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## 2. Principles for taking a dynamic perspective

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Think about how common it is to find phrases about dynamics scattered throughout an introduction to an article, phrases like “we are going to address the dynamics,” “taking a dynamic perspective,” “prior research has not appreciated the dynamics,” “we consider the phenomenon as dynamic,” or “we examine it on a dynamic basis.” What do these mean? How do researchers take a dynamic perspective?

Dynamics refers to a specific branch of mathematics/mechanics where the fundamental concept is that the past constrains future behavior (Boulding, 1955; Flytzanis, 1976; Simon, 1991). Researchers in organizational psychology tend to study dynamics, however, with respect to a statistical model or class of models. For example, researchers that are familiar with growth models will talk about the importance of growth in a variable or how within-person trajectories have been ignored in prior research; they will then estimate a growth curve, and ultimately convey something about trend or growth over time and how this result has added a new dynamic perspective to our understanding (e.g., Dunford, Shipp, Boss, Angermeier, & Boss, 2012; Hülshager, 2016). “Growth model thinking,” as well as other recent ways of discussing phenomena over time, has produced great insights into important processes in organizational science, and we see them as initial steps toward dynamics. Ultimately, though, they miss many fundamental principles of dynamics.

When researchers couch their thinking in a particular statistical model some concepts naturally go unnoticed. Our field is accumulating tremendous knowledge by collecting longitudinal data, focusing on how things happen over time, and opening the door of dynamics; but there are dynamic principles that have yet to be exposed in our literature—researchers have not yet stepped fully through the door. In this chapter, we discuss a variety of dynamics principles; some are concepts that will reorient how researchers think about dynamics, and others are statistical properties that, if ignored, result in biased inferences.

Below, we first discuss two broad classes of “thinking with respect to a statistical model” that have done much of the hard work—they are sets of empirical studies from organizational psychology taking initial steps towards dynamics. The first we call “growth” and the second “relationships,” and we discuss example studies in each to briefly show our field’s interest in dynamics and how researchers approach it. These first two sections are not exhaustive; we simply sample common ways researchers currently think about dynamics to motivate the core of the chapter. There, we unpack the principles of dynamics.

### STEPPING TOWARD DYNAMICS: GROWTH

One of the first steps our field is taking toward dynamic thinking is by examining whether something goes up or down over time, thus examining trend or growth patterns. Hülshager (2016, p.906) explores fatigue trends. He motivates his study by stating that

his examination of “the continuous ebb and flow of fatigue over the course of the day and about the factors that influence this temporal ebb and flow” responds to calls to “empirically address the dynamic process of recovery and thereby helps refine recovery theory.” For five consecutive workdays, he assesses fatigue with self-report surveys—one in the morning, another at the first work break, a third at the end of work, and the last in the evening—among a sample of Dutch employees. He examines his questions via growth-curve modeling, estimates fatigue growth curves, and correlates sleep quality and psychological detachment with both the fatigue intercept and slope, respectively. As another example, Dunford and colleagues (2012, p. 637) examine burnout trajectories over two years. They motivate their study by stating that, “theoretically, much of the burnout literature suggests that burnout should be progressive and dynamic, yet most empirical research has focused on explaining and testing the antecedents of static levels of burnout,” therefore “knowing for whom burnout changes and when this pattern of change occurs leads to a more realistic view of the dynamism of human experience.” Over two years, they assess healthcare workers with five measurements, each separated by six months. All surveys measure burnout, and the researchers also collect between-person assessments of job transitions (a categorical variable indicating whether an employee is a newcomer, recently underwent an internal job change, or remained in the same position throughout). They estimate a sequence of growth curves and examine linear and quadratic slope terms for all three burnout dimensions. They also covary job transition type with the intercept and slope terms.

## STEPPING TOWARD DYNAMICS: RELATIONSHIPS

Another popular approach to “getting dynamic” is to examine relationships across time rather than trends or covariates of trend. Rosen, Koopman, Gabriel, and Johnson (2016, p. 1) explore the relationship between incivility and self-control. They motivate their research by stating that “although examinations of incivility have gained momentum in organizational research, theory and empirical tests involving dynamic, within-person processes associated with this negative interpersonal behavior are limited.” They also argue that “previous studies focused almost exclusively on chronic forms of incivility that occur on average during unspecified periods of time, which overlooks the dynamic and temporal nature of incivility and its effects. Consistent with ego depletion theory, we consider a dynamic process that explains why employees become more uncivil” (Rosen et al., 2016, p. 2). Their participants respond to three surveys a day (morning, afternoon, and evening) for ten workdays. The morning survey assesses self-control; the afternoon survey assesses self-control, experienced incivility, and instigated incivility; and the evening survey measures experienced incivility and instigated incivility. They regress afternoon self-control on afternoon incivility and morning self-control. Another model regresses evening incivility on afternoon self-control.

Koopman, Lanaj, and Scott (2016, p. 415) examine the costs and benefits of organizational citizenship behaviors on behalf of the actor; specifically, how organizational citizenship behaviors relate to positive affect and work goal progress. They motivate their study by stating that they “respond to calls in the literature to examine the consequences of organizational citizenship behavior on a more dynamic basis.” Their respondents fill out

three surveys (morning, afternoon, and evening) for ten workdays. The morning survey assesses organizational citizenship behaviors, positive affect, and work goal progress. The afternoon survey measures work goal progress, and the evening survey assesses outcome variables irrelevant to the discussion here. They examine the relationship between organizational citizenship behaviors and positive affect by regressing afternoon positive affect on morning organizational citizenship behavior and morning work goal progress.

