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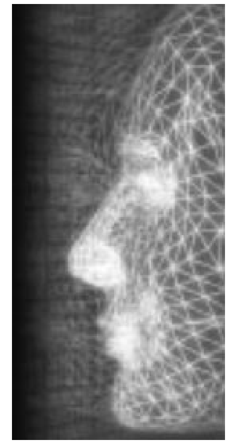
A social agent pedestrian model



By Andrew Park and Tom Calvert*

This paper presents a social agent pedestrian model based on experiments with human subjects. Research studies of criminology and environmental psychology show that certain features of the urban environment generate fear in people, causing them to take alternate routes. The Crime Prevention Through Environmental Design (CPTED) strategy has been implemented to reduce fear of crime and crime itself. Our initial prototype of a pedestrian model was developed based on these findings of criminology research. In the course of validating our model, we constructed a virtual environment (VE) that resembles a well-known fear-generating area where several decision points were set up. 60 human subjects were invited to navigate the VE and their choices of routes and comments during the post interviews were analyzed using statistical techniques and content analysis. Through our experimental results, we gained new insights into pedestrians' behavior and suggest a new enhanced and articulated agent model of a pedestrian. Our research not only provides a realistic pedestrian model, but also a new methodology for criminology research. Copyright © 2008 John Wiley & Sons, Ltd.

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KEY WORDS: pedestrian models; social agents; virtual environments; CPTED; fear of crime

Introduction

It is natural to combine human character animation and artificial intelligence (AI), particularly, agent technology because an agent represents an autonomous entity like a human that behaves independently. Agent technology becomes more appealing when crowd simulation is needed because it is economic to use multi-agent systems. Pedestrian or crowd simulations have been studied for decades using agent technology.[1,2] The AI community has been focusing on developing a comprehensive agent architecture so that the agent behaves realistically (in either 2D or 3D), whereas the computer animation community has been trying to produce realistic 3D animations using agent technology. However, there have not been many studies in connection with social science research. Currently, many social science researchers are beginning to seek ways to visualize or simulate their findings using available technologies. Our interdisciplinary research is a result of the demands from both applied and social science communities, particularly, computer science and criminology. Our goal is to develop a pedestrian model based on the findings of social science research and to validate it. Many research studies in criminology and environmental psychology have discovered that people are afraid of certain features of the urban environment such as narrow passageways, hidden space created by corners, tall bushes, and dumpsters. They also fear the confrontation with potential offenders who might be hiding themselves using these environmental characteristics. If they sense possible dangers or risks, they take alternative routes to reach their destinations. We employed these findings in our pedestrian agent model and simulation system. In order to validate our model, we constructed a VE resembling a well-known fear-generating urban area. We intentionally set up five decision points with distinct environmental features that we wanted to test. We then recruited 60 subjects to navigate our VE making decisions at the decision points. We collected data describing their choices, demographics, and comments during post experimental interviews. Through analyzing the data, we gained new insights into pedestrian behavior, finding new factors that influence pedestrians' choice of routes. Based on these results, we suggest a new enhanced and articulated model of a pedestrian in this paper.

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Background

Fear of Crime and CPTED

Fear of crime is a very practical and prevalent issue for those who live in today's urban environment. One of the definitions for the fear of crime is "emotional reaction characterized by a sense of danger and anxiety produced by the threat of physical harm...elicited by perceived cues in the environment that relate to some aspect of crime for the person."[3] Even though a higher level of fear of crime does not always mean that there is a higher chance to be victimized, it still lowers the quality of life. Depending on the definition of the fear of crime, various measures and various indicators could be used. If the fear of crime is understood as an emotional response, we have to measure such indicators.[4] However, in the tradition of the fear of crime research, many scholars blend cognitive and affective fear of crime measures. Some scholars use behavioral measures as an indicator of the fear of crime.[5] No matter what is measured, most of the fear of crime research uses the traditional research methods such as surveys and interviews.

There are numerous factors that are related to the fear of crime. Gender has been proved to be the strongest predictor of the fear of crime.[6] This predictor shows that women have a higher level of fear of crime than men, although women have been victimized less than men. Age is the second factor that is strongly related to the fear of crime. The general conclusion from the related work is that as people grow older, they tend to be more fearful.[6,7] Like gender, research findings show that the older people's fear level is inversely related to their actual risk of victimization.

Some environmental cues serve as signals interpreted by individuals as threats. These cues are interpreted as either social incivility (disorder) or physical incivility.[8] The signs of social incivility can be prostitution, drug dealing, panhandling, public drunkenness, or homelessness. The signs of physical incivility can be litter, broken windows, abandoned storefronts, unkempt lots, graffiti, or vandalism. Almost all related studies report that there is a strong relationship between incivility and fear of crime. However, social incivilities seem to be more predictive of fear than physical incivilities. In other words, untended people generate more fear than untended properties.

