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ABSTRACT
On the 50th anniversary of its publication, we look back on some of the intellectual contributions of Gibson's (1966) *The Senses Considered as Perceptual Systems*. This work is often seen as contributing a new perspective to our understanding of the 5 senses. In this paper, we explore another intellectual contribution: Gibson's treatment of perception–action as an irreducible, functional system. We review select examples of systems thinking from the physical, animal, and human social domains. Our suggestion is that a systems-level approach to social interactions would have been a natural extension of Gibson's ideas.

In *The Senses Considered as Perceptual Systems* (1966), Gibson introduced the idea that perception needs to be understood in the context of the supporting motor apparatus. This suggestion continues to have far-reaching impact on research in perception and action. Inherent in his ideas is the need for a systems perspective to understand perceiving and acting. Such an idea can be traced back to the Gestalt school, with the well-known claim that the whole is different from the sum of the parts. In fact, Köhler, who was a student of the physicist Max Planck, identified systems as providing the connection between psychological experience and physiological processes: "The relation between the two orderly systems will be simple and clear only if we postulate that both have the same form of structure *qua* systems" (Watson, 1979, p. 299). Gibson's suggestion was much more radical than Gestalt psychology in that the system of interest encompassed not just the visual mode of perception but also multiple modalities supported by multiple types of movement. In that sense, we already see the emergence of a global system, a person, from the concurrent consideration of multiple modalities supported by and supporting multiple types of movement.

In the years since this publication, there has been a lot of progress in developing a systems approach in which a global phenomenon emerges out of but is not reducible to the mere interaction of components. (More details about systems are provided in the section "A Systems Perspective.") The systems approach has implications for perception and action through the introduction of tools and perspectives from outside of psychology, most specifically from dynamical systems and complexity. Nevertheless, Gibson still deserves credit for identifying the psychological impact of this work. In this paper, we consider modern

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examples of systems thinking. We argue that a natural extension of Gibson's (1966) ideas would have been the treatment of social interactions across persons as an integrated perception–action system.

Perception is different from a sense

Gibson wrote *The Senses Considered as Perceptual Systems* (1966) twice, starting in the 1950s but then again starting in 1963, after in-depth study of 17th- to 18th-century philosophy and sensory anatomy and physiology. Those influences are clear in later chapters that focus on the details of individual sensory organs. However, Gibson deviated notably from an anatomical description of perception whose distinction from a sense was not based on physiology but on functionality. He wrote, "Units of anatomy are not the units of function" (p. 42). The organs are multiply nested and networked systems: at the single-cell level, receptors record energy. Those receptors are grouped into receptive units that are further grouped into organs. The organs do not exist in isolation but occupy stable relative positions with respect to each other. For example, the fixed relative positions of the eye and the inner ear provide a stabilizing function to the visual system. So, early on, Gibson made clear that the anatomical units that support perception do not exist in isolation and in fact derive their functionality through their position as components of a system.

Simply noting connections across sensory organs opens the door to new perspectives on perception (see Stoffregen & Bardy, 2001), but Gibson did not focus on those physiological connections. Both in his 1966 book and in other contemporaneous writings (1963, 1964/1982), Gibson was developing the concept of active, exploratory perceptual systems. This concept was essential to his move from an anatomical perspective with its emphasis on physiological structure to a functional perspective that emphasizes the way in which the system behaves. It also enables the jump from comparisons that rely on anatomical similarity to a broader perspective, like dynamical systems theory, that draws comparisons based on behavioral similarity.

Gibson foreshadowed the interdependence of perception and action that became a hallmark property of ecological psychology when he noted the connection between the body's perceptual and motor systems. Even the most basic functional units involve muscles, so Gibson was including both sensory and motor organs in his hierarchically organized and networked systems. This is a radical contribution from the 1966 book. In each modality, Gibson included activity as a part of the perceptual process by including muscles at even the most basic descriptive level. By incorporating muscles into the system, Gibson's perceptual system became a truly active, rather than a passive, system in which muscles drive the activity of the sensory organs to explore the environment. Movement, Gibson surmised, is not just the response to perception.