## OPENING THE DOOR TO DYNAMICS

The point of highlighting the studies above was not to review every instance of the word “dynamic” being used in research, but to sample ways in which researchers in applied psychology approach dynamics in an empirical way. Both frameworks are valuable because they move beyond cross-sectional research, address new and interesting questions, and consider great notions such as growth, relationship patterns over time, between- and within-person variance comparisons, and inter-individual differences in intra-individual trend. However, the concepts that receive most attention are couched in specific statistical models, and some, as we argue below, are actually not dynamics. When ideas are couched in a specific statistical model, they miss other fundamental concepts and emphasize observed and manifest results rather than core notions about the phenomenon. Describing dynamics with manifest results from specific statistical models rather than fundamental concepts about the underlying process is like trying to convey how an engine works by only describing its temperature trend. Dynamics is a much broader concept, with principles that describe and characterize processes over time that merit attention irrespective of the specific statistical model employed by the researcher.

In what follows, we provide a host of dynamic principles to create consensus on what it means to take a dynamic perspective. Some of the principles are ways of thinking that are necessary to appreciate as researchers and theorists explore dynamic phenomena, whereas other principles are statistical properties that arise when researchers apply models to longitudinal data structures; they are statistical issues that produce inferential errors if left unchecked, and they are important across all types of statistical models applied to panel data.

## DYNAMICS

Dynamics refers to a specific branch of mathematics/mechanics, but the term is used in different ways throughout our literature. It is used informally to refer to “change”, “fluctuating,” “volatile,” “longitudinal,” or “over time” (among others), whereas formal definitions in our literature are presented within certain contexts. Wang, Zhou, and Zhang (2016, p. 242) define a dynamic *model* as a “representation of a system that evolves over time. In particular it describes how the system evolves from a given state at time  $t$  to another state at time  $t + 1$  as governed by the transition rules and potential external inputs.” Vancouver, Wang, and Li (2018, p. 604) state that dynamic *variables* “behave as if they have memory; that is, their value at any one time depends somewhat on their previous value.” Finally, Monge (1990, p. 409) suggests that in dynamic *analyses*, “it is essential to

know how variables depend upon their own past history.” The crucial notion to take from dynamics, then, is that the past matters and future states are constrained by where they were at prior points in time (Boulding, 1955; Flytzanis, 1976; Petris & An, 2010; Simon, 1991). Below, we unpack a number of important principles couched in this simple idea.

## CONCEPTS AND CONVENTIONS

These first principles are concepts to help researchers think about dynamics.

### States

In organizational science we typically use the term “variable” to describe a measured construct, and our lens is usually across people. Burnout, depletion, fatigue, organizational citizenship behaviors, performance, and job satisfaction are all variables; they are quantities with values that fluctuate across people. When we instead focus on how those values fluctuate across time, we call them “states.” Performance as a variable, therefore, focuses on the set of values across people, whereas performance as a state focuses on its values across time.

Researchers have indirectly called attention to the dynamic notion of states by distinguishing traits, or stable individual differences, from states. This distinction is prevalent in personality research (e.g., Dalal et al., 2015; Hamaker, Nesselroade, & Molenaar, 2007), but also emerges in research on motivation (e.g., Beck & Schmidt, 2013; Dragoni, 2005) and emotion (e.g., Miner & Glomb, 2010), among others.

The convention to label states is to use what is called a “state vector.” A state vector for depletion, fatigue, and performance would be (depletion, fatigue, performance), and its mathematical equivalent is,  $(x_1, x_2, x_3)$  or  $(x_1 \dots x_n)$ . We will use this notation later after introducing more concepts.

### Memory and Self-similarity

A fundamental concept in dynamics is that states often have memory; they are self-similar across time (Cronin, Weingart, & Todorova, 2011). Individual, dyadic, and team performance may vary or fluctuate over time, but they retain self-similarity from one moment to the next. Job satisfaction at one point in time is some function of what it was just prior to that point in time. My conscientiousness tomorrow will carry over from what it was today, as will the number of people I communicate with. Researchers may argue that some states have no memory, but the point here is that states tend to retain something about what they are from moment to moment.

### Constraints

When a state has memory or self-similarity it can still fluctuate or change over time—to say that Rachel’s job satisfaction will predict itself over time does not mean that we expect her job satisfaction to be identical every day. Instead, it will fluctuate or vary, but under the constraints of where it was in the past. Imagine we argue that job satisfaction has no

memory, then Rachel's job satisfaction from moment to moment is unconstrained and it can swing (potentially) to positive or negative infinity based on the states that cause it. But if the concept of job satisfaction does have memory, then it cannot swing explosively. When Rachel experiences something negative at work (e.g., being ridiculed), her job satisfaction will certainly decrease in the moment; but what is her job satisfaction decreasing from? Most likely Rachel's job satisfaction will decrease from its previous level in time, meaning that the negative experience is pushing against her prior level of job satisfaction. States vary over time, but where they go is constrained by their history.

### **Lags**

Memory is not limited to a single variable. Job satisfaction may also be influenced by the prior history of other states such as, for example, autonomy, fatigue, and co-worker support. Imagine we believe that fatigue has a lag effect on performance, where the influence of fatigue on performance does not happen immediately but instead after some period of time. Despite collecting longitudinal data many researchers still examine concurrent relationships by regressing dependent variables (DVs) on independent variables (IVs) at the same moment. That is, they regress performance at time 4 on fatigue at time 4, and performance at time 6 on fatigue at time 6 despite having the possibility to explore lag effects. What these concurrent models imply is that the researcher expects fatigue to instantaneously influence performance. With some states immediate cause makes sense, but, as our "over time" thinking progresses, there will be many opportunities to explore lags.

### **Reciprocal Influence**

Many research questions can be boiled down to trying to find antecedents and outcomes, but when we focus on dynamics and start thinking about memory, constraints, and lags across multiple states we focus less on "true causes" or antecedents and more on reciprocal influence (DeShon, 2012; Duggan, 2016). This kind of thinking often takes the form, "and then this happens." Consider the reciprocal relationships between performance, superior support, and fatigue. I perform my assignment well, so my boss sends a nice email letting me know that she appreciates my work. Feeling inspired, I subsequently increase my performance and again perform well on my second assignment. Having increased my performance, however, I am now more fatigued, and on my third assignment I perform poorly—and this poor performance is not followed by another congratulatory email. In this simple example, performance, fatigue, and superior support fluctuate across time. We are not necessarily interested in finding the "true" cause, direction of effects, or the exact coefficient between one state and another, but instead the pattern of reciprocal relationships across time.

