

A model for personality at three levels

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Abstract

A three level model for personality dynamics and structure is proposed.

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

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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](#); [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. This is unfortunate, for the study of dynamics integrates choice, persistence, latency, frequency and time spent in a common framework: the analysis of actions over time. E.g., the initiation of an activity should be analyzed in the same manner as the persistence of an activity, for the latency of onset of an activity is equivalent to the persistence of not doing that activity. By understanding temporal dynamics within people, we are also able to explain patterns of choice between people and by examining the cumulative effect of these choices in terms of time spent, to understand how groups of people may form that differ drastically in their personality traits.

Personality is an abstraction used to describe and explain the coherent patterning over time and space of affect, cognition, and desire as they result in behavior for

an individual. People differ from themselves on a moment to moment basis. That is people 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 to be psychotic. 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 is examining the patterning in the ways which people change. To observers, an individual's dynamic processes of the stream of feelings, thoughts, motives and behavior show a unique temporal signature for each individual. To an individual differences theorist, the how and why individuals differ in their patterns is the domain of study ([Costa and McCrae, 1992](#); [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 et al., 2013](#); [DeYoung et al., 2010](#); [Smillie, 2008](#); [Smillie et al., 2012, 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](#)) or the control theory models of [Carver \(1979\)](#) and [Carver and Scheier \(1982\)](#).

By examining patterns of change it is possible to organize the study of personality at a second level, 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 their frequency distribution of 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](#);

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Gray and McNaughton, 2000; Smillie, 2008; Smillie et al., 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 the life choices they make in terms of college majors and careers. **CITATIONS**. 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 between individual level.

1.1. Different levels can be different

Although it is well known that the structure within a 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 this has been labeled the Yule-Simpson paradox (Armistead, 2014; Kievit et al., 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 incorrectly to assume ergodicity of behavior (Molenaar, 2004).

In a multilevel structure, observed correlations across individuals may be decomposed into within individual correlations and between individual correlations. Similarly, the correlations between individuals when individuals are members of different groups reflects this within and between group correlational structure:

- $r_{xy} = eta_{x_{wg}} * eta_{y_{wg}} * r_{xy_{wg}} + eta_{x_{bg}} * eta_{y_{bg}} * r_{xy_{bg}}$
- $r_{xy_{wg}}$ is the within group correlation
- $r_{xy_{bg}}$ is the between group correlation
- $eta_{x_{wg}}$ is correlation of the data with the within group values
- $eta_{x_{bg}}$ is correlation of the data with the between group values

This distinction will be important as we consider models of coherency and differences within-individuals, between-individuals, and between groups of individuals.

2. Dynamics within individuals

Two basic concepts of individual dynamics is that time is a variable, and that motivations and actions have *inertial* properties. Inspired by the earlier work by Gestalt psychologists influenced by Kurt Lewin (e.g., Zeigarnik, 1967) as well as Feather (1961) and Atkinson and Cartwright (1964), Atkinson and Birch (1970) proposed that a wish persists until satisfied and a wish does not increase unless instigated. (This is, of course, a restatement of 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 to do computer modeling of difference equations. 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.

Recent discussions of the CTA model include Revelle (2012) which applied the model to the dynamics of emotion (e.g., Frijda, 2011) and Fua et al. (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 in the *psych* package (Revelle, 2014) which is available on line 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*).

Table 1: The basic elements of the dynamics of action. Adapted from [Atkinson and Birch \(1970\)](#)

Approach		Avoidance	
Instigating Forces	F	Inhibitory Forces	I
Action Tendencies	T	Negaction Tendency	N
Consumatory Value	c	Resistance Value	r
Consumatory 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)

$$dT = F - CT \quad (1)$$

where

$$C = cT \quad (2)$$

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

That is, for a set of action tendencies, T , with instigating forces, F ,

$$\begin{cases} dT_i = F_i - c_i T_i & \text{if } T_i \text{ is ongoing} \\ dT_A = F_A & \text{if } T_i \text{ is not ongoing} \end{cases} \quad (3)$$

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

$$T_\infty = F/c \quad (4)$$

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 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).

