PREDICTABILY OF EXTREME EVENTS

FAST OVERAL CHANGES ALSO KNOWN AS CRITICAL TRANSITIONS, DISASTERS, CRISES, REGIME SWITCHING

"It became clear for me that it is unrealistic to have a hope for the creation of a pure theory [of the turbulent flows of fluids and gases] closed in itself. Due to the absence of such a theory we have to rely upon the hypotheses obtained by processing of the experimental data…"

Kolmogorov, 1991

PREDICTABILITY

LAPLACE, 1776:

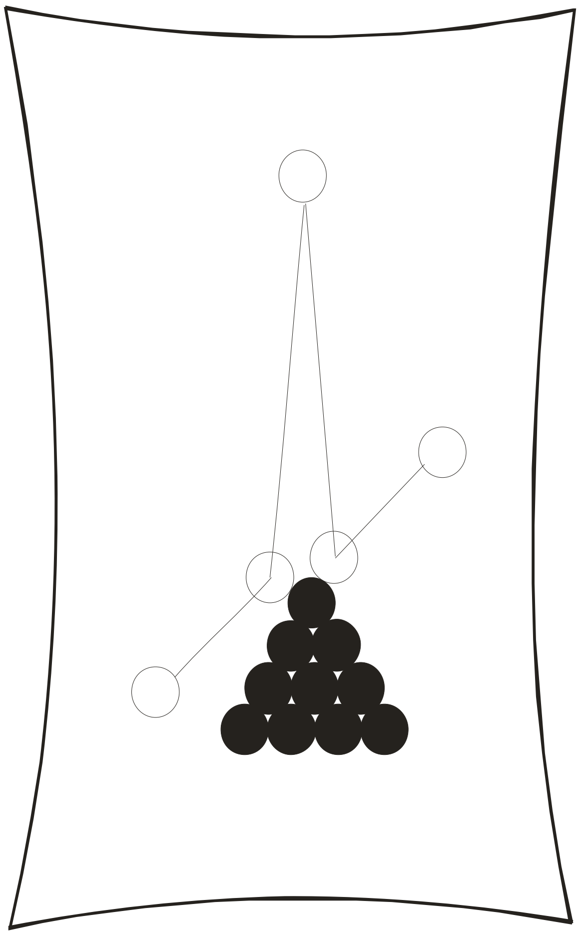
“If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment."

POINCARE, 1903:

“… it is not always so. It may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the latter. Prediction becomes impossible.... ”

This refers to exact precision. However after coarse-graining (averaging) the regular *behavior patterns* emerge and the system becomes predictable – up to the limit.

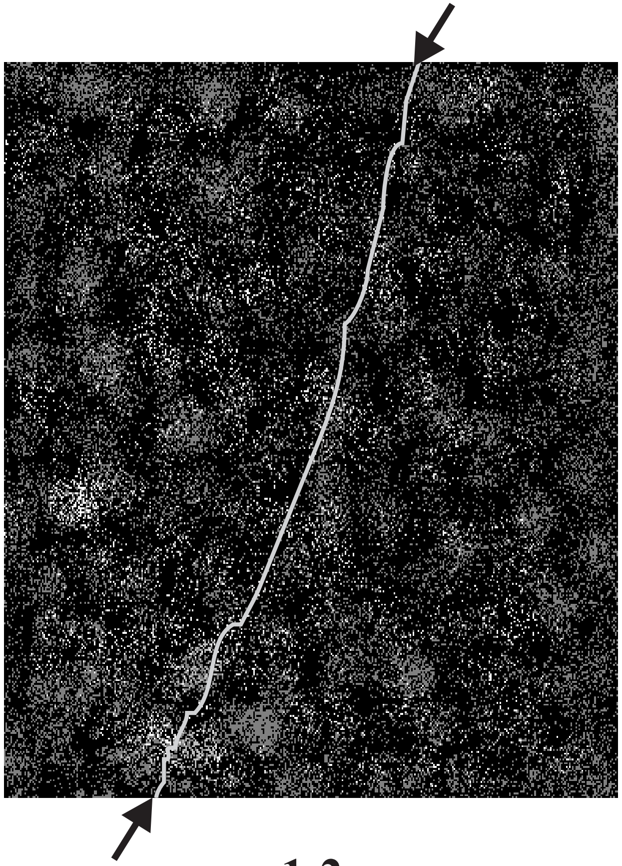
CHAOS



Sinai billiard:
A simple chaotic system

THE NEED FOR HOLISTIC APPROACH

20:1



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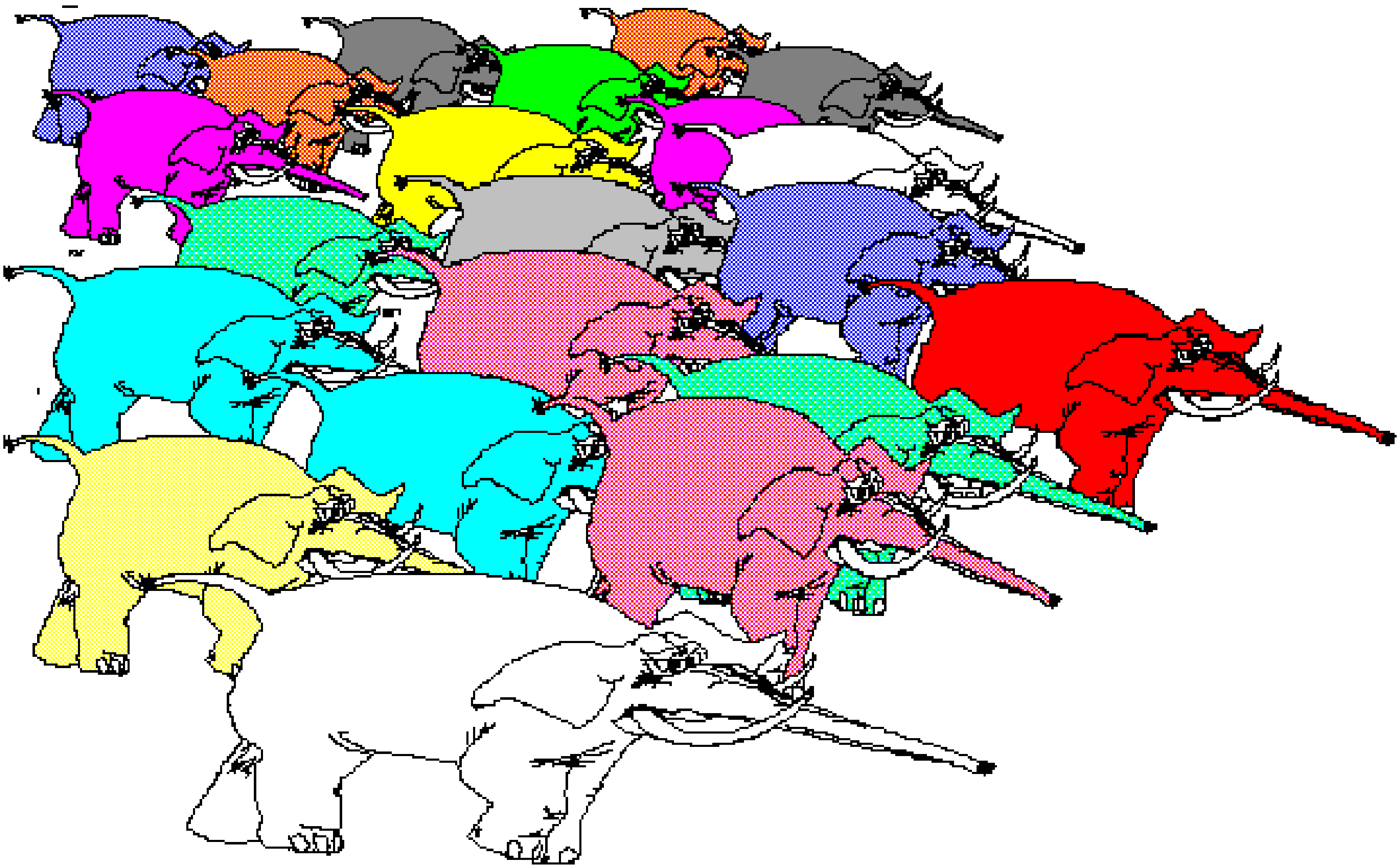


