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SEISMIC TEMPERATURE AND ENTROPY IN MINE

Summary. A method of hierarchical presentation the set of seismic data has described. This method has used to calculate the Shannon entropy of sets of seismic events and seismic temperature. The area of high entropy and the structure of seismic events has presented.

TEMPERATURA SEJSMICZNA I ENTROPIA W KOPALNI

Streszczenie. Praca zawiera opis metody hierarchicznego zapisu danych sejsmologicznych. Hierarchia danych umożliwia obliczenie entropii Shannona zbioru wstrząsów sejsmicznych i powiązanej z nią temperatury sejsmicznej. Ponadto przedstawione zostały w technice anaglifów, obszary wysokiej entropii i struktury geometrycznej wstrząsów.

Introduction

Many systems and phenomena in nature are often represented in terms of time sequences or strings of characters. For example, in experimental investigations of physical processes, one typically has access to the system only through a measuring device which produces a time record of a certain observable, i.e. a sequence of data. On the other hand other systems are intrinsically described by string of characters, e.g. DNA, language. In this regard a system, whether or not chaotic, generates messages and may be regarded as a source of information. This observation opens the possibility to study dynamical systems, as well as other systems, from a very interesting point of view: that of information theory and thermodynamic. The bridge between this two points of view has been given by the hierarchical construction of any system including sets of seismic events.

Originally information theory was introduced in the practical context of electric communications, nevertheless in a few years it became an important branch of both pure and applied probability theory with strong relations with other fields as computer science, cryptography, biology and physics [1].

Hierarchy

Let a set Ω be a domain of same function f, and a finite elements set Ξ (mes(Ξ) = n ;n > 0) be a codomain of that function. For any elements of $\xi \in \Xi$ can be produced subset

$$\Omega^{\xi} = \{\omega \in \Omega \wedge f(\omega) = \xi\} \tag{1}$$

such that:

$$\begin{gathered} \textit{if } \xi_i \neq \xi_j \textit{ then} \\ \Omega^{\xi_i} \cap \Omega^{\xi_j} = 0, \Omega \supseteq \bigcup_{i=0}^{i=n-1} \Omega^{\xi_i} \end{gathered} \tag{2}$$

The set:

$$\mathrm{H}^{(l)} = \{\Omega^{\xi_i}\} \textit{ for } l = 1 \textit{ and } i = 1, \dots, n \tag{3}$$

defined the first level of hierarchy. Any higher levels l =1,..., L of hierarchy can be prepared at that same meaner if for some of subsets S^t existed suitable set of functions. In general, the hierarchy is a system of two or more levels of sets or units, the lower levels controlling at least to some extent the activities of the higher levels in order to integrate the group as a whole. Any elements of hierarchy can be associated with their address (code) h it is with the sequence of elements $\xi_i \in \Xi^1$

$$h = \{\xi_L \xi_{L-1} \cdots \xi_1\} \tag{4}$$

denoted all subsets to which that element belong on all hierarchical levels. Because all hierarchical levels contain finite numbers of subsets then marking each by integers , code h can be treated as a sequence of integers

$$h = \{i_L i_{L-1} \cdots i_1\} \tag{5}$$

or like a single integer

$$h = n^{L-1} * i_L + n^{L-2} * i_{L-1} \cdots n^0 * i_1 . \tag{6}$$

where n = max{ mes(Ξ^l)}, l = 1,2,...,L.

The complete hierarchy can be treated as an sequence H of individual codes of their elements

$$H = \left\{ i_L^{(N)} i_{L-1}^{(N)} \cdots i_1^{(N)} \cdots i_L^{(1)} i_{L-1}^{(1)} \cdots i_1^{(1)} \right\} \tag{7}$$

or, if it is needed, hierarchy can be treated like the integer

$$H = n^{NL-1} * i_L^{(N)} + n^{NL-2} i_{L-1}^{(N)} + \ldots + n^0 i_1^{(1)} \tag{8}$$

Now the history of developed system can be recorded by time sequence of codes or integers H_t. The future state of deterministic dynamical systems can be calculated. In this case exist a function F(), in many cases given by a sets of equations of motion (see for example [2]) , which can be written in the form:

$$H_{t+1} = F(H_t, H_{t-1}, \ldots H_0) \tag{9}$$

But, even in deterministic systems exist some kind of chaos and sometime calculations lost sense.