In parallel with 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 .

$$dN = I - R = I - rN. \quad (5)$$

In contrast to Equation 3 where action tendencies are reduced only if the action is happening, Equation 5 suggested the negaction would always achieve an asymptote, even if the action were not occurring. Because it requires effort to resist even if not doing a task, the force of resistance is always present and negaction will achieve an asymptotic level of

$$N_\infty = I/r \quad (6)$$

The resultant action tendencies are the difference between Action and Negaction $T_r = T - N$. [Atkinson and Birch \(1970\)](#) assumed that action choice between competing action tendencies simply followed the maximum action tendency.

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](#)), the instigating force was thought to be a quadratic function of task difficulty 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 task difficulty and the need to avoid failure (N_{af}).

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

Early suggestions for inertial properties of motivations were found in the studies by [Zeigarnik \(1967\)](#) 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 ([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 carry over 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”.

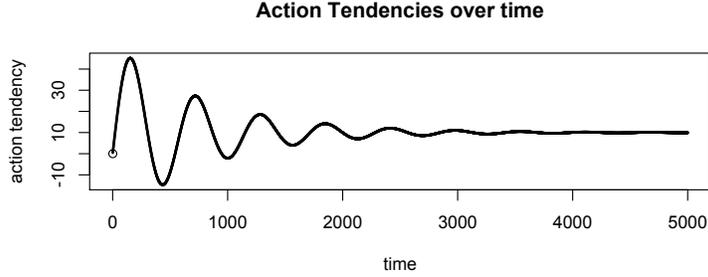


Figure 1: A single action tendency will achieve an asymptotic value of the ratio of instigating force to consummatory value as corresponding action is expressed and leads to consummation.

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 could be measured on a different scale from what determined negaction. This was a marked improvement over the prior work (Atkinson, 1957) that had suggested that resultant action tendencies were a function of the difference between achievement strivings and fear of failure

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

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 consummation of that need (eating a pizza does not immediately reduce the need to eat a pizza).

Although successful computer simulations of the model were implement, 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 that kept the dynamic properties of behavior has been developed by Sorrentino (1993) and his colleagues (Sor-

rentino et al., 2003) who have applied it to a variety of social contexts.

2.2. A simple reparameterization: the CTA model

To avoid the problem of instigating and consummatory lags and 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 possible to think of actions themselves as having inertial properties. In an environment which cues for action (**c**) enhance action tendencies (**t**) which in turn strengthen actions (**a**), behavior is a constantly varying stream of mutually inhibitory actions. This may be expressed as two differential equations, one describing the growth and decay of action tendencies (**t**), the other of the actions themselves (**a**).

$$dt = \mathbf{S}\mathbf{c} - \mathbf{C}\mathbf{a} \quad (10)$$

$$da = \mathbf{E}\mathbf{t} - \mathbf{I}\mathbf{a} \quad (11)$$

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 reinforcement and subsequent learning (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, and the tendency and

the action are presumably increased. The model, although expressed in equations 10 and 11 may also be represented 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, nor between action tendencies and different actions. Thus, cue_1 can excite $tendency_2$, and $action_3$ can reduce the desire for another action $tendency_1$.

This model is similar to a basic connectionist architecture where the action tendencies are hidden units relating environmental cues to behavioral responses (McClelland et al., 2010). The **cta** parameterization is partly based upon some of the control theory models discussed in Toates and Halliday (1980). It is implemented as the **cta** function in the *psych* package (Revelle, 2014) in the open source statistical programming and modeling language R (R Core Team, 2014).

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

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. Actions that are not mutually inhibitory both rise and fall independently of each other (Figure 3 upper panel). 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 parameter, **I**, affects the asymptotic level of action tendencies as well as the dampening of the actions themselves and indirectly, of the action tendencies (Figure 3 lower panel).

The model becomes much more interesting when we

consider the case of mutually incompatible (mutually inhibitory) actions. If a person can do only one of a set of actions at a time, then although the tendency or desires to do the action can run off in parallel, the actual expression of the action runs off 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 is 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.

Although somewhat similar in structure to the cybernetic control theory models of Carver and Scheier (1982) the two models differ in that there is no set point or comparison level in the **cta** model. For, as Bolles (1980) has shown, stable rates of eating behavior and subsequent body weight can result as a balance between the taste of the food and the effort needed to be expended to get the food, with no need for positing a set point for adiposity.

