The Dynamics of Personality

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Abstract

The study of personality dynamics has a long history of being said to be important, but a much shorter history of actually being examined. We give an overview of the past 100 years of research on dynamic processes and suggest how recent methodological and analytic techniques can be applied to the important problem of studying individual differences in the coherent patterning over time of affect, behavior, and cognition.

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Introduction

Just as a song is a coherent patterning over time of different notes and rhythms, so is personality a coherent patterning over time and space of feelings, thoughts, goals and actions. A song is not the average note played, nor should a person be seen as an average of affects, cognitions, desires and behaviors. For it is the dynamic patterning of these components that is the unique signature of a song as well as of a person. That it is the patterning, not the specific notes is clear when the haunting tune of Gershwin's "Summertime" is played by a guitar trio, or a Beatles' tune is played by the London Symphony Orchestra. Unfortunately, although easy to define personality in terms of dynamic patterns, it is much more difficult to study these patternings over time.

The study of personality has long been divided into two broad approaches variously known as nomothetic versus idiograpic, between person versus within person, structure versus process, statistical versus narrative, sociological versus biographical, cross sectional versus developmental, and static versus dynamic. We hope to provide some linkage between these two cultures of personality research in the hope of an eventual integration. Although this chapter will not be nearly as thorough a review of the state of the field as that provided by Allport & Vernon (1930) we hope it is as useful today as their review 90 years ago. They provided a history of the study of personality dynamics up to 1930. Here we try to bring this forward to 2020. Or at least to about 2010. For the past 10 years have seen such an explosion of studies of the dynamics of affect, behavior, and cognition that it would be impossible to cover them all. Although exciting to witness such growth, we think it is important for the readers of this volume to appreciate the foundations behind much of the current work.

That people differ from each other in the patterns of their feelings, actions, thoughts, and desires is obvious, and it is equally obvious that each individual person varies in his or her thoughts, feelings and behavior over time. We have claimed before that the study of personality is the study of the coherent patterning over time and space of affect, behavior, cognition, and desire (the ABCDs of personality) both between and within individuals. Although our long term goal is an integrated model of human actions, to study coherence implies within person patterning, it is the between person differences in these patterns that have received most of our attention. An integrated theory requires combining the nomothetic between person and idiographic within person approaches into a unified framework. Unfortunately, this is difficult for the types of analysis that work between individuals do not necessarily work within individuals (Molenaar, 2004). To generalize from the group aggregate to the individual, or from the individual to the group, the process needs to be ergodic (Molenaar, 2004; Fisher et al., 2018) (but see Adolf & Fried, 2019). Conventional trait approaches suggest that when controlling for trait level, item responses will be uncorrelated. That is, what is left over after the between person signal is removed is just noise. We disagree and believe that to have an adequate understanding of personality, we need to be able to model responses within the individual over time as well as the between individual differences (Beck & Jackson, 2019; Nesselroade & Molenaar, 2016; Revelle & Wilt, 2016).

Biographers and students of narrative identity disagree with the naive trait approach and suggest that the richness of a person's life story is suitable for scientific investigation (McAdams, 1993, 2008). Indeed, this volume is concerned with the study of within person dynamics and it is appropriate to try to frame such research in terms perhaps more familiar to those of us who study individual differences between rather than within individuals. We hope this attempt to integrate nomothetic and idiographic approaches is not naive, and we know it is certainly not new. Almost 80 years ago, Cattell (1943) reviewed six categories of traits, including the *dynamic unities* discussed earlier by Allport & Vernon (1930) and Allport (1937) as well as Stern (1910). The experimental psychologist, Woodworth, named his classic textbook *Dynamic Psychology* (Woodworth, 1918) as he attempted to answer both the questions of how (structure) and why (dynamic processes) of human and animal behavior. He continued this emphasis on dynamics for the next 40 years (Woodworth, 1958).

Much of what is currently included in dynamic models reflects either explicitly or implicity theories of motivation: the how and why of behavior. The terminology of motivation is that of needs, wants, and desires. The study of motivation is the study of how these needs and desires are satisfied over time. That is to say, to study motivation is to study dynamics (Atkinson & Birch, 1970; Heckhausen, 1991) However, there is more to dynamics than just motivation. For the patterning of thoughts, feelings and desires can be seen to reflect stable individual differences in rates of change of internal states in response to external cues. We think this emphasis on dynamics should continue.

Early dynamic models

Perhaps because of an envy for the formalism of physics, Kurt Lewin wrote that to study behavior was to study its dynamics, for behavior was a change of state over time (Lewin, 1951). People's states changed in response to the self perceived situation, not the situation as defined by an observer (Lewin et al., 1935). They responded to the entire field, not to any particular cue. To Lewin, "field theory is probably best characterized as a method: namely a method of analyzing causal relations and of building scientific constructs" (p 45, Lewin, 1951). To understand the individual, one had to understand the field of forces impinging on the individual and the way those forces were perceived. An understanding of the goals of action were essential in understanding the action (Zeigarnik, 1927/1967). Behavior was not a reaction to a particular stimulus but rather of the entire field of potential rewards and punishments.

A very important summary of Lewin's work was the introduction to American psychologists by J. Brown (1929). To read this is to understand the excitement of dynamic thinking that Lewin was emphasizing in contradistinction to the behaviorist movement which was becoming popular in the US. In his review Brown emphasizes the tension between the Gestalt psychologists of Europe and the behaviorism that was coming to dominate research in the US. Lewin's distinctions between identical motor movements needing to be understood in terms of their broader meaning (copying text versus writing a letter), or the significance of a post box when one has a letter to mail versus not make clear the need to study the motivational dynamics of behavior rather than the behavior per se.

As Atkinson & Birch (1970) put it, motives had inertia and persisted until satisfied. They could not be studied without considering their dynamics over time (Zeigarnik, 1927/1967). Just as Berlin waiters could remember what their customers ordered for dinner until they had paid for it and then not be able to recall it, so did children remember the games they had been playing but had not yet finished rather than games that had reached a conclusion (Zeigarnik, 1927/1967). Similar results have been reported for unsolved versus solved anagrams (Baddeley, 1963) and depending upon the task, reflects competing motivations for success and failure avoidance (Atkinson, 1953). Inspired by Zeigarnik's initial study, examination of the effects of interrupted tasks continues to this day to address the modern problem of timesharing between many tasks (Couffe & Michael, 2017) and is a major concern for computer scientists and human factor engineers. To what extent is the writing of a manuscript hindered by frequent interruptions from email or text notification? To what extent is the learning of material by students hindered by their attempts at balancing the many demands, both social and intellectual as they attempt to time share their responses to these demands? Indeed, a web page with the delightful name of `https://interruptions.net` is dedicated to the memory of Bluma Zeignarnik with a voluminous reading list of the costs and benefits of interruptions and the dynamics of behavior.

The Data Box

In order to integrate the study of temporal changes with cross sectional measurement, Cattell (1946) introduced P techniques in his three dimensional organization of data (the *data box*) that considered Persons, Tests, and Occasions[1]. Traditional personality descriptions (R analysis) were correlations of Tests over Persons, but some had proposed correlations of people over tests (e.g., Q analysis Stephenson, 1935, 1936) which allowed identifying clusters of people who showed similar profiles across tests. Finding the correlation of items for single individuals across time (P technique) allowed Cattell and his colleagues (Cattell, 1950; Cattell et al., 1947; Cattell & Luborksy, 1950; Cattell & Cross, 1952) to analyze dynamic traits. We now would view the Data Box as a way of conceptualizing nested multilevel data. For normally, variations over time (P technique) are nested within individuals (R-technique).

Early use of P technique tended to be demonstrations for one or a few subjects. e.g. one subject suffering from a peptic ulcer was studied on 49 variables over 54 days (Cattell

[1](Cattell (1966) subsequently enlarged the data box to include 10 dimensions, but it is the three dimensional organization that is most helpful. He also varied the names for the six slices (P, Q, R, T, etc.) from publication to publication.

& Luborksy, 1950). The variables included psychophysiological measures such as blood glucose concentration and lymphocyte counts as well as objective personality measures, self reports, and peer ratings. Some of the personality variables had been chosen based upon prior R analyses with other subjects. Of the P factors identified within this subject, some matched R (between subject) factors, but some did not.

