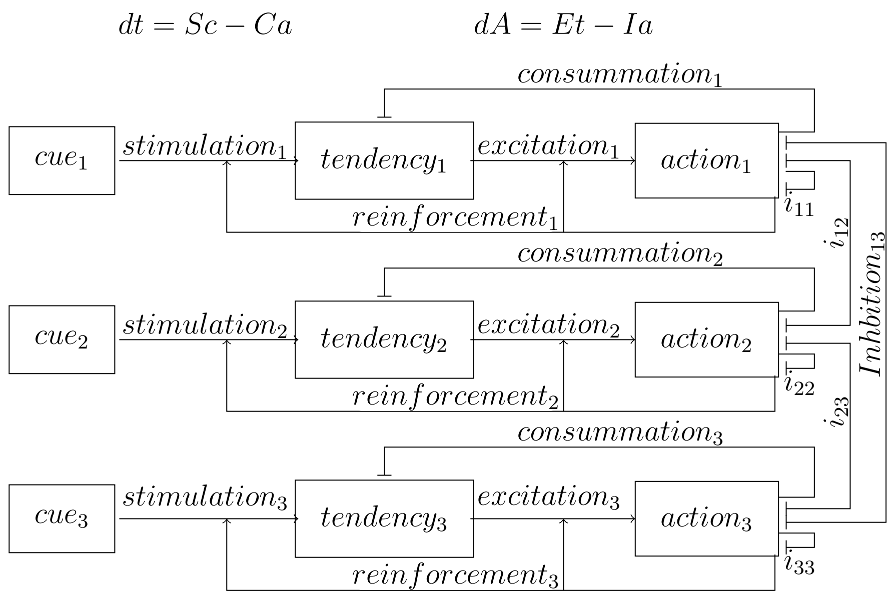

Figure 2: A simplified model of the cues, tendency, action (**cta**) model. Cues stimulate action tendencies which in turn excite actions. Actions may be mutually inhibitory and also reduce action tendencies. Extensions of this model allow for learning by changing the stimulation, excitation, and inhibition weights. These longer term learning paths are shown as reinforcement paths and reflect the reinforcing effects of successful actions upon the **S** and **E** matrices. Mutually compatible activities do not inhibit each other, and thus have inhibition strength of 0. The inhibition effect of an action upon itself reflects the cost of doing the action. Not shown in the figure, but implied by the use of matrices, are cross connections between $cues_i$ and $tendencies_{i \neq j}$ and similar cross connections between tendencies and actions, and consummations of actions on different tendencies.

Table 2: The basic elements of the **cta** model. The environmental input to the system (the cues) are variable as the individual interacts with the world. The strength of these cues upon action tendencies is moderated by the connection strengths in the stimulation matrix. The resulting tendencies have inertial properties (increasing when stimulated, decreasing when consummated.) The action tendencies induce actions through the excitation connections. Actions also have inertial tendencies but are reduced by other actions as well doing the action (self inhibition). The connections of the matrices may change over time to reflect learning in a long term response to the reinforcement of actions.

Dynamic Vectors		Stable matrices	
Cues	**c**	Stimulation strength	**S**
Action Tendencies	**t**	Excitation	**E**
Actions	**a**	Consummation	**C**
		Inhibition	**I**

eter, **I**, affects the asymptotic level and the dampening of action tendencies and indirectly of the dampening of the action tendencies (Figure 3 lower panel).

Although somewhat similar in structure to other cybernetic control theory models (e.g., Carver and Scheier, 1982, Miller et al., 1960), the models differ in that there is no set point or comparison level in the **cta** model. Inspection of Figure 2 or of equations 10 and 11 shows the lack of a comparator process or a set point. Stability is achieved when $d\mathbf{a} = \mathbf{Et} - \mathbf{Ia} = 0$ and $d\mathbf{t} = \mathbf{Sc} - \mathbf{Ca} = 0$, that is, when the stimulation from the cues is matched by the consummation of the actions. A similar process has been reported for eating behavior and weight gain. In the presence of ad lib food and no need to work to get it, rats put on weight. But if access to food requires effort, or if the palatability of the food is decreased, eating is reduced and weigh gain is decreased (Bolles, 1980, Mrosovsky and Powley, 1977).