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. But, with the introduction of daily diaries (Green et al., 2006), but more importantly, telemetric methods (Wilt et al., 2011a) and better computational methods (Bates et al., 2014; Pinheiro and Bates, 2000), it is now possible to study within subject variation in affect, behavior, and cognition (Fleeson et al., 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 Reizenzein, 2002; Thayer, 1989, 2000) or of Positive and Negative Affect (Watson and Tellegen, 1985, 1999) (see also Rafaeli and Revelle,

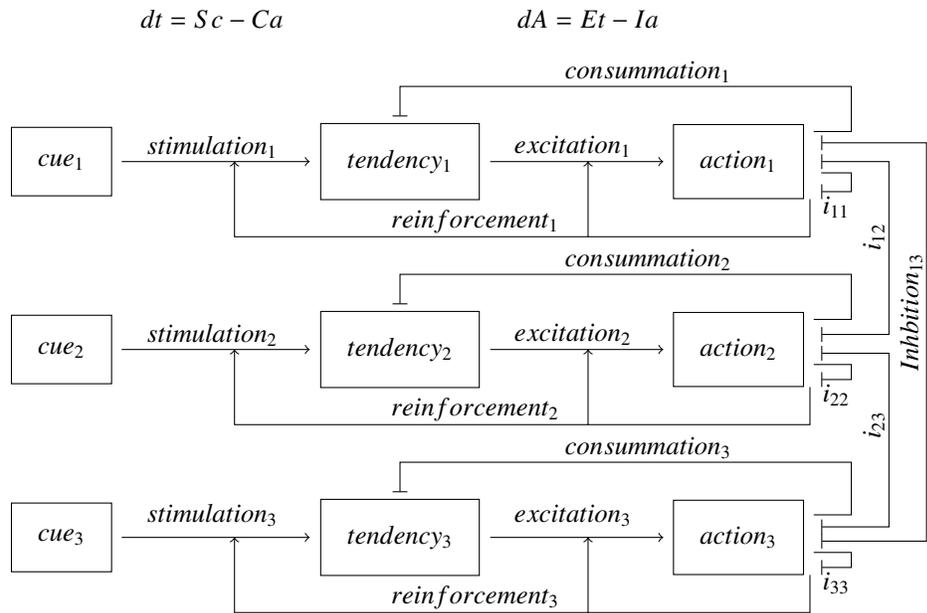


Figure 2: A simplified model of the cues, tendency, action (**cta**) model. Cues stimulate action tendencies which in turn excite actions. Actions may be mutually inhibitory and also reduce action tendencies. Extensions of this model allow for learning by changing the stimulation, excitation, and inhibition weights. These longer term learning paths reflecting the reinforcing effects of successful actions upon the **S** and **E** matrices are shown as reinforcement paths. 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.

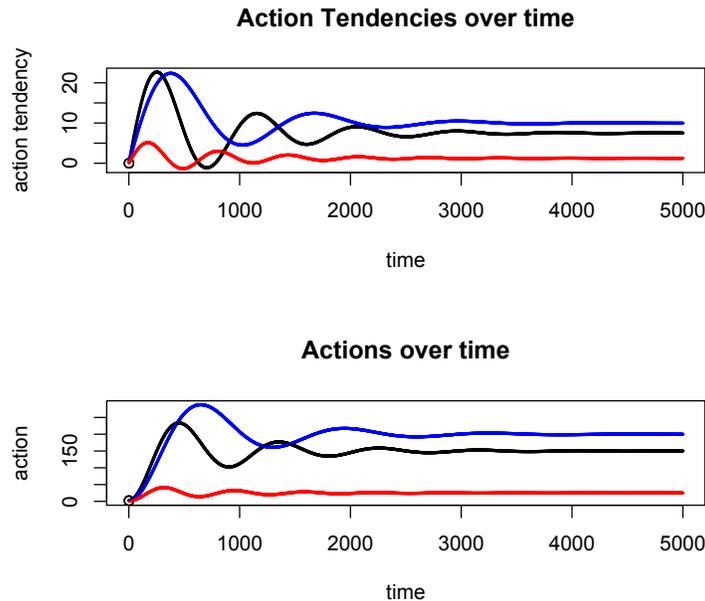


Figure 3: Three action tendencies representing three compatible actions. Because all three actions are mutually compatible, they each achieve their asymptotic value.

2006) shows reliable individual differences in structure within individuals (Rafaeli et al., 2007).

