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Disaster Series: High-Reliability Organizing (HRO) as Self-Organization

Daved van Stralen, MD, FAAP, Sean D. McKay, Thomas A. Mercer, RAdm, USN (Retired)

Abstract

Oscillatory processes, basic to the functions of life, are intrinsic to the stability of physiological systems. After oscillations gain stochastic resonance, the power spectrum increases in lower frequencies – as environmental stochastic noise, uncommon events gain greater influence on the system. Even weak or relatively small stochastic noise can create and sustain significant oscillations. In physiology, stochastic noise disruption beyond normal bounds is associated with disease, creating the phenomena we observe and treat. Pink noise, the 1/f oscillation, has an increasing power spectrum at low frequencies producing abrupt, rapid fluctuations that bring catastrophic failure. Self-organization promotes stability and stable patterns. As a response to stochastic noise, self-organization is an agile, adaptive response that starts with the engagement of the situation. Paraconsistent and modal logics work with inconsistent and contradictory information and the different ways things are true. Motor cognition adjusts our actions to changing situations; we learn through physical actions. Mirror neurons help us understand the intent and actions of others during self-organization, creating a gateway to social cognition. During a disaster, operations occur in a topological space which constrains and facilitates actions in pink noise crises. Self-organization is the natural and effective response to disruptive environmental stochastic noise.

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Introduction:

Random fluctuations of energy, independent of time, form 'white noise' following a Gaussian distribution. Feedback within the system creates stochastic resonance and time dependence, increasing the power spectrum in the lower frequencies, called 'red noise.' Time dependence forms a power distribution describing greater influence on the system from uncommon low-frequency events. These red noise events are also poorly predictable. A special relationship occurs at the 'flicker' frequency, the 1/*f* oscillation, where increased power spectrum at low frequencies produces abrupt, rapid fluctuations and catastrophic failure. This noise is 'pink noise.'

As critical infrastructures, hospitals have a dual function for reliability. They must maintain stability and prevent failures while responding to infrastructure failures. Emery Roe and Paul Schulman described the similarities and differences of these two approaches in nuclear power plant control operators and wildland fire emergency responders. 'Control room operations' prevent failure of healthcare infrastructure and undertake recovery while 'emergency response' activates when the infrastructure fails (1).

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In a disaster, healthcare professionals accustomed to the support of the hospital infrastructure must continue the infrastructure-*dependent* control operator approach and assume the infrastructure-*independent* emergency response. Healthcare professionals and administrators often lack experience with the 'logic of operations' used in emergency response, which differs significantly from control room operations (1-3). Environmental stochastic noise, particularly the rapid fluctuations from fractal 1/*f* 'pink noise,' affects both responsibilities for healthcare infrastructure. The method to respond by organizational control room operations and emergency response is the same – self-organization.

Healthcare professionals focus on protecting and treating neonates within an extreme environment (4-6). And the environment may have changed, but the processes did not. "All natural disturbances of various sizes can be seen as part of a seamless l/*f*-noise process. In this picture, we need not make any special distinction between normal environmental variation and ecological 'catastrophes': it is the same thing seen at different scales," John M. Halley (7).

Onsite healthcare professionals *are* the hospital's and NICU's response to a disaster. We cannot foresee every possible deviation in the disaster. Increased task uncertainty and exceptions to routine operations will overload the organizational hierarchy. Control transfers to the work domain level where teams embrace structural forms that *fit* situational demands by 'self-organizing' (8).

Pre-planned routines are inherently 'brittle' and, when rotely invoked and followed, performance breaks down. Instructions are under-specified for the conditions and contexts. "This is the problem of *unanticipated variability*, which frequently happens during emergencies at complex technological systems. Operators need to continue operating and controlling the system in a new and unprecedented environment and adverse conditions. Coming up with an unprecedented plan is strongly culturally driven," Najmedin Meshkati and Yalda Khashe (8).

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The 2011 Fukushima earthquake and tsunami damaged the Fukushima Daiichi and Fukushima Daini nuclear plants. (Geologists refer to this earthquake as the "2011 Tōhoku earthquake and tsunami.") The majority of the "pre-planned" response plans did not apply to the situations that operating staff encountered. Control operators became emergency responders. Fukushima Daini operators made personal sacrifices to bring the four reactors to the cold shutdown state. The Fukushima Daiichi operators used their ingenuity on the scene to develop and implement alternative mitigation plans in real-time, showing "courage and resilience … under extraordinarily difficult conditions. Their actions potentially prevented even more severe outcomes at the plan." "The Fukushima Daiichi accident reaffirmed that people are the last line of defense in a severe accident" (9).

Emergency response problems did occur, generally described as coming from the Emergency Response Center (ERC) or with external teams. Planning was also faulted, "...they did not assume that a situation in which multiple nuclear reactors losing all power sources almost simultaneously would occur and thus did not provide the training and education necessary to implement measures to control such a serious situation." "You can't adequately prepare for a disaster that you don't admit can ever happen" (9).

At the Onagawa Nuclear Power Station plant, the earthquake and tsunami damaged some equipment and structures without affecting structural integrity. The plant "shut down safely" and was "remarkably undamaged." The Onagawa plant experienced the most vigorous shaking that any nuclear plant has ever experienced from an earthquake.

