Knowledge-Based Systems 75 (2015) 87–103

Contents lists available at ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

Developing an expert system based on association rules and predicate logic for earthquake prediction

Aqdas Ikram, Usman Qamar *

Computer Engineering Department, College of Electrical and Mechanical Engineering, National University of Sciences and Technology (NUST), Islamabad, Pakistan

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form 20 November 2014
Accepted 20 November 2014
Available online 28 November 2014

Keywords:
Earthquake
Data mining
Prediction
Predicate logic
Expert system

ABSTRACT

Expert systems (ES) are a branch of applied artificial intelligence. The basic idea behind ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. ES provide powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional and orthodox methods. Thus, their use is proliferating to many sectors of our social and technological life, where their applications are proving to be critical in the process of decision support and problem solving. Earthquake professionals for many decades have recognized the benefits to society from reliable earthquake predictions, but uncertainties regarding source initiation, rupture phenomena, and accuracy of both the timing and magnitude of the earthquake occurrence have often times seemed either very difficult or impossible to overcome. This research proposes and implements an expert system to predict earthquakes from previous data. This is achieved by applying association rule mining on earthquake data from 1972 to 2013. These associations are polished using predicate-logic techniques to draw stimulating production-rules to be used with a rule-based expert system. The proposed expert system was able to predict all earthquakes which actually occurred within 12 h at-most.

1. Introduction

More than 200,000 earthquakes are recorded each year, though it is estimated that several million occur globally. Many of these go undetected because their magnitude is small or they occur in areas which are not closely monitored. Most seismic events (earthquakes) are very minor, and do not cause any damage – they may not even be felt by the local population. Others cause devastation, much of it due to collapsing buildings. Geoscientists are able to identify particular areas of risk and, if there is sufficient information, to make probabilistic prediction about the likelihood of earthquakes happening in a specified area over a specified period. These predictions are based on data gathered through global seismic monitoring networks, high-density local monitoring in known risk areas, and geological field work, as well as from historical records.

The United States National Research Council, Panel on Earthquake Prediction of the Committee on Seismology, suggested the following definition [1]: "An earthquake prediction must specify: the expected magnitude range, the geographical area within which it will occur, and the time interval within which it will happen with sufficient precision so that the ultimate success or failure of the prediction can readily be judged."

This definition is followed, as a necessary precondition of any scientific prediction study, although it is recognized that a confidence level could be assigned rather to a method than to just a single specific earthquake prediction. It is also recognized that predictions may be different in their accuracy related to (1) magnitude range, (2) geographical area, and (3) time interval.

Expert systems (ES) are a branch of applied artificial intelligence (AI), and were developed by the AI community in the mid-1960s [2]. The basic idea behind ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. This knowledge is then stored in the computer and users call upon the computer for specific advice as needed. The computer can make inferences and arrive at a specific conclusion. Then like a human consultant, it gives advices and explains, if necessary, the logic behind the advice. ES provide powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional and orthodox methods. Thus, their use is proliferating to many sectors of our social and technological life, where their applications are proving to be critical in the process of decision support and problem solving.

* Corresponding author.
E-mail addresses: aqdas27sep@yahoo.com (A. Ikram), usmanq@ceme.nust.edu.pk (U. Qamar).

http://dx.doi.org/10.1016/j.knosys.2014.11.024
0950-7051/

Intelligent models have been used for forecasting and prediction in various sectors such as health, finance, energy etc. For example, [3] proposed an ensemble model for intelligent heart disease prediction. It uses five different prediction models, combines the results of each in an ensemble model and generates the prediction information for heart disease diagnosis. Similarly [4] developed a new methodology ML-STWP namely Machine Learning based Short Term Wind Power Prediction for short-term wind power prediction. [5] proposed an algorithm which utilizes the fuzzy system and similarity/dissimilarity concepts to modify the initial predictions as produced by three different predictions models. The algorithm was applied on bank failure financial data and the results showed that it would predict failure in banking system 10 years ahead of time.

This research focuses on creation of a prediction model which may be used to predict future earthquakes. This is achieved by constructing a rule-based expert system from global earthquake data.

