석사 학위논문

Master's Thesis

자의식 이론에 의거한 군중 시뮬레이션

Crowd Simulation based on Self-consciousness Theory

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전산학과

Department of Computer Science

KAIST

2015

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Department of Computer Science

KAIST

A thesis submitted to the faculty of KAIST in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the Department of Computer Science . The study was conducted in accordance with Code of Research Ethics[1].

2014. 11. 28.

Approved by

Professor Yoon, Sung-Eui

[Advisor]

[1]Declaration of Ethical Conduct in Research: I, as a graduate student of KAIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

자의식 이론에 의거한 군중 시뮬레이션

이 가 연

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학위논문심사위원회에서 심사 통과하였음.

2014년 12월 17일

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MCS 20123453

이 가 연. Lee, Ga-Yeon. Crowd Simulation based on Self-consciousness Theory. 자의식 이론에 의거한 군중 시뮬레이션. Department of Computer Science . 2015. 20p. Advisor Prof. Yoon, Sung-Eui. Text in English.

ABSTRACT

Crowd simulation is a technique that models a large number of different characteristics. It is widely used in psychology, robotics, virtual reality, film, and game. Previous researches on crowd simulation have studied to find a path to reach the destination (global path finding) and to avoid collision with obstacles and other agents (local planning). However, recent researches have focused on combining path finding algorithms with psychological approaches for more humanlike crowd results. In this paper, we apply a self-consciousness theory of concerning other people nearby into crowd simulation. Based on this theory, people is divided into three categories as public self-consciousness, private self-consciousness, and social anxiety. We did an user study for obtaining agent's properties to combine self-consciousness theory and crowd simulation. Then, we mapped three self-conscious elements to physical elements of crowd simulation. Through this process, we simulate the crowd affected by the action of the surrounding neighbors unlike conventional crowd moves based on their specified properties. Also agents show different behavior depending on whether they have nearby neighbors or they are alone. We compare self-consciousness model with PEN model and it shows better simulation result.

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Chapter 1. INTRODUCTION

Crowd simulation is modeling the behaviour of heterogeneous crowd. This simulation mimicking multiple people is more important nowadays and is used in many fields like animation, film, emergency simulation and robotics etc. [14].

There are two techniques of crowd simulation named particle motion and agent based model. Particle motion attaches a person into particle to simulate but it is non realistic because it is hard to give different velocity to each people and it is insufficient to present local interaction [11]. Agent-based modeling (ABM) is a approach to modeling system composed of autonomous agents [12]. Each agent has state, functions and many parameters. We use the agent-based modeling technique to describe individuals with different characteristics. This technique is used in biology, ecology, social science as well as computer graphics [13].

Although initial studies of crowd simulation were focused on collision avoidance and physical pathfinding and it still being actively researched areas. However these days people want to simulate more powerful crowd which psychological factors are added to the physical elements [1, 2, 4].

Main contributions. We want to add psychological element as self-consciousness theory into the pathfinding crowd. So we want to simulate the behavior of people depends on the presence of the people nearby. In order to map the self-consciousness elements to physical elements, we surveyed user study and parameterized several scenes based on it. Then we show the simulation result of two scenes named escape and bystander. In previous works, all agents start to escape at the same time and they focused on how quickly escape in emergency situation [2, 21]. But in our research, we simulate agents that are more realistic with real people who reads others' countenance. We can simulate difference of when a public agent or private agent is alone and when there are multiple agents at the scene. In bystander scene, we compare our result and PEN model which is proposed at the [4]. Our model works seamlessly with a similar radius with default agent while radius of agents are very smaller then default in PEN model.

Chapter 2 describes the pathfinding problem used in crowd simulation and extension of crowd simulation to the other domain. In Chapter 3, we try to point out the problem we want to solve, and explain self-consciousness theory and RVO library. Then we show the overview of our approach. Chapter 4 describes method of user study. Chapter 5 explains how to map the low-level parameter and self-consciousness theory. Chapter 6 shows the results and concludes the paper with a discussion in Chapter 7.

Chapter 2. RELATED WORK

In this section we discuss prior works on planning technique and crowd simulation integrated with psychological element.

