there between the whole system and its parts, and no special form of causality needs to be invented to enforce them.

Obviously, something special *is* going on in self-organizing systems. Unlike cars, self-organizing systems can "spontaneously" go from unordered regimes to ordered regimes that have surprising complexity, without any obvious, external instruction or programming agency – and this type of behavior may be very relevant for understanding cognition. However, there are already many appropriate concepts to describe what is special about it: self-organization, emergence, phase transitions, attractors, nonlinearities, and so forth. There is no need or justification for invoking a special kind of causality here (circular causality), as distinguished from normal causality.

One might agree with this argument in principle, but not see the relevance beyond a philosophical discussion of fairly arbitrary definitions and semantics. Unfortunately, however, the concept of circular causality leads to identifiable problems in scientific practice, both in Lewis's target article and in other work.

The main problem is that circular causality suggests an interaction between separable entities which does not exist. At worst, this leads to suggestions of Cartesian dualism: "circular causality has been identified between superordinate mental states (e.g., attention, expectancy) and subordinate neural events" (sect. 4, para. 2). At best, it becomes very difficult for the reader (and the author) not to confound circular causality, which according to the definition is about parts and wholes of a *single* system, with "bidirectional" or "reciprocal" causality, which refers to the mutual interaction (feedback) between *different* systems (e.g., sects. 1, 2.4, 3.1–3.3, 4.1, 4.2, 5.1, 5.3, 6.1, 6.2, 7). Not surprisingly, this is particularly apparent when the situation being considered is one of interaction between systems located at different levels of the brain hierarchy or neuroaxis: "Vertical integration could instantiate circular causality at the whole-brain level, thus providing an additional mechanism of neural integration" (sect. 5.3, para. 2). Here it is hard not to interpret this as putting on a par, on the one hand, vertical integration, which refers to connecting systems at different levels of the brain hierarchy through bidirectional feedback loops, and, on the other hand, circular causality, which refers to different levels of analysis of a single system.

All this makes it difficult to determine what exactly are the claims put forward by Lewis, and what scientists should do to verify the claims. Should experimentalists start looking for mechanisms that realize circular causality in the brain? Should theorists start developing mathematical theories that describe formally how circular causality operates in the brain? This commentary argues that circular causality cannot and will not be found in the brain, no matter the amount or the sophistication of experimentation. And mathematical formalization of the proposed self-organizing emotion/appraisal system (or any self-organizing system) should reveal immediately that the relationship between parts and the whole form is not properly understood as causal. For instance, the equations governing the parts of a self-organizing system do not need, as input, variables describing the whole form; instead, they depend only on variables describing other parts. This is why the system is self-organizing in the first place. In general, this highlights the value of providing, together with a conceptual theory, corresponding equations that clarify the concepts and make them precise.

In summary, circular causality is a concept that does not make sense, does not add anything to the theory, and leads to problems in scientific practice. Therefore, it should be discarded. In Lewis's article, the concept of circular causality unfortunately distracts and takes away from his otherwise comprehensive, novel, and important contributions.

Psychological-level systems theory: The missing link in bridging emotion theory and neurobiology through dynamic systems modeling

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Abstract: Bridging between psychological and neurobiological systems requires that the system components are closely specified at *both* the psychological and brain levels of analysis. We argue that in developing his dynamic systems theory framework, Lewis has sidestepped the notion of a psychological level systems model altogether, and has taken a partisan approach to his exposition of a brain-level systems model.

Dynamic systems theory (DST) has produced some elegant modeling solutions in well-constrained contexts and the general concepts and principles involved naturally invite generalisation to emergent "macroscopic unities" such as schemas, expectancies, scripts, or intentions (e.g., Kelso 1995). We therefore have considerable sympathy with Lewis's endeavour to use DST as a tool to explore integration across psychological and neurobiological systems through focusing on the dynamics of discrete emotion episodes.