A subsequent study (Cattell & Cross, 1952) followed one subject over 40 days with two observations per day. They choose marker variables from R analysis and then searched for matching factors in the P analysis. They refer to these motivational factors as *ergs*[2] and they plot the rise and fall over time of 10 such ergs as mating, parental protection, self-sentimental, etc.

Both of these studies used normal correlations of the measures, and although graphically showing the changes of "ergs" over time, the actual factor analyses did not take the temporal patterning into account, That is, the correlations and their loadings on the factor structure would have been the same if the temporal sequence had been randomized. Unfortunately, this problem still plagues many P analyses and has started to be addressed with lagged correlations (Beck & Jackson, 2019) and dynamic factor analysis (Molenaar, 1985; Molenaar & Nesselroade, 2009).

Many of these early models emphasized how people differed in their perceptions of the situation and that to understand the individual dynamics, we needed to understand these perceptions (Kelly, 1955). Kelly's theory lives on with the use of his Role Construct Repertory Grid Test which emphasizes the assessment of an individual's important constructs rather than relying on some predetermined set. A perceptual model incorporating the dynamic effects of feedback was proposed by Combs & Syngg (1952). For the negatively motivated individual (concerned with avoiding failure or the pain of failure) worries about failure lead to poor performance which feeds back to produce even more worry. The more approach oriented individual, however, perceives effort as an opportunity for success and tries harder which tends to lead to success.

Time and change

To study the dynamics of personality is to study changes in Affects, Behavior, Cognition and desires (ABCD) over time. These temporal changes need to analyzed in terms of the psychological spectrum (Revelle, 1989) which ranges from the milliseconds of reaction time to the seconds of emotion, the minutes of mood, the diurnal variation ($8.64 * 10^4$ seconds) of arousal, testosterone and body temperature, monthly menstrual rhythms ($2.5 * 10^6$ seconds), seasonal variations in weather related affect and behavior, year to year changes of educational experience, and the lifespan changes in development over 95 years (or $3 * 10^9$seconds, See Figure 1). Seemingly distinct domains of study differ in the duration examined but all can benefit from thinking dynamically. Physiological studies

[2]To read Cattell is to discover a completely idiosyncratic vocabulary which although useful in not carrying excessive meaning, has not been widely adopted.

of EEG or MRI examine neural changes over milleseconds to seconds, studies of basic signal detection focus on the accuracy and reaction time to make simple or complex choices. Those who study the emotional effect of success and failure feedback examine changes in emotion and performance over minutes to hours. The diurnal rhythmicity of arousal interacts with stable trait measures of impulsivity to affect cognitive performance (Revelle et al., 1980). Testosterone levels systematically decline during the day and affect the emotional reactions to angry faces (Wirth & Schultheiss, 2007). "Owls" and "larks" differ in the phase of their diurnal body temperature rhythm (Baehr et al., 2000). Decrements in sustained performance known as failures of vigilance affect drivers, sonar operators, and TSA security inspectors (Broadbent, 1971; Mackie, 1977) and has been associated with trait differences in extraversion (Koelega, 1992). Life span developmental psychologists focus on the dynamic stages of lives as well as the cumulative record of accomplishment (Damian et al., 2018; Lubinski, 2016; Lubinski & Benbow, 2006; Oden, 1968; Terman & Baldwin, 1926; Spengler et al., 2018). The understand how the systematic changes in life demands from childhood through adolescence, young adulthood, parenthood and aging shape behavior is to study the dynamic coherence of being. Just as the day to day weather fluctuates drastically, and seasonal changes in climate lead to large changes in mean levels, so can we need to analyze individual differences at these different temporal frequencies (Baumert et al., 2017; Revelle & Condon, 2017).

One such approach was discussed by Larsen (1987) who introduced spectral analysis to the study of personality and emotion and provided a very helpful review of the prior literature. In his examination of mood variation over multiple days, Larsen (1987) specifically rejected using time series design and rather focused on the spectrum of frequencies that represent mood variation. In a compelling footnote, he distinguishes between deterministic periodicity (equivalent to the timing of a pendulum) versus randomly perturbed stochastic processes such as a pendulum being shot at by a mischievious child with a peashooter.

A relatively unknown but important early study showing the rhythmicity and variability of mood was done by Johnson (1937) who examined the mood of 30 female students over 65-90 days at the University of California, Berkeley. The rating scale was a single item with ratings of euphoria versus depression ranging from "I almost never feel more elated," to "as depressed as I practically ever feel." Although euphoria and depression are probably not bipolar opposites, but reflect rather two independent dimensions (Rafaeli & Revelle, 2006), their difference is still an important indicator of mood. Johnson tested her subjects when they reported being elated and also when they were depressed. Spontaneous utterances were much more likely to be emitted when in a positive rather than in a negative mood. Similarly, decisions were made faster when in a positive mood as contrasted to a negative mood. Perhaps because of a lack of power, perhaps because a lack of an effect, there was no noticeable patterning of mood associated with the weather, nor day of week, nor the month.

Just as body temperature shows striking individual differences in the phase of the diurnal rhythms (Baehr et al., 2000), so does positive and negative affect vary over the

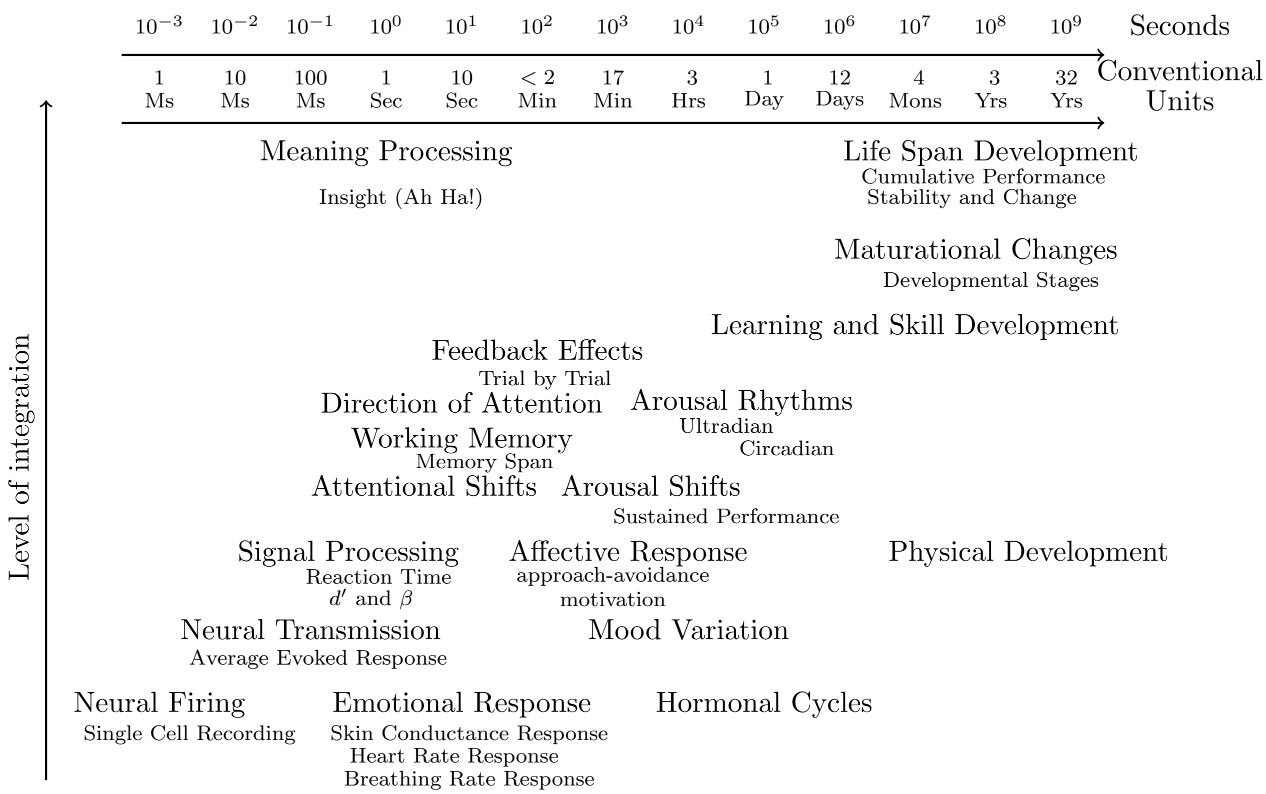

Figure 1. The psychological spectrum: The domain of psychological studies covers 12 orders of magnitude from the milliseconds of reaction time to the more than three billion seconds of a lifetime. Psychological phenomena range from the very biological to the complex adaptations and adjustments occurring over a lifespan. Dynamic processes occur at all of these temporal durations and although they require different measurement techniques and are studied by scientists in seemingly different areas (e.g. cognitive, motivational, developmental psychologists) they may all be analyzed in terms of their dynamics over time. Adapted from Revelle (1989)

day (Rusting & Larsen, 1998; Thayer et al., 1988). Using daily diary reporting from 82 participants three times a day for 28 days Zelenski & Larsen (2000) found that the within subject mean and variation of affect and arousal terms show remarkable consistency across multiple weeks. Affective reactions to varying situations also show strong and stable individual differences when aggregating data over multiple observations (Diener & Larsen, 1984).

