Real-Time Earthquake Forecasting using Multidimensional Hierarchical Graph Neuron (mHGN)

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Abstract. Various earthquake forecasting technologies have been introduced for a while, but the quality of the results is not yet convincing. The attempt to achieve a stable technology is still very demanding, due to increasing number of earthquake incidences lately. Since it is not trivial working on complex—with numerous parameters—and big data, the research on discovering such earthquake forecast system takes long and winding roads. It is still very difficult to establish a sophisticated system that can be used to forecast earthquake effectively, but the concept of Multidimensional Hierarchical Graph Neuron (mHGN) has opened up a new opportunity to forecast earthquake not only effectively but also in real-time manner. The 91% of its accuracy in recognizing almost 11% distorted/incomplete patterns has given a strong indication that the accuracy of mHGN in forecasting earthquake will be high as well.

1. Introduction

The occurrences of earthquakes have caused a lot of damages and casualties [1] [2] [3]. Up to now, many countries still suffer from such a natural disaster. To deal with this, some kind of earthquake forecasting is required. When such a forecasting system is available, the number of casualties can be reduced and damages can be minimized.

The occurrence of an earthquake is not only caused by the movement of the plates on the earth crust. The condition of the boundaries of the plates [4], determines whether or not the movement will increase the tension—at the same time the energy—or it just increases or decreases the gap between them. Additionally, the increasing energy at a boundary of two plates will not necessarily generate an eminent earthquake, as it depends on the elasticity of the structure of the plate [1].

The variety of the conditions is the main challenge of researchers to develop an earthquake forecasting system [5]. They have used different types of phenomena in their approaches that may have tight relation with the occurrence of an earthquake [1] [5] [6]. Water level in wells, release of particular gas from the earth, seismic wave velocity, electromagnetic field, soil temperature, etc, have become the main issues that have been brought up in their research [7] [8]. Unfortunately, none of those have been proven as the successful key parameter to be used to forecast the occurrence of an earthquake [9].
For future discussion, the complete terminologies of an earthquake are depicted in Figure 1. The other interesting thing regarding an earthquake is that it happens not orderly, it occurs randomly [10] [9]. So, it is not appropriate to forecast an earthquake based on statistical data. Still, some researchers have attempted to figure out through such approach [11] [5] [12]. This is an example that such earthquake forecaster has been expected desperately.

![Figure 1. Earthquake property terminologies](image)

Because it seems to be very difficult to have an earthquake forecaster through the previously mentioned ways or even through mathematical equations [13], different approaches to solve this problem such as using artificial intelligence becomes apparent [2]. Although water level, gas level, electromagnetic field, soil temperature, and seismic velocity have not yet given a better contribution to forecast the occurrence of an earthquake, all of those phenomena are caused by physical states [14]. It means that earthquakes are generally caused by particular physical patterns, and those patterns are changing dynamically. So, time-series of several physical values will determine particular earthquake condition.

Related to time-series patterns, multidimensional Hierarchical Graph Neuron (mHGN) has been proven to be capable of working as a pattern recognizer. The latest architecture to prove its capability was the one that uses five-dimension (5X5X5X15X15) neurons. The architecture has been tested to recognize 26 patterns of alphabetical figures. Despite of 10% of distortion in all the figures, the architecture was able to recognize in average more than 90% of those patterns. This experiment result is a positive indication that mHGN has a potential to be developed as an earthquake forecaster.

![Figure 2. The distribution of epicentres of 358,214 earthquake events (courtesy of NASA)](image)
2. Earthquake Forecast

The main focus when working on earthquake forecast is the fact that an earthquake occurs within three kinds of slides at the earth plate boundaries [10] [15] [16] [10], they are: transform, convergent, and divergent (see Figure 3).

![Figure 3. Three types of slides](image)

All the three types of the slides are caused by the movement of earth plates. The movements are so far irregular, so many researchers believe that this is the main reason that earthquake occurrence is unpredictable. But, it is still thinkable that the movements are physically measurable and following physical rules. This fact is actually a strong indication that there exist patterns of earthquake occurrence.

