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WORKSHOP
GLOBAL GEOPHYSICAL INFORMATICS WITH APPLICATIONS TO RESEARCH IN EARTHQUAKE PREDICTIONS AND REDUCTION OF SEISMIC RISK

(15 November - 16 December 1988)

THE BLOCK MODEL OF EARTHQUAKE SEQUENCES: INSTABILITY AND PREDICTION

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The Block Model of Earthquake Sequences:

Instability and Prediction

Objective:
To simulate an artificial catalog of seismicity for long-term earthquake prediction studies

COMPUTER SIMULATION:

Generation of earthquakes by interaction of lithospheric blocks.

Blocks are divided by thin layers, elastic or with more complicated rheology.

GOALS:

- Imitate real earthquake country.
- Find basic regularities on the model with simple geometry.

RELEVANCE TO PREDICTION:

- Internal parameters are known, unobservable in reality. This promises physical interpretation of observed "external" phenomena.
- Long catalog can be generated (hundreds of strong earthquakes) to test algorithms

Seismotectonic process:

Constant influx of energy released by discrete events

Stochastic behaviour: main shock sequence is close to Poissonian

Stationary process: No noticeable trend in behaviour

Earthquake sequences:

frequency of occurence law

clustering, aftershocks, foreshocks

migration, long-range interaction

seismic cycle

premonitory seismicity patterns

Lithosphere:

spatial heterogeneity

hierarchical block structure

nonlinear rheology

thermodynamical processes

physico-chemical and phase transitions

fluid migration, stress corrosion

NONLINEAR SYSTEMS

Instability:

- strong dependence on initial values and external disturbances
- pseudostochastic behaviour

Self organisation:

- stable statistical characteristics
- attractors
- spatial-temporal correlations

Block model:

two-dimensional

rigid blocks

thin boundary layers

linear elastic interaction

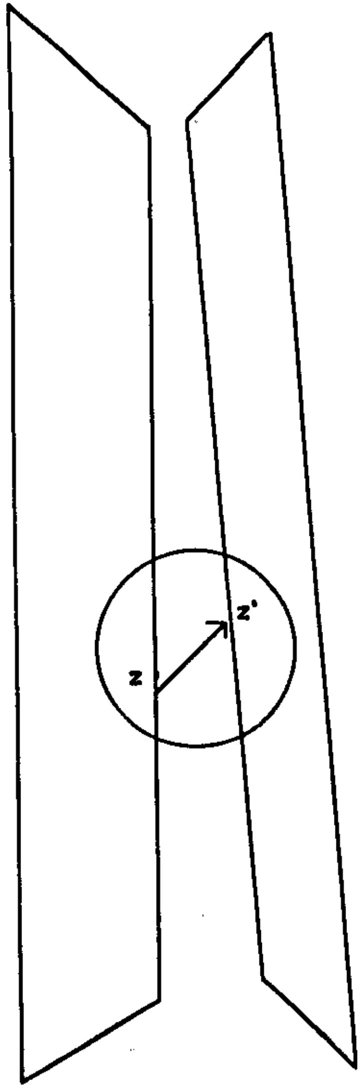
dry friction law for failure

instant healing

all displacements are small relative to geometric size of blocks

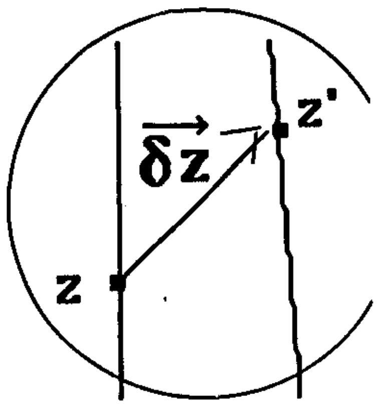
slow motion of boundary blocks
→ quasistatic equilibrium

