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Temporal Interpersonal Emotion Systems: The "TIES" That Form Relationships

Emily A. Butler[1]

Abstract

Emotion is often framed as an *intrapersonal* system comprised of subcomponents such as experience, behavior, and physiology that interact over time to give rise to emotional states. What is missing is that many emotions occur in the context of social interaction or ongoing relationships. When this happens, the result can be conceptualized as a temporal *interpersonal* emotion system (TIES) in which the subcomponents of emotion interact not only within the individual but across the partners as well. The present review (a) suggests that TIES can be understood in terms of the characteristics of dynamic systems, (b) reviews examples from diverse research that has investigated characteristics of TIES, (c) attempts to clarify the overlapping terms that have been used to refer to those characteristics by mapping them to the statistical, mathematical, and graphical models that have been used to represent TIES, and (d) offers pragmatic advice for analyzing TIES data.

Keywords

emotion, relationships, dynamic systems

Many contemporary theories frame emotion as an *intrapersonal* dynamic system comprised of subcomponents such as appraisals, experience, expressive behaviors, and physiology that interact over time to give rise to emotional states (Boker & Nesselroade, 2002; Butner, Amazeen, & Mulvey, 2005; Cacioppo et al., 1992; Fogel & Thelen, 1987; Kuppens, Allen, & Sheeber, in press; Lewis, 2005; Lodewyckx, Tuerlinckx, Kuppens, Allen, & Sheeber, in press; Witherington & Crichton, 2007). Imagine, for example, that you're at a dinner party hosted by your boss and your young son suddenly asks you very loudly what you meant in the car when you said your boss is a tyrant. Traditional emotion theories focus on your reaction, your combination of flushing cheeks, feeling of embarrassment, and attempts to hide your emotional response. As the example makes obvious, however, emotions serve social functions and are central to interpersonal functioning, which suggests that an extension of intrapersonal emotion models may be useful (Diamond & Aspinwall, 2003; Kappas, 1991; Kappas & Descoteaux, 2003; Keltner & Gross, 1999; Keltner & Haidt, 2001; Keltner & Kring, 1998; Parkinson, 1996). Specifically, when emotional episodes occur in the context of a social interaction or an ongoing relationship, the result can be conceptualized as an *interpersonal* emotion system in which the subcomponents of the emotional response interact not only within the individual but across the partners as well. In the present example, your boss is likely to be experiencing anger or embarrassment, depending on her appraisal of the situation, with accompanying changes in her physiology and behavior that are linked to your own response, and the outcome of the episode will depend on coordinated emotional interactions between yourself, your son, and your boss.

Many processes that fit this conceptualization have been studied (e.g., reciprocity, transmission, contagion, synchrony, coregulation) in various interpersonal contexts, including parent–child, peer, romantic, therapist–client, and workplace relationships, but these phenomenon and relationship types have generally been discussed in isolation from each other. The present review brings together these traditionally distinct bodies of research by considering them within the framework of temporal interpersonal emotion systems (TIES) and selectively summarizes examples of this work. The core of the TIES model is that the temporal flow of the subcomponents of emotion (experience, expressive behavior, physiology, etc.) in one person is connected directly to a parallel stream of emotional components in another person or persons. Pragmatically, this means that TIES can be assessed whenever you have repeated emotional observations taken over time from at least two partners in a relationship or interaction.

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In essence, if we think of emotional processes that occur in the context of relationships as dynamic systems made up of subsystems constituted by the emotions of the social partners, then it becomes apparent that emotional synchrony in parent–child relationships and negative reciprocity in marital interactions, as well as many other processes, have in common an underlying structure that can be described in terms of the characteristics of dynamic systems. As such, general systems theory (Buckley, 1968) could provide an overarching framework for organizing research on interpersonal emotions (for similar suggestions in developmental science and social-personality psychology, see Granic & Hollenstein, 2003, 2006; Granic & Patterson, 2006; Lewis, 2000; Vallacher, Read, & Nowak, 2002). A comprehensive review of general systems theory is beyond the scope of this article, and the intention is not to integrate all existing literature on interpersonal emotions using a systems approach. Rather, the focus of the present review is to provide examples that show how TIES can be understood in terms of the characteristics of dynamic systems, to suggest that doing so could help researchers to think systematically about the various characteristics of TIES, and to offer pragmatic advice for analyzing data relevant to TIES in a principled way.

One central limitation of the existing literature is that the same social-psychological term is often used to refer to different statistical parameters. For example, *synchrony* sometimes refers to cross-correlations estimated with time-series analysis (Feldman, 2003), but at other times it refers to conditional probabilities estimated with lag-sequential methods (Julien, Brault, Chartrand, & Begin, 2000), or any of a number of other parameters from other statistical models. Although these parameters capture some overlapping information, they are not identical. The converse also occurs, with specific model parameters being referred to with different substantive terms. For example, lagged partner regression coefficients have been referred to as transmission (Larson & Gillman, 1999), coregulation (Schoebi, 2008), contagion (Bolger, DeLongis, Kessler, & Wethington, 1989), and linkage (Soto & Levenson, 2009). Given this confusion, another goal of the present review is to clarify these terms by mapping them directly to the statistical and mathematical models that generate the parameter estimates and by providing substantive interpretations based on relevant empirical results.

Human beings are embedded in a social matrix from the instant they are conceived until the moment they die. We exist as subcomponents of larger social systems, ranging from dyads to nations. This is an exciting time for research on TIES because many investigators are now collecting repeated emotional observations from partners in relationships, thanks to the widespread proliferation of methods such as daily diaries, experience sampling, videotaping, and real-time physiological assessments. In addition, recent advances in analytic techniques and increased availability of software make the analysis of TIES data much more tractable than it has been in the past. This combination of high quality data and readily available analytic tools promises to revolutionize our understanding of interpersonal emotional systems. To further our understanding of TIES, this review begins with an overview of how relationships can be conceptualized as dynamic systems. The following sections are organized around specific characteristics of TIES that have been empirically studied, such as covariation of emotion channels between social partners, flexibility of interpersonal emotion systems, and convergence of shared emotional states. Each of these characteristics of TIES is defined, a sampling of substantive findings is reviewed, and analytic recommendations are provided.

Relationships as Dynamic Systems

Relationships can be understood as dynamic self-organizing systems (Beek & Hopkins, 1992; Boker & Laurenceau, 2006; Gottman, Swanson, & Swanson, 2002; Granic & Hollenstein, 2006; Steenbeek & van Geert, 2005; Vallacher, Nowak, & Zochowski, 2005; van Geert & Lichtwarck-Aschoff, 2005). This means several things. First, the defining feature of a system is that a set of variables is tightly integrated in an organized ensemble (Boker & Nesselroade, 2002; Vallacher et al., 2002). Consider the case of a family. Each member of the family represents one "variable" within the family, and the qualities of the family as a whole are characterized by the ways in which the family members are organized in terms of closeness, power hierarchies, and so on.

Second, a dynamic system has the additional property that the state of the system is at least partially dependent on its past states (Boker & Nesselroade, 2002; Gottman, Swanson, et al., 2002; Steenbeek & van Geert, 2005) and undergoes change over time as a function of interactions among the elements (Granic & Hollenstein, 2003, 2006; Lewis, 2005; Vallacher et al., 2002). For example, a family's current level of habitual conflict is partially dependent on its past levels, but conflict levels can change over time as the "elements"—that is, family members—become more or less adept at managing negative interactions, perhaps due to a treatment intervention.

Third, self-organizing systems are also characterized by the fact that global forms and stable system-level structures can emerge and dissolve through the actions of internal feedback processes among the constituent components (Fogel & Thelen, 1987; Granic & Hollenstein, 2003, 2006; Lewis, 2005; Steenbeek & van Geert, 2005; Vallacher et al., 2002). In this way, interaction among the system elements, with each element adjusting to others, gives rise to higher order coherent patterns that then constrain and coordinate the lower level elements (Granic & Patterson, 2006; Lewis, 2000, 2005; Vallacher et al., 2002). These patterns can display both stability (morphostasis) and change (morphogenesis). Thus, if a parent expresses anger at a child that is not contingent on the child's behavior, it may cause a child to increase his or her own anger expression, resulting in an escalation of conflict (morphogenesis). The more often this happens, the more entrenched it becomes, creating an overall pattern of habitual conflict that then reduces the likelihood that the parent and child will engage in some other pattern of interaction (morphostasis), such as the child responding to the parent's anger with submission.

Characterizing relationships in these terms is not new. More than 60 years ago, Kurt Lewin referred to dyads and small groups as "natural dynamic units or wholes" that must be understood as a set of interdependent parts within a unified "life space" and whose structural properties arise from the interactions of the individuals involved (Cartwright, 1951). Forty years later, Kelley and colleagues' highly influential attempt to systematically define relationships for the purpose of scientific study explicitly included a multivariate temporal chain of events within each person, along with causal connections between the partners' chains (Kelley et al., 2002). The type, pattern, and strength of the interchain connections were proposed to be the key features of interdependence and hence the determining characteristics of whether a relationship exists at all (Cappella, 1988; Kelley et al., 2002; Vallacher et al., 2005). In the clinical domain, family systems theorists have long conceptualized families as dynamic systems that oscillate around homeostatic balance points, driven by positive and negative feedback loops. Problematic behavior is thought to be embedded within the family system and to be maintained and exacerbated by circular causation processes regardless of the original source of that behavior (Bateson, 1979; Haley, 1976; Hoffman, 1981; Rohrbaugh & Shoham, in press).

Developmental psychologists also have a long history of thinking of relationships in terms of complex self-organizing systems (e.g., Beek & Hopkins, 1992; Evans & Porter, 2009; Feldman, 2007b; Fogel, 1992, 1993a, 1993b; Fogel & Thelen, 1987; Granic & Hollenstein, 2003; Granic & Patterson, 2006; Lewis, 2000; Lewis, Lamey, & Douglas, 1999; Lewis, Zimmerman, Hollenstein, & Lamey, 2004; Steenbeek & van Geert, 2005; Thelen & Smith, 1994; Thelen & Ulrich, 1991). Much of this work has emphasized social-synchronizing processes whereby individuals dynamically alter their actions with respect to the ongoing and anticipated actions of their partner. Extensive evidence has been amassed suggesting that social coordination between caregivers and infants provides the basis for child development in domains as diverse as maintaining physiological homeostasis, cognition, motor behavior, emotion regulation, communication, and symbol use.

Nothing in a dynamic systems approach to relationships requires that the lower order elements be emotional in nature. Nevertheless, much of the research that models relationships as dynamic systems has assessed some aspect of emotion. Multiple theoretical frameworks provide a context for this centrality. Perhaps the most general is the social-functional approach to understanding emotion (Keltner & Gross, 1999; Keltner & Haidt, 2001; Keltner & Kring, 1998; Schoebi, 2008). Humans are extremely social animals. As such, we deal with most of our survival problems in the context of relationships. Emotions are proposed to be adaptations for dealing with specific problems related to the formation and maintenance of those relationships. A related conceptual framework appears in the literature on empathy, emotional contagion, and mimicry. This work emphasizes the importance of shared emotions and emotional similarity for promoting coordinated action, mutual understanding, and social cohesion (Anderson, Keltner, & John, 2003; Preston & de Waal, 2002; Vallacher et al., 2005; Wallbott, 1995; Walter & Bruch, 2008). Finally, another conceptual framework that emphasizes the interplay of emotions and relationships can be found in the literature on psychobiological attunement, or coregulation, in the context of attachment bonds (Randall & Butler, under review-a). In infancy, this psychobiological connectedness allows the caregiver to directly regulate the physiological and emotional functions of the infant, thereby providing critical scaffolding for the child to develop self-regulatory capacities (Brazelton, Koslowski, & Main, 1974; Feldman, 2003, 2007b; Field, 1985; Field, Healy, Goldstein, & Guthertz, 1990; Hofer, 1984, 1994; Kraemer, 1992; Sbarra & Hazan, 2008; Tronick, 1989). In adulthood, sexual and other intimate behaviors, such as kissing and cuddling, similarly activate biological systems that reduce distress and induce pleasure (e.g., opioid and oxytocin systems). As in infancy, conditioning of these systems occurs due to repeated pairing with the presence of a romantic partner, which results in both partners coming to serve as external emotional and biological regulators for each other (Sbarra & Hazan, 2008). Taken together, these theoretical approaches posit that TIES exist due to our evolutionary history, are critical to our survival as a species, and contribute to successful emotion regulation, health, and well-being across the lifespan.

