SOCIAL INTERACTION IN PEDESTRIAN EVACUATION: A CELLULAR DISCRETE EVENT SIMULATION APPROACH

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ABSTRACT

This paper presents a cellular simulation model for pedestrian emergency evacuation, which takes into account social factors such as individual vision, environmental familiarity, communication and conduction, and velocity adjustment. Variables are introduced to describe the relationship between the evacuees and their environment, as well as the interaction with each other. RESTful CD++ has been used as a middleware to run simulations remotely. The results obtained confirm the role of social interactions in emergency evacuation. This work, on the one hand, shows the advantages and advancement of model-driven theory and DEVS formalism to address social science issues; on the other hand, it helps to better integrate evacuation planning and public safety management in the design of urban architectures.

Keywords: pedestrian evacuation, social interaction, communication, Cell-DEVS, RESTful CD++.

1 INTRODUCTION

Emergency events such as fire, earthquake and terrorist attack often lead to crowd disasters, which result in catastrophic and devastating consequences, especially in public places with high-density population such as library, office building, subway station, theater and stadium (Helbing et al. 2002). A recent stampede event happened during New Year EVE 2016 in Shanghai, China, in which 36 people died and more than 49 suffered injuries. Another example is the terrorist attack at State de France football stadium and Bataclan concert Hall in Paris on November 13, 2015. Therefore, the urgent issues are to explore the behavior of pedestrian evacuation system, and to improve the efficiency of crowd evacuation.

Compared to large-scale evacuation exercises, model-driven theory and computer simulation technology have economic advantages; therefore, they become the inevitable solution to the above-mentioned problems. Current research efforts on pedestrian evacuation systems emphasize on three factors: (1) physical locations(i.e., all aspects related to the environment, hazard, position and movements, etc.), (2) management processes (like training and emergency plans), and (3) psychological (panic) and social organizational characteristics (i.e., aspects related to communication, group and flocking, etc.) (Santos and Aguirre 2004, Duives et al. 2013). However, all insights that could be derived from the third factor have not been taken into account in simulation models.

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In this paper, we propose a cellular pedestrian evacuation model that integrates psychological and socio-organizational dimensions. The model takes advantage of the occupancy model proposed in Wang et al. (2013) and uses several variables to describe physical locations, including layout (information about building architecture), pathway (movement directions), phase and movement (route choice); in addition, the description of social interaction factors are improved by the introduction of variables such as environment familiarity and velocity adjustment into the model. Based on these variables, we have defined a set of pedestrian behavioral rules, which show how the evacuees deal with pre-evacuation, obstacles, collision, velocity matching, and isolated decision making, as well as follow-up of actions during the evacuation, and communication and interaction with each other. We used CD++ (López and Wainer 2004) to describe the model, using a multi-variables (ports) approach, and we ran simulations using RESTful CD++ (Al-Zoubi and Wainer 2015), a web service for remote simulation execution.

This paper is structured as follows: Section 2 discusses related works. In section 3, we clarify the relationship between personal attributes, social interaction and evacuation behavior. In section 4, the cellular model is proposed, and the rules are illustrated, using the Cell-DEVS formalism. Section 5 analyzes the simulation results. We finally make a conclusion in section 6.

2 RELATED WORK

Pedestrian movement modeling can be done from three perspectives: macroscopic, mesoscopic and microscopic (Guo et al. 2008), which respectively focus on flow, group and individual (Low 2000). Santos and Aguirre (2004) reviewed some of the most well-known simulation models (flow-based, cellular automata and agent-based), and examined the extent to which social dimension has been incorporated. It appears that flow-based models, like EVACNET4, just estimate flow formations during the evacuation, and emphasize on the management of physical position rather than the social behavior of evacuees (Kisko, Francis, and Nobel 1998). Cellular automata based models, like EGRESS, discretize space, and focus on trajectories of individual movements, but not on the social aspects (Ketchell et al. 2002). Agent-based models, like SIMULEX and EXIT89, try to introduce individual attributes into the algorithm for movement, and explore the influences of gender, age, rule, disability, preference and other social factors on the evacuation as well (Thompson and Marchant 1995, Fahy 1999). FIRSCAP and EXODUS introduce social psychology and social organization (panic, environmental familiarity, leadership, gesture communication, etc.) into the model (Feinberg and Johnson 1995, Galea et al. 2006). All these efforts share the following common limitations:

- the algorithm for global movement is limited to the shortest route; this leads to a lack of differentiation between evacuees and an underestimation of the social interactions impacting them;
- the simulation objectives always focus on finding bottlenecks and identifying emergent collective behavior; this results in a poor consideration of the psychology and the decision-making ability of individuals, as well as communication between them;
- the natural asymmetry of information is not valued, therefore all evacuees usually move to a same unique exit uniformly, while pre-evacuation information and velocity adjustments should have been taken into account depending on evacuees various positions.

3 PERSONAL ATTRIBUTE AND SOCIAL INTERACTION IN PEDESTRIAN EVACUATION

Social interactions in emergency evacuation systems can be classified into three categories: (1) individual-environment, (2) individual-individual and, (3) group-group. This paper focuses on the former two, which it extends by the following:

1. introduction of *familiarity* ports, that describe the ability of individuals to deal with building environment information;
2. enrichment of evacuees with social attributes such as personal vision, communication and guidance, and establishing action selection mechanisms based on the inter-individual dissemination of architecture information and decision-making;
3. design of *velocity* blocks to differentiate evacuees according to the distance from event source, and establishing speed matching mechanisms.

