Formalism Study in Nuclear Emergency Response: Path-Finding Problem

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1. Introduction

The development of evacuation models is important when establishing nuclear emergency response strategies. Currently, research is being conducted on the development of an evacuation model using an agent-based model. However, the evacuation process in this mode was difficult to be explained or understood by stakeholders. [1] To solve this problem, researchers have generally used pseudo-codes or flowcharts.

In spite of its benefit, there is a limitation as the pseudocode should know the appropriate language. In addition, a flowchart becomes vast with complex logic, or there is an inconvenience to re-creating a flowchart when modifying or changing it. The goal of this study is to propose an approach called formalism to backup such conventional approaches. The key idea is to express the evacuation process using a hierarchical structure.

Nuclear emergencies are accompanied by extraordinary conditions such as complex infrastructure and radioactive material leakage. There is a lot of infrastructure involved, and it should be managed through a systematic method. Formalism can show the evacuation process through simple mathematical formulas and intuitive models. Furthermore, it is possible to partially modify and change with re-creating, enabling efficient maintenance when modifying or changing. This paper attempted to express the path-finding model (an element of the infrastructure) using formalism. The path-finding model uses the A* algorithm.

2. Methods

2.1 Agent-Based Model (ABM)

The Agent-Based Model (ABM) is a computational approach that explains macroscopic phenomena through interaction with microscopic agents' actions. Macroscopic phenomena are related to large and complex systems that are difficult to be explained without holistic approaches, such as politics, economy, and society. On the other hand, microscopic agents are the elements that make up a huge system and act on their own and interact with other agents. A computational approach refers to a model in which an input value is an input and an output value is obtained through a certain formula or processing process. Thus, the agent-based model is a model that can calculate a complex system consisting of individual agent behavior and interaction through a certain formula and process.

In an ABM, the complexity of the model may increase significantly depending on the purpose or size of the simulation. In this case, insight or lessons-learned from the model may not be enough to meet a certain goal. Thus, it is necessary to systematically identify the characteristic variables, behavior models, and interaction models of the agents involved in the system in advance. [2]

2.2 Formalism

Formalism is a theory to effectively perform such systematization, typically with the Discrete Event System Specification (DEVS) method. The DEVS is a method of systematizing the target system through the theory of sets-based formulas and schematic rules. The DEVS systematizes the system into an atomic model describing individual agents and a coupled model describing interactions between atomic models. The atomic and coupled models are expressed in the same way as Equations 1,2 and Figure 1,2.

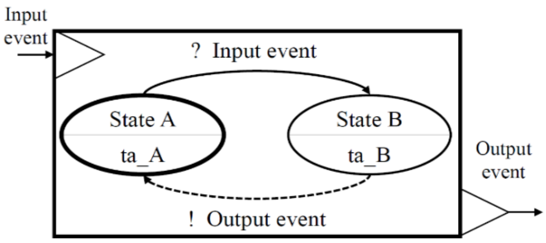


Figure 1. Atomic model

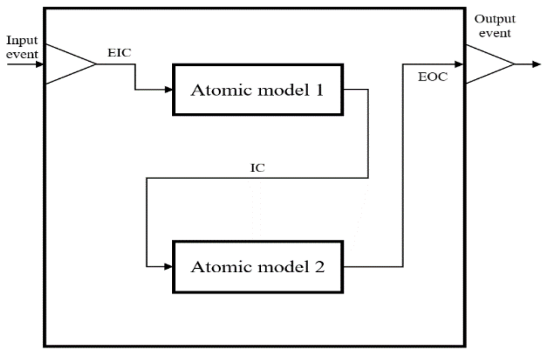


Figure 2. Coupled model

$$A = < X , Y , Q , \delta_{ext} , \delta_{int} , ta , \lambda > \quad (1)$$

$$CM = < X , Y, M, EIC, EOC, IC, SELECT > \quad (2)$$

The atomic model(A) is defined as follows. X, Y, and Q are sets of inputs, outputs, and state variables. δ_{ext} defines the next state Q for all possible combinations $(Q \times X)$ of the input set and state set. δ_{int} defines the following states for each element in the set of states. ta defines the maximum time for each element q of the state set Q. λ defines each element of the output set for each element of the state set.