The distances from the epicenter were: Fukushima Daini 100 miles (160 km), Fukushima Daiichi 93 miles (150 km), and Onagawa 50 miles (80 km). Fukushima Daiichi and Daini plants were owned and operated by Tokyo Electric Power Company (TEPCO). Only the Onagawa power plant, owned by Tohoku Electric, went unscathed (9).

> *"Operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination."*

Jens Rasmussen (10)

Oscillations and Self-Organization

Oscillations and oscillatory processes are basic to the functions of life and the physical world. Nonlinear feedback systems responding to the entry of noise energy into the open system create oscillations. Through stochastic resonance, weak or relatively small noise creates and can sustain significant oscillations. Temporal dependence of the noise causes these effects on the system to lag.

Time correlation of perturbations creates the stochastic effect of noise. White noise has equal power in every unit of bandwidth; therefore, it is uncorrelated in time. Increased averaging of measurements over time increases accuracy in white noise. A delta-function impulse, or time lag, produces a filter response that correlates perturbations with a copy of itself on all timescales in bounded continuous-time processes. Measurements converge at ever-closer intervals in time, creating temporal autocorrelation and reddened noise. Temporal autocorrelation increases variance of the oscillation and the possibility of negative outcomes (11, 12). Spectral densities reflect the power of the frequencies and give the pattern their 'color' [Table 1]. The color of the noise has a major impact on system responses (13).

White noise $1/f^{0}$
Brown noise $1/f^{2}$
Red noise $1/f^{\alpha}$
value of α between 0.5 and 1.5
Pink noise $1/f^{1}$

Table 1. Spectral densities of noise

The hallmark of pink noise, 1/*f*, is the presence of rapid fluctuations and a power spectrum that increases at lower frequencies. Pink noise represents long-timescale fluctuations without a well-defined long-term mean. Accuracy does not improve by averaging more measurements over time (12).

Stochastic noise develops from factors intrinsic to the system or extrinsic within the environment. The intrinsic variables we measure, such as vital signs or blood gas analysis, are statistical averages of continuous variables. Because these are continuous processes, the actual measurements constantly change. We see and monitor averaged values; the system experiences fluctuating aggregates of the real measures (11).

Environmental stochasticity reflects the effects of variable parameters within the environment that we simplify by disregarding or treating as constants. Lack of interest or awareness in these processes leads to their exclusion as variables in scientific models. Including them creates variation that may obscure patterns of significance (11). Oscillations develop collective behavior and contribute to the aggregation of oscillations into waveforms (14). Increasing environmental stochastic variance influences these collective behaviors and waves to create unpredictable complexity and chaos within the system.

The order also comes out of chaos through self-organization (15). These systems stabilize and develop order by self-organizing through local, nonlinear feedback. Positive feedback contributes to growth and structure, while negative feedback restricts growth. These oscillatory, self-organizing processes bring stability and order to the environment, but the nonlinear interactions degrade any ability for predictions. Environmental self-organizing processes create stochastic noise that can increase to a level that forces a system or population to respond. The system or population responses to these forcing functions are also self-organizing oscillatory processes with poor predictability of outcomes. The noise process is independent of timescale or magnitude; we need not characterize normal environmental variation differently from catastrophes (7). A disaster is an open system where energy and entropy freely flow.

"When a NICU experiences a disaster, the external environment enters the NICU (16), and the isolated system, which constrains the flow of energy and entropy, becomes an open system. Energy and entropy freely flow in or out."

When a NICU experiences a disaster, the external environment enters the NICU (16), and the isolated system, which constrains the flow of energy and entropy, becomes an open system. Energy and entropy freely flow in or out. Entropic energy, the energy not available for useful work, changes order within the NICU system to disorder. Note that entropy is not a measure of disorder *in the moment,* such as scattered, randomized elements. Rather, entropy is disorder as poor predictability because of many possible permutations or possible futures. The *more random* the system becomes, the greater the number of possibilities develops and the greater the increase in entropy. The forcing function of stochastic environmental energy drives the disaster into the NICU, forcing the NICU to become an open system and increasing the possible permutations the Neonatologist must navigate.

Self-organizing systems are dynamic, requiring continual interactions. The disaster environment is an open system with the continual flux of energy and matter. Reactions, therefore, can occur away from their equilibrium state. Structures – termed dissipative structures – emerge through nonlinear kinetics. Patterns then arise from energy dissipation into the environment (17).

However, in healthcare, we are more accustomed to a static, closed system with parts that operate like a jigsaw puzzle – complete once assembled. This utilizes a "static process employed to analyze puzzles in matrixed depictions of the world. In that approach, all assumptions about a problem or mission are built into the matrix at the start, thereby limiting the range of eventual deductions," Adrian Wolfberg (18).

Self-organizing has a purpose. Disregarding these processes for whatever reason constrains our analysis, as described by Wolfberg above. Adopting full-spectrum analysis, approaching problems as mysteries, expands our experience and findings (19, 20). Stochastic phenomena have significant contributions to the gap between theory and practice (21), discrete concepts and continuous perceptions (22), and abstractions and context (23, 24). Once considered a source of interference, stochastic noise may create the phenomena we observe and treat. Noise, then, may inform us of occult influences (11).