2.1 Planning

Simulated crowd must arrive at their destination passing through moving car or other agents, and various obstacles [15]. Existing crowd simulation studies have been conducted to find a way to reach a global planning destination (global planning) and to avoid obstacles and other agents (local planning). Agents are in a crowd simulation loop, avoiding obstacles and collisions with other agents performing global planning going towards its destination. At the start of progress each agent obtain the preferred speed to goal and each agent can adjust the preferred speed slightly and they are moving to perform collision avoidance with actual speed [16]. Representative pathfinding algorithms include social force [8], HiDAC (High-Density Autonomous Crowds) [7], RVO (Reciprocal Velocity Obstacles) [17], and the like. We do the planing using RVO library in this study.

2.2 RVO library

RVO library has several agents moving in real time that an algorithm arriving a goal position without collisions. Each agent avoids the static or dynamic obstacles proceed independently and this algorithm can simulate multiple agents at the same time. Also presented a new concept for collision avoidance as called Reciprocal Velocity Obstacle. RVO is a range that it is proved of collision free using the current speed of the two agents to go toward. Agent is safe and it can move oscillation free through this concept [17]. This algorithm has several low-level parameters: maxNeighbors (the maximal number of other agents the agent takes into account in the navigation), maxSpeed (the maximum speed of the agent), neighborDist (the maximal distance to other agents the agent takes into account in the navigation), position (current position of the agent), radius (radius of the agent), timeHorizon (the minimal amount of time for which the agent's velocities the are computed by the simulation are safe with agents), timeHorizonObst (the minimal amount of time for which the agent's velocities the are computed by the simulation are safe with obstacles) [18].

2.3 Psychological crowd

People wanted to depict the crowd more similar with people. So it is emerging research that combines the psychological element with pathfinding crowd. Guy [4] has mapped personality trait to the physical elements of the crowd. He simulate crowd with P,E,N factors and 6 adjectives (Aggressive, Assertive, Shy, Active, Tense, Impulsive). Duruponar [1] has simulated the Ocean personality parameters (Openness, Conscientiousness, Extroversion, Agreeableness, Neuroticism) and 12 behavior parameters. Kim [2] had mapped the four kinds of stress which are time, area, positional, interpersonal stressor to the personality attributes.

Chapter 3. Overview

We first present our observation that influenced this paper and define our problem, followed by a brief overview of self-consciousness theory. Then we give an overview of our approach.

3.1 Observation

We have seen a lot of insensitive people in crisis situations in the real world. They does not attempt to escape although they perceive risk if people in around would not escape. safety frigidity makes small accident bigger. We examine the theory deals with the properties of such person, and map this theory to RVO to simulate the crowd affected by people around.

3.2 Problem definition

Previous psychological crowd acts following pattern on it. The latest research [2] simulates crowd responding to the stressful situation. We want to simulate not Individually floating crowd at his or her own personality but crowd Influenced by the neighbors moving around. We want to show different behavior of agents depends on whether they have neighbors nearby or they are alone.

3.3 Self-consciousness Theory

Self-consciousness theory is associated with self-awareness theory a lot. Self-awarenesss is that people are focused on themselves, they will evaluate and compare their behavior to the standards and values of their inner self [9]. People are self-conscious when they are observed by others, it is self-consciousness to people concentrate directly inward or outward of themselves [19]. Self-consciousness theory divides the tendency of people into three categories. There are public self-consciousness, private self-consciousness, and social Anxiety. Public self-consciousness is tendency that they read others' countenance and they are affected by others easily when they do something. Contrastively private self-consciousness is inclined to do by themselves and not affected by external influences. Social anxiety is a tendency to feel anxiety and it is difficult to come forward in front of many people. These tendencies are not independent and not mean contrary so high private self-consciousness does not low public self-consciousness certainly [20].

3.4 Overview of Our Approach

Figure 3.1 show overview or our approach. This is for escape scene which has danger in simulation. $\mathbf{d}_n$ is degree of danger and we set moving state of self-consicous agent true or false depending on escape probability $\mathbf{P}_e$ and affective neighbor $\mathbf{N}_a$ of it. Then we simulate agents following multi-agent simulation algorithm.

