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Prediction of Critical Phenomena: Four Paradigms

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PREDICTION OF CRITICAL PHENOMENA: FOUR PARADIGMS

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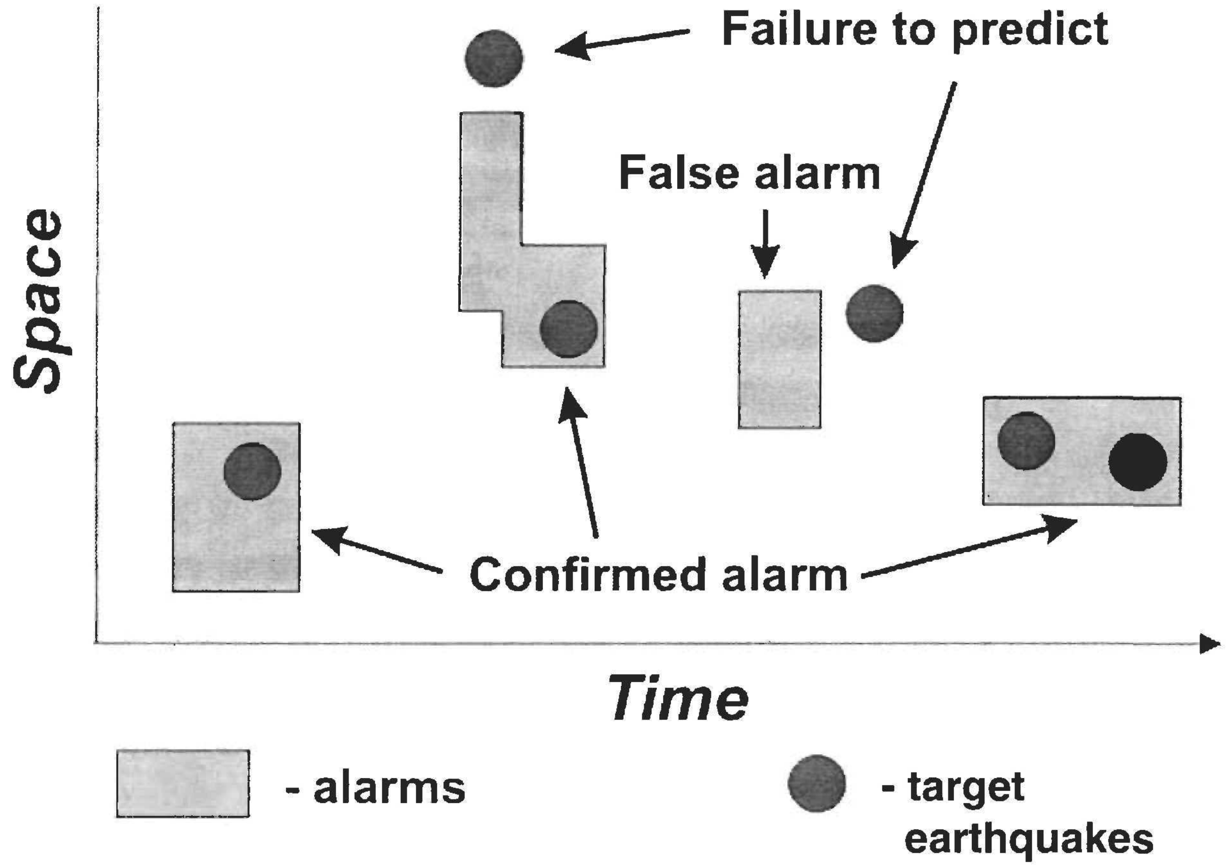
Our prediction problem: ***where and when a strong earthquake will occur*.**

Prediction is formulated as a discrete sequence of alarms.

POSSIBLE OUTCOMES OF PREDICTION

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



This problem is different from and complementary to forecasting – extrapolation of seismicity by classical Kolmogoroff – Wiener approach

PERFORMANCE OF PREDICTION ALGORITHMS

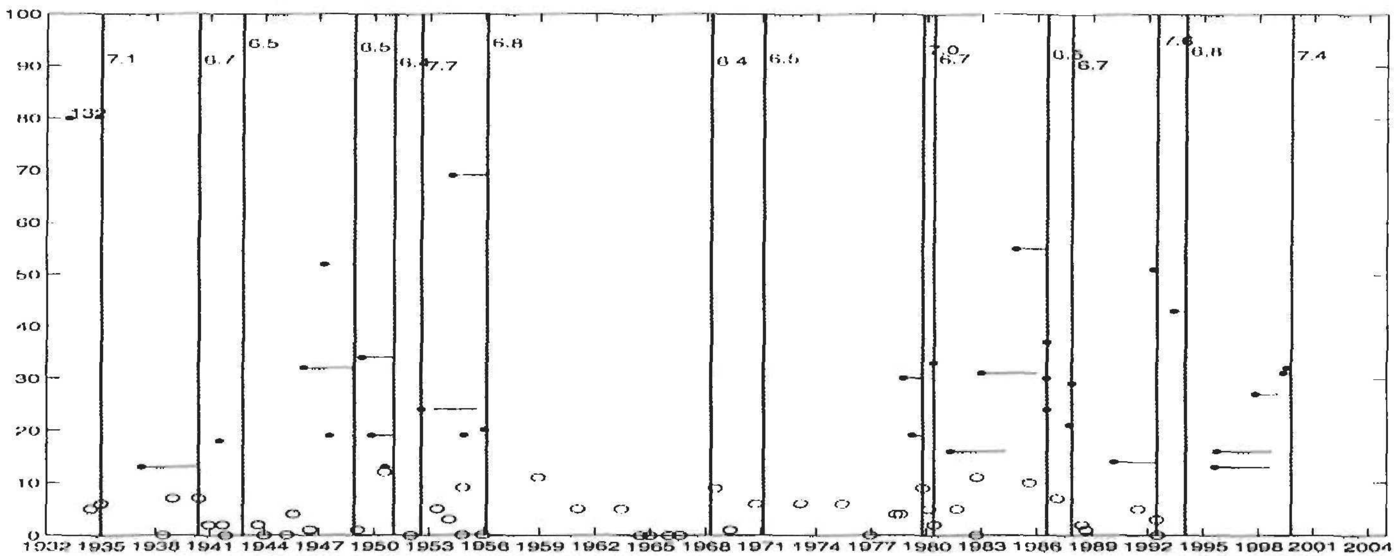
ILLUSTRATIONS

Burst of aftershocks (“Pattern B”)