There are certain environmental structures or space configurations where people might feel fear. In fact, people constantly monitor their environments for signs of danger.[9] Once a danger is seen, they try to avoid it. Alcoves, bushes/shrubs, sharp bends in passageways, and any blind spots can be hiding places for potential offenders.[10] These environmental structures increase people's fear. Some studies show that narrow alleys are seen as more dangerous.[11] Well-maintained, orderly alleys with good surveillance make people feel safe, whereas alleys with no care generate fear.

Crime Prevention Through Environmental Design (CPTED) is a multidisciplinary approach to deter criminal behavior by careful environmental design, which reduces the occurrence and fear of crime, thereby improving the quality of life. This approach was originated from the ideas of Jacobs and Whyte[12,13] who had discovered that different urban settings influence peoples' behavior. Newman and Jefferey,[14,15] further developed the ideas to devise crime prevention strategies with built environments. Some CPTED strategies are natural surveillance, access control, territorial reinforcement, and proper placement of land uses. Paul and Patricia Brantingham[16] have found that criminals' behavior is related to the urban structure. They argue that by analyzing the temporal and spatial data of crimes, spatial patterns of the crimes and behavioral patterns of the offenders can be discovered.

Social Agent

An intelligent agent is an entity that perceives and acts upon its environment with a certain degree of autonomy. The intelligent agent is usually realized through a software program. A social agent is an intelligent agent with the characteristic of dynamic social interaction with other agents or humans.[17,18] We extend this definition to include the agent's dynamic social interaction with its environment. In other words, the agent senses and interprets its environment in the social context and acts upon it accordingly.

Magnenat-Thalmann and Thalmann[1] have been studying the creation of "believable" virtual human characters over 30 years. Creating such human characters is a very comprehensive process, involving aspects such as realistic appearance, motion, and behavioral modeling. There are many challenges in producing realistic human motions, employing many techniques such as motion capture, computational models with controllable parameters, and motion engines. For believable behavior, autonomous agent technology is utilized with an agent architecture that has sensors, emotions, memory,

Comp. Anim. Virtual Worlds 2008; **19**: 331–340
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learning, cognitive maps, and path planning. When a crowd (multiple agents) is simulated, each agent has its own attributes and states, shares common behavioral rules and interacts with other agents. The resulting outcome is an emergent behavior of the crowd.

Silverman *et al.*[19] focused on realistic agent behavior rather than appealing animation. Developing a comprehensive agent architecture with the various elements of the cognitive appraiser, utility generators (OCC model[20]), concern ontologies, and Markov chains, they could demonstrate the emergent behavior of the people who protest.

In modeling a pedestrian as a social agent, Donaldson *et al.*[21] used an OCC model to show how emotions influence the pedestrian agent's choice of routes. Park and Calvert[22] developed a pedestrian agent model that navigates through an urban environment that creates fear of crime. The agent chooses a path through the environment that minimizes passage close to features known to generate fear. We extend their study and validate the model in our research.

Pedestrian Model

From the beginning of our research, we planned to test our pedestrian model against real human behavior. Thus, we decided to make the model simple enough that we could validate it with experiments with human subjects. If we developed a complicated internal architecture for an agent, such as an emotion system with all the different emotions, it would be very difficult to test with real human subjects. There is a popular slogan among social scientists, which says "Keep It Simple Stupid" or KISS. In other words, we do not have to make a model more detailed that it really needs to be. Our research goal is to develop a pedestrian agent model that makes a choice of routes according to his/her fear of crime during the navigation in the environment. We do not need a complex emotion engine or system but focus on the fear of crime. There are many different kinds of fear: fear of height, fear of water and so on, but we are interested in fear of crime caused by features of the urban environment such as narrow passageways without escape routes, hidden space created by corners, dumpsters, and threatening individuals on the street.

A pedestrian is defined as a person who goes or travels on foot or a walker. The pedestrian navigates from his/her starting position to a goal position. His/her logical choice of path would be the shortest one assuming the pedestrian has a knowledge map of the area where he/she navigates. As the pedestrian navigates, he/she constantly scans the surroundings. If the pedestrian has to make a choice of routes, one of which seems more dangerous or risky than the other(s), then he/she would choose the safer one. This process is repeated until he/she reaches the goal position. With this assumption, we have developed a pedestrian agent model with an agent architecture as seen in Figure 1. We have used the Dark Basic Professional game engine to implement all the components of the pedestrian agent model.