The distribution of the paper is described as follows. Section 2 provides the background of both earthquake physics as well as expert systems. Section 3 details the process of data acquisition and Section 4 describes the process of creating association rules. Section 5 introduces the proposed rule-based expert system while Section 6 discusses the results. Finally Section 7 summarizes the work which has been done.

2. Background

This section provides a background to earthquake physics as well as an overview of the expert systems.

2.1. Earthquake physics

Physics of earthquakes is a very complex and broad topic. Earthquake occurrence is connected with the earth's crustal dynamics. The crust and the upper layer of the mantle form the lithosphere consists of semi-rigid plates of different sizes. The slow movement of these plates over the asthenosphere and ocean floor extension is called plate tectonics [6]. Collision of these plates leads to the diving of one plate edge under another (convergent or subduction boundaries). Subduction leads to the formation of different geological structures and zones of volcanic activity. The place on earth where the rupture occurs is called '*hypocentre*' and the point right above hypocentre is called '*epicenter*'[7]. These enormous forces put tremendous amount of stress on the ground, forcing it to break and fracture from different places.

Average annual earthquakes and their magnitudes as recorded by USGS [8] based on observations since 1900 to 1999 is shown in Table 1.

Table 2 describes relationship between magnitudes, respective ground motion and energy changes. A magnitude 7.2 earthquake produces 10 times more ground motion than a magnitude 6.2 earthquake. However magnitude 7.2 earthquake releases about 32 times more energy as compared to magnitude 6.2 earthquake. The energy release best indicates the destructive power of an earthquake.

Table 3 identifies number of earthquakes worldwide for 2000–2012 located by the US Geological Survey's National Earthquake Information Centre (NEIC).

2.2. Expert systems

In the early 1950s, the development of computer software began with a focus in numerical systems. People began rapidly relying on computers to deal with data process at the beginning of 1970s. Stanford University developed a rule-based expert system called MYCIN back in mid 1970s. Although the system was invented almost some 40 years ago, it is still the representative of the state of the art expert system. MYCIN is developed to help diagnose the likely cause of patients' infection and provides suggested therapy for the patients. Its rule base consists of 450 rules which could be used to classify various meningitis infections [9]. The system was successful and it proved that with a rather simple representation of rules in a form of if-then-else statements is enough to handle with a rather complicated but focused domain area such as meningitis infection diagnosis. During 1980s, researchers began research artificial intelligence. United States, Japan, as well as many countries in Europe, began investing in the area of artificial intelligence and expert systems and during these time, many expert system tools began to emerge. The purpose of artificial intelligence is to broaden the application of computers to not only include numerical calculations but also to possess knowledge and therefore enhance the utilization of computers. The major research area for artificial intelligence includes natural language processing, symbol processing, rule-based system and logic systems.

Table 1
Average annual earthquakes and their magnitudes as recorded by USGS[1] based on observations since 1900 to 1999 [8].

Magnitude	Average annually
8 and higher	1
7–7.9	15[1]
6–6.9	134[1]
5–5.9	1319[2]
4–4.9 (estimated)	13,000[2]
+3–3.9 (estimated)	130,000
2–2.9 (estimated)	1,300,000

Table 2
Relationship of magnitude, ground motion and energy changes [8].

Magnitude change	Ground motion change (displacement)	Energy change
1.0	10.0 times	About 32 times
0.5	3.2 times	About 5.5 times
0.3	2.0 times	About 3 times
0.1	1.3 times	About 1.4 times

The development of functional expert systems is always centered on the organization of a knowledge base. Fig. 1 shows the typical integration of expert systems components [10]. Knowledge engineers collects and organizes knowledge gathered from domain expert then convert the expert knowledge into a form which computer expert system understands and save those converted knowledge into the knowledge base. Users enter the collected facts into the system via the user interface and save the data into the fact base. Finally, users get the results, recommendations and explanations from the system.

As it can be seen from Fig. 1, an expert system communicates with the end users through the user interface while gathers the knowledge it required through a knowledge acquisition interface which is used by knowledge engineers. Therefore, the expert system has two features.

1. *Frequent user interactions*: An expert system collects data from the users and formulates the end results based on these data.
2. *Independent and dynamic knowledge base*: The major difference of an expert system from a traditional program is that the knowledge is independent from the program flow.