S. California, 1932-2004, target earthquakes M≥6.4

Keilis-Borok et al., Nature 283, 1980; Molchan et al., PEPI 61, 1990

Courtesy of Z. Liu



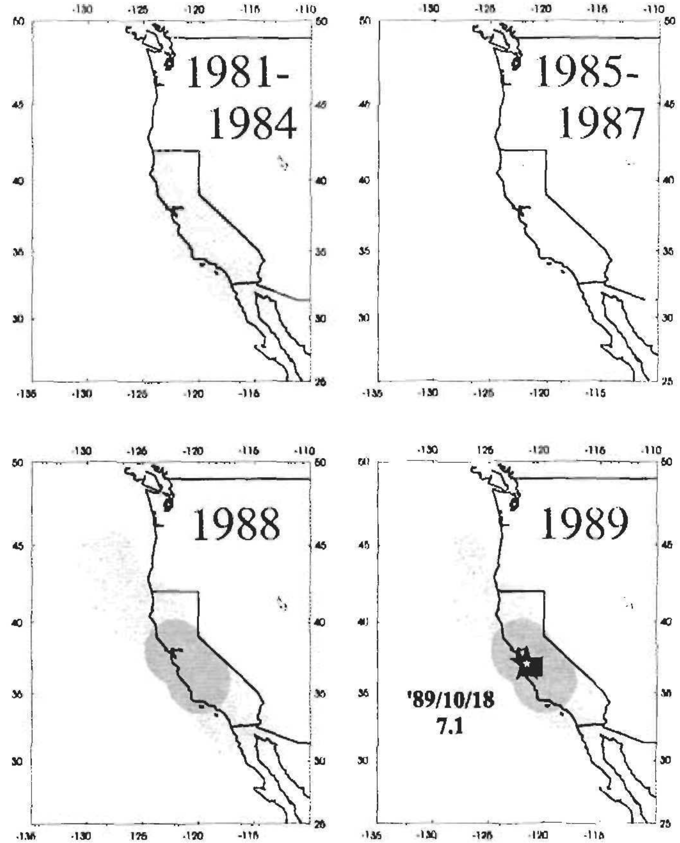
Precursor is a medium magnitude main shock with abnormally large number of aftershocks. Place of earthquake within a region was not localized

Retrospective analysis with parameters fixed after 1980.

Retrospective applications are promising in many regions worldwide

Other promising single precursors - “∑” and “UB” and deviation from GR relation

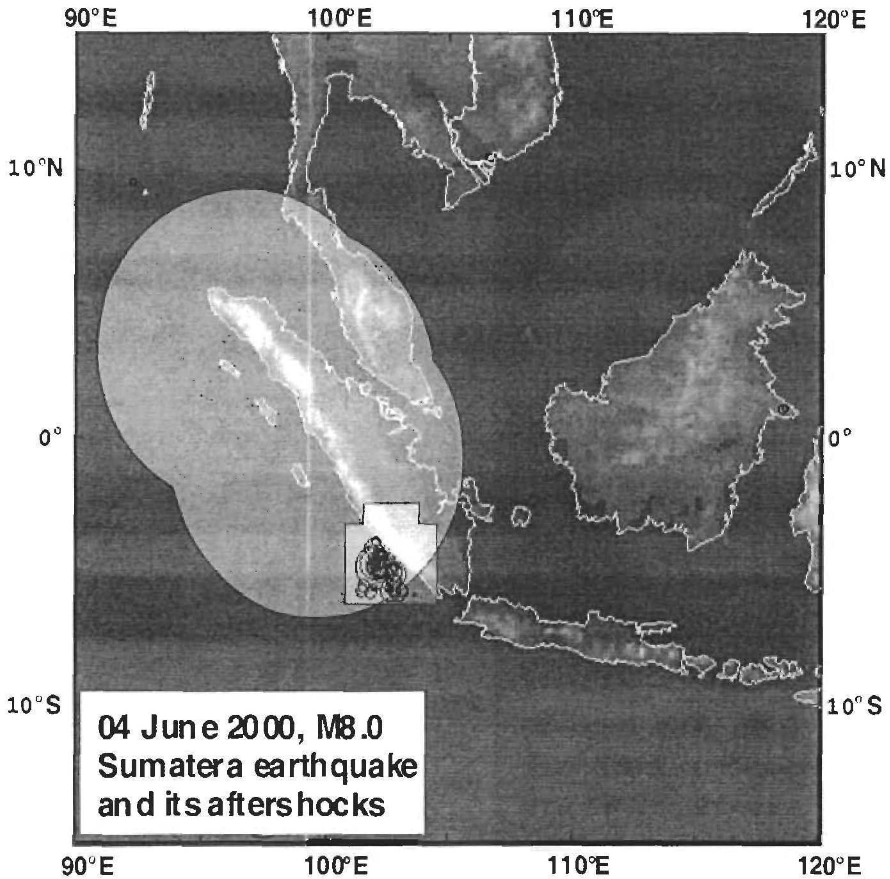
Algorithm M8. Prediction of Loma Prieta ea-ke, 1989, M = 7.1

