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Dynamic prediction model of mining subsidence based on Cellular Automata

Sun Xueyang[1, a], Xia Yucheng[2,b]

[1]College of Geology and Environment, Xi'an University of Science and Technology, Yanta Road NO.58 Xi’an City of Shaanxi Province, PRC.

[2]College of Geology and Environment, Xi'an University of Science and Technology, Yanta Road NO.58 Xi’an City of Shaanxi Province, PRC.

[a]sxy163@163.com [b]xiayc@xust.edu.cn

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Abstract. Cellular Automata is a discrete dynamic model based on space-time, and is one of the effective methods to study complex systems. The CA, a new method applied to coal mining subsidence dynamic evolution model, provide a new idea for the prediction research of mining subsidence. Definition and basic theory of CA were introduced briefly. According to the particularity of the research in the field of mining subsidence, the definition of CA is extended. The model of dynamic evolution of mining subsidence is built on the CA. Then modeling method and the structure of model are elaborated, and the advantages of the CA are applied to coal mining subsidence prediction model is analyzed.

Introduction

Cellular Automata (CA for short) is used to simulated the auto replication function of life system, it was putted forward by vonNeumann firstly, its mathematical structure is very simple: time, space and state variable are all discrete sets, and the condition is limited, according to the operation of the simple local rules at the same time and it can get all the status of the cell in a moment, that is a Configuration of the CA, the structure of CA changes and presents a rich and complex transient evolution process according to the change of the time, so CA can be used as an infinite dimensional dynamical system. It is not only an important model of computation theory, attracting large numbers of science from the field of computer to study its calculating ability, but also is widely used in the nonlinear phenomenon and the research of fractal structure in mathematics, physics, biology, chemistry, geography, economics and so on.

In the coal mining area, after mining area reaches a certain scope, the balance of original stress state is to be broken the, in the process of coal mining and later period, rock ,soil and land surface through the destruction of the continuous movement, deformation and discontinuous (crack, caving, etc), makethe stress redistribution, in order to reach a new equilibrium, which leads to surface movement eformation, all called mining subsidence.

In recent years, geology and mining sector began a systematic and comprehensive ideas on multidisciplinary research of mining environment and disasters (eg references listed), and in coal mining subsidence prediction it also made some impressive research results. Begley, etc. (1996) made the cover thickness, the lithologic descriptions and the percentage of hard rock in the immediate roof, the old roof and of the entire cover etc. as an input parameter, and developed the long arm of mining subsidence prediction software (MPSM); rock fracture and instability research Center of Northeastern University in our country developed RFPA2000 software system and it can simulate rock failure process.

Coal mining subsidence damage is a complex open systems and dissipative system, and have many other complex fractal characteristics, making it difficult that the traditional research methods meet the requirements of mining subsidence disaster prevention evaluation and forecast. Therefore, it is

necessary to resort to new technology to simulate the temporal and spatial variation of mining subsidence and recently development of CA technology provides a new way of thinking.

Nonlinear characteristics of mining subsidence

Mining Subsidence is a complex nonlinear mechanical problems, rock initial damage occurred by mining disturbance, then evolution of mining under stress, fracture network formed by the rock caving, fracture, delamination, and many crack propagation, which result in the overlying strata and even the entire surface movement and deformation until the damage. The damage occurs not only in the coal seam overburden, but also occurs in surface geological environment. In this process, the coal mining subsidence produce different degrees of damage on the surface construction (structures) underground aquifers and so on. when the extent of the damage is Lesser , the surface building (structures) appear small cracks, etc.; when the extent of the damage is larger, the surface construction (structures) damaged heavily, and it may lost its original function or loss of groundwater resources which have significance of regional water supply, causing coal mining subsidence damage. The hazard occurring conditions of mining subsidence hazard is subsidence caused by underground coal mining subsidence, overlying rocks roadway, caverns of disaster bodies, underground equipment, personnel, surface building (structure), roads, farmland and so on. Coal mining subsidence damage include a large area roof collapsed suddenly, roof fall accident, flooded shaft caused by mine water bursting, coal and gas outburst or mine earthquake, Aquifer have meaning of supplying water to the ecological environment ,and the destruction of Aquifer has caused land desertification, using water difficultly on production or living, and surface construction (structures) damage and other types of disaster. The several salient features will be introduced bellow:

(1) A muti-level and interrelated. Coal mining subsidence damage system is a muti-subsystem, muti-level, complex structure and function integrated system, each subsystem or part subsystem interactions, interconnected, forming a complex association. The complexity associated not only in structure, but also in content. They can be associated on material, energy or information, that is the relationship between the various subsystems are diverse.

