here a contrastive approach between perception and reception (Taylor 1999) – Lehar goes down the beaten track of thinking about consciousness as some kind of a substance that is present in all matter, although sometimes in watered-down form. The conclusion of this line of reasoning is absurd: protoconsciousness of soap bubbles.

Of course, because the concept of consciousness is not defined, one may try to extend it to all matter, but talking about stomachs being "conscious" leaves no semantic overlap with the word "conscious" applied to a baby, or to a cat. If consciousness is a function and plays a functional role, as Lehar seems to believe ("It seems that conscious experience has a direct functional role" – sect. 6.5, para. 10), the inescapable conclusion is rather that not all brains are equal. Language is unique to humans, and even though one can extend the concept of language to some more primitive forms of communication, interaction between internal organs of the body or messages passing between components of a computer system is not the same "language" as natural languages. The difference between a "field" in agriculture and "field" in physics is comparable to the difference between animal "consciousness" and "consciousness" of a soap bubble due to the physical forces that determine its shape. We should not be deceived by words.

7. It remains to be seen if the main contribution of the target article, the Gestalt Bubble model, will be useful for understanding or even for a description of perception. The goal of science is not modeling per se but rather explaining and understanding phenomena. Modeling perception should not become an exercise in computer graphics, creating volumetric representations of space and objects. Bubbles of neural activity, as presented by Taylor (1999), have real explanatory power and are amenable to empirical tests. The perceptual modeling proposed by Lehar promises a new language to describe high-level visual perception. Any language that is useful in design and analysis of experiments must reflect more basic neural processes. Nothing of that sort has been demonstrated so far, and it is doubtful that the Gestalt Bubble model can explain observations that have not been hidden in its premises.

Empirical constraints for perceptual modeling

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Abstract: This new heuristic model of perceptual analysis raises interesting issues but in the end falls short. Its arguments are more in the Cartesian than Gestalt tradition. Much of the argument is based on setting up theoretical straw men and ignores well known perceptual and brain science. Arguments are reviewed in light of known physiology and traditional Gestalt theory.

Steven Lehar's article purports to present a new model of perception based on Gestalt principles. Lehar raises some interesting issues but in the end falls short of his claims. His heuristic model is more Cartesian than Gestalt and much of his argument is based on setting up straw men. He ignores much of what is known in perceptual and brain science. I will confine myself to these issues, although there are others.

Lehar maintains the Cartesian mind-body distinction and assumes internal representation as a requirement. He also ignores the distinction between conscious perception as active construction and the perception/action continuums implied by physiology and direct perception data. Lehar recycles the Cartesian machinelike body now inhabited by the "ghosts" of mental representations and computations. This dualism is at odds with traditional Gestalt theory (Köhler 1969).

The target article ignores the contemporary distinction between (1) perceptual mechanisms that subserve action; and (2) the cognitive mechanism of recall and analysis; instead, it suggests the latter as the sole perceptual mechanism. This emphasis stems from Lehar's belief that "introspection is as valid a method of investigation as is neurophysiology" (sect. 2.3, last para.). This is not the position of traditional Gestalt theory, which states that "a satisfactory functional interpretation of perception can be given only in terms of biological theory" and warns that "The value of biological theories in psychology is not generally recognized." Gestalt psychology adopted the program of building bridges between psychological rules and the activities of the central nervous system (Köhler 1940; 1947; 1961). Köhler recognized this task as "beyond present *technical* possibilities." These purely technical limits are being overcome today, yet the target article ignores a large body of empirical physiological evidence, some of which is presented below (see also Milner & Goodale 1995 and Gallese et. al. 1999 for summary of some areas). Although we should not limit our theories to physiology, theory must account for known physiology. The target model does not. To take a specific example, the model ignores the important role of eye movements even though they were of concern to the early Gestalt theorists (Koffka 1935) and are a critical part of contemporary perceptual theory (Ebenholtz 2001). More generally, there is ubiquitous evidence, collected over many decades, for the important role of physiological systems in perception. Simply consider the differential perceptions resulting from anatomical and physiological states of sensory end organs. Visual perception in the myopic, dark-adapted, or macular-degenerated eye is more influenced by anatomy and physiology than by computations on a mental image.