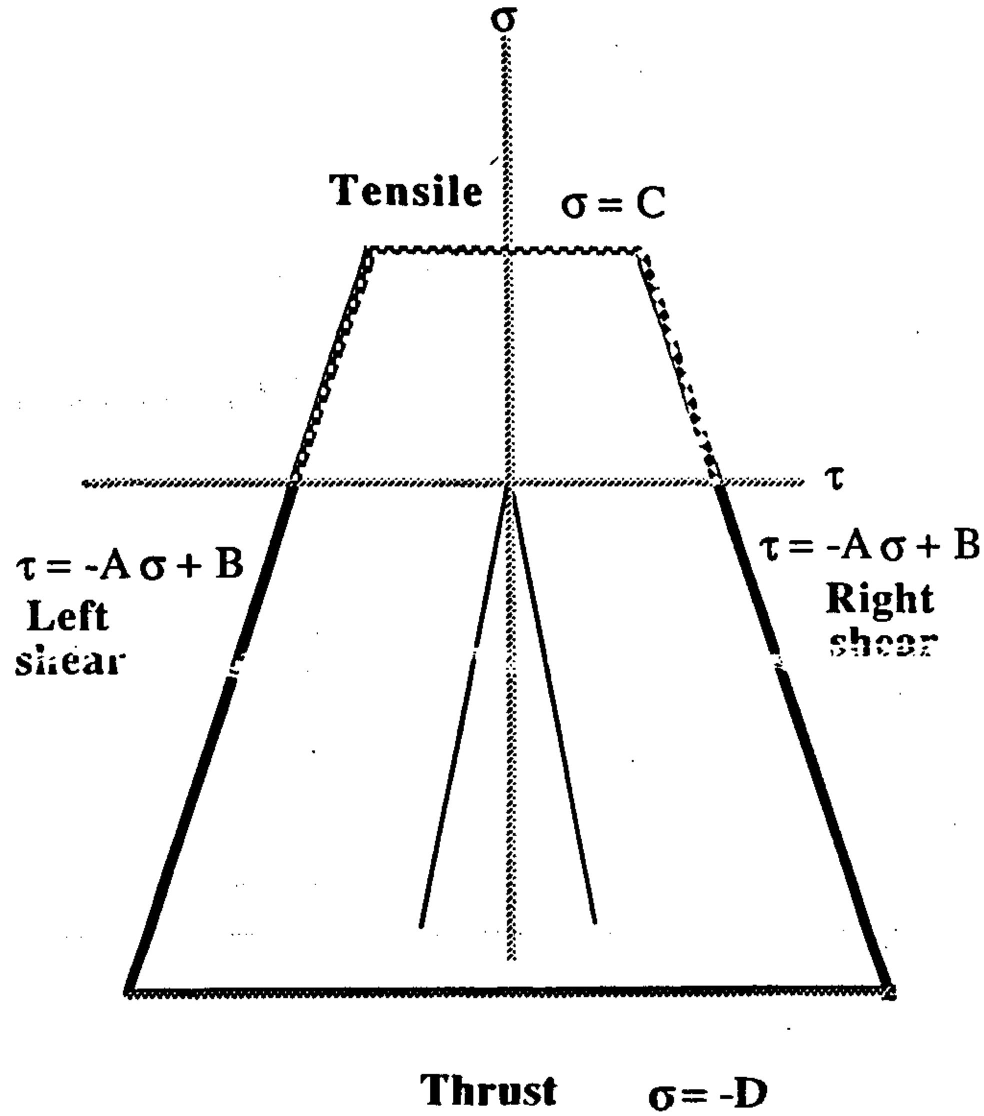
two time scales:
slow - tectonic
fast - elastic stress-drop