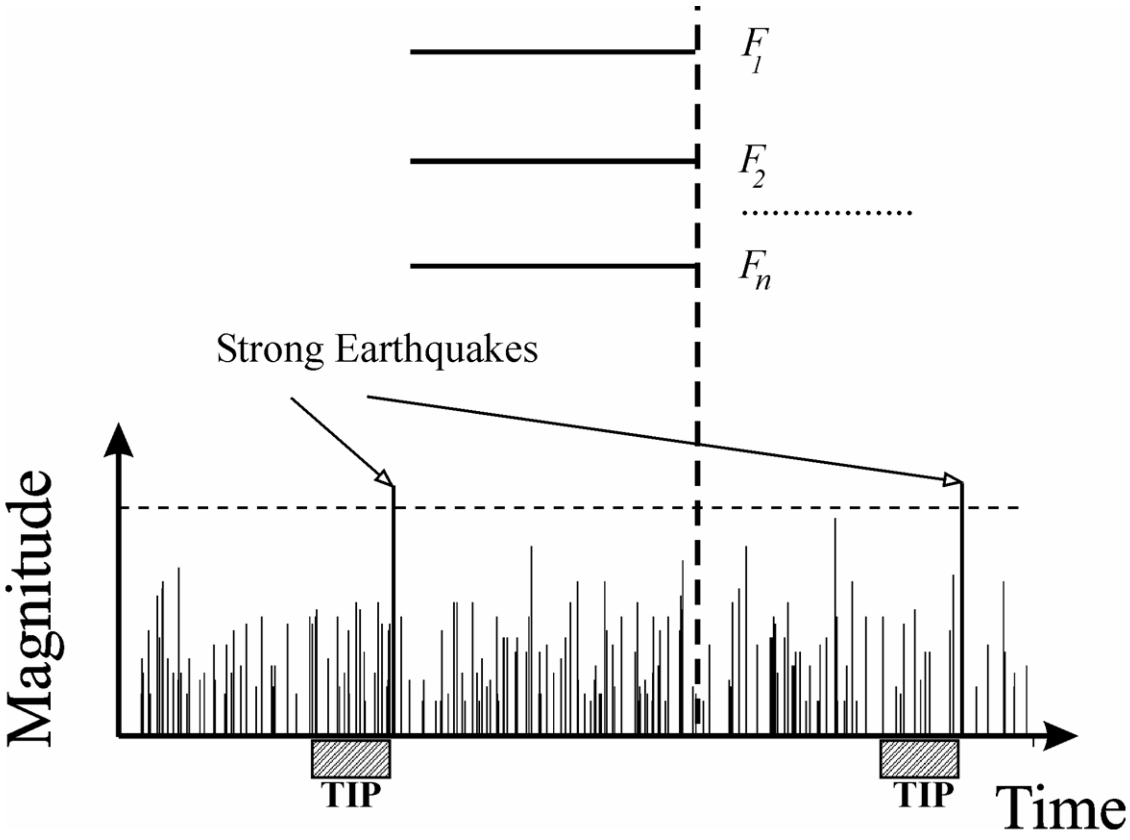
PREDICTION BY ANALYSIS OBSERVED TIME SERIES (e.g. of earthquake sequences)

(i) This sequence is robustly described **by the functionals $F_p(t)$, p=1,2, …, each depicting certain premonitory seismicity pattern P.**