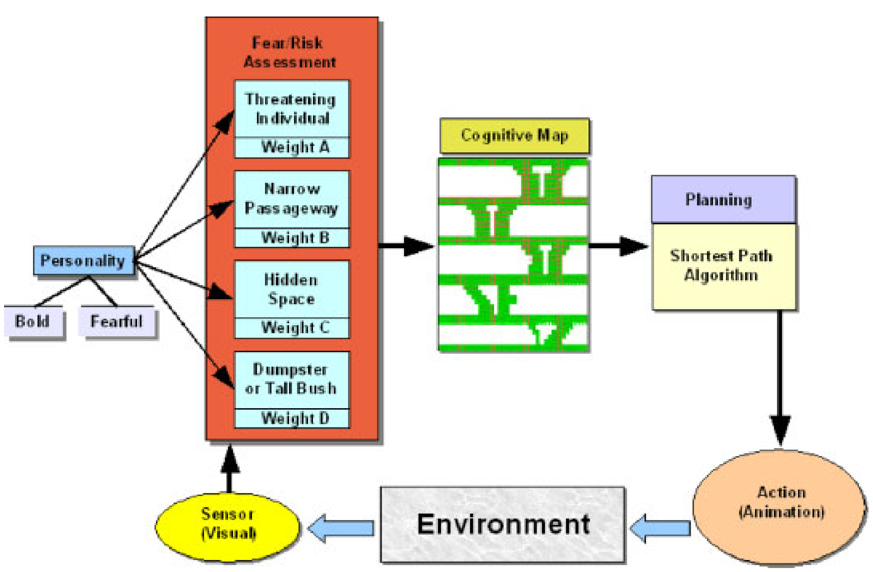

Figure 1. Pedestrian agent architecture.

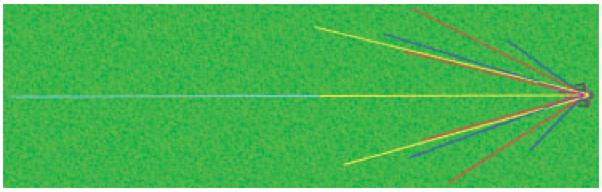

Figure 2. The pedestrian's simulated visual sense.

Sensor

The sensor component simulates the pedestrian visual sense to detect his/her surroundings such as people, objects, and buildings.

Figure 2 shows the pedestrian agent's eye rays that are used for many different purposes. The long eye ray can detect far off objects, whereas short side eye rays detect narrow passageways and hidden spaces. This sensor is implemented using the collision detection system of the Dark Basic Professional game engine. All the eye rays are, in fact, thin cylinders from which we can identify different objects when they intersect the objects. These identifications of the objects are delivered to the fear/risk assessment component.

Personality

The personality component influences the fear weight values of different environmental features and has simply two kinds: bold or fearful. The reason that we had just two kinds of personality was again to test our pedestrian agent model against real human subjects. It would be very difficult to determine a subject's personality, whether he/she is "very" bold or "slightly" fearful. We take the behavioral approach to this: if he/she avoids a certain feature of the environment, we believe that he/she might be fearful of that feature. Otherwise, he/she is bold about the feature. We confirm this assumption through post experimental interviews with the human subjects. In general, the bold personality of our pedestrian agent lowers the fear weight values, whereas the fearful personality raises the values.

Fear/Risk Assessment

The fear/risk assessment component has a list of the environmental features with their fear weight values. Depending on the agent's personality, the fear weight values can be either higher or lower. Different environmental features have different fear weight values. For example, as noted earlier, social incivilities seem to generate more fear than physical incivilities. Thus, we assigned higher fear weight values to threatening individuals than other environmental features such as narrow passageways or hidden spaces. The fear/risk assessment component finds the environmental feature in the list, if there is any, based on the information given by the sensor component at each cycle. Then it delivers that information along with its fear weight value to the cognitive map component.

Cognitive Map

The cognitive map component contains a mental map of the environment where the pedestrian agent navigates. At the beginning of the navigation, the map only has the information about the route configuration and fixed buildings, not movable objects such as dumpsters or individuals. As the agent navigates, the sensor detects the objects and environmental features. This information is interpreted by the fear/risk assessment component and given to the cognitive map component along with any fear weight values. Based on this information, the mental map is updated.

As we see in Figures 3 and 4, the surrounding cells of the detected objects or environmental features would have higher cost values after the update for the shortest path calculation. As a result, the pedestrian agent avoids such objects and environmental features. It is like creating a repulsive potential field around them. However, the range that covers cells with higher cost values depends on the fear weight values. If an object or an environmental feature has a higher fear weight value like that of a threatening individual, the range covers more cells around it, whereas an object or an environmental feature with a lower fear weight value like a dumpster has a smaller range . The resulting behavior would be that the pedestrian agent keeps at a greater distance from a threatening individual than from a dumpster while he/she avoids them.