The model becomes much more interesting when we consider the case of mutually incompatible (mutually inhibitory) actions (Houston and Sumida, 1985). If a person can do only one of a set of actions at a time, then, although the tendencies or desires to do the actions run off in parallel, the actual expression of action runs off

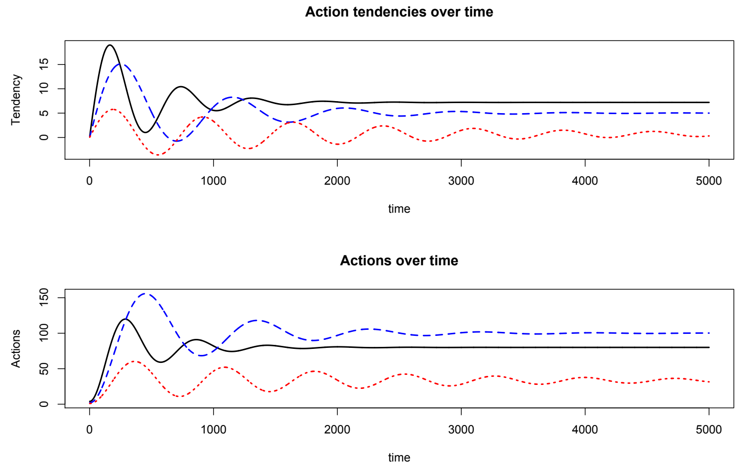

Figure 3: Three action tendencies representing three compatible actions. Because all three actions are mutually compatible, they each achieve their asymptotic value. Within the `cta` function, the parameters are set so that the solid black line represents cue strength of 4, self inhibition of .09, and consummation of .05. The dashed blue line represents cue strength of 2, an inhibition strength of .05, and a consummation of .02. The dashed red line represents a cue of 1, I of .02 and C of .03.

serially (Figure 4). A memorable example of incompatible responses is found in the newt, which copulates under water, but breaths at the surface. By increasing the oxygen content of the atmosphere, the length of each copulatory bout is prolonged (Halliday, 1980, Halliday and Houston, 1991). Not quite as dramatic is the said inability of Gerald Ford to walk and chew gum at the same time. Similar incompatibilities involving the allocation of attention include the detrimental effect of talking on a phone while driving, or checking email while working on a manuscript.

The power of a dynamic model is that it predicts change of behavior even in a constant environment where the instigating cues are not changing. With mutually incompatible actions, action tendencies can all be instigated by the environment but only one action will occur at a time. Action tendencies resulting in actions will then be reduced while other action tendencies rise. This leads to a sequence of actions occurring in series, even though the action tendencies are in parallel.

2.3. *Exploring within subject dynamics*

When originally proposed, the Dynamics of Action was hard to study except by computer simulation and by arguments based upon aggregated behavior. The DOA theory was primarily used to model achievement behavior in the face of success and failure (Kuhl and Blankenship, 1979, Revelle and Michaels, 1976) and data were aggregated across simulated subjects. But, with the introduction of daily diaries of mood and behavior (Green et al., 2006), and more importantly, telemetric methods (Wilt et al., 2011a) and better computational methods (Bates, Maechler, Bolker, and Walker, 2014, Pinheiro and Bates, 2000), it is now possible to study within subject variation in affect, behavior, and cognition (Fleeson, Malanos, and Achille, 2002, Fleeson, 2007b, Rafaeli et al., 2007, Wilt et al., 2011b). When the structure of affect is examined within individuals, the results are strikingly different from that found between individuals. The well known two dimensional structure between individuals of Energetic Arousal and Tense Arousal (Schimmack and Reisenzein, 2002, Thayer, 1989, 2000) or of Positive and Negative Affect (Watson and Tellegen, 1985, 1999) (see also Rafaeli and Revelle, 2006) shows reliable individual differences in structure within individuals (Rafaeli et al., 2007).