Self-organization creates the oscillations and waveforms that disrupt the environment, forcing responses from populations. Self-organization is also the response of populations to reduce the effect of environmental oscillations. The flow of energy and entropy alter the self-organization of these oscillations. *Stochastic environments become stable from the oscillations of self-organization; populations maintain stability through the oscillations of self-organization.*

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The Color of Noise:

Oscillations occurring with a time component will form waves having frequencies. Noise is a disorganized pattern of waves that do not carry information. Stochastic waves carry energy, and their stochastic character means their probability values will unexpectedly change. Environmental stochastic noise describes the ambi-

Color	Structure	Variance	Distribution
White	No frequencies dominate Flattened spectrum Spectral density has equal amounts of all frequencies	Data *decreases* variance Forms Gaussian curve	Gaussian distribution - Elements fully independent - No autocorrelation
Red	Low frequencies dominate Long-period cycles	Data *increases* variance Forms power distribution	Power law distribution - Elements *not* independent - Mutual/ reciprocal relations
Pink	The midpoint of red noise Slope lies *precisely* midway between white noise and brown (random) noise	Data *continuously increases* variance Distinguishes pink noise from reddened spectra	Power law distribution - No well-defined long-term mean - No well-defined value at a single point

Table 2. Patterns and Characteristics of Noise

ent noise of the world in which we live.

Environmental stochastic noise can fluctuate over time and through space, correlating with itself (autocorrelation) as serial correlations of that flux. Environmental stochastic noise can also exist as dominant frequencies, longer wavelengths within a power spectrum with greater power or spectral density (7, 25). These differences are critical to understanding the effect of environmental stochastic noise in a system. To visualize the structure of these differences, it helps think of a graph with the *power* of the noise fluctuations on the vertical (y) axis. Power represents the quantity of energy, relative influence, or the spectral density of the waves. The *frequency* of the aggregate waves is on the horizontal (x) axis. The frequency is mapped as the *inverse* of frequency 1/*f*; a critical value called fractal or 1/*f* noise.

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With the analogy of visible light, these fluctuations are termed 'color' to describe the pattern of predominant frequencies in a certain fluctuation range (26) [Table 2]. The various colors of noise refer to the disruptive potential of stochastic energy within the environment and the characteristics of that environment. Low-frequency events (longer wavelengths) have a greater effect on the environment than frequent events with short wavelengths.

The meaning of the types of environmental stochastic noise comes from the characteristics of their fluctuations that cause unpredictable events and the energy of their 'forcing functions.' Frequencies with the power to force a system or population to respond to the environment are forcing functions.

- Completely random fluctuations, like Brownian motion, are *brown noise.*
- The absence of a predominant energy frequency is *white noise*, like the white noise of sound-canceling earphones.
- Fluctuations with long frequencies, slow in onset, and that carry greater power to affect the environment are *red noise,* as in long-wavelength red light.
- Fluctuations with long frequencies that can cause abrupt catastrophic events are *pink noise* because they are *precisely* between white noise and red noise or between white noise and the randomness of brown noise.

The variances from data for the different types of noise produce different probability distributions:

- *White noise* is characterized by equal energy over all frequencies.
    - o Environmental elements are fully independent.
    - o Variance decreases over time or with increasing data.
    - o Frequencies are uncorrelated in time with an equal distribution of energy.
    - o They form a Gaussian distribution amenable to statistical analysis and calculated probabilities.
- *Red noise* contains low frequencies with the energy to affect the environment
    - o Environmental elements are *not* independent
    - o Variance *increases* over time or with increasing data.
    - o Red noise has rapid fluctuations.
    - o Red noise forms a power distribution.
- *Pink noise* (fractal or 1/*f* noise) power spectral density is inversely proportional to the frequency with the possibility of low frequency, *catastrophic* events.
    - o Environmental elements, over time, do not form a well-defined mean.
    - o Variance *continuously increases* over time; time-series become 'messier' with more data making deductions difficult (7).
    - o Pink noise forms a power distribution.

The effect of noise on a population as variance comes from the relative time scales between environmental and population-level processes. This is from the relative magnitudes of environmental stochastic auto-correlation times and population dynamics. Short environmental auto-correlation times act as white noise on populations. The contribution of environmental stochastic noise will dominate in large systems (11).

Red and pink noise disturbances occur on any timescale with any order of magnitude. There is no particular distinction between normal environmental variation and ecological 'catastrophes': it is the same thing seen at different timescales (7).

Environments of Noise

Our environment contains background noise from everyday stochastic processes. Changes in entropy within our open environment amplify this natural noise. We routinely operate with environmental stochastic noise having fluctuations that can sometimes exceed our capabilities. We are then forced to respond to the environment.

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Within a NICU environment and over short time horizons, we may not be able to differentiate the color of noise in a particular NICU. A person with limited experience in white noise environments may find a sudden stochastic increase in white noise threatening. Low-frequency red noise events mislead outsiders into believing they are operating in a white noise environment. People transferring from a NICU with a different population of neonates or administrators with authority over equipment and finances may not recognize the NICU by the low frequency of its forcing functions or

Noise	White	Red	Pink
Space	Euclidean	Topological	Topological
Distribution	Gaussian	Power	Power Fractal
Stochastic processes	Independent	Correlated	Correlated
Variance	Decreases with data Constrained	Increases with data	Continuously increases with data
Problem type	Well-structured Algorithms, protocols	Ill-structured Heuristics	Embedded in environment Engagement
Social response	Hierarchical	Self-organizing	Self-organizing
Environment	Linear Deterministic	VUCA Long frequencies mimic white noise	VUCA-2T Liminality

Table 3: Characteristics of Noise

the presence of 1/*f* noise. When developing a PICU, one author (DvS) was summoned by the hospital's equipment committee to explain why the PICU needed more central venous catheters than the adult or neonatal ICUs. Bewildered what to say, the author suggested it might be related to the limited variance in the physical length of patients in the other two types of ICUs, whereas the PICU had patients from a foot long to over six feet.