### **Timescales**

Timescales are an important concept in systems with lags, memory, constraints, and reciprocal influence (Meadows, 2008; Petris & An, 2010). Even within one phenomenon, effects can occur on different timescales. Consider the temperature of a building. The

quick dynamics occur from room to room, where air molecules pass between rooms until all rooms are roughly the same temperature. The exterior weather, conversely, influences the building under a different, delayed timescale. Heat confronts the exterior walls, warms them, and ultimately influences the entire building only after a much longer period of time than the interior air-flow.

Mathieu and Taylor (2006, p. 1035) provide another timescale example with respect to employee motivation:

Consider a work redesign effort intended to empower employees and thereby to enhance their work motivation with the aim of increasing customer satisfaction. How long does it take to establish the new work design? If employees are indeed more motivated to perform, how long will it take for customers to notice and for them to become more satisfied?

Note, that we are emphasizing the timescales of the phenomena, not measurement timing. Measurement timing is of course an important issue, but it has received attention elsewhere (James, Mulaik, & Brett, 1982; Kenny, 1979).

### **Boundary Space**

When researchers estimate a growth curve and argue for a positive linear trend, they are implying that the trajectory increases forever. Job satisfaction perpetually increases, or organizational citizenship behaviors go down (for negative linear trends) endlessly. Of course, researchers do not explicitly argue for perceptual increases in their discussions; but when researchers employ particular statistical models those models say something about the states that they attempt to represent. In dynamic systems with reciprocal influence and constraints, there are boundaries on where processes can go. Communication may fluctuate day to day, and it may even increase steadily as an employee transitions into a new role, but it is unlikely that it will endlessly continue to increase or decrease without bound. Estimating a quadratic term does not resolve this issue. A predicted quadratic line can appear to level off, but it appears so because the prediction line is cut off by the number of observed time points in the study—a quadratic term implies a full U-shaped trajectory.

### **Initial Conditions**

The last concept is that initial conditions may or may not influence the overall dynamics (Garfinkel, Shevtsov, & Guo, 2017; Wooldridge, 2005). Imagine an employee's climate perceptions fluctuating over time and showing a reciprocal pattern with a number of other important states. The dynamics of her climate perceptions may depend on an employee's first encounters with the company—her initial perceptions. Perhaps her initial perceptions were positive and over time showed reciprocal patterns with performance, dyadic social exchanges, burnout, and leadership perceptions. A researcher paying attention to initial conditions would examine if those same reciprocal patterns emerge under different starting conditions, like a bad first encounter.

An example is in Liebovitch, Vallacher, and Michael's (2010) explanation and model of conflict and cooperation between two actors. Their explanation involves three states in a two-person situation, including (1) each individual's general affective state, (2) feedback from one person to the other, and (3) each individual's general tendency to change based

on the feedback. They argue that the patterns of conflict and cooperation that two individuals demonstrate over time differ dramatically if both individuals start with the same affective tone (positive and positive or negative and negative) versus opposing tones; that is, the dynamics of conflict and cooperation are sensitive to the initial conditions of the actors involved.

### **Describing Trajectories**

In this chapter, we introduce concepts and statistical properties that merit attention as we approach dynamics. Readers should also see a paper by Monge (1990) that provides basic vocabulary for describing trajectories. He discusses terms such as trend, periodicity, and cycles—a lexicon for patterns over time rather than key concepts that are emphasized here.

## **MATHEMATICS AND STATISTICS**

We now translate some of the concepts into math. Doing so (1) reiterates the principles above, (2) introduces new dynamic principles, and (3) makes it easier to talk about some of the more complicated statistical properties of dynamic modeling that we turn to in the final section.

Remember that dynamics emphasizes memory, self-similarity, and constraints as states move across time. Here, we capture those ideas with equations using performance as an example. First, consider performance across time:

$$\text{Performance}_t = \text{Performance}_{t-1}$$

where performance at time  $t$  is exactly identical to what it was at  $t-1$ . This equation says that performance does not fluctuate, change, move, or grow across time; hence there is zero trend. Performance is, for example, 4 on a 5-point scale at time 1, 4 at time 2, 4 at time 3, and so on. This type of equation is called a difference equation, and it is a foundational tool in dynamics (Boulding, 1955; Flytzanis, 1976; Hunter, 2018).

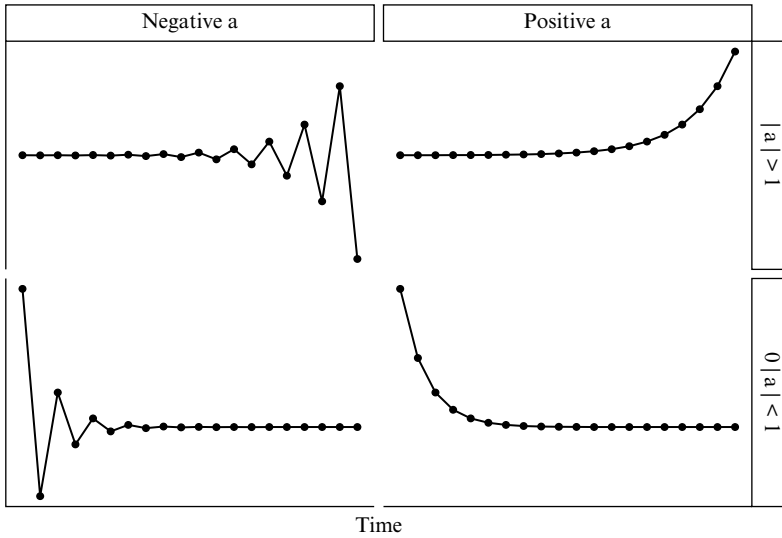
Although this first equation seems deceptively simple, we already captured memory. Performance in this case is perfectly self-similar. What if, instead, performance is similar but not perfectly self-similar across time? To capture this idea, we need a new term:

$$\text{Performance}_t = a * \text{Performance}_{t-1}$$

where  $a$  is the extent to which performance is self-similar and all other terms are defined above.