Recently, in seismic activities, we have rather poor knowledge about F. We known that it exist on the 0 level of hierarchy so now we are able to say: seismic event will appear in active area for time to time. It is probably not reasonable to suppose that function F can be establish without additional information about non seismic properties like that of stress, damage of rocks, and tectonic. Fortunately into any hierarchical level can be additionally included that information.

At the end of forties Shannon [3] introduced rather powerful concepts and techniques for a systematic study of sources emitting sequences of discrete symbols (e.g. binary digit sequences). The Shannon entropy S is a measure of the "surprise" the source emitting the sequences can reserve to us, since it quantifies the richness (or "complexity") of the source.

The Shannon entropy is defined as follows. Let consider the words of N*L characters (L-words) and the probabilities of their occurrence in the sequences emitted by an source.

The Shannon entropy is given by:

$$S = -\sum_{k=1}^{N} P_{i_L^{(k)} i_{L-1}^{(k)} \ldots i_1^{(k)}} \ln P_{i_L^{(k)} i_{L-1}^{(k)} \ldots i_1^{(k)}} , \tag{10}$$

where N is the ensemble of all the L-words and p is the generic probability of a specific L-word. Though well defined, the use of S is not as practical as one could imagine. It is not easy, in fact, to compute the probabilities of the L-words in long (in N*L) sequence.

Entropy and seismic temperature

In the hierarchical model in order to study the behavior of a large system of seismic events, we first consider large cube containing all active area. It is the 0 level of hierarchy.

That cube is divided to 8 smaller equal-size cubical cells (the 1st level) . Each cell of the 1st level of hierarchy is consider to be either empty or occupied by seismic event. Occupied cell is marked by an integer numbered its position (fig.1) and divided at that some manner to produced the next hierarchical level. This construction is finished when dimension of some less cube exceed the hypocenter uncertainties.

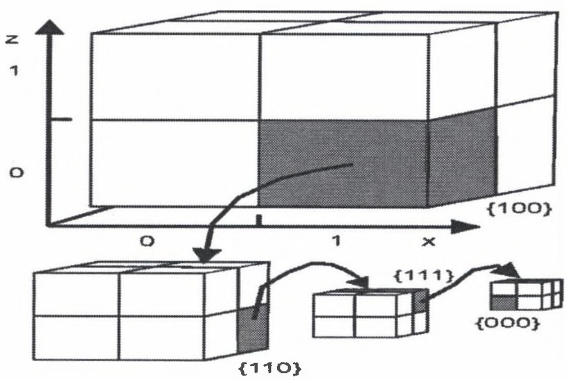

Fig. 1. The method of hypocenters of seismic events coded
Rys. 1. Metoda kodowania hipocentrów wstrząsów

The relative positions of subcubes inside theirs parent are given by binary numbers from 000 to 111 (0 to 7). It's mean that 8 symbols are enough to describe the hypocenter of seismic events on any level of hierarchy, end the code of hypocenter is represented by octagonal number.

Graphical representation of hierarchy can be achieved on many ways. Only two of them, the flat hierarchical tree and the perspective view of active seismic area are presented on Fig.2. The hierarchical tree contains circles and branches. Circles are equivalent to cubes contained seismic events, branches indicates subcubes inside their parents.