Rafaeli et al. (2007) found that the correlation within subjects over time between positive and negative affect (and between tense and energetic arousal) showed reliable individual differences in affective synchrony. In other words, individuals were reliably synchronous (showed positive correlations), asynchronyous (no correlation) or de-synchronous (negative correlations). Further, “[n]euroticism, extraversion, sociability, and impulsivity – major personality dimensions often associated with affective experience – were not associated with synchrony” (Rafaeli et al., 2007, p 921). In a subsequent study examining the cognitive interpretation of situations, although the between individual cor-

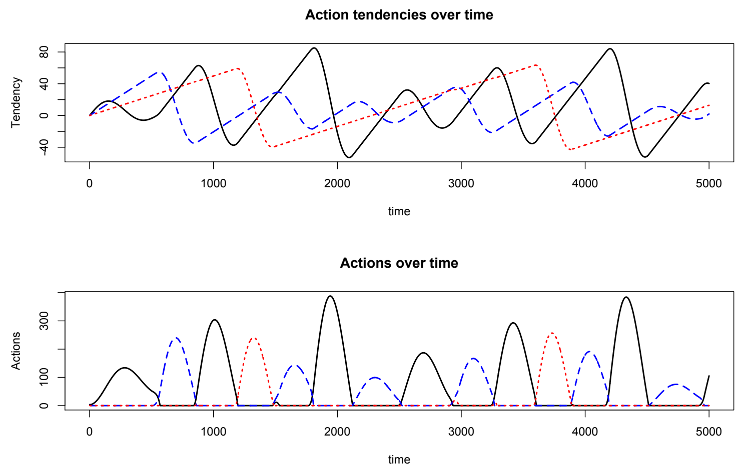

Figure 4: Three mutually incompatible activities inhibit each other and thus their respective action tendencies rise and fall over time. The flow of action tendencies run off in parallel, but because of inhibition, the actions occur sequentially. In the `cta` function, cues are set to be 4 (black/solid line), 2 (blue/dashed line), and 1 (red/dotted line). By default, all actions are mutually incompatible, and thus the I matrix is set to all 1s, with a diagonal of .05, the consummation matrix is diagonal with values of .05.

relation of energetic and tense arousal was the prototypical null, the correlation between energetic and tense arousal within subjects was a reliable individual difference that reflected the level of challenge vs. threat perceived by the subjects (Wilt et al., 2011b).

What occurs within individuals is the complex interplay of affects, behaviors, cognitions and desires rising and falling over time and we observe the correlations of levels of these measures within individuals over time. Within individuals, the basic parameters are rates of change: how rapidly do action tendencies grow, how rapidly do they decay, and how do some actions inhibit others? The speed of growth in action tendencies presumably reflects differential sensitivities to the environmental contingencies of reward and punishment while the speed at which action tendencies decay reflects differential rates of habituation/adaptation/consummation. That is, what is stable within an individual is the rate at which he or she adapts to the environment. Matrices of stable traits (**S, E, C, I**) are the derivatives of states (**c, t, a**).

Most importantly, the predictions of the **cta** or DOA models are that motivation carries over from trial to trial, and that effort will increase following failure but be quenched by success. This observation is one of the more compelling predictions of the **cta**/DOA models. Contrary to simple reinforcement theories, the immediate effect of success is to reduce effort on the subsequent trial, while the immediate effect of failure is to increase effort on the subsequent trial (Revelle and Michaels, 1976). This is clearly an adaptive response, because success signals that less effort is required, but failure signals that more effort is required. Thus, trial by trial there is a negative autocorrelation as individuals respond to the outcomes but over the longer term, a positive autocorrelation as individuals acquire expertise and interest. A somewhat similar prediction follows from the model of passive goal guidance (PGG) which considers the unconscious effect on goal seeking behavior of prior outcomes (Laran and Janiszewski, 2009). The longer term effect of reinforcement is to modify the **S**, **E**, **C**, and **I** matrices to reflect the pattern of successes and failures. That is, although a success will have a short term quenching effect on effort, over the long term, success is reinforcing and increases the likelihood of engaging in an activity.

