Application of artificial intelligence in earthquake forecasting

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Significance

It is still very difficult to forecast an earthquake up to now. However after a large earthquake, seismologists can often summarize a lot of phenomena called earthquake precursors. Using earthquake precursors and the occurrence regularity, some earthquake predictions have been made successfully by the seismological experts. But the earthquake precursors are very complicated, and they do not reoccur simply. And there are a large number of various phenomena before the earthquakes. What is the relation between those phenomena and the earthquakes? Do the combinations of those phenomena reflect the earthquakes? This is a very complicated problem. Therefore, the computer and artificial intelligence are used to study it. The various precursory phenomena are stored effectively, the method of automatically learning is used to find out the relation between earthquakes and various phenomena, and the comprehensive prediction is curried out by automatically reasoning. It is undoubtedly very significant work.

As we know, China is an earthquake-prone country. The Chinese government has been paying great attention to the earthquake prediction. In order to reduce the loss caused by the earthquake disaster, the earthquake consultation meetings are held for every week, month and year by the organizations of the various regions in China. At present, the earthquake prediction is still based on various precursors and seismologist's experiences. If the daily works (data processing, anomaly discrimination and the comprehensive decision of earthquake prediction) are done by computer automatically. It is not only for the earthquake prediction experts to save their time, but also it makes the earthquake prediction more objective, overall, and easy to summarize and improve.

The structure of the IDSSEP

We developed an Intelligent Decision Support System for Earthquake Prediction (IDSSEP) to help seismologists to forecast earthquakes. The general structure and flowchart of IDSSEP is shown in figure 1. It consists of several databases and processing subsystems.

Knowledge representation

According to the features of experiences of the earthquake prediction experts and the earthquake cases, we adopt the following format to represent the knowledge of earthquake forecasting:

IF $A_1E_1\Delta T_{11}\Delta T_{12}$

$A_2E_2\Delta T_{21}\Delta T_{22}B/P$

… …

$A_KE_K\Delta T_{K1}\Delta T_{K2}B/P$

THEN $AT_1T_2C_iMtM_1M_2Mm$ P

Every rule is composed of several premises (condition) and one conclusion, and the premises must meet certain relationship in time order. There are 5 attributes in a premise, which are defined as follows:

A_I............ Area or station where anomaly appears.

E_I............ A certain precursory anomaly

ΔT_{i1}...... Delay period. This anomaly must appear delaying ΔT_{i1} after the preceding anomaly or the first anomaly appears.

ΔT_{i2}...... Effective period. After this anomaly ends it is still possible that earthquakes occur during ΔT_{i2} period.

P/F....... P represents that this anomaly must delay after the preceding anomaly, F represents that this anomaly must delay after the first anomaly.

The conclusion contains the following 9 attributes:

A .... Area of coming earthquake

T_1............ Parameter 1 for calculating origin time.

T_2......... Parameter 2 for calculating origin time.

C_i .... Parameter 3 for calculating origin time.

Mt........ Method for calculating origin time. For instance, when Mt=4, the C_i represents the order number of the premise, T_1 represents the onset time of the anomaly related to the premise, T_2 represents the end time of this anomaly. During the T_1— T_2 period, the earthquake will occur.

M_1........ Parameter 1 for calculating magnitude

M_2........ Parameter 2 for calculating magnitude

Mm...... Method for calculating magnitude. For instance, When Mm=1• M_1 is the minimum magnitude of the coming earthquake, M_2 is the maximum magnitude of the coming earthquake.

P .... Probability of Earthquake Occurrence(PEO) .

Ai may be defined as any area or any station in a rule. It means this rule can fit anywhere. It is very easy to store and manipulate the knowledge represented in such format.

Reasoning method

The experiences of earthquake prediction experts are gathered, sorted out, formalized, and then are stored in knowledge database as rules. Generally there are tens or hundreds of rules in the knowledge database. Meanwhile, various anomalies appearing as events are sorted out and stored in the event database in uniform format. An event record includes the following attributes:

A .... Area or station where the anomaly appears

E.......... A certain precursory anomaly

t_1.......... Onset time of the anomaly

t_2.......... End time of the anomaly. If the anomaly hasn't ended, it is defined as present time.