But moods are more complicated than just varying from situation to situation or diurnally over the day. Moods vary daily, and seasonally and also show weekend effects. Larsen & Kasimatis (1990) considered the rhythmicity associated with week days versus weekends. Going beyond examining just mood Wessman et al. (1960) in a study with 14 Radcliffe students over 42 days examined how self concept related to within subject changes in elation versus depression. That within subject variations in mood relate to partners mood has been an important set of findings of marital satisfaction (J. M. Gottman, 1981; J. M. Gottman et al., 1969).

Variables showing dynamic processes

The studies discussed above made use of measures that were expected to change across time. Thus, measures of state mood ("how happy do you feel right now?") rather than trait measures of affect ("Are you normally happy?"). Other studies examined physiological measures expected to show variation (heart rate, breathing rate, variability in Reaction over trials). Zelenski & Larsen (2000) examined mean emotion rating over days as well as the the frequency of a particular emotion being given a non-zero rating and intensity of that emotion. Pooled within subject and between subject correlations of the affect measures suggested a dimensional structure between subjects but a more discrete structure within subject. When Rafaeli et al. (2007) examined differences in the within subject correlation structure they found that people systematically differ in their correlation between Positive and Negative Affect. The within subject correlation of PA and NA was stable over a delay of several weeks and varied between subjects from strongly negative to strongly positive. More detailed examination of these individual differences, found that how one perceives the environment (threatening versus challenging) predicted the within subject affective correlation (Wilt et al., 2011).

Perhaps because of their obvious psychological signficance, perhaps because of ease of measurement, many of the within person dynamic studies have emphasized emotions. But there are far more psychologically relevant variables that show systematic variability over time. Variations in the rhythmicity of heart rate and breathing rate are used as measures of cognitive load (Durantin et al., 2014; Porges, 1972; Reyes del Paso et al., 2013), variability and extreme values of reaction time are taken as measures of inattention, fatique and mindwandering (Seli et al., 2013). Although not focusing on rhythmicity, (Berli et al., 2018) examined how social support in dyadic couples was related to variations in daily activity over a period of 28 days. The dynamics of coping behavior when given the stress of studying for the Bar Exam related to subsequent anxiety a day later. Active coping on one day lead to reduced anxiety on the subsequent day (Iida et al., 2017).

In a very thoughtful tutorial and review of the state of the art of modeling affective processes, Hamaker et al. (2015) consider eight ways that data and analyses differ when studying intensive longitudinal data. Studies differ in terms of studying single versus multiple subjects, examining one versus multiple variables, assuming constant versus varying effects over time, treating time as discrete or continuous, treating variables as discrete or continuous, modeling time versus modeling frequency, modeling processes versus describing the data. Each of these eight dichotomies leads to different kinds of data collection and different ways to analyze the resulting data. With the advent of new open source software, it is now possible to apply elegant data analytic techniques that were a dream just 10 years ago.

Descriptive models

Solomon's opponent processes model (Solomon & Corbit, 1974; Solomon, 1980) examined five stages of affective dynamics ranging from a strong immediate peak, followed by adaptation to a steady level, and then a remarkable after reaction followed again by a steady state. Whether the affect was that of one of Pavlov's dogs in a harness, or the emotional expressions of sky divers, the affective reaction showed a similar pattern suggesting two opponent processes. The initial process is in response to a cognitive/perceptual signal, while the second process is in response to the first. The second process down regulates the first, and the resulting emotional state eventually returns to baseline. But removing the cue for the first process leads to a strong over response by the second process. This model has been applied to drug addiction (contrasting the initial rush associated with new users versus the contentment of an addict after many occasions) interpersonal relations, and even the experience of sauna bathing (the pain and burning sensation of the first time followed by relief versus the hot excitement followed by exhilaration of the frequent user).

An alternative model that also suggests multiple processes is reversal theory (Apter, 1984). Originally proposed in contrast to the arousal seeking/avoiding models of (e.g.,) Eysenck (1967), reversal theory proposed that motivation was bistable, and that rather than seeking homeostatic equilibrium alternating orientations drove behavior. These alternative orientations were said to be goal directed (or telic) as contrasted with activity directed (or paratalic) Originally considering the hedonic tonie associated with various levels of arousal, subsequent extensions of this model grew to include more motivational pairs (Apter, 2001) growing to four sets of reversals in the most recent statement: serious versus playful, conforming versus rebellious, sympathy versus mastery, and self versus other (Apter, 2018). These models, like many others, although appealing, are more descriptive than testable.

The importance of these descriptive models is that they emphasize the temporal component. They focus on latency and persistence, the rise time of a feeling, the decay time of another feeling. Recognizing that the persistence of a feeling state is the latency to another feeling state, and that action is set of changes between states over time, these models forced dynamic thinking.

Control theory: the power of feedback

In response to the communications need of the Second World War, and the subsequent introduction of communication theory (Shannon, 1948; Shannon & Weaver, 1964) it became possible to quantify information as it flows through noisy channels. With the addition of the concept of feedback, information theory blossomed into cybernetic theory (Wiener, 1948). (Wiener coined the term cybernetic from the Greek term for steersman.) Similar work by Ashby (1940) on the meaning of dynamic equilibria had led to the generalization known as control theory (Ashby, 1957). Biological systems could be analyzed in terms of feedback leading to stable equilibria. For "a variable is in stable equilibriuim if, when it is disturbed, reactive forces are set up which act back on the variable so as to oppose the initial disturbance." (p 479, Ashby, 1940). The dynamics of pendula, springs, and electric circuits are similar (but simpler) to the dynamics of pupilary dilation or the stabillzation of the ph of blood by the activity of the mendula and the rate and depth of breathing.

That behavior was not merely a response to particular stimuli (e.g., Dollard & Miller, 1950) but rather reflected cognitive schemas/maps in the purpose of goal satisfaction had been suggested by Tolman (1932, 1948). Tolman's dissatisfaction with the behaviorist agenda led him to study how rats solved mazes in a way best understood in terms of their cognitive maps of the maze. He also demonstrated the importance of motivation as it affects performance. For hungry non-rewarded rats did not exhibit any knowledge of mazes until rewards were added to the goal box (Tolman & Honzik, 1930). As a demonstration of the distinction between competence and performance, and of the importance in understanding the motivational determinants of performance this was a very influential study. Tolman's writing on purposive behavior (Tolman, 1932) in combination with Lewin's on the need to understand the entire psychological environment helped shape the resistance to simple Stimulus-Response approaches then so common in experimental psychology.

Taking advantage of the feedback systems of Wiener (1948) and Ashby (1957) the cognitive psychologists Neal Miller and Eugene Galanter collaborated with the neuropsychologist, Karl Pribram in their influential book on *Plans and the Structure of Behavior* (Miller et al., 1960). Popularizied in psychology as the TOTE unit (Test-Operate-Test-Exit) feedback and a comparison to a standard was seen as a way to instantiate goals as the drivers of behavior (Miller et al., 1960) (Figure 2a). Given an initial state of the world, a test is done against the desired state, if there is a discrepancy, an action (operation) is taken. The resulting state is then tested again. If the incongruity remains, the operation is performed again. When the resulting state matches the desired state, the system exits. (Thus, although referred to as a TOTE unit, the action is more likely to be test-operate-test-operate ... test-operate-test-exit). TOTE units can be hierarchically nested, such that a lower level unit is called to as an operation in a higher level unit.