2.1. Earthquake Pattern Recognition

Earthquakes have become common issues in the world recently. Since earthquakes have occurred in many countries, people across the globe are helping each other in facing earthquakes. This situation will help researchers in gaining data which is mainly taken from seismograph scattered in the world. Researchers have started since long time ago [5] [9] investigating the best approach in forecasting earthquakes. Since many parameters and conditions need to be considered [5], challenges related to forecasting earthquakes need to be investigated further more.

The possibility of the occurrence of an earthquake varies, but the likelihood is still there in all parts of the world. For instance, the big earthquake that hit Aceh, Indonesia, in 2004 had never been experienced by Indonesians for hundreds of years. This situation applies for other earthquakes. Some countries have experienced natural disasters more than others [17]. This situation has been the main reason why these countries have spent many efforts to deal with earthquakes. When the circumstances of an earthquake to turn up in an area have reached, it is very likely that the area will suffer from an earthquake soon. Most big earthquakes have caused damages, losses, casualties, and costs [5] [3]. However, this does not mean that only those hit countries must concern with the occurrence of earthquakes.

The randomness of the occurrence of a earthquake is not only in terms of the location, but also of the time and the severity [18]. However, the location of earthquakes to occur is generally the same, that is along the faults (plate boundaries). Although many researchers are in opinion that the frequency, the severity and the average magnitude of earthquakes have increased since the last decades. However, it is still not clear how severe future earthquakes might be. The impossibility of measuring, or predicting the
severity of earthquakes, has been the major cause of the difficulties in anticipating their occurrences \[19\]. Many other researchers have suggested that, one way to deal with the randomness of the occurrence of earthquakes is through an earthquake forecaster.

Early warning system and now-casting that have been investigated and developed are not yet able to help people avoiding and mitigating earthquakes. If the time frame of detecting a earthquake is short, people will not be able to save themselves away from the earthquake. Despite those efforts of researchers, some researchers argue that in terms of prediction and forecasting, still no radical breakthroughs have been developed in the past twenty years. Due to its complexities, most earthquake researchers are working on technologies that are not focusing on the forecasting techniques. Rather, they are more concerned with how earthquake alerts can be disseminated to the public. The suggest that most difficult part in facing a earthquake is about how to handle people when a earthquake occurs \[19\] \[20\]. Additionally, most common recommendation for an early warning system is “how to evacuate.” In relation with earthquake alerts, it is also important that special attention must be paid for those who have disabilities.

It seems to be that researchers have tried to find an appropriate approach for working on three areas: earthquake forecaster, now-casters, or early warning systems. However, they also still integrate their system with disaster management systems. Even Doong et al. \[21\] suggest that the success of a disaster mitigation concept lies in the quality of the disaster management. This shows that their approach alone is not yet adequate to handle earthquakes. The potential reason to this case is the fact that a system for handling earthquakes requires very complicated mathematical analysis. So many parameters and values need to be considered and included in their calculation, and it is time consuming, but the system must run fast, that it can be used to warn people as early as possible.

As already mentioned, although the randomness of the occurrences of an earthquake has caused difficulties in handling it, the development of every earthquake still follows natural science characteristics and rules. Each part of an earthquake owns specific location, time, patterns and characteristics. An earthquake occurs due to the move of two neighboring earth plates. Not only the neighboring plates play a role in developing a earthquake, the type of the movement, the increased energy in the tension, and the characteristic of the plates are also significant contributors for an earthquake’s development. Yet, the difficulty to gain the measured values of those characteristics has become a new challenge in recognizing earthquakes before it turns up.

The time-series steps that build up an earthquake before its final slide can be treated as a pattern. It means that the recorded data from previous earthquake disasters plays a big role in recognizing it. Therefore, the data must be kept properly. The data is the important source of clue for researchers to analyse patterns of an earthquake. When patterns of earthquakes can be recorded, it is a strong possibility that when the same one of the previously recorded patterns turns up, a system that can recognize patterns can be used to recognize a earthquake early before it strikes \[22\] \[3\]. Such patterns are the most important part of mHGN for forecasting earthquakes hours or even days before they strike. Unfortunately, the data provided by seismograph stations is not so complete.

