A Mechanism for Detecting Trigger Points and Irreversibility Thresholds in Shock and Trauma for Catastrophic Events

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Abstract. We investigate the model of unstable recurrent patterns that emerge within chaotic and highly turbulent systems as a possible avenue for linking shifts in clinical parameters that can be indicators of nonlinear and irreversible transitions leading to mortality. The argument presented is that in the case of mass injury and trauma events from natural or intentional causes, large numbers of people may be in situations where clinical testing infrastructures have been disabled or destroyed, further reducing the ability of medical caregivers to accurately notice indicators and signals of impending critical and irreversible conditions. Identification of a reduced set of observables that can be linked with unstable yet recurrent patterns may provide a means for improved monitoring and life support under such adverse conditions.

Keywords. shock, trauma, catastrophe, recurrent systems, anomaly detection, chaos, turbulence, dissipation, emergency preparedness, first response, triage

Introduction

Events such as natural disasters and deliberate terrorist-type attacks have the capability of overtaxing even the most advanced systems for dealing with shock syndrome and trauma which are generally tailored to the individual patient. Anomaly and intrusion detection methods developed for network capacity planning, system configuration management and information security, as well as the disciplines of fluid dynamics and turbulence, appear to be distant from trauma medicine and the challenge of dealing with mass trauma events such as from natural disasters, accidents or terrorist actions. However, there may be a new class of parameters that can be measured rapidly for large numbers of patients which can aid in the dual process of triage and forecast for critical phases in emergency treatment of patients. Examination of unstable and semi-stable recurrent patterns in dissipative extended systems may offer a set of advance-warning indicators that can be associated with impending critical life support

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conditions, in some cases clearly irreversible, in others treatable if addressed sufficiently early in time. The target situation is that which occurs when there are hundreds or even thousands of persons subjected, within a comparatively short period of time (minutes or hours) by exposure or ingestion to toxic biological agents, chemicals, or radiation, or alternatively subjected to injuries from impact events (e.g., shock waves, blunt trauma).

Our goal in this brief speculative note is to set the stage for inquiry and investigation first at an abstract level and then to identify if the abstract model that results can find a match with known observable parameters from the critical care world, working abductively and intuitively toward defining a dataset that can in turn be tested for a fit with both the turbulence characteristics and the existence of unstable and semi-stable recurrent patterns (hereafter referred to as λ-recurrence) fitting the initial abstract model. No experiments have yet been conducted and the present work reflects early stage simulation and modeling.

We begin by considering the complex space of biochemical and behavioral parameters that are observable and with constraints as described earlier. Thus, automatically we must rule out any medical testing that requires remote and time-intensive laboratory testing that cannot be performed in an emergency room "live" without sending samples or patients to other facilities. In fact we prefer to focus upon those parameters that can be collected reliably in a field setting such as that of a combat area field hospital or onboard a medivac helicopter. Certainly within the space of possible parameters are those employed in the Glasgow Outcome Scale but from the outset we do not know if we should be considering one particular parameter p (e.g., SpO2/SaO2) or a set S = {p, q, r}, for which the relationship between two or more members of S is the critical meta-parameter; i.e, where we may find chaotic behavior of the "interesting" sort (meaning, with λ-recurrence).

Given the constraints of our interest in mass trauma events coupled with disruption of basic infrastructure and resources, we are automatically limited in the range of clinical tests that can be considered, although as technology evolves, there may be new non-invasive or rapid and portable analyses opening up other dimensions. Parameter sets useful for tracking λ-recurrence may emerge including quantities that are relatively stable on scales of minutes or even hours but for which modest changes coupled with other set members can serve as triggers of a λ-recurrence. Measures of pro- and anti-inflammatory cytokine and adhesion molecule patterns [1] are already employed on a 2 to 4 hour basis for indications of septic shock onset or susceptibility. Within our investigations, the In-Check microfluidic diagnostic chip and platform [2] offers the possibility of such new classes of tests through highly-automated PCR-based analysis in a portable lightweight and low-power configuration capable of performing up to five tests and protocols in parallel.

Recurrent Patterns in Dissipative Turbulence - the Kuramoto-Sivashinsky Model

Our goal is to find behaviors similar to the basic Kuramoto-Sivashinsky (KS) system,

$$u_t = (u^2)_x - u_{xx} - \nu u_{xxxx} \tag{1}$$

representing, for example, the general case for amplitudes of interfacial instabilities such as flame fields, nonlinear through term $(u^2)_x$, t referring to time and *v* a damping parameter. The solution u(x,t) = u(x+L, t) is periodic and can be expanded into a discrete spatial Fourier series

$$u(x,t) = \sum_{k=-\infty}^{+\infty} a_k(t) e^{ikx} \tag{2}$$

It is possible to extend periodic orbit theory to spatiotemporal chaotic systems and the KS system [3] and reduce a high-demensional system (from 16 to 64 dimensions) down to one, namely a return map. Following the seminal work of Cvitanović and others [4,5] we postulate that a predictive system for non-equilibrium turbulence of the type that may exist in breathing irregularities, cardiac beat-to-beat chaos and other chaotic-like behavior measured through electrocardiograms, or in molecular pattern[2]s such as cytokine levels, may require only 10^2 – 10^4 recurrent pattern instances as opposed to classical expectations (≈ 10^{10}) from Monte Carlo and other PDE simulations. This means fewer cycles of per-patient monitoring and possibly a manageable cycle of acquire-search-compare-evaluate computations to perform (returning to our clinical focus) for large populations when situations impose sparser data collection intervals and less robust computational resources.