a b

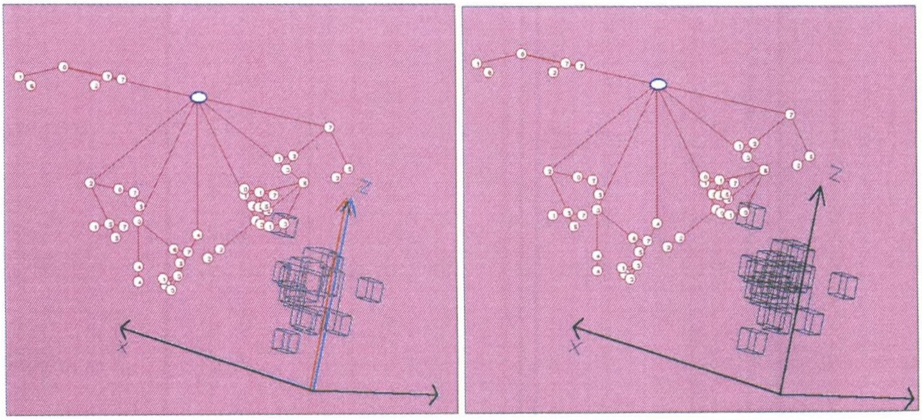

Fig. 2. The 3[ed] level of hierarchical tree and geometrical structure of 100 seismic events inGen. Brandt Gold Mine R.S.A.: a) Anaglyph picture (red blue glasses are needed). b) Perspective view

Rys. 2. Drzewo i geometryczna struktura trzeciego stopnia hierarchii100 zdarzeń sejsmicznych na kopalni złota Generał Brandt RPA: a) Anaglif (do oglądania potrzebne są okulary czerwono niebieskie). b) Obraz perspektywiczny

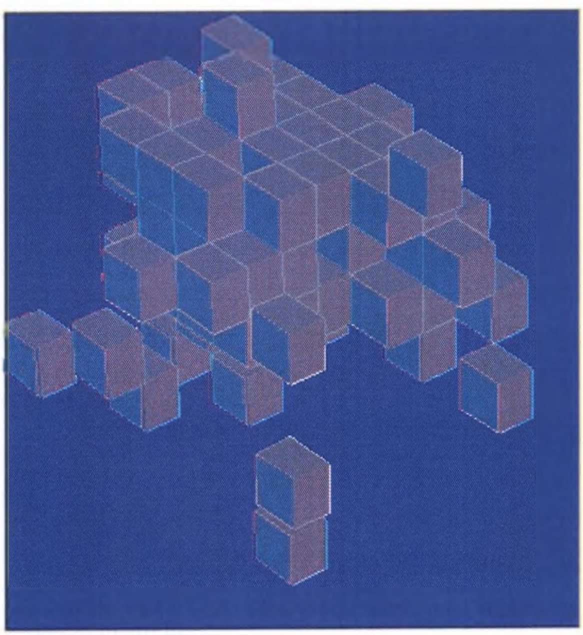

Fig. 3. The geometry of all seismic events on the 3[ed] level of hierarchy at 01.01.93 – 04.30.93 Gen. Brandt Gold Mine R.S.A. Anaglyph picture (red blue glasses are needed)

Rys. 3. Struktura geometryczna wszystkich zdarzeń sejsmicznych na trzecim stopniu hierarchii w czasie od 01.01.93 do 04.30.93 na kopalni złota Generał Brandt RPA. Trójwymiarowe efekty anaglifu widoczne są przez okulary czerwono niebieskie

The hierarchical tree is very useful for communication reasons. Typically, when the level of hierarchy grow up growing it complexity (Fig. 3.), but the connectivity between 2 dimension hierarchical tree and 3 dimension objects enabled all operations on areas in consider.

Materials break down according to two broadly defined scenarios. In the first one, exemplified by a pure crystal, there is no or little damage up to the rupture which occurs suddenly with no appreciable precursors. In the second scenario that applies ideally in the limit of very heterogeneous media, the system is progressively damaged, first in an uncorrelated way reacting the pre-existing heterogeneity. As stress or strain increases, the damage becomes more and more correlated with crack growth and fusion, announcing the incipient rupture. This second regime is like percolation at the beginning and correlated percolation later and at the end of the process. This second scenario is characterized by a growing susceptibility and well-defined precursors.

The fracture process strongly depends on the degree of heterogeneity of materials : the more heterogeneous, the more warnings one gets; the more perfect, the more treacherous is the rupture. The failure of perfect crystals is thus unpredictable while the fracture of dirty and deteriorated materials could be forecasted. For once, complex systems could be simpler to apprehend ! However, this idea has not been much developed because it is hard to quantify the degrees of "useful" heterogeneity, which probably depend on other factors such as the nature of the stress field and boundary conditions, the presence of chemical contaminants, etc. Nowadays, finding clear earthquake precursors is an active and controversial research domain whose ultimate objective is still eluding the scientific community. We hope, that hierarchically ordered seismic area will emerged the fragile and the sound parts of mine. Disordered, chaotic area must be characterized by high entropy (Fig. 4.) This area is slowly but steadily growing by swallowing the large part of seismic events.