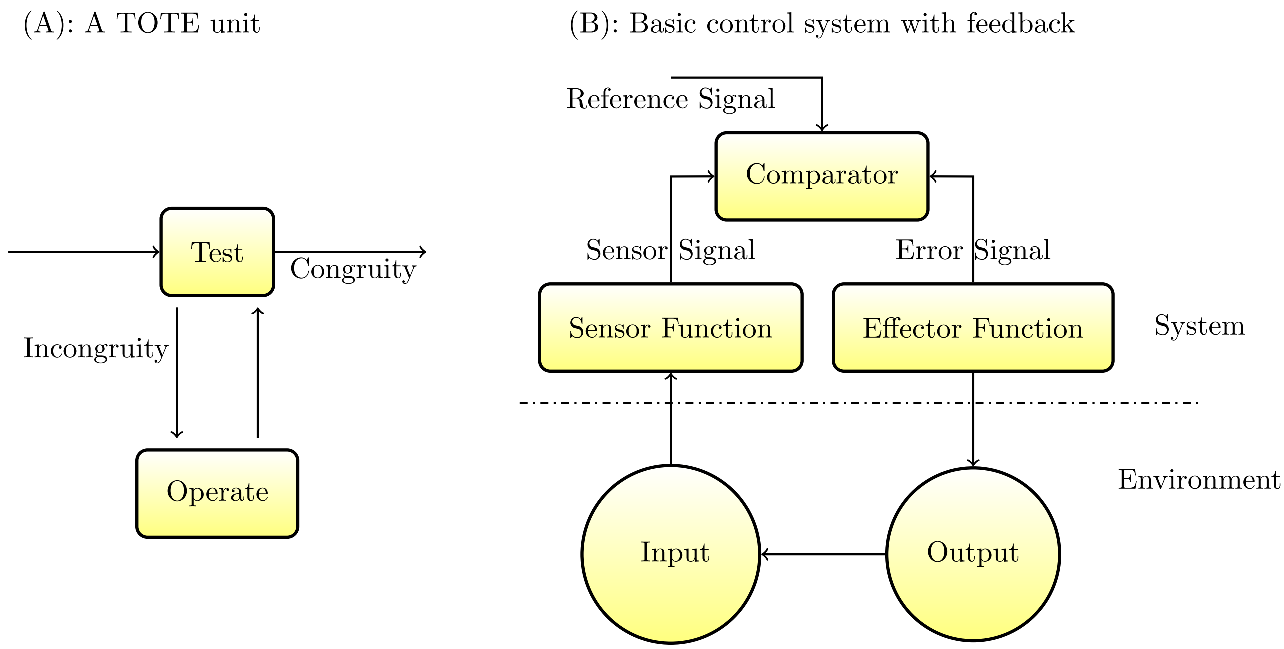

Figure 2. A): The basic Test-Operate-Test-Exit (TOTE) unit from Miller et al. (1960). B) The basic feedback loop with a comparator (adapted from Powers, 1973).

Actions need to be studied over time as people (and animals) dynamically reduce the discrepancy between the current state and some goal state as they achieve a homeostatic equilibrium (Powers, 1973) (Figure 2b). The resulting motivational models are implicitly (and usually explicitly) dynamic as individuals behave to approach reinforcement and avoid punishment. Many examples of such control systems include the concept of a *set point* or reference level and the analogy is frequently made to the control of temperature in a room to achieve the setting of a thermostat. When the room is colder than the set point, heat is called for, when it achieves the set point, the heating is turned off. (In warmer climates, deviations above the set point are corrected for by the use of air conditioners.) Although such homeostatic processes were a common model for physiology (Cannon, 1929; Cooper, 2008; Woods & Ramsay, 2007), applying the same concepts to cognition and behavior was an important contribution to the study of dynamics.

The conventional approach to control systems was the reference signal or set point.

Just as the temperature of a room is controlled through the setting of a thermostat, so was dietary intake seen as controlled through a "ponderostat" (Cabanac, 2001; Toates, 1983). Eating behavior in response to food cues and bodily needs was seen as a prototypic example of control theory. Obesity was seen as a function of the setting of the ponderostat which in turn affected the palatability of food (Cabanac et al., 1971). Such a set point was proposed to be related to the activity of the ventro-medial hypothalmous (Nisbett, 1972). The set point is the reference signal in Figure 2b. Assuming that being on a diet put people below their set point Herman and Mack showed that "restrained eaters" (people on diets) responded more strongly to environmental cues of food availability than did non-restrained eaters, who decreased their eating subsequent to prior eating (Herman & Mack, 1975).

Animal models

However, further research suggested that rats (and probably humans) do not defend a particular body weight (as suggested by the ponderostat or set point model) but rather balance out the palatability of food versus the effort needed to achieve the food. Weight gain was seen as the dynamic balance in eating behavior between a preference for good tasting food and an aversion to work hard for it (Bolles, 1980). Rats will go into cold rooms to acquire highly palatable food, but will not for less palatable food (Cabanac, 1992). Similarly showing a balance between competing motives, the duration of underwater copulatory behavior of the oxygen breathing newt could be lengthened by changing the oxygen content of the atmosphere. Newts would persist copulating underwater longer following breathing at an oxygen rich surface (Halliday & Houston, 1991). For an excellent review of control theory with particular application to animal models (Toates, 1975) see Toates & Halliday (1980). Toates elaborated this model to include multiple levels of control, including cognitive control of conscious and unconscious processes (Toates, 2004, 2006).

Human models

Control theory models were emphasized in a number of very important papers by Charles Carver (1979, 2003) and his colleague Michael Scheier (Carver & Scheier, 1982, 2012). These were elegant models of hierarchical self regulatory processes with set points of subordinate goals modified by those of superordinate goals. Each control process is under the influence of higher level systems. The goal of returning a book to friend can be seen as satisfying a higher level goal of seeing oneself as a responsible person, which in turn leads to the goal of getting the book back to the friend, which sets the local goals of keeping the car on the road which sets even more subordinate goals of appropriate motor control. Interruptions to the lower level goals (a detour in the road) lead to reseting of these local goals in service of meeting the superordinate goals.

Following the biological models of Gray (1981, 1982), Gray & McNaughton (2000) and others (Depue & Collins, 1999; Depue et al., 1994; Fowles, 1987) Carver considered how dynamic progress towards goals affected emotion. Dividing goals into approach and avoidance goals, the velocity of progress towards an approach goal was seen as related to positive affect, as was the velocity of progress away from an avoidance goal. Failure to achieve an approach goal would lead to anger as well as sadness (Carver, 2004).

An elaboration of control theory as a way of integrating multiple motivational approaches was proposed by Hyland (1988) who showed how "motivational control theory is an integrative framework for examining the relation between different theories of motivation" (p 650, Hyland, 1988). To Hyland (1988), motivational control theory integrated the principals of control theory with higher level theories such as those of Atkinson (1957); Locke (1968), and Weiner (1972).

A very thoughtful article by Van Egeren (2009) integrates the personality dimensions known as the "Big 5" with a cybernetic theory model. This an impressive integration of the biological models of Gray (1991) and Depue & Collins (1999) with the descriptive taxonomies of Goldberg (1992, 1993) and Saucier & Ostendorf (1999), goal constructs (Austin & Vancouver, 1996) and the control theory of Powers (1973) and Carver & Scheier (2012). "Personality-regulatory relationships should be clearer to psychologists if abstract cybernetic theoretical constructs are translated into terms (e.g., goals, situation, outcome) that are more familiar to psychologists" (p 92, Van Egeren, 2009). The B5 traits of extraversion, neuroticism and conscientiousness are seen as regulating approach to goals (extraversion) error detection and response to threats (neuroticism) and constraint of the response to match output to the environmental needs (conscientiousness). Openness is linked to the disposition and allocation of attention to the environment as well as the breadth of attention. Agreeableness is associated with the regulatory control of partnership formation. The basic theme of this paper is that personality traits are dispositions or bias settings in a self regulatory system

In a subsequent paper, DeYoung (2015) expanded on the ideas of Van Egeren (2009). In his explicitly dynamic proposal "traits are equivalent to persisent attractor states of the cybernetic system: they indicate states towards which the person will gravitate but do not preclued the person from being in other states" (p 33, DeYoung, 2015). This is an attempt to integrate the genetic/biological propensities of the B5 with goal directed actions (Austin & Vancouver, 1996) and the three levels of personality discussed by McAdams & Pals (2006).