3. Between Individual differences

Dynamic models can be applied to differences between individuals, not to predict trial to trial dynamics, but rather to model relative rates of growth and decay. Between individuals, we notice differences in time spent doing various activities. We do not observe growth rates, but we do observe frequencies, latencies, and persistence. Perhaps most notably, we learn to recognize the patterning of behaviors, feelings, thoughts, and desires within ourselves and others.

Whether one focuses on the behavioral dimensions of approach, avoidance, and inhibition (Gray and McNaughton, 2000, Corr, 2008a, Smillie, 2014, Eysenck, 1990) or the five/six dimensions reflecting individual differences in self description examined by Ashton, Lee, and Goldberg (2007), Digman (1990), Goldberg (1990), McCrae and Costa (1997) and numerous others, one is taking average levels of affects, behaviors, cognitions, and desires (Hilgard, 1980, Ortony, Norman, and Revelle, 2005, Scherer, 1995, Wilt and Revelle, 2009).

We prefer to focus not on the average levels, but rather the rates of change of these levels. Acting extraverted is not always being talkative, but it is being talkative in the presence of others. How rapidly one initiates a conversation, how long one persists in the conversation are the appropriate measures of extraversion. Similarly, trait anxiety is not always being anxious, but is a tendency to become state anxious more rapidly, in more situations, and to have a slower decay rate of that state anxiety (Gilboa-Schechtman, Revelle, and Gotlib, 2000, Oehlberg, Revelle, and Mineka, 2012).

These average levels of what one tends to do may be distinguished from maximum levels of what one can do. This distinction is most obvious when considering cognitive ability. We have known since Spearman (1904) that it is almost impossible to find a cognitive task that does not correlate with other cognitive tasks. The dominant models in cognitive abilities research (Carroll, 1993, Horn and Cattell, 1966, Johnson and Bouchard, 2005, McGrew, 2009) support the notion of general cognitive ability ("**g**") though the manner in which they organize the abilities below this highest level varies considerably. But ability is not just a high score on an ability test, it is succeeding on many daily tasks and even leads to survival, for life is an intelligence test with many subtests (Gottfredson, 1997). Not only does ability relate to the risk of mortality throughout one's life (Deary, 2008) it is stable: ability measured at age 11 correlates .67 with ability measured 79 years later (Deary, Pattie, and Starr, 2013). Just as we think of trait extraversion as the speed and persistence of responding to others, in terms of the **cta** model, we interpret trait ability as the speed at which one can move through a problem space, from the initial configuration to the solution. Because schooling presents a number of cognitive challenges to be surpassed, for the same level of education, there will be a high correlation between knowledge or crystallized intelligence (g_c) and speed of processing or fluid intelligence (g_f). But once formal education is finished how one spends one processing abilities will vary across people and the (g_c) – (g_f) correlation will diminish.

If temperament is what you usually do, and ability is what you can do, interests are what you like to do and how you spend your time. Just as the dimensions of temperament may be analyzed through factor analysis, so can the dimensions of interest. At a very high level, interests can be grouped into the dimensions of people vs. things and of facts versus ideas (Prediger and Vansickle, 1992). These high level dimensions themselves can be decomposed into the lower level facets of specific interests known as the RIASEC model (Holland, 1959, 1996).

3.1. Categorization of Differences as Temperaments, Abilities, and Interests

Until the mid-1950s, it was the tradition in personality research to integrate ability, temperament, and interests (Cattell, 1946, Eysenck and Himmelweit, 1947, Kelly and Fiske, 1950). While this has continued among many European psychologists, there has been a tendency among American personality psychologists to focus on dimensions of temperament to the exclusion of ability or interests. Thus, there has been an emphasis upon the Giant 3/Big 5/Big 6 dimensions of temperament without considering how these relate to dimensions of ability or interests. Exceptions to this general rule include Ackerman (1997), Ackerman and Heggestad (1997), Deary, Whiteman, Starr, Whalley, and Fox (2004), Deary (2008), Deary et al. (2013), DeYoung (2014), Ferriman, Lubinski, and Benbow (2009), Gottfredson (1997),
Lubinski and Benbow (2000), Lubinski, Webb, Morelock, and Benbow (2001),
von Stumm, Chamorro-Premuzic, and Ackerman (2011) and they are notable for their rarity. We follow the example of Ackerman (1997) and von Stumm et al. (2011) by preferring to focus on the integration of these three domains, as this approach is consistent with the theoretical work of Plato (Hilgard, 1980, Scherer, 1995) and early personality scholars (Cattell, 1946, McDougall, 1923). These domains may be denoted by the labels Temperament, Abilities and Interests (Condon, 2014, Revelle, Wilt, and Condon, 2011)