Gibson's emphasis on the exploratory activity of the senses foreshadowed the sentiment written in 1976 (*The Myth of Passive Perception*) that "the kind of activity that seems to be important is the looking, listening, sniffing … these acts are not mental, nor physical for that matter, but functional" (p. 234). He continued to encounter critics who interpreted the activity of the muscles as reflexive responses to incoming stimuli, or feedback (Gibson, 1963, 1964/1982, 1979/1986). For Gibson, perception and action were active, integrated processes: perception was not initiated by the arrival of sensations at particular modalities and action was not relegated to motor responses. Sensory and motor components were not isolated, passing information from one to another, but were part of a holistic *system*.

Of course, Gibson would go on to integrate the environment into this system and would further develop his concept of *affordance*, which first appears in his 1966 book (p. 285) but is substantially different from the affordance that we hear about in Gibson's next book, *The Ecological Approach to Visual Perception* (1979/1986). In 1966, the affordance is defined as a *value*, something that provides for the "good or ill" of a perceiver. Foundational to Gibson's (1979/1986) development of the affordance concept was the treatment of the perceiver and environment as inseparable and a part of the same system. Then, relationships across parts of the perceiver-actor-environment system, the affordances, became the key to understanding perception. We jump ahead to consider more modern conceptions of systems-level behavior that would be consistent with and serve to extend Gibson's initial ideas.

A systems perspective

Today, 50 years from the publication of Gibson (1966), we have a fully realized understanding of his vision of a systems approach as well as all of the tools and ideas in systems theory that have developed in the intervening decades. A system is defined as a group of units (generically defined: molecules, social insects, bodily subsystems, people) that behave as a cohesive entity. In its simplest form, systems thinking is captured by the sentiment that *the whole is different from the sum of the parts* that inspired Gestalt psychologists to base their perceptual theory on systems thinking in physics. According to a systems view, global, irreducible properties emerge from the interaction of those components, and the global level is the phenomenon of interest rather than the components themselves. The argument extends further that the global behavior cannot even be understood if it is decomposed into elements. Although those individual elements can themselves be an object of study, like Gibson's eye, understanding the element will not clarify the behavior of the system as a whole. This approach captures the essential elements of Gibson's message that the eye, for example, is just a component of a larger system in which the eye interacts with the muscles and limbs.

The significance of moving to a systems view can be illustrated with examples from the physical and animal world. We favor a start in the physical world to rid ourselves of the belief that system-level cohesion requires the act of an executive system or central command. Central command is just one of many alternatives for imposing order from outside the system rather than treating it as emergent from the interaction of the components within a system (see Chapter 4 of Camazine et al., 2001, for a full treatment). Implicit in that interaction is the exchange of information between the components that enables global-level organization to emerge. That information exchange occurs through the processes of perception and action in living systems.

What better way to start outside of living systems than with a bunch of chemical molecules? A paradigmatic example is the formation of hexagonal cells in Rayleigh-Bénard convection. The preparation is simple: a thin layer of viscous liquid is positioned between two wide plates. The temperature differential across the plates can be controlled by heating the bottom plate. That temperature differential will serve as an important (control) parameter. We do not present all of the features of this system but focus on characteristics that are relevant to our discussion of Gibson (1966). The reader is referred to other sources for a more complete description (e.g., Nicolis & Prigogine, 1989).

In the Rayleigh-Bénard preparation, the molecules move about in a random fashion when there is no temperature differential, that is, when no heat is applied to the bottom plate. In that subcritical condition, the molecules cannot be said to act as a cohesive or organized system because knowledge of one molecule in one part of the system bears no information with respect to another molecule in another part of the system. Instead, the exchange of information, or the influence of any one of the molecules, is local: colliding with a neighbor molecule only affects the neighbor's behavior. Heating the bottom plate slightly only increases the speed at which molecules move about, but they still do so randomly. As long as the temperature differential stays below a critical value called the Rayleigh number, whose value is dependent upon the viscosity of the liquid and the dimensions of its container, any increase in temperature results in a proportional increase in molecular speed. The observed change is linear—molecules simply move faster in order to dissipate excess energy.

At some critical value, however, that conduction process is not sufficient to dissipate the excess energy that is produced when the two plates are at sufficiently different temperatures. A sudden, global change is observed as molecules organize into large hexagonal cells in which molecules move in a coherent fashion and in bulk to dissipate thermal energy through convection. Those cells are called Rayleigh-Bénard convection cells. Now, the activity of any one molecule is correlated with hundreds of other molecules that transport heat from the warmer bottom plate to the cooler top plate. Global cohesive behavior in this system emerges through the exchange of information across even very distally located molecules. If those molecules were human beings, then we would label the processes of information exchange as *perception and action*.