The entropy can be calculated according to equation (10) and probabilities estimated for seismic events are belongs to consecutives cells at all levels of hierarchy. But in physic wee never need the value of entropy. Physicals rules depends of the grow of entropy. In open systems entropy must always grow, and in our case, that's happen in active area (Fig. 5) even if on the higher levels of hierarchy local drop of entropy has been appear for time to time. The height of entropy grow took place near the border of high entropy area indicated on figure 4.

That's allow us to suppose that highly damaged area spreads in that direction.

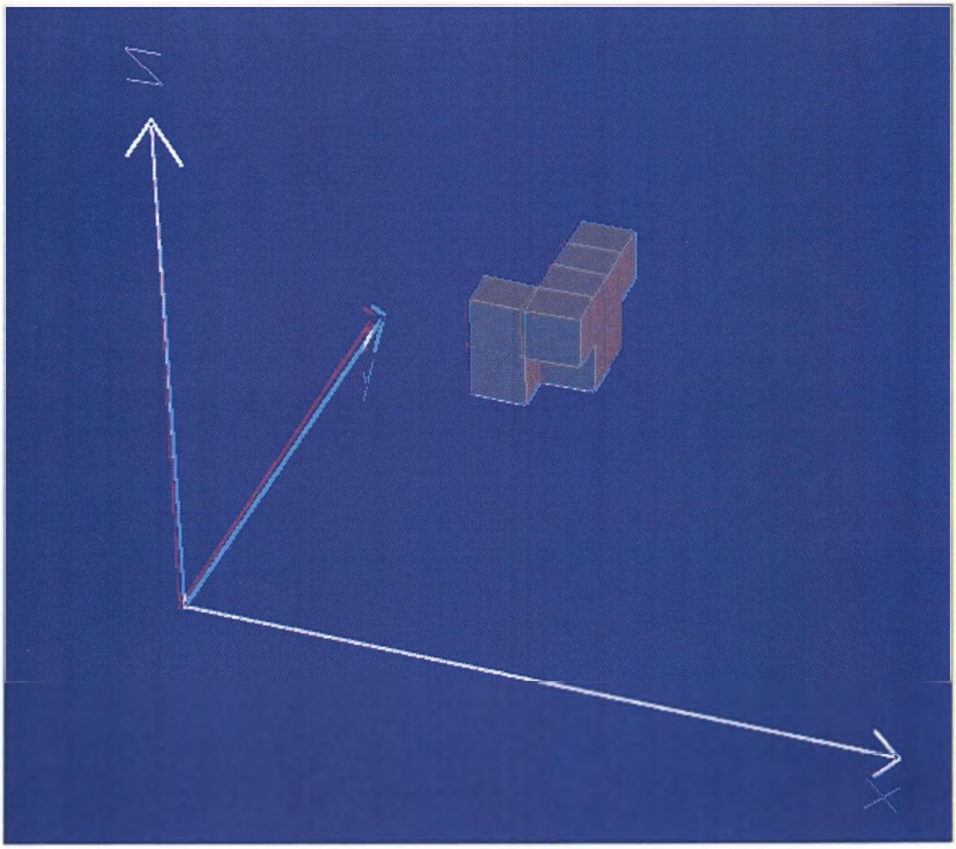

Fig. 4. The geometry of high entropy area on the 3ced level of hierarchy at 01.01.93 – 04.30.93 Gen. Brandt Gold Mine R.S.A. Anaglyph picture (red blue glasses are needed)

Rys. 4. Geometria obszaru wysokiej entropii przedstawiona na trzecim stopniu hierarchii w czasie od 01.01.93 do 04.30.93 obserwowana na kopalni złota Generał Brandt RPA. Trójwymiarowe efekty anaglifu widoczne są przez okulary czerwono niebieskie

By analogy to classical thermodynamic one's can defined the seismic temperature T of an active area by equation:

$$T = \frac{Q}{\Delta S}, \tag{11}$$

where:

Q – the grow total energy of seismic events in the area and time period in consider.