Characteristics of TIES

Dynamic systems display various characteristics, or temporal patterns, as a result of positive and negative feedback processes among the constituent elements (Buckley, 1968). For example, elements can covary with each other in either morphostatic (stable) or morphogenic (changing) patterns, subsystems can become coupled such that they mutually influence each other's patterns of stability and change, or a system can be drawn into stable attractors, which are multidimensional states that recur over time and become increasingly predictable. Some of the recent research on TIES makes explicit reference to these system characteristics for understanding interpersonal emotional processes, framing research questions and analyses in terms such as attractors, phase transitions, or entropy (see later sections for examples). A large body of research also exists, however, that meets the criteria for TIES in that emotions are assessed over time in at least two social partners, but that does not frame the analysis in terms of dynamic systems. Nevertheless, if we adopt a dynamic systems lens, it can be seen that this work investigates either morphostatic or morphogenic

Table 1. Overview of General Systems Terms, Social-Psychological Constructs, and Pragmatic Descriptors for Characteristics of Temporal Interpersonal Emotion Systems (TIES)

General system term	Social-psychological construct	Pragmatic descriptor
Morphostatic covariation	concurrent synchrony	concurrent covariation, level removed
	time-lagged synchrony	time-lagged covariation, level removed
Morphogenic covariation	transmission/contagion	time-lagged covariation with level change
	reciprocity	time-lagged sequential patterning
	reactivity	behavior followed by experience (time-lagged covariation or sequential patterning)
	escalation/de-escalation	increasing or decreasing time between emotional events
Coupling		influence of one nonlinear subsystem on another
Permeability		moderators of covariation or coupling
Convergence		increasing similarity of emotion
Inertia		tendency to remain in a given emotional state
Flexibility/rigidity		variability of emotional states
Attractors		stable and recurring emotional states
Phase transitions		reconfigurations of emotional state-space
Entropy		predictability of emotional patterns

patterns of covariation between social partners' emotions (see later sections for examples). The central advantage of adopting this view is that it provides a starting point for clarifying the often overlapping terms used to refer to interpersonal emotional covariation.

One central confusion in this literature is that the characteristics of TIES (e.g., morphostatic covariation of emotion channels between social partners) have often been discussed at a different level of abstraction, using terms such as synchrony that imply an entire theoretical framework including the origin and functions of that system characteristic (e.g., Butner, Diamond, & Hicks, 2007; Feldman, 2007b). There are at least four types of representation possible for characteristics of TIES: (a) terms derived from general systems theory (e.g., morphostatic covariation), (b) constructs derived from social-psychological theory (e.g., synchrony), (c) pragmatic descriptors such as "concurrent covariation," and (d) mathematical and statistical model parameters such as partner regression coefficients. These different forms of representation are not always distinguished in the literature. As a result, the same parameter (e.g., partner regression coefficients) has been referred to by different social-psychological terms such as coregulation (Schoebi, 2008), contagion (Bolger et al., 1989), and transmission (Larson & Almeida, 1999), as well as the converse with the same social-psychological term (e.g., synchrony) being indexed by different parameters such as cross-correlations (Feldman, 2003) and canonical correlations (Davis, Haymaker, Hermecz, & Gilbert, 1988).

To reduce this confusion, the following sections suggest combinations of terms that together refer to a specific characteristic of TIES based on (a) general systems theory, (b) social-psychological usage where relevant, and (c) pragmatic descriptors (see Table 1 for an overview). These suggestions are based on the most common usage in the literature or, where such consensus is completely lacking, based on which terms appear to be most closely linked on theoretical grounds. Each section then reviews examples of empirical research that use various model parameters to indicate that characteristic and provides recommendations for the simplest ways to assess it.

Statistical, Mathematical, and Graphical Models of TIES. Before turning to a review of TIES characteristics, it is worth considering the analytic models that have been used to assess them because what we know about TIES is dependent on how they have been represented. As such, our substantive knowledge is directly linked to the parameters of the statistical, mathematical, and graphical models that have been used for examining TIES. A parameter is a numeric quantity that is defined by a mathematical model and in the present context represents a certain characteristic of an interpersonal emotion system. Various approaches have been taken for modeling TIES. Most fall into one, or a combination, of three general strategies. The first is statistical model fitting, an approach that is very familiar to social scientists. In this tradition, TIES have been investigated using multilevel and structural equation modeling, as well as lag-sequential and time series analyses. This approach is characterized by focusing on empirical observations, positing a statistical model, and testing the fit of that model to the data (Ram & Pedersen, 2008). Perhaps the largest advantage of this approach is that it is familiar to most social scientists and therefore probably the easiest for many to use. The primary limitation is that most investigators will be restricted to the types of models implemented in readily available software packages and those models may or may not provide the best representation for any given interpersonal emotional process.

The second strategy is to develop a set of mathematical equations that explicitly represent the theoretical mechanisms involved in the process of interest (Gottman, Murray, Swanson, Tyson, & Swanson, 2002; Gottman, Swanson, et al., 2002; Ram & Pedersen, 2008; Vallacher et al., 2005; Vallacher et al., 2002). Although empirical data may be used to establish starting values for the model parameters, it is not the central focus. Instead, the model is used to generate synthetic data, also referred to as simulations, which can be assessed for plausibility or compared to empirical observations. Parameters of the model can be set to different values and the simulation rerun, allowing tests of theoretically based hypotheses about how the parameter values affect system outcomes. The strength of this approach is that it allows explicit hypothesis testing concerning fairly complex system behaviors. The primary limitation is that relatively extensive mathematical and computer programming skills are required, suggesting that many social scientists will need to collaborate with colleagues from other disciplines to use this approach.

The third general approach is to use graphical methods. These are often used in combination with mathematical modeling to provide a visual representation of complex system behaviors. In addition, some graphical procedures generate parameter estimates representing the information captured by the graph, which can then be used as outcomes or predictors within a statistical modeling approach (Granic & Lamey, 2002). One graphical method in particular, state-space grids, has recently become readily available due to free software (see Flexibility Versus Rigidity section for details). An advantage of this approach is that it supports both exploratory and theory driven analyses of fairly complex system behaviors, although still being relatively easy to use. Examples of each of the three major approaches are described in subsequent sections.

Overview of Emotional Covariation. One of the most widely studied characteristics of TIES is the covariation of emotion channels between two people. This literature can be confusing, however, because there are several important distinctions between forms of covariation that are not often considered. The first is the critical distinction between covariation around a stable level (morphostatic covariation) versus around an increasing or decreasing linear trend (morphogenic covariation). The former is an indicator of a coordinated stable pattern that may, or may not, involve the transfer or exchange of emotions between partners. In contrast, the latter is more likely to indicate that some aspect of emotion is being actively transmitted or reciprocated between partners resulting in a jointly altered emotional state (Randall & Butler, under review-b). All existing research on emotional covariation that the author is aware of can be categorized into one of these two broad categories (see Table 1). A second distinction is between concurrent and time-lagged covariation. The former refers to emotional linkages between people in their current state, whereas the latter refers to emotional linkages between one person's prior state and the other person's subsequent state. A third distinction is between linear associations among dimensional indices of emotions (e.g., correlations of minute-by-minute emotional experience and anger expressions) as contrasted with the sequential patterning of categorical emotional states (e.g., conditional probability of an anger state following a sadness state from one minute to the next). A fourth distinction is that any form of covariation can involve associations between partners on the same emotion channel (e.g., both partners' positive experience) or between one channel in one partner and a different channel in the other partner (e.g., one partner's behavior and the other partner's experience). A fifth distinction is that these associations can be symmetric, whereby both partners influence each other to the same degree, or asymmetric, with one partner differentially affecting the emotional state of the other. Finally, there are multiple emotional valence combinations possible. For example, one partner's positive emotion may predict increases in the other partner's positive emotion at a subsequent time point, or decreases in the partner's negative emotion, or even increases in negative emotion if the relationship were an adversarial one. Thus, the same system characteristic (covariation) may index very different interpersonal processes depending on the emotions assessed and the relationship context. It is unfortunate that all of these types of covariation have been referred to indiscriminately throughout the literature with terms such as synchrony, transmission, linkage, contagion, coupling, cross-over, reciprocity, reactivity, and coregulation. The following sections attempt to disambiguate some of these terms by drawing relevant distinctions and by linking them directly to the statistical and mathematical models that have been used to assess specific forms of emotional covariation.

Morphostatic Covariation. Morphostatic covariation refers to between-partner emotional covariability around a stable, homeostatic level. The most commonly used social-psychological term that maps onto this is synchrony, which has often been defined very broadly, including any nonrandom, patterned, temporal covariation of the timing or form of behaviors, internal states, or events (e.g., Bernieri & Rosenthal, 1991; Feldman, 2007b). Much of this work focuses on synchrony as a fundamental aspect of social coordination, necessary for stabilizing all human interaction (Bernieri & Rosenthal, 1991; Field, 1985; Schmidt & O'Brien, 1997; Vallacher et al., 2005; Wallbott, 1995). Such all-inclusive definitions have the problem that they blur distinctions that may be important for understanding underlying process. The present review restricts the definition of emotional synchrony to concurrent and time-lagged covariation of the same (or similar) emotion between two people around a stable level (see Figure 1). Establishing a stable level is usually achieved mathematically by removing information about partners' absolute emotional levels (e.g., are they on average in a positive, negative, neutral, or linearly changing emotional state) before assessing covariation. This implies that

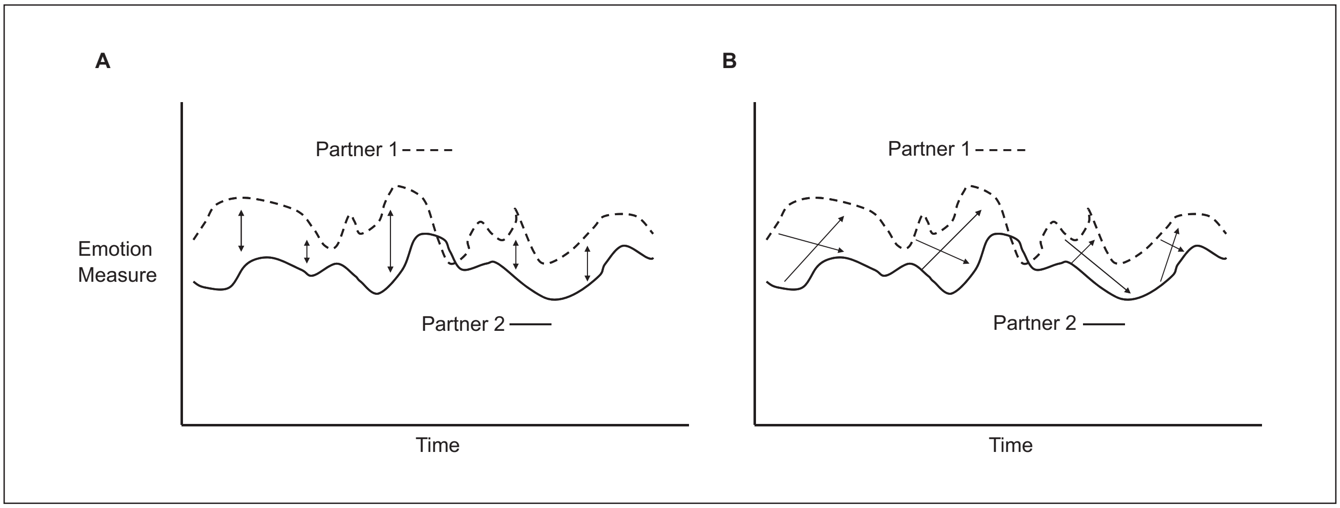

Figure 1. Examples of concurrent synchrony (Panel A) and time-lagged synchrony (Panel B)
Note: The arrows indicate the emotional linkage that synchrony refers to in each case.

level information is not relevant for understanding the focal process. I first review research on synchronous processes that appear to warrant this assumption, followed by work on interpersonal synchrony of physiological responses where this seems less tenable.

Concurrent synchrony: Concurrent covariation with level removed. Despite the fact that concurrent covariation is probably the system characteristic that most directly reflects the dictionary meaning of synchrony as "coincidence or coexistence" ("Synchrony," n.d.), results based on models that assess it are relatively rare. This is possibly due to inherent interpretive ambiguities accompanying concurrent covariation (Larson & Almeida, 1999). In most cases, covariation is of interest as an indicator of a tightly linked system with strong bidirectional influences between social partners, but concurrent covariation is equally likely to arise due to third variables such as shared experiences. For example, if a romantic couple watch a disturbing movie at the same time (even if they are in hotel rooms in different cities and it was chance that they both turned on the same channel), they would likely both report an increase in negative emotions that evening, but that covariation would be due to the film rather than any emotional linkage between the partners.