Table 1 shows how social attributes (as suggested by Durupınar (2010)) are mapped onto behavioral rules:

- *walking speed* means adjustment according to the information about emergency event and emotion level;
- *right preference* shows preference of turning when individual is about to face an obstacle;
- *waiting radius* refers to the space individual tend to keep before moving;
- *trained* (which is influenced by factors such as visiting frequency, evacuation drill, etc.) expresses the extent to which the evacuee has familiarities with the environment; it significantly impacts on the choice of the route the evacuee will follow. These above attributes are all related to the rules of *pre-evacuation*, *independent* or *random decision-making* and *exit*;
- *flexibility*, which is mapped onto the rule *obstacle avoidance*, means the ability to dynamically modify the route selection based on environmental changes;
- *panic*, which maps onto the rule *velocity matching*, may lead to speed acceleration;
- an isolated evacuee who is not familiar with the environment is more likely to *explore environment* and do *isolated decision-making*;
- *communication* expresses means (words and gesture, extroverted personality, etc.) by which information about the explored areas is giving to other evacuees during a building evacuation; that's why it triggers the rule *"follow-direction"*;
- *pushy*, *personal space/avoidance* and *waiting timer* illustrate in different ways whether an individual has respect for others and let them walk first or in *priority order* (queuing if necessary)or not at all;
- *leadership* expresses the level of help to other evacuees to find their route; that's why it triggers the rule *"follow-me"*;
- *emotion contagion* indicates that there will be emotional contagion among individuals.

4 CELLULAR MODELING OF PEDESTRIAN EVACUATION

We used the Cell-DEVS formalism to define a cellular model of pedestrian evacuation movement. Cell-DEVS is based on DEVS (Discrete Event System Specification), a system simulation modeling language proposed by Zeigler et al. (2000), which provides a hierarchical and modular framework for discrete event systems. Cell-DEVS, proposed by Wainer (2009), combines DEVS with cellular automata and introduces explicit timing delays. In Cell-DEVS, each cell is defined as an atomic DEVS model; an atomic Cell-DEVS model is a coupled DEVS model. In recent years, a series of Cell-DEVS models have been used in the field of crowd behavior (Wang et al. 2012, Wang and Wainer 2015, Al-Habashna and Wainer 2016). They took into consideration random movement (port *movement* and variable *pathway*) and varied speed of the crowd (*hotzone* variable), and introduced a technology which abstracts the building information data (standard IFCs) into the crowd modeling (*layout* variable), combining both the building information and pedestrian evacuation movement. The novelty of the work is that, we fully considered social attributes and interactions that the previous works did not taken into account. The modeling process is shown in Figure 1 (modified based on Wang et al. (2012)). In addition, our reasons to choose Cell-DEVS are the following:

Table 1: Personality parameters and social interaction.

Type	Attribute	Rule Name
individual-environment	walking speed	①pre-evacuation;
	trained	⑤independent decision-making;
	right preference	⑥random decision-making;
	waiting radius	⑩exit rule
	flexibility	⑨obstacle avoidance
	panic	②velocity matching
	exploring environment	⑧isolated decision-making
individual-individual	communication	④vision; ⑦"follow-direction"
	pushy	③priority order
	personal space/avoidance	③collision avoidance
	waiting timer	③priority order;conflict solution
	leadership	⑦"follow-me"
	Emotion contagion	—

- The Cell space is quite suitable for describing the discrete space in a building. The building information can easily be captured by the *layout* variable embedded into the Cell-DEVS model, and any change of the experimental environment can easily be obtained by just adjusting the value of this variable (rather than building a new architecture information model from scratch).
- Cells within the system can communicate with neighbors through multi-port, which achieve simplification from n-dimensional cell space to one-dimensional space; intercellular communications can be used to describe social interactions.
- Cell-DEVS has an open access toolkit (named CD++) and remote modeling and simulation facilities (RESTful CD++).

4.1 Data Collection

Data collected (and stored in the CD++ $*.stvalues$ file) include:

1. The coordinates of layout elements (exits, wall, stairwells, seats, desks, etc.). In this paper, we use one floor of a library located in Tongji University (Shanghai, China), as the background of the simulation experiment. The floor covers an area of $2304m^2$, both width and length are about $48m$, and there is one main stairwell and three emergency stairwells. The useful space (i.e. excluding the external surface) can be divided into 53×53 cells; each cell covers the area of $0.9 \times 0.9m^2$ (Figure 2).
2. The shortest pathway from any position to the target exit. The Voronoi diagram for pathways is shown in Table 3(⑤).
3. The velocity block which allows to take into account the asymmetry of information that impacts on the pre-evacuation preparation time (see Table 3(①)). There are three categories of velocity depending on the distance to the source.