### **Fundamental Behaviors**

There are fundamental behaviors of dynamic states based on their self-similarity or memory terms, and these are shown in Figure 2.1. The top row of Figure 2.1 shows the trajectory of states with terms that are greater than one in absolute value. These large



*Note:* When the coefficient is greater than one (in absolute value) the trajectory oscillates explosively or grows exponentially. When the coefficient is between zero and one (in absolute value) the trajectory converges to equilibrium.

**Figure 2.1** Trajectories driving toward equilibrium or explosive behavior based on their autoregressive coefficient

terms produce explosive behavior: exponential growth when  $a$  is positive and extreme oscillations when  $a$  is negative. When the term falls between zero and one in absolute value, conversely, the state converges to equilibrium, shown in the bottom two panels of Figure 2.1. Either the state oscillates at a decreasing rate until it reaches equilibrium (when  $a$  is negative) or it converges there smoothly (when  $a$  is positive). Again, these behaviors hold for all states given the respective self-similarity terms shown in Figure 2.1.

## Equilibrium

Notice that we introduced a new word in our description above: equilibrium. Equilibrium describes the state of a variable that no longer changes unless disturbed by an outside force. It can also be used to describe multiple variable systems; equilibrium again means that the state remains constant unless disturbed by an outside force, but here state refers to the entire system (i.e., all of the variables). In *static* equilibriums, the system has reached a point of stability with no change, whereas *dynamic* equilibrium refers to systems with changes and fluctuations but no net change. That is, the variables fluctuate across time in periodic ways, but the general state of the system does not diverge so as to change the behavior of the entire system.



## Stochastics

Our route so far has been deterministic—the mathematical representations do not contain error. Stochastics, stated simply, refers to processes with error, and there are a host of additional principles to consider once error enters the conceptual space. Consider the difference equation from above, adding an error component produces:

$$\text{Performance}_t = a * \text{Performance}_{t-1} + e_t$$

where all terms are defined above but  $e_t$  represents an error term that is incorporated into performance at each time point. Error causes performance to be higher or lower at specific points in time than we would have expected given a deterministic process. For example, at time  $t$  the error might push performance to a higher value, and at  $t + 1$  to a lower value. Errors are therefore said to be random because we cannot predict their value at any specific  $t$ . However, in aggregation (i.e., averaged across time) positive errors cancel negative errors and large errors are less likely than small errors. In stochastic systems, therefore, the errors are said to be distributed  $N(0, \sigma^2)$ —that is, random and unpredictable at any specific  $t$  but distributed with certain constraints across time. It can also be helpful to think about what error is not. Anything that is systematic, predictable, or common (using those in lay terms) cannot be error, thus leaving error to be the random “left overs.”

## White Noise and Random Walks

There are two fundamental stochastic processes: white noise and random walks (Petrus, Petrone, & Campagnoli, 2009). White noise is a process that only has error. Setting  $a$  to zero in the aforementioned equations produces a white noise process:

$$\begin{aligned} \text{Performance}_t &= a * \text{Performance}_{t-1} + e_t \\ a &= 0 \end{aligned}$$

Here, all we have is error over time. Random walks are similar, but  $a$  is equal to 1:

$$\begin{aligned} \text{Performance}_t &= a * \text{Performance}_{t-1} + e_t \\ a &= 1 \end{aligned}$$

This representation is also an error process, but with an additional operator alongside error itself: performance retains self-similarity across time as well. Although random walks can sometimes appear to be moving in a systematic direction, ultimately their behavior is unpredictable; they could go up or down at any moment.

Random walks and white noise are error processes over time. Both fluctuate randomly, but random walks retain some self-similarity through time. These two principles are the null hypotheses of time series analysis in econometrics, where the first task in a longitudinal study is to demonstrate that you are investigating something that is not a random walk or white noise. That is, if a researcher wanted to show the effect of IVs on performance across time, they would first need to demonstrate that performance and all of their IVs are not random walks or white noise processes.

## Dynamic Systems

Up to this point we have focused on a single state, performance. Remember that dynamic perspectives also consider reciprocal influence; but before moving to two or more state equations notice how much researchers can explore with single states. It is of course interesting to ask how two or more states are related or posit a complex sequence among a set of states. But understanding whether or not one state exhibits white noise or random walk behavior across time is a valuable study in itself.

With multivariate systems we need multiple equations—one for each state. Before, we demonstrated a simple difference equation for performance. In a multivariate system with two states, such as performance and effort, we need one equation for each.

$$\begin{aligned}\text{Performance}_t &= a * \text{Performance}_{t-1} + e_t \\ \text{Effort}_t &= a * \text{Effort}_{t-1} + e_t\end{aligned}$$

Here, both equations posit that their state is a function of its prior self to the extent of the autoregressive term ( $a$ ). Notice that there are no cross-relationships; we are simply representing a system with two independent variables over time. It is of course also possible to introduce relationships among the different states with more terms. First, consider a system where effort concurrently causes performance, or where effort<sub>*t*</sub> influences performance<sub>*t*</sub>:

$$\begin{aligned}\text{Performance}_t &= a * \text{Performance}_{t-1} + b * \text{Effort}_t + e_t \\ \text{Effort}_t &= a * \text{Effort}_{t-1} + e_t\end{aligned}$$

All terms are defined above, but now the equation for performance also includes Effort<sub>*t*</sub>, which is the value of effort at time  $t$ , and  $b$  the coefficient relating effort to performance. This set of equations says that effort is simply a product of itself over time (with error), whereas performance is a function of itself and also effort at the immediate time point.