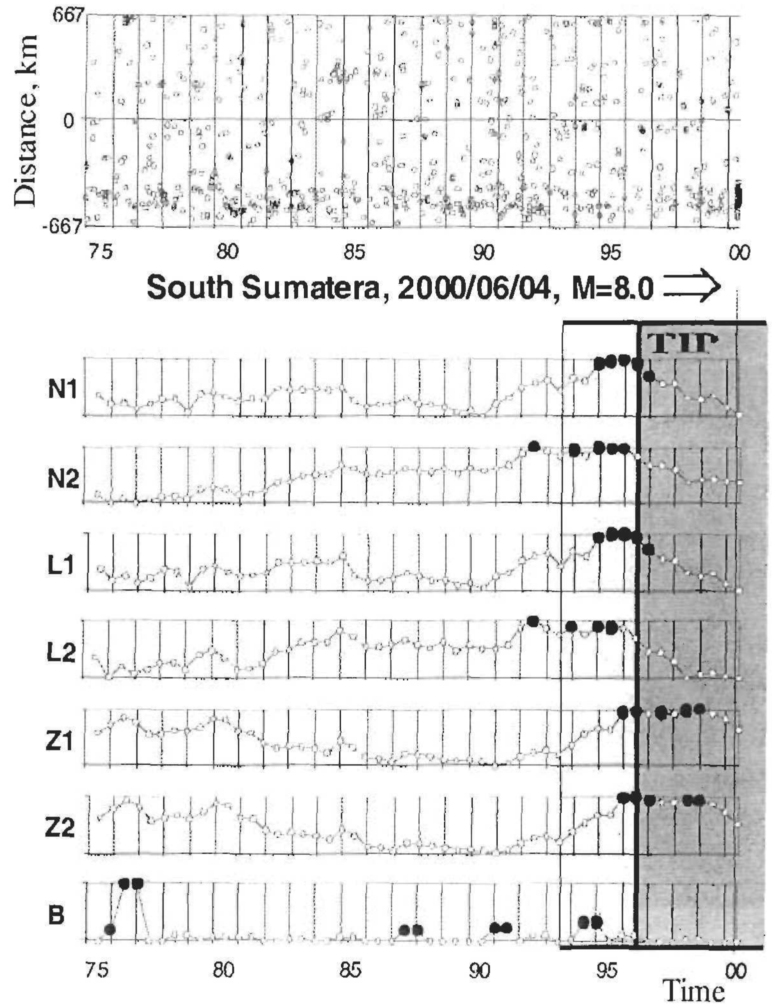


Subject of correspondence between M. Gorbachev and R. Reagan in 1988

Algorithms M8 and MSc

http://www.mitp.ru/predlist.html;
Kossobokov et al., PEPI 1999, Vol 111.





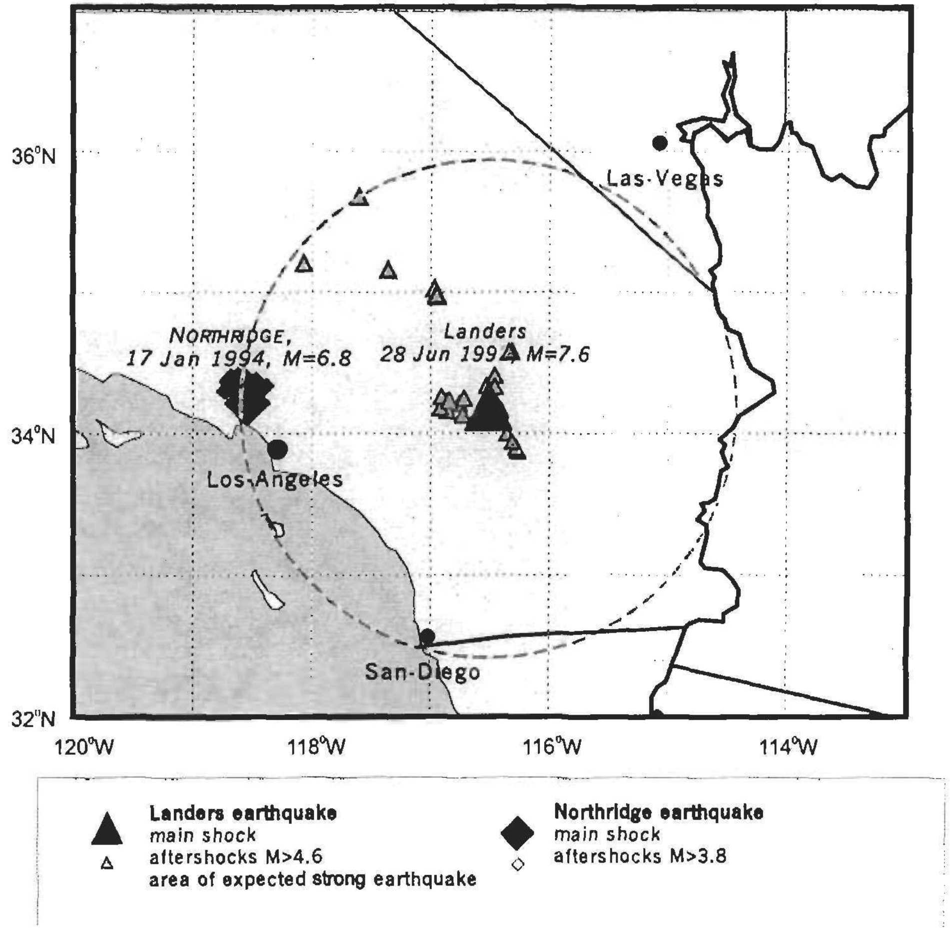
SCORING:

Since 1985, 11 out of 15 M8+ earthquakes have been captured by M8 alarms occupying altogether 33% of the time-space considered. 9 of them have been captured by MSc alarms occupying 17% of time-space.