Another interpretive threat when assessing covariation is autocorrelation, which refers to the degree to which a person's present state can be predicted from his or her prior state. If two partners have similar autocorrelation in their time series, then their emotional states may rise and fall in covariation with each other, but it could be due to factors that are entirely external to the individuals (Gottman, 1981; Warner, 1992). For example, there is some evidence that positive emotions follow a diurnal cycle (Clark, Watson, & Leeka, 1989). If this were true, then both partners in a relationship would show a similar oscillating pattern of positive emotion across a 24-hour period if they followed a standard sleep–wake cycle. A simple correlation would suggest strong connections between the partners, even though they may not be influencing each other at all. Thus, optimally assessing between-partner emotional linkages requires controlling for variance attributable to autocorrelation, as well as taking third variables into account.

One way of minimizing interpretive threats is with an experimental or quasi-experimental design, whereby the situation in which the emotional covariation is assessed is held constant and it is known that the partners are responding to each other and not to some unobserved external influence. One example of this approach comes from a laboratory study of committed romantic couples in which either one or both partners were a habitual smoker (Rohrbaugh, Shoham, Butler, Hasler, & Berman, 2009; Shoham, Butler, Rohrbaugh, & Trost, 2007). The protocol involved having the couples discuss a health-related disagreement during a nonsmoking baseline and then continue discussing the issue while one or both partners smoked. Following the discussion, the partners separately reviewed the videotape of their conversation and provided a continuous report of their recalled emotional experience (positive/negative). The central hypothesis was that smoking together would increase emotional cohesiveness for joint-smoking couples but disrupt emotional connection for couples in which only one partner smoked. Concurrent synchrony was assessed using a simple adaptation of multiple regression (see Recommendations section below). As predicted, single-smoker and dual-smoker couples did not differ in their degree of emotional covariation during the nonsmoking baseline, however, once the couples entered the smoking phase, covariation increased for dual-smoker couples and decreased for single-smoker couples, resulting in a significant difference between them. These results suggest that one factor that may perpetuate smoking in dual-smoking couples is the increased emotional coordination that accompanies the shared behavior.

Another approach for minimizing interpretive ambiguities due to third variables is to take into account shared experiences. An example of this approach comes from a diary study of romantic couples (Butner et al., 2007). Participants reported daily for 3 weeks on their positive and negative emotional experience, the quality (positive/negative) of their shared interactions with their partner, the quality (positive/negative) of the events they experienced that day, and the amount of time they spent with their partner. Concurrent covariation of emotional experience was assessed using a multilevel modeling approach (MLM, a.k.a. hierarchical linear modeling or HLM) whereby one partner's emotion is predicted from the other partner's same emotion at the same time point (Butner et al., 2007; see Recommendations section). The results clearly showed symmetric covariation of both positive and negative emotion, even after controlling for the quality of daily events and shared interactions. In addition, covariation was found to be higher on days when participants reported spending more time together, suggesting that it was driven by interpersonal processes that depend on proximity. Finally, covariation varied as a function of the attachment styles of both partners, but the pattern of results was complex and difficult to interpret. Given the strong theoretical links between attachment and covariation discussed earlier, one important direction for further research will be to disentangle the complex relationship between the two.

Recommendations for assessing concurrent synchrony. One simple approach for assessing concurrent synchrony is to first regress each person's outcome on the same variable from the previous time point (i.e., a time-lagged version of the outcome variable), output the residuals, and then use the correlation of the partners' residuals as an estimate of synchrony (Rohrbaugh et al., 2009). A statistically more powerful approach is to use multilevel modeling (MLM) or structural equation modeling (SEM) to implement the covariation model suggested by Butner et al. (2007). An additional advantage of their approach is that if there is some nonarbitrary way to tell partners apart, such as one partner in each couple is male and the other is female, then asymmetric synchrony estimates are possible. For example, if women's emotions were easier to predict from their male partner's than vice versa, which may be the case if women were more sensitive to their partner's emotional nuances, then the synchrony estimate for men predicting women would be higher than the synchrony estimate for women predicting men. An example of SAS code to implement this model is provided in the appendix found online at http://pspr.sagepub.com/supplemental. As discussed above, however, these models should not be used if absolute levels of emotion may be relevant to the question at hand. For example, if the hypothesis were that less satisfied couples would engage in more conflict, and therefore show stronger mutual influence for negative emotions, then the fact that the emotions are expected to be negative on average is relevant. The models suggested here for concurrent synchrony remove all level information before assessing covariation. In cases where levels may be relevant, one of the models discussed later for assessing morphogenic covariation processes would be more appropriate.

Time-lagged synchrony: Time-lagged covariation with level removed. The majority of the literature on synchrony has minimized the interpretive difficulties associated with concurrent assessment of partners' emotions by focusing instead on time-lagged covariation, most commonly by using cross-correlation functions (CCFs) obtained from time-series analysis (Feldman, 2003, 2006, 2007a; Field, 1985; Gottman, 1981). A CCF plot shows the strength of association between two time series for each possible time lag after removing any linear trends. Positive spikes show evidence of association with Partner-1 leading, negative spikes show evidence of association with Partner-2 leading, and spikes in both directions suggest association with both partners alternately leading (see Recommendations section).

Feldman (2003, 2006, 2007a, 2007b) has used several indices based on CCF plots to assess time-lagged behavioral covariation in parent–infant interactions. In this work, affective behaviors are rated every second with a scale that ranges from negative through positive engagement (Monadic Phases coding system; Feldman, 2003, 2006, 2007a). One index of symmetric covariation is the size of the largest cross-correlation between parents' and infants' engagement ratings. In one study, Feldman suggests the importance of parent–infant covariation for cognitive development by showing that greater engagement cross-correlations predicted infants' increased complexity of symbolic play (Feldman, 2007a). Another study investigated the role that infant biological development plays as a precursor to social coordination. This work showed that high-risk premature infants had lower cross-correlations of engagement with their mothers than low-risk and full-term babies (Feldman, 2006). In addition, greater cross-correlation was predicted by more regular infant sleep–wake cycles, higher infant vagal tone, more infant orienting to the environment, and better infant arousal modulation. These results suggest that the development of organized biological rhythms within infants plays a role in supporting social coordination between infants and parents at a later stage.

Another study focused on the regulation of positive emotions and compared father–infant and mother–infant dyads (Feldman, 2003). Clear differences in parent–infant emotional covariation emerged depending on the gender composition of the dyad. Specifically, father–son dyads showed higher covariation then father–daughter dyads, but no gender differences were observed for mother–infant dyads. In addition, for mother dyads, higher covariation was predicted by more social orientation from the infant and greater infant negative emotionality. In contrast, for father dyads, higher covariation was predicted by positive arousal and father attachment security. This pattern of findings supports the author's contention that both mothers and fathers provide important scaffolding for the development of infant emotion regulation through the coordination of affective engagement but that they do so in different ways, with mothers providing coordination of socially oriented affective signals and fathers providing coordination of high-intensity positive arousal.

An additional piece of information that can be obtained based on the spikes in a CCF plot is which partner is leading the covariation, thus giving an assessment of asymmetric covariation as well as symmetric. In the one study described above, full-term babies showed more evidence of infant lead/mother follow covariation than premature babies, which is consistent with this form of coordination being normative for that age period (Feldman, 2006). In the other study described above, same gender dyads (mother–daughter, father–son) showed more alternating covariation, suggesting more mutual influence, than did mixed gender dyads (Feldman, 2003). In addition, alternating covariation was higher for mother–child dyads when the interaction was lower in arousal, but the reverse was true for father–child dyads. Finally, the time-lag to the first peak in the CCF plot was also assessed and showed that same-gender dyads (mother–daughter, father–son) showed a shorter time lag to the first peak than mixed-gender dyads, implying that emotional coordination was reached quicker in matched dyads (see also the Escalation Versus De-escalation section for related latency measures).

In all the results reviewed so far, the assumption that information about absolute emotional levels is not relevant appears warranted because the studies focused on typical daily interactions in supportive relationships in which there was no reason to expect extreme or linearly changing levels of emotion. As such, the prior results are compatible with a concept of synchrony that emphasizes interpersonal coordination in the form of an oscillating pattern of fluctuations around an optimal emotional level. The studies that are reviewed next, however, also assess covariation with level information removed, but their theoretical framework, and the conditions under which covariation is observed, strongly suggest that changes in level would be relevant for understanding the processes involved. As such, the following examples of synchrony may actually be better understood as instances of morphogenic covariation whereby some aspect of emotion is actively transferred or reciprocated between partners resulting in an altered dyadic emotional state.

The relevant body of research focuses on time-lagged covariation of physiological channels between adult interaction partners. This phenomenon is often referred to as physiological linkage (Guastello, Pincus, & Gunderson, 2006; Levenson & Gottman, 1983; Levenson & Ruef, 1992; Saxbe & Repetti, 2010; Soto & Levenson, 2009). Early work in this area was driven by the hypothesis that conflict should increase physiological linkage because negative emotions such as fear and anger are accompanied by increased autonomic arousal (Ekman, Levenson, & Friesen, 1983; Levenson, 2003; Stemmler, Heldmann, Pauls, & Scherer, 2001). As such, if partners engage in a tightly coupled negative emotional exchange (i.e., negative reciprocity), then their physiological responses should also show high covariation. A seminal study in this area investigated physiological linkage in married couples during a neutral conversation and a conflict conversation (Levenson & Gottman, 1983). As predicted, physiological linkage was higher during the conflict conversation. In addition, during the conflict, physiological linkage was negatively correlated with marital satisfaction, with less satisfied couples showing higher levels of linkage. In a recent demonstration of this effect, marital partners reported their positive and negative mood 4 times a day on 3 separate days (Saxbe & Repetti, 2010). At each time point, they also provided a salivary cortisol sample. Results showed significant covariation of negative, but not positive, emotional experience and of cortisol between partners. These effects were stronger for couples with lower marital satisfaction, thus supporting the contention that the linkage was driven by mutual negative affect and strife.

Recent work, however, suggests that empathy as well as conflict can produce physiological linkage (Guastello et al., 2006; Levenson & Ruef, 1992; Marci, Ham, Moran, & Orr, 2007; Soto & Levenson, 2009). Empathy is a complex construct, including the cognitive process of knowing what another person is feeling (cognitive empathy), as well as the emotional process of actually feeling what the other person is feeling (emotional empathy) (Davis, 1983; Hatfield, Cacioppo, & Rapson, 1994; Preston & de Waal, 2002; Strayer, 1987). It has been argued that contagion provides one basis for emotional empathy, whereby observing someone's emotional display results in automatic mimicry of his or her expressive behavior, which in turn leads to feeling some semblance of the same emotion due to facial feedback (Chartrand & Bargh, 1999; Kappas & Descoteaux, 2003; Preston & de Waal, 2002; Wallbott, 1995). To the extent that emotions have an autonomic physiological signature, this should result in similar physiological responses in the target and the viewer (Levenson & Ruef, 1992; Soto & Levenson, 2009). Several studies provide empirical support for this hypothesis. First, observers were most accurate at rating the negative emotions of a target when they showed high physiological linkage with the target (Levenson & Ruef, 1992). Second, physiological linkage between therapists and clients was associated with higher ratings of therapist empathy (Marci et al., 2007). Third, Chinese Americans showed higher physiological linkage when rating the emotions of other Chinese Americans than when rating other ethnic groups, suggesting an in-group advantage for recognizing and sharing emotions (Soto & Levenson, 2009). Fourth, self-reported social sensitivity predicted greater electrodermal linkage using both a traditional linear analysis and a novel nonlinear assessment (Guastello et al., 2006), again supporting the idea that physiological linkage can come about due to emotional contagion arising from empathic responding.

As discussed previously, the findings on physiological linkage are based on the same statistical models as those for time-lagged synchrony, but theory suggests that distinct processes may be driving the observed covariation. On one hand, synchrony is usually assumed to be a form of interpersonal coordination and to contribute to emotional homeostasis. On the other hand, physiological linkage is theorized to appear in situations characterized by altered joint emotional states, such as conflict or contagion. This suggests that removing information about absolute levels of emotional responding may obscure our understanding and that further research will be better served to routinely assess and report whether emotional covariation is occurring around a stable or changing level and whether that level is positive, negative, or neutral in tone.