The coupled model (CM) is defined as follows. X, Y, and M are the atomic sets of inputs, atomic sets of outputs, and atomic sets of components, respectively. External Input Coupling (EIC) defines the connection relationship between the input of the coupled model and the input of the internal component model. External Output Coupling (EOC) defines the connection relationship between the output of the internal component model and the output of the coupled model. Internal coupling (IC) defines an output and input connection relationship between internal component models. Finally, $SELECT$ defines priorities for sequential processing of events that occurred at the same time. [3]

2.3 Path-finding problem

2.3.1 A* algorithm [5]

A* search is one of the well-known path-finding algorithms. There are three main concepts. First, the minimum spot is searched first. This is different from the Dijkstra algorithm, which finds the shortest path of all nodes based on one node. Second, the heuristic estimate is used. This path-finding algorithm uses the path weight as a heuristic estimate. Finally, the node is managed using an open list/closed list. The open list refers to a set of searchable nodes, and a closed list refers to a set of nodes that have already been searched. Accordingly, the A* algorithm has the advantages of saving time cost and low time complexity.

2.3.2 Expression algorithm using Formalism

Using a simple map with 10 nodes and 1 shelter (potential destination in an emergent situation), a simple path-finding model was made. Figure 3 is the evacuation path-finding model used in this paper.

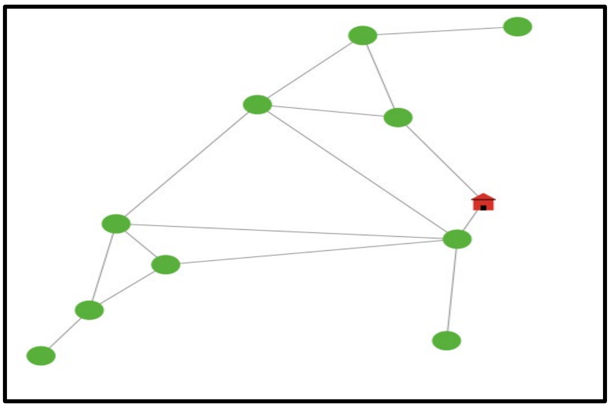


Figure 3. Path-finding model

First, the procedure of expressing the A* algorithm in formalism is described.

(1) Search for nodes connected to the evacuation starting point (A_0)
(2) G value calculation (A_1)
(3) H value calculation ($\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$) ($A_2$)
(4) F value calculation (F = G + H) (A_3)
(5) The lowest value of F value is selected. (A_3)
(6) Corresponding node # is entered in the close list. (A_4)
(7) Iteration of this procedure

Second, the meaning of each parameter is defined that used in the model.

(1) G value: necessary time (from the start node to the current node)
(2) H value: heuristic estimate (from the start node to shelter: shortest time)
(3) x_i, y_i: 2D coordinate position of each node
(4) tick: unit time in evacuation simulation
(5) link: connections between nodes (evacuation routes)
(6) close list: the sequential set of nodes according to path-finding.

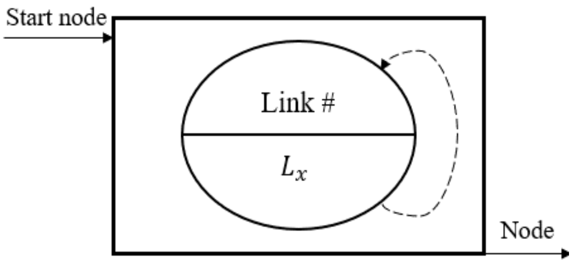


Figure 4. Search for nodes (A_0)

$$A_0 = < start\ node, node, L_x, X, Link\ \#,\ tick, X > \quad (3)$$

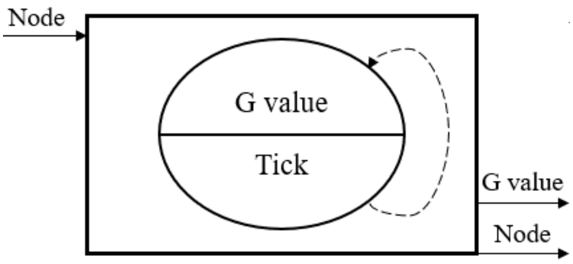
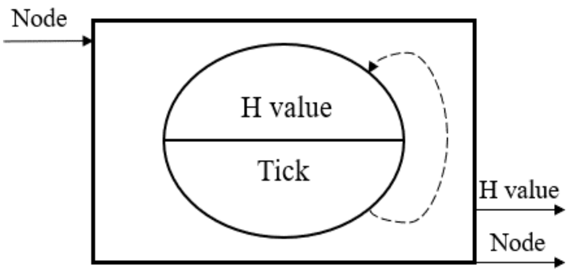