There is a difference between a normal environment consisting of multiple *independent* stochastic processes (white noise) and an environment of intermittent *correlated* (linked) stochastic processes (red noise) [Table 3]. Correlation *amplifies* stochastic processes. The first has some degree of predictability while the latter does not. Further, the variance in white noise environments is constrained; collecting more data reduces variance. In red noise environments, more data and time increases variance. In pink noise environments, time and data continuously increase variance. That is, wait long enough, and the catastrophe comes to you. The differences profoundly affect how systems and populations adapt to their environment. 'Environmental stochasticity' describes the unpredictability of the environment (27).

"Despite their stochastic characteristics, white noise environments follow the Gaussian distribution and are amenable to algorithms, rules, and protocols associated with known success. These are the well-structured problems described by Herbert Simon (28)."

Despite their stochastic characteristics, white noise environments follow the Gaussian distribution and are amenable to algorithms, rules, and protocols associated with known success. These are the well-structured problems described by Herbert Simon (28). The environmental stochastic variance of white noise can appear daunting to the uninitiated, believing they have experienced a reddened environment.

Red noise environments with low frequency forcing events have a greater influence on the system than white noise—reddened events within the normal variation of activity act as forcing functions on populations. Red noise environments contain ill-structured problems requiring the use of heuristics (28) and bias-correcting error (29), decision-making driven by feedback (John Boyd's OODA Loop) (30), and practical, common-sense problem-solving approaches (31).

In the pink noise environment, catastrophes occur when the environment becomes a major aspect of the problem. Catastrophic events arising from the change in entropy due to environmental stochastic noise differ only in magnitude and timescale (7). The external and internal environments share feedback, embedding the problem into the external environment. We see this with neonatal care during abrupt and prolonged disasters when the environment intrudes into the NICU, effectively embedding the NICU into the environment (4, 6). This moment-to-moment feedback can create a "loss of cosmology," which can collapse sensemaking (32), or the individual allows 'abstractionism' to supersede contextualization of the problem (24).

In the pink noise environment of a disaster, the shorter time scales and rapid fluctuations will embed the problem into the environment. More insidious is the assimilated problem where problem-boundary issues become diffuse. We see this with white-noise management styles operating in a reddened environment or assimilating "failure by not acting" into the organization (33).

The salience of signals in the environment is learned through experience (19, 20). Signals are cycles with predictability that have meaning. Noise is the residual variability that causes unpredictability. The rarity of severe perturbations and unrecognized salience allows administrators to sustain their assumptions that experience in white noise environments suffices for red and pink noise. Also, leadership practices in white noise environments are loosely coupled to administrative and management practices (34). Too readily, management science displaces the leadership necessary for dangerous contexts in the pink noise environment (35).

Self-organizing is an innate property of human interaction. Self-organizing actions always change the situation. All problems run their course. Self-organization can make any response appear successful or fail, depending on interpretation. This underscores the importance of recognizing the purpose of high-reliability operations and self-organization.

Self-organizing starts with the engagement of the situation (23). For the embedded problem, individuals must enter the environment, that is, become "part of the problem" and work it from within (16). More specifically, we engage negative feedback that some call error or failure. Negative feedback represents the location of uncertainty, gaps in knowledge, hazards, boundaries of performance, and the border of effective operations. This locus is motor cognition driven by our executive functions – to think by acting and the source of the agency during a crisis (36). People come together to self-organize, supported by mirror neurons (37, 38), and a team forms with a natural leader, though more often an ephemeral leader as leadership migrates to the individual in the best position to lead (35, 39). This hierarchy becomes self-directed self-organizing.

"Self-organizing can make any action or belief look correct through the noncritical use of inductive reasoning. There will always be sufficient ambiguity present to support any decision or outcome."

. Signs of using white noise approaches in a reddened environment include:

- The drive for precision, what exactly to do, rather than seek accuracy, a product of motor cognition
- Avoiding negative feedback, especially if the feedback relates to a decision that directly leads to failure by not acting, a failure that is not visible, that will easily and uncritically become organizational knowledge
- Self-organized cognitive or affective feedback between members can develop unknowingly into groupthink – signals are missed, salience is lost, and false meaning is given to information
- Protocols and algorithms for gaps between theory and practice (21) or between discrete concepts and continuous perceptions (22)
- Language for white noise is passive and abstract rather than active and concrete, utilizing a different part of the brain

Long periods between events in the red noise environments can be mistranslated as relatively stable white noise, just as the constrained stochastic surprises in the white noise environment can challenge those with less experience. To better describe these environments, civilians borrowed the US Army acronym VUCA (Volatility, Uncertainty, Complexity, Ambiguity) (40, 41) for environments with the characteristics of red noise. We find a more accurate description for pink noise includes time compression and threat; pink noise is a VUCA-2T environment (Volatility, Uncertainty, Complexity, Ambiguity-Threat, and Time Compression see Table 4) (42).