Recommendations for assessing time-lagged synchrony. One approach for assessing time-lagged synchrony involves using time-series methods (Feldman, 2003). The strength of this approach is that covariation is simultaneously assessed across a wide range of time lags (e.g., Person1 predicted from Person2 1 minute earlier, 2 minutes earlier, 3 minutes earlier, etc.). Therefore, this approach is optimal if you do not have an a priori idea about where to look in time for the best evidence of synchrony. The disadvantages of this approach are that it requires a fairly large number of repeated observations (in the order of hundreds) and it requires separate preliminary analyses for each person in your sample, followed by preliminary analyses for each dyad. Specifically, autoregressive integrated moving average (ARIMA) models are applied one at a time to each person's data to partial out the autocorrelation. The residuals from these models are saved and then cross-correlation functions are used to assess the covariance of these residuals between dyad partners across a range of lag times. Various pieces of information from the CCF plots can be noted, such as the value of the largest cross-correlation for each dyad, and then used as synchrony indicators in subsequent analyses of variance (ANOVAs) or regression analyses comparing those indicators across dyads. Many software programs provide the capability to do these analyses, but for the novice the Time Series add-on for PASW (formerly SPSS) is probably the easiest to use. It includes an "Expert Modeler" feature that automatically chooses the best-fitting model for each person and provides a point-and-click interface for all the steps in the analysis. One should be aware, however, that optimal model fit is actually a fairly complex process and there is no guarantee that the Expert Modeler is providing a valid result unless the user has the knowledge to evaluate it (see Gottman, 1981, for a complete discussion of time-series analysis and the complexities of model fit).

A second approach to assess time-lagged synchrony is to use MLM or SEM to implement an extension of the concurrent synchrony models discussed previously. An example of SAS code for the MLM version is provided in the appendix. This approach works best for assessing a particular time-lag, for example Person1 predicting Person2 at a specified later time point, as compared to the time-series approach, which allows investigation of many time-lags simultaneously. It is also better than the time-series approach if moderators of covariation are of central interest or if there is a limited number of repeated observations. One additional advantage is that separate preliminary analyses are not required, but rather variability is simultaneously assessed both within and between people and dyads. Finally, as with the concurrent synchrony models, the approaches listed here should not be used if information about absolute emotional levels is likely to be relevant.

Morphogenic Covariation. Morphogenic covariation refers to between-partner emotional covariation around a changing trajectory. There are a number of social-psychological constructs, such as transmission, contagion, reciprocity, and reactivity, that map onto morphogenic covariation. These constructs all theoretically involve the exchange or transfer of some aspect of emotion from one person to another, resulting in a change in emotional state for one or both partners (Almeida, Wethington, & Chandler, 1999; Bolger et al., 1989; Gottman & Levenson, 1986). All of these processes would lead to an alteration, amplification, or de-amplification of relationship partners' joint emotional state, with an overall emotional pattern characterized by displacement (see Figure 2). The following sections present several appropriate models for assessing morphogenic covariation, grouped by the most commonly used social-psychological terms. The distinctions between the various social-psychological terms depend on a combination of whether the emotion assessed was continuous or categorical, which emotional channels are involved (e.g., experience, behavior), and whether the covariation is indicated by standard linear covariance, sequential patterning, or time latencies between emotional events (see following sections for details). As such, these processes have a great deal in common due to being examples of morphogenic covariation, whereas the distinctions appear relatively superficial. Future systematic research will need to establish whether these subtypes are in fact all forms of the same fundamental interpersonal emotion process.

Transmission/contagion: Time-lagged covariation with change in level. A large body of research has focused on situations in which one person's emotion predicts changes in a partner's emotion at a subsequent time-point. This phenomenon has been referred to as emotional transmission (for a review, see Larson & Almeida, 1999), and crossover (for a review, see Westman, 2001), and contagion (Bolger et al., 1989), and coupling (Ferrer & Nesselroade, 2003), and coregulation

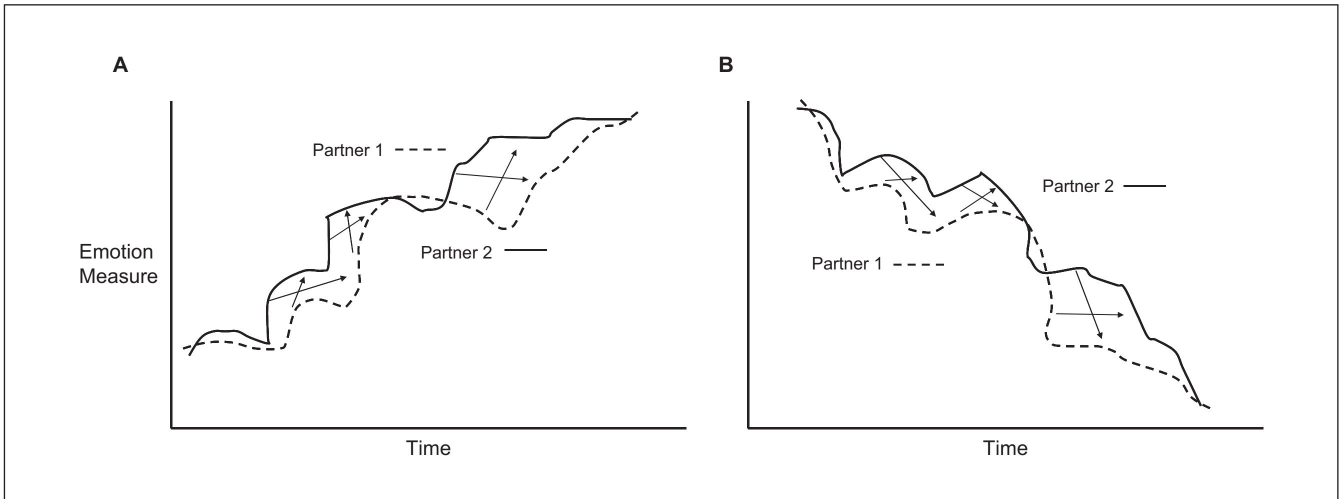

Figure 2. Examples of an increasing morphogenic covariation process (Panel A) and a decreasing morphogenic covariation process (Panel B)
Note: These are identical to time-lagged synchrony, except for the presence of increases or decreases in average emotion levels over time.

(Schoebi, 2008), making it one of the more confusing topics in the literature. The partners' emotions may be either the same, such as when one person's depressed mood is transmitted directly to his or her partner, or different, such as when a parent's anger results in a child's anxiety (Larson & Almeida, 1999). The present review adopts the joint term of transmission/contagion, because it clearly indicates an underlying process involving the transfer of emotions from one person to the other.

Probably the most widely used approach to assess emotional transmission/contagion is to employ multilevel modeling to implement a prospective change model (see Recommendations section). In much of this work, transmission/contagion is assumed to be asymmetrical, with one person "sending" and the other person "receiving." The essence of this model is that a receiver's outcome is predicted from both his or her own score on the outcome at a prior time point and the sender's score on a predictor variable also assessed at a prior time point (Larson & Almeida, 1999). Because the receiver's own prior emotion is included in the model, the effect of the sender can be interpreted as predicting changes in the receiver's outcome, over and above the receiver's prior state. Representative findings include that wives are more likely to be influenced by their husbands' emotions than vice versa (Bolger et al., 1989), parents are more likely to transmit their emotions to their children than vice versa (Almeida et al., 1999), fathers' work stress is likely to affect other family members (Repetti, 1989) but mothers' work stress may not (Larson & Richards, 1994), and negative emotions appear to be transmitted more readily than positive emotions (Thompson & Bolger, 1999).

Recent research on emotion transmission/contagion has moved away from specifying one partner as the sender and the other as the receiver, opting instead to allow both partners to play both roles. One example is a study of married couples in which both partners reported their emotional experience on the two dimensions of "hard affect" (angry–calm) and "soft affect" (sad–upbeat) 6 times a day for 7 days (Schoebi, 2008). Analyses focused on reunion occasions, defined as time points when partners were together but they reported having been apart at the prior assessment. Results showed that individuals who scored higher on interpersonal insecurity showed greater partner influence on changes in hard affect when they reunited. In contrast, husbands who were higher on perspective taking showed greater influence from their wives' soft affect. These findings suggest that emotional experiences outside the relationship can alter the dyadic system's joint emotional state and that individual differences can moderate these effects.

It is also possible to use SEM to assess transmission/contagion, with the advantage being that multiple indicators of the target emotion can be combined as a latent construct. One investigation used a dynamic factor model to assess the factor structure and cross-partner influences of emotional experience for one married dyad (Ferrer & Nesselroade, 2003). Specifically, a husband and wife recorded their experience of 20 emotions (positive and negative) every day for 6 months. The first finding was that emotional experience showed different structures for the husband and the wife, both in terms of factor configuration and the degree of stability over time. The second finding was that the husband appeared to have a greater influence on his wife's subsequent emotion than vice versa. His negative experience, in particular, predicted elevations in her subsequent negative experience as well as dampening her positive experience.

Recommendations for assessing transmission/contagion. One simple extension of time-lagged synchrony models that would make them appropriate for assessing morphogenic covariation would be to theorize and report on overall changes in emotional level, in addition to reporting covariation (Randall, Corkery, Duggi, Kamble, & Butler, under review). For example, conflict might increase the synchrony of both negative and positive emotions, but it would do so by increasing both partners' levels of negative emotions while decreasing both partners' levels of positive emotions. Indeed, a recent diary study of romantic couples found exactly that (Randall et al., under review). If only covariation had been investigated, it would appear that conflict was having a similar influence on negative and positive emotions, whereas it was actually having opposite effects. An example of this approach is provided in the appendix.

Although the most common way to assess transmission/contagion is to use a prospective change model, the model by itself does not distinguish between morphostatic and morphogenic processes. Technically, the model is identical to a time-lagged synchrony model, except for the addition of the target person's own prior emotion as a predictor. This allows stronger inference that one partner's emotions are connected to subsequent changes in the other partner's, but if linear trajectories are not included, then information about abolute levels has been removed in the same way as in the synchrony models. Thus if a morphogenic process is suspected prospective change models should be extended by including linear trajectories over time. Numerous appropriate models are possible both in an MLM context (see, e.g., Kenny, Kashy, & Cook, 2006; Laurenceau & Bolger, 2005; Sanford, 2007; Schoebi, 2008) and in a SEM framework (see, e.g., Ferrer & Nesselroade, 2003; Kim, Conger, Lorenz, & Elder, 2001; Ram & Pedersen, 2008). An MLM example is provided in the appendix. One of the main advantages of the MLM approach is that sample average results and person/dyad specific variances are both provided. In contrast, with SEM, an appropriate model (dynamic factor analysis) can be found in Ferrer and Nesselroade (2003), but here the analysis must be applied to one dyad at a time, with no established way to pool the results across dyads. The advantage, however, is that multiple indicators can be used to define a latent emotional state.

Reciprocity: Time-lagged sequential patterning. Time-lagged synchrony is poorly differentiated in the literature from reciprocity. Both refer to time-lagged covariation between social partners on the same (or similar) emotion, but synchrony usually refers to associations between continuous measures of emotion whereas reciprocity focuses on the sequential patterning of categorical states. In addition, synchrony is generally assumed to be a homeostatic process, maintaining a stable (although perhaps oscillating) emotional dyadic state. In contrast, reciprocity is generally portrayed as the basis for emotional escalation of both negative and positive emotions, making it an example of a morphogenic covariation process (e.g., Gottman, 1994; Greene & Anderson, 1999; Julien et al., 2000).

Most research on reciprocity has used lag sequential analysis, which is an approach that assesses whether pairs of observed emotional behaviors or self-reported emotional experiences follow each other sequentially between interaction partners at greater than chance rates (Allison & Liker, 1982; Gottman, 1979; Levenson & Gottman, 1983). This approach is based on comparing conditional probabilities (the chance that Behavior A occurs, given that Behavior B just occurred) with unconditional probabilities (the chance that A occurs at all, regardless of antecedent events). Information about changes in level are implicit in the increased likelihood of an event (see Recommendations section). For example, if I am more likely to express anger immediately after my partner did compared to normal, then it can be inferred that my partner's anger expression led me to increase my own level of anger expression.

A classic finding obtained with this method is that negative emotional experience is more likely to be reciprocated between marital partners in dissatisfied relationships as compared to more satisfied ones (for a review, see Gottman, 1994). In contrast, satisfied couples are more likely to reciprocate positive behaviors (Julien et al., 2000). Negative reciprocity has also been shown in parent–child interactions (Carson & Parke, 1996). For example, in one study, negative emotional behaviors (e.g., pout, anger, whine, mock) were coded during a physical game between parents and children. Results showed that fathers who reciprocated children's negative behaviors had children who shared less, were verbally and physically aggressive, and avoided others (all based on teachers' reports). In addition, parents who reciprocated child-negative behaviors were more likely to have children who reciprocated parent-negative behaviors as well.