As a way of integrating multiple dynamic systems, each trying reduce the difference between a goal state and the current state, Cabanac (1971, 1992) introduced pleasure as the common currency. Balancing out the gustatory pleasure of sweet with the displeasure of sourness it was possible to trace out a tradeoff function between the two (Cabanac, 1992). Similarly, tradeoffs could be shown between the displeasure of fatigue and cold discomfort. Tradeoffs between monetary reward, fatique, game playing, cold discomfort all lead to the hypothesis of pleasure as the unifying common pathway as humans and rats dynamically balance out the competing rewards and punishments.

In a discussion of effective functioning and its relationship with affect, (Ortony et al., 2005) suggested that the ABCDs of personality need to be analyzed at multiple levels of dynamic control. At the lowest level, reactive processes take inputs and respond with outputs without conscious or affective awareness. The timing of such events is in the milleseconds to seconds of the psychological spectrum (Figure 1). Such behavior is also known as automatic and requires few cognitive resource. More typical is the routine level of action which is the level of unconscious, uninterpreted expectations and well learned automatized activity and although characterized by awareness is not by self awareness. The third level of these interacting systems, the reflective, is seen by higher level cognitive processes and consciousness. While the routine level has access to the immediate past and immediate future, it is at the reflective level that one can time travel to the more distant past and long term future (the right hand part of Figure 1).

Although the development of cybernetic and control theory descriptions of the dynamics of personality has great theoretical appeal, and provide very compelling organizations of disparate literatures, there has been less emphasis on testing these dynamic models. At the descriptive level, the approach of Van Egeren (2009) and DeYoung (2015) is very appealing. What is needed however, is some experimental tests of these these theories. Do affect and behavior actually follow the predictions made from these cybernetic models?

Formal models of personality dynamics

Based upon the findings of Zeigarnik (1927/1967) and Atkinson (1953), Feather (1961) examined the carryover effect of motivation from trial to trial. Subjects high and low in resultant achievement motivation were given supposedly easy or difficult tasks on which they failed. High achievers persisted longer following failure on easy tasks than they did following failure on very difficult tasks. These results could be interpreted as a carryover of motivation from trial to trial or as a change in probability estimation following failure. Subsequent research emphasized the carryover of motivation. The fundamental concept of motivational carryover is that motivations show inertia: they are not completely situational specific, but rather reflect the prior state as well as the current environment. Although not frequently recognized, it is this inertial property of affect or motivation that is the key to the study of dynamics. We discuss this in some detail later when we consider how dynamic processes are more than just stochastic variation.

In the affective domain Suls et al. (1998) discussed affective inertia, in terms of the carryover of prior mood to subsequent time periods. In an intensive longitudinal design, 48 male community residents reported their mood 6 times per day for 8 days. Trait measures of personality included extraversion and neuroticism. Trait neuroticism predicted mean level of negative affect, but more importantly predicted the strength of the lag effect of negative emotion: more neurotic participants had stronger affective inertia than did the less neurotic. The lag effect of negative mood was observed within days, but this could have been due to the longer lags between days (12 hours) than that within days ($\approx$ 3 hours).

A more recent study based upon modeling within subject affect examined the valence and arousal of six participants measured over 500 days (in a simulation of a trip to Mars). Using a time varying auto regressive model, Bringmann et al. (2017) found that emotional intertia did not just vary between subjects but also showed systematic changes over time within subjects.

Dynamics of Action

The conclusion from the motivation and affective dynamic studies is that motivation and affect do indeed have inertial properties. A formal model of these effects of inertia was developed by Atkinson & Birch (1970) which they labeled as the Dynamics of Action (DOA). The original DOA proposed was analogous to basic Newtonian physics, replacing inertial masses with inertial motives, and physical forces with psychological instigating forces. In analogy to Newton's first law, motives were thought to persist until satisfied, and to only change when acted upon by instigating and consummatory forces. In parallel with approach motivation (action tendencies) was avoidance motivation (negaction) which increased with threats of failure decreased by the force of resistance. The trait of achievement motive interacted in a multiplicative manner with the probability of success to affect the resulting instigating force. Thus traits acted as rates of change in the motivation in a particular situation. Traits were not seen as likelihoods or frequency distributions, but rather as rates of change. What is stable in a person is how rapidly that person changes.

The inertial principal (and Zeigarnik's findings) led to the prediction that the motivation to achieve would carry over from trial to trial following failures but not following success (Revelle & Michaels, 1976). With this simple assumption of carryover of motivation following failure the inverted U relationship between task difficulty and effort of Atkinson (1957) could be reconciled with the empirical observation that people try harder the harder the task (Locke, 1968). For harder tasks led to more failures, and thus more carryover from trial to trail. This was predicted to be the case for those higher in achievement motivation and could be summarized by the popular idiom that "when the going gets tough, the tough get going". Subsequent work by Kuhl & Blankenship (1979) took the basic model of Revelle & Michaels (1976) and applied the full DOA theory.

Unfortunately, although theoreticallly appealing, the DOA was perhaps overly complicated with a number of extra parameters reflecting instigating and consummatory lags. Heckhausen (1991) suggested that although the DOA properly introduced dynamics and feeback into the study of action, that it was unwieldy in its complexity. The DOA model was subsequently reparameterized to what could be seen as simpler model representing the effects of environmental cues inciting action tendencies, which in turn led to actions (the CTA model of Revelle, 1986). Although graphically shown as a simple block diagram, the basic model was just two equations linking the rates of changes in tendencies and actions to the instigating strength of environmental cues and the consummatory effects of action.

$$d\mathbf{t} = \mathbf{Sc} - \ \mathbf{Ca} \tag{1}$$

$$d\mathbf{a} = \mathbf{Et} - \mathbf{Ia} \tag{2}$$

This is a simple control theory model with individual differences in personality represented as the values of the matrices ($\mathbf{S}$, $\mathbf{C}$, $\mathbf{E}$ and $\mathbf{I}$) thought to affect the linkage between the vectors of external cues ($\mathbf{c}$), latent tendencies ($\mathbf{t}$) and observed actions ($\mathbf{a}$). Four classes of individual differences are hypothesized: cue sensitivities, ($\mathbf{S}$), the excitatory strength between tendencies and actions ($\mathbf{E}$) and the consummatory linkage ($\mathbf{C}$) of actions reducing action tendencies. Choice between actions was an automatic function of actions inhibiting other actions ($\mathbf{I}$). A simplified box diagram of the flow of control in the CTA model is shown in Figure 3.

Although formalized as two differential equations (Equations 1 and 2), this reparameterization was then implemented in computer code as two difference equations written in the open source statistical system, R (R Core Team, 2019), and included as the `cta` function in the *psych* package (Revelle, 2019). Revelle & Condon (2015) showed how the CTA model could model dynamics at three levels of analysis: within individuals (e.g. the rise and fall of emotions), between individuals (talking behavior in groups of individual), and between groups of individuals (choice of college major or occupation). Once again, traits were seen as parameters of the CTA model and thus as influencing the rates of change of states. States were the dynamic consequences of traits affecting rates of excitation and inhibition. Although not yet implemented in the `cta` function, the individual difference parameters presumably could be changed in response to learning and the to reinforcement.

Subsequent research combined the CTA dynamic mode with the biologically based Reinforcement Sensitivity Theory (Gray & McNaughton, 2000; Corr, 2008) to form the CTARST model (A. D. Brown, 2017; A. D. Brown & Revelle, 2019). A. D. Brown (2017) showed how the CTARST model provides strong agreement with dynamically collected mood data from several studies (e.g., Smillie et al., 2012; Wilt et al., 2017).