Algorithm SSE

Northridge, California earthquake, 1994, M=6.8, was predicted by analysis of aftershocks of the Landers earthquake, 1992, M=7.6.

Prediction (T.Levshina and I.Vorobieva, EOS, Oct 1992): Earthquake with *M* = 6.6 or larger is expected during 18 months after Landers ea-ke within the 169-km distance from its epicenter (circle)
Outcome: Northridge ea-ke, 28 Jan 1994, 20 days after alarm expired



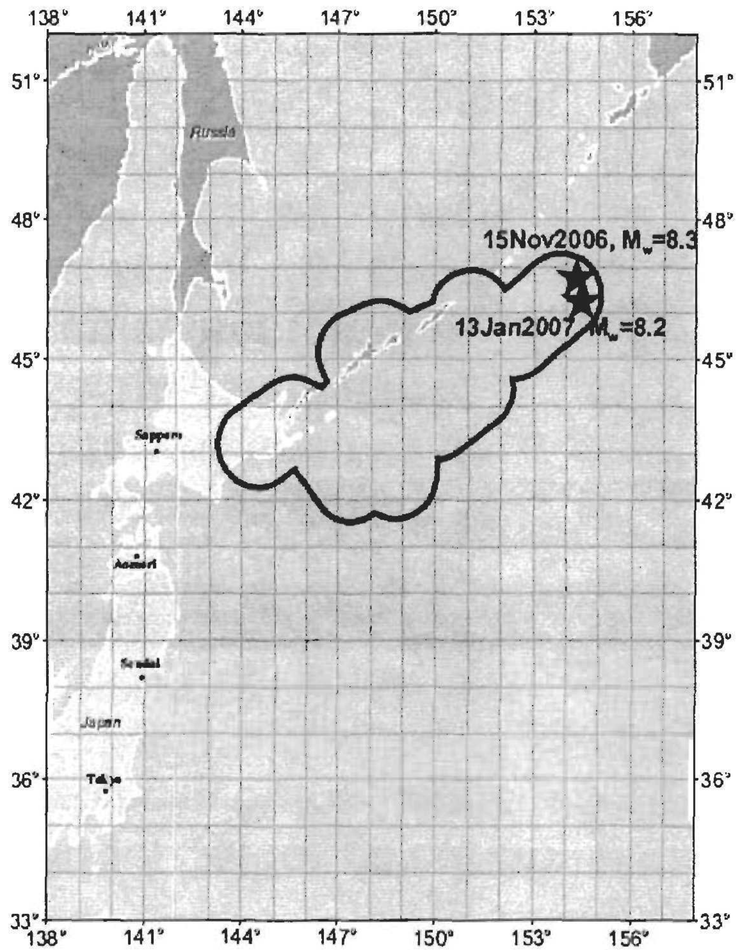
SCORING:

Algorithm SSE was applied since 1989 in 30 cases with 6 errors (2 failures-to-predict a second strong earthquake and 4 false alarms).

Algorithm RTP

(e.g., P.Shebalin, Tectonophysics, 424, 335-349, 2006)

Advance prediction of Simushir earthquake, Kuril islands, Russia, Nov. 15, 2006, M_w = 8.3 and second large earthquake, Jan. 13, 2007, M_w = 8.2



Case history, 2006-2007

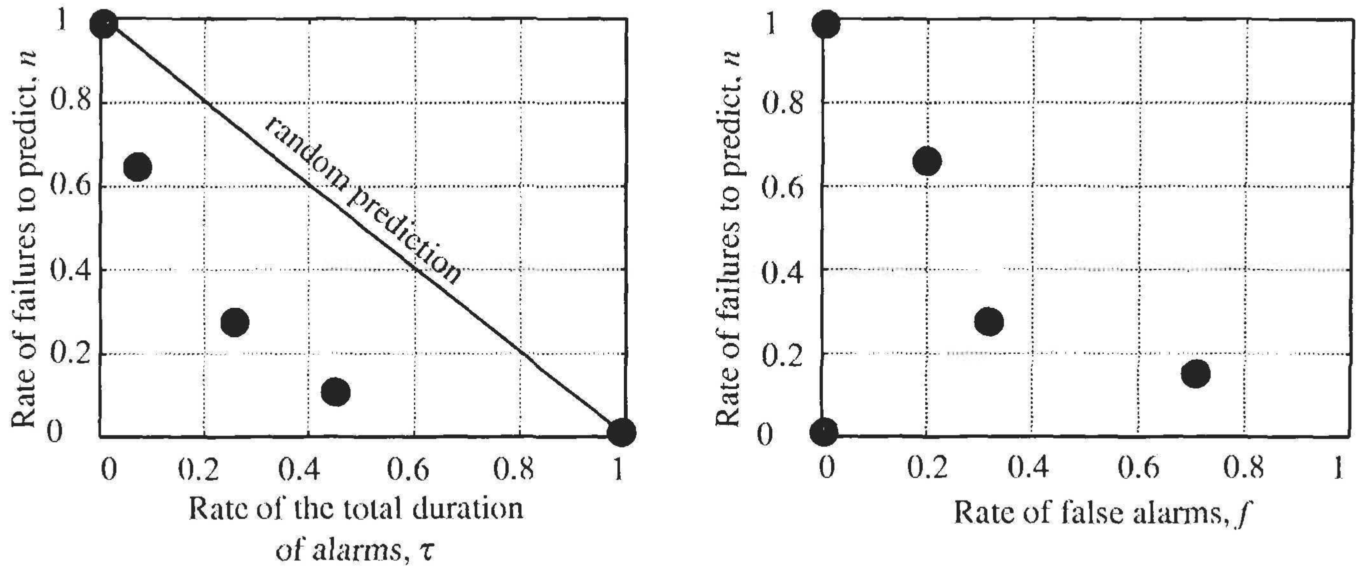
Septemer 30, 2006: Precursory chain of earthquakes was formed. It indicates that an earthquake with magnitude 7.2 or more will occur in an area shown by red contour within 9 months.