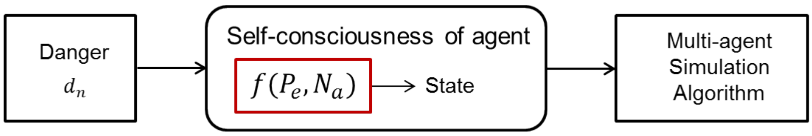


Figure 3.1: Overview of our approach

Chapter 4. User study

We want to simulate a crowd have different behaviors by tuning low-level parameter differently depending on the element of self-consciousness theory. So we use six parameters of RVO library (neighbor Distance, max Neighbors, time Horizon, time Horizon Obstacle, radius, max Speed). In many crowd simulation algorithms use similar parameters like these [4]. And we add a new parameters called affect Neighbor and escape Probability. Affect Neighbor is a parameter that indicates how many neighbors affect to agent when it stopped then start to escape. Escape Probability is a probability of escape for each agent.

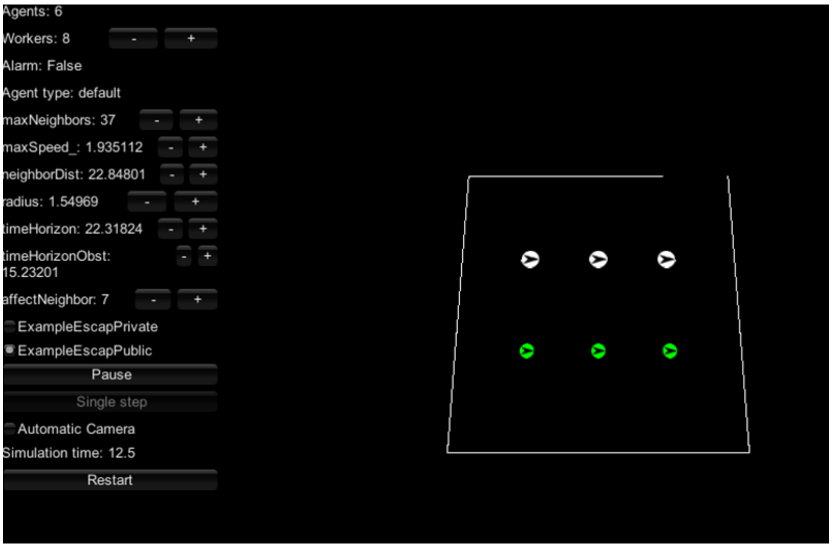
We designed three steps for user study. First of all, we describe the self-consciousness theory and respective elements. And we explained seven parameters described above. Based on the self-consciousness theory, participants are asked which parameter values are set for self-conscious agent compared with agent that has a default value (the degree of 1 2 3 4 5). We use these values for intuitive mapping. Table 4.1 shows value and range of parameters for default agnet. These values are from RVO library [18].

Table 4.1: Parameters with default agent.

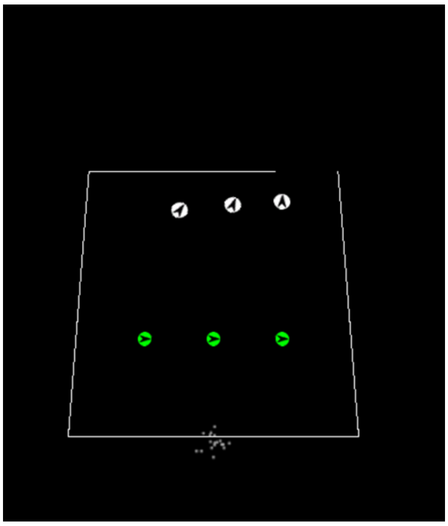
Parameter	Default value	Range
neighborDist	15.0 m	3 ~ 30 m
maxNeighbors	10	1 ~ 50
timeHorizon	10.0 s	1 ~ 30 s
timeHorizonObst	5.0 s	1 ~ 30 s
radius	2.0 m	0.3 ~ 2.5 m
maxSpeed	2.0 m/s	1.2 ~ 2.2 m/s
affectNeighbor	3	0 ~ 10

For the second step, we prepared the two scenes. There are still agents at the room with one exit and start smoking from the wall in the opposite direction. We want to look for reaction of agents in this scene. The other one has still a group of agents in the middle of it, and the agents of the four groups are in the four corners moving diagonally. The scene shows the process that several agents are united in middle of the scene and scatter to own goal position. We explained these scenes and asked participants to predict what results come out. Figure 4.1 shows sequence of moving agents in the escape scene. At start of this scene, every agents are still. Then when smoke appears, default agents escape first, then public agents follow (This is the prediction of participants).