Modeling goals

Viewing personality traits as "as configurations of goals and motives, plans, resources, and beliefs," (p 237, Read et al., 2017) and thus as the drivers of behavior, Read, Miller and their colleagues have proposed a formal computational model (Read et al., 2010) that can simulate "viirtual personalities". This was based upon their formulation of personality traits as representing differences in approach and avoidance goals (Read & Miller, 1989b,a) and alternative strategies for achieving these goals. They are addressing the problem of how to model the many systematic ways people can differ in their behavior over time. The model allows them to integrate the structure of between person variation with the dynamics within people. Their more recent work combines their earlier computational model with a biologically plausible simulation (Read et al., 2018) based upon concepts from Reinforcement Sensitivity Theory. Their model is a multi-level neural net that they have used to simulate the cognitive, affective, and behavioral patterns associated with the "big 5". The Read and Miller model is perhaps the most completely stated dynamic model

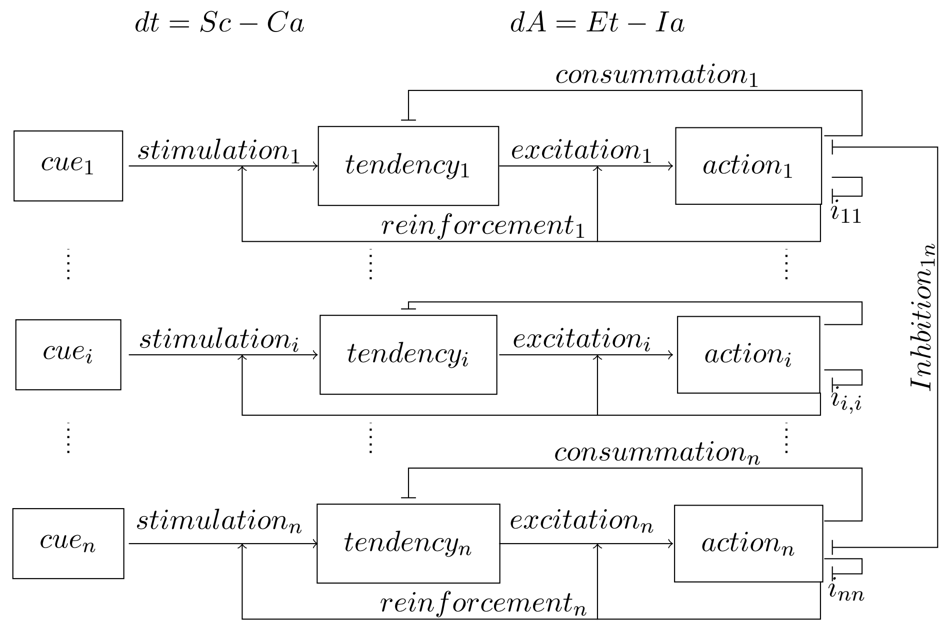

Figure 3. A simplified model of the cues, tendency, action (**cta**) model. Cues stimulate action tendencies which in turn excite actions. Actions may be mutually inhibitory and also reduce action tendencies. Extensions of this model allow for learning by changing the stimulation, excitation, and inhibition 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. Not shown are the inhibitions from $action_1$ to $action_i$, etc. Adapted from Revelle & Condon (2015)

of personality and would require far more space than is available here to summarize.

Modeling the dynamics of emotion and personality

Recent work in modeling inertial properties of emotional states (Kuppens, Allen, & Sheeber, 2010; Kuppens, Oravecz, & Tuerlinckx, 2010) as well as of personality states (Sosnowska et al., 2019) takes a somewhat different approach. In a model of the dynamics of affect (DynAffect) that "explicitly incorporate time-varying factors to enable the study of how momentary processes such as appraisals and ongoing emotion regulation efforts impact the unfolding of affect over time." (p 1056, Kuppens, Oravecz, & Tuerlinckx, 2010) Kuppens and his colleagues model individual differences in the mean level of affect (the affective "home base"), variability from the home base, and the strength of the attractor returning affect to the mean. Personality traits such as extraversion and neuroticism relate to the mean level as well as the variability around the mean.

An extension of the DynAffect model to personality states and traits is the PersDyn model (Sosnowska et al., 2019) where once again the important parameters are the personality baseline, variability, and attractor strength. Both DynAffect and PersDyn are explicitly dynamic and represented as differential equations modeling how affect and personality states return to an individual's baseline. Person parameters are the home base, variation around home base, and strength of the attractor (rate of return to home base).

Dynamic processes $\neq$ stochastic variation

It is important when discussing dynamic models to not confuse patterned variation over time with stochastic variation. Simply saying that people vary over time and occasions (Fleeson, 2001; Fleeson & Jayawickreme, 2015; Jayawickreme et al., 2019; McCabe & Fleeson, 2016) is not the same as discussing the dynamics of such change (Read & Miller, 1989b,a; Revelle & Condon, 2015). Trait values may indeed be considered the central tendencies of state values (the central tendency of a density distribution), but it is more useful to think of traits as rates of change in states rather than the probability of being in a state.

Thinking dynamically implies that there are conditional dependencies between actions. (Drinking coffee leads to subsequent urination, not sleeping leads to sleepiness, deprivation of a goal state leads to a rebound of the motivation). By ignoring the temporal dependencies when examining the density distribution of behavior, a simple cross sectional study would conclude that drinking water is negatively related to urination, although when modeling the dynamics, there is clearly a positive and causal relationship. The need to consider dynamics is even more obvious when examining social interaction. That each of two people spend 50% of their time talking when in a two person group does not imply that 25% of the time they are both talking and 25% of the time neither is talking (the implication of talking behavior as showing a density distribution of independent probabilities). If there were no sequential dependency, two people each with a probability of talking of .5 would be expected to both be talking at the same time with probability of

.25. But because most people take turns talking and listening, the talking of one person is negatively correlated with the talking of the second person, but positively correlated with subsequent talking.

Although Fleeson (2001) and his colleagues emphasize the frequency of activity, thinking dynamically implies that it is more appropriate to think about the latency and persistence of affective and behavioral states as well as just their frequency distribution. For example, the relative balance of positive and negative statements in couple interactions show systematic temporal patterns. Indeed, J. M. Gottman & Levenson (1992); J. Gottman et al. (1999) examined the sequential dynamics of romantic couples and in an explicitly dynamic model of within couple feedback and were able to predict subsequent probability of divorce with surprising accuracy.

Another approach that is said to be dynamic, but we would view as merely complicated is the CAPS model (Mischel & Shoda, 1998). Behavior is the outcome of a set of "If-Then" decision rules that may be unique to each individual. That people show consistent, and different, patterns of responses to situations is just evidence for situation x person interactions and implies nothing about dynamic processes. That behavior is context dependent is perhaps tautological, for an individual who does not change behavior across contexts has some serious psychopathology. More importantly, studying variation across situations is not studying dynamics. To be described as dynamic, the process must be time dependent. The CAPS model does not seem to meet this criterion, for it ignores the temporal component.

The knowledge and appraisal model of personality architecture (KAPA, Cervone, 2004) is a variant of the CAPS model and emphasizes the importance of the appraisal process. Although emphasizing the unique appraisals of individuals as they interact with their environment in their daily lives, it is not a dynamic model in the formal sense. This is in spite of a very clear statement of the meaning of dynamics:

> By 'dynamics' we refer to psychological processes that unfold across time. The time period may be relatively long (e.g., the formation of identity; Marcia, 1980) or short (e.g., processes contributing to conscious awareness; Dennett & Kinsbourne, 1992). Processes may occur serially or in parallel (Kuhl, Quirin, & Koole, 2015). Yet in all cases, dynamics 'have duration and a course' (Wittgenstein, 1980, p836). Note that this usage of 'dynamics' is much broader than its meaning within psychodynamic theories, which highlight dynamic processes involving conflict and unconscious mental mechanisms.(p 13, Cervone & Little, 2019).

However, the personal projects analysis of Little (1983, 2005) discussed by Cervone & Little (2019) is definitely dynamic: for a personal project is "regarded as a set of interrelated acts extending over time, which is intended to maintain or attain a state of affairs forseen by the individual" (p 276, Little, 1983). Personal projects are in some sense reminscent of TOTE units (Miller et al., 1960).