These data are stored as$(x,y) = (m,n,k)$, where x and y denote the coordinates of a cell and m, n and k represent the values of layout, velocity and pathway respectively. Table 2 gives the meaning of cell state values. For example, $(9,30) = (2,0,0)$ indicates that the cell at coordinates $(9,30)$ is an obstacle area (such as wall, bookcase or desk) where an evacuee cannot move in: *layout* = 2, *velocity* = 0, *pathway* = 0. Another instance, $(21,50) = (1,2,8)$ indicates that, firstly, the coordinate position is a seat that can be occupied by

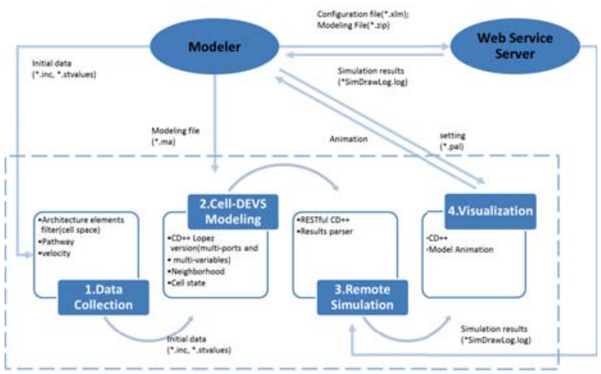


Figure 1: Cell-DEVS modeling and simulation process.

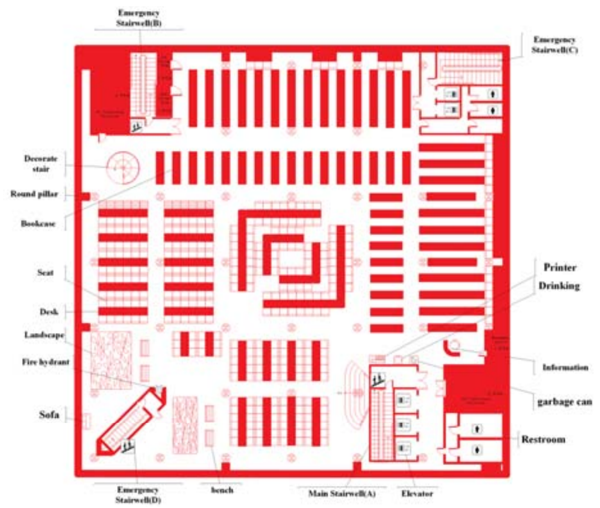


Figure 2: Architecture layout.

an evacuee; and then, that it is available for moving in (out) with a moderate speed; finally, the most efficient route selection is going down (↓).

4.2 Variables Definition and Behavioral Rules

We define the neighborhood as an extended Moore type, $\eta = 5 \times 5$, as shown in Table 3(④). Each cell is assigned six state variables (defined in Table 2): *phase*, *familiarity* and *movement* are input/output ports, whose values can change (this is indicated by the symbol "∼"); *layout*, *velocity* and *pathway* are the initial values, which are constant values (this is indicated by the symbol "$").

Table 2: Cell state & definition.

Variable	Value	Definition	Port	Value	Definition
pathway	5	→	phase	1	intent
	6	↑		2	grant
	7	←		3	wait
	8	↓		4	move
velocity	0	high	familiarity	0	empty
	1	medium		1	high
	2	low		2	medium
				3	non
layout	0	space	movement	0	empty
	1	seat		1	occupied
	2	obstacle		10-18	direction selection
	3	exit		20-28	ask for grant
	4-11	close to exit		31-38	get grant
				39	get rejected
				40-48	send grant

We used the occupancy model proposed by Wang et al. (2013) as the basis to define the movement processes, such as entering an empty cell and leaving an occupied cell. One movement cycle consists of 4 delay time steps, and the *phase* port completes the change from 1 to 4. The basic process of individual movement (without taking into account social attributes like familiarity) is as follows: an individual first selects a neighbor cell as the destination based on its physical position, and after obtaining the authorization to move into this target cell, will either immediately leave its current cell or wait for 1-2 cycles. The waiting time depends on the velocity block where the individual is located. If the request to move is rejected by the conflict resolution mechanism, the individual remains in its current cell and enters a new cycle of decision-making and action. The algorithm of the empty cell is the one that grants the approval or rejection of move into it, in accordance with assigned priority rules. The specific rules for emergency evacuation behavior are defined in Table 3, where the corresponding interpretation are drawn in diagrams (a)-(j).

4.3 Cell-DEVS Model

In Cell-DEVS model, the behavior of the local computing function is defined using a set of rules, which are stored in $*$*.ma* file, consists of predicate-like statements that appear in the following form:

$$\langle value \rangle \ \langle delay \rangle \ \langle precondition \rangle$$

value is the designated postcondition which the state of the cell changes to, if precondition is satisfied;
delay is an explicit time units, after which, the state change will be transmitted;
precondition is the condition for triggering the rule(i.e., the values of neighborhood pattern).