The temperament domain encompasses those individual differences which are typically researched by modern personality psychologists. While the Big Five model enjoys wide acceptance as a relatively inclusive descriptive framework for the temperamental differences, several alternative models have been proposed as well. To a substantial extent, these alternative models merely reflect higher or lower level descriptions of the same multi-dimensional universe of individual differences. For example, the tendency to rely upon five-factor structures does not preclude the possibility of organizing the same individual differences with more (DeYoung, Quilty, and Peterson, 2007, Ashton et al., 2007, Costa and McCrae, 1992b) or fewer dimensions (DeYoung, 2010, Saucier, 2009, Digman, 1997). No matter how many dimensions are deemed most appropriate for a given context, it is generally the case that these individual differences can also be evaluated according to the degree to which they describe an individual's stable tendencies in terms of affect, cognition, desire, and behavior (Wilt, 2014, Wilt and Revelle, 2009) Thus, it is important if we can model these between individual differences using our **cta** approach.

The cognitive ability domain, which is perhaps the oldest line of research among modern personality psychologists, encompasses individual differences in cognitive abilities ranging from executive functioning and attention to more traditional measures of intelligence. Unlike the temperamental differences, cognitive abilities are typically measured with "maximal performance" tasks that incorporate items or tests that span a range of difficulties. It should also be noted that individual differences in cognitive ability are not only a function of the narrowly defined abilities which relate to specific tasks (e.g., spatial navigation or verbal reasoning) but also differential contributions between crystallized and fluid ability.

Research on conative individual differences (i.e., differences in desires, motivations, volition and striving) is most frequently conducted through the assessment of interests, especially vocational interests. The dominant interests framework, known as the RIASEC model of vocational interests (Holland, 1959, 1996), organizes both interests and jobs according to six categories (and related scales) – Realistic, Investigative, Artistic, Social, Enterprising, and Conventional. The framework itself allows for hierarchical organization of specific occupations which can be grouped according to shared basic interest categories and these in turn can be grouped at a higher level of six general interest factors (Armstrong, Smith, Donnay, and Rounds, 2004). In other words, the basic interests may be seen as equivalent to the facet level of the Big Five in the temperament domain. It has also been suggested that the six factor structure can be further simplified to two dimensions which are known as data/ideas and people/things (Armstrong, Allison, and Rounds, 2008, Prediger and Vansickle, 1992).

It should be noted that the assessment of vocational interests as a proxy for conation is practical but inadequate. It does not typically include the assessment of preferences, values, avocational interests or pastimes. More generally, the assessment of conative differences is hampered by the fact that specific activities are often idiosyncratically rooted in previous experience and are generally pursued sequentially, with varying degrees of intensity, in accordance with circumstantial factors. In other words, the use of interests to capture conative differences is problematic because (1) interest in a behavior or activity is often dependent on knowledge about that activity and (2) interest does not reflect the intensity with which an activity is pursued, the enjoyment derived from it, or the circumstantial factors which may impede or demand the pursuit of any given activity (e.g., socioeconomic status, cultural influences, etc.). Related to these issues is the fact that the various aspects of conation are seemingly quite distinct: the assessment of interests provides a means of describing one's preferences; motivation is generally framed as a measure of intensity (Carver and White, 1994, Gray and McNaughton, 2000), goals and values are often framed as trait-like heuristics that individuals use to navigate through the stream of choices in life (Liberman, Molden, Idson, and Higgins, 2001, Molden and Higgins, 2005, Peterson and Seligman, 2004). In essence, it seems that the conative domain is perhaps more sensitive than the temperament and ability domains to variability in the nature of action tendencies at the within individual level.