Another study using these methods focused on problem-solving interactions of agoraphobic and obsessive-compulsive patients with their relatives (Chambless, Floyd, Rodenbaugh, & Steketee, 2007). The relatives were rated as hostile or not toward the patient based on a structured interview. Both partners were rated for positive, negative, and neutral behaviors during the interaction. As predicted, dyads with a hostile relative showed more sequences of negative reciprocity, with relative-negative followed by patient-negative. In addition, dyads with a hostile relative showed more relative-negative behaviors following any patient behavior. In other words, these relatives behaved negatively regardless of the patient's prior behavior. These results are important because they provide a window into the behavioral mechanisms underlying the often observed phenomenon that a hostile family atmosphere, as assessed by self-report, predicts increased risk of relapse for patients with mental health disorders (Chambless et al., 2007; Greenley, 1986; Shields, Franks, Harp, McDaniel, & Campbell, 1992).

Another approach that has been used to test hypotheses about the sequential organization of emotional processes is to model changes in emotion within families over time using

SEM. One example of this employed data from the Iowa Youth and Families Project, a long-term longitudinal study, to assess linkages between adolescents' and parents' negative emotional displays directed at each other (Kim et al., 2001). These displays included expressions of hostility, angry coercion, and resistance assessed during the 8th, 10th, and 12th grades. Clear evidence was found of negative reciprocity. The greater the negative emotion expressed by a teenager toward his or her parents during the 8th-grade assessment, the greater that parent's increase in negative expression toward the teenager several years later in the 10th grade, which in turn predicted increases in the adolescent's negative expressions toward his or her parents in the 12th grade. It is worth noting that although SEM is based on the covariation of continuous dimensions, the research question and conclusions emphasize the sequential patterning of hostility, demonstrating that reciprocity does not necessarily have to be assessed with categorical methods.

Recommendations for assessing reciprocity. Methodological confusion exists in the literature on reciprocity because early work used a Z-score approach, but that method has been shown to be overly sensitive to the total number of behaviors observed and is no longer recommended (Howe, Dagne, & Brown, 2005). More recent, Gottman, Bakeman, and their colleagues have developed other approaches that avoid this problem and have provided free software (Bakeman & Quera, 1995a, 1995b; http://www2.gsu.edu/~psyrab/gseq/index.html). These authors have also provided an introductory text on the topic that complements the software and makes learning this method tractable with limited background knowledge (Bakeman & Gottman, 1997). A recent extension of these methods into a multilevel framework has been suggested by Stoolmiller and Snyder (2006). Another option if you have continuous data is to use SEM following Kim et al. (2001).

Reactivity: Behavior followed by experience (time-lagged covariation or sequential patterning). Reactivity is the same as transmission/contagion or reciprocity, except that the emphasis is on one partner's emotional behavior provoking an experiential response in the other partner. One example comes from a study that found that children who were rated as being more antisocial (e.g., aggressive, oppositional, sneaky) by their parents were more likely than other children to get angry when their parent was not obviously provoking them during an interaction, but they were not more likely to become fearful or sad (Stoolmiller & Snyder, 2006). In addition, when the parent of an antisocial child began to display more negative behaviors, their child was less likely to become fearful, sad, or positive in response. In other words, the antisocial children were less likely than other children to respond to parental negatives with compliant or submissive emotions. These results begin to clarify what *antisocial* means in concrete emotional terms. They also demonstrate the importance of differential emotional responding (anger vs. sadness/fear in response to parental anger) in characterizing the quality of relationships (defiant vs. submissive).

A second example of reactivity comes from a study of mothers' disciplinary tactics. This work used an analytic approach based on time-series analysis that allowed the simultaneous assessment of within-person and between-person emotional processes (Lorber & Smith Slep, 2005; Warner, 1992). Results showed that mothers whose emotional experience showed less inertia (i.e., less serial predictability), and whose negative experience was more influenced by their child's negative emotion expression, were more likely to engage in both harsh and overly lax discipline attempts (Lorber & Smith Slep, 2005). This pattern demonstrates the joint importance of within-person emotional dynamics (mother's highly variable emotional experience) combined with between-person dynamics (mother's increased emotional reactivity to her child) for predicting quality of parenting behaviors.

Recommendations for assessing reactivity. Any of the methods recommended for transmission/contagion or reciprocity could be used to assess reactivity, with the only distinction being that emotional behavior in one partner would be used to predict emotional experience in the other partner.

Escalation versus de-escalation: Increasing or decreasing time between emotional events. Emotional escalation and de-escalation imply changes in the intensity of interpersonal emotional states and therefore suggest that a morphogenic process is involved. Both can be studied either using the sequential patterning of emotional states, as described above, or by assessing changes in the amount of time between emotional events. As discussed in the previous section, the sequence whereby an emotional state in one partner is followed by a similar emotional state in the other partner has generally been interpreted as evidence for emotional escalation (e.g., Gottman, 1994; Greene & Anderson, 1999; Julien et al., 2000). A more direct approach is based on the argument that decreasing time between the emotional responses of social partners indicates an intensification of an interpersonal state (see Recommendations section). One study using this method investigated the time between emotional displays of parents and children (Snyder, Stoolmiller, Wilson, & Yamamoto, 2003). Results showed that parents' angry, contemptuous, and dismissive responses to child anger predicted shorter latency to the next child anger episode and that this pattern was related to child development of externalizing behavior problems. In another example, Bakeman and Gottman (1997) plotted the inter-event interval between married couples' successive negative emotional expressions across the duration of an interaction (see Recommendations section). They found that the time between negative emotional displays became shorter and shorter for distressed couples, suggesting that they had a tendency to escalate toward joint negative emotional states.

De-escalation has been less studied than escalation. Although in theory, increasing latency could be used to represent de-escalation, no examples of this were found in the literature. In terms of sequential patterning, de-escalation is observed when a negative emotion in one partner is followed by nonnegative emotion in the other (Gottman, Coan, Carrere, & Swanson, 1998; Greene & Anderson, 1999). In one study of newlywed couples, de-escalation during a conversation about a disagreement was a strong predictor of relationship stability and happiness 6 years later (Gottman et al., 1998). In another study that assessed both escalation and de-escalation, families were categorized as low, medium, and high functioning based on the persistence of negative behaviors. In the low functioning group, the mother, father, and older child all tended to escalate negative behaviors, whereas the younger child de-escalated in response to the parents. In the medium functioning group, fathers de-escalated mothers' negative behaviors. In the high functioning group, the older child escalated the younger child's negative behaviors, but all other interpersonal transactions involved de-escalation. The implications of this pattern of findings are unclear. For example, what is the clinical significance of younger versus older children using de-escalation? Nevertheless, de-escalation may be important for interrupting negative emotional sequences, suggesting that it warrants further research to better understand its role in families.

Recommendations for assessing escalation/de-escalation. As mentioned, an indirect method for assessing escalation/ de-escalation is to use one of the methods described under reciprocity. More direct approaches all assess actual changes in time between an emotional indicator of interest. One such method uses Cox survival models to estimate hazard rates (Snyder et al., 2003). Advantages of this approach are that it is very versatile, various software packages support it including SAS, and it is easy to find documentation online and in books for how to proceed (for an excellent introduction, see Singer & Willett, 2003). The disadvantage is that it is somewhat complex for the user with no prior background on the topic. An alternate, very simple approach is to calculate either the length of time spent each time a dyad enters a given emotional state (state-length) or the amount of time between successive states (interval-length) and use those as the focal variables (Bakeman & Gottman, 1997; Granic & Dishion, 2003). Regression can be used to predict the state-lengths or interval-lengths over the time course of the interaction. For example, if a dyad spends increasingly longer times in a given state as the interaction continues, then the time-lengths will become longer and the slope over the entire time will be positive. Conversely, if the dyad moves into a state quicker and quicker, then the interval-lengths will decrease over the entire time course and show a negative regression slope.

Coupling: Influence of One Nonlinear Subsystem on Another. Coupling has sometimes been used to refer to time-lagged covariation, whereby a component of emotion in one person varies linearly in time with a component of emotion in another person (e.g., Ferrer & Nesselroade, 2003). This review, however, reserves the term for models that specify a coupling parameter between two nonlinear subsystems. These models take the form of two connected equations, whereby each subequation represents the emotional dynamics of one person in a dyad. Each partner's emotion is modeled as a joint function of their own emotions and their partner's emotions. A coupling parameter determines the influence between the emotions of the two partners.

Numerous forms of the subequations are possible depending on the specific emotional dynamics to be modeled. All of these coupled equations, however, take the general form,

$$f(P1\_X) = f(P1\_X)\ Cf(P2\_X)$$

$$f(P2\_X) = f(P2\_X)\ Cf(P1\_X),$$

where P1 is the first partner, P2 is the second partner, X is some aspect of emotion measured repeatedly, and C is a coupling parameter that determines the influence from one partner's emotion to the other's. The outcome variable can be either the observed value of X or some function of that observed value, such as the derivative (i.e., change in X). In essence, the first term in each subequation represents emotional dynamics intrinsic to the person and the second term represents the emotional dynamics of his or her partner. The coupling parameter C allows each partner's emotional dynamics to directly influence the other's. Because the functions are nonlinear, the value of C can alter not only the amount of influence but the actual form of influence as well, allowing for very complex total system behavior (see Figure 3 for some examples).

One version of this approach uses a coupled oscillator model to investigate cyclical behavior and couplings in the acceleration of partners' emotions over time (Boker & Laurenceau, 2006, 2007; Butner et al., 2005; Butner et al., 2007; see Recommendations section). One study investigated attachment influences on the emotional cycles of cohabiting couples over a 3-week period (Butner et al., 2007). Results showed that anxious individuals had a faster cycle of positive emotional experience, whereas avoidant women had a slower cycle. In addition, the cycles of highly avoidant individuals were less influenced by changes in their partners' positive experience cycles, which is in keeping with the notion that avoidant individuals regulate emotion by disengaging and not attending to emotional cues. Another study used this approach to model the dynamics of intimacy, as assessed by self-disclosure, in a sample of married couples (Boker & Laurenceau, 2006, 2007). These analyses showed that wives were more affected by how far away their husbands were from their equilibrium level than by how rapidly they were changing. In contrast, husbands were affected more by how quickly their wives' level was changing rather than by how far they were from equilibrium.

All examples reviewed so far have focused on estimating parameters of a model from data. Coupled equations have

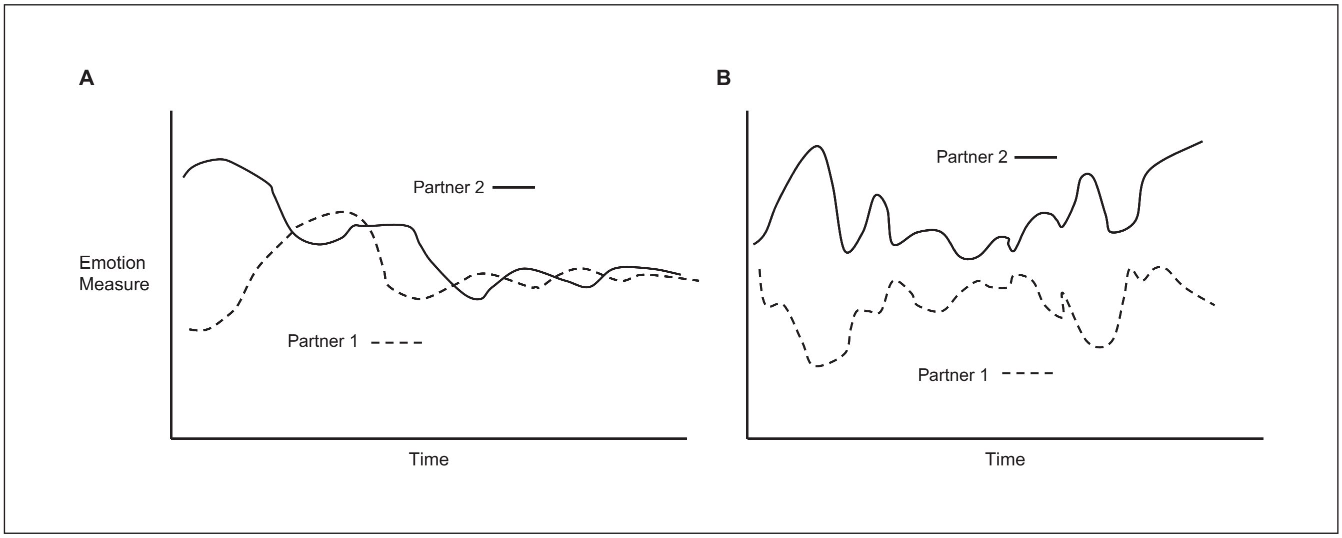

Figure 3. Examples of converging in-phase coupling (Panel A) and oscillating anti-phase coupling (Panel B)
Note: These are only two possibilities out of the infinite number of possible coupled system behaviors. In addition, no arrows are included because there can be multiple connections between the two partners' time series simultaneously. For example, partners could be influencing each other's emotional levels as well as rates of change at the same time.

also been used, however, as the basis for testing hypotheses concerning interpersonal emotional dynamics using computer simulations (Cook et al., 1995; Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002; Vallacher et al., 2005). One version of this approach has been developed by Gottman and his colleagues (Cook et al., 1995; Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002). They use coupled nonlinear difference equations to model emotional behavior during couples' conversations (see Recommendations section). The outcome variables for the subequations are the partners' observed positive minus negative behaviors during each turn at speech. This behavioral variable is modeled as a function of the person's own prior turn at speech, termed the "uninfluenced" component, and his or her partner's previous turn, referred to as the "influenced" component. Although initial values for the parameters are estimated from the data, the focus is on using the equations to test hypotheses concerning system behavior as the values of the parameters are modified.