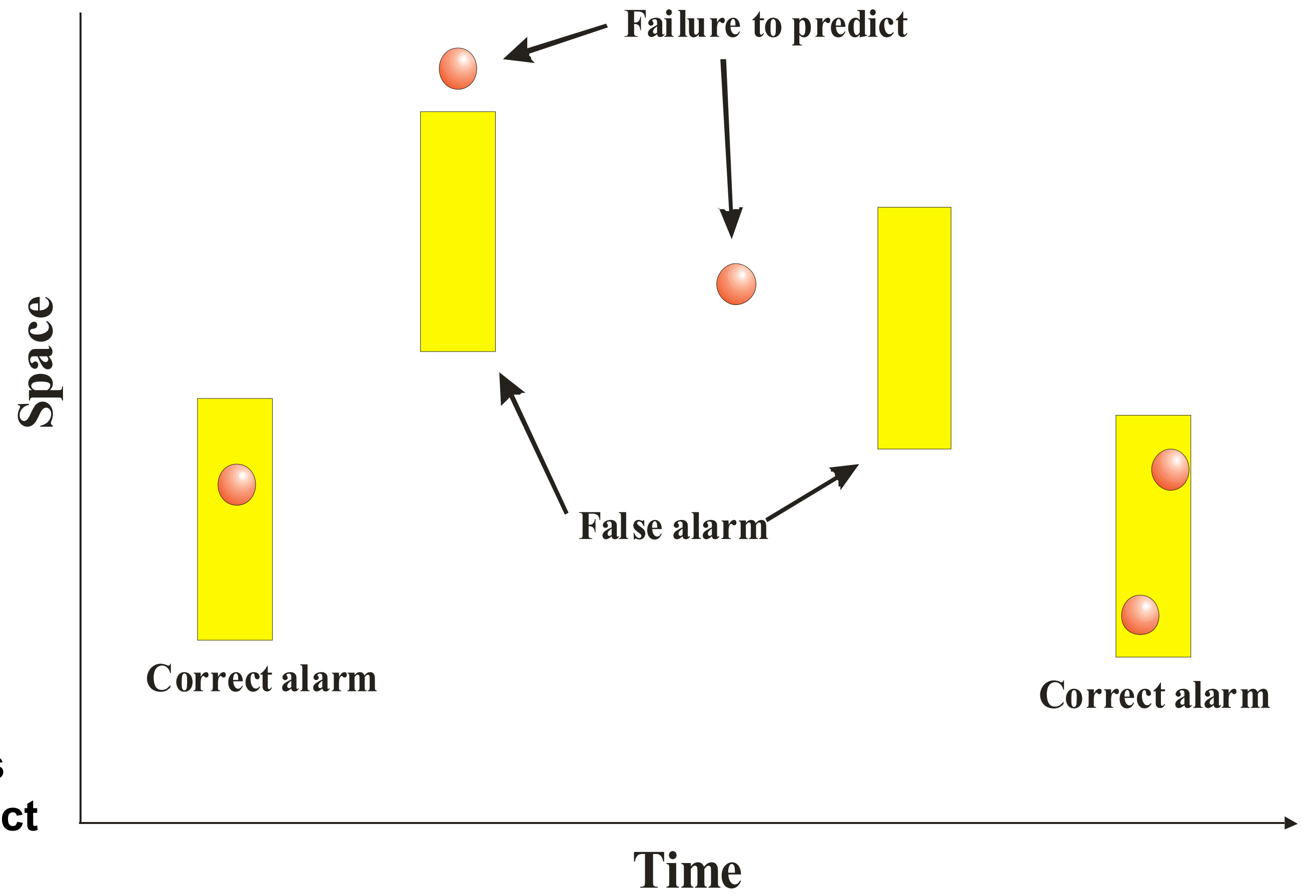
(ii) Emergence of a pattern P **is defined by condition $F_p(t) \geq C_{p.}$ The threshold C_p is usually defined as a certain percentile of the functional F_p.**

(iii) An alarm is triggered **when a single pattern or certain combination of patterns emerges. That combination is determined by pattern recognition.**

An alarm lasts for a time interval τ.



POSSIBLE OUTCOMES OF PREDICTION



Probabilistic component of prediction is represented by probability gain and rates of false alarms and failures to predict

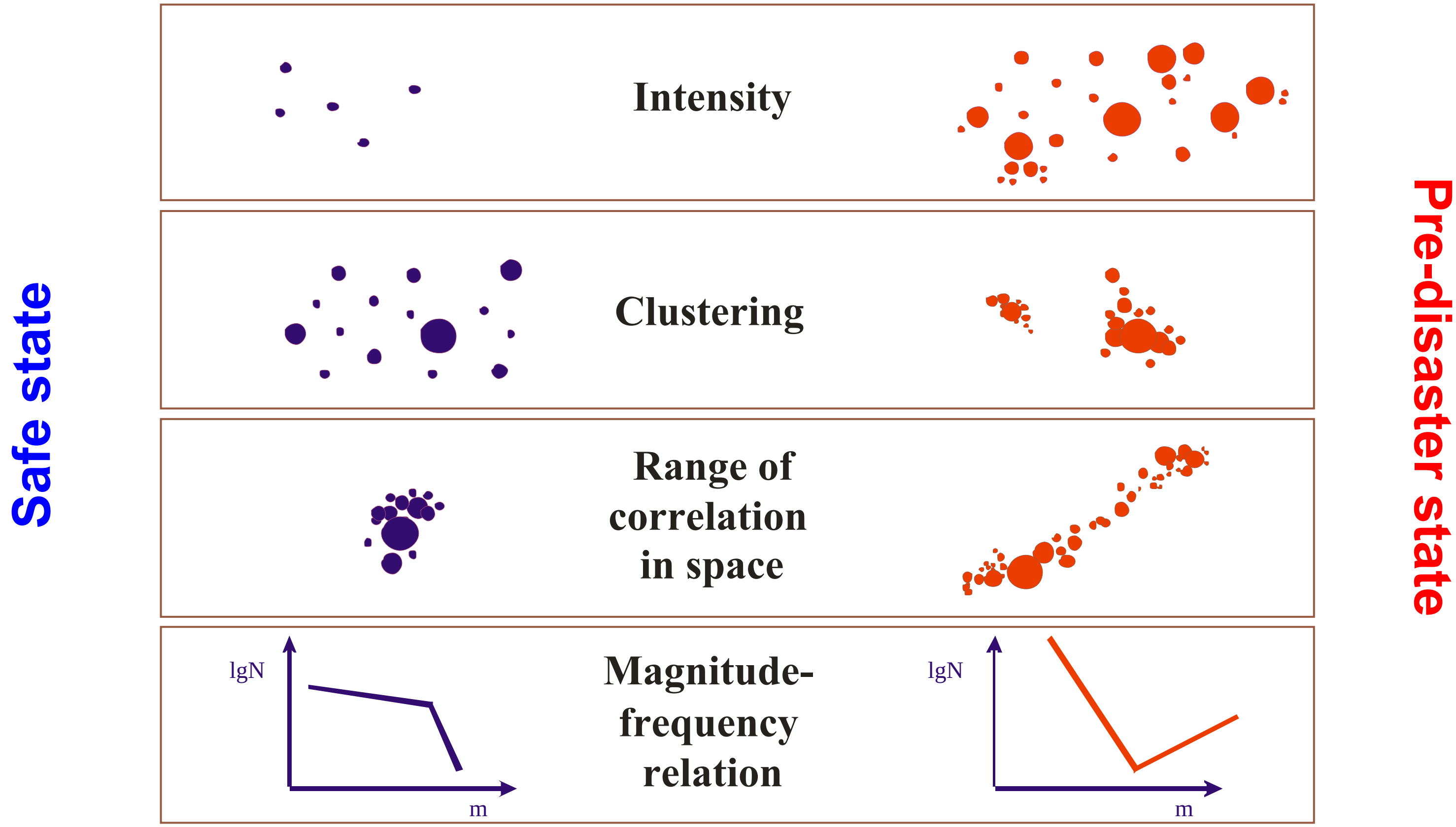
This is prediction of *extreme point events*, with predictor being a discrete sequence of alarms. This is different from Kolmogorov-Weiner prediction of continuous functions where predictor is also continuous.