Planning

The planning component calculates the shortest path from the pedestrian agent's current position to the goal position using the A* algorithm[23] based on the mental map created by the cognitive map component. If there is no update on the map, the component does not calculate a new shortest path.

Comp. Anim. Virtual Worlds 2008; **19**: 331–340
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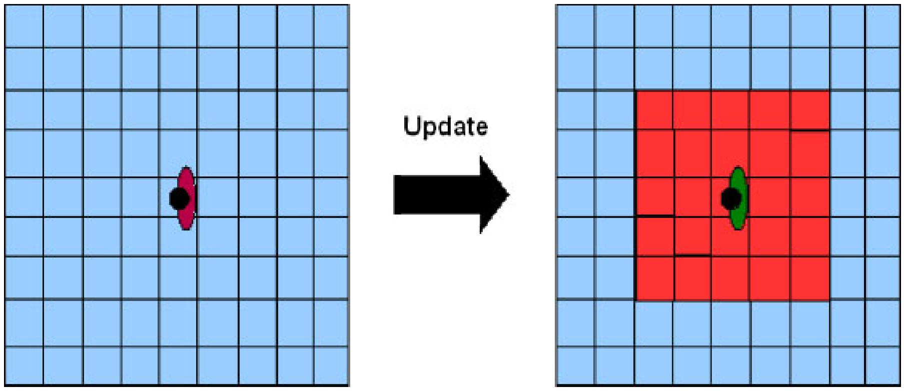

Figure 3. Mental map updated with a threatening individual.

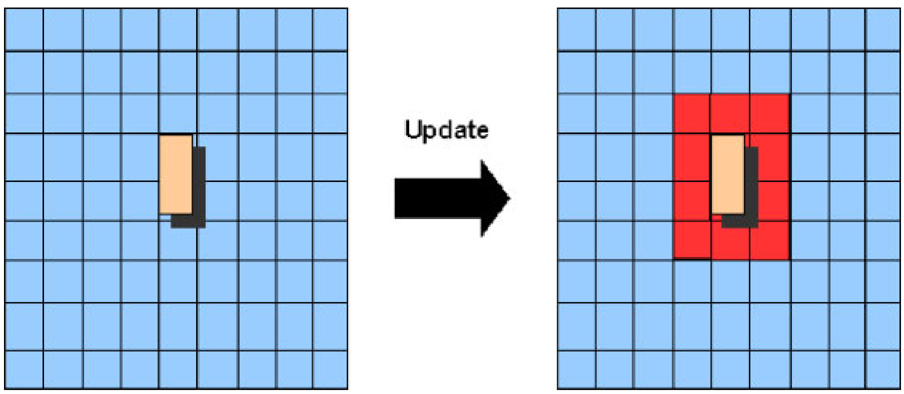

Figure 4. Mental map updated with a dumpster.

Action

The action component moves the pedestrian agent one cell per one cycle along the path that has been planned and runs a pre-made walking animation sequence.

Simulation Experiments

We simulated our pedestrian agent model in the simulated urban environment. The urban environment was carefully designed to test the agent's behaviors with different environmental features.

As we see in Figure 5, the urban environment has five decision points on the way to the goal position. Each decision point has its own specific environmental features: wide/narrow passageways, streets with/without a hidden space, streets with/without dumpsters, streets with/without a threatening individual, and streets with a single threatening individual or multiple threatening individuals.

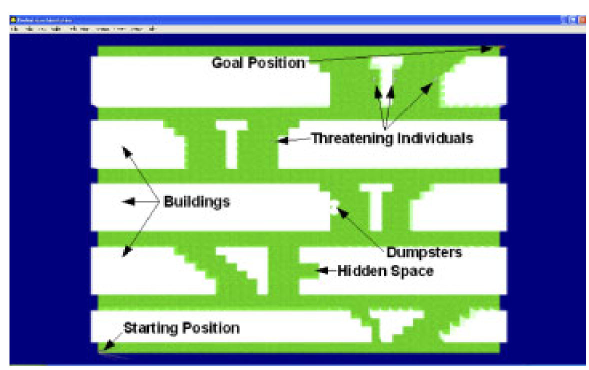

Figure 5. Simulated urban environment.

We ran the first simulation with the "bold" personality. Figure 6 shows that the pedestrian agent did not mind going through the environmental features that seem more

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Figure 6. Pedestrian's path with "bold" personality.

