

GENEVAC: Evolving Exits for Evacuation Models via Steady-State Genetic Search

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Abstract

Evacuation models have been developed to evaluate human behavior during evacuations and to assess the safety of buildings designs. According to the *Life Safety Code*[®], the geometry of a building, the location of exits, and the number of exits dictate the means of egress for all people occupying a building. In this paper, the authors introduce a steady state genetic algorithm (GA) approach to answer the following questions: how many exits and how should they be positioned in a room to minimize the evacuation time for a fixed number of people. The results show promising applications for GA in evacuation modeling. Also, against popular beliefs, the results show to a certain extent that more exits may not speed up evacuation.

1. Introduction

Evacuation modeling has been a major concern for fire engineers, architects, computer scientists, and psychologists. In spite of advanced knowledge of fire behavior, building designs and specifications, computer applications, and human behavior at risk, emergency evacuation still presents a challenge to researchers in such fields. The stochastic nature of evacuations, created mainly by the human element and the type of hazard, makes it more difficult to reach a realistic level of modeling. Moral, practical, and

financial considerations prevent researchers from conducting actual evacuation drills. Thus, the other alternative is to conduct evacuation experiments using computer-based models.

Computer evacuation modeling has been available for the last three decades. Predtechenskii & Milinskii [10] and Fruin [3] introduced the earliest research on crowd dynamics and the movement of people under normal conditions in crowded areas and in stairways. Stahl [11] conducted one of the earliest studies of emergency egress during fires.

The genetic algorithm (GA) is one of the three algorithms that were known as the first generation of evolutionary algorithms (EA). GAs were originally developed by Holland [12] as a general purpose problem solver. It was inspired by the process of evolution on the genetic level. In Holland's GA, the problem was encoded into a binary string which is then manipulated by the selection, crossover and mutation operators to create progressively better candidate solutions (CS) [13]. Here, a GA will be used to evolve the positioning of the exits in a room to minimize the amount of time it takes for the occupants of the room to escape.

This paper will be divided into the following sections. In section 2, the evacuation model used will be explained. Section 3 discusses the GA in more detail. Section 4 will describe the implementation of the GA on the current problem and the platform on which we

will be conducting our tests. Section 5 presents the current test results, while section 6 will contain the current conclusions. Lastly, further research will be presented in section 7.

2. Crowd Dynamics and Evacuation Models

One approach that has been used to describe crowd dynamics in evacuations is the social force model. Helbing [5, 6] introduced the idea of using self-driven particles interacting through physical forces to represent occupant movement. It is worth noting that social forces are different from environmental forces exerted on the body. In fact, they are more like quantified motivated actions. The idea originated from Henderson's [7] comparison between pedestrian flows and the Navier-Stokes equations. The main factors that determine the motion of a pedestrian in this model are the desire of reaching a certain destination within a certain period of time that determines direction and velocity, the repulsive effect created by a pedestrian on others or when attempting to avoid an obstacle, and the attractive effects as a result of group formation.

The social model was used in two simulations containing a large number of interacting pedestrians. One simulation had pedestrians moving in the same direction in a walkway, while the other had different pedestrian groups that tried to pass through a narrow door in opposite direction [6]. The experiments assumed values for the model parameters which were chosen in a compatible way with empirical data. Another application was to study the impact of individual agents' characteristics in emergency groups on the evacuation efficiency as a result of local interactions [1]. Simulations based on a free-space presentation model of pedestrian behavior could provide valuable insights into the mechanisms of panic and jamming [5]. Several important phenomena were simulated including the building up of pressure, clogging effects at bottlenecks, jamming at widenings, the faster-is-slower effect, inefficient use of alternative exits, and initiation of panics by counter flows and impatience. Kirkland and Maciejewski [8] used the framework of the social

force model to study the effects of introducing autonomous robots into crowds.