What causes the pattern to emerge? Although the change to system behavior is observed as a result of heating the bottom plate, it is important to realize that the temperature differential is a *nonspecific* control parameter. That means that it contains no blueprint or instructions for the hexagonal cells that emerge. The understanding that global-level behavior can emerge through the interaction of components rather than through central command will be important when we consider the emergence of systemic behavior in humans, where the dominant practice is to attribute order to an executive. Likewise, even though the existence of those Rayleigh-Bénard cells is dependent upon the individual molecules of which they are composed, convection cannot be understood through an analysis of the behavior of an individual molecule. An important feature that translates to our consideration of Gibson's perceptual system is the concept of mutual constraint: just as the global pattern of convection relies upon the activity of individual molecules, the behavior of those individual molecules is constrained by the activity of the Rayleigh-Bénard cell. There is no privileged scale at which the cause of the global pattern can be understood. The system-level behavior is truly emergent.

Group-level behavior is observed in many biological species as well. We present another nonhuman example to avoid reference to an executive system like the brain that might be considered as an organizer of the observed pattern. In biological systems, it is easier to consider perception and action as modalities through which information might be exchanged. Schooling behavior in fish, swarm behavior in social insects, flocking in birds all make good examples. Schools of fish move together as a group, changing direction, avoiding obstacles, and evading predators as if they were a single organism (Camazine et al., 2001). They alter shape regularly, with individual fish changing their location in the group so that no individual fish can be thought of as a leader.

With biological systems, we might be tempted to give a global-level reason for the observed group-level organization. Fish that travel in schools exhibit greater swimming efficiency and endurance (Wiehs, 1973), presumably similar to birds in a V-shaped formation or bicyclists in a pelleton. Fewer fish in the school are consumed by predators, leading to the conclusion that perhaps the schooling fish are more confusing to predators or at least better at evading capture (Driver & Humphries, 1988; Neill & Cullen, 1974). They do that by forming different patterns, for example, a ball, a split, and a flash expansion (Pitcher & Parrish, 1993). In some cases, however, predator fish make use of a prey fish's schooling behavior to harvest more prey fish.

These group-level facts do not explain the formation of the school, though. There is no director fish that instructs other fish how to behave or determines the best time to gather. Instead, the group-level phenomenon of the school emerges from simple interactive rules between individual fish. Camazine et al. (2001) characterized those rules as an interplay between positive and negative feedback loops that are made available through perception and action. Individual fish are attracted to swim close to other fish but they also prefer not to get too close, presumably because that would interfere with swimming. With a critical number of fish, all abiding by those relational rules, we see the emergence of schooling behavior. Alterations in the swimming speed or direction of fish at the periphery, in response to environmental stimuli available to them but perhaps not the whole school, have the potential to ripple through the rest of the school to change the pattern of the group as a whole.

Schooling behavior is less well understood than Rayleigh-Bénard convection, but candidate control parameters seem to be the number of the fish and their speed of travel, particularly when it comes to characterizing the shape of the school. Larger groups of fish are more oblong, with the most dense area of the school being located in the front. When fish move at faster speeds, the shape of the school becomes more symmetric with a denser core (Hemelrijk & Hildenbrandt, 2008). Like the temperature differential in the Rayleigh-Bénard convection, those control parameters are nonspecific because they themselves do not contain instructions for the global pattern that emerges.

Systems of human social behavior

In general, a systems perspective of human social behavior mimics the approach we see in biology: group-level cohesive behavior emerges from the interaction of individuals that comprise the group (Marsh, 2010; Marsh, Richardson, Baron, & Schmidt, 2006). The social group is defined as a system through its functionality rather than its structure, that is, the individuals that compose the group. This distinction is the same as Gibson's (1966) replacement of an anatomical explanation of perception with a functional one. It is clear that information is exchanged within a social group through the processes of perception and action. Marsh and Meagher (2016) wrote, "Making physical contact, taking part in a conversation, or even making eye contact is enough to pull individuals into a 'social eddy' (Marsh, Johnston, Richardson, & Schmidt, 2009) with the other person" (p. 249). What is often less clear is how the social system can be treated as the level of analysis.