Lehar emphasizes computational neuroscience at the expense of known physiology despite his assertion that "most fundamental principles of neural computation and representation remain to be discovered" (sect. 2.4, para. 3). This leads to oversimplification to the point of error. For example, he dismisses direct perception because "No plausible mechanism has ever been identified neurophysiologically which exhibits this incredible property" (sect. 2.2, para. 3) and "all that computational wetware" (sect. 2.1, para. 2) must serve some "purpose" (i.e., "produce an internal image of the world"; sect. 2.1). Yet there is growing physiological evidence to the contrary. As I have discussed elsewhere (Fox 1999), area MST in monkeys (similar to area V5 in humans) shows cells that are responsive to three-dimensional motion information that is characteristic of the type of flow field emphasized by direct perception theory (Duffy & Wurtz 1995; 1997a; 1997b). More recently, direct perception theorists have examined the relation of neural information systems to Tau, a property of environmental optics (Grealy 2002; Lee et al. 2002). Hence, contemporary physiology supports an emerging model suggestive of an environmentally adapted physiology rather than the metaphor of representational/computational "wetware."

Lehar further misrepresents direct perception theory as describing perception "as if perceptual processing occurs somehow out in the world itself rather than as a computation in the brain" (sect. 2.1, para. 1). Using the term "perceptual processing" or "computation" is a serious misrepresentation of direct perception (Gibson 1966; 1979), regardless of where one attributes it. Gibson contends that the perceptual system is sensitive to "affordances" that are naturally occurring and require no processing but rather are directly perceived. The exact characteristics of affordances are disputed, but a recent paper (Chemero 2003) provides a critical analysis and comprehensive definition of the concept of affordances and makes it very clear that affordances are perceived relations that are dynamic but neither computed nor components of computations. This is consistent with the physiology described above.

Gestalt psychology is also misrepresented as a representational/computational approach. I content that a key – perhaps *the* key – insight of Gestalt theory is that adequate knowledge of wholes, such as objects, comes from observing wholes. Such understand-

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ing does not come from a "humpty-dumpty" approach that tries to put the object "back together again" through computation. The target model is reductionist/empiricist and, as such, is contrary to Gestalt theory (Koffka 1935; Köhler 1947). The relevant properties of things are not computational properties superimposed on the object system, but rather, the intrinsic relational properties within the object and between the object and the perceiver/actor (Köhler 1947). For example, Köhler certainly did not suggest that perception is a mental computation when he wrote: "While climbing once in the Alps I beheld . . . a big dark cloud . . . nothing could be more sinister and more threatening. . . . the menace was certainly in the cloud." The menace stems not from computations on mental images but from physiological sensitivity to relations among environmental physical energies, and between these relations and the state system of the observer/actor. I suggest a dynamic, person-environmental mechanism rather than internal representation and computations. This is consistent with the Gestalt statement: "rules in which we formulate (functional, psychological) relationships imply occurrences of certain functions in a realm that is surely not the phenomenal realm" (Köhler 1940).

A final, critical point concerns isomorphism: Isomorphic relations are ubiquitous, so one needs to be specific. Gestalt "Psychophysical Isomorphism" is a hypothesis that rejects Cartesian dualism and is informed by physiology (Köhler 1969). Lehar, using a digital computer metaphor, suggests a point-to-point isomorphism between the internal image and external objects/space. However, this is not supported by physiology. Cells in the supplementary eye field of the monkey show firing patterns (Olson & Gettner 1995) that do not encode visual space in any one-to-one manner. Rather, they incorporate higher dimensions of information such as attention or purpose (Fox 1999). Hence, even if we accept isomorphic, internal representations, there is neurophysiologic evidence that such representations are more complex than suggested in Lehar's model.

The target model does not accomplish its ambitious goals of presenting a modern Gestalt perceptual model. A more fruitful heuristic for understanding perception is a physiology that has evolved a sensitivity to meaningful environmental relational information, or, as suggested by Clark (1998), one that represents action-oriented systems.

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Linking visual cortex to visual perception: An alternative to the Gestalt Bubble

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Abstract: Lehar's lively discussion builds on a critique of neural models of vision that is incorrect in its general and specific claims. He espouses a Gestalt perceptual approach rather than one consistent with the "objective neurophysiological state of the visual system" (target article, Abstract). Contemporary vision models realize his perceptual goals and also quantitatively explain neurophysiological and anatomical data.