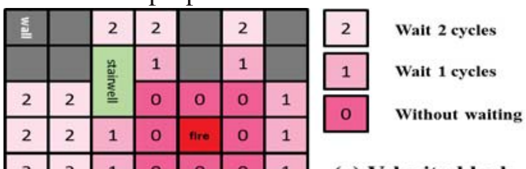
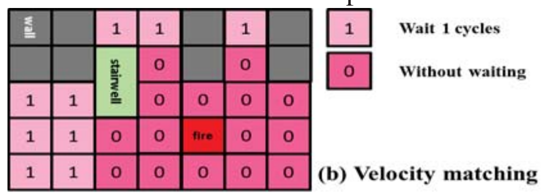
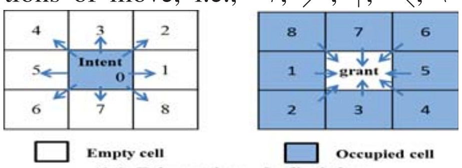
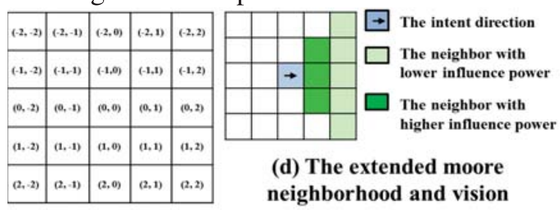
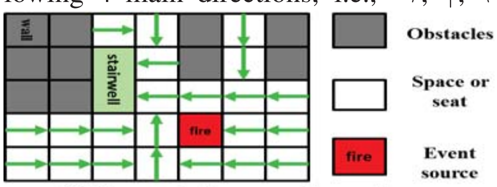
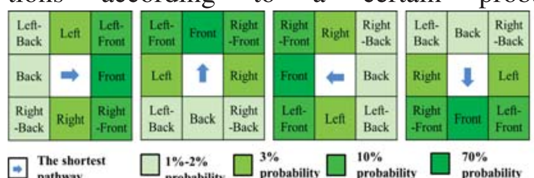
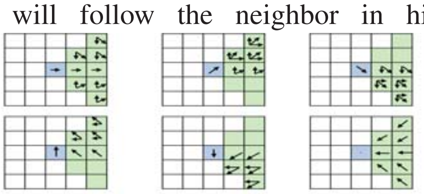
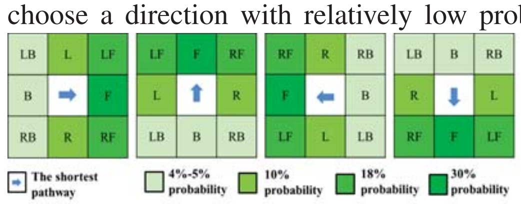
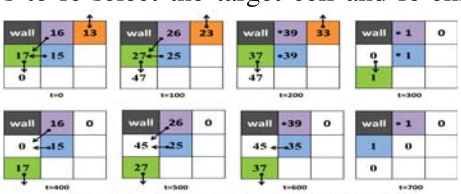
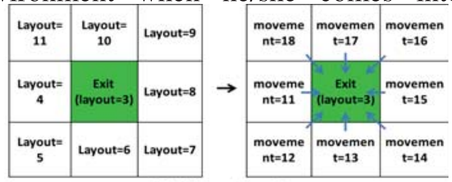
We used HiLLS (High Level Language for System Specification) (Aliyu et al. 2016), a DEVS-based visual language, to provide a system-theoretic description of cells behavior. This description is then used to extract the statements of the Cell-DEVS model. This description is then used to extract the statements of the Cell-DEVS model. Figure 3 is an example of a state transition ($S \rightarrow S^{'}$) for a cell, where $S = (layout, velocity, pathway, phase, familiarity, movement)$. It depicts a process, in which a cell either empties itself from a current individual ($S_0 \rightarrow S_1 \rightarrow S_2 \rightarrow S_3 \rightarrow S_5$) and then accepts another individual from one of the neighbor cells ($S_5 \rightarrow S_6 \rightarrow S_0$), or maintains the current individual in place ($S_0 \rightarrow S_1 \rightarrow S_2 \rightarrow S_4 \rightarrow S_0$). The cell is occupied by an evacuee who has no information about the building (*familiarity* = 3), and it is located in the block of high velocity (*velocity* = 0), where the shortest pathway indicates the direction $\rightarrow$ (*pathway* = 5). The port familiarity receives the information whether it exists another individual with higher familiarity degree in his/her vision or not; the ports *movement* and *phase* obtain the decision-making and action information from neighbors. Further, it outputs its new state values to all its neighbors through the same ports. The CD++ statements obtained from Figure 3 are given in Appendix A.

5 SIMULATION RESULTS

The simulation runs in two scenarios: a) homogeneous evacuees (see Figure 4(a)); black blocks represent walls and other obstacles, green cells stand for persons, and dark green cells indicate exits; all of the evacuees make their decisions randomly according to rule ⑥ (i.e., medium familiarity degree), but not considering rule ④, ⑤, ⑦ and ⑧; b) evacuees with familiarity differences (see Figure 4(b)); the darker is the blue, the higher is the familiarity degree; the proportions of people with high, medium and low familiarity are respectively 30%, 50% and 20%.

For both experiments a and b, the desired walking speed is 1.5*m*/s, i.e., one second equals to 1.5 cycles(600 simulation time steps).In line with the daily attendance rate of the library, the initial distribution of the seats occupancy is 60%, and the occupancy of the rest space is 10%. The source event is supposedly happening

Table 3: Behavioral rules.