$$\tau = K_t \, \delta z_t$$

$$\sigma = K_n \, \delta z_n$$





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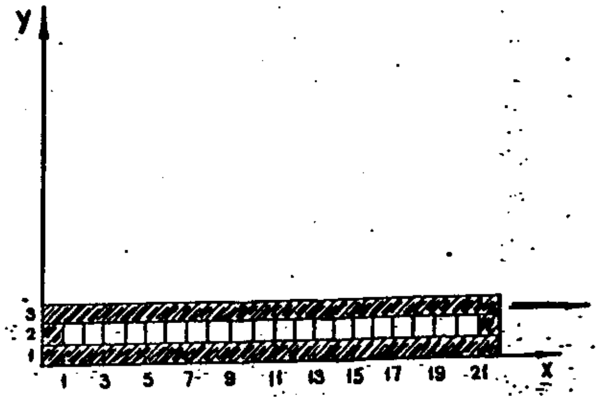
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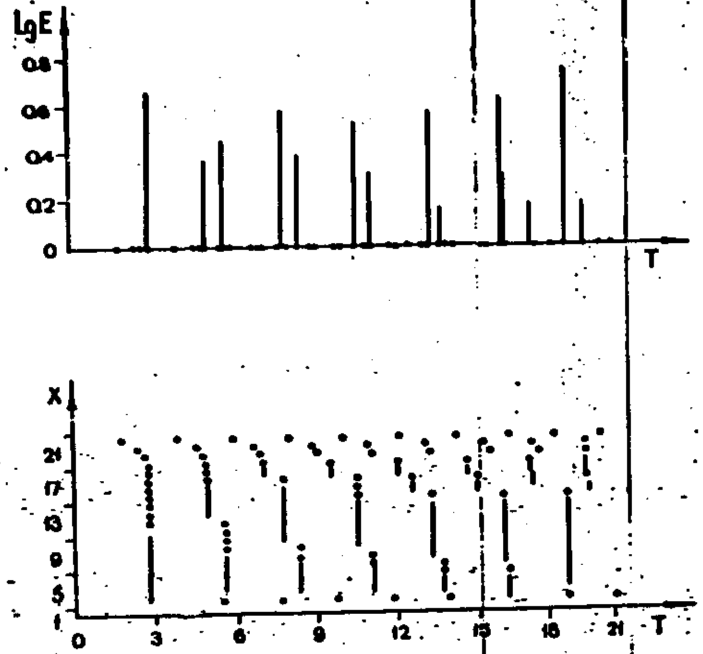
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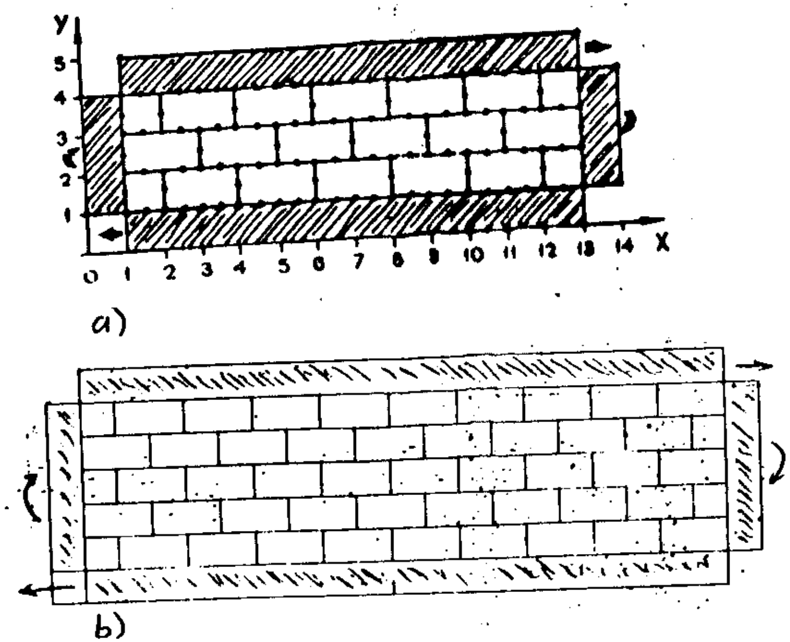
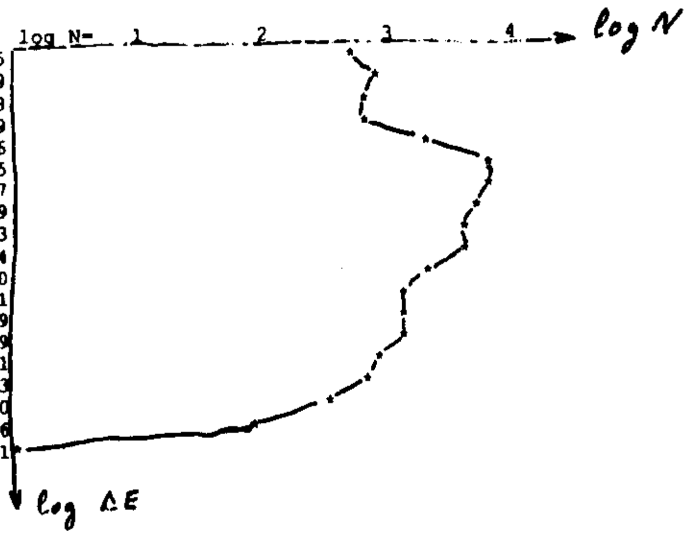