Along with the development of evacuation modeling, the National Fire Protection Association (NFPA) has been the developer and publisher of the *Life Safety Code*[®] [2] for 80 years, formerly known as the *Building Exits Code*. The *Life Safety Code*[®] addresses specific requirements that have a direct influence on safety in both new construction and existing buildings. The purpose of the *Life Safety Code*[®] [2] is to provide *minimum* requirements, with due regard to function, for the design, operation, and maintenance of buildings and structures for safety from fire. According to the *Code*, the geometry of a building, the location of exits, and the number of exits dictate the means of egress for all people occupying a building. Notake [9] assessed the legibility of egress route in evacuation modeling. Travel distance during evacuation and evacuation time were the physical measures considered for legibility of an egress route. The legibility of an egress route was assessed by studying the effect of number and layout of exits on travel distance, number of layout of end points on travel distance, and probability of backward motion. Traditional codes and standards, which limit engineering designs, reflect historical and invalid theories about occupants' characteristics. Therefore, Groner [4] suggested integrating engineering approaches for physical systems with human behavior.

3. Genetic Algorithms

Holland [12] developed the concept of GAs as a robust problem solving technique. GAs were inspired from the evolution of organisms on the genetic level [12–14]. They imitate the processes of crossover, mating of parent genes to form offspring with a new combination of the parents' genetic patterns, mutation, the random genetic transcription error during crossover, and selection, the process of selecting better fit parents for reproduction and removing less fit parents from the population.

The canonical GA uses a population of binary coded strings [13].

This population of strings is manipulated through the use of crossover, mutation, and selection that change and replace members of the population [13, 14]. Before the evolutionary process begins, the population is initialized, where each member (candidate solution) of the population is randomly generated. After initializing the population, the fitness of each member of the population is calculated. This fitness defines how good a candidate solution (CS), is. The fitness will be determined by the evaluation function. After the fitness for all the CSs is calculated, parent selection occurs. There are various methods of selecting parents including proportional, rank-based and tournament selection [13]. Here we will simply be using a random parent selection process. After two parents are selected, their genetic information is spliced to create the new offspring. There are four general ways of performing crossover, single-point crossover, two-point crossover, multi-point crossover, and uniform crossover [13]. Here we will use uniform crossover, which for every bit in the offspring, it will have a 50% chance of either inheriting the corresponding bit from the first parent or 50% chance of inheriting the second parent's bit. Since we will be working with a steady state GA, every generation, one offspring is created from two random parents and the offspring will replace the worst member of the current population [13]. After the offspring replaces the worst member, its fitness is also calculated and the algorithm starts over again. At the end of a fixed number of cycles, the best candidate solution from the population is taken as the final solution.

4. Problem and Test Suite

For the current problem at hand, the question is how many exits and how should they be positioned in a room to minimize the evacuation time for a fixed number of people in the room. To simplify the problem, we will assume that the room will also be of a fixed size (80 units x 60 units) and that there are already a number of possible exit locations, 28 in this case. Each possible exit will also be assumed to have a fixed size of 8 units wide. Thus,

the problem is reduced to that given 28 possible locations of exits, how many in total must be present and which ones must be present to minimize the evacuation time.

The GA used here, as mentioned earlier will be a steady state GA. The population size of the GA will be varied between 25, 50, and 100. Each CS will be a binary bit string of length 28. Every bit corresponds to a respective position of a possible exit where a 1 will mean that the exit is present and available, while 0 means that the exit is not available. The fitness will be the time it takes for all the people to leave the room. For each population size, the GA will be executed for a total of 200 cycles, after which the best CS is taken. Thus, for a steady state GA, this would mean that a total of 200, plus the population size, candidate solutions will be examined. This will be considered one run. The results will be averaged over 100 runs to root out any random variations caused by the random number generator.

At current, the GA is implemented on a stripped down evacuation model, which only takes into condition of very simple forces. Each person will be attracted to all exits and repelled by other people if they get too close. This forms a simple gradient field in the room. The simple approach is just a general way of showing that it is possible to evolve exit positioning with a GA.

The final goal is to implement the GA on top of the *pedsim* program, a fully functional evacuation modeling application, available here: <http://www.twerner42.de/ped/>. The simulator code for *pedsim* will be modified to be able to store and manipulate various different environmental constructs, manage and build them in real-time, and return the fitness, evacuation time, after each internal run.