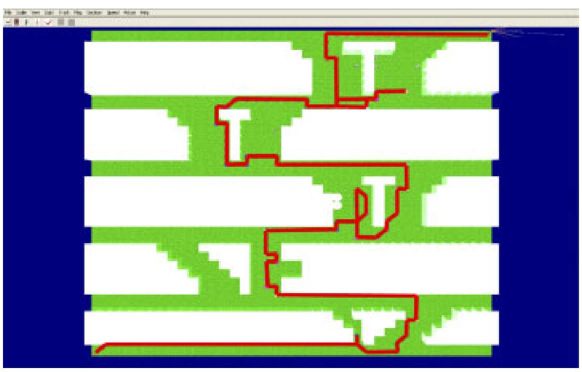

Figure 7. Pedestrian's path with "fearful" personality.

fearful (the narrow passageway → the street with a hidden space → the street with dumpsters → the street with a threatening individual → the street with multiple threatening individuals). The resulting path turned out to be the shortest path.

The second simulation was done with the "fearful" personality (Figure 7). At the first decision point, the agent chose the wide passageway, avoiding the narrow one. Although the agent chose the street with a hidden space at the second decision point, he/she kept distance from the hidden space. This shows that the hidden space did not generate enough fear (a lower fear weight value) for the agent to choose the other street but just keep some distance from it. On the street with dumpsters, the agent was about to pass through, but he/she turned around and took the other way that has no dumpsters. At the next decision point, the agent simply avoided the street with a threatening individual because the threatening individual generated strong fear (a higher fear weight value). At the final decision point, the agent was heading toward the street with multiple threatening individuals, which is the shortest path. But when the agent saw the multiple threatening individuals, his/her mental map was updated with the high cost values on the cells around the individuals. The plan was then changed to take the other route. In contrast to the first simulation with the bold personality, the second simulation with the fearful personality shows lots of dynamic path changes during the navigation.

Validating the Pedestrian Model with a Virtual Environment

We have developed our pedestrian agent model based on the general findings of social science research, but in order to refine the weights of the model it is necessary to test it against real pedestrians in a real-world environment. However, it was difficult to find suitable environments where we could test our model. Observing real pedestrians in a fear-generating area would also be difficult due to both ethical issues related to the risk and danger involved in the experiment and to our inability to control experimental variables. We then decided to use a virtual environment(VE) where human subjects freely navigate as if they were in the real environment. In fact, some other researchers have also used VEs for their fear of crime research.[24]

We have constructed a VE whose space configuration is the same as the one of the urban VE in the earlier section (Figure 8). We also put 3D models of dumpsters and threatening individuals at the same positions as they were in the urban VE. In order to add realism to the VE, we used textures from the photographs taken in a well-known fear-generating area to map on the 3D building models. Using a big screen (about 5 × 4 m) also helped the subjects to feel presence.

Using this VE, we conducted experiments with 60 subjects.[†] Each subject stood in front of the screen in the dark room and navigated from the starting position to the goal position using a wireless remote control. At each decision point, they had to choose one of two routes. We recorded the subjects' path, videotaped them, and measured their galvanic skin response during the navigation. We then had post experimental interviews with them to find out the reasons for their choices.

[†]Figure 10 has the total number 59, not 60 because one subject was disqualified.

Comp. Anim. Virtual Worlds 2008; **19**: 331–340
DOI: 10.1002/cav

Figure 8. Virtual environment for experiments with human subjects.

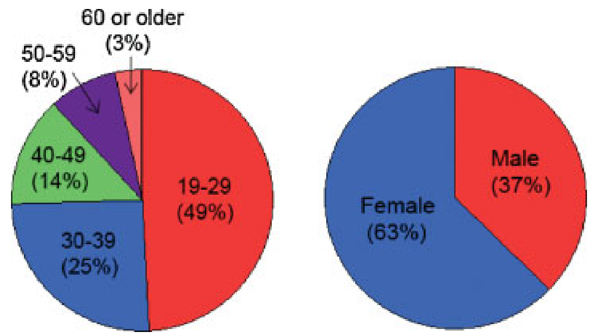

Figure 9. Demographic of age and gender.

