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Bursty Human Dynamics

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To Ábel, Lilla and Sophie;
To Ik-Sang Jo and Hyoung-Soon Ryu;
To Tuulikki; Juha, Tuomas, Annina and their families.

Preface

Bursty dynamics is a common temporal property of various complex systems in nature but it also characterises the dynamics of human actions and interactions. At the phenomenological level, it is a feature of all systems that evolve heterogeneously over time by alternating between periods of low and high event frequencies. In such systems, bursts are identified as periods in which the events occur at a rapid pace within a short time-interval while these periods are separated by long periods of time with low frequency of events. As such dynamical patterns occur in a wide range of natural phenomena, their observation, characterisation and modelling have been a long-standing challenge in several fields of research. However, due to some recent developments in communication and data collection techniques, it has become possible to follow digital traces of actions and interactions of humans from the individual up to the societal level. This led to several new observations of bursty phenomena in the new but largely unexplored area of human dynamics, which called for the renaissance to study these systems using research concepts and methodologies, including data analytics and modelling. As a result, a large amount of new insight and knowledge as well as innovations have been accumulated in the field, which provided us a timely opportunity to write this brief monograph to make an up-to-date review and summary of the observations, appropriate measures, modelling and applications of heterogeneous bursty patterns occurring in the dynamics of human behaviour.

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Contents

Acronyms

This non-complete list of acronyms only collects the most frequently used notations in the text.

t	Time or timing
t_i	Timing of the ith event
n	Number of events
T	Total observation period
$x(t)$	Binary signal of a point process
Δt	Time window for event adjacency
t_0	First observation time
τ	Inter-event time
$P(\tau)$	Inter-event time distribution
$\langle\tau\rangle$	Average inter-event time
σ	Standard deviation of $P(\tau)$
α	Exponent of inter-event time distribution
$x_i(t)$	Interaction sequence of an individual i
$\tau^{(i)}$	Inter-event time in sequence $x_i(t)$
a_i	Activity (number of actions) of an individual i
$x_{ij}(t)$	Interaction sequence between individuals i and j
$\tau^{(ij)}$	Inter-event time in sequence $x_{ij}(t)$
Λ; Λ_i	Group of individuals; the set of neighbours of an individual i
$x_\Lambda(t)$	Interaction sequence between individuals in the group Λ
λ; $\lambda(t)$	Event rate; time-dependent event rate
τ_c	Cutoff of inter-event time distribution
B	Burstiness parameter
E	Bursty train size
$P_{\Delta t}(E)$	Bursty train size distribution
β	Exponent of bursty train size distribution
t_d	Delay time
$A(t_d)$	Autocorrelation function

γ	Exponent of autocorrelation function
τ_w	Waiting time
α_w	Exponent of waiting time distribution
τ_r	Residual time
M	Memory coefficient
N	Network size
L	Number of links in a static network
k	Node degree

Chapter 1
Introduction

To begin with, one defines bursty behaviour or burstiness of a system as intermittent increases and decreases in the activity or frequency of events. Such a dynamical system showing large temporal fluctuations cannot be characterised by a Poisson process with a single temporal scale. Rather it can be considered as a result of non-Poissonian dynamics with strong temporal heterogeneities on various temporal scales.[1]

There are a number of systems in Nature that evolve following non-Poissonian dynamics. One of the commonly known examples is the emergent dynamics of earthquakes [17, 55, 58, 59, 255], in which the times of shocks occurring at a given location show bursty temporal patterns, as illustrated in Fig. 1.1a. The occurrence of such events is governed by the modified Omori's Law [234], which states that the frequency of aftershocks decreases as a power law and can lead to a broad inter-event time distribution of shocks, when observed over a longer period of time. Another example of a natural phenomenon exhibiting bursty temporal patterns is solar flares induced by huge and rapid releases of energy [193, 297]. It has been shown that the stochastic processes underlying these apparently different phenomena show such universal properties that lead to the same distributions of event sizes, inter-event times, and temporal clustering [59]. These kinds of heterogeneities in the behaviour of systems emerging from different origins have been explained in the frame of self-organised criticality (SOC) [16], which provides a commonly accepted example of a theory for describing the burstiness of a system.

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[1] Non-Poissonian bursty dynamics is in general characterised by the heterogeneous distribution of inter-event times passing between the consecutive occurrences of a given type of event. In contrast a system with Poissonian dynamics, inter-event times are distributed exponentially. However, many empirical inter-event time distributions are broad and follow a log-normal, Weibull, or power-law form, implying that the underlying mechanisms behind them maybe different than a Poisson process. See more about this question in Chap. 2.

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