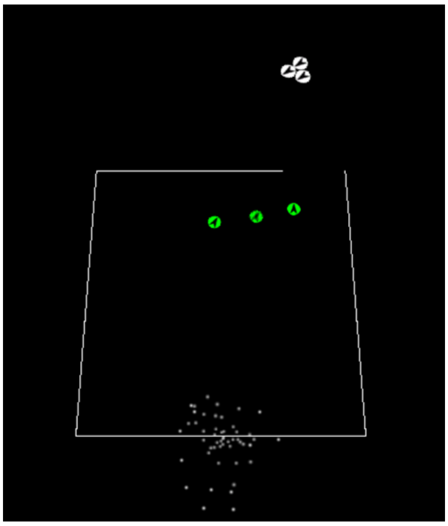
As the third step, we placed on the random value of corresponding area to the respective parameters for two kinds of scenes in the computer. Participants can change the value as they want. And they choose a scene the closest to expected results and write down parameters of selected scene. We use these datas for parameter mapping. Figure 4.2 shows sequence of moving agents in the bystander scene. At start of this scene, every agents are still. at their intial positions. Then agents are united in middle of the scene and scatter to own goal position. Social anxiety agents go around group of agents (This is the prediction of participants).



(a) Still agents

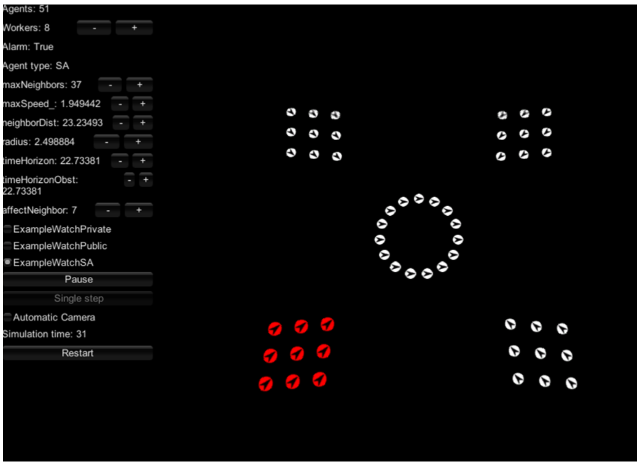


(b) Default agents moving start

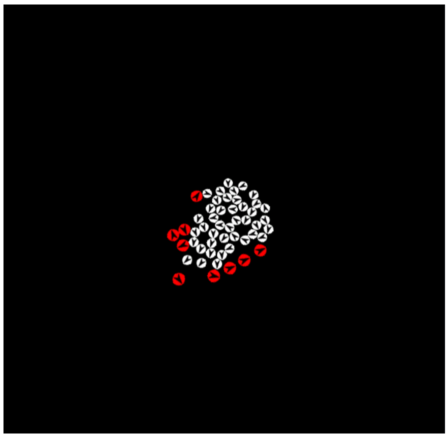


(c) Following public agents

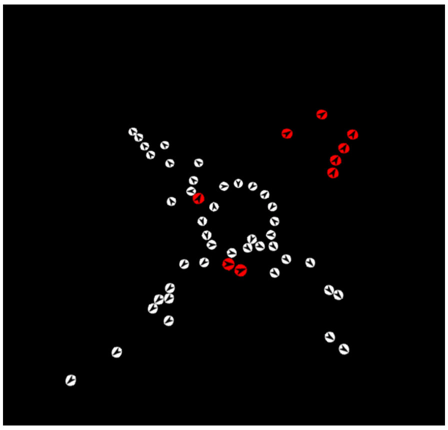
Figure 4.1: This figure shows sequence of moving agents in the escape scene. White agents are default agents and green ones are public self-consciousness agents.