The best examples are crowd behavior, cooperativity, and traffic patterns, all of which emphasize holistic function and behavior over structure. Like the molecules in Rayleigh-Bénard convection and the fish in a school, the group-level behavior that emerges cannot be predicted from the activity of the individuals. It is categorically different. At the largest scale, agent-based modeling techniques (Janssen & Ostrom, 2006) focus on the identification of patterns in large groups that emerge as a function of control parameters like the number of individuals in a group and the level of connectivity (i.e., information exchange) between them. There is no leader or blueprint for the global pattern, just individuals abiding by simple rules that are, for modeling purposes, much like the feedback loops of fish in a school. The rules that govern this behavior are so simple that they can be implemented in software that allows a novice user to step in and model relatively complex group behavior (Netlogo, CCL).

For much smaller social groups, the emphasis shifts to characterizing patterns that emerge as a function of the connectivity among group members rather than group size. Team dynamics were studied by having teams of three individuals navigate an unmanned air vehicle to take reconnaissance pictures of group targets in a command-and-control simulator (Gorman, Amazeen, & Cooke, 2010). Connectivity was manipulated by maintaining a team's membership or changing team members after a retention interval. Teams experienced randomly presented perturbations, like a lapse in communication between two team members, that tested their flexibility. Those perturbations served to disrupt information exchange, which had the expected result of altering the system-level group performance. Gorman, Amazeen, and Cooke (2010) used attractor reconstruction and other dynamical analysis techniques to characterize the different functional solutions that emerged. Although intact teams experienced less of a decrement in performance following the retention interval, their behavior was more rigid and less adaptive in response to perturbations. The control parameter of connectivity altered the functionality of the group, the group dynamics.

The finding that changing team membership produced a more flexible team led to the development of a team training technique that incorporated perturbations during the course of training (Gorman, Cooke, & Amazeen, 2010). Those random disruptions encouraged teams to actively explore solutions to novel problems through the active exchange of information among team members. In the end, that disruption produced a better team.

It is important to note that the characterization of the team dynamics, as well as response to perturbations that were an index of team stability, occurred at the level of the team rather than in individual team members. In contrast to traditional approaches that aggregate individual behavior to characterize team behavior, the emphasis was on the functionality that emerged through the interactions of team members.

A slightly different approach, and one that brings us closer to the interconnectedness of Gibson's perceptual systems, was the identification of neural signatures of team coordination using multifractal analysis (Likens, Amazeen, Stevens, Galloway, & Gorman, 2014). The brain activity of six individual team members engaged in a Submarine Piloting and Navigation task was measured using electroencephalography (EEG). Teams engaged in rhythmic activities, like reporting on the ship's position every three minutes, and experienced perturbations, like the possible spotting of an enemy ship. Those events were experienced by the team as a whole, and yet, because the body's physiological processes are interconnected, it was possible to identify team-level experiences in the coordinated brain activity of those individual team members.

Like Gibson's perceptual system, where the receptors that record energy are grouped into receptive units that are themselves grouped to organs belonging to a single body, so the EEG signals of an individual capture the electrical impulses of the very many neurons that reside in the brain of an individual who is breathing, speaking, moving, and interacting with other team members. The system consists of multiply nested and networked subsystems that can themselves be studied but whose interesting behavior, for a psychologist, resides at a global level. For a social psychologist, the interesting behavior resides at a level outside of the body of the individual. It was possible to use brain activity to tell us something about the team dynamics when we treat the team—the multiply nested social group—as a system. Although Gibson (1966) defined his system within the confines of the skin, by his 1979/1986 book, Gibson had expanded his system beyond the skin and into the environment. It seems to us a natural progression of Gibson's ideas to consider the perceiver–actor as nested within a social environment as well.

We presented just a small sample of the research on a systems approach to social behavior. There is a vast literature on social motor coordination that extends these same principles to dyads and small groups (see review in Schmidt & Richardson, 2008) as well as many other studies on both large and small group dynamics.