3. Multidimensional Hierarchical Graph Neuron

The purpose of describing the technology of multidimensional Hierarchical Graph Neuron (mHGN) \[23\] \[24\] in this paper again is to provide a quick way for readers to review its concept and its principle.

The need for solving multidimensional problems has also been discussed since a long time ago. People are aware of that to handle complex problems, values taken from numerous dimensions must be considered and calculated. Otherwise, the result that comes up after the calculation—analyzing just using a few parameters—cannot be considered correct. In most cases, such a condition will produce very high false positive and true negative error rates. Another issue related to solving multidimensional problems is the method that will be implemented. In a complex system, not only the number of dimensions is large, but how all the dimensions are interrelated to each other, or independent on one another, is often not clear.
Natural disaster system such as an earthquake is a suitable example as a multidimensional system. Therefore, forecasting earthquakes can also be considered as solving a multidimensional problem. Not only the earth plates need to be considered, the type of the movement, the energy in the tension, and the characteristic of the plates are also significant contributors in generating natural disasters of earthquakes. Another problem that still exists is the interdependency amongst those values. It is also difficult to figure out a formula that constitutes such interdependency. This is, therefore, a strong indication that such multidimensional problems may be solved using artificial intelligent approaches such as mHGN.

The current version of mHGN has been tested as a pattern recognizer. The results of the test are presented in Table 1. In this results, it is shown that mHGN has first been stored with 26 non-distorted alphabetical figures (A to Z). After that, a lot of distorted alphabetical figures with various distortion percentages has been fed to mHGN to be recognized. Based on the results it is clear that mHGN is capable of recognizing those distorted patterns. The worst distorted patterns with 10.7% distortion can be recognized the mHGN with the accuracy of 91%. If the steps of building up an earthquake produce a kind of a not-complete pattern, then this not-complete pattern will be recognized as a the precursor of an earthquake.

Table 1: The summary of the mHGN results

| 5X5X5X15X15 Patterns | Distortion (%) |
|-----------------------|----------------|
|                       | 1.3  2.7  4.4  6.7  8.0  8.9  10.7 |
| A 100 100 100 100 100 100 100 100 100 100 |
| B 100 100 100 100 100 98 97 94 |
| C 100 100 100 100 100 100 96 100 |
| D 100 100 100 100 100 100 98 |
| E 100 100 100 100 100 100 100 100 |
| F 100 99 94 89 83 85 74 |
| G 100 100 100 100 100 100 100 100 |
| H 100 100 89 67 48 50 55 |
| I 100 100 100 100 100 100 100 100 |
| J 100 100 100 100 100 100 100 100 |
| K 100 100 98 81 70 72 67 |
| L 100 100 100 100 100 100 100 100 |
| M 100 100 93 76 55 66 49 |
| N 100 100 97 77 63 60 55 |
| O 100 100 100 100 100 100 100 100 |
| P 100 99 87 79 80 81 81 |
| Q 100 100 100 100 100 100 94 99 |
| R 100 100 100 100 95 100 99 95 |
| S 100 100 100 100 100 100 100 100 |
| T 100 100 100 100 100 100 100 100 |
| U 100 100 100 100 100 100 100 100 |
| V 100 100 100 100 100 100 100 100 |
| W 100 100 100 100 100 99 98 92 |
| X 100 100 100 100 100 100 100 100 |
| Y 100 100 100 100 100 100 100 100 |
| Z 100 100 100 100 100 100 100 100 |

| Average    | 100 100 98 95 92 92 91 |
4. mHGN Architecture for Earthquake Forecasting

To give more details how mHGN can be implemented, the following are the main points for the architecture of an earthquake forecaster.