Rule &Definition	Rule &Definition
①Pre-evacuation: asymmetric information makes individual who is close to event source has short preparation time to start evacuate.  (a) Velocity block	②Velocity Matching: individual attempts to match velocity with nearby neighbors after a certain pre-evacuation time.  (b) Velocity matching
③Priority Order: the empty target cell will attribute priorities in a decreasing order depending on directions of move, i.e., →, ↗, ↑, ↖, ←, ↙, ↓, ↘.  (c) Direction definition	④Vision: it is a fan-shaped range, which includes 8 cell neighbors in its potential direction of movement.  (d) The extended moore neighborhood and vision
⑤Independent Decision-making: individuals with high familiarity evacuate in the shortest path, following 4 main directions, i.e., →, ↑, ←, and ↓.  (e) Voronoi diagram for pathway	⑥Random Decision: individuals with medium familiarity evacuate in 8 directions according to a certain probability.  (f) Intent probability distribution （familiarity=2）
⑦"Follow-me/Follow-direction": individuals who are unfamiliar with the environment will follow the neighbor in his/her vision.  (g) Follow the neighbors with a higher familiarity according to vision(pathway=5)	⑧Isolated Decision-making: non-familiarity individuals have no neighbor to follow, will randomly choose a direction with relatively low probability.  (h) Intent probability distribution（familiarity=3）
⑨Obstacle Avoidance: when an individual into a cell where the request was rejected, he/she needs to re-select the target cell and re-emit a request.  (i) The rule of obstacle avoidance	⑩Exit Rule: an individual will move towards exit and then vanish in the simulation environment when he/she comes into exit cell.  (j) The exit rule

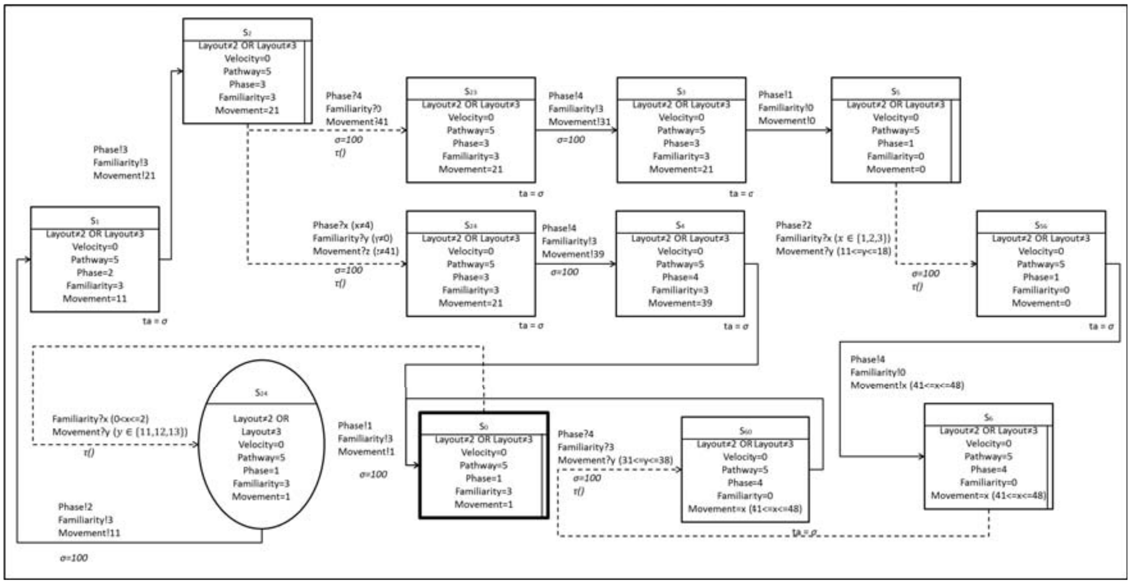
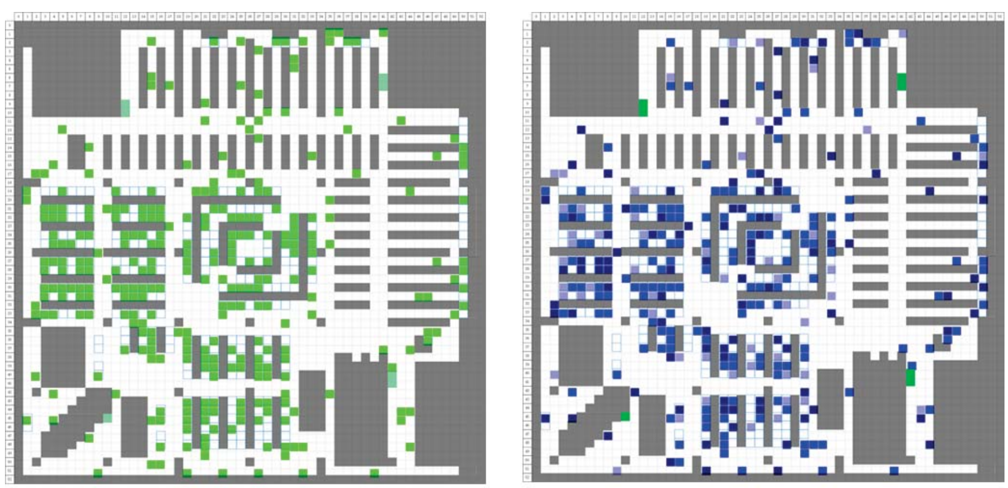


Figure 3: HiLLS diagram of state transition(*familiarity*=3, *velocity*=0).

at location $(25,11)$, and evacuees around it start action with maximum desired velocity once the danger is perceived (*velocity* = 0). The rest two velocity blocks have 8 seconds for pre-evacuation preparation(*velocity* = 1); the longest pre-evacuation time is 16 seconds(*velocity* = 2). After pre-evacuation time, the *velocity matching* rule is triggered, until all walking speeds reach identical level.



(a) Initialization for evacuees without familiarity degrees

(b) Initialization for evacuees with familiarity degrees

Figure 4: Snapshot of simulation visualization at initialization(t=0).