The simple categorization of temperament, abilities and interests is a useful heuristic but does not capture the complex interplay of these three domains. Some of our prior work has examined the distinction between ability and performance as they relate to temperament (Humphreys and Revelle, 1984, Revelle, 1993). That what one can do (ability or competence) is not necessarily shown by what one does has been known since at least Tolman and Honzik (1930) who studied the effect of reward on maze performance. With the same number of learning trials, non-rewarded rats take far longer to run a maze than when given a reward. Complex cognitve performance also differs as a function of the experimental condition. The impulsivity component of extraversion (Revelle, 1997) shows systematic interactions with caffeine induced stress and time of day in its effect on cognitive performance. The performance on complex reasoning tasks of less impulsive individuals is hindered by caffeine in the morning, but facilitated in the evening, while that of more impulsive individuals is facilitated in the morning and hindered in the evening (Revelle, Humphreys, Simon, and Gilliland, 1980). In a separate set of studies, the poor cognitive performance of highly anxious individuals was probably due to too much time spent in off task thoughts and not enough time spent on task (Leon and Revelle, 1985, Wine, 1971).

3.2. Modeling social behavior at two levels: cta and TAI

The expression of social behavior at the between individual TAI level is typically construed as an example of extraversion. Social interaction can also be modeled using the **cta** model. If, for example, a group of four individuals gather together, each individual in the group will have a desire (action tendency) which reflects their interest in talking. When one person in the group is talking, the others are generally inhibited. At the between individual level, differences in the desire to talk (and the willingness to remain inhibited from talking) are a function of temperamental differences, but these might also be viewed as within individual sensitivities (growth rates) to cues for talking. When one person in the group is talking, the extent to which others are inhibited will reflect their sensitivity to other cues (e.g., the desire to listen, understand, not interrupt, etc.) Desires to talk run off in parallel, but behaviors are sequential. Differences in growth rates result in differences in latency and persistence. Figure 5 demonstrates how such an interaction might unfold by plotting the action tendencies for talking for four individuals over 5,000 arbitrary units of time. Note that, in this example, one person talks frequently while another is much less involved; these two might be viewed as extraverted and introverted, respectively.

An important point from this simulation is the recognition that both the DOA and **cta** models involve temporal measures (latency and persistence) which are functions of the choices available. Contexts differ in the sets of alternative activities. We simulated talking versus listening (not talking), but one could also think of each situation as offering a range of alternatives. Consider the context of a "lively party". To some, this is an opportunity to talk to many different people, to others the chance to talk to a few special friends, to others the opportunity to put a lamp shade on their head. The choices made, and the latency and persistence of the various action tendencies, are all functions of cue strength for those activities, and inhibitory effects from other activities.

That the situation is not just the physical environment, but also the social context may be seen when we simulate four different groups of individuals (Table 3). When the group consists of all introverts, or of all extraverts, everyone shares equally in the amount of time spent talking. But when the groups differ in the range of introversion-extraversion within the group, the extraverts will tend to dominate the conversation. Data supporting this prediction were reported by Antill (1974) who examined the interactive effect of group size and introversion/extraversion upon talking behavior. The effect of group composition on the frequency distribution of extraverted behaviors also is compatible with Fleeson's analysis of the relationships between state and trait measures of extraversion (Fleeson, 2004, 2007a).

By focusing on the frequency domain, we can integrate the average level of behavior analyzed by most individual differences psychologists with our dynamic models. For the **cta** model predicts differences in frequency of feelings and actions as a function of the latent rates of change parameters that we prefer. Extraverts, across situations, will have shorter latencies and greater persistence in social behaviors than will more introverted people. Similarly, conscientiousness can be seen as a delay in onset of inappropriate behaviors, and a persistence of appropriate behaviors. Neuroticism is a measure of the speed and generalization of reaction to stressful or threatening environments, agreeableness is a sensitivity and rapid response to the cues exhibited by others, openness is the speed, frequency, and duration of engaging in intellectually challenging tasks. This approach is reminiscent of that of Denissen and Penke (2008) and Penke, Denissen, and Miller (2007) who view stable traits as reaction norms to situational cues.