Figure 9 shows the demographic data of the subjects' age and gender. Figures 10–14 show some of our experimental results. In general, the subjects chose the wide passageway (69%) more than the narrow one (31%), the street without dumpsters (68%) more than the ones with dumpsters (32%), and the street without a threatening individual (75%) more than the street with one (25%). The fact that most subjects avoided the street with a threatening individual confirms that social incivilities generate more fear than physical incivilities. We were right to assign higher fear weight values to threatening individuals and lower values to other objects and features. We need

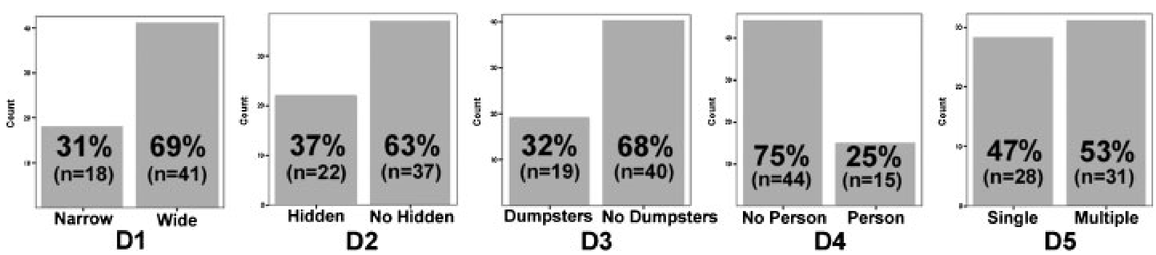

Figure 10. All subjects' choices at each decision point.

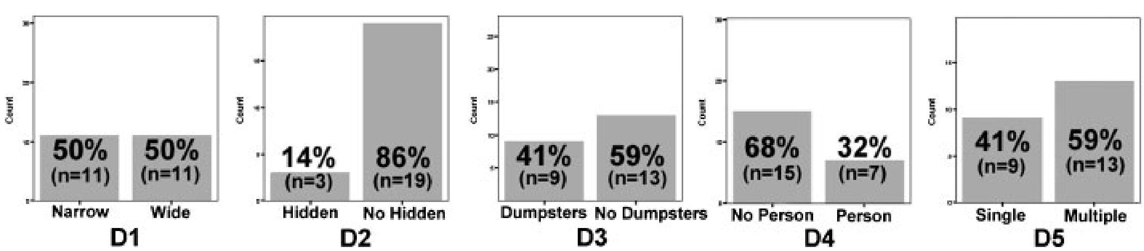

Figure 11. Male subjects' choices at each decision point.

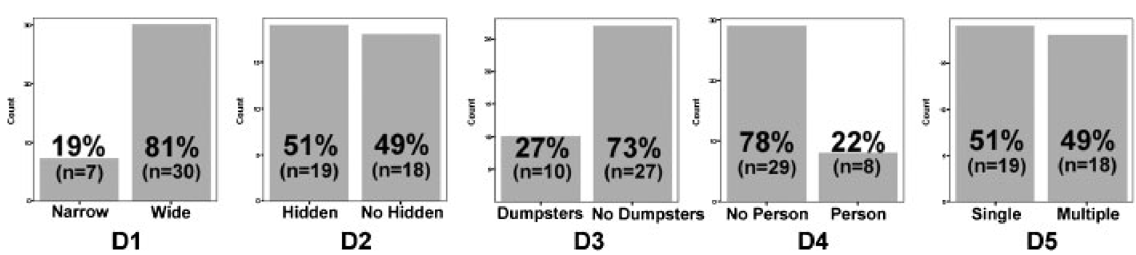

Figure 12. Female subjects' choices at each decision point.

DOI: 10.1002/cav

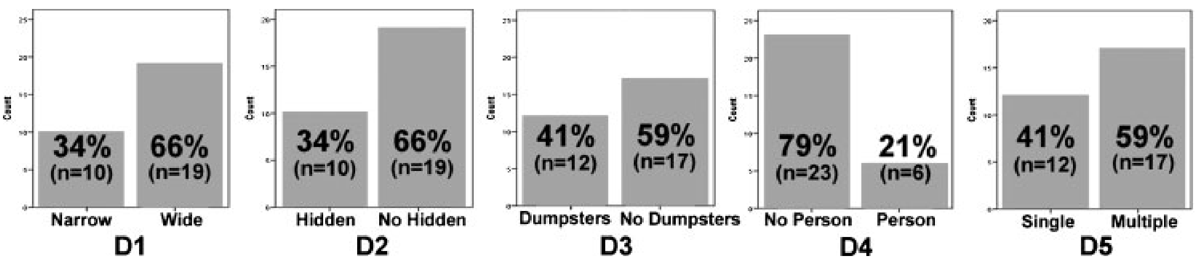

Figure 13. Young subjects' (under 30) choices at each decision point.