Karl Weick (32) described how "cosmology episodes" collapse sensemaking and leadership. This occurred even with seasoned wildland firefighters during the 1949 Mann Gulch Fire. Pink noise catastrophes are cosmology episodes in a VUCA-2T environment, creating liminal experiences. Liminality is a transition (43), the space between the world we know and the world we do not. Old rules do not apply, we have not learned new rules, and we do not know what rules will work. This magnifies the gap between theory and practice (21), discrete concepts and continuous perceptions (22), abstractions and concreteness (Karl Weick, personal communication), and the static normative stance and the pragmatic stance from within the trajectory of events (23). In pink noise catastrophes, we find ourselves in a space we do not belong, a space meant for the passage where discomfort arises from the loss of context.

Mistranslation of HRO and the transfer of white noise approaches to a reddened environment risks the creation of the ecology of fear (44). In these organizations, the damage from the fear of error or failure becomes greater than the act itself.

Logics and the Color of Noise

Increasing entropy increases future possibilities. Oscillations reverse the truth value of information. Taken together, they create stochastic cycles of changing salience, relevance, and meaning for data and information. Certainty becomes ephemeral. However, formal systems of logic have completeness (all formulas can be proved) and consistency (never a contradiction). Truth and falsity are incompatible. Classical logic systems must manage incompleteness and inconsistency.

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Working with contradictory data in flux, reasoning in complex, time-compressed situations, and solving ill-structured problems under uncertainty, cannot be accomplished with classical logic (2). Practical common-sense problem solving supports immediate engagement (31) but does not offer insight for the study of performance, teaching, or knowledge transfer.

Paraconsistent Logics

The rigid restraints of classical logic impair usage for uncertainty and inconsistency, particularly the law of the excluded middle. Paraconsistent logics were developed to handle inconsistent information and allow contradictory yet non-trivial theories (45). Paraconsistent logics permit inference from conflicting information in a non-trivial fashion, accommodate inconsistency in a

Volatility	Rapid, abrupt change in events
Uncertainty	Lack of precise knowledge, need for more information, unavailability of necessary information
Complexity	Large number of interconnected, changing parts
Ambiguity	Multiple interpretations, causes, or outcomes
Threat	Impaired cognition and decision-making
Time Compression	Limitation acquiring information, deciding or acting before consequential changes

Table 4. VUCA-2T (42)

Logic	Domain	Operators
Modal	Qualify the truth of a judgment	“necessarily,” “possibly”
Epistemic	Knowledge and belief	“It is known that” “*x* knows that” “*x* believes that”
Doxastic	Belief revision (add information) Updating (world has changed)	“*x* holds after contraction / revision / expansion”
Deontic	Moral expression, duty	“ought to be” “obligatory,” “permitted,” “forbidden.”
Temporal	Future, past Linear & branching-time	“it will be / it was” “it will be / it will always be”

Table 5: Modal Logics

controlled way, and treat inconsistent information as potentially informative (46, 47). Paraconsistency is also an important feature of common-sense reasoning which can use exceptions and counterfactuals (31, 48, 49).

Three-valued, paraconsistent logics have an additional third value that is “both true and false.” This allows reasoning with variables that are not embedded directly in a contradiction (49, 50).

Modal Logics

Classical logic evaluates a premise by its appearance or form. The modal logics evaluate a premise by the different ways or modes that things are true. We can use these logics to infer reliable information from imperfect information, understand our changing beliefs in a dynamic world, manipulate uncertain information, appreciate how time changes the truths and information we work with, and comprehend how situations create different but logical duties and obligations. Modal logics use partial operators that limit the action of the operator. Modal logic classifies propositions as *contingently* true or false and allows claims about what is necessary, possible, contingent, essential, and accidental. Modal logic is the logic of “modalities,” *modes* (means) of truth, by using a variety of operators dependent on the domain of the logic (51) [Table 5].

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Epistemic logic helps understand how operators perceive the actual world. The person may have belief as conviction, meaning that everything they believe is true. They may only believe what is objectively true; belief is independent of their subjectivity (52, 53). Their knowledge of the situation depends on the frame of reference (23, 54): the subjective internal, the perfect (objective) external, and the imperfect external points of view. In Newtonian mechanics, the physicists must always specify which frame of reference is considered when studying a natural phenomenon. We must do the same for epistemic logic.

The *internal approach* assumes the modeler is one of the agents involved in the situation. The modeler has a subjective point of view that represents how the world is perceived without perfect knowledge of the situation. Any models built might be erroneous (54).

The *external approach* is traditional epistemic logic with the modeler uninvolved and external to the situation. Having an omniscient view, the observer has perfect knowledge of the situation and has access to the minds of the people involved.

Doxastic logic (Greek *Doxa*, “belief”) is a form of epistemic logic but is concerned with the logic of belief of participants. Doxastic logic provides *reasons about belief* rather than knowledge; the difference is that a belief is probably, though not necessarily, true. When we are not careful, we may collapse knowledge and belief into the same system, creating conviction of belief as epistemic logic. Our beliefs will become refractory to disconfirming evidence-motivated reasoning (55). In the worst case, such logic strengthens cognitive dissonance. Doxastic operators capture belief change, as “belief revisions” or “belief updates,” when they receive conflicting information or encounter a discrepancy or disruption.

We have found that a doxastic approach helps subordinates operate around those with certitude or in a hierarchy with a steep authority gradient that suppresses honest communication (56). Here, “honest” is one of van Stralen and Mercer’s five HRO values. What you say represents what is happening (3). One author (DvS) has had numerous encounters with staff who misrepresent or withhold information because of a management culture that blocks the free flow of information. We encourage such staff who have disconfirming or contradictory information to offer “updates” to their superior:

- A *belief update* refers to accounting for a change in the situation and acquiring new, more reliable information; this requires changing our inaccurate old beliefs to more accurate, new ones.
- *Belief revision* occurs when we identify the old information as less reliable, and we use new, more reliable information to revise our older beliefs; we keep the new belief as close as possible to the old belief while accepting the newer, accurate information.