One representative set of findings showed that marriage types can be distinguished by the form of their influence functions, with unstable marriages destined for dissolution being characterized by a mismatch between the form of the partners' influence on each other (Cook et al., 1995). In addition, the effect of influence in unstable marriages was to make the couples' state more negative, whereas the reverse was true for stable marriages (Cook et al., 1995). The model can also be used to estimate steady states, or attractor basins, a topic that is addressed in a subsequent section. Finally, the models can be estimated based on data for a given couple under one set of conditions and then used to simulate that couple's behavior under different conditions. For example, it could be asked, "How would the conversation have changed if the threshold for the male partner's influence function for positive emotion was lowered?" If the results of the computer simulation suggest desirable relationship effects, then the simulated change can be targeted in a clinical intervention with the couple. In this way, mathematical modeling becomes a therapeutic tool.

Another particularly elegant version of mathematical modeling used coupled logistic equations to assess whether two partners' behavior can become synchronized as a result of either increased coupling or increased similarity of internal states such as emotional experience (Vallacher et al., 2005). Logistic equations represent an outcome at Time T as the product of two competing forces at Time T-1. Specifically, the first force is that the higher the previous value of the outcome, the higher the current value, multiplied by a control parameter. The second force is the higher the previous value, the lower the current value, again multiplied by the control parameter. This model was deemed appropriate on the theoretical grounds that much of human psychology appears to involve competing forces, such as approach–avoid, autonomy–interdependence, and impulse–control. The behavior of the outcome over time can vary dramatically, depending on the value of the control parameter, ranging from convergence on a single value, to oscillating cycles, to very complex patterns that appear random.

In the present example, the outcomes represent two partners' observed behavior and the control parameters represent their internal states, such as emotional experience. The full model combined two logistic equations for each person, such that each person's outcome was a function of his or her own competing forces and his or her partner's competing forces, as well as control parameters for each of them. In addition, a coupling parameter linked the two subequations, representing cross-partner bidirectional influence. Simulations were run, varying the values of the control and coupling parameters and observing the effects on the synchronization of the outcome variables. As expected, increasing synchronization of the two partners' behavior was found for either increases in the similarity of their control parameters (representing more similar internal states) or for increased coupling (representing more cross-partner influence). It is interesting that the type of synchronization varied across the range of coupling. For high values of coupling, the partners' behaviors showed in-phase synchronization. In other words, they began to move in unison. For low values of coupling, however, other patterns of coordination occurred, including anti-phase synchronization analogous to turn-taking and other complex forms of coordination. These results suggest that relationships characterized by moderate mutual influence are likely to show more diverse and flexible forms of synchronization than those involving high levels of interpersonal control. It is also worth noting that these findings underscore the importance of distinguishing synchrony from coupling, since this work shows that coupling is one mechanism by which synchrony can come about.

Recommendations for assessing coupling. The methods needed to assess coupling involve more advanced mathematical and computer programming skills than the methods for covariation processes. As such, many social scientists may want to collaborate with someone who has training in specifying and simulating coupled equations. There is an infinite number of possible models that one could develop, based on the theorized system behaviors being investigated, and so collaborations of social and mathematical scientists will open up exciting new possibilities in the study of TIES.

The most widely used coupling model is the one developed by Boker, Bunter, and their colleagues (Boker & Laurenceau, 2006, 2007; Butner et al., 2005; Butner et al., 2007). In this model, the outcome variables of the two equations are the acceleration of each partner's emotion or, more specific, the second derivative of their emotion, which represents change in their rate of change. This outcome is modeled as a function of each partner's emotional displacement and velocity, along with coupling parameters that determine how similarly the two subsystems (i.e., the two partners) are oscillating and the degree to which each partner influences the other. The approach involves first using a local linear approximation to produce estimates from the data of each partner's displacement, velocity, and acceleration (Boker & Nesselroade, 2002). These estimates are then used as input variables in a multilevel dyadic model that uses the linear equation for a coupled oscillator.

The second coupling model that has been used fairly extensively is Gottman's nonlinear difference equations (Cook et al., 1995; Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002). As described above, this model includes both an uninfluenced and an influenced component for each partner. The uninfluenced component is modeled by an elevation constant and an autoregressive term, used to indicate inertia, or the tendency of the person to remain in the same state (see also the Inertia section). The influenced component is graphically represented as a plot of one partner's average behavior over the entire conversation at Turn T on the X-axis and the other partner's average behavior on the subsequent turn (T + 1) on the Y-axis. For example, a point on the graph at location X = 2, Y = 1 would represent all the turns during the conversation in which the first partner had a behavioral score of 2 and on the subsequent turn his or her partner had a score of 1. These graphs are used to suggest a theoretical form for the influence function, such as a linear model or a step-function.

Permeability: Moderators of Covariation or Coupling. The concept of permeable versus rigid emotional boundaries has always been central to family systems theory. Moderators of either covariation or coupling of emotional channels between people provide a concrete way of assessing such permeability (Larson & Almeida, 1999). High levels of emotional covariation or coupling point to more permeable interpersonal boundaries, whereby one partner's emotions readily influence the emotions of the other partner. In contrast, low levels of covariation or coupling suggest a more rigid interface. As such, a variable that moderates any of the indicators of covariation or coupling in the models discussed above qualifies as a moderator of the permeability of interpersonal emotional boundaries (see Recommendations section).

Several moderators have already been discussed. Smoking increased the permeability of boundaries for couples in which both partners smoked but decreased it for single-smoker couples (Rohrbaugh et al., 2009). Dissatisfied couples have more permeable boundaries with respect to negative emotions than do happier couples (for a review, see Gottman, 1994). Individual differences including attachment style (Butner et al., 2007), interpersonal insecurity (Schoebi, 2008), and perspective taking (Schoebi, 2008) have been shown to moderate covariability and hence permeability. Larson and Almeida (1999) reviewed other moderators of emotional covariability and highlighted the important roles of psychological resources and cognitive coping. For example, they summarize extensive evidence that negative emotions are more likely to be transmitted between partners when one or both partners are stressed. In terms of coping, they summarize two particularly interesting studies (Downey, Purdie, & Schaffer-Neitz, 1999; Thompson & Bolger, 1999) in which individuals who had a salient cause for their negative emotions (mothers with chronic pain; romantic partners preparing for the New York State Bar Examination) were less likely to transmit their distress to other family members, suggesting that they actively coped in ways that reduced the family's permeability to negative emotion. These studies point to an important direction for further research on TIES, which is understanding the system level effects that occur when one individual attempts to control his or her own emotion. Although some research shows that conscious attempts to regulate emotion have clear social consequences during face-to-face interaction (Butler et al., 2003; Butler, Lee, & Gross, 2007), the dynamic processes leading to those consequences have not yet been studied.

Recommendations for assessing permeability. Moderators can be included in any of the models discussed so far and provide a direct assessment of permeability. A particularly useful set of tools for interpreting the results from moderation models has been made available by Kristopher Preacher (http://www.people.ku.edu/~preacher/interact/index.html; Preacher, Curran, & Bauer, 2006).

Convergence: Increasing Similarity of Emotion. The work described above with coupled logistic equations also addressed the issue of convergence, or the increasing similarity of partners' emotional states (Vallacher et al., 2005) (see Figure 3A). Emotional similarity has been argued to promote coordination, mutual understanding, interpersonal cohesion, and attraction (Anderson et al., 2003; Hatfield et al., 1994; Vallacher et al., 2005). As such, partners in successful relationships are expected to converge in their emotional responses over time (Anderson et al., 2003; Walter & Bruch, 2008). In the research described above (Vallacher et al., 2005), a second set of simulations was conducted to explore whether internal states, such as emotions, can be caused to converge by allowing each subsystem (i.e., each partner) to modify their own control parameter (i.e., internal state) in a way that reduced the discrepancy of the partners' outcome variables (i.e., observable behavior). In other words, although social partners often do not have direct access to each other's internal states, they are able to observe each other's behavior and modify their own internal states to make their external behaviors more similar. The simulations showed that under relatively weak coupling, this process did indeed lead to convergence of internal states as well as perfect synchrony of observable behaviors. In contrast, under high degrees of coupling, the observable behavior synchronized almost immediately, but the internal states failed to converge because once synchrony is established, the two partners have no information concerning the status of each other's internal states and thus no way to modify their own states in the direction of similarity. As the authors noted, these results "suggest that using very strong influence to obtain behavioral coordination is likely to hinder synchronization at a deeper level" (p. 45).

Emotional convergence has also been demonstrated to occur in actual human relationships, not only computer simulations, and to be associated with desirable outcomes (Anderson et al., 2003). A series of three studies used laboratory emotion induction techniques to assess emotional responding in romantic partners and college roommates at two time points at least 6 months apart. The partners' responses were correlated at each time point and results showed that these correlations increased over time. Increased similarity was also associated with greater relationship satisfaction, closeness, and longevity. In addition, partners responded similarly to each other even when not in each other's presence, suggesting that the convergence was partly due to them developing similar appraisal patterns.

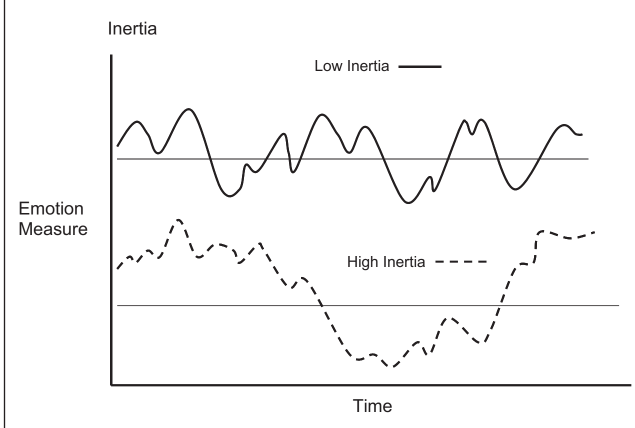

Figure 4. Examples of low and high inertia
Note: For low inertia, the emotional level at one time point is not very predictive of the emotional level at the next time point; sometimes, values above the mean are followed by values also above the mean, but at other time points, values above the mean are followed by values below the mean. In contrast, for high inertia, values that are above the mean are very likely to be followed by values above the mean, and vice versa for values below the mean.

Recommendations for assessing convergence. The simplest way to assess convergence is by comparing regular between-partner correlations at different time points, as done by Anderson et al. (2003). A more powerful approach is to use MLM and an adaptation of the concurrent synchrony model that includes the effect of time and the interaction of the synchrony terms with time (see the appendix for SAS code). This model allows the estimation of both convergence and divergence and would allow for the inclusion of moderators.