What if effort causes performance after some lag? That is, perhaps we posit that effort does not immediately cause performance, but instead causes performance after some period of time. If the lag effect were 2, that would mean that Effort<sub>*t*</sub> causes Performance<sub>*t+2*</sub>, and to express the “lag 2 effect” mathematically we would use the following:

$$\begin{aligned}\text{Performance}_t &= a * \text{Performance}_{t-1} + b * \text{Effort}_{t-2} + e_t \\ \text{Effort}_t &= a * \text{Effort}_{t-1} + e_t\end{aligned}$$

Here, all terms are nearly identical to what we saw above, but now there is a lag 2 effect from effort to performance. Performance is now a function of both its immediately prior self and the value of effort from two time points ago.

What if we want to convey feedback, or a reciprocal relationship between effort and performance? That is, now we posit that both effort measures trigger change in performance and performance triggers change in effort. To do so we update our equations with a simple change:

$$\begin{aligned}\text{Performance}_t &= a * \text{Performance}_{t-1} + b * \text{Effort}_{t-2} + e_t \\ \text{Effort}_t &= a * \text{Effort}_{t-1} + b * \text{Performance}_{t-2} + e_t\end{aligned}$$

where all terms are defined above but now effort and performance are reciprocally related. Both are determined by themselves at the immediately prior time point and the other state two time points in the past. Effort happens and two moments later it influences performance, and two moments later performance goes back to influence effort, and so on throughout time. All the while, both states retain self-similarity; they fluctuate and develop but only under the constraints afforded by the autoregressive terms.

We can make the equations more complicated by continuing to add variables or longer/shorter lag effects, but the beauty of math is its freedom to capture whatever the researcher desires. These equations are language tools to help researchers convey dynamics. In addition, researchers who are interested in studying dynamic phenomena will likely find use in explicitly stating their hypothesized relationships in equation form. In general, language-based theorizing is good at description but struggles with specificity and complex relationships. The shortcomings of such theories can be amplified when a researcher attempts to discuss how variables interact dynamically over time because it is difficult for people to conceptualize how these systems develop as time iterates (Cronin, Gonzalez, & Serman, 2009). Placing one's theorizing into the actual underlying equations will help formalize and organize the researcher's thoughts and assist in avoiding inferential and logical errors in the theory.

## DYNAMIC MODELING

Above, we introduced fundamental concepts for dynamics. Memory, constraints, initial conditions, equilibrium, reciprocal influence—these elements constitute the underlying dynamics and are ingredients to grapple with as researchers consider dynamic phenomenon. Mechanisms give rise to observed data, distributions, and statistical properties for us to witness, and it is those observed data that we apply statistical models to. In a perfect world, researchers could put a magnifying glass up to their observed data and its statistical properties and clearly identify the dynamics. Instead, there are a host of challenges that must be considered when researchers collect longitudinal data and estimate models to make inferences about dynamics. In this section we describe stationarity, dynamic panel bias, and ergodicity. Note that throughout the rest of the chapter we replace the lay term for *a* (self-similarity) with its more common name in the statistical literature: autoregression, serial correlation, or autocorrelation; all of these refer to the relationship between a state and itself over time.

### Stationarity

States and systems have statistical properties; stationarity is about the stability of those properties. Rachel's performance across time is called a time series; it is the trajectory of performance for a single unit (Rachel) over time. That trajectory has properties: it has a mean and a variance (and autocorrelation or serial correlation). If the mean is unstable, then Rachel's performance either grows or decreases unconditionally over

time. Instead, if the mean is stable, then Rachel's performance across time fluctuates, but within the constraints of its memory and bounds on the system. Growth models assume no stationarity in the data they model, whereas virtually all other models used in the applied organizational literature assume that the data they are modeling are realizations of a stationary process. That is, they assume that the states and systems they are trying to estimate parameters for have properties at time  $t$  that are the same as the properties at time  $t + 1$ .

In simple terms, a stationary process has stable properties across time; data that demonstrate trend, growth, or random walk behavior are (almost certainly) non-stationary. Any system in equilibrium will be stationary, whereas unstable systems will be non-stationary. Here is the hard part: two independent time series will appear related if both are non-stationary (Granger & Newbold, 1974; Kuljanin, Braun, & DeShon, 2011). That is, if we measure Rachel's performance and it is consistent with a random walk, and we also measure rainfall at Rachel's mother's house across the state and it demonstrates increasing trend for the day; although these two things are completely unrelated we will more than likely find a relationship between them in a regression-based analysis like those presented at the start of this chapter. There are many other articles that describe how to test for stationarity (e.g., Braun, Kuljanin, & DeShon, 2013; Jebb, Tay, Wang, & Huang, 2015); the point here is to convey how important this notion is.

That said, there is a class of models known as cointegration models that can be used to evaluate relationships in a non-stationary system. They are more complicated and require a deep understanding of mathematics and econometric modeling. Interested readers can see Engle and Granger (1987), Johansen (1991), Phillips (1991), Phillips and Hansen (1990), and Phillips and Durlauf (1986).

### Dynamic Panel Bias

Another challenge for dynamic modeling is dynamic panel bias, which is the combined effect of two issues. The first issue has to do with statistically accounting for memory. Remember that the dynamic equations above took the form:

$$y_t = ay_{t-1} + e_t$$

where the only change is that we replaced performance with a generic  $y$ . The equation above has what is called a "lagged DV," where  $y_t$  is predicted by the lagged DV:  $y_{t-1}$ . Including lagged DVs helps us *conceptually* represent dynamics (Keele & Kelly, 2006); but including a lagged DV in a *model* applied to data with actual statistical properties causes the errors to correlate with the predictors, and ultimately violate the well-known independence of errors assumption—specifically, the magnitude of the bias is  $1/T$  such that the bias decreases as the number of time points increases (Hurwicz, 1950; Marriott & Pope, 1954).

The second issue arises when we are interested in relationships with a multiple-unit sample across time. Almost all organizational studies are multiple-unit; that is, they collect data on more than one participant. If the people in the sample are not perfectly exchangeable, which means that we can learn the same thing about performance and fatigue by studying either Bob or Rachel, we lose no information by restricting our

analysis to one of them; then the parameter estimates are influenced by what is known as unobserved heterogeneity (Nickell, 1981). Unobserved heterogeneity represents aggregate and stable individual differences. Rachel's fatigue over time may look different from Bob's fatigue over time due to unmeasured individual differences and states. These unacknowledged effects are responsible for individual differences on fatigue, so they need to be incorporated in statistical models. We acknowledge them by incorporating unobserved heterogeneity; again it is a term that is meant to represent all of the unmeasured things that make Rachel's trajectory different from Bob's trajectory.