October 9, 2006: Precursor is reported on the RTP web site (http://www.igpp.ucla.edu/predictio n/rtp2/RTP10a.pdf)

Nov. 15, 2006 and Jan. 13, 2007: *Simushir earthquake*, M_w=8.3, and a second strong earthquake, M_w=8.2, have occured, their epicenters in the area shown by blue stars.

Quality of prediction

Scheme of the error diagram



Such diagrams show performance of a prediction method: the tradeoff between the rate of false alarms, f; the rate of failures to predict, n; and the relative time-space occupied by alarms, τ.

Definitions: **Consider a prediction algorithm applied to a certain territory during the time period T. A certain number A of alarms is declared and A_f of them are false. N extreme events did occur, and N_f of them have been missed by alarms. Altogether, the alarms cover the time D. Performance of the algorithm is characterized by three dimensionless parameters: the total relative time-space of alarms, $\tau = D:T$; the rate of failures to predict $n = N_f:N$; and the rate of false alarms $f = A_f:A$.**

Points on the diagonal on the left plot correspond to a random binomial prediction. Three other points illustrate comparison of different prediction algorithms; the choice among them belongs to a disaster manager..

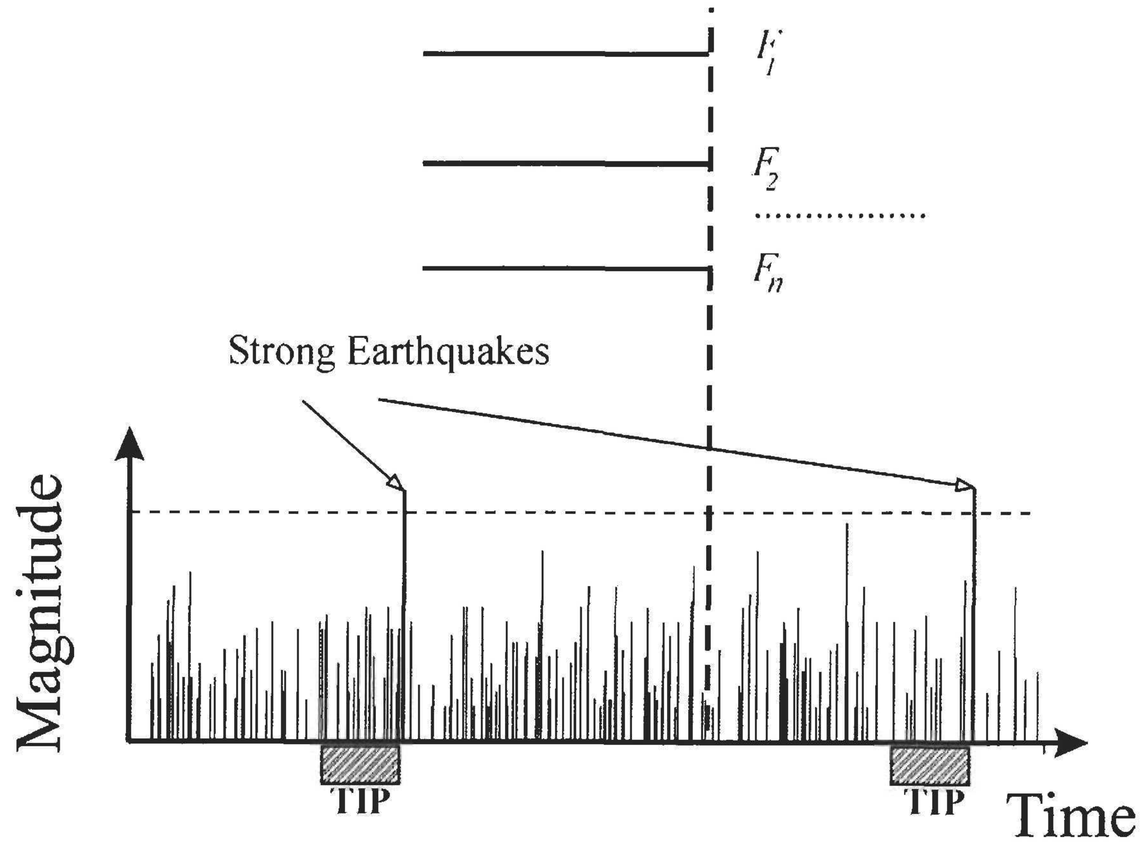
G. Molchan developed that approach for ***interdependent events.***

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

These series are robustly described **by the functions $F_p(t)$, capturing hypothetical precursory patterns P. Hypotheses might come from:**

--Geo-specific models (e.g. fault network; stress corrosion)
--"Universal" models of stat. physics kind
--Exploratory data analysis

An alarm is triggered **when certain set of patterns emerges. This set is determined by "pattern recognition of extreme events".**