Traits, in the **cta** model are captured as rates of change ($d\mathbf{c}$ and $d\mathbf{t}$) (Equations 10, 11). But these in turn reflect the stable connections expressed in the **S, E, C** and **I** matrices. It is the structure of those matrices that should be related to the stable individual differences we know as traits. This conceptualization implies that we need to consider not just average levels of affect and behavior, but latencies, persistence and intensity of the behavior as well as choice between behavior. Speed of onset of an activity is related to the **S** matrix, while persistence will be related to both **S** and **C** as well as the inhibitory strength **I** of other actions.

4. Group differences as the consequence of individual choices

Dynamic models at a longer span reflect changes in interests and goals to reflect past histories of reinforcement. Over the long run, the connection strengths between cues and action tendencies, **S**, and between action tendencies and actions, **E**, will change to reflect experience. The **cta** model is one of motivation and choice; it involves choice between incompatible outcomes. Students who find a topic challenging enough to be interest-

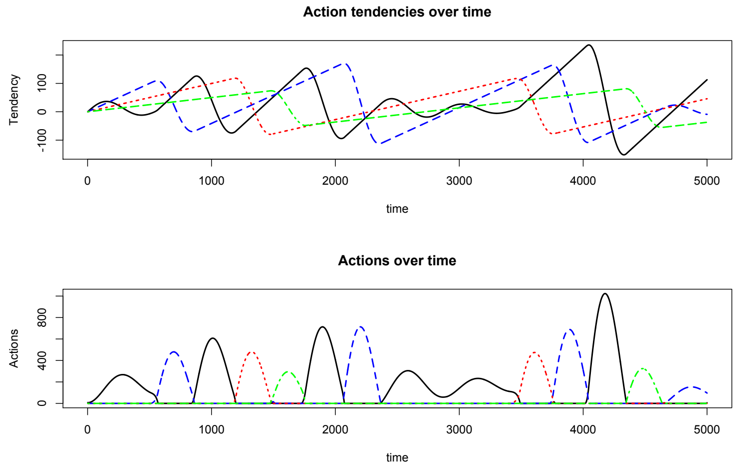

Figure 5: Simulation of 4 individuals differing in their excitation of a tendency. Default values for the `cta` function are used. Black/solid has a cue strength of 8, blue/dashed 4, red/dotted 2 and green/dotted 1.

Table 3: Hypothetical amount of time spent talking and the hypothetical intensity of the talking behavior in four different groups of four individuals. The first group is composed of four introverted individuals who share equally in the conversation, but engage with low average levels of action. The second group, composed of four extraverts also share equally in the conversation, but talk with much more intensity. The third group, a mix of two introverts and two extraverts shows how the amount of time spent talking decreases for the introverts as the extraverts take 50% more than their share. Although the introverts talk less, they still talk with the same intensity as in the first group. Similarly, the talkative extraverts act with the same intensity as they did in the second group. The final case is when people cover the whole range of introversion/extraversion. Simulation done using the `cta` function in *psych* with cue values as specified and running over 10,000 "time units".

Talking behavior

Subject	Cue Strength	Time Spent	Frequency	Av. Tendencies	Av. Actions
Four introverts					
I1	0.95	0.24	16	6	80
I2	1.00	0.25	16	5	80
I3	1.05	0.24	16	5	83
I4	1.10	0.27	16	6	79
Four extraverts					
E1	3.95	0.25	16	21	322
E2	4.00	0.24	15	26	335
E3	4.05	0.25	16	20	313
E4	4.10	0.26	15	23	297
Two introverts, two extraverts					
I1	0.95	0.11	8	14	167
I2	1.00	0.13	9	14	150
E1	4.05	0.37	22	15	215
E2	4.10	0.38	21	15	210
Full range of Introversion-Extraversion					
IE1	1.00	0.17	11	9	123
IE2	2.00	0.21	14	12	182
IE3	3.00	0.28	18	14	208
IE4	4.00	0.34	19	16	230