V .... Characteristic value of the anomaly.

CF........ Certainty factor of the anomaly.

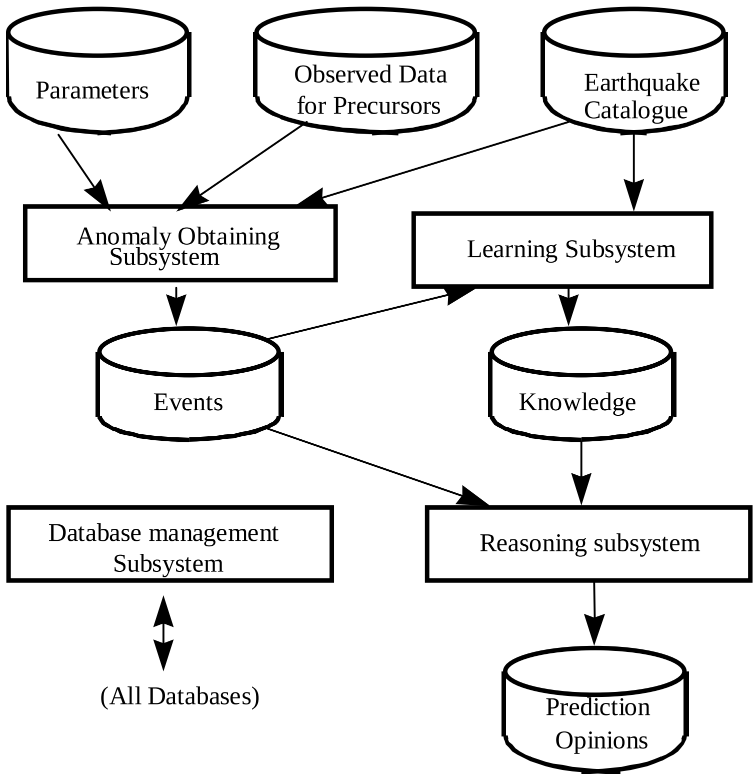

Figure 1. Components and flowchart of IDSSEP

Reasoning is a process that matches premises of a rule with events. If all premises in a rule are matched fully, then the conclusion of the rule is tenable. Because the value of observations are varying continuously, probably several anomalies of an observation appear during a period. Therefor, it is possible that there is more than one combination of anomalies related to premises of one rule. Every combination must be judged to see if it fits the relationship in time order. Maybe several combinations are matched.

As mentioned above, the Ai of premises may be any area. In this case, if an area contains all anomalies concerned in premises of a rule and they are fitted in time order, then the region of a coming earthquake is calculated according to the areas of anomalies and parameters.

Thus it can be seen that one rule can be matched several times successfully, namely it is possible to predict several earthquakes in different regions and different periods using one rule. More conclusions will be obtained when various rules are used. Assign N predictive conclusions are obtained:

A_i— Predicted area of the ith conclusion

T_{i1}—T_{i2}— Predicted period of the ith conclusion

M_{i1}—M_{i2}—Predicted magnitude of the ith conclusion

P_i—Predicted probability of the coming earthquake. It is gotten from P of related rule and CFs of related anomalies by computing.

Generally, these predicted results are in different areas, different periods and different magnitudes, and they are overlapped together. Every predictive result is an amount with four dimensions and one occurrence probability. For getting the comprehensive predictive conclusion from those individual results, we synthesize them in space, time and magnitude separately. First get the spatial probability distribution map. Then on the map distinguish some regions where the probability value is relatively larger than others. Finally let every region distinguished as the target region, reason several times again and again to get more exact probabilities and their spatial, time, magnitude distribution maps.

To calculate the spatial distribution of PEO, We divide a region into squares formed by latitude lines and longitude lines, and code these squares from bottom to top and from left to right.