PROBLEMS: CHOOSING FUNCTIONALS; STATISTICAL SIGNIFICANCE; and LINKING PREDICTION WITH DISASTERS PREPAREDNESS

FOUR PARADIGMS

WHAT PRECURSORS TO LOOK FOR?
Paradigm I. BASIC TYPES OF PREMONITORY PHENOMENA

An extreme event is preceded by the following changes in observed fields:



These phenomena are reminiscent of asymptotics near the phase transition of second kind. However, we consider not the equilibrium, but the growing disequilibrium, culminated by an extreme event.

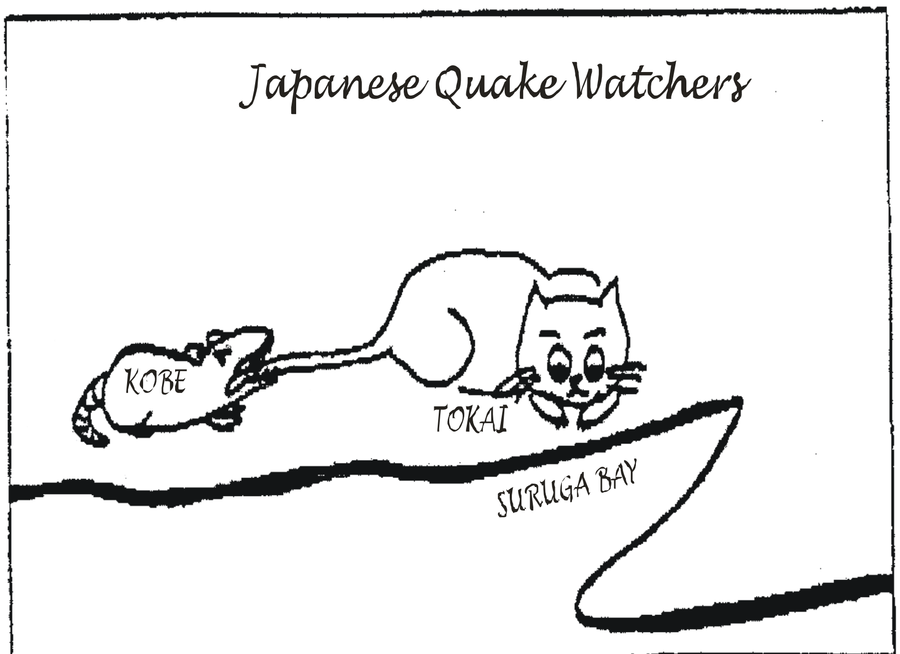
PROBLEMS: DEFINING THAT SET THROUGH SMALL NUMBER OF PARAMETERS and MERGING PRECURSORS INTO SCENARIOS

WHERE TO LOOK FOR PRECURSORS?
Paradigm II. LONG-RANGE CORRELATIONS
IN GENERATION OF EXTREME EVENTS

For example, generation of an earthquake is not localized around its future source. A flow of earthquakes is generated by a lithosphere, rather than each earthquake – by a segment of a fault.

In the time scale up to tens of years, precursors to an earthquake with linear source dimension L(M) are formed with the fault network of the size up to 10L, and in some cases 100L.

This is inevitable due to the impact of large-scale processes: perturbations in mantle flow, plates' movement and Earth rotations; invasion of fluids, etc.



Ch. Scholz, Geotimes, March '97

Up to 10L:
Pattern Σ (Malinovskaya, KB 1964); long-range aftershocks (Prozoroff, 1975; clusters (Caputo et al, 1977, Knopoff et al, 1980, Molchan et. al); Benioff strain release (Varness, 1989); algorithms CN (Rotwain et al, 1990), M8 (Kossobokov et al, 1986, 1990), SSE (Vorobieva and Levshina, 1992), RTP (Shebalin et. al, 2002)

Up to 100L:
Interaction of large earthquakes (Romanovicz, 1993); perturbations in Earth rotations (Press, Allen, 1995), etc.

Scholz, 1997

SELF-ADJUSTMENT OF PRECURSORS
Paradigm III. SIMILARITY

Premonitory phenomena are similar (identical after normalization) in the extremely diverse conditions and in a broad energy range.

In fracturing/seismicity that similarity was observed for

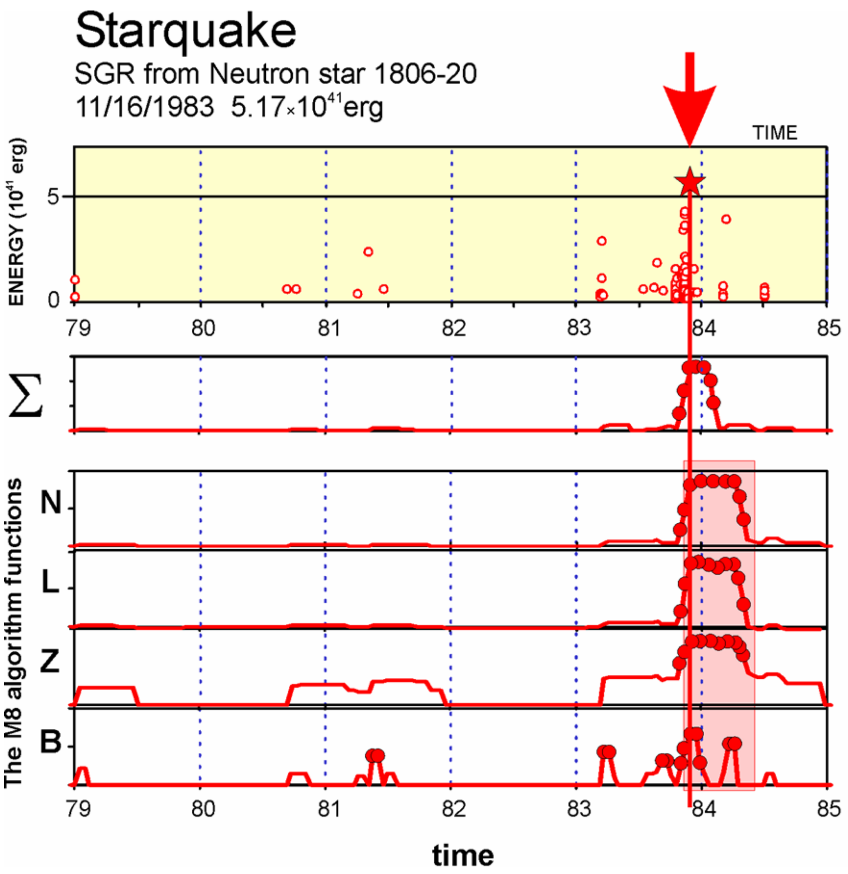
breakdown of laboratory samples ⇒
⇒ Rockbursts in mines ⇒
⇒ Earthquakes with magnitude from 4.5 to 8+ worldwide ⇒
⇒ Possibly, starquakes, magnitude about 20, ⇒