Figure 5. G value calculation (A_1)

$$A_1 = < node, (node, G\ value), time, X, G\ value, tick, X > (4)$$



H : $\sqrt{(x_2 - x_1)^2 - (y_2 - y_1)^2}$

Figure 6. H value calculation (A_2)

$$A_2 =< node, (node, H\ value), H\ value, X, H, tick, X > \quad (5)$$

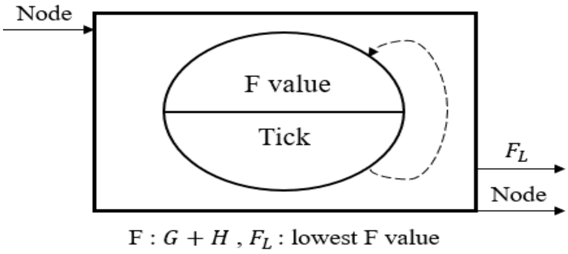


Figure 7. F value calculation (A_3)

$$A_3 =< node, (node, F_L), F\ value, F, X, tick, X > \quad (6)$$

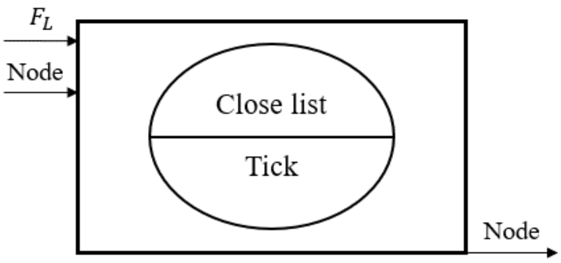


Figure 8. Close list (A_4)

$$A_4 =< (F_L, node), node, Close\ list, X, X, tick, X > \quad (7)$$

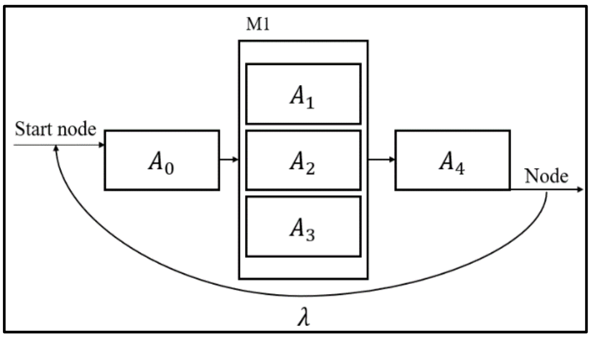


Figure 9. Path-finding model (Formalism)

Figure 4,5,6,7,8 represented the atomic model of path-finding, and finally, Figure 9 expressed the overall path-finding problem. Equations 3,4,5,6,7 also showed the formulation of the atomic model.

Original code for the A* algorithm in an ABM was difficult to be understood and maintained. Particularly, to insert the additional agents, the entire code needed to be modified.

On the other hand, the modified code borrowing formalism could be represented as shown in Figure 11. This code used formulas and models expressed in formalism. Public users may easily understand the composition of the algorithm.

```
;========path find functions=============================
to path-find ;A* model

  ask nodes with [color = blue] [set color green]
  ask links with [color = yellow][set color 5 set thickness 0]

  let start min-one-of (nodes) [distance myself]
  ask start [set color blue set size 5]
  let goal one-of nodes with [shape = "house"]
  ;ask goal [set color green set size 10]
  set path (A* start goal)
  if path != false [highlight-path path]
  print "finish path-find"

end

to-report heuristic [#Goal]
  report [distance [localization] of myself] of #Goal
end

to-report A* [#Start #Goal]
  ask #Start
  [
    hatch-searchers 1
    [
      set shape "circle"
      set color red
      set size 2
      set localization myself
      set memory (list localization)
      set cost 0
      set total-expected-cost cost + heuristic #Goal
      set active? true
```

Figure 10. Path-finding code (original)

```
;===========Path finding functions============
to A0 ; Search for nodes
  ask start
  [
   set father self
   set visited? true
   set active? true
  ]
end
to-report A1 [#Goal] ; G value calculation
  report Cost-path
end
to-report A2 [#Goal] ; H value calculation
  report Heuristic #Goal
end
to-report A3 [#Goal] ; F-value calculation
  report Cost-path + A2 #Goal
end
to-report A4 ; Close list
  report father
end
```

Figure 11. Path-finding code (using formalism)

3. Conclusion & Discussion

Using formalism, the path-finding problem was expressed. Many complicated factors were composed in the nuclear emergency evacuation model. That is, adding various factors increased the accuracy of the evacuation model. At this time, the expression method through formalism is expected to be useful.

Currently, only path-finding is expressed as Formalism. However, if expressed in combination with the infrastructure previously studied [4] through a hierarchical structure, it can become complicated, and additional research is needed on this topic.

Acknowledgments

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