In dynamic modeling, unobserved heterogeneity must be handled appropriately: if it is modeled as independent but in fact correlates with the model predictors, then omitted variables bias is introduced into the estimates; and if unobserved heterogeneity is ignored, then serial correlation will be introduced into the errors.

Dynamic panel bias is the combined effect of these two biases. Lagged DVs conceptually convey a dynamic process but they create estimation problems, and researchers must account for unobserved heterogeneity. Unfortunately, the current workhorse in our literature to examine dynamic phenomena (the hierarchical linear, random-coefficient, or multilevel model) is not well suited to handle dynamic panel bias.

### **Ergodicity**

In the section above we spoke about unobserved heterogeneity, which can be thought of as heterogeneity of individual differences or unit effects. That is, there are unmeasured differences that result in Rachel's trajectory being different from Bob's. An appropriate next question is, When is it reasonable to pool Rachel and Bob's data? When can we be confident in homogeneity of dynamics? This is the notion of ergodicity.

A set of time series trajectories are considered to be ergodic when: (1) all trajectories are covariance stationary such that they have constant statistical properties over time (i.e., constant mean, variance and correlation); and (2) the trajectories are the result of sampling the same underlying process including both the error process and the dynamic parameters (Kelderman & Molenaar, 2007; Molenaar, 2004). In other words, the statistical model used to represent the underlying dynamics must demonstrate invariance across units. If the trajectories are non-ergodic, the results of longitudinal or panel analyses obtained by pooling time series from different units may not represent the actual dynamics of any units included in the analysis. It is also interesting to note that if a set of trajectories is ergodic, then the analysis of inter-individual variation and intra-individual variation support the same inference.

## **DISCUSSION: A DYNAMIC PERSPECTIVE**

We opened this chapter by briefly discussing how researchers in applied psychology are stepping toward dynamics. We pointed to two frameworks—growth and relationships—as examples of empirical research doing the hard work of getting our thinking beyond static, cross-sectional associations. They were appropriate first steps given our field's history with random coefficient models and more recent emphasis on growth curve modeling; but ultimately these frameworks miss many fundamental concepts of dynamics. Taking

a dynamic perspective means focusing on memory, constraints, timescales, reciprocal influence, and initial conditions, and exploring an array of statistical properties like serial correlation and stationarity. Taking a dynamic perspective means being concerned that your trajectory is not simply a random walk or white noise process.

We close this chapter with two short, unique sections to solidify the principles and what we mean by a dynamic perspective. In the first section we consider what dynamics is not, and we conclude by presenting the linear dynamic systems model as the fundamental framework for dynamic investigations. The linear dynamic systems model embodies the fundamental concepts discussed in this chapter.

## **What Dynamics Is Not**

During a time when authors were discussing what constitutes theory, Sutton and Staw (1995) produced a useful article describing what theory *is not*; their manuscript became a cornerstone reading for management, organizational behavior, human resources, and organizational psychology programs. A similar approach may be useful here, where addressing what dynamics is not could help researchers fully grasp its content.

### **Time as a predictor is not dynamics**

Our field has a number of great papers discussing the idea that time cannot be causal. Ployhart and colleagues have probably said it best: “constructs do not change, evolve, or develop because of time; rather they do so over time. For example, time does not cause children to grow into adults. Even though time is highly related to physical growth, the causes of growth are genetics and environment” (Ployhart & Vandenberg, 2010, p. 98). Moreover, our theories do not specify time as a causal variable, but instead specify that changes happen over time due to other causes (Pitariu & Ployhart, 2010).

We agree with these statements, but extend them slightly to encompass a dynamic perspective. Imagine a study that evokes time as a moderator and then makes a conclusion such as, “early on A happens, whereas later on B happens.” They do not discuss time as the cause, but they do argue that they are studying dynamics because state behaviors differ at time 3 compared to time 2. Identifying that time 3 states and relationship patterns are different from those at time 2 is useful; but it is not dynamics because it is not characterizing how past behavior constrains new state patterns or how states from one moment reach others at subsequent moments. In concrete terms, finding that job satisfaction is high for newcomers and low for old-timers is not dynamics; neither is recognizing that it positively relates to performance during week one but negatively relates to performance after a month on the job. Dynamics is studying how job satisfaction unfolds through time based on its constraints, self-similarity, initial conditions, and reciprocal sources of influence.

Voelkle and Oud (2015) and Serang, Grimm, and Zhang (2019) make a similar distinction in their discussions of the difference between static and dynamic statistical models. Static models employ time as a predictor, meaning that time is treated explicitly in the model. Dynamic models, conversely, treat scores at a given time as a function of scores at previous times such that time enters the model implicitly through the order of measurement occasions.

**Static relationships across time are not dynamics**

Longitudinal data do not automatically make the focus of a study dynamics. Many studies that collect longitudinal data do not examine dynamics, but instead assess static relationships across time. Consider two simple (mock) examples of studies on burnout and job satisfaction. The first study collects self-reports of burnout and job satisfaction every day for three weeks. The researchers regress burnout at time  $t$  on satisfaction on time  $t$  and report the relationship. Their analysis, therefore, considers the following relationship:

$$\text{Satisfaction}_t = a * \text{Burnout}_t + e_t$$

where satisfaction at time 1 is related to burnout at time 1, satisfaction at time 2 is related to burnout at time 2, and so on.

Now consider a slight change. The researchers instead examine self-similarity in satisfaction and a lag effect from burnout. That is:

$$\text{Satisfaction}_t = a * \text{Satisfaction}_{t-1} + b * \text{Burnout}_{t-1} + e_t$$

where satisfaction at time 5 is related to its prior self and burnout at time 4, satisfaction at time 6 is related to satisfaction and burnout at time 5, and so on.