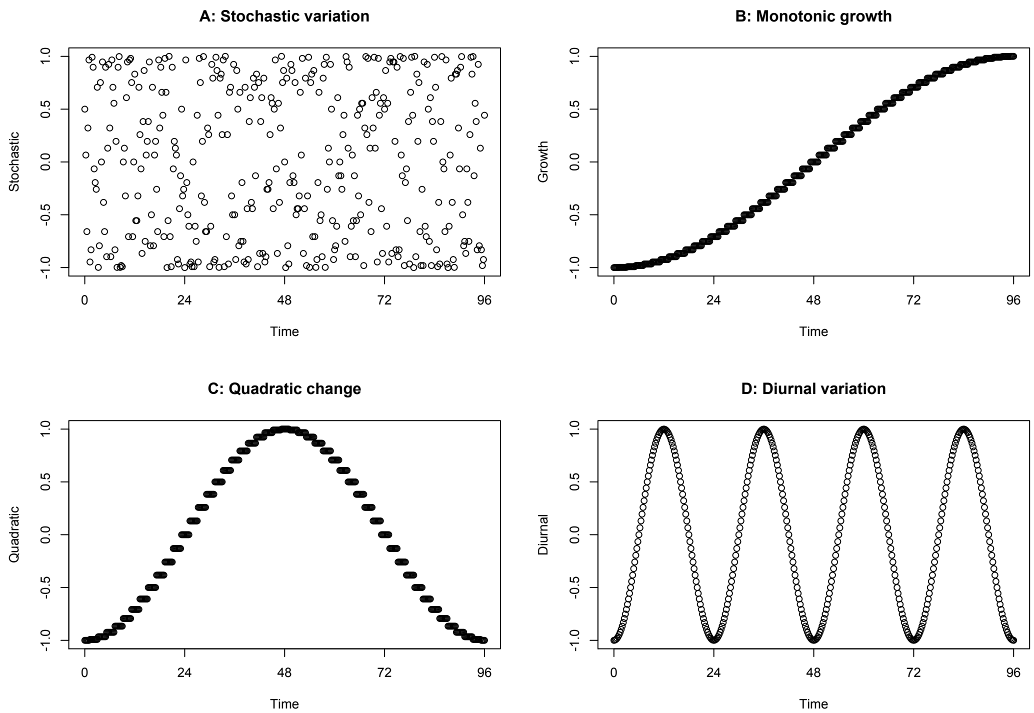

Figure 4. That stochastic variation is not dynamic is easily seen by comparing these four panels. Although these four hypothetical processes have identical means (0), variances (.5) and density distributions, the graphical display shows they are very different. The Mean Square of Successive Differences are twice the variances - the autocorrelation and are 1.07, 0, 0, and 0. Panel A represents observations with no inertia and is the consequence of a stochastic process. Panel B represents a monotonic growth process over time. Panel C represents a quadratic growth process. Panel D shows diurnal variation (e.g. arousal) over 4 days.

To summarize a dynamic process by its density distribution is to say the Mozart Requiem varies around D. Even to say the Requiem is in the key of D major is to equate it with the Beatles' "We can work it out". As we hope everyone will recognize, a person, like a musical composition, is far more than a density distribution.

Dynamic processes differ from stochastic variation not in their basic descriptive statistics, but rather in their autocorrelations over time. It is perhaps helpful to visualize the difference between three different dynamic process versus a simple stochastic process by comparing by comparing them graphically (Figure 4). Although all four of these graphs have exactly equal means and variances, and three of the four (B, C, D) have very small Mean square Successive Differences, they represent four very different types of processes. Panel A represents complete stochastic variation, panel B some monotonic growth process with a very large autocorrelation, panel C a quadratic growth process and panel C represents diurnal variation over four days.

Some classic diary studies

In the late 1970s and 1980s, intensive sampling of personality data over time began in earnest. In perhaps the first paper to coin the term experience sampling methodology, participants carried small paging devices on which they received reminders to complete reports via one-way radio communication (Csikszentmihalyi et al., 1977). Pages were sent randomly five to seven times per day from 8 A.M. to 11 P.M. When a page was received (as indicated by several beeps on the paging device), adolescent participants ($N = 25$) filled out paper-and-pencil booklets containing questions about their location, mood, activities, and reasons for engaging in their activities. A total of 753 reports were completed. Lebo & Nesselroade (1978) collected data from fewer subjects (5 pregnant women) but over many more occasions (120 consecutive days; 10 weeks pre-partum and 5 weeks post-partum). Subjects were given booklets containing rating forms on which they recorded their current mood (on 75 adjectives) once a day during a randomly specified time-period. This study represents one of the first uses of P-technique factor analysis to examine the intraindividual structure of mood. In the most-cited early ESM study (Zevon & Tellegen, 1982), a similar procedure was used to obtain mood ratings (on 60 adjectives) once per day from 23 undergraduates over 90 consecutive days. The inclusion of more subjects allowed for the use of both P-technique and R-technique factor analyses, as well as comparisons of results using these methods. McAdams & Constantian (1983) reported another early study that used the combination of pagers and paper-and-pencil diaries to collect personality data over time (7 times per day over one week). Fifty subjects (undergraduate and graduate students) rated variables in the A (positive affect), B (interpersonal behavior such as conversation and letter-writing), C (thoughts about other people), and D (wishes related to spending time with others) domains. Each of these variables was predicted by intimacy motivation and affiliation motivation as assessed by the Thematic Apperception Test.

These studies are not meant to be exhaustive of early ESM work but rather illustrative examples of investigations into a variety of personality processes. It was clear that ESM was thought of as a novel technique in these studies, as authors devoted space to describing the aims that could be achieved and types of questions answered with this approach. Though by today's standards the technology somewhat primitive and the sample sizes modest, these studies constituted groundbreaking developments that paved the way for the ESM revolution. By the mid 1980s, researchers were giving serious consideration to the ways in which intensive, repeated measures could advance longitudinal research (Nesselroade & Ford, 1985).

Data collection methods

Self-report

Early ESM studies used paper-and-pencil diaries to collect self-report data (Bolger et al., 2003). Though this method generally yielded high quality data (Green et al., 2006), dynamic analyses were hindered because there was no way to verify the time at which participants completed each report. With the adoption of portable recording devices such as the Palm Pilot®, the cell phone and even more useful, the smart phone, it became possible to collect data from subjects "in the wild" and achieve more certainty about the time at which reports were completed (Trull & Ebner-Priemer, 2014). Using apps or internet surveys, participants could be asked to report on their ABCDs across naturally occurring situations in daily life (time-driven sampling), and requests for responses could be made multiple times during particular events (event-driven sampling) (Himmelstein et al., 2019).

Researchers may also consider the Daily Reconstruction Method (Kahneman et al., 2004) as a proxy for collecting dynamic data; this method, which may be employed using paper-and-pencil diaries or a web-based survey, attempts to reconstruct at the end of day the person's ABCDs throughout the day. In comparison to ESM which takes very briefs samples at different times of day, the DRM takes 45-75 minutes to complete at the end of the day. One obvious limitation of this method is that feelings at the end of the day may affect memories of the events throughout the day. Diener & Tay (2014) provide a thoughtful comparison of the advantages and disadvantages of DRM vs. ESM and consider when they provide similar and dissimilar results.

Now there are a plethora of commerically and freely available apps and internet survey generators that may be employed for collecting self-report data, and there are numerous sources detailing advantages and disadvantages of different tools depending on the nature of research questions and study designs (for reviews, see Allemand & Mehl, 2017; Harari et al., 2016; Mehl & Conner, 2012; Wrzus & Mehl, 2015).

Behavior and physiology

The Electronically Activated Recorder (EAR) deserves special mention as a breakthrough allowing for the unobtrusive assessment of dynamic behavior (Mehl et al., 2001;

Mehl & Conner, 2012; Mehl & Robbins, 2012). The EAR started off as simply a small recording device that is programmed to turn on and off throughout the day and record for a few minutes at a time, and it is has progressed to the iEAR app that may be used on an iPod touch and iPhone devices (Mehl, 2017). Recordings may be coded manually for a variety of personality relevant characteristics, such as time spent in conversation, conversation themes, number of people present, ambient sounds etc. We also highlight the Snapshot, a wearable camera that can be programmed to take pictures of the environment on fixed interval (e.g., 1 minute) schedules (N. A. Brown et al., 2017). Being able to hear and see daily contexts has added a new level of ecological validity to dynamic personality research, yet it is essential to mention that ethical and legal issues much be considered carefully before running studies using these methods.