The simulation results, as depicted by Figure 7, show that for experiment a, 302 evacuees need 304 seconds to complete evacuation, while it take 371 seconds in experiment b. The evacuation process is more uniform in experiment a than in experiment b. A possible reason is that homogeneous individuals take similar decisions. During the first moments of evacuation (i.e. about 50 seconds), experiments a and b display similar results, since, at this stage, more evacuees can successfully leave the simulation environment per time unit time. Thereafter, experiment b shows a slower trend. These results confirmed several crowd evacuation phenomena, including "faster is slower", i.e. the faster is the desired walking speed, the lower will be the overall evacuation efficiency. Figure 5 is the snapshots of simulation at 100s, 200s and 300s respectively. During these simulations, we have observed the few more following specific facts:

1. Shape: in experiment a, the simulation results show arched distributions squeezing with each other (see Figure 5(a)). This arched-shape was also observed by previous research (Helbing et al. 2002). The possible reason is that, in emergent situation, evacuees are similar to mobs (Durupınar 2010). Fear emotion results in a competitive behavior, people rather attend to their own need, and do not care for the fate of others (Quarantelli 1957), neither social radius with each other. On contrary, if given individuals some social factors, for example the familiarity degree (experiment b), they prefer to respect the norms and social relations, as illustrated in Emergent Norm Theory(ENT)(Stott and Drury 2000). The collective behavior is not irrational but social and normative behavior. Evacuees in experiment b prefer to wait in the queue when crowded, and the arched shape appears only in the wide corners(see Figure 5(b)).

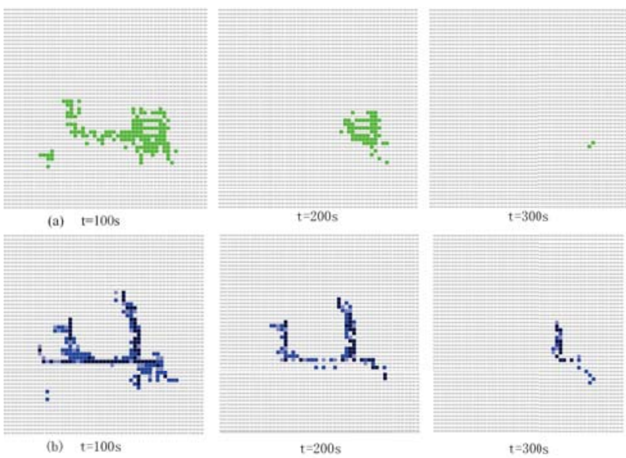


Figure 5: Comparison of simulation results.

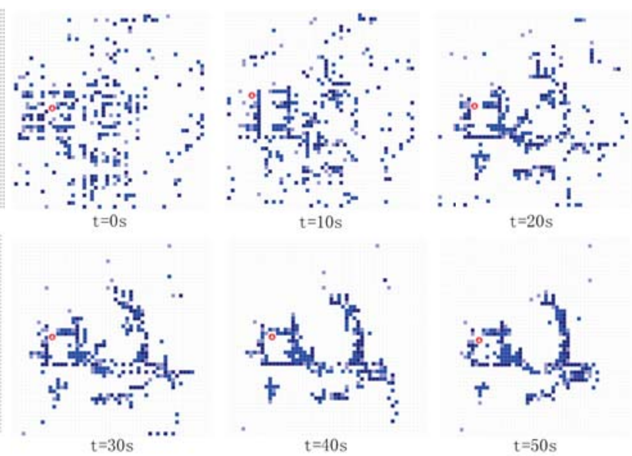


Figure 6: Simulation results of experiment b.

2. Uniform gathering: Figure 6 shows snapshots of experiment b, where we find that there is obvious gathering to aisles in a non-uniform way. People close to where the emergent event happened, have greater motivation to act rapidly, while those far away from where the danger is, participate in the gathering about 20 seconds later. This discrepancy may be attributed to asymmetric information about the event.
3. Route choice: In experiment a, most individuals are trying to evacuate from the shortest path. As a result of the competition for the shortest paths, there is more pushing around the desired routes. In experiment b, high-familiarity evacuees prefer to occupy the shortest paths, the competition among medium-familiarity individuals is more obvious, and non-familiar individuals always follow the nearest guidance in their vision rather than focusing on a particular leader. We tracked the walking trajectories of 3 individuals with different familiarity degrees (see Figure 8). Their original locations are (31, 14), (31, 12) and (31, 13) respectively. The high-familiarity person can easily occupy the most efficient pathway, he/she just takes about 50 seconds to reach half point. At this time, the non-familiarity individual who is following his or her guides, almost access to the same location. However, the medium-familiarity one is still in the queue and trying to break through a bottleneck. Obviously, the medium-familiarity person has higher flexibility to adjust his/her route than the non-familiarity one (who is suffering a greater bottleneck with high-familiarity agents in their desired pathways), and evacuates from simulation environment firstly. This is another evidence of “faster is slower”.

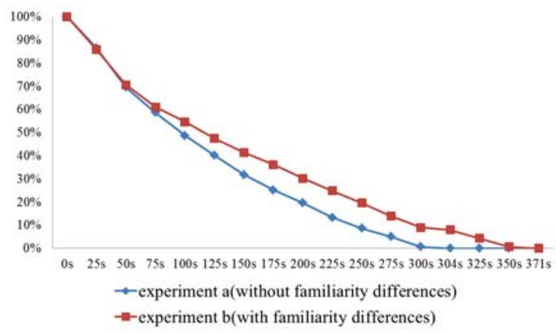


Figure 7: Comparison of evacuation efficiency.