ing, and who have the required mix of temperament and ability to do well, will become progressively more interested in the topic. Others, who do not have the temperament or ability needed for that topic will find other topics more reinforcing. Over time, people will gravitate to certain college majors, occupations, or ways of behaving as a consequence of their histories of reinforcement. Over a longer time period, this will lead to group differences in the mean levels of temperament and ability traits in different college majors. But, as at the individual level, these choices are themselves mutually incompatible. For time is a finite resource and time spent in the lab doing chemistry is time not spent socializing. Time spent in doing volunteer activities is time not spent studying business administration. Such patterns of histories of different choices will result in different patterns of experiences and reinforcement which will in turn lead to trait constellations that reflect these choices. Feldman and Newcomb (1969) referred to this effect as accentuation, where small initial differences in interests and attitudes were accentuated by exposure to college.

In a large scale, web based assessment of temperament and ability characteristics associated with different occupations and college majors, we have shown (Revelle and Condon, 2012) striking differences in the level of cognitive ability (as assessed by the ICAR measure of ability (Condon and Revelle, 2014)) and the structure of the Big Five temperament measures as a function of college major. Rather than the conventional between individual structure showing independence of the dimensions of temperament and the measure of ability, when aggregated at the level of the college major, ability was highly negatively correlated with Extraversion and Agreeableness. In terms of intellectual ability, students who went into physics were 1.01 standard deviations above those who went into psychology who in turn were .70 standard deviations above those who went into medical assisting. But this pattern was reversed for Extraversion and particularly, Agreeableness. Although at the individual level, E, A and ability were independent, at the aggregate level across 91 majors with more than 100 students each, the median (absolute) correlations were .72 between ability and temperament measures. Interestingly, given DeYoung's (2014) discussion about ability and the intellect subdomain of Openness, the between individual correlation was .17 between cognitive ability and intellect/openness, but this correlation increased to .71 at the aggregate level. That is, those students who go into the more intellectually challenging majors also report more interest in intellectual activity and less agreeableness.

5. Analytic tools

A revolution in analytic techniques has occurred during the past few years. We no longer are constrained to use proprietary software to analyze data, nor are we constrained to analyze data at one level of analysis. With the development of multi-level model procedures and dynamic data collection, it is now possible for anyone to model data within and between levels. Open source software packages available in the R data analysis system (R Core Team, 2014) allow for the identification of Simpson's paradox (Kievit and Epskamp, 2012), to do multilevel analysis (Bates et al., 2014, Bliese, 2009), to do factor analyses at the individual and group level (Revelle, 2014), to do dynamic factor analysis (Molenaar, 1985, Molenaar and Nesselroade, 2009), and to model the dynamic processes represented by the **cta** model (Revelle, 2014). What was once a theory too complicated to model has now become one open to test and verification.

6. Conclusion

We started this paper with the simple premise that people differ. They differ within themselves over time, they differ between individuals cross sectionally, and they form into groups over time that differ in their structure. We have tried to show that "how" and "why" people differ may be considered in terms of the same basic dynamic model that considers motives and behaviors to have inertial properties and that can be modeled dynamically. These dynamics are not ergodic, in that the average outcome does not reflect the basic processes at the individual level, nor is the structure of group differences just the average of the structure of the individuals. We believe that personality needs to be conceived at multiple temporal durations. At the individual level, the short term dynamics over seconds to days reflect the personal signature of an individual. Over longer periods of days to months, we see the typical structure of individual differences. However, when the patterns of individual choices are accumulated over the long term, over a period of years, the structure between groups is different yet again.

The study of personality needs to be considered at multiple levels of analysis: within and between individuals, and between groups of individuals. It also needs to be considered at different temporal frequencies, from the high frequencies within individuals to the long term tides of aggregated behavior. We hope that we have shown that it is time for theorists of personality and individual differences to realize the power of formal models implemented in open source software.

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