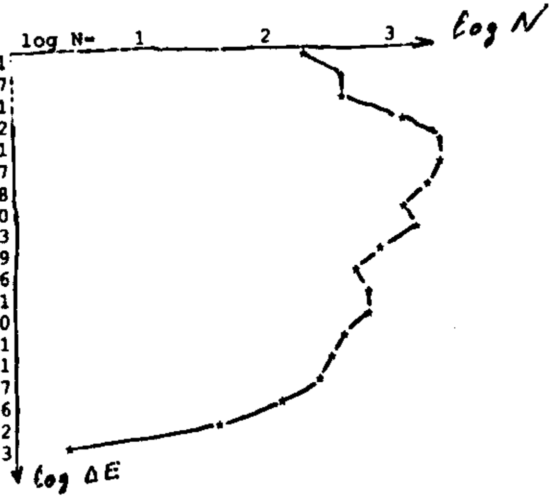
Fig. 1 System of blocks a) 3-layer model, b) 5-layer model

	de	N
2	0.025	625
3	0.040	979
4	0.063	668
5	0.100	729
6	0.158	2266
7	0.251	6795
8	0.398	7307
9	0.631	6089
10	1.000	4843
11	1.585	4074
12	2.512	2280
13	3.981	1561
14	6.310	1559
15	10.000	1549
16	15.849	961
17	25.119	673
18	39.811	350
19	63.096	86
20	100.000	1



a)

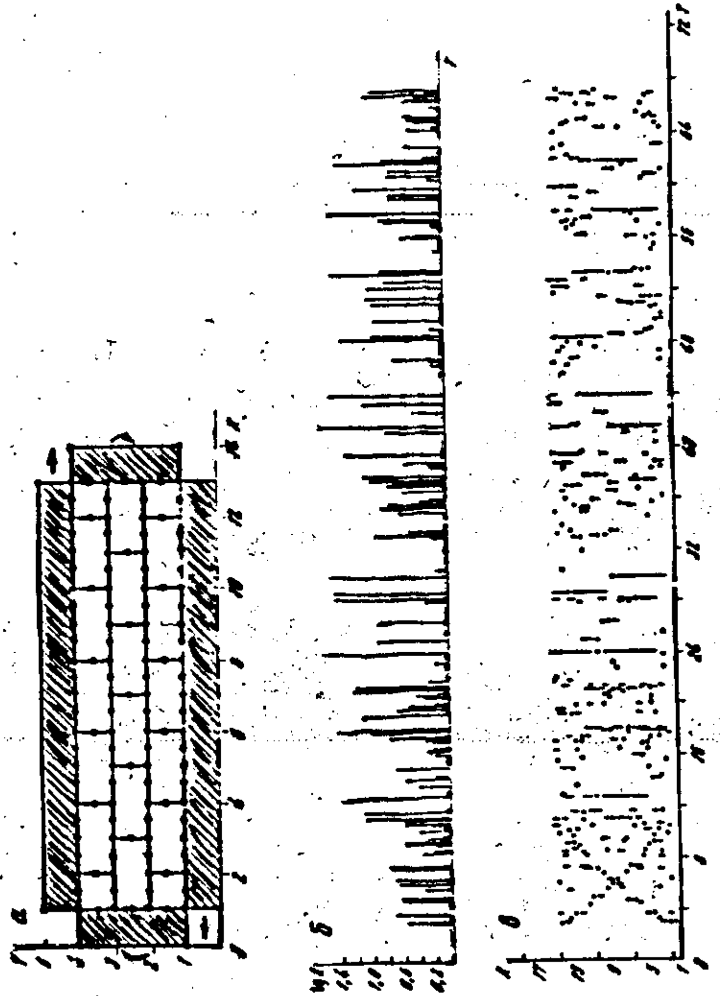
	de	N
2	0.025	241
3	0.040	457
4	0.063	481
5	0.100	1272
6	0.158	2811
7	0.251	2797
8	0.398	2108
9	0.631	1450
10	1.000	1633
11	1.585	879
12	2.512	556
13	3.981	701
14	6.310	650
15	10.000	461
16	15.849	331
17	25.119	257
18	39.811	146
19	63.096	42
20	100.000	3