(2) Many factors, the level of uncertainty. Coal mining subsidence damage formation is affected by many factors, and each factor in turn contain many forms, forming complex causal expressing relationships between the factors of the coal mining subsidence damage system so that the causal link between the levels of each factor relationship is unclear.

(3) Systematic uncertainty. Mining Subsidence Disaster system is non-deterministic systems. Non-deterministic one hand, the performance of natural features, the other is for a specific time period mankind coal mining subsidence damage reflects the level of awareness. Coal mining subsidence damage system boundaries, structure and function have a vague and difficult to identify, and the system in various disasters are random, unpredictable elements of its disaster, and even harm caused by disasters is very complex, difficult to judge and measure . Because of these non-deterministic, coal mining subsidence damage to the system caused a lot of research work difficult.

(4) Openness of the system. Coal mining subsidence damage system is a person-Nature-Society system that is constantly exchanged with its environment on substances , energy and information, reflecting the openness of the system.

(5) The systematic dynamics. The time-sensitive of coal mining subsidence damage system is strong, which varies over time constantly. This is due to its constant change on surrounding environment, causing constant change of input and output intensity and nature on the coal mining subsidence damage system, and causing changes in the structure and function of coal mining subsidence damage system, so that the coal mining subsidence disasters system presents a significant dynamics.

(6) Social economy. Social economy is one of the important subsystems in coal mining subsidence damage system, and it has close interaction mechanisms with mining subsidence damage: on the one hand, various kinds of human activities affect the evolution of the geological environment and the

formation and development of mining subsidence damage directly or indirectly; the other hand, the geological environment and mining subsidence damage restrict social economic development directly or indirectly.

(7) Non-linear. This refers to that the output characteristics of coal mining subsidence damage system in response to environmental input does not have a linear superposition of nature, its overall functionality is greater than or less than the simple sum function or factors. For one input below a certain level, coal mining subsidence damage system does not work; for one input above a certain level, coal mining subsidence damage system mutated to a different nature disaster system; For one input between a certain level, the response and the output levels of mining coal subsidence damage system present curvilinear correlation. See from the view of systematic science, the seven characteristics described above, illustrates that the coal mining subsidence damage system is not only a dynamic developed, non-linear, opened system, but also a dynamic complex system of uncertainty, social-economic characteristics and so on.

Cellular Automata

2.1 The basic concepts and components of CA

CA is mentioned by Von Neumann on the computer simulation of biological reproduction in early 1950s. It is defined into a dynamical system evolved in the discrete time dimension and is in discrete, finite state cellular composition of the element extracellular space, accordance with certain local rules. In mathematical notation, standard cellular automaton is a quadruple form:

$A = (Z_n, S, N, F)$ ・(1)

Where in A represents a cellular automaton system; Z_n is n-dimensional Euclidean space and N is cellular space's number of dimensions; Cellular networks distributed in space is a collection of cellular space, which can be one-dimensional, two-dimensional or multidimensional. The division of cellular space can have multiple forms and two-dimensional is most common. CA grid generally can be arranged in accordance with triangle, square or hexagon.

S is a finite set of discrete states, $S = \{S_1, S_2, S_3, ..., S_i ..., S_k\}$, S_i represents the i-th state of CA; N, neighborhood of central cell, is the subset of Zn's finite sequence, $N = (x_1, x_2, ..., x_i, ..., x_n)$, in which x_i is the position adjacent cell relative to the center one; common neighborhood (Neighbor) types include von Neumann (Vonneumann) type, Moore (Moore) type, Marco DeGeneres (Margolus) type, and so on.

F is the evolutionary rule of $S_i^t \longrightarrow S_i^{t+1}$. It is the core of CA, which expresses the logic simulation of the process imitated to determine spatial variation's results. If a cellular automaton has no evolutionary rules, then it can only describe a static phenomenon, and only after introducing of the evolution of the rules, it can imitate complex dynamic spatial phenomena.

2. 2 Characteristics of CA

CA model has strong vitality because of its simple framework, open, and ability which can simulate the behavior of complex systems. From present study, it has the following characteristics:

(1) Spatial. Cell CA are defined by grid space, which can make a lot of space data sets be compatible. Unlike standard CA, the definite of the cell is an abstract concept, but in this paper it has a clear geographical meaning, which actually represents a certain area of the surface element.

(2) Discrete. CA's status, time and space are discrete, so it has good computer interface.

(3) Synchronization. It means each cell synchronously operate in time to comply with different rules. The change of CA' state can be seen as the calculation of the data or information .And this important feature is the calculate parallelism.