Inertia: Tendency to Remain in a Given Emotional State. Emotional inertia is typically represented by autocorrelation, which indicates the degree to which a present emotional state can be predicted from a prior state (Kuppens et al., in press; see Figure 4 and Recommendations section). Research on intrapersonal emotional dynamics suggests that

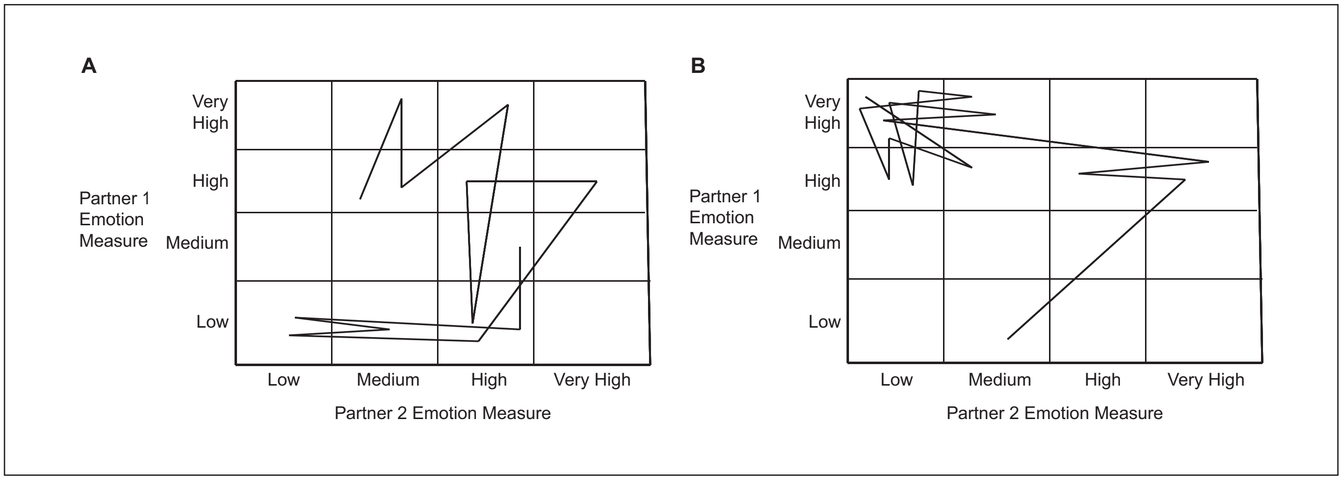

Figure 5. Examples of state-space grids showing flexibility (Panel A) and an attractor (Panel B)
Note: For flexibility, the dyad moves through a wide range of the available cells, whereas for the attractor, once they enter the "high" corner of the grid, they tend to remain there.

inertia is associated with poor psychological functioning (Kuppens et al., in press). Similarly, in relationship research, autocorrelation terms for each partner are included as part of the uninfluenced component in Gottman and his colleagues' coupled equation model of couples' conversations (Cook et al., 1995; Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002; Ryan, Gottman, Murray, Carrere, & Swanson, 1999). In their work, they have consistently found that higher inertia is associated with worse functioning marriages. They argued that these negative effects arise because inertia represents a resistance to emotional change or a lack of emotional flexibility. Similar conclusions have been drawn in the context of family interactions (Greene & Anderson, 1999; Hollenstein, Granic, Stoolmiller, & Snyder, 2004; Hollenstein & Lewis, 2006). For example, one study focused on the observed interactions of families with two parents and two children and found longer lagged sequences (i.e., more significant lagged autocorrelation terms) of negative behaviors for distressed marriages with boys than for other families (Greene & Anderson, 1999). This research has generally focused on negative emotions, but at least in that domain, the evidence suggests that emotional inertia does not bode well for interpersonal functioning or relationship outcomes.

Recommendations for assessing inertia. An autocorrelation term can be included in almost any model and provides an indicator of inertia. An example using MLM is provided in the appendix.

Flexibility Versus Rigidity: Variability of Emotional States. The dimension of emotional flexibility versus rigidity is closely related to inertia because on one end of the dimension, a rigid interpersonal system would likely show high inertia as assessed by autocorrelation. On the other extreme, however, a flexible system implies more than a lack of inertia; it implies variability across a range of emotional states and the ability to move quickly between different emotional states (Hollenstein, 2007; Hollenstein et al., 2004; Hollenstein & Lewis, 2006; see Figure 5A). This conceptualization of emotional flexibility is particularly relevant given that current research on emotion regulation suggests that optimal self-regulation does not involve simply getting rid of negative emotional states but rather entails the ability to move adaptively between emotional states as environmental demands shift (Bonnano, Papa, O'Neill, Westphal, & Coifman, 2004; Butler & Gross, 2004; Granic, O'Hara, Peplar, & Lewis, 2007; John & Gross, 2004; Thompson, 1994).

A recently developed graphical method, state-space grids (SSGs) and accompanying software (Lamey, Hollenstein, Lewis, & Granic, 2004), has made the assessment of interpersonal flexibility highly tractable (Granic & Hollenstein, 2003, 2006; Hollenstein, 2007; Hollenstein et al., 2004; Hollenstein & Lewis, 2006; Lewis et al., 1999) (see Recommendations section). SSGs were inspired by a dynamic systems approach to studying development. One central assumption is that a system will typically have many possible states but can be in only one state at a given moment. The dynamics of the system are reflected in changes from state to state over time (Hollenstein, 2007). The range of all possible states constitutes the state space and, for a bivariate ordinal system, this can be represented by a two-dimensional grid with one dimension on the X-axis and the other dimension on the Y-axis. For example, one partner's emotional expression could be represented on the X-axis and the other partner's expression on the Y-axis. The temporal sequence of observed behaviors (or whatever emotional indicator has been measured) are plotted on the grid, with size of plot point indicating the duration spent in a given cell and transitions between cells tracked with linear trajectories.

SSGs are useful for visual exploratory assessment of interpersonal emotion dynamics. In addition, several measures indexing flexibility are provided by GridWare and allow hypothesis testing. The three that have been most reported are (a) dispersion, which represents how broadly distributed the behaviors are across all cells, (b) transitions, which represents the number of changes between cells, and (c) average cell duration, which represents the tendency to remain in a given state, indicating low flexibility. These measures have been used in several studies of parent–child interactions. In the first, lower flexibility of observed emotional behavior across a range of interaction tasks predicted increases in children's aggressive and antisocial behavior from kindergarten through first grade (Hollenstein et al., 2004). It is important that low emotional flexibility was predictive of behavior problems even after controlling for the predominant valence of the interactions. In other words, children in low-flexible dyads showed increasing behavior problems even if the dyad spent most of its time in a mutually positive state. A second study investigated change in flexibility following a successful intervention program for aggressive children (Granic et al., 2007). Parent–child dyads engaged in a sequence of interactions before and after treatment. Families in which the child showed significant improvement at the end of treatment also showed increased flexibility of emotional behavior during their interactions. In addition, although dyads with children who improved continued to express negative emotions, they also became better able to shift from a mutually negative state to a positive one.

A third study assessed the interplay of negative emotions and interpersonal flexibility (Hollenstein & Lewis, 2006). Rather extensive evidence from research on nonsocial emotion suggests that negative emotion restricts cognitive and behavioral flexibility, whereas positive emotions increase them (Fredrickson, 1998). In keeping with this, an investigation of flexibility of emotional expression in mother–daughter pairs showed that interpersonal flexibility decreased as negative emotionality increased. One explanation for this may be that intrapersonal narrowing of attention and cognition associated with negative emotion in turn contributes to interpersonal emotional rigidity. If true, this could explain why so many couples get stuck in escalating patterns of negative reciprocity and find it so difficult to disengage from conflict. Further research that combines intrapersonal and interpersonal indicators of flexibility under both positive and negative emotional situations is clearly needed to unpack this complexity.

Recommendations for assessing flexibility. It is relatively easy to assess flexibility using GridWare (Lamey et al., 2004). The measure of emotion must be in ordinal form (i.e., high positive, low positive, neutral, low negative, high negative), such that each cell in the grid represents the simultaneous occurrence of a unique combination of the two partners' emotional states (see Figure 5). Continuous measures can be converted to ordinal if necessary prior to analysis. The only challenging step is formatting the data appropriately for the program, but the documentation is clear and the creators of the software are very responsive to user queries.

Attractors: Stable and Recurring Emotional States. In dynamic systems theory, an attractor is a state that is recurrent and stable, a highly absorbing state to which the system returns frequently (Gottman, Swanson, et al., 2002; Granic & Hollenstein, 2003; Hollenstein, 2007). Attractors have been assessed in several ways in the literature on interpersonal emotion. The first makes use of state-space grids and considers the duration and frequency of dyadic emotional behavior in a cell or group of cells (see Figure 5B and Recommendations section). One example of this approach compared parent–child conversations for children with different subtypes of aggression (Granic & Lamey, 2002). The first group were "externalizers" who suffered primarily from an inability to inhibit impulsive behavior. The second group were "mixed" and showed problems with anxiety or depression, in addition to impulsive behavior. The conversations were rated for emotionally valenced behaviors (positive, neutral, negative, hostile), first while the dyad discussed a conflict and then after receiving instructions to "try to wrap up the conversation and end on friendly terms." These instructions were intended as a perturbation that would increase the pressure on the dyad and thereby trigger a reorganization of their joint emotional system. As predicted, prior to the perturbation, both groups concentrated their behavior in the "permissive" region of state-space, defined as the child being hostile or negative and the parent being neutral or positive. Following the perturbation, the mixed group showed a shift to the "hostile" region, with both parent and child being negative or hostile, whereas the externalizing group remained in the permissive zone. These results highlight the potential value of assessing characteristics of TIES for distinguishing between clinical subgroups that have been traditionally treated as homogeneous.

A second method for assessing emotional attractors is based on Gottman's coupled difference equations (Cook et al., 1995; Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002). The parameters of the equations are first estimated from the observed conversational behavior for a given couple. The equations are then used to calculate the null clines for the couple, which are curves for each partner in state-space (i.e., one partner's behavior on the X-axis, the other person's behavior on the Y-axis) for which their behavior is predicted to remain unchanged over time. In other words, the wife's null cline designates all behavioral states for which she would be predicted to remain the same indefinitely once she entered that state. The husband's null cline is similarly defined, and points in the state-space where the partners' null clines intersect represent dyadic attractors that, once entered, are predicted to remain stable indefinitely. Simulation studies (i.e., using the equations to simulate couples' behavior for different parameter settings) have shown that these attractor states are highly sensitive to initial conditions. In other words, the state that a couple will settle into during a conversation is likely to be highly predictable from the mood they are in at the beginning of the conversation. This would be particularly true for high inertia, high influence couples; on one day, they may be able to discuss a conflict in a very positive way, and yet the next day appear highly combative, completely dependent on the way the conversation began (Cook et al., 1995).

Recommendations for assessing attractors. There are numerous ways to assess attractors using advanced mathematical models, such as the Gottman approach. These methods are likely to require most social scientists to collaborate with someone with strong mathematical training. GridWare offers a simpler, although less sophisticated, alternative (Lamey et al., 2004). The software provides several numeric indicators that suggest an attractor is present, such as duration of time in a cell or set of cells, or the frequency of return to those cells. Those indicators can be output and used as outcome variables in subsequent regression or multilevel models.

Phase Transitions: Reconfigurations of Emotional State-Space. Phase transitions refer to changes in the structure of a dynamic state-space, such as changes in the size, shape, or location of attractors (Hollenstein, 2007). Typically, a system will go through a transformation period whereby the old configuration breaks down and a new configuration emerges. As such, the transitional period will be marked by increased variability of behavior during which the system is unstable and less predictable. This makes phase transitions potentially important for therapeutic interventions, since it is during the transition that external influences have the most likelihood of perturbing the system and bringing about fundamental structural change (Hollenstein, 2007).

Phase transitions are central to dynamic theories of human development and have been used to account for qualitative shifts in motor movement (Thelen & Smith, 1994), socio-emotional capabilities (Lewis et al., 2004), and language (Ruhland & van Geert, 1998). One study in the context of interpersonal emotion systems focused on phase transitions in family conflict over the course of adolescence (Granic, Hollenstein, Dishion, & Patterson, 2003). Parents and sons were observed during conflict conversations at five time points in a longitudinal study, starting when the boys were 9 to 10 years old and ending when they were 17 to 18 years old. State-space grids were used to assess the number of behavioral states the dyads entered and the number of transitions between states. As predicted, both measures of flexibility peaked at the ages of 13 to 14 and then decreased steadily. Similarly, the number of visits to the mutually negative-hostile zone also increased during the ages of 13 to 14 but, unlike the flexibility measures, continued to increase at 15 to 16 and only dropped off later. Thus, parents and sons engaged in more conflict and were more variable during the transition period, but their patterns of conflict became more stable following the transition, which is in accord with theories of adolescence that characterize it as a time of reorganization and qualitative changes in socio-emotional functioning.

Phase transitions have also been used to explain divorce (Gottman, Murray, et al., 2002; Gottman, Swanson, et al., 2002). Simulation studies using Gottman's coupled difference equations have shown that it is possible to slowly change the parameters of a couple's model in such a way that the couple may lose all positive attractor basins and be left with only negative ones. Once this occurs, every conversation is destined to end badly. This model is in accord with extensive research suggesting that divorce follows a long cascade of negative reciprocity, emotional flooding, increased distancing, and increased loneliness and vulnerability to alternate relationships (Gottman, 1994; Gottman et al., 1998; Gottman & Levenson, 1992). Each change appears to be small and the couple may assume that they are just going through a temporary bad spell. It is unfortunate that if the changes cumulate in a reorganization of their emotional state-space, then the marriage will suddenly become fundamentally different, and potentially unworkable, with no stable positive states.