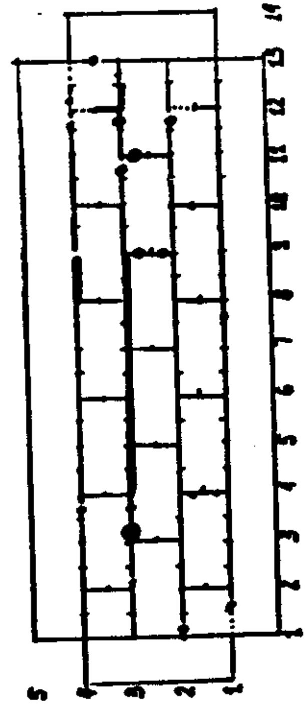


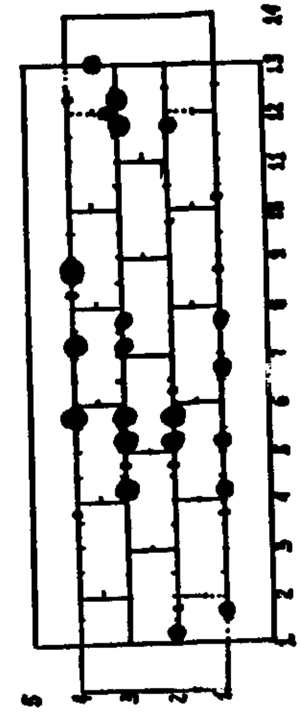
b)

Fig. 2. Energy / frequency distribution

a) 3-layer model, b) 5-layer model







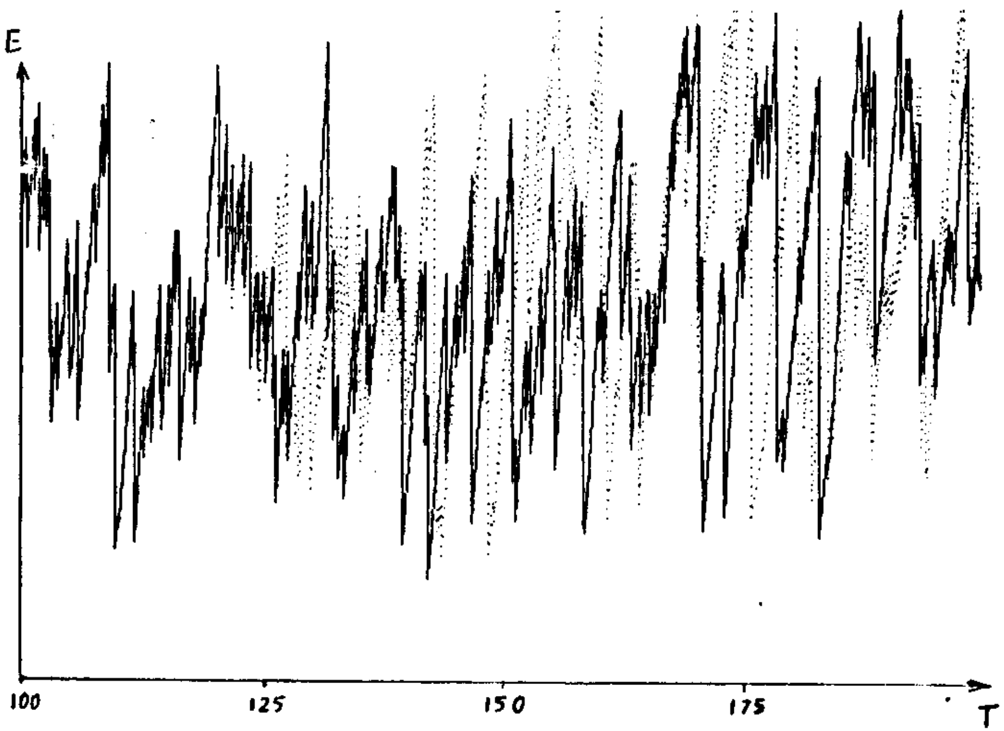


Fig. 3. Energy as function of time (100 ≤ T ≤ 200):

——— - undisturbed system

...... - disturbance 10^{-2} at T=100.