There appear to be a number of sequential steps in the development of Lewis's argument. First, he adopts a particular model of the psychological processes implicated in emotion with his focus on "emotional interpretations (EIs)." Second, he proposes that EIs emerge as a result of a dynamic interaction between a number of separable "global" appraisal (e.g., perception, attention, evaluation) and emotion (e.g., arousal, action tendency) components (Lewis's Fig. 1). Third, he proposes that psychological levels of explanation cannot move beyond descriptions of the problem space in terms of these global components and, consequently, "the psychological level of description has little more to offer" (sect. 3.4). Finally, he sets out to overcome these purported limitations at the psychological level by endeavouring to reconceptualise these appraisal and emotion components at the level of neurobiology, within a DST framework. As it stands we feel there are significant issues concerning each step of this argument; however, here we focus on the third and the final steps.

Lewis's contention that the psychological level of explanation has reached the end of its shelf life seems premature. The psychological level of description is perfectly capable of "filling in the detail" beyond the level of global components (such as attention or arousal). For example, there exist a range of modeling strategies that can fulfil this role in which properties of processing resources, varieties of mental representation, and/or mental coding attributes are specified in detail. In other words, there are modeling approaches that can provide a *systems account* at the psychological level rather than just a description in terms of global components. Though additional work may be required to extend some of these approaches, such as ACT-R (e.g., Anderson et al. 2004), into the domain of emotion (e.g., see Belavkin 2001; Dalgleish 2004a; Teasdale & Barnard 1993), others already address both cognitive and motivational elements (e.g., Bond 1999). Furthermore, these system-level accounts are open to more formal specification using process algebra (Barnard & Bowman 2003) or even formal logic (Duke et al. 1998).

The essential point here is that if we are to map effectively between comprehensive psychological accounts and neural subsystems, we need to be quite explicit about how to decompose specific processing components, such as those identified by Lewis, at *both* the level of psychological systems analysis and brain-level system analysis. Without the support of explicit system models at a psychological level that endeavour to provide an analysis of what the "elements" of attention, evaluation, memory, or emotion are, DST is stuck with having to map these rather poorly specified global components onto putative brain circuits. This approach

https://doi.org/10.1017/S0140525X05240049 Published online by Cambridge University Press

leaves substantial scope for ambiguities in relating the behaviour of neural circuits to psychological indices.

Turning now to this mapping exercise, in terms of the neurobiology of emotion, Lewis follows a particular trajectory from perception (sect. 4.2.1) through to feelings and consciousness (sect. 4.3.4). Understandably, this specific treatment of the anatomy and function of neural mechanisms follows the theoretical schema of Lewis's Figure 1. He then concludes (sect. 4.4) that each appraisal and emotion component "defined at a psychological level, becomes a distributed system in itself, or even a collection of fairly distinct systems, when analyzed at the neural level." This, then, is the systems model at the level of the brain. It is the interaction of these neural "parts" that Lewis then seeks to conceptualise in terms of DST. Our problem with this exercise is that Lewis has ended up with a particular brain-level systems account which seems to ignore the numerous other systems accounts in affective neuroscience (see Dalgleish 2004b).

For example, many affective neuroscientists, beginning with Schneirla (1959), have proposed that emotions can be conceptualised in terms of "approach" and "withdrawal," though they often use different terminology and propose different neuroanatomical substrates for each component – for example, behavioural activation and behavioural inhibition systems (Cloninger 1987; Gray 1982); approach and withdrawal systems (Davidson et al. 1990); and appetitive and aversive systems (Lang et al. 1990). Others (e.g., Rolls 1990; 1999) have conceptualised emotions in terms of states elicited by positive (rewarding) and negative (punishing) instrumental reinforcers, within a dimensional space. Yet others have argued for a neo-Darwinian categorical account where a small set of discrete emotions is underpinned by relatively separable neural systems (Calder et al. 2001; Damasio et al. 2000; Izard 1971; Panksepp 1982; Tomkins 1982). In our view, any brain-level systems model needs to demonstrate that it can offer a convincing account of the profiles of data underpinning these other approaches before they can be set aside.

In summary, the likely success of any bridging operation between psychological and neurobiological systems will rest on how well the components of these systems are specified at both the psychological and brain levels of analysis. Lewis has made an important start down this road. However, we suggest that in developing his DST framework, Lewis has sidestepped the notion of a psychological-level systems model altogether and has taken a somewhat partisan approach to his exposition of a brain-level systems model. Further progress, we feel, will depend at least in part on addressing these issues.