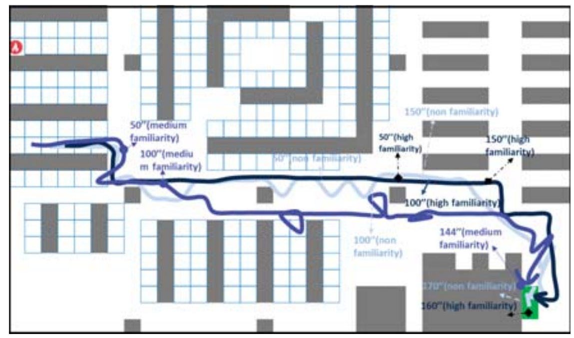


Figure 8: Walking trajectories by individuals with different familiarity degrees in experiment b.

4. Target adjustment: evacuees in experiment a never switch a target exit, while individuals in experiment b may leave the crowd and move to another target exit once walking in the coverage of another emergency exit signs. Especially, evacuees with no familiarity follow the higher familiarity individual to adjust their target as well.
5. Behavior delay: in experiment b, individuals with no familiarity and who cannot collect environmental information, need to make isolated decisions, and hence take a long time to decide, until one exit occurs in their field of vision. This situation undoubtedly delays the overall evacuation time.

6 CONCLUSION

In this paper, we presented a pedestrian evacuation model, in which, architecture information has been integrated with the description of physical positions and movement rules, and social interactions have been taken into account as well. This has resulted in a more realistic simulation. The Cell-DEVS formalism has simplified the modeling process, and the Restful CD++ web simulation service has provided a powerful development and experimentation environment. However, social interaction factors during evacuation are quite plentiful. In our next research effort, we intend to introduce more aspects such as emotional contagion, leadership and group-group interaction into a multi-modeling based on this cellular model. That way, we aim at further deepening the model-driven theory and the application of computer simulation technology in the field of social science. Another major step in our study is the validation process. We started by carrying out experiments to sensitivity analysis of our model, which we do not present and discuss the results here, due to lack of space. Further work will include comparison of our results with the ones excepted theoretically, and the ones obtained with other methods/models as well.

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A CD++ STATEMENTS

(1)Initialization(the values of density and familiarity are stored in $*.inc$ file as the #macro variables):
rule : $\{\sim movement := 1; \sim phase := 0.6; \sim familiarity := 0;\}$ 0 $\{(0,0) \sim movement <= \#Macro(Density\_space)$ and $(0,0) \sim movement > 1$ and $(0,0) \sim phase = 0.6$ and $\$layout != 2$ and $\$layout != 1$ and $\$pathway >= 5\}$ %% Initialization of personnel density(Figure 4(a))
rule : $\{\sim movement := 1; \sim phase := 1; \sim familiarity := 3;\}$ 0 $\{(0,0) \sim movement = 1$ and $(0,0) \sim$

$phase = 0.6$ and $(0,0) \sim familiarity >= \#Macro(Medium - Familiarity)$ and $(0,0) \sim familiarity <$ 1 and $\$layout! = 2$ and $\$pathway >= 5\}$ %% Initialization of personnel familiarity(Figure 4(b))

(2)Empty cell grant one of neighbors to move in this cell with the direction→(*phase* 1 → *phase* 4):
rule : $\{\sim movement := 41; \sim phase := 4; \sim familiarity := 0;\}$ 100 $\{(0,0) \sim movement = 0$ and $(0,0) \sim phase = 1$ and $(0,-1) \sim movement = 11$ and $\$layout! = 2$ and $(0,0) \sim familiarity = 0\}$

(3)Direction selection (→) following the individual with higher familiarity in vision(*phase* 1 → *phase* 2):
rule : $\{\sim movement := 11; \sim phase := 2; \sim familiarity := 3;\}$ 0 $\{(0,0) \sim movement = 1$ and $(0,0) \sim phase = 1$ and $(0,0) \sim familiarity = 3$ and $\$pathway = 5$ and $(0,1) \sim familiarity <= 2$ and $(0,1) \sim familiarity > 0$ and $((0,1) \sim movement = 11$ or $(0,0) \sim movement = 21$ or $(0,0) \sim movement = 31)$ and $\$layout < 3\}$

(4)Ask for the grant to move to direction → (*phase* 2 → *phase* 3):
rule : $\{\sim movement := ((0,0) \sim movement + 10); \sim phase := 3; \sim familiarity := 3;\}$ 100 $\{(0,0) \sim movement >= 10$ and $(0,0) \sim movement <= 18$ and $(0,0) \sim familiarity = 3\}$

(5)Wait for moving to → (*phase* 3 → *phase* 4):
rule : $\{\sim movement := 31; \sim phase := 4; \sim familiarity := (0,0) \sim familiarity;\}$ 100 $\{(0,0) \sim movement = 21$ and $(0,0) \sim phase = 3$ and $(0,1) \sim movement = 41$ and $\$velocity = 0\}$
rule : $\{\sim movement := 39; \sim phase := 4; \sim familiarity := (0,0) \sim familiarity;\}$ 100 $\{(0,0) \sim movement >= 20$ and $(0,0) \sim phase = 3$ and $(0,0) \sim movement <= 28\}$ %%get reject to move