ΔS – the entropy grow in that some area and time period.

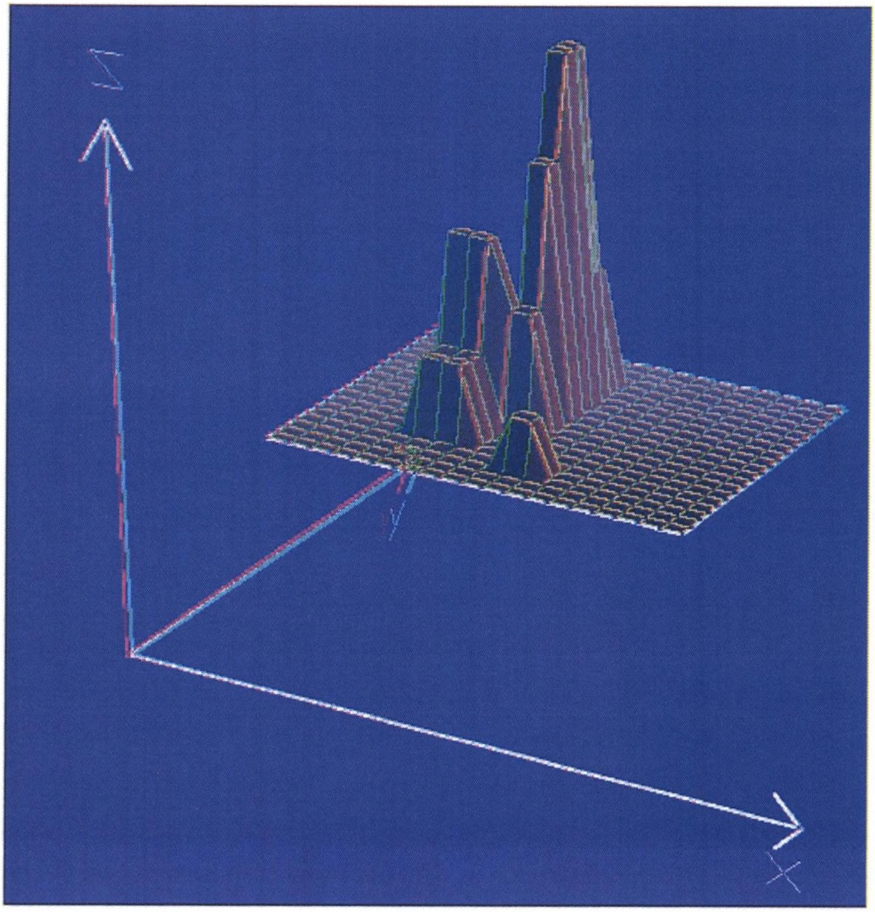

Fig. 5. The entropy drop on 1794 [m] deep. Gen. Brandt Gold Mine R.S.A. The 3[ed] level of hierarchy at 04.30.93. -05.10.93.Anaglyph picture (red blue glasses are needed)
Rys. 5. Zmiany entropii, przedstawione na trzecim poziomie hierarchii, na głębokości 1794 m w czasie od 04.30.93. do 05.10.93 obserwowane na kopalni złota General Brandt RPA. Trójwymiarowe efekty anaglifu widoczne są przez okulary czerwono niebieskie

In typical situation (Fig.6) the hot area lie fare from the high entropy region where the seismic temperature is relatively low. The hottest areas appears in places of small entropy grow for which the denominator of eq. 11 is very less. Seismic temperature is a good indicator for the risk of seismic disaster. At the places where a lot of events appears seismic temperature became less at the areas of accidental events seismic temperature stay to be high.