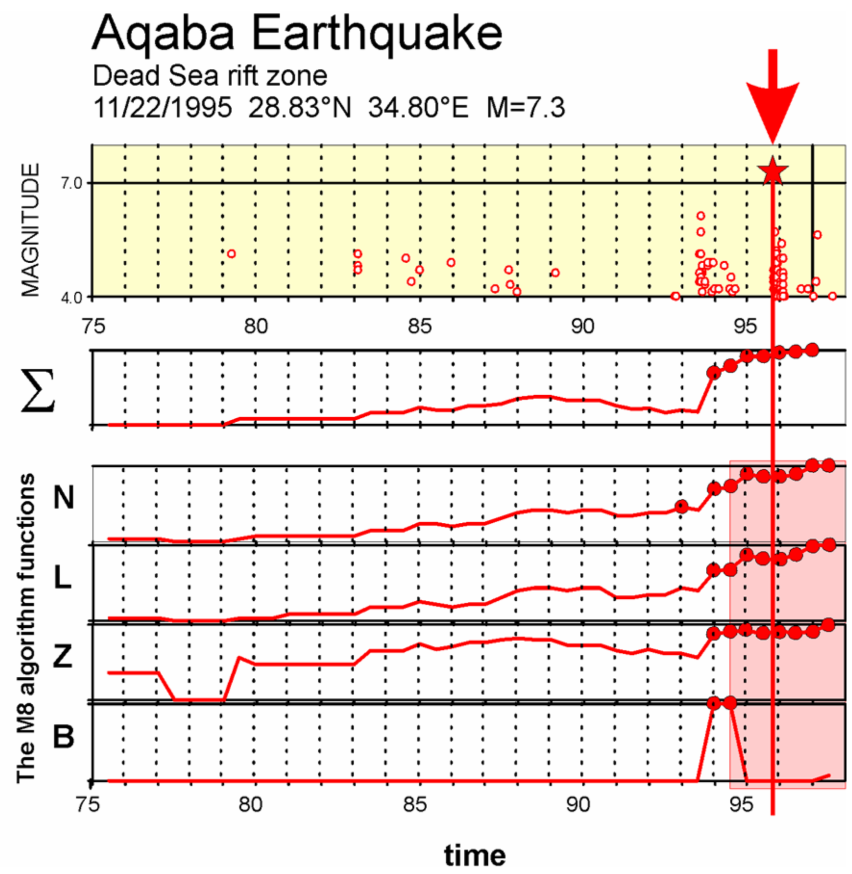
in the energy range from erg to 10^{23} erg, and possibly 10^{41} erg.

The similarity holds only after a robust coarse-graining, and is not unlimited: on its background some regional variations of premonitory phenomena emerge.

PROBLEMS: RENORMALIZATION and
RELATION BETWEEN TIME-, SPACE-, and ENERGY- SCALES

FRONTIERS OF SIMILARITY

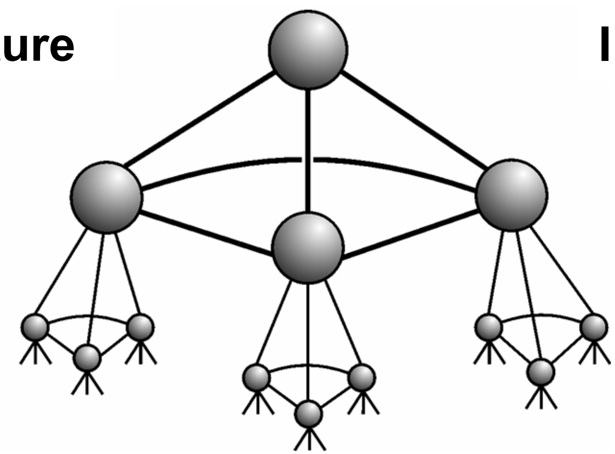




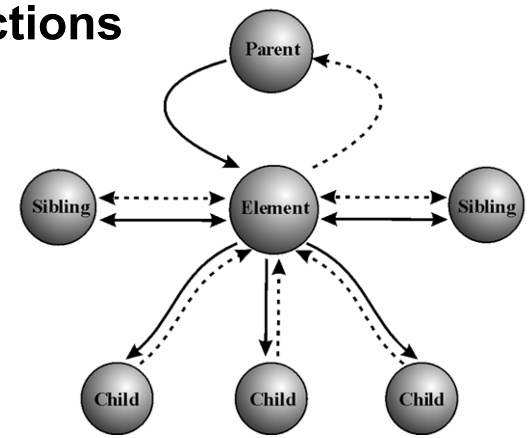
WHERE IS PHYSICS?
Paradigm IV. DUAL NATURE OF PREMONITORY PHENOMENA

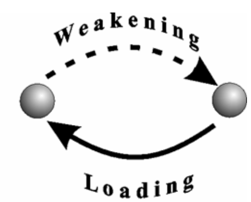
Some are "universal", common for hierarchical complex non-linear systems of different origin. **Example: Colliding Cascades/BDE model reproducing major types of precursors**