Gibson, 50 years later

From Gibson's visual perceptual system to the Rayleigh-Bénard convection to schooling fish and teams engaged in navigating unmanned air vehicles and submarines, there was no structural distinction between action and the sharing of information. Each of the components in these very different examples simultaneously acted and interacted with other components in the system. Gibson's 1966 book is often thought of as offering a new way to think about the five senses, but it represented an early foray into the use of systems terminology and thinking in the field of psychology. We believe that the generalization of systems principles across multiple persons would have been a natural extension of Gibson's philosophy.

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References

Camazine, S., Deneubourg, J.-L., Franks, N. R., Sneyd, J., Theraulaz, G, & Bonadbeau, E. (2001). *Self-organization in biological systems*. Princeton, NJ: Princeton University Press.

Driver, P. M., & Humphries, D. A. (1988). *Protean behavior: The biology of unpredictability*. Oxford, UK: Oxford University Press.

Gibson, J. J. (1963). The useful dimensions of sensitivity. *American Psychologist*, *18*, 1–15.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton Mifflin.

Gibson, J. J. (1976). The myth of passive perception: A reply to Richards. *Philosophy and Phenomenological Research*, *37*, 234–238.
Gibson, J. J. (1982). The uses of proprioception and the detection of propriospecific information. In E. Reed & R. Jones (Eds.), *Reasons for realism: Selected essays of James J. Gibson* (pp. 164–170). Hillsdale, NJ: Erlbaum. (Original work published 1964).
Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Erlbaum. (Original work published 1979).
Gorman, J. C., Amazeen, P. G., & Cooke, N. J. (2010). Team coordination dynamics. *Nonlinear Dynamics, Psychology, and Life Sciences*, *14*, 265–289.
Gorman, J. C., Cooke, N. J., & Amazeen, P. G. (2010). Training adaptive teams. *Human Factors*, *52*, 295–307.
Hemelrijk, C. K., & Hildenbrandt, H. (2008). Self-organized shape and frontal density of fish schools. *Ethology*, *114*, 245–254.
Janssen, M. A., & Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society*, *11*, 37–49.
Likens, A. D., Amazeen, P. G., Stevens, R., Galloway, T., & Gorman, J. (2014). Neural signatures of team coordination are revealed by multifractal analysis. *Social Neuroscience*, *9*, 219–234.
Marsh, K. L. (2010). Sociality from an ecological, dynamical perspective. In G. R. Semin & G. Echterhoff (Eds.), *Grounding sociality: Neurons, minds, and culture* (pp. 43–71). London, UK: Psychology Press.
Marsh, K. L., Johnston, L., Richardson, M. J., & Schmidt, R. C. (2009). Toward a radical embodied, embedded social psychology. *European Journal of Social Psychology*, *39*, 1217–1225.
Marsh, K. L., & Meagher, B. R. (2016). Affordances and interpersonal coordination. In P. Passos, K. Davids, & J.-Y. Chow (Eds.), *Interpersonal coordination and performance in social systems* (pp. 245–258). London, UK: Routledge.
Marsh, K. L., Richardson, M. J., Baron, R. M., & Schmidt, R. C. (2006). Contrasting approaches to perception and acting with others. *Ecological Psychology*, *18*, 1–38.
Neill, S. R. S. J., & Cullen, J. M. (1974). Experiments on whether schooling by their prey affects the hunting behavior of cephalopods and fish predators. *Journal of Zoology*, *172*, 549–569.
Nicolis, G., & Prigogine, I. (1989). *Exploring complexity: An introduction*. New York, NY: Freeman.
Pitcher, T. J., & Parrish, J. K. (1993). Functions of shoaling behavior in teleosts. In J. K. Parrish (Ed.), *Behaviour of teleost fishes* (2nd ed., pp. 363–439). London, UK: Chapman & Hall.
Schmidt, R. C., & Richardson, M. J. (2008). Dynamics of interpersonal coordination. In A. Fuchs & V. K. Jirsa (Eds.), *Coordination: Neural, behavioral and social dynamics* (pp. 281–307). Berlin, Germany: Springer-Verlag.
Stoffregen, T. A., & Bardy, B. G. (2001). On specification and the senses. *Behavioral and Brain Sciences*, *24*, 195–213.
Watson, R. I. (1979). *Basic writing in the history of psychology*. New York, NY: Oxford University Press.
Wiehs, D. (1973). Hydromechanics of fish schooling. *Nature*, *241*, 290–291.