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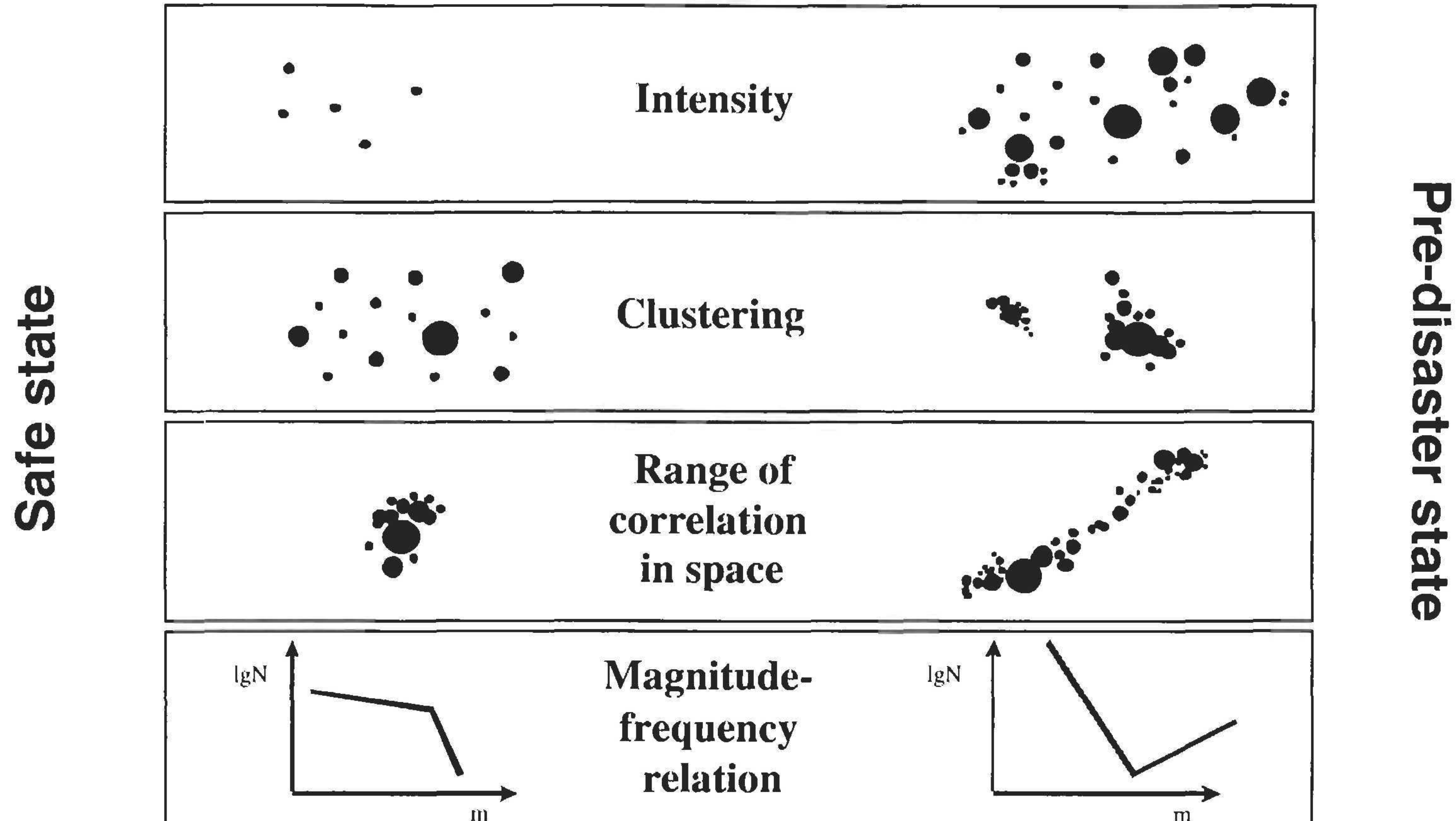
FOUR PARADIGMS

WHAT PRECURSORS TO LOOK FOR?

Paradigm I. BASIC TYPES OF PREMONITORY PHENOMENA

A strong earthquake 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 return to equilibrium, but the growing disequilibrium, culminated by an extreme event.

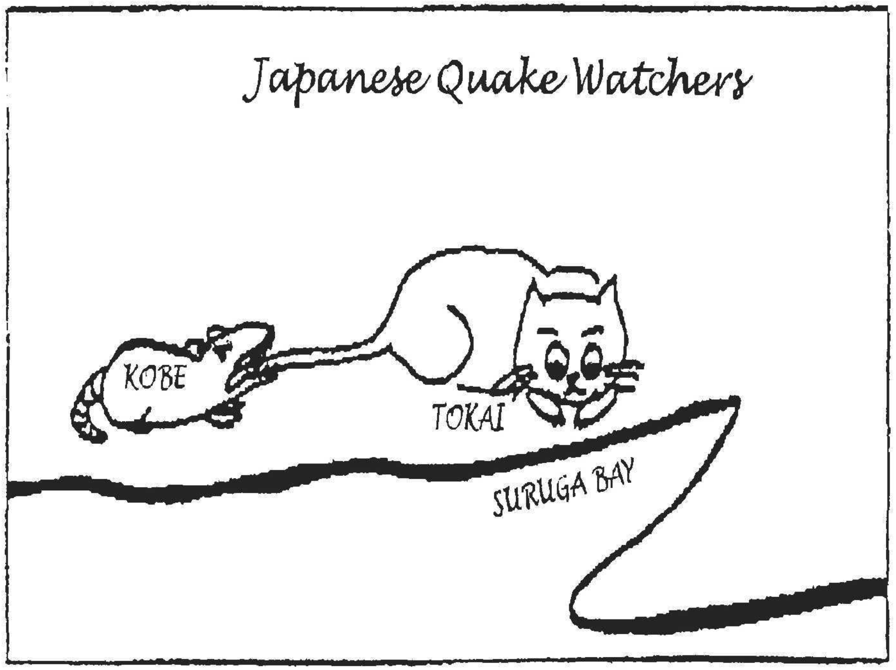
Prediction algorithms may use combination of precursors.
But in the *learning by doing* you should start with a single precursor.
PROBLEMS: LOW-PARAMETRIC DEFINITION OF THAT SET and MERGER OF PRECURSORS INTO SCENARIOS.