The review articles and chapters cited in the Self-report section are also excellent references for detailed information about behavioral and physiological tools for assessing dynamic data. A wide variety of commercial smartphone apps hardware have been developed to record nuanced sound parameters (e.g., voice pitch) and translate them to meaningful personality variables such as emotion, stress, and social activity. There are a bevy of choices for researchers who want to assess behavioral parameters such as location, physical activity, sleep, and even smartphone-specific behaviors (e.g., usage, content viewed) and app-specific behaviors (content posted to Facebook and Twitter for instance). Smartphone sensors and wearable devices now allow for dynamic tracking of just about any physiological index, such as heart rate, blood pressure, temperature, posture, skin conductance, and hormones (e.g., salivary cortisol) over time, just to name a few. Though collecting these types of data presents logistical and sometimes financial challenges, such technologies are essential for realizing the full potential of dynamic personality assessment.

The ESM revolution

The advent of new data collection tools likely contributed to exponential increases of ESM designs over the last two decades, and now several hundred ESM studies published every year (Hamaker & Wichers, 2017). As it is impossible to address all novel dynamic theories, methods, and results made during the ESM revolution, this section will review different ways to model dynamic data from ESM studies with illustrative examples that fall within the personality literature.

In ESM data involving multiple measurement of the same subjects over time (i.e., observations are nested within subjects), the within subject errors of observations are correlated. This violates assumptions of conventional least squares regression approaches and analysis of variance. Multilevel modeling (MLM) approaches (e.g., Bolger & Laurenceau, 2013; Bryk & Raudenbush, 1992; Fox, 2016) handle this type of data appropriately by decomposing variation between- and within-subjects. Within-subject level data are typically referred to as level 1, and data between subjects are known as level 2.[3] When subjects are

[3]Levels simply refer to the hierarchical organization of data, with lower levels indicating data nested

measured multiple times, MLMs are able to estimate within-subject mean and variance over time, as well as the within subject correlation of measures over time. MLMs are called random coefficient models because the within-subject parameters may be allowed to vary randomly across subjects. MLM techniques are now incorporated in factor analytic and structural equation modeling analyses (Edershile et al., 2019; Wright et al., 2017) The importance of MLM approaches for advancing dynamics models cannot be overstated and is perhaps rivaled only by ESM methods themselves.

As noted previously, dynamic modeling is not equated to within-person stochastic variation. Yet all dynamic models rest on the on the assumption that within-person variation in personality across time is systematic and meaningful rather than random error. Ideas related to this assumption can therefore be tested by examining stochoastic variation (using ESM data and MLM techniques) without modeling time explicitly. For example, within-person means of Big Five states are highly correlated with means obtained via traditional trait measures (Fleeson & Gallagher, 2009). Within-person standard deviations of Big Five states were larger than expected by chance and larger than between-person standard deviations (Fleeson, 2001; Heller et al., 2007). Other studies have shown that Big Five states are related to but distinct from state affect, goals, and perceptions of situations (Wilson et al., 2017; Wilt et al., 2017). And yet other investigations have determined that traits and situations uniquely predict manifestation of Big Five states (Rauthmann et al., 2014; Sherman et al., 2015) All of these studies advanced our understanding of basic questions about personality functioning in daily life.

Researchers have also been increasingly interested in developing parameters to quantify stochastic within subject variability. For instance, standard deviation, skew, and kurtosis of density distributions can be estimated easily (Fleeson, 2001). Other indices of variability are specific to circumplex data: for instance, flux (overall variability), pulse (extremity of behavior), and spin (variability of the angular coordinate) add richness to the ways in which we can assess overall amount of variation across two orthogonal dimensions (Moskowitz & Zuroff, 2004). More sophisticated techniques allow examination of within-person factor structures and individual differences in those structures (Molenaar et al., 2009). For example, one study used multilevel exploratory factor analysis to specify within- and between-person factor structures for grandiose and vulnerable narcissism (Edershile et al., 2019). Novel developments continue to expand dynamic statistical toolkits, such as analytical methods to estimate within- and between-subject variability over different time frames (Scott et al., 2018). Additionally, several parameters for quantifying within-person reliability statistics can be applied to repeated measures data (Nezlek, 2017; Revelle & Wilt, 2019; Shrout & Lane, 2012).

Recently, time has been modeled explicitly in personality data. The simplest way of looking at temporal dependence is to examine lagged relationships between variables. By

within higher levels. For instance, items (level 1) could be considered as nested within scales (level 2) that are nested within people (level 3). Or people (level 1) could be nested within schools (level 2).

doing so it is possible to touch upon dynamic concepts such as latency (the time before engaging in a behavior in a specific situation) and persistence (amount of time spent in a situation); these parameters that cannot be modeled by looking at stochastic variation alone (Wilt & Revelle, 2017). For example, studies have examined temporal dependencies between personality states and the situational characteristics (Rauthmann et al., 2016; Wrzus et al., 2016) that may be understood as reflecting latency and persistence (Wilt & Revelle, 2017). Other studies revealed nuanced dynamic associations among clinically relevant personality variables, such as self-esteem, affect, anxiety, and coping (Iida et al., 2017; Santangelo et al., 2017). Models that account for lagged associations in within-person data (Fisher et al., 2018; Rauthmann et al., 2018) have also been applied to study the important general question of whether whether within-person data exhibits the same characteristics as between-person data (i.e., ergodicity).

Statistics for quantifying variation that take temporal order into account have been developed over the last decade or so (see e.g., Ebner-Priemer et al., 2007; Jahng et al., 2008). The mean squared successive difference (MSSD, von Neumann et al., 1941) combines within person variation and the lag1 autocorrelation to quantify rapidity of change (Jahng et al., 2008). The probability of acute change (PAC) statistic assesses likelihood of experiencing extreme changes from one time to the next. The aggregated point-by-point change (APPC) statistic indexes the degree to which instability over time is typically distinguished by increases or decreases. Furthermore, modeling techniques that estimate associations between variables now incorporate sophisticated time-dependent components. For instance, models can accommodate autoregressive associations that change over time in individuals (Bringmann et al., 2017) as well as dyads (Bringmann et al., 2018). Several within-person reliability estimates that account for time are available (Nezlek, 2017; Revelle & Wilt, 2019; Shrout & Lane, 2012).

More sophisticated techniques have emerged over the past few years. Time series analyses, which are commonly used in econometrics, engineering, and physics, focus on analyzing a large number of repeated measures within a single system (models may be applied to individuals or dyads) (Hamaker & Wichers, 2017). In the personality literature, time series analyses have been used to model affective and personality patterns; parameters include homebase (mean), attractors (areas of the distribution that affect and personality states are drawn toward), and attractor strength (Kuppens, Oravecz, & Tuerlinckx, 2010; Sosnowska et al., 2019) Time series models have also been used to test complex models of affective dysregulation in Bipolar Disorder (Hamaker et al., 2016). Dynamic multilevel modeling takes time series analysis a step further by allowing for examination of individual differences in time series data (Hamaker & Wichers, 2017). Krone et al. (2018) specified perhaps the most comprehensive analytical toolbox for univariate and multivariate time series data. Parameters from this vector autoregressive Bayesian model include overall variability (including predictable and random changes over time), inertial properties of one variable (typically quantified as autocorrelation), cross-lags between different variables, differentiation (the degree to which conceptually variables are empirically distinct), and overall intensity.

Finally, network analyses have been applied to dynamic data (Bringmann et al., 2016; Costantini et al., 2019, see). This approach conceives of psychological processes as a complex system of interacting units; for instance, personality may be seen as ABCDs interacting with each other and features of the environment over time. Network models have been used to study how emotion networks differ among people with varying levels of neuroticism (Bringmann et al., 2016) and the temporal dynamics of affective symptoms in individuals diagnosed with Major Depressive Disorder and Generalized Anxiety Disorder (Fisher et al., 2017). Costantini et al. (2015, 2019) provide excellent tutorials on network statistics.

Conclusions

Although frequently discussed over more than a century, the study of dynamic processes has come of age. With new means of collecting data and even newer ways of analyzing them, it is now possible to address the important problem of within person consistency and between person differences in patterns of consistency. These are not new questions but rather there are new ways of answering these questions. To simply say that people differ in their thoughts, feelings, and actions is no longer adequate. It is now possible to address the how and why questions of inter and intra person dynamics. Formal models of dynamic processes combined with advanced statistical techniques can take advantage of the wealth of data that now can be collected from subjects in the wild. This will require collaborative research with psychologists, data scientists and statisticians. But the joy of applying complex mathematical or computational models should not supplant the close examination of the fundamental questions of dynamics: how to recognize the coherent patterning in human feelings, thoughts, goals and actions over time and space.

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