(4) Locality. That is, each cells' state in the next time is decided by its neighbor's current state.

(5) Dimensions. In the power system the number of variables is generally called dimension. From this perspective, the dimension of CA is infinite greatness.

(6) Temporal dynamics. CA can be used to simulate the temporal dynamics of complex systems, so it makes up shortness of the traditional model which considers isolate of the time and the spatial characteristics.

(7) Simplicity. CA can determine cell the cell's next time state by its initial state of the state of the surrounding cell, with no need of building a complex differential or partial differential equations

2.3 Model Structure

Based on the definition of CA, CA model is actually a methodological framework. If it's under this framework, cell being the calculation unit, building mining subsidence prediction model in each cell, simulating cellular unit dynamic evolution of mining subsidence and considering the various links between cell units, from the local to the whole state of cellular evolution, we can simulate and predict any one time, any cellular process of coal mining subsidence.

According to this idea and the extend of standard CA defined above, combining CA with coal mining subsidence prediction model can build CA mining subsidence prediction model. As is shown in Fig. 1, the entire model is structured in three parts: ① the input module that provides spatial input data and determines the model parameters, such as underground mining engineering, mining intensity, the stratigraphic structure of cap rocks in mining areas, the structure of cap rocks in mining area and tectonic stress field. ②the core part— the unit cell model, including the adjustment of model parameters, the identification of the seed point and the analysis of controlling factors. ③ the result output module that provides dynamic information about mining subsidence of any time.

Advantages of the based on CA model of mining subsidence expected dynamic evolution

A cellular automaton is a distributed computing model in which the time, space and states are discrete. Its "bottom-up" research ideas, powerful and complex calculations, inherent parallel computing capabilities, highly dynamic and spatial concepts characteristics make it have a strong ability when it is simulating the space spatiotemporal evolution of complex systems. In theory, it is very suitable for researching the coal mining subsidence damage model. Overall, when the cellular automaton evolution is expected to be applied to coal mining subsidence damage expected evolution model, it mainly has the following advantages:

(1) CA uses the "bottom-up" modeling approach. Instead of using complicated equations describing complex whole seam overburden system, it uses the interaction among unit of overburden system to simulate the overall behavior of the complex overburden undermine system. This modeling approach is more conducive than traditional coal mining subsidence prediction model to analyze and research the process of overburden failure mechanism, which can further reveal the overburden mining disturbance in the regularity of the failure process.

(2) CA separates space and time automatically, and unifies the geographic entity's special and time characteristics. This is suitable of building distributed computer models which is easy to combine with the coal mining subsidence prediction models. It also has the characteristics of parallel computing which improve the computational efficiency of the model.

(3) From the perspective of the data model, CA cell and raster data grid, are both discrete expression of space. This data structure' natural consistency make cellular automaton can directly use the existing raster data as well as many mature meshing algorithm, so CA is easy to integrate with GIS, remote sensing and other raster data processing system.

(4) The integration of CA and GIS, on the one hand, due to the integrated CA spatial and temporal analysis capabilities, enhanced temporal dynamics modeling capabilities of GIS; On the other hand, GIS provides powerful spatial data processing capabilities which can prepare data for CA, define a valid cellular transformation rules and visualize the simulation results. Therefore, integrating CA and GIS can overcome their shortcomings, which becomes a new complementary dynamic system to simulate the complex mining subsidence process.