PREDICTION IN MODEL CATALOGS

CN ALGORITHM

Model	Time period	Strong earthquakes Total	Predicted	Alarm time
3-layer	720 yr	92	43 (48%)	32.6%
5-layer	720 yr	89	42 (47%)	31.4%

M8 ALGORITHM

Model	Time period	Strong earthquakes Total	Predicted	Alarm time
3-layer	1800yr	219	62 (28.3%)	20.4%

Total number of alarms - 50
Number of false alarms - 9

MODEL OF ENERGY REDISTRIBUTION

SYSTEM OF ELEMENTS (e.g. fault patches)
HAVING THE ABILITY
TO ACCUMULATE ENERGY IN SLOW (tectonic) TIME SCALE
AND
TO BREAK, RELEASING ACCUMULATED ENERGY IN FAST (elastic rupture) TIME SCALE, PART OF RELEASED ENERGY BEING REDISTRIBUTED BETWEEN OTHER ELEMENTS.

SERIES OF BREAKS IN FAST TIME SEPARATED BY PERIODS OF ENERGY ACCUMULATION IN SLOW TIME CONSTITUTE A CATALOG OF EARTHQUAKES

EACH EARTHQUAKE IS CHARACTERIZED BY:

THE (slow) TIME MOMENT
SOURCE (set of broken elements, first of them considered as epicenter)
ENERGY RELEASE

e_i - energy of i-th element

$$0 \le e_i \le E_i$$

ε_i - state of i-th element

$\varepsilon_i=0$ - whole, $\varepsilon_i=1$ - broken

i-th element
breaks when its energy exceeds E_i
and
heals when its energy becomes 0

<u>Slow (tectonic) time:</u>
all elements are whole

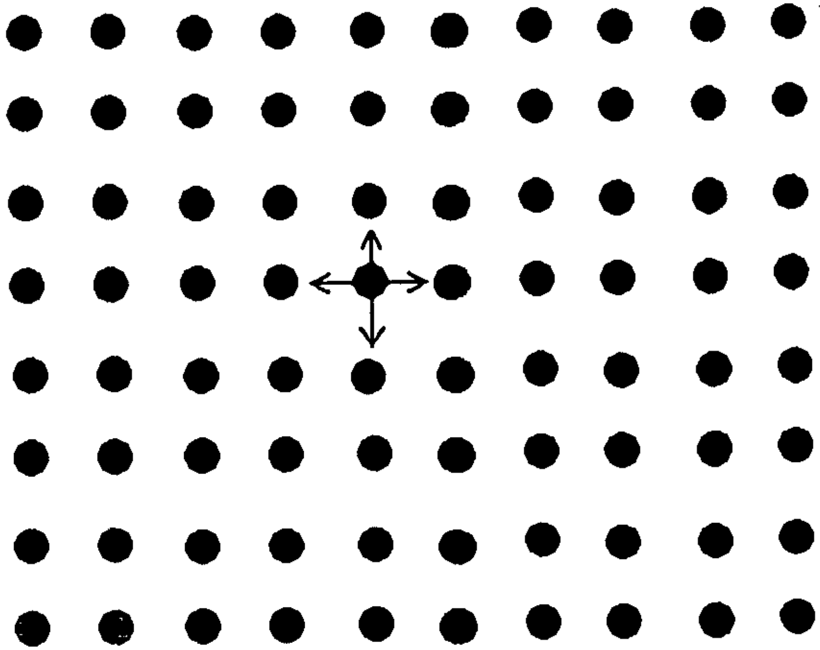
$$\dot{e}_i = 1 \text{ for all } i$$

<u>Fast (rupture) time:</u>
at least one element is broken

$$\dot{e}_i = -\varepsilon_i + \sum_{j \neq i} \varepsilon_j \, p_{ji}$$

EXAMPLE:

two-dimensional periodic lattice



$E_i=1$ for all i

$p_{ij}=p$ for neighboring elements

$p_{ij}=0$ otherwise

ENERGY - FREQUENCY DISTRIBUTIONS
FOR A MODEL WITH 30*30 PERIODIC LATTICE

VARIANT 1: p=0.15 (weak interaction)