The only difference between the aforementioned mock studies is that one acknowledges memory and lags whereas the other does not; but those aspects represent and imply fundamentally different things about the world. The first considers the world as a sequence of cross-sectional slices, a perspective that Ilgen and Hulin (2000) call “multiple snapshots,” where static associations are compiled across time. It also implies that any state behaviors or relationships among the states follow a seemingly odd sequence: relationships happen at one moment and then are wiped out and replaced by completely new behavior and relationship patterns at the next. Finally, it represents a world where burnout instantaneously causes satisfaction. The second, dynamic perspective with satisfaction included as a lagged DV represents a much different structure. Satisfaction is constrained by where it was in the past, and therefore it cannot bounce to extreme levels without first moving from its prior state. Moreover, the effect from burnout takes time to occur and aligns with intuitive and theoretical notions of causality. Finally, the patterns between satisfaction and burnout will ultimately drive toward equilibrium. A study of relationships over time is useful, but it is not dynamics.

**Dynamics is not synonymous with growth**

A dynamic phenomenon does not have to grow or exhibit increasing/decreasing trend. The mechanisms in the data-generating process may or may not produce trend, but growth is not a fundamental concept in dynamics. Similarly, observing growth or correlates of growth in an empirical study is not dynamics. It is useful and we hope researchers continue to explore growth patterns in their content areas, but a study that “unpacks dynamics” is much different from a study that estimates trend and predictors of trend.

## CONCLUSION: THE LINEAR DYNAMIC SYSTEMS MODEL

Much of the historical research in our field emphasized bivariate, cross-sectional relationships that are embodied in the general linear model. As we incorporate dynamics, there are a number of additional principles to consider, and we discussed many of them in this chapter. The principles of dynamics are all represented in a different fundamental model: *the linear dynamic systems model*.<sup>1</sup> Just as the general linear model subsumes historical research focused on static relationships, the linear dynamic systems model will embody our upcoming dynamic investigations. In its simplest form, the linear dynamic systems model is:

$$\mathbf{x}_t = \mathbf{A}\mathbf{x}_{t-1} + \mathbf{b}$$

where  $\mathbf{x}_t$  is a vector of states at time  $t$ . The vector is similar to the state vector we presented in the concepts section (depletion, fatigue, burnout), but here we use a generic term to capture any state or set of states of interest. The equation also captures the states at the prior time point,  $\mathbf{x}_{t-1}$ , and those states are multiplied by  $\mathbf{A}$ , a matrix of transition weights. The transition weights capture memory, constraints, lags, and reciprocal influence within the system—the diagonal elements represent self-similarity and the off-diagonal elements are cross-state influence;  $\mathbf{b}$  is a vector of constant values (time-invariant) that are commonly referred to as forcing terms. Although they do not receive a term in the equation, initial conditions are also inherent to the linear dynamic systems model because specifying or identifying a trajectory requires starting values. The principles described in this chapter are embodied in the linear dynamic systems model, and it will serve as the underlying framework as we enter the exciting domain of dynamics.

## NOTE

1. A full statistical model contains an equation explaining the data and assumptions on the errors. We present the linear dynamic systems “model” not as a fully specified statistical model but as a framework that embodies the dynamic concepts presented in this chapter. It is a mathematical tool that conveys the dynamic principles and can be translated into a statistical model with ease.

## REFERENCES

- Beck, J. W., & Schmidt, A. M. (2013). State-level goal orientations as mediators of the relationship between time pressure and performance: A longitudinal study. *Journal of Applied Psychology*, 98(2), 354–363.
- Boulding, K. E. (1955). In defense of statics. *Quarterly Journal of Economics*, 69(4), 485–502.
- Braun, M. T., Kuljanin, G., & DeShon, R. P. (2013). Spurious results in the analysis of longitudinal data in organizational research. *Organizational Research Methods*, 16(2), 302–330. doi:10.1177/1094428112469668
- Cronin, M. A., Gonzalez, C., & Stermann, J. D. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, 108(1), 116–130.
- Cronin, M. A., Weingart, L. R., & Todorova, G. (2011). Dynamics in groups: Are we there yet? *Academy of Management Annals*, 5(1), 571–612.
- Dalal, R. S., Meyer, R. D., Bradshaw, R. P., Green, J. P., Kelly, E. D., & Zhu, M. (2015). Personality strength and situational influences on behavior: A conceptual review and research agenda. *Journal of Management*, 41(1), 261–287.