Dynamical behavior such as 3-D Navier-Stokes turbulence in many different media often exhibits a variety of unstable recurrent patterns. Such recurrent behavior can in turn be applied to provide indicators of general characteristics or imminent phase shifts. The challenge is how to find such patterns since by definition they are themselves unstable and not the same in amplitude or other dynamical characteristics in each recurrence. Why they may be indicators of trigger-like conditions, including irreversible conditions leading to death, in the case of individuals experiencing a variety of trauma conditions is not at all obvious. However, on the one hand there is the evidence of sudden death linked with a larger variety of CNS and cardiovascular conditions for which there are no externally observable nor commonly measureable (e.g., pulse, pressure, breath rate, consciousness) indicators but which have may have increases or decreases in chaotic patterns such as EKG.

How to find and associate recurrent patterns with biomedical conditions

Finding periodic orbits may be enhanced by algorithms but it is still an exploratory and somewhat “trial and error” process. More so is the conjectured association with medical conditions. Recent studies by Cvitanović and Lan involve an iterative approach to begin with a calculated guess and then to monitor the attraction of the solution towards or away from this target. This in turns builds an approach using Newton-Raphson or alternatively by minimizing a cost function related to the difference between approximate flow and discrete flow of that which is circulating or

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[2] It is important to remember that recurrent patterns of interest are not necessarily themselves chaotic and in fact the absence or decrease of chaos in certain bioparameters may be the indicator of on onset of a disabling or life-threatening condition, as pointed out by Poon and Merrill regarding congestive heart failure [6]

has a potential for doing so actively. These and other methods like them will not tell which patterns are recurrent nor how "near" everything is in the interpolative process. Here additional heuristics and probabilistic data can be used to reduce the iterative cycle. There are known techniques within the study of anomaly detection and tracking, such as multivariate statistics and neural network classification. At a higher scale probabilistic (Bayesian) networks can be employed with specific rules drawn from the operations domain.

Once there is a library of unstable spatio-temporally recurrent solutions there must be some form of application in this case to a type or configuration of biometric parameters. Periodic orbit theory [7] proposes that the greater the unstability, the more accurate will be the predictions that are based upon a small number of the shortest recurrent patterns. In turn, once a sufficient number of individual unique patterns can be discriminated, then these can be use together to predict global averages. Average is considered as a sum over all possible patterns which are grouped hierarchically according to the likelihood of each pattern's occrrence in the system.

$$\langle a \rangle = \lim_{t\to\infty} \frac{1}{t} \langle A^t \rangle, \;\; A^t(x) = \int_0^t d\tau a(x(\tau)) \tag{3}$$

where the dynamical trajectory x(t) is some point in a high-dimension state space and the object is for short cycles, short patterns, to contribte information collectively as an aggregate to information on the invariant set, the long-term cycle. Returning to the shock-trauma context of individuals potentially injured internally and unconscious or delirious and unable to assist informationally, with medical caregivers overburdened, with resources and infrastructures stretched or non-operable, the idea here is to have a way to make a logical step from simple observable patterns that can be captured relatively easily, through pulse oxymetry, temperature, pressure, pulse, and other means, to information about impending, imminent shifts in the long-term cycle, the :big picture" of systemic changes that could be the difference between death and life.

References

[1] V von Dossow, K Rotard, U Redlich, O V Hein and CD Spies, Circulating immune parameters predicting the progression from hospital-acquired pneumonia to septic shock in surgical patients, *Critical Care* 2005, **9:**R662-R669

[2] White papers and other technical data on the In-Check platform are available from ST Microelectronics http://www.st.com/stonline/prodpres/dedicate/labchip/labchip.htm

[3] P Cvitanović and T Lan, Turbulent fields and their recurrences, in N Antoniou, ed., *Proc. Of 10th Int'l Workshop on Multiparticle Production: Correlations and Fluctuations in QCD*, World Scientific, Singapore 2003

[4] E Hopf, A mathematical example displaying features of turbulence, *Commun. of Applied Math.* **1**, 303 (1948)

[5] P Holmes, JL Lumley and G Berkooz, Turbulence, Coherent Structures, Dynamical Systems and Symmetry, *Cambridge Univ. Press*, Cambridge 1996

[6] CS Poon and CK Merrill, Decrease of cardiac chaos in congestive heart failure, *Nature* 1997 Oct 2;389(6650):492-5

[7] P Cvitanović et al, Chaos: Quantum and Classical, *Niels Bohr Institute*, Copenhagen 2003