TIME from 0 to 20, 14023 records

```
  ΔE   |   N  | Log N
       |      |0_________1_________2_________3_________4
  .398 | 5496 | ......... ......... ......... ......*
 1.000 | 3491 | ......... ......... ......... ....*
 1.585 | 2593 | ......... ......... ......... ...*
 2.512 | 1302 | ......... ......... .........  *
 3.981 |  817 | ......... ......... .........*
 6.310 |  269 | ......... ......... ...*
10.000 |   54 | ......... ......*
15.849 |    1 |*
```

VARIANT 2: p=0.23 (strong interaction)

TIME from 0 to 15, 12096 records

```
  ΔE   |   N  | Log N
       |      |0_________1_________2_________3_________4
  .100 | 4735 | ......... ......... ......... ......*
  .158 | 1574 | ......... ......... ......... .*
  .251 | 1074 | ......... ......... .........*
  .398 |  888 | ......... ......... ........*
  .631 |  818 | ......... ......... ........*
 1.000 |  744 | ......... ......... ........*
 1.585 |  579 | ......... ......... .......*
 2.512 |  565 | ......... ......... .......*
 3.981 |  417 | ......... ......... .....*
 6.310 |  347 | ......... ......... ....*
10.000 |  214 | ......... ......... ..*
15.849 |   98 | ......... .........*
25.119 |   38 | ......... .....*
39.811 |    5 | ......*
```

The same, TIME from 0 to 1, 863 records

AE	N
.100	339
.158	114
.251	84
.398	63
.631	56
1.000	58
1.585	33
2.512	41
3.981	23
6.310	26
10.000	16
15.849	9
25.119	1

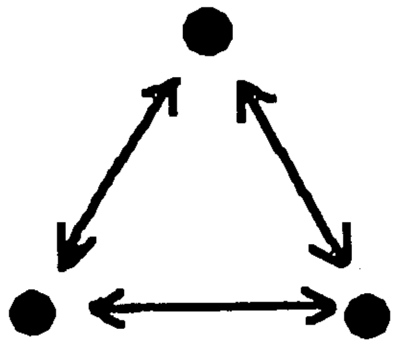
The same, TIME from 10 to 11, 724 records

AE	N
.100	276
.158	97
.251	61
.398	52
.631	53
1.000	46
1.585	35
2.512	31
3.981	24
6.310	18
10.000	17
15.849	7
25.119	4
39.811	1

The same, TIME from 14 to 16, 842 records

AE	N
.100	325
.158	121
.251	76
.398	58
.631	46
1.000	59
1.585	40
2.512	45
3.981	25
6.310	27
10.000	10
15.849	4
25.119	5

Example: 3 elements



$E_i=1$ for all i

$p_{ij}=p$ for $i \neq j$

This system may be considered as a billiard (non-standard) in 3D unit cube with the following rule of reflection from the boundary:

IF $x_i=1$ THEN

if $\dot{x}_j=1$ for all j then

$\dot{x}_i=-1$, $\dot{x}_j=p$ for $j \neq i$

(break in slow time, fast time begins)

else

$\dot{x}_i=\dot{x}_i-1$, $\dot{x}_j=\dot{x}_j+p$ for $j \neq i$

(break in fast time)

IF $x_i=0$ THEN

$\dot{x}_i=\dot{x}_i+1$, $\dot{x}_j=\dot{x}_j-p$ for $j \neq i$

(healing in fast time)

if $\dot{x}_j=0$ for all j then

$\dot{x}_j=1$ for all j

(end of fast time, slow time begins)

POINCARE MAPPING FOR 3-ELEMENT MODEL

TIME DELAY MECHANISM:

TIME-DEPENDENT STRENGTH (FATIGUE)

ENERGY DEFICIT: DIFFERENCE BETWEEN STRENGTH OF AN ELEMENT AND ITS ACCUMULATED ENERGY

IF ENERGY OF AN ELEMENT INCREASES IN FAST TIME BY HALF OF ITS ENERGY DEFICIT OR MORE (ACTIVATION IN FAST TIME)

THEN STRENGTH OF THIS ELEMENT BEGINS TO DECREASE WITH CONSTANT RATE IN SLOW TIME

ENERGY - FREQUENCY DISTRIBUTIONS
FOR A MODEL WITH TIME DELAY

TIME from 0 to 24, 18983 records

ΔE	N
.251	734
.398	9023
.631	638
1.000	3773
1.585	2364
2.512	1180
3.981	739
6.310	331
10.000	135
15.849	43
25.119	19
39.811	3
100.000	1