The correlation over time between positive and negative affect, or between tense and energetic arousal within subjects show reliable differences in affective synchrony. Individuals were reliably synchronous (showed positive correlations), a-synchronous (no correlation) or de-synchronous (negative correlations). “Neuroticism, 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 the situations one was in, although the between individual correlation of energetic and tense arousal was the proto-typical null, the correlation between energetic and tense arousal within subjects reflected the level of challenge vs. threat perceived by the subjects (Wilt et al., 2011b).

What we see 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.

Most importantly, the predictions of the **cta** or DOA models is 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. 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 (Rev-elle 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. 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).

3. Between Individual differences

Dynamic models can be applied to differences between individuals as well, not just to predict trial to trial

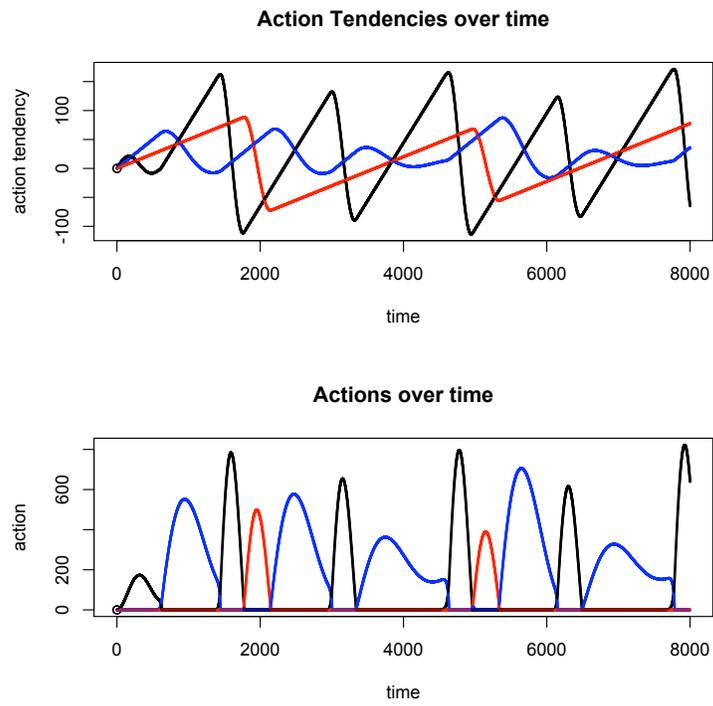


Figure 4: Three mutually incompatible activities inhibit each other and thus their respective action tendencies rise and fall over time. The flow of action tendencies run off in parallel, but because of inhibition, the actions occur sequentially.

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. It is possible to examine rates of change. [Gilboa and Revelle \(1994\)](#) showed individual differences in decay rates of the effect of anxiety on an emotional “Stroop” task. The fundamental observations become how we spend our time, what is the patterning of our behaviors, our feelings, and our thoughts.

3.1. Traditional model of Temperament, Abilities, and Interests

Although the tradition in personality until the mid 1950’s was to integrate ability, temperament, and interests [Cattell \(1946\)](#); [Eysenck and Himmelweit \(1947\)](#); [Kelly and Fiske \(1950\)](#) and this tradition continued among many European psychologists, there has been a tendency, at least among American personality psychologists, to focus on dimensions of temperament at the expense 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 et al. \(2004\)](#); [Deary \(2008\)](#); [Deary et al. \(2013\)](#); [Ferriman et al. \(2009\)](#); [Gottfredson \(1997\)](#); [Lubinski and Benbow \(2000\)](#); [Lubinski et al. \(2001\)](#); [von Stumm et al. \(2011\)](#) but they are notable for their rarity.

We follow the example of [Ackerman \(1997\)](#) and [von Stumm et al. \(2011\)](#) and prefer to focus on the integration of these three domains. That is to say, we follow the Platonic tradition of examining the trilogy of affect, cognition, and desire as they relate to behavior ([Hilgard, 1980](#); [Scherer, 1995](#)).

Whether one focuses on the general behavioral approach, avoidance, and inhibitions dimensions of [Gray and McNaughton \(2000\)](#) and the reinforcement sensitivity theorists ([Corr, 2008a](#); [Smillie, 2014](#)) or [Eysenck \(1990\)](#), the five/six dimensions reflecting individual differences in self description examined by [Ashton et al. \(2007\)](#), [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 et al., 2005](#); [Scherer, 1995](#); [Wilt and Revelle, 2009](#)).