WHERE TO LOOK FOR PRECURSORS?
Paradigm II. LONG-RANGE CORRELATIONS

The generation of an earthquake is not localized around the 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 10L to 100L (global scale for $M \geq 7.5$).

This is inevitable due to perturbations of large-scale processes in:
-- Ductile lower crust (Aki)
-- Plate movements (Press, Allen)
-- Mantle flows (Schubert, Turcotte, Ismail-Zadeh, Soloviev)
-- Chandler wobble, Earth rotation, drift of magnetic field (Press, Briggs)



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); Benioff strain release (Varness, 1989); algorithms CN (Rotwain et al, 1990), M8 (Kossobokov et al, 1986, 1990), SSE (Vorobieva and Levshina, 1992)

Up to 100L:

Interaction of large earthquakes (Romanovicz, 1993). Alternation of source mechanisms (Press, Allen, 1995).

Scholz, 1997

SELF-ADJUSTMENT OF PRECURSORS TO ENVIRONMENT
Paradigm III. SIMILARITY

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

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.

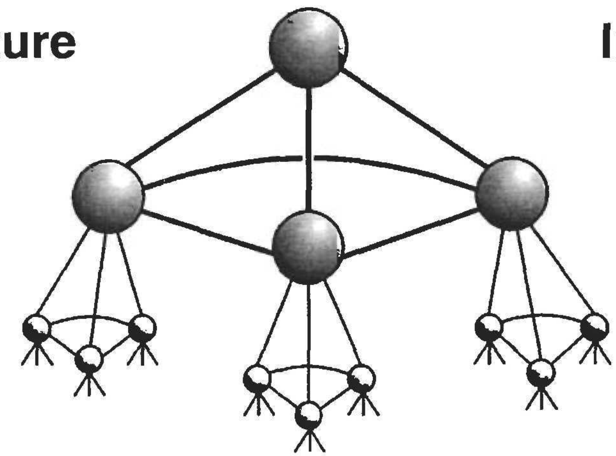
PROBLEMS: RENORMALIZATION and
RELATION BETWEEN TIME, SPACE, and ENERGY SCALES

WHERE IS PHYSICS? /L. Kadanoff/
Paradigm IV. DUAL NATURE OF PRECURSRY PHENOMENA

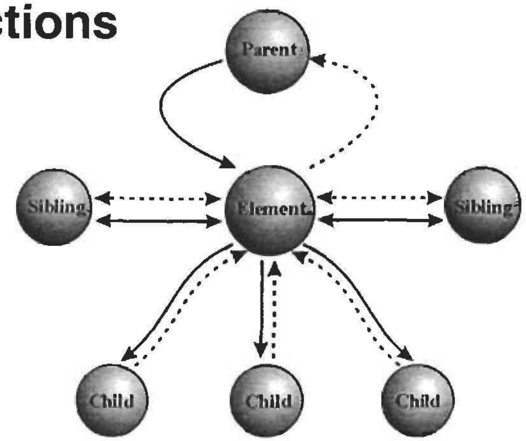
Some are "universal", common for hierarchical complex non-linear systems of different origin.

Example: Colliding Cascades/BDE Model reproducing major premonitory seismicity patterns

Structure



Interactions

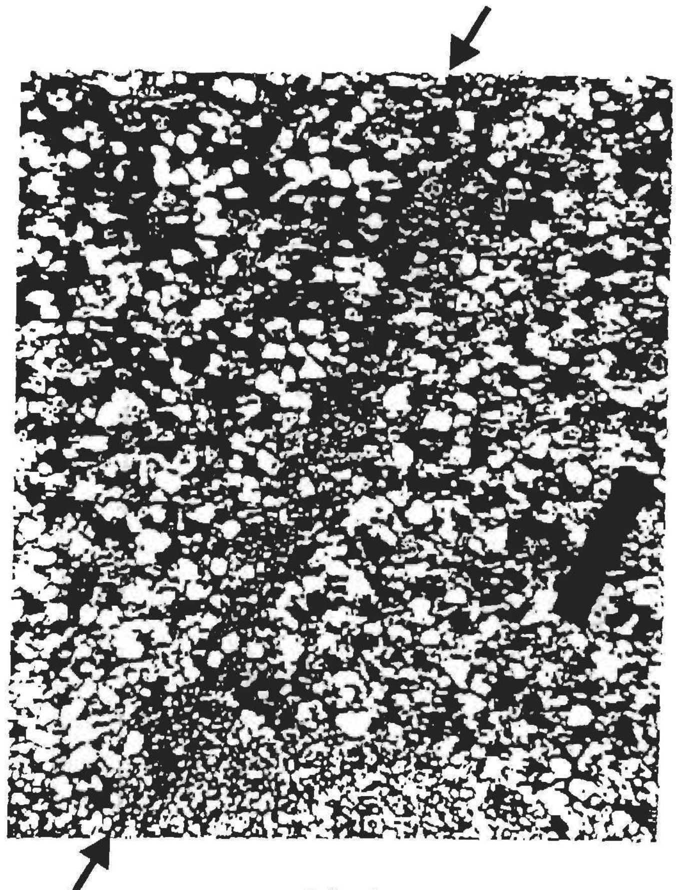


Other phenomena are specific to the geometry of the faults' network, or to a certain mechanism like stress corrosion, stress transfer, heat flow, model of blocks-and-faults dynamics etc.

PROBLEMS: SELF-ADJUSTING, LOW-PARAMETRIC DEFINITION OF PRECURSORY PHENOMENA

THE NEED FOR HOLISTIC APPROACH

Complex systems are not predictable in the Laplacean sense, with accuracy limited only by accuracy of data. However, after a coarse graining, in a not-too-detailed scale, such systems exhibit regular behaviour patterns and become predictable, up to the limits. The holistic approach, "from the whole to details" opens a possibility to overcome the complexity itself and the chronic imperfection of data as well.