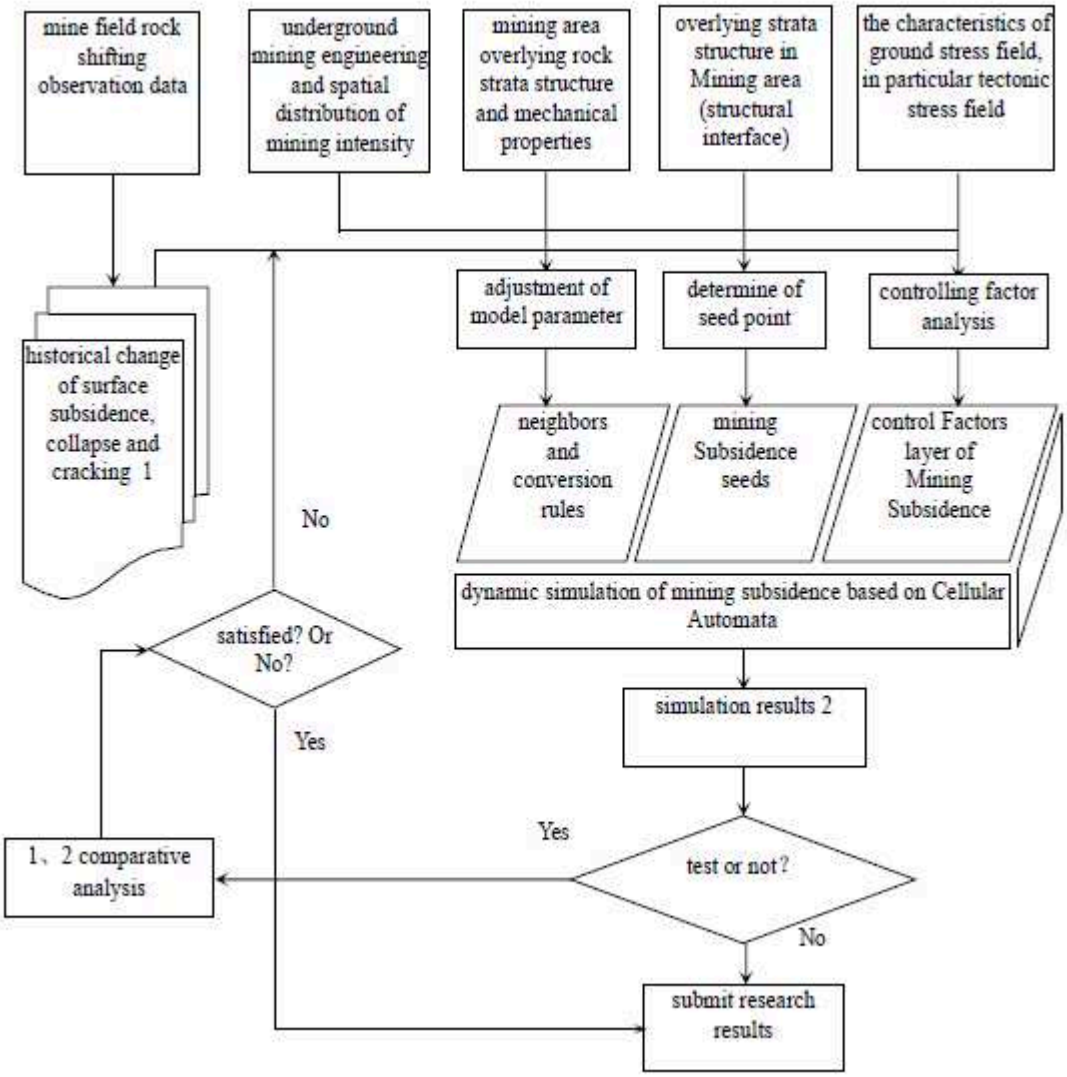

Fig. 1 Prediction Model of mining Subsidence dynamic evolution coal based on CA

Summary

CA is a common spatial dynamical method with spatiotemporal dynamics feature. It's the earliest, the most in-depth and the most abundant in theory and practice to research the urban growth, proliferation and simulation of the evolution of land, and also the current central issue on CA. The project will be considered by the mining damage synergy multiple subsystems complexity non-equilibrium open system, which attempts to introduce CA into mining damage research, and simulate coal mine geological environment as an open dissipative system that showed mutations, self organization, chaos and other complex characteristics for different tectonic environments of mine to build dynamic evolution of mining damage prediction model. The successful application of CA in mining subsidence studies, is bound to find a good space-time dynamic model for the dynamic evolution of mining subsidence prediction and meanwhile further expand the range of applications of cellular automaton method.

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References

[1] Zhou Hucheng, Sun Zhanli, Xie Chunyi. *Geographical Cellular Automata Studies*. Science Press. 2001

[2] Zhang Sijing, Wang Sijing, Zhang Zhuoyuan, etc. *Chinese engineering geology*. Science Press. 2000

[3] He Guoqing, YangLun, Ling Gengdi, etc. *Mining subsidence study*. China University of Mining Press. 1994

[4] Chen Shupeng .*Urbanization and Urban geographic information systems.* Science Press. 1999

[5] Singh, Rajendra; Singh, T.N.; Dhar, Bharat B. *Coal pillar loading in shallow mining condition*. International Journal of Rock Mechanics and Mining Sciences & Geomechnics Abstracts 1996,33: 757~768

[6] Luo,Y, Peng,S.S. *Integrated approach for predicting mining subsidence in hilly terrain*. Mining Engineering .1999,51：100~104

[7] Begley,R.;Beheler,P.;Khair,A.W. *A window based mechanistic subsidence prediction model for longwall mining.* Proceedings of the 5th conference on the use of computers in the coal industry. West Virginia University. 1996:74~82