The tension between belief (doxastic logic) and accuracy (epistemic logic) underscores the resistance to and utility of HRO.

False belief can develop within self or public image, reinforced by serial successes or the routine interpretation of outcomes as successful. Failure to use doxastic logic can produce individual narcissism or social groupthink. Disconfirming information is ignored, and disagreements are punished. Accuracy is a process especially true in reddened noise environments. In dangerous contexts, inaccurate information and models can kill (57). Every member has valuable information to share freely. Disconfirming information is sought, and disagreements are objectively evaluated.

From "duty" and "ought," Deontic logic is the logic of conditional obligations for action. Conclusions in Classical Logic do not lead to action. Deontic logic provides reasons about duty or obligation and drives action from states. In this logic, every proposition exists in one of three mutually exclusive states: necessary, contingent, or impossible (58). Deontic logic takes us from "is" to "ought to"—that is, if an event occurs, then an action may be *obligated* or *not permitted*. Deontic logic is the logic of norms or accepted standards.

Temporal logic reasons how time qualifies statements and propositions with two basic operators, future and past. The asymmetry of time describes how the past is fixed, yet the future is branching and open to influence and change (59). This fits the effect of increasing entropy as an increase in possible futures rather than an increase in disorder.

Temporal logic can also be modified for concepts of time. For example, *X* is true at all times, while *Y* is true only sometimes. While the past is fixed and already determined, logical processes can account for the branching of time in the future. "Temporal logic" addresses problems of causality and mechanism, continuous change, planning actions, concurrent or discontinuous events, and the persistence of a fact rather than the truth of a fact.

Temporal logic moves us from a deterministic view of linear time that focuses on the path to the future. While there may be a feeling of security for families to know the percentage survival rate, such discussions do not reflect time experienced as a liminal state. During live-or-die experiences, there is no sense of time.

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Self-Organizing Physiology

It is easy to appreciate the situation of a premature neonate living with various sources of stochastic noise from numerous complex physiological rhythms and oscillations. These rhythms fluctuate irregularly over time (60). The neonate exists in an environment with stochastic noise, though the constrained environment of the closed NICU system may limit some sources of variance. In utero, the developing infant is exposed to unregulated environmental stochastic noise. Further, there are various levels of increasing or decreasing stochastic noise from developing physiology, emerging pathology, inflammatory responses, counter-inflammatory responses, and treatments. These rhythms arise from stochastic, nonlinear biological mechanisms interacting with a fluctuating environment.

Fluctuations themselves are intrinsic to the stability of the physiological systems. Disruption of the rhythmic processes beyond normal bounds or emergence of abnormal rhythms is associated with disease (60). Disruption in physiology occurs as the body self-organizes around the pathology through sympathetic inflammatory and counter-inflammatory responses. Our treatment causes disruption in pathology with more sympathetic inflammatory and counter-inflammatory responses to the treatment. Healing is a self-organizational process supported by the patient's physiological responses and treatments.

In our intuitive minds, the nonlinearity of stochastic noise is undesirable and likely pathological compared to the more desirable linear and predictable noise we associate with health. Multiple regulatory systems and environmental influences operate over different time scales in a fluctuating manner. These systems operate far from equilibrium. Constancy may not be the goal of physiologic control (61, 62). Pink noise is common with many of these processes, such as the organization of neural networks, Purkinje fibers in the heart, the vascular tree, bronchial tree, bone trabeculae, electroencephalographic rhythms, heart rate variability, and respiratory intervals (62).

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Pink noise (fractal organization) may confer system resiliency, adaptability, and structural integrity, and its degradation may expose a person to sudden death (61, 62). Heart-rate variability displays 1/*f* noise, and as stochastic properties degrade, the risk of sudden death increases. With age starting in the late 60s or the onset of disease, heart functional capacity decreases, and heart-rate variability shifts from 1/*f* pink noise to white noise characteristics (61, 62).

In the brain, stochasticity (pink noise, 1/*f*) of random spike firing may influence the cognitive operations of decision-making, the stability of short-term memory, memory recall and attention, motor learning, and motor cognition, while movement errors modify planning future movements. Stochastic noise promotes decision-making, creativity, and shifting attention to new tasks (62).

Uncertainty and Chaos

Many interactions are nonlinear with inherent uncertainty, yet even linear interactions can create uncertainty and randomness. Linear, time-variant systems, basically oscillating systems, have an inherent *uncertainty principle* that we can know the frequency or the position but not both. The better-known example from quantum physics is Heisenberg's Uncertainty Principle. Increasingly precise measurement of one decreases the precision of the other.

This uncertainty affects the causality and prediction of the particle's behavior. Uncertainty principles result from wave mechanics and oscillation in linear time-variant systems (as their name implies, they vary or oscillate linearly over time). Collecting information for a decision takes time. When information is sufficient for a decision, the situation has changed.

"The oscillation continues when the 'output becomes the new input' in the same deterministic equation. This is the logistic equation, as the equation for a parabola but using the output for the next input. The constant, r, is the rate of reaction for the system. As r increases, the system passes through a series of stable equilibria."