Recommendations for assessing phase transitions. As with attractors, phase transitions can be assessed either with mathematical modeling approaches similar to Gottman's or with state-space grids using GridWare. The focus of the analysis would be on showing changes in the indicators of attractors over time. This can be accomplished by using the indicators as outcome variables in a multilevel model in which they are predicted from time. A significant effect of time would show that the indicators of the attractors have changed over time, suggesting that a potential phase transition has occurred.

Entropy: Predictability of Emotional Patterns. Entropy was initially conceptualized in the context of information theory and is a measure of organization or predictability (Shannon & Weaver, 1949). Transitions between events are conceptualized as units of information. Systems can range from highly ordered, predictable events (low entropy) to very complex, uncertain patterns of events (high entropy). A low entropy system is a low information system, because there is a limited number of unique sequence types. A high entropy system, on the other hand, contains greater information because there are more forms of event sequences. In essence, in a low entropy dyad, little information is required to predict Partner B's reaction to Partner A, because Partner B tends to respond to Partner A in a highly patterned manner. In contrast, in a high entropy dyad, knowing about Partner A's action tells us very little about Partner B's likely reaction.

Entropy in interpersonal emotion systems has not received much empirical attention, however, one study shows its utility for predicting long-term outcomes from current interpersonal dynamics (Dishion, Nelson, Winter, & Bullock, 2004). Adolescent boys were videotaped interacting with a friend at ages 14, 16, and 18. Early onset antisocial boys' conversations were characterized by less organization (higher entropy) and higher levels of deviant talk than were the conversations of well adjusted boys, suggesting both low social skills (i.e., the inability to maintain conversational organization) and an attraction to deviant content. This finding was qualified, however, by an interaction of entropy and deviant talk, such that boys who showed a combination of greater organization (low entropy) and more deviant talk were the most likely to continue their antisocial behavior into adulthood. Thus, it was the boys who could organize their conversations in a patterned way around deviant topics who were most likely to show a stable pattern of antisocial behavior.

Recommendations for assessing entropy. There is an extensive mathematical literature on entropy, but most social scientists will need to collaborate in order to make use of the methods (for a reference book targeted at psychologists, see Heath, 2000).

General Guidelines for TIES Research

This review has considered the characteristics of TIES that have received the most empirical investigation. Other characteristics no doubt exist and await study. No characteristic of TIES is inherently good or bad for interpersonal emotional functioning, as can be seen from the empirical examples reviewed. Rather, it depends on the relationship context and which emotions are involved. The starting point for any investigation, therefore, should be a theory about the functioning of interpersonal emotions systems that can guide decisions about study details, such as the type of relationship to be investigated, which emotional components to assess, what time frame is most relevant (minutes, hours, days, years), and which characteristics of TIES to focus on. Regardless, data should be collected repeatedly over time (in general, the more observations the better) from at least two people in a relationship or social interaction. If your theory emphasizes homeostatic processes, whereby relationship partners' joint emotional state oscillates around a stable level, then you will want to focus on synchrony. If, however, you are more concerned about partners' emotions affecting each other and resulting in an altered emotional state for one or both of them, then you will want to assess one of the morphogenic covariation patterns (transmission/contagion, reciprocity, etc.). Theories about complex forms of coordination suggest an emphasis on coupling, whereas a pattern of increasing similarity of emotions suggests convergence. If the emphasis is on how rigid or variable the system is, then you should assess inertia or flexibility. Finally, if you are interested in the stability and recurrence of emotional states, then assessing attractors and phase transitions will be most relevant. As reviewed above, most of these characteristics can now be assessed relatively easily with existing software, although a few require more extensive mathematical training or collaboration with scientists in other fields.

Directions for Further Research

This review is not intended to be exhaustive, and yet even this partial sampling of prior research on temporal interpersonal emotion systems demonstrates the breadth of phenomena incorporated by the topic. TIES are relevant for every type of human relationship, including parent–child, adult romantic, therapist–client, families, work groups, peer groups, and enemies. Whenever people come together in close interaction, TIES are formed. Once this occurs, understanding the interpersonal processes and outcomes that emerge demands a knowledge of the dynamic principles and characteristics of interpersonal emotion systems. The research reviewed here has taken the first steps toward this goal, but much is left to be done. The tools for collecting and analyzing multivariate data from several people at once, with high temporal precision, have only recently become tractable for social scientists. As such, the existing research represents early forays into new territory, but inroads have been made and the way has been cleared for a systematic, integrated field of research on TIES.

Given the relatively recent nature of most research on TIES, it is not surprising that the field is fragmented, with any given study focusing on a particular characteristic of TIES, in a specific relationship context, and usually on only one aspect of emotion (physiology, appraisal, behavior, experience). Very little systematic work exists whereby a characteristic of TIES is investigated across relationship types, or across developmental periods, or the interplay of multiple TIES characteristics is considered, or the various emotion channels are considered in unison. This fragmentation is exacerbated by the lack of agreement on terms and nomenclature, making it difficult to integrate findings from across the field. One clear example of this is the term *coregulation*, which has been used to refer to emotional covariation (both concurrent and lagged), transmission, coupling, and reciprocity of both negative and positive emotional experience, expressive behavior, and autonomic physiology (Randall & Butler, under review-b). The purpose of the present review is not to argue for the terminology proposed here but rather to encourage researchers to work toward an agreed upon language for describing and referring to the characteristics of TIES, and the interpersonal processes that emerge from them, to provide a coherent basis for scientific dialogue.

One issue that demands more systematic research is that covariation or coupling of different emotional valence combinations likely represent different underlying mechanisms, but most research considers only a limited set of possibilities. For example, the transmission of emotion may take the form of negative escalation (one partner's negative emotion increasing the other partner's negative emotion), positive escalation (one partner's positive emotion increasing the other partner's positive emotion), dampening (one partner's negative emotion reducing the other partner's positive emotion), and soothing (one partner's positive emotion reducing the other partner's negative emotion). Gottman and his colleagues have made some efforts to draw these distinctions, but further work is needed to compare and contrast these processes, especially since some may contribute to well-being, whereas others are destructive (Gottman et al., 1998).

A related question is under what circumstances tighter emotional covariation or coupling represents healthy versus unhealthy functioning. One possibility is that interpersonal linkages that contribute to the up-regulation of positive emotions and the down-regulation of negative ones are desirable, whereas the reverse is harmful (Butner et al., 2007). Another possibility is that the timescale is important. For example, interpersonal transmission of negative emotion may be stressful and uncomfortable in the short term but may allow for conflict resolution and mutual understanding in the longer term. Similarly, the specific emotion that is transmitted may matter. Although escalating anger may undermine relationships, sharing another person's anxiety may enhance interpersonal bonds. A related issue is seen in the literature on physiological linkage, where it appears that either conflict or empathy can contribute to tighter interpersonal covariation. It is unfortunate that no research systematically considers both possibilities in tandem, and so it remains unclear how the two mechanisms relate to each other, when one or the other is more likely to operate, and whether they produce differential health effects.

More general, the question has been raised as to whether strong interpersonal patterning of behaviors or emotional experience is a good or bad thing (Cappella, 1988; Dishion et al., 2004; Warner, 1992). On one hand, tight linkages increase predictability and help to coordinate interpersonal exchanges. On the other hand, they reduce flexibility and can result in an interpersonal system that is stuck in a limited set of potential sequences. Again, as with the issue of emotional valence, it is likely that the behavioral content or meaning of the patterned sequence matters. Being stuck in a conflict has very different implications from being stuck in a pattern of mutual support. In addition, probably neither extreme patterning nor complete unpredictability are optimal for health and well-being. Research that systematically investigates entropy, or flexibility, across the full range of these dimensions is needed to better understand what levels are most desirable, under what circumstances, and in what types of relationships.

Three large unaddressed questions about TIES that demand more systematic research are those of developmental trajectory, cross-cultural differences, and groups larger than dyads. Fairly extensive literatures exist concerning characteristics of TIES in parent–infant, parent–child, peer, and adult romantic relationships, but these research programs rarely address each other. As such, questions of continuity and change in the functioning of TIES across the lifespan remain unanswered. Similarly, although extensive research exists on cross-cultural similarities and differences in both emotions and relationships, there is almost no research comparing characteristic of TIES across cultural contexts (for exceptions, see Larson, Verma, & Dworkin, 2001; Randall et al., under review). This is a critical gap, given our increasingly multicultural society and the importance of understanding cultural nuances for developing successful health interventions. Finally, in theory, TIES form not only in dyads but also in larger groups of people if they interact in some way. For example, Coleman (2007) has hypothesized that intractable large-scale conflict, such as war, can be described as an attractor that is maintained at least partially by emotional processes. Although this is an interesting possibility, it remains to be empirically tested.

Another important direction for further research is to develop and test interventions to improve relationships and health, based on an understanding of TIES. Multiple authors have argued for the importance of TIES in the development and maintenance of psychopathology. For example, emotional convergence between social partners has been argued to contribute to affective disorders such as depression (Anderson et al., 2003). Similarly, the development and stabilization of problematic within-person and between-person attractor basins may contribute to interpersonal psychopathologies such as aggression and antisocial behavior (Granic & Patterson, 2006; Snyder et al., 2003), whereas the loss of positive interpersonal attractors may result in relationship breakdown and divorce (Gottman, Murray, et al., 2002). As such, interventions that target characteristics of TIES, such as emotional convergence, attractors, and flexibility, may have broad efficacy across a range of relational and emotional problems.

Systematically tackling the complexities of TIES may benefit from a greater use of experimental manipulations. Much of the existing research has adopted a correlational, essentially descriptive, approach. This has been appropriate, given the early nature of the research and the complexity of the topic. However, there now exists enough baseline work to warrant more targeted research tools. The dearth of controlled manipulations may also be due to an assumption that an experimental approach must decompose a phenomenon into an additive set of factors, which is clearly not appropriate for studying a dynamic system in which nonlinear, emergent properties not only are possible but are in fact the target of interest. Perturbation experiments, however, offer an alternative that combines the power of systematic, controlled manipulations with the ability to appropriately address the multivariate, emergent nature of dynamic systems (Granic & Hollenstein, 2006; Hayes, Laurenceau, Feldman, Strauss, & Cardaciotto, 2007). The basic framework is to observe a system in its homeostatic baseline state, then to affect the system with some external manipulation (the perturbation), and finally to observe the transition period and new emergent state of the system. The transition period is expected to be especially important for understanding the underlying system dynamics because it is during that period that the organization and factors inhibiting or enhancing change are most apparent. This method is also useful for investigating the effects of preexisting differences between dyads on resulting system dynamics.

Finally, one critical area that must be advanced if we are to continue to develop our understanding of TIES is that of analytic methods. Numerous appropriate models have recently become available and tractable for social scientists and have been reviewed in this article. Essentially all of these models are bivariate, however, with only one emotion channel represented for each of two people. Thus, the development of readily usable multivariate models is one crucial research target. As the complexity of the models increases, advancing the field may require increasing collaboration between social and computational scientists. For example, several recent articles have reported on the use of Bayesian hierarchical state-space models (Lodewyckx et al., in press) and hierarchical Ornstein-Uhlenbeck models (Kuppens, Oravecz, & Tuerlinckx, under review) for investigating within-person emotional dynamics. Such models are commonly used in engineering and computer science and could be extended to accommodate multivariate interpersonal emotional dynamics, but the implementation is beyond the abilities of most social scientists. As such, one way to advance the field of TIES will be to form TIES across disciplines.

Concluding Comment

When something happens, externally or internally, that may be relevant for your goals or well-being, changes in autonomic physiology, cognitive appraisals, expressive behavior, and subjective experience start to occur. Feedback across these emotional components tailors and coordinates a full-body response to optimally meet the evolving situational demand. The resulting emotional state constrains further feedback within the system, channeling the components of emotional responding in a loosely coupled temporal pattern. If this occurs in the presence of another person, and especially if it involves interaction with that person, feedback will begin to occur not only within you but between yourself and that other person as well. At that moment, a temporal interpersonal emotion system will have been formed. Diverse existing research demonstrates that the characteristics of that system, such as between-person synchrony of emotion channels, transmission, convergence, escalation and de-escalation of emotional states, flexibility, and inertia, contribute to developmental, relational, and health outcomes as diverse as learning language, divorce, and quitting smoking. It is an exciting time, because the methodological and analytic tools for studying TIES are rapidly becoming readily available, setting the stage for an explosion of systematic scientific efforts to uncover the mechanisms, constraints, and nuances of TIES that give rise to so many outcomes with relevance to personal, interpersonal, and societal well-being.

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