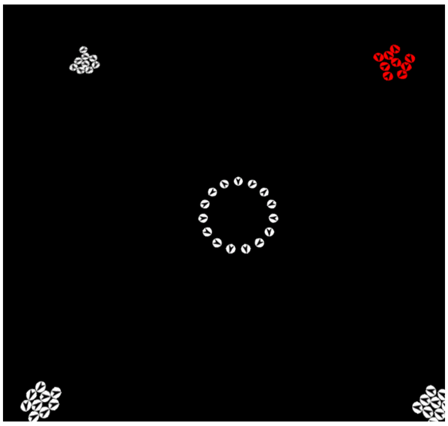
(a) Start to move



(b) Social anxiety agents going around group of agents



(c) Social anxiety moving fast



(d) Agents arrived at their goal position

Figure 4.2: This figure shows sequence of moving agents in the bystander scene. White agents are default agents and red ones are social anxiety agents.

Chapter 5. Mapping

In this part, we describe two method for parameters mapping.

5.1 Intuitive parameter mapping

The first is an intuitive parameter mapping. For this mapping, we asked participants to compare each RVO parameters and parameters of default agent and express parameters of self-conscious agent as degree of 1,2,3,4,5. The participants map each parameter as 1 or 2 when they thought this parameter should be smaller than default parameter. The participants map each parameter as 3 when they thought this parameter should be similar with default parameter. The participants map each parameter as 4 or 5 when they thought this parameter should be bigger than default parameter. The mean and standard deviation of the results is shown in table 5.1. We obtain the intuitive mapped value from thess degree value as method which is represented in Figure 5.1 intuitively. **S** is the starting value for the range of some parameter **E** is the end value of the parameter range. When mean is greater than 3, we can obtain the intuitive value from equation 5.1. In the opposite case, we can obtain the intuitive value from equation 5.2. **f(mean)** is the value to be mapped to the mean.

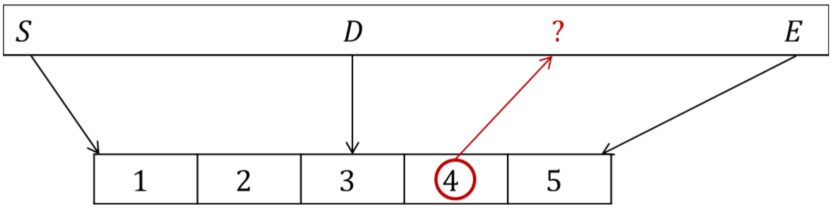


Figure 5.1: Intuitive mappeing degree to real value.

$$f(mean) = D + \frac{E-D}{2}(mean-3) \tag{5.1}$$

$$f(mean) = S + \frac{D-S}{2}(mean-1) \tag{5.2}$$

5.2 Hand-tuning parameter mapping

The second is a hand-tuning parameter mapping. The participants choose the scene when the scene is similar appearance with they are expected by tuning parameters as they want. We write down these values for parameters. We took the average values and used the as a hand-tuning mapping values. There are two scenes named escape and bystander. We show the mean and standard deviation of the parameters of the bystander scene in the table 5.2.

5.3 Escape Algorithm

We modify part of updating preferred velocity in RVO library for simulating escape scene. In this part, we update preferred velocity of agents that has moving state as true only. PV_{agent} is preferred velocity of agents.

Table 5.1: Intuitive mapped parameters depend on self-consciousness element.

(a) Intuive mapped parameters for Public self-consicousness

Parameter	Mean	Std dev	Mapped value
neighborDist	4.0	0.89	22.5
maxNeighbors	4.3	0.64	36
timeHorizon	3.4	1.01	14
timeHorizonObst	3.2	0.6	12
radius	3.2	0.97	2.0
maxSpeed	2.9	0.94	1.9
affectNeighbor	3.5	1.20	5

(b) Intuive mapped parameters for Private self-consicousness

Parameter	Mean	Std dev	Mapped value
neighborDist	2.2	1.32	10.1
maxNeighbors	1.8	0.87	4
timeHorizon	2.8	0.87	9
timeHorizonObst	3.4	0.66	14
radius	2.2	1.24	1.3
maxSpeed	3.5	1.02	2.0
affectNeighbor	2.5	1.20	2

(c) Intuive mapped parameters for Social anxiety

Parameter	Mean	Std dev	Mapped value
neighborDist	3.7	1.41	20.2
maxNeighbors	4