Lehar describes a "serious crisis," "an impasse," and a "theoretical dead end" (target article, sect. 1, para. 1) in contemporary models of vision and advances as a possible alternative his Gestalt Bubble approach, "which is unlike any algorithm devised by man" (Abstract). He also claims that "Gestalt aspects of perception have been largely ignored" (sect. 1, para. 3) by neural models of vision, and then goes on to describe presumed dichotomies between equally desperate attempts to understand how the brain sees. Lehar particularly comments about modeling work by my colleagues and myself, noting that "the most serious limitation of Grossberg's approach . . . is that, curiously, Grossberg and his colleagues did not extend their logic to . . . three-dimensional spatial perception [and] . . . no longer advocated explicit spatial filling-in" (sect. 3, para. 5). He also says it is "impossible for Grossberg's model to represent transparency" (sect. 3, para. 5). These general and specific claims unfortunately do not accurately represent the published literature about neural vision models. Lehar seems motivated to trash neural vision models because his own model makes no contact with neurophysiological and anatomical data about vision.

In reality, there is an emerging neural theory of three-dimensional vision and figure-ground perception called the FACADE theory, for the multiplexed Form-And-Color-And-DEpth representations that the theory attempts to explain (Grossberg 1987; 1994; 1997). Lehar refers to my 1994 article in summarizing the deficiencies of our models. However, this article explains many three-dimensional figure-ground, grouping, and filling-in percepts, including transparency, and uses an explicit surface filling-in process. Later work from our group has developed these qualitative proposals into quantitative simulations of many three-dimensional percepts, including three-dimensional percepts of da Vinci stereopsis, figure-ground separation, texture segregation, brightness perception, and transparency (Grossberg & Kelly 1999; Grossberg & McLoughlin 1997; Grossberg & Pessoa 1998, Kelly & Grossberg 2000; McLoughlin & Grossberg 1998).

These studies laid the foundation for a breakthrough in understanding how some of these processes are organized within identified laminar circuits of cortical areas V1 and V2, notably processes of cortical development, learning, attention, and grouping, including Gestalt grouping properties (Grossberg 1999a; Grossberg & Raizada 2000; Grossberg & Seitz 2003; Grossberg & Williamson 2001; Grossberg et al. 1997; Raizada & Grossberg 2001; 2003; Ross et al. 2000).

This LAMINART model has been joined with the FACADE model to develop a three-dimensional LAMINART model that quantitatively simulates many perceptual data about stereopsis and three-dimensional planar surface perception, and functionally explains anatomical and neurophysiological cell properties in cortical layers 1, 2/3A, 3B, 4, 5, and 6 of areas V1 and V2 (Grossberg & Howe 2003; Howe & Grossberg 2001), using three-dimensional figure-ground and filling-in concepts to do so. More recently, the three-dimensional LAMINART model has been generalized to explain how three-dimensional percepts of slanted and curved surfaces and of two-dimensional images are formed, and to clarify how three-dimensional grouping and filling-in can occur over multiple depths (Grossberg & Swaminathan 2003; Swaminathan & Grossberg 2001). This work includes explanations of how identified cortical cells in cortical areas V1 and V2 develop to enable these representations to form, how three-dimensional Necker cube representations rival bi-stably through time, how slant aftereffects occur, and how three-dimensional neon color spreading of curved surfaces occurs even at depths that contain no explicit bottom-up inputs. All these studies are consistent with the grouping interpolation properties that Kellman et al. (1996) have reported (p. 51), and with the three-dimensional grouping properties summarized in Lehar's Figure 16, which he seems to think cannot yet be neurally explained.

These modeling articles show that many of the perceptual goals of Lehar's Gestalt Bubble model are well handled by neural models that also provide a detailed account of how the visual cortex generates these perceptual effects. In summary, we do not need analogies like the soap bubble (sect. 8.2), or rod-and-rail (sect. 8 and Fig. 6), or different local states to represent opaque or transparent surface properties, as Lehar proposes. The brain has discovered a much more interesting solution to these problems, which links its ability to develop and learn from the world with its ability to see it.

Lehar makes many other claims that are not supportable by present theoretical knowledge. He claims that "we cannot imagine