Structure



Interactions

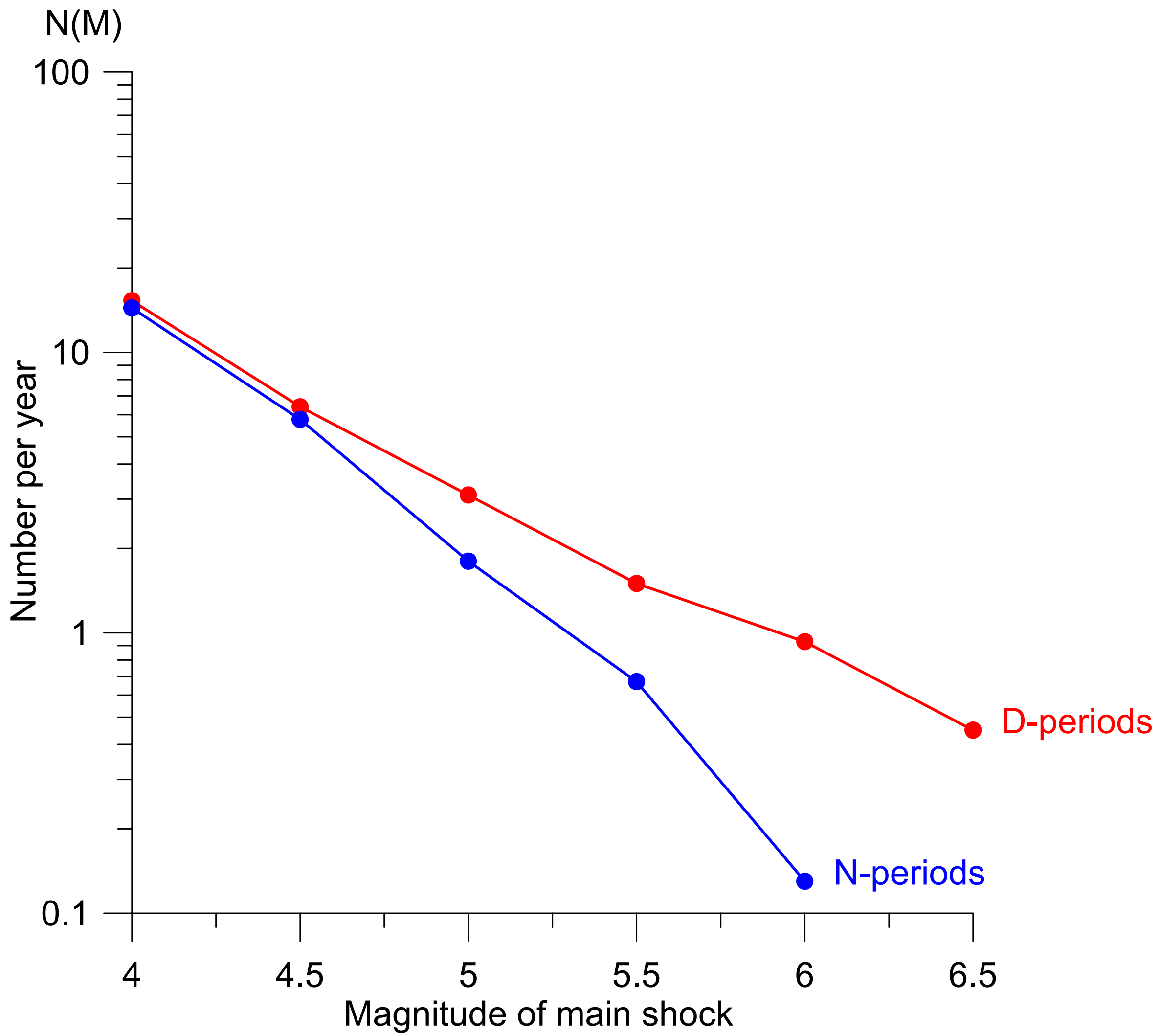




Some precursory seismicity patterns are specific to the geometry of the faults' network, or to a certain mechanism like stress corrosion, stress transfer, heat flow, etc.

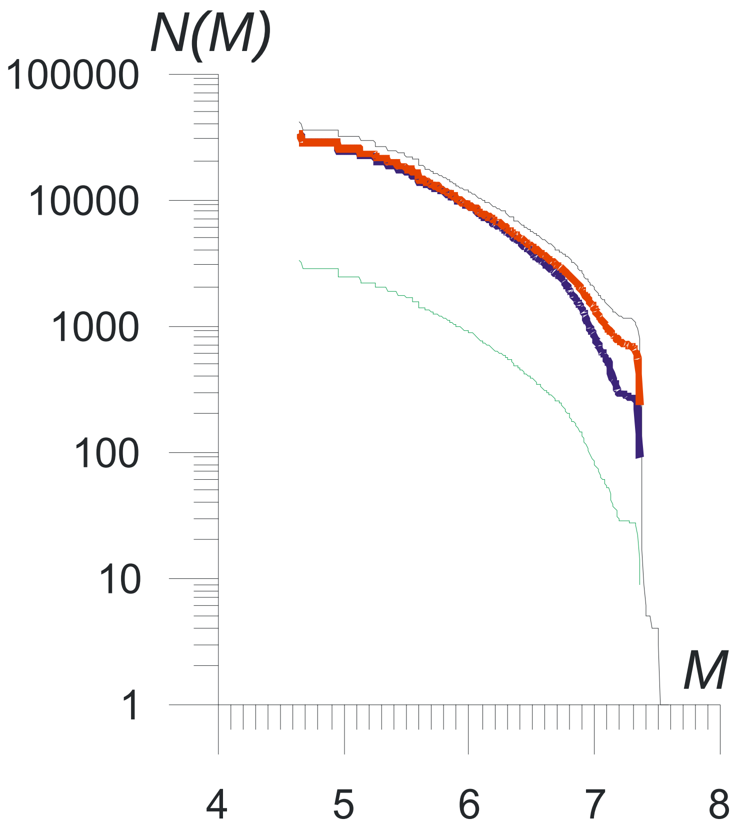
PROBLEMS: SIMILAR PRECURSORS TO OTHER GEOLOGICAL / GEOTECHNICAL DISASTERS

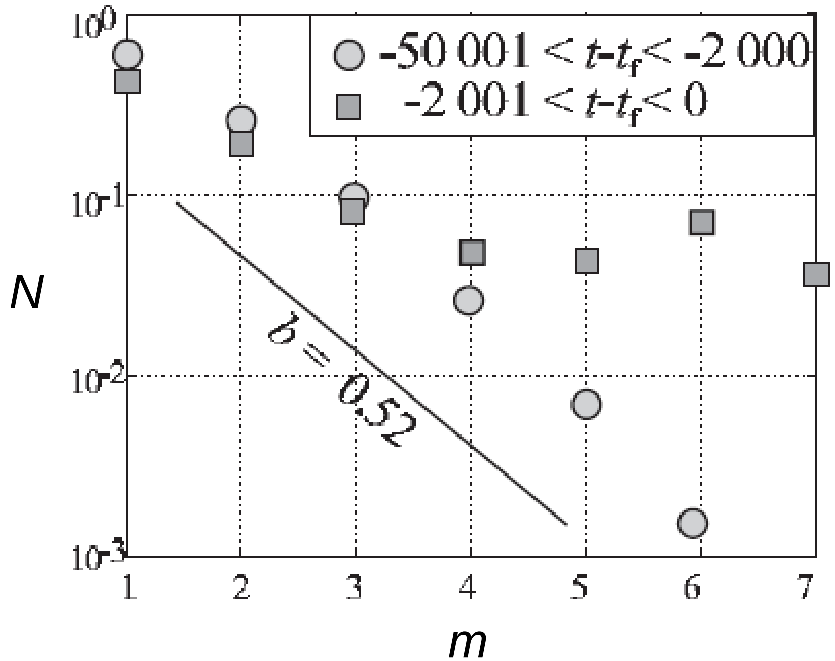
PRECURSORY TRANSFORMATION OF SCALING RELATION



EARTHQUAKES IN S. CALIFORNIA 1932 – 1999.