At current, only the initial testing of the simplified model has been completed. The testing involved creating a simple room of size 80x60 in units and placing 30 individuals into fixed locations in the room at the beginning. Each individual is allowed to move a maximum of 4 units every time unit. Since there was no accurate way to measure time within

GA Population Size	Average Number of Cycles	Average Number of Exits	Best Solution	# of Exits for Best Solution Found
25	324.96	3.17	309	6
50	330.76	4.37	265	5
100	338.16	5.12	267	5

Table 1. Results of Simplified Model with 100 runs of each GA

the simulation, every 30 iterations of the modeling algorithm was considered as one time unit. Based on these settings, the positions of the exits were varied by the GA. For practical purposes, a constraint was added such that the number of available exits should not exceed 6. This constraint was added by implementing a penalty to the evacuation time based on the number of exits exceeding 6.

5. Results and Discussion

The results of the 100 runs of the GA with population sizes of 25, 50, and 100 are shown in Table 1. As expected, the GA with population size of 25 did not come up with the best solution. Surprisingly, however, the GA of population size 50 was able to get the best solution of the three. The GA with the population size of 100 came as a close second.

Looking at the average number of exits found, it is interesting to see that as the population size of the GA went up, so did the average best solution and average number of exits of the best solution over 100 runs. This is fairly in line with expectation though, since the steady state GA with a larger population size will keep a more diverse set of candidate solutions. From the results, it may seem that there is a local optimal when trying to keep the number of exits less than 6 while minimizing evacuation time. This optimal seems to be around 3 exits. The results show that once past this optimal point, the proper placement of more exits will speed up evacuation time. However, with only 30 people in the room, 5 exits currently look to be the optimal setting.

As mentioned earlier, every 30 cycles of the simulation is considered as one time unit. So, the differences between the best solutions found by the GA at the three settings vary around 1 time unit or less, which in this case is

around 10%. Figures of the best placement of exits found by the 3 GAs are in the Appendix.

6. Conclusions

Though the current set of results are fairly limited, but they show great promise as to what can be done with the combination of GAs and current evacuation models. It should also be noted that the results also point to the fact that given the average number of people that are usually in a room, more exits may not actually speed up evacuation time as it may possibly cause confusion and indecisiveness for the people trying to leave.

7. Further Research

The current study is still very preliminary, but it has already shown a lot of promise. Though at current stages, the number of possible exits are fixed along with their location and size, these can very easily be evolved by a GA as well in future studies. Also, completing the modification of the *pedsim* application and using a GA on that may give us a better picture of a more realistic evacuation model. The results may very well prove or disprove the guidelines presented by the *Life Safety Code*[®] to be either accurate or based on flawed assumptions.

8. References

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Appendix

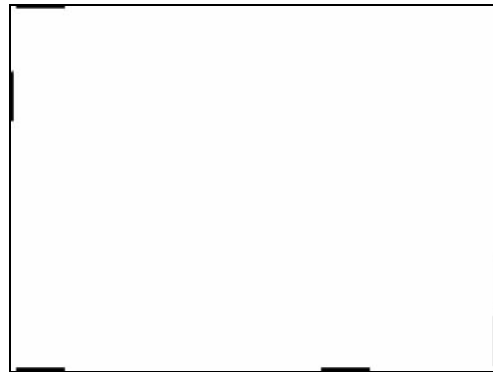


Figure 1. Best Placement found by GA of population size 25

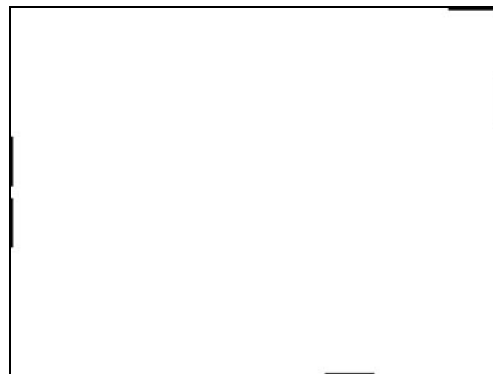


Figure 2. Best Placement found by GA of population size 50



Figure 3. Best Placement found by GA of population size 100