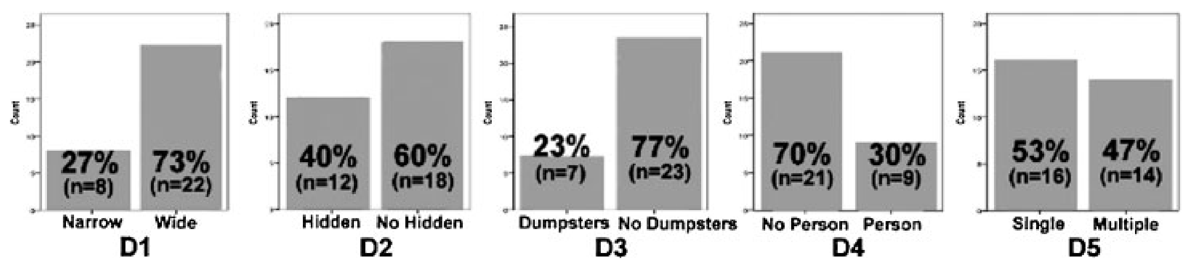

Figure 14. Older subjects' (30 or older) choices at each decision point.

further investigation to understand the results at the decision points #3 and 5. One possible explanation for the results at the decision point #3 is the paradoxical role of a hidden space.[11] In other words, people feel it is dangerous to go toward the unknowns of the hidden space. At the same time, they also feel curious about them. It seems that the hidden space in our experimental setting generated curiosity more than fear.

Figures 11 and 12 show the gender differences in the behaviors influenced by the fear of crime. The results suggest that female subjects are more fearful than male subjects. It is interesting to see that 86% of the male subjects chose the street with a hidden space, whereas a little bit more than half of the female subjects (51%) chose the street without a hidden space. The street with a threatening individual generates fear in both male and female subjects, but still much more in the female subjects. The narrow passageway and the street with dumpsters generate high fear in the female subjects but not that much in the male subjects. At the decision point #5, more than half of the male subjects went to the street with multiple threatening individuals rather than the street with a single one. But for the female subjects, it was the other way around.

Figures 13 and 14 indicate that young subjects are as fearful as older subjects. This result seems contrary to the general findings of criminology research. However, some studies show that in cases of stranger attacks and sexual attacks, the younger people tend to be more fearful than the older people although in cases of mugging and break and enter, it is the other way around.[25] In fact, the young subjects are more fearful about the street with a threatening individual than the older subjects are. More than half of the young people preferred the street with multiple threatening individuals to the one with a single threatening individual, whereas for the older subjects it was opposite.

In order to find out the reasons for their choices, we analyzed the post experimental interviews using content analysis methods. Content analysis is a research technique for condensing many words of text into fewer content categories based on explicit rules of coding by making replicable and valid inferences.[26] Three coders coded the transcribed interview contents independently. If two of the three coders agreed on their coding per category per subject, we considered it as a valid coding. These results will be reported elsewhere. In this way, we have gained new insights into the pedestrians' behavior. Table 1 shows some of the top reasons for choosing a certain route at each decision point.

New Pedestrian Model and Future Research

Based on our experimental results, we are improving our pedestrian agent model. The results suggest that it would be better to have more detailed human types in terms of

DOI: 10.1002/cav

Decision Point	Reasons	
#1	Narrow: shortest path	Wide: personal space or more space
#2	No hidden: did not like hidden space, implication of hostile humans, graffiti. Liked bright, friendly buildings, implication of friendly humans.	Hidden: shortest path, but noticed hidden space, some objects, implication of humans.
#3	With dumpsters: shortest path.	No dumpsters: did not like dumpsters, garbage, bottles. Implication of hostile humans behind/in dumpsters.
#4	No person: afraid of drunken person, unexpected behavior or talk.	With person: notice of person
#5	Single: afraid of multiple people, did not want to distract them. Feel safer with a single person, can handle the person, friendly appearance.	Multiple: feel safer with multiple people, friendly appearance and activity. Single person looked hostile, did not like to confront a single person alone.

Table 1. Content analysis for reasons of route choices

gender and age groups, not in terms of simple personality type (bold or fearful), such as a female older pedestrian or a male young pedestrian. This would better reflect the findings of social science research. A statistical approach in making a choice of routes based on the experimental results might be interesting. The results also suggest that pedestrians are not only concerned with physical structures of the environments, but also with their appearances such as a bright store, a dark entrance, and scary graffiti. We are employing this finding in our new pedestrian model development. A choice between a single threatening individual and multiple ones is a complicated problem. Each subject judged the same situation differently. We are currently investigating this issue and trying to find out whether we can categorize it in terms of human types.

Our future research includes multiple pedestrians' navigating together (we expect that it would lower their fear level), navigation after dark, and testing other environmental features such as bushes, unknown space without a map, and different ethnic groups. We would also like to investigate the influence of sound and smell on the fear of crime.