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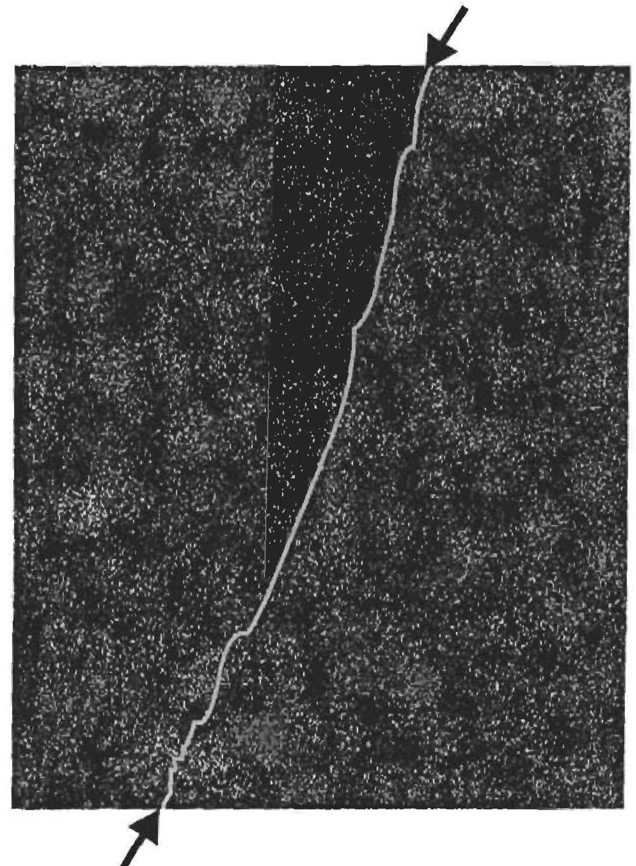

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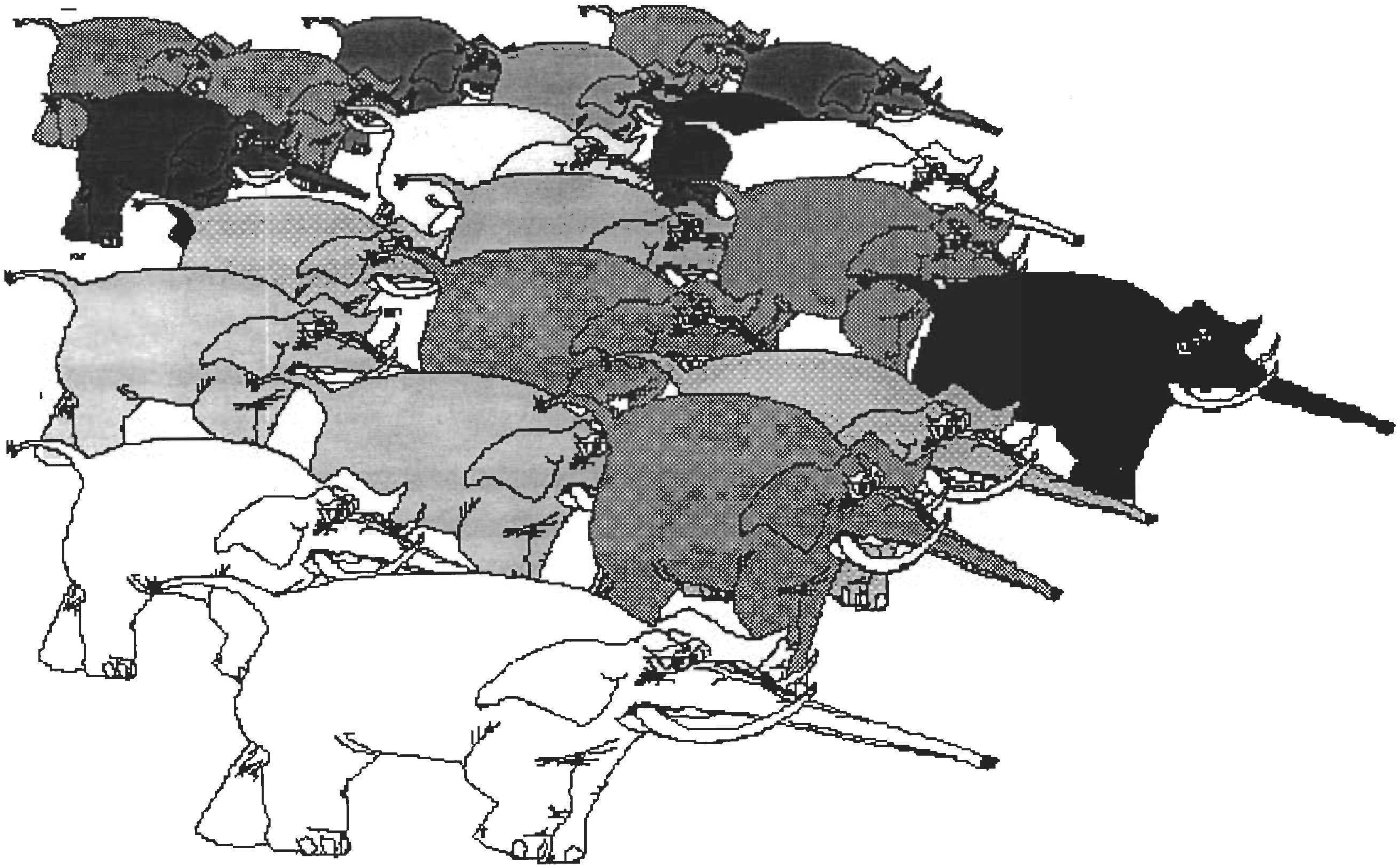

The idea is simple, but realization requires quite a lot of learning-by-doing.

Start thinking of your projects