The oscillation continues when the 'output becomes the new input' in the same deterministic equation. This is the logistic equation, as the equation for a parabola but using the output for the next input. The constant, *r*, is the rate of reaction for the system. As *r* increases, the system passes through a series of stable equilibria. At *r* greater than three, the results become random and sensitive to initial conditions, *deterministic chaos* (63). "Deterministic" as it is determined by the logistic equation and "chaos" because the unpredictable outcomes are sensitive to initial conditions" (63, 64). While matter, energy, and probabilities are conserved, information and entropy are not conserved (15).

Veterans of pink noise environments use these concepts. Jim Denney, Capt., LAFD, a veteran of two Vietnam combat tours, would tell his crew, "In the face of a void, move forward." An LAFD firefighter, approaching a volatile incident to assist one author (DvS), uttered a powerful version of a pragmatic stance: "I may not know what's happening, but I know what to do." Both approaches generate information and structure by actions, which generate thinking by acting (65). This process is motor cognition (36). These actions focus on reducing *r* to slow the rate of environmental activity, moving the system away from deterministic chaos. Anything that reduces the rate of change for one element will reduce the rate of change for the whole system. There is no wrong decision, no wrong act. This is experienced from within these dangerous contexts. The directed self-organization is not visible to spectators no matter how close they may stand.

Motor Cognition and Mirror Neurons

HRO extends operations and the organization into uncertain, adverse, and hostile environments. The physical actions of care come from motor cognition, the influence of the cerebellum and motor cortex on cognition, and how we learn through physical activity to understand events (36). *Motor cognition* describes how we adjust our actions to changing situations and learn through physical actions.

The cerebellum and motor cortex also influence cognition. Executive and higher-level cognitive cortical functions draw upon interactions with cerebellar motor functions (66-68). High-level knowledge is grounded in sensory and motor experience (66). This action shapes the motor system on anticipation and provides information for the meaning of potential action (69, 70). We rely on reciprocal feedback from the environment (42). We think by acting (65).

Because uncertainty, adverse situations, and hostile environments have different *environmental* geometry, they require a different *engagement* geometry. Circumstances may change during sensemaking or acting, and your mind must keep up. The time course described is not necessarily minutes but could be days. Time compression matches the time horizon, minutes for an active resuscitation, weeks for a growing, healing lung. The problem is how we mentally map events and our responses. We are taught by organizing knowledge and concepts in hierarchies that show relationships and connect terms with measurable distances between points. This is a Euclidean space. There is growth but no movement.

Self-Organizing Teams

HRO operations have common elements with motor cognition. We focus on the consequences of our actions and bottom-up feedback (23). This is similar to pragmatist philosophy and represented in motor cognition by perceivable effects as bottom-up feedback. (71, 72).

Cognitive processes for action include the urge and intention to act and adjust those actions while acting immediately. A mirror system allows us to understand the intent and actions, creating a gateway to social cognition. Mirror systems have motor output, differentiating them from visual perception processing (72). Mirror systems support the heedful interrelating and trust found on an aircraft carrier flight deck (73), physical rescue in the field (42), or neonatal resuscitation.

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Mirror systems are how we learn by watching others (37) and figuring out their intent without speaking (38). Because the mirror system neurons are in the pre-motor cortex, they do not respond unless action is executable. Through the mirror system, we can communicate to others through our actions, called communicative intention (74).

The Topology of Self-Organization

The circumstances during COVID-19 and neonatology as a discipline are in a continuously changing actual world. Our team's actions are continuous, independent, and interdependent. This geometry describes a *scale-free topology* (75). The central concept of topology is continuity, a notion of nearness preserved by a continuous function. Topology does not localize an object in Euclidean space, allowing a discipline to self-organize and extend beyond Euclidean restrictions (76).

Topological geometry constrains and facilitates actions. Geometry is preserved under continuous motions because distance and dimension are not relevant. During a disaster, operations occur in different kinds of space, with the distance between objects a matter of function of the relations. Differences between objects are a matter of variety in the relations (76). Topological social relations made possible several NICU evacuations and brought to government attention a "lost" NICU (4, 6).

Topological geometry also constrains self-organization and pattern formation. Topological continuity is maintained by transport paths and communication not connected to the process. In embryologic studies, epigenetics builds on topological constraints and self-organization within the egg (77).

"The color of environmental noise relates to the timescale (78). The relevant timescale influencing topological relations may be hours to days for individuals. For the parents of a neonate, timescale and topological relations can be dynamic, from minutes to months, but have a farther social reach with consequent geometric constraints. "

The color of environmental noise relates to the timescale (78). The relevant timescale influencing topological relations may be hours to days for individuals. For the parents of a neonate, timescale and topological relations can be dynamic, from minutes to months, but have a farther social reach with consequent geometric constraints. For the organization, relevant timescales may be years. Environmental color is pertinent as it has greater influence at the level of the organization. Self-organization as a response to color, on the other hand, acts on the individual level and at the organizational level.

Self-Organization brings Order from Chaos

Self-organization promotes stability and stable patterns. Self-organizing systems can have an abrupt transition from one pattern to another even with a small change in the system, termed a *bifurcation.* Transitions can be dramatic and related to a single parameter – such as *r* in the logistic equation. (17, 63).

Instability is a measure of lack of information and loss of knowledge about a system, yet instability is also associated with acquiring information and knowledge. We create information when we convert uncertainty to certainty (79). In terms of self-organization, some organizations develop from the loss of information and organizations that develop from acquiring new information (80). The color of environmental noise as a measure of variance is pertinent to self-organization. Self-organization is the response to color at the point of contact with the environment.