Extreme events: M ≥ 6.4. Scaling relation N(M) is defined for main shocks of magnitude M or more. Courtesy I. Rotwain





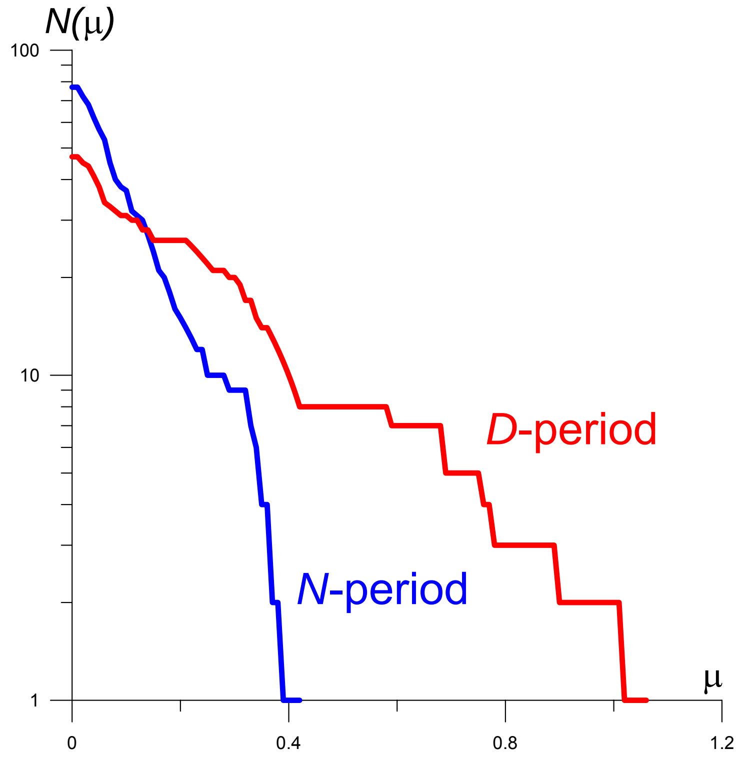
EARTHQUAKES IN BLOCKS&FAULTS MODEL.

Extreme events: M = 7.4. Scaling relation is defined for main shocks.

FRACTURES IN COLLIDING CASCADES / BOOLEAN DELAY EQUATIONS MODEL.

AMERICAN ECONOMIC RECESSIONS

Extreme events – recessions' starts. Scaling relation is defined for the changes of industrial production trends. N(μ) is the number of cases when that change is ≥ μ.
http://www.igpp.ucla.edu/prediction/ref/Pre-recession.pdf