These average levels of what one tends to do may be distinguished from maximum levels of what one can do. That is to say, from 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. 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 et al., 2013](#)).

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1. g
2. $gfgc$

If temperament is what you usually do, and ability is what you can do, interests are what you like to do. 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 [CITATION](#). These high level dimensions themselves can be decomposed into the lower level facets of specific interests known as the RIASEC ([Holland, 1959, 1996](#)).

3.2. Social behavior can also be modeled using the CTA

TAI applied to social behavior is typically seen as an example of extraversion. That is, extraverted behavior may be thought of as a greater sensitivity to the cues for social reward and subsequent positive affect ([Smillie et al., 2012](#); [Wilt and Revelle, 2009](#)). Such social interaction can be modeled using the **cta** model. Rather than associating the trait of extraversion with the mean level of extraverted behavior, the **cta** model equates the trait with the rate of change of the action tendency and the subsequent actions. That is, what is stable within an individual (the trait) is not the behavior, but rather the rate one achieves the behavior. Traits are the first derivatives of states. The desires to talk (action tendencies) of people in a small group reflect their interest in talking and when one person is talking, that inhibits the others. Consider four individuals with different sensitivities (growth rates) to cues for talking. One person talking inhibits the others. Desires to talk run off in parallel, but behaviors are sequential. Differences in growth rates result in differences in latency and persistence. Note that one person talks frequently while another is much less involved (Figure 5).

The amount of time an individual spends talking is a function not just of his her rate of change in the desire to talk, but also a function of the others in the group. Thus, introverts in a group of introverts, or extraverts in a group of extraverts will all talk about the same amount, but the differences in introversion-extraversion

will be most apparent in a mixed group. The stream of behavior is a complex result of the individual trait levels and of the situational demands. (See Table 3 for an analysis of the effect of the group composition upon an individual's talking behavior). This prediction from the model is consistent with experimental evidence of the effect of group size and composition upon talking behavior [Antill \(1974\)](#).

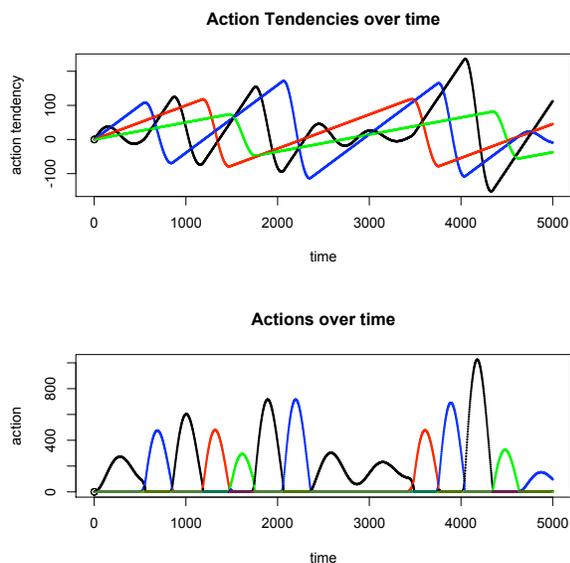


Figure 5: Simulation of 4 individuals differing in their excitation of a tendency (e.g., talking behavior). Trait sensitivities (cue strength) are set as 1, 2, 4, and 8. The behavior of one individual inhibits that of the others. Simulation done in the `cta` function in the `psych` package.

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. The `cta` model is one of motivation and choice; it involves choice between incompatible outcomes. Students who find a topic challenging enough to be interesting, 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 temperamental or ability needed for that topic will find other topics more reinforcing. Over time, this will lead to group differences in the mean levels of temperamental and ability traits in different college majors. Over a longer time period, people gravitate to certain college

majors, occupations, or ways of behaving as a consequence of their histories of reinforcement. But 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 lead to trait constellations that reflect these choices.

In a large scale, web based assessment of temperamental 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 5 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. [give some correlations here](#).

5. 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 may be modeled dynamically. These dynamics are not ergodic, in that the average outcome does not reflect the basic processes at the individual, 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. But when looking at time spent in the mid term, 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 year, 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

Table 3: Hypothetical amount 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

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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