Assign one square (jth) is predicted by m conclusions, and *P*k (k=1,2...m) are the PEO of the kth conclusion, then the PEO of the square predicted by the kth conclusion is:

$$p_k \approx P_k / NN_{k,i} \prod_{l<k} \left(1 - r_{k,l}\right), \tag{1}$$

where $r_{k,l}$ is the correlation coefficient between the kth rule and the lth rule, and NN_K is the total number of squares of the region predicted using the conclusion. The synthetic PEO of the square (jth) is calculated by following recursion formula:

$$\begin{aligned} P_j &= p_{j,m} \\ p_{j,k} &= p_{j,k-1} + p_k - p_{j,k-1} p_k \quad , \text{(k=2……m)} \\ p_{j,1} &= p_1 \end{aligned}$$

For any designated region A, its PEO is calculated by the following recursion formula:

$$\begin{aligned} P_A &= P_n \\ P_i &= P_{i-1} - p_i' - P_{i-1} p_i' \quad , \text{(i=2 ……n)} \\ p_i' &= p_i \cdot mm_i \\ P_1 &= p_1' \end{aligned}$$

where mm_i is the number of common squares of the region A and the region predicted by the ith conclusion. Using the similar way, we can calculate the time PEO and its distribution, as well as magnitude PEO and its distribution.

Finally, for a given region, period and magnitude range, their PEO is the minimum one of the region PEO, time PEO and magnitude PEO.

Application

The IDSSEP was implemented in 1995, and provided the analysis opinion for the annual earthquake trend consultation for all areas of China. The results predicted in 1995 and 1996 were very successful and well received by the China Seismological Bureau. In 1997, 9 risk regions were raised using the system. Among which, Jiashi earthquake with M6.6 in Xinjiang, Kunlunshan earthquake with M5.4 in Qinghai, Chongqing earthquake with M5.2, Lijiang-Jiangcheng earthquake with M5.5 in Yunnan, Liancheng earthquake with M5.2 in Fujian, one after another occurred. However, there was not strong earthquake in the two risk regions of North China (border of Hebei and Inner Mongolia, northwestern Beijing, and Bohai Sea) by the end of 1997. In December of 1997, the research group analyzed the earthquake situation of 1998 using IDSSEP, and found that there was still abnormal phenomenon on the border of Hebei and Inner Mongolia, northwestern Beijing. Therefore, it was stressed again that there would be still occurrence possibility of strong earthquake in the region. In Jan.10, 1998, the Zhangbei earthquake with M6.2 in Zhangjiakou region occurred in the center of the predicted area. On the basis of some analyses, it was considered that there would be possibility for a strong earthquake occurring after the Zhangjiakou earthquake. But, the research group pointed out that there would not be larger earthquake in Zhangjiakou and its vicinity, especially in Beijing area, by use of IDSSEP. The result has shown that the prediction opinion for the Zhangjiakou earthquake and the opinion without earthquake in Beijing area are concordant with the real facts.

Reference

[1] Zhou Shengkui, Wang Chengmin et al: *The Architecture of Intelligent Decision Support System,* 2nd Symposium of Intelligent Interface and Intelligent Application of China, 685~690, 1995.

[2] Zhou Shengkui et al: *Knowledge Representation and Calculation of Earthquake Occurrence Probability,* Third symposium of Intelligent Interface and Intelligent Application of China, 574~578, 1997.

[3] Zhou Shengkui, Shen Yu et al: *Overview on the Practical System for Earthquake Prediction,* Earthquake Research in China, Vol.9 No.1 33~38, 1993.

[4] Zhang Zhaocheng et al: *Earthquake Cases of China,* Vol. 1-3, Earthquake Press, 1989.

[5] Adams J B.: *A Probability Model of Medical Reasoning and the MYCIN Model.* Mathematical Bioscience, Vol.32, 177~186, 1976.

[6] Wu Qanyan et al: *Artificial Intelligence and Expert System,* Defense Science & Technology University Press, 1997.

[7] Zhuang kuengyan et al: *Expert System for Earthquake Forecasting,* Earthquake Press, 1990.