- Each value of a parameter taken from every station is represented by 3-bit, 4-bit, and 5-bit binary values. So, there are 6, 12, and 24 levels of measurement.
- The time series period is in various times, for instance every 1, 2, 5 hour, 1 day, or 7 days.
- There are 5 sources of data (spherical coordinate, date, time, seismic value, energy tension, plate flexibility).
- If five locations are used, and 5-bit data and 21 times of measurements, the dimension of mHGN is: 5X21X25.

The following table (Table 2) shows how the data are represented using binary values. It is important to mention that these values are cyclic. Such characteristic is important in case the start value needs to be changed according to the most suitable one.

**Table 2: The data representation**

| Value | 3-bit | 4-bit | 5-bit |
|-------|-------|-------|-------|
| 1     | 101   | 0101  | 00101 |
| 2     | 100   | 0100  | 00100 |
| 3     | 110   | 0110  | 00110 |
| 4     | 010   | 1110  | 01110 |
| 5     | 011   | 1111  | 01111 |
| 6     | 001   | 1101  | 01101 |
| 7     | 1001  | 01001 |
| 8     | 1000  | 01000 |
| 9     | 1010  | 01010 |
| 10    | 0010  | 11010 |
| 11    | 0011  | 11011 |
| 12    | 0001  | 11001 |
| 13    |       | 11101 |
| 14    |       | 11100 |
| 15    |       | 11110 |
| 16    |       | 10110 |
| 17    |       | 10111 |
| 18    |       | 10101 |
| 19    |       | 10001 |
| 20    |       | 10000 |
| 21    |       | 10010 |
| 22    |       | 00010 |
| 23    |       | 00011 |
| 24    |       | 00001 |
There are a number of issues that need to be taken care of when running mHGN as an earthquake forecaster.

- Logically, the training data is first clustered and then fed to the mHGN to be stored (bold binary values are values during clustering).
- To measure true-negative and false-positive (e.g. using clusters), non-earthquake data is also fed to mHGN.
- Each data is fed to mHGN four times to anticipate the same pattern of an earthquake occurs from different directions.
- It means, 16 patterns will be fed to mHGN.

**Table 3: The Hamming distances of the data**

| Time | 01000 | 00100 | 01100 | 00110 | 01010 | 00010 | 01001 | 00101 | 01101 | 00111 | 01011 | 00011 | 01010 | 00001 | 00000 | 01011 | 00011 | 00101 | 01101 | 01110 | 01111 |
|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Time | 01000 | 00100 | 01100 | 00110 | 01010 | 00010 | 01001 | 00101 | 01101 | 00111 | 01011 | 00011 | 01010 | 00001 | 00000 | 01011 | 00011 | 00101 | 01101 | 01110 | 01111 |
| Time | 01000 | 00100 | 01100 | 00110 | 01010 | 00010 | 01001 | 00101 | 01101 | 00111 | 01011 | 00011 | 01010 | 00001 | 00000 | 01011 | 00011 | 00101 | 01101 | 01110 | 01111 |

The above table (Table 3) shows that the Hamming distance of each non-bold binary value will be exactly 1 to the nearest cluster, that is supposed to belong to. The other Hamming distances are more than 1.
5. Previous Results
The following are the results taken from the previous real-time pattern recognition of tornados research, as an evidence of the capability of mHGN in recognizing patterns of natural disasters before they happen.

Figure 4. The Hackleburg 3-bit data taken every 5h

Figure 5. The Hackleburg 4-bit data taken every 5h

Figure 6. The Hackleburg 5-bit data taken every 5h
6. Conclusion
From the experiment results it is shown that mHGN has the capability to recognize multidimensional patterns. For simulating an earthquake forecast, we have presented results of up to 5D architecture. As already discussed in [24] and [23] there is no modification required if the architecture needs to be extended to bigger sizes of patterns. In the future this capability will be improved to the extent so, that multi oriented of multidimensional patterns will also be recognizable. At this stage it is also observed that mHGN still use a single cycle memorization and recall operation. The scheme still utilizes small response time that is insensitive to the increases in the number of stored patterns.

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