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References

1. Magnenat-Thalmann N, Thalmann D. Virtual humans: thirty years of research, what next? *The Visual Computer* 2005; **21**(12): 997–1015.
2. Shao W, Terzopoulos D. Autonomous pedestrians. In *Eurographics/ACM SIGGRAPH Symposium on Computer Animation*, Anjyo K, Faloutsos P (eds). ACM: New York, 2005; 19–28.
3. Garofalo J. The fear of crime: causes and consequences. *The Journal of Criminal Law and Criminology* 1981; **72**(2): 839–857.
4. Ferraro KF, Grange RL. The measurement of fear of crime. *Sociological Inquiry* 1987; **57**(1): 70–97.
5. Skogan WG. The impact of victimization on fear. *Crime & Delinquency* 1987; **33**(1): 135–154.
6. Wilcox P, Quisenberry N, Jones S. The built environment and community crime risk interpretation. *Journal of Research in Crime and Delinquency* 2003; **40**(3): 322–345.
7. Will JA, McGrath JH. Crime, neighborhood perceptions, and the underclass: the relationship between fear of crime and class position. *Journal of Criminal Justice* 1995; **23**(2): 163–176.
8. LaGrange RL, Ferraro KF, Supancic M. Perceived risk and fear of crime: role of social and physical incivilities. *Journal of Research in Crime and Delinquency* 1992; **29**(3): 311–334.
9. Goffman E. *Relations in Public : Microstudies of the Public Order*. Basic Books: New York, 1971.
10. Fisher BS, Nasar JL. Fear of crime in relation to three exterior site features: prospect, refuge, and escape. *Environment and Behavior* 1992; **24**(1): 35–65.

DOI: 10.1002/cav

11. Herzog TR, Flynn-Smith JA. Preference and perceived danger as a function of the perceived curvature, length, and width of urban alleys. *Environment and Behavior* 2001; **33**(5): 653–666.
12. Jacobs J. *The Death and Life of Great American Cities*. Random House: New York, 1961.
13. Whyte WH. *The Social Life of Small Urban Spaces*. Conservation Foundation: Washington DC, 1980.
14. Newman O. *Defensible Space: Crime Prevention Through Urban Design*. Macmillan: New York, 1972.
15. Jeffery CR. *Crime Prevention Through Environmental Design*. Sage: Beverly Hills, CA, 1971.
16. Brantingham PJ, Brantingham PL. *Environmental Criminology, Sage Focus Editions*, Vol. 39. Sage Publications: Beverly Hills CA, 1981.
17. Fasli M. From social agents to multi-agent systems: preliminary report. In *Multi-Agent Systems and Applications III, Lecture Notes in Computer Science*, Vol. 2691 of *Lecture Note in Computer Science*, Mařík V, Müller J, Pěchouček M (eds). Springer: Berlin, 2003; 111–121.
18. Foner LN. Are we having fun yet? using social agents in social domains. In *Human Cognition and Social Agent Technology*, Dautenhahn K (ed.). John Benjamins Publishing Company: Philadelphia, PA, USA, 2000; 323–348.
19. Silverman BG, Johns M, Weaver R, O'Brien K, Silverman R. Human behavior models for game-theoretic agents: case of crowd tipping. *Cognitive Science Quarterly* 2002; **2**(3/4): 273–301.
20. Ortony A, Clore GL, Collins A. *The Cognitive Structure of Emotions*. Cambridge University Press: Cambridge, 1988.
21. Donaldson T, Park A, Lin I-L. Emotional pathfinding. In *Advances in Artificial Intelligence*, Tawfik AY, Goodwin SD (eds). Lecture Notes in Artificial Intelligence, Springer: Berlin, 2004; 31–43.
22. Park A, Calvert T. Validating a social agent model for pedestrians with a virtual environment. In *Computer Animation and Social Agents*, Van Reeth F, Thalmann D, Di Fiore F, Magnenat-Thalmann N, Shin SY, Van Laerhoven T (eds). Hasselt University: Belgium, 2007; 11–17.
23. Hart PE, Nilsson NJ, Raphael B. A formal basis for heuristic determination of minimum cost paths. *IEEE Transactions on Systems Science and Cybernetics* 1968; SSC**4**(2): 100–107.
24. Cozens P, Neale R, Whitaker J, Hillier D. Investigating personal safety at railway stations using virtual reality technology. *Facilities* 2003; **21**(7/8): 188–194.
25. Evans K. It's all right "round here if you're a local": community in the inner city. *Contested Communities: Experiences, Struggles, Policies*. Policy Press: Bristol, 1997; 33–50.
26. Krippendorff K. *Content Analysis: An Introduction to its Methodology*, 2nd edn. Sage: Thousand Oaks, CA, 2004.

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