Self-organization can occur strictly as a physical phenomenon, such as water on the hood of a freshly waxed car. Surface tension holds the bead in a spherical shape. As it grows, the force of gravity on the water increases until it overcomes surface tension, at which point the bead collapses, shearing into two.

Self-organization can develop through behaviors due to decisions, such as a termite mound where termites deposit material from local physical cues. "Individual organisms may use simple behavioral rules to generate structures and patterns at the collective level that are relatively more complex than the component and processes from which they emerge" (17). This is from nonlinear amplification and cooperativity, making the results sensitive to the initial state. *Complexity* can thus emerge without many rules or components and can be mistaken for the mathematical concept of *chaos*.

The judgment of individuals builds behaviors into self-organization. When a crosswalk signal turns green, the people from both sides cross into each other. There is no outside director, no written rules. There are unwritten rules: do not look at or approach anyone too closely. The crossing self-organizes and occurs in a timely and efficient manner worldwide. Self-organizing of biological or physical systems occurs through nonlinear, local interactions internal to the system without external intervention or any external driving forces. Self-organization creates patterns that can appear to result from design or intention, leading us to claim responsibility or assign blame for outcomes inadvertently. However, these patterns result when the energy driving self-organization has dissipated.

Social systems direct self-organization through the behaviors of each member; therefore, the self-organization does not become dissipative. A well-informed leader may direct group activity, but the system is not self-organized. External technical or engineered design is another means for external leadership. Self-organizing as a response appears messy with little control over operators, while engineered designs in a socio-technical system (STS) would appear more reliable and trustworthy.

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STS was first described in British underground coal mining with the introduction of technology to mine longwall segments at one time. The new process replaced the self-organization of lifetime teams of two men who used the "room-and-pillar" technique. During the transition, the technical management of mines did not give miners the security necessary for undertaking new developments. Those mines had low productivity. The technology of mechanization had decreased adaptability and responsible autonomy (81). Both are outcomes from effective social self-organization (36).

> *"Technological systems become organized by commands from the outside, as when human intentions lead to the building of structures or machines. But many natural systems become structured by their own internal processes: these are self-organizing systems, and the emergence of order within them is a complex phenomenon that intrigues scientists from all disciplines."*

Eugene F. Yates (82)

The elements of a system continuously and actively self-organize from local, nonlinear interactions.

Alternatives to Self-Organization

Other paths bring order to chaos – a leader, a representation, sequential instructions, and templates.

- A well-informed leader internally or externally directs the group's activity what each member should contribute. Having a leader means the activity is not self-organized (83).
- Representations like blueprints guide *what* is done but not *how* and do not synchronize workers.
- Sequential instructions are recipes to guide *how* it is done, but they do not allow for judgment, do not coordinate work-

ers' activity, nor adjust for temporal events (84).

- *Templates* are full-size guides that direct the process of pattern formation.

Some leadership styles are invisible, becoming apparent only in the crisis (3, 35). A symphony conductor confided in one author (DvS) that he, the conductor, was not needed during a performance. The orchestra could play as well without him. Individual fire officers have told the author that they did not do their job if you can see the leader. Leadership should be invisible. That is HRO leadership.

The authors have interviewed civilians and public safety personnel regarding actions during dangerous crises. They all describe ephemeral leadership as the title of "leader" rapidly and quietly shifts between participants (39).

Conclusion

The study of white-noise influences and environments relies on time independence and equal energy across all frequencies. Feedback creates stochastic resonance, increasing the power spectrum in low frequencies. This is not a gradual change, but an abrupt, punctuated shift as the power distribution replaces the Gaussian distribution. New properties emerge but not new principles. We make no special distinction between normal environmental variation and catastrophes – we can adapt our routines through self-organization.

> ***"This is not a gradual change, but an abrupt, punctuated shift as the power distribution replaces the Gaussian distribution. New properties emerge but not new principles. We make no special distinction between normal environmental variation and catastrophes – we can adapt our routines through self-organization."***

This assumes that we developed our operations used in the white noise environment from operations effective in red or pink noise environments. There is a smooth transition from pink noise to white noise operations. When a dramatic fluctuation occurs, we readily engage through self-organization. This is HRO.

On the other hand, operations developed *for* or *in* the white noise environment will fail during catastrophic fluctuations. The difference is whether the stochastic noise creating the fluctuations is time-*dependent* or time-*independent*. White noise operations can handle time-*independent* fluctuations.

Catastrophes will happen, but they arise from normal processes and respond to human self-organization. Staff must routinely practice self-organization for it to be effective.

In his discussion of issuing orders, George S. Patton, Jr. (85), wrote, "Never tell people *how* to do things. Tell them *what* to do, and they will surprise you with their ingenuity."

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Corresponding Author

Daved van Stralen, MD, FAAP
Associate Professor, Pediatrics
Department of Pediatrics
Loma Linda University School of Medicine
11175 Campus Street
CP-A1121
Loma Linda, CA 92350
Email: DVanStra@llu.edu

Sean McKay
Executive Partner / Director, Disruptive Rescue & Austere Medicine
Element Rescue - Response Solutions within Nonlinear Complex Environments
Greenville, South Carolina, United States

Thomas A. Mercer
Rear Admiral
United States Navy (Retired)

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