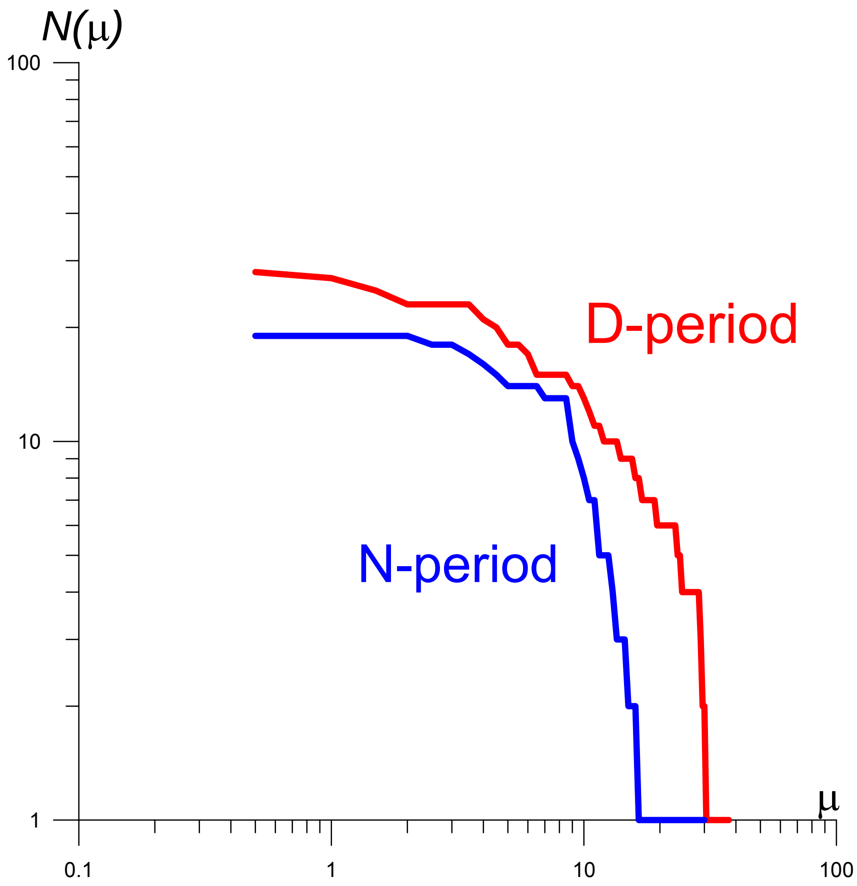


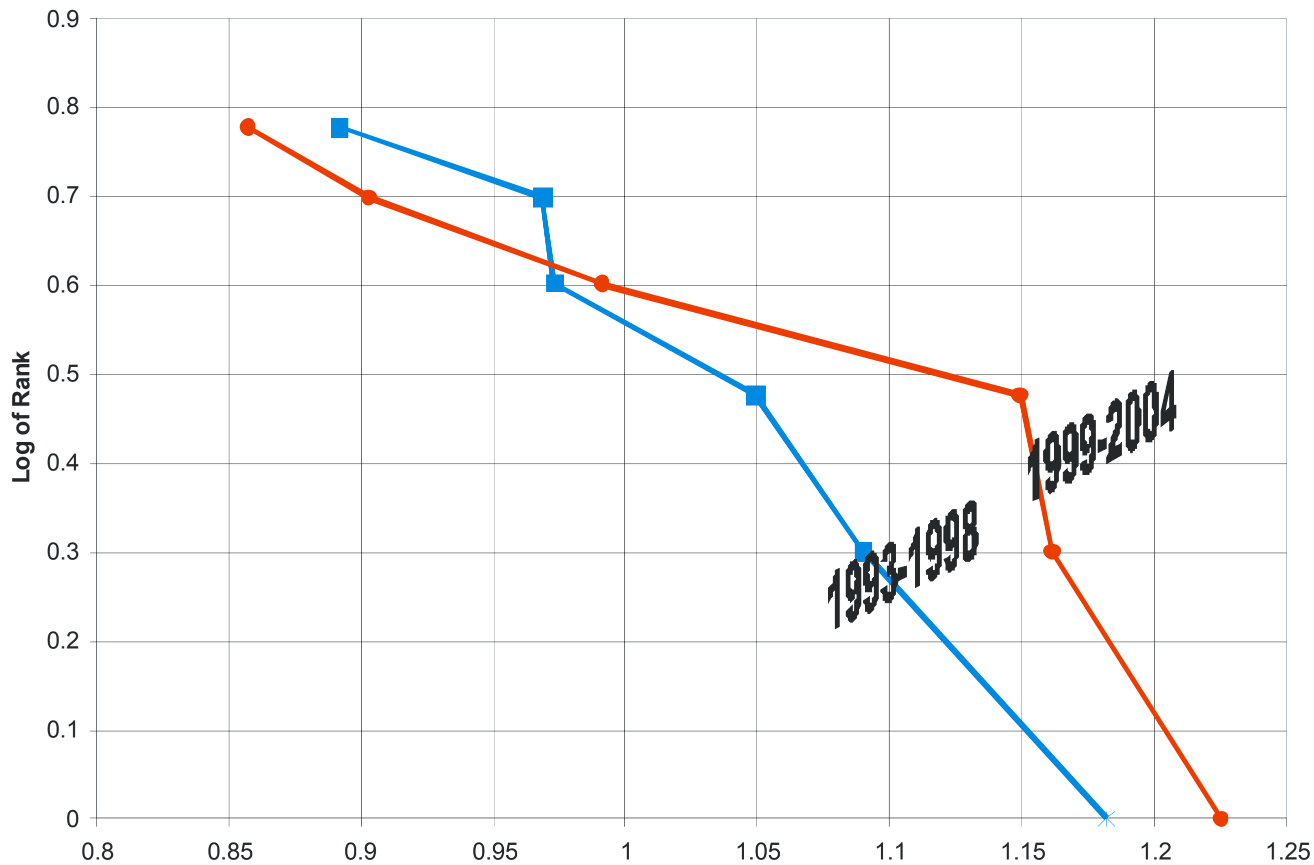
N(μ) is the number of events with "magnitude" ≥ μ.

HOMICIDES IN LOS ANGELES, 1975 - 1993.

Extreme events – starting points of lasting surge of homicide rate.
Scaling low is defined for the lesser crimes – assaults with firearms.

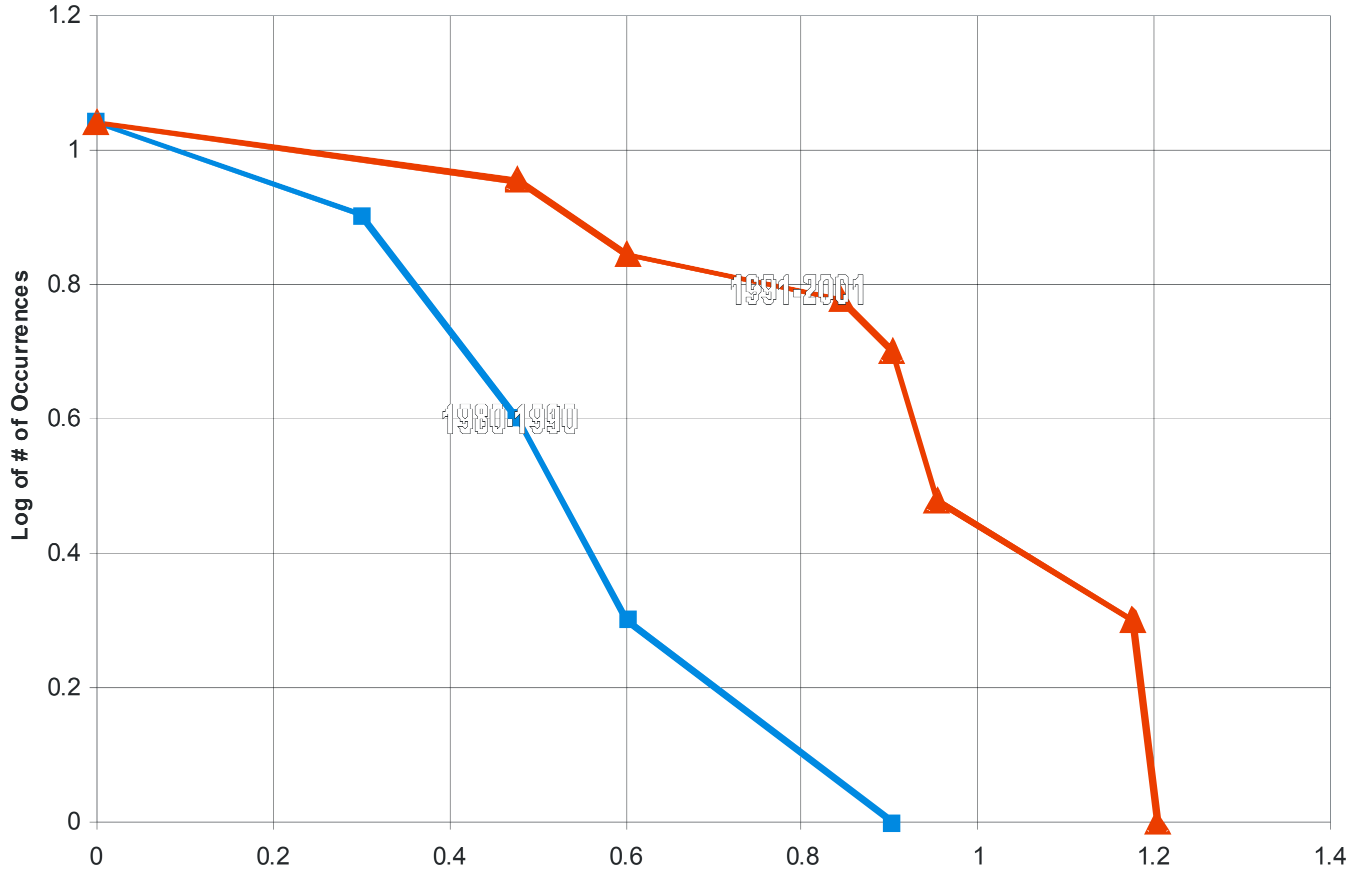
http://www.igpp.ucla.edu/prediction/ref/Homicide.pdf





GROSS BOX OFFICE FOR US FILM INDUSTRY, 1993 – 2004.

Extreme event – large drop of the gross in 2005. Scaling relation is defined for year-to-year changes in the gross Courtesy of D. Gabrielov



RANKING OF THE FILMS BY A CERTAIN STUDIO, 1993 – 2004.

Extreme event – large drop of the rank of the top gross film by that studio. Scaling relation id defined for yearly ranks such films, Courtesy of D. Gabrielov

TEST OF METHODS BY PREDICTING IN ADVANCE

Earthquakes worldwide

Elections, US

Recessions, US

Surge of unemployment, (US, EU)

Surge of homicides (Los Angeles)