- DeShon, R. P. (2012). Multivariate dynamics in organizational science. In S. W. J. Kozlowski (Ed.), *The Oxford Handbook of Organizational Psychology* (Vol. 1, pp. 117–142). New York: Oxford University Press.
- Dragoni, L. (2005). Understanding the emergence of state goal orientation in organizational work groups: The role of leadership and multilevel climate perceptions. *Journal of Applied Psychology*, 90(6), 1084–1095.
- Duggan, J. (2016). *Systems dynamics modeling with R*. Cham, Switzerland: Springer.
- Dunford, B. B., Shipp, A. J., Boss, R. W., Angermeier, I., & Boss, A. D. (2012). Is burnout static or dynamic? A career transition perspective of employee burnout trajectories. *Journal of Applied Psychology*, 97(3), 637–650. doi:http://dx.doi.org.proxy2.cl.msu.edu/10.1037/a0027060
- Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica*, 251–276.
- Flytzanis, E. (1976). Linear dynamical systems. *Proceedings of the American Mathematical Society*, 55(2), 367–370.
- Garfinkel, A., Shevtsov, J., & Guo, Y. (2017). *Modeling life: The mathematics of biological systems*. Cham, Switzerland: Springer.
- Granger, C. W., & Newbold, P. (1974). Spurious regressions in econometrics. *Journal of Econometrics*, 2(2), 111–120.
- Hamaker, E. L., Nesselroade, J. R., & Molenaar, P. C. (2007). The integrated trait–state model. *Journal of Research in Personality*, 41(2), 295–315.
- Hunter, M. D. (2018). State space modeling in an open source, modular, structural equation modeling environment. *Structural Equation Modeling: A Multidisciplinary Journal*, 25(2), 307–324. doi:10.1080/10705511.2017.1369354
- Hurwicz, L. (1950). Least squares bias in time series. *Statistical Inference in Dynamic Economic Models*, 10, 365–383.
- Hülshager, U. R. (2016). From dawn till dusk: Shedding light on the recovery process by investigating daily change patterns in fatigue. *Journal of Applied Psychology*, 101(6), 905–914. doi:http://dx.doi.org.proxy2.cl.msu.edu/10.1037/apl0000104
- Ilgen, D. R., & Hulin, C. L. (2000). *Computational modeling of behavior in organizations: The third scientific discipline*. Washington, D.C.: American Psychological Association.
- James, L., Mulaik, S., & Brett, J. M. (1982). *Causal analysis: Assumptions, models, and data*. Newbury Park, CA: Sage.
- Jebb, A. T., Tay, L., Wang, W., & Huang, Q. (2015). Time series analysis for psychological research: Examining and forecasting change. *Frontiers in Psychology*, 6, 727.
- Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica: Journal of the Econometric Society*, 1551–1580.
- Keele, L., & Kelly, N. J. (2006). Dynamic models for dynamic theories: The ins and outs of lagged dependent variables. *Political Analysis*, 14(2), 186–205.
- Kelderman, H., & Molenaar, P. C. (2007). The effect of individual differences in factor loadings on the standard factor model. *Multivariate Behavioral Research*, 42(3), 435–456.
- Kenny, D. A. (1979). *Correlation and causality*. New York: Wiley.
- Koopman, J., Lanaj, K., & Scott, B. A. (2016). Integrating the bright and dark sides of OCB: A daily investigation of the benefits and costs of helping others. *Academy of Management Journal*, 59(2), 414–435. doi:10.5465/amj.2014.0262
- Kuljanin, G., Braun, M. T., & DeShon, R. P. (2011). A cautionary note on modeling growth trends in longitudinal data. *Psychological Methods*, 16(3), 249–264. doi:http://dx.doi.org.proxy2.cl.msu.edu/10.1037/a0023348
- Liebovitch, L. S., Vallacher, R. R., & Michaels, J. (2010). Dynamics of cooperation–competition interaction models. *Peace and Conflict*, 16(2), 175–188.
- Marriott, F., & Pope, J. (1954). Bias in the estimation of autocorrelations. *Biometrika*, 41(3/4), 390–402.
- Mathieu, J. E., & Taylor, S. R. (2006). Clarifying conditions and decision points for mediational type inferences in organizational behavior. *Journal of Organizational Behavior*, 27(8), 1031–1056.
- Meadows, D. H. (2008). *Thinking in systems: A primer*. White River Junction, VT: Chelsea Green.
- Miner, A. G., & Glomb, T. M. (2010). State mood, task performance, and behavior at work: A within-persons approach. *Organizational Behavior and Human Decision Processes*, 112(1), 43–57.
- Molenaar, P. C. (2004). A manifesto on psychology as idiographic science: Bringing the person back into scientific psychology, this time forever. *Measurement*, 2(4), 201–218.
- Monge, P. R. (1990). Theoretical and analytical issues in studying organizational processes. *Organization Science*, 1(4), 406–430.
- Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica*, 1417–1426.
- Petris, G., & An, R. (2010). An R package for dynamic linear models. *Journal of Statistical Software*, 36(12), 1–16.
- Petris, G., Petrone, S., & Campagnoli, P. (2009). *Dynamic linear models with R*. New York: Springer.
- Phillips, P. C. (1991). Optimal inference in cointegrated systems. *Econometrica*, 283–306.

- Phillips, P. C., & Durlauf, S. N. (1986). Multiple time series regression with integrated processes. *Review of Economic Studies*, 53(4), 473–495.
- Phillips, P. C., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I (1) processes. *Review of Economic Studies*, 57(1), 99–125.
- Pitariu, A. H., & Ployhart, R. E. (2010). Explaining change: Theorizing and testing dynamic mediated longitudinal relationships. *Journal of Management*, 36(2), 405–429.
- Ployhart, R. E., & Vandenberg, R. J. (2010). Longitudinal research: The theory, design, and analysis of change. *Journal of Management*, 36(1), 94–120.
- Rosen, C. C., Koopman, J., Gabriel, A. S., & Johnson, R. E. (2016). Who strikes back? A daily investigation of when and why incivility begets incivility. *Journal of Applied Psychology*, 101(11), 1620–1634.
- Serang, S., Grimm, K. J., & Zhang, Z. (2019). On the correspondence between the latent growth curve and latent change score models. *Structural Equation Modeling: A Multidisciplinary Journal*, 26(4), 623–635. doi:10.1080/10705511.2018.1533835
- Simon, H. A. (1991). The architecture of complexity. In G. J. Klir, *Facets of systems science* (pp.457–476). Boston, MA: Springer.
- Sutton, R. I., & Staw, B. M. (1995). What theory is not. *Administrative Science Quarterly*, 40(3), 371–384.
- Vancouver, J. B., Wang, M., & Li, X. (2018). Translating informal theories into formal theories: The case of the dynamic computational model of the integrated model of work motivation. *Organizational Research Methods*, 109442811878030. doi:10.1177/1094428118780308
- Voelkle, M. C., & Oud, J. H. L. (2015). Relating latent change score and continuous time models. *Structural Equation Modeling: A Multidisciplinary Journal*, 22(3), 366–381. doi:10.1080/10705511.2014.935918
- Wang, M., Zhou, L., & Zhang, Z. (2016). Dynamic modeling. *Annual Review of Organizational Psychology and Organizational Behavior*, 3, 241–266.
- Wooldridge, J. M. (2005). Simple solutions to the initial conditions problem in dynamic, nonlinear panel data models with unobserved heterogeneity. *Journal of Applied Econometrics*, 20(1), 39–54.