(6)Move in/ leave(*phase* 4 → *phase* 1):
rule : $\{\sim movement := 1; \sim phase := 1; \sim familiarity := (0,-1) \sim familiarity;\}$ 100 $\{(0,0) \sim movement = 41$ and $(0,0) \sim phase = 4$ and $(0,-1) \sim movement = 31\}$ %%move into the empty cell
rule : $\{\sim movement := 0; \sim phase := 1; \sim familiarity := 0;\}$ 100 $\{(0,0) \sim movement = 31$ and $(0,0) \sim phase = 4$ and $(0,1) \sim movement = 41\}$ %%leave current cell
rule : $\{\sim movement := 1; \sim phase := 1; \sim familiarity := (0,0) \sim familiarity;\}$ 100 $\{(0,0) \sim movement = 39$ and $(0,0) \sim phase = 4\}$ %%keep stay in current cell and then reselect intent direction

REFERENCES

Al-Habashna, A., and G. Wainer. 2016. “Modeling pedestrian behavior with Cell-DEVS: theory and applications”. *Simulation* vol. 92 (2), pp. 117–139.

Al-Zoubi, K., and G. Wainer. 2015. “Distributed simulation of DEVS and Cell-DEVS models using the RISE middleware”. *Simulation Modelling Practice and Theory* vol. 55, pp. 27–45.

Aliyu, H. O., O. Maïga, and M. K. Traoré. 2016. “The high level language for system specification: A model-driven approach to systems engineering”. *International Journal of Modeling, Simulation, and Scientific Computing* vol. 7 (01), pp. 1641003.

Duives, D. C., W. Daamen, and S. P. Hoogendoorn. 2013. “State-of-the-art crowd motion simulation models”. *Transportation research part C: emerging technologies* vol. 37, pp. 193–209.

Durupınar, F. 2010. *From audiences to mobs: Crowd simulation with psychological factors*. Ph. D. thesis, Bilkent University.

Fahy, R. 1999. “User’s Manual, EXIT89 v 1.01, An Evacuation Model for High-Rise Buildings”. *Quincy, Ma, National Fire Protection Association*.

Feinberg, W. E., and N. R. Johnson. 1995. “Firescap: A computer simulation model of reaction to a fire alarm”. *Journal of Mathematical Sociology* vol. 20 (2-3), pp. 247–269.

Galea, E., P. Lawrence, S. Gwynne, L. Filippidis, D. Blackshields, and D. Cooney. 2006. "Building EXODUS V4. 06 User Guide and Technical Manual Ver. 1.2". *University of Greenwich, England*.

Guo, J.-y., S. Liu, S.-k. Chen, and B.-h. Mao. 2008. "Review of pedestrian movement simulation studies". *Journal of System Simulation* vol. 20 (9), pp. 2237–2241.

Helbing, D., I. J. Farkas, P. Molnar, and T. Vicsek. 2002. "Simulation of pedestrian crowds in normal and evacuation situations". *Pedestrian and evacuation dynamics* vol. 21 (2), pp. 21–58.

Ketchell, N., A. Holt, and K. Kinsella. 2002. "A technical summary of the AEA egress code". Technical report, Tech. Rep. 1, AEA Technology.

Kisko, T. M., R. Francis, and C. Nobel. 1998. "Evacnet4 user's guide". *University of Florida*.

López, A., and G. Wainer. 2004. "Improved Cell-DEVS model definition in CD++". In *International Conference on Cellular Automata*, pp. 803–812. Springer.

Low, D. J. 2000. "Statistical physics: Following the crowd". *Nature* vol. 407 (6803), pp. 465–466.

Quarantelli, E. 1957. "The behavior of panic participants". *Sociology and Social Research* vol. 41 (3), pp. 187–194.

Santos, G., and B. E. Aguirre. 2004. "A critical review of emergency evacuation simulation models".

Stott, C., and J. Drury. 2000. "Crowds, context and identity: Dynamic categorization processes in the'poll tax riot"'. *Human relations* vol. 53 (2), pp. 247–273.

Thompson, P. A., and E. W. Marchant. 1995. "Testing and application of the computer model 'SIMULEX'". *Fire Safety Journal* vol. 24 (2), pp. 149–166.

Wainer, G. A. 2009. *Discrete-event modeling and simulation: a practitioner's approach*. CRC press.

Wang, S., M. Van Schyndel, G. Wainer, V. S. Rajus, and R. Woodbury. 2012. "DEVS-based building information modeling and simulation for emergency evacuation". In *Simulation Conference (WSC), Proceedings of the 2012 Winter*, pp. 1–12. IEEE.

Wang, S., and G. Wainer. 2015. "A simulation as a service methodology with application for crowd modeling, simulation and visualization". *Simulation* vol. 91 (1), pp. 71–95.

Wang, S., G. Wainer, V. S. Rajus, and R. Woodbury. 2013. "Occupancy analysis using building information modeling and Cell-DEVS simulation". In *Proceedings of the Symposium on Theory of Modeling & Simulation-DEVS Integrative M&S Symposium*, pp. 26. Society for Computer Simulation International.

Zeigler, B. P., H. Praehofer, and T. G. Kim. 2000. *Theory of modeling and simulation: integrating discrete event and continuous complex dynamic systems*. Academic press.

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