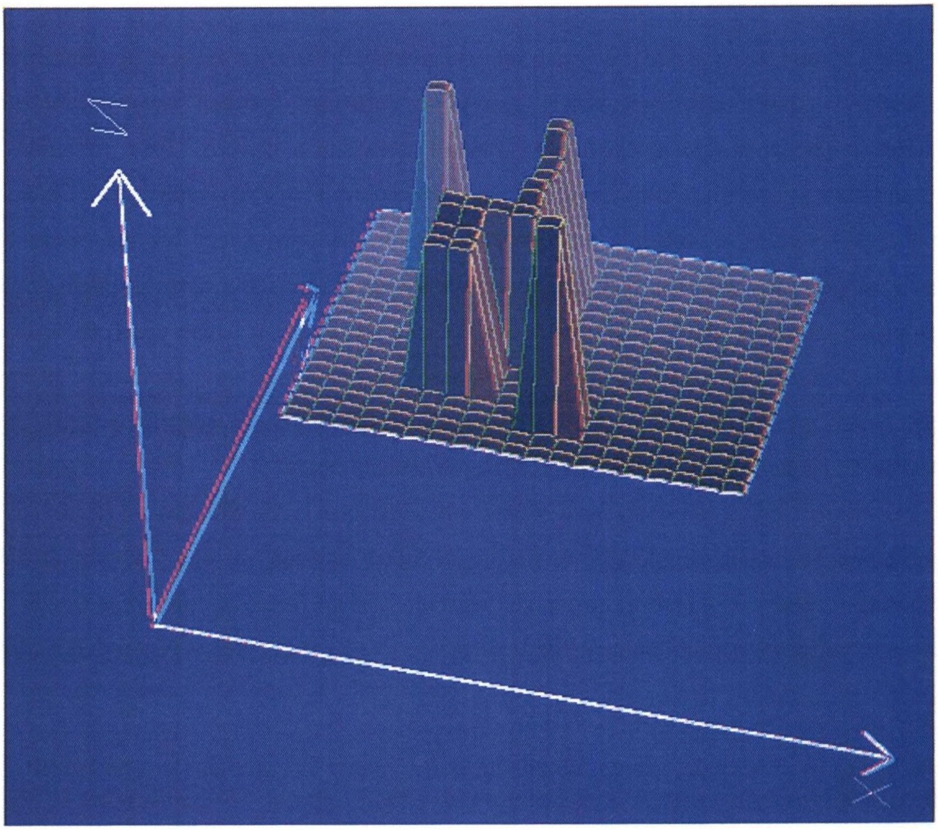

Fig. 6. The logarithm of seismic temperature on 1794 [m] deep. Gen. Brandt Gold Mine R.S.A. The 3[ed] level of hierarchy at 04.30.93. -05.10.93. Anaglyph picture (red blue glasses are needed)

Rys. 6. Przedstawiony na trzecim poziomie hierarchii logarytm temperatury sejsmicznej. Trzeci poziom hierarchii, głębokość 1794 m w czasie od 04.30.93. do 05.10.93. Trójwymiarowe efekty anaglifu widoczne są przez okulary czerwono niebieskie

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Omówienie

Wiele systemów i zjawisk jest często reprezentowanych czasową sekwencją symboli. Dla przykładu, w fizyce eksperymentalnej dostęp do badanego systemu zapewnia interfejs urządzenia pomiarowego produkujący czasowe sekwencje danych. Inne systemy są utożsamiane z pewnym kodem symboli jak np. cząsteczki białek opisywane kodem DNA. W takim ujęciu system, niezależnie od tego czy jest on chaotyczny, czy też nie, może być uznany za generator informacji. Umożliwia to studiowanie układów dynamicznych w taki sam sposób jak pozostałych. Szczególnie interesujące jest podjęcie badań opartych na bazie teorii informatycznych i termodynamiki. Połączenie obydwu sposobów percepcji zapewnia hierarchiczna struktura danych. Dzięki temu dynamiczne układy wstrząsów mogą być skojarzone z ciągami kodów i badane metodami informatycznymi.

Pierwotnie, teoria informatyczna została wprowadzona przez Shannona [3] dla celów komunikacji elektronicznej, jednak w przeciągu kilku lat stała się ona ważnym działem stosowanej i teoretycznej teorii prawdopodobieństwa. Zyskała liczne zastosowania w technice komputerowej, kryptografii, biologii i fizyce [1].