Adding ingredients to the self-organizing dynamic system stew: Motivation, communication, and higher-level emotions – and don't forget the genes!

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Abstract: Self-organizing dynamic systems (DS) modeling is appropriate to conceptualizing the relationship between emotion and cognition-appraisal. Indeed, DS modeling can be applied to encompass and integrate additional phenomena at levels lower than emotional interpretations (genes), at the same level (motives), and at higher levels (social, cognitive, and moral emotions). Also, *communication* is a phenomenon involved in dynamic system interactions at all levels.

In his target article, Marc Lewis points out problems inherent in appraisal approaches to emotion that employ linear causality and traditional cognitivist assumptions. Such approaches often ignore the demonstrated influences of emotion upon cognitive processes, even such relatively "primitive" cognitive processes as perception and attention. The application of self-organizing dynamic systems (DS) modeling to the appraisal-emotion interaction draws upon more recent cognitive approaches to conceptualize appraisal itself as a coherent higher-order unity that emerges in real time from the spontaneous coordination and synchronization of constituent elements. Emergent order and coherence, as well as increasing complexity, can arise based upon interactions among system elements involving patterns of nonlinear causation. Nonlinear causative processes include *feedback* – both positive feedback fostering growth and change, and negative feedback fostering stability and equilibration – as well as *circular causality*, which is bidirectional causality between levels of a system. Lewis applies this reasoning to the analysis of emotion-appraisal amalgams, or *emotional interpretations* (EIs), in which the constituent elements of emotion include arousal, attentional orientation, feeling tone, and action tendency, whereas the constituent elements of cognition are perception, evaluation, attention, memory, and reflection. These are aroused by a triggering event, and Lewis provides an example of a road-rage episode where initial anger and frustration are elaborated to involve feelings of helplessness, unfairness, shame, and humiliation, which in turn motivate extreme action. Lewis's DS approach is valuable in that it directs our attention away from traditional issues in the field which have become unproductive, such as the question of the "primacy" of emotion or cognition, to new and important issues: the nature of the constituent elements, how they interact, and at what level they function.

In conceptualizing dynamic interactions between elements, it is often useful to explicitly recognize that such interactions involve *communication*, and communication involves specific components – sender, channel, receiver, message, feedback – that may be usefully distinguished. Communication is a phenomenon at all levels of interaction within and between dynamic systems: from atoms, molecules, genes, to the EI level considered in this target article, to higher-order entities. As it is, Lewis's article is a largely "inside-the-head" account that arguably does not explicitly recognize the expressive and communicative functions of emotion. For example, display is not considered as a constituent element of emotion. This does not deny the value of the DS approach but rather suggests its application to a whole new, interpersonal, social, and communicative realm that is actually implied in Lewis's account. For instance, in his road rage example, some elements of the response involve emotion systems with a relatively clear biological basis (fear, frustration, anger), which may indeed be expected to interact relatively directly at a biological level and to be related to relatively specific neurochemical systems in the brain. Other elements of the response of the angry driver involve higher-level social, cognitive, and moral emotions (feelings of unfairness, shame, and humiliation) that require a relatively long period of socioemotional learning and development to become maturely experienced and expressed (Buck 1999).

An important aspect of Lewis's argument, related to the biological versus higher-level emotion distinction, is his contention that the constituent elements or "parts" that interact in self-organizing EI states should be neural entities. I fully agree in the case of biological emotions, but a consideration of the communicative aspects of emotion suggests complexities. For instance, it is noteworthy that in the road rage example the display of the other driver was presented as a triggering event for shame and humiliation. Specific emotion displays, such as facial expressions, vocal qualities, postures, and even pheromones, may be expected to constitute particularly specialized and effective triggers of specific EIs, resulting in a communicative process where the relevant elements are not only within the sender and/or receiver, but in their personal and social relationship as well. In many respects, this consideration takes the analysis of the elements of EIs outside the brain. Nevertheless, neural entities continue to constitute critical

https://doi.org/10.1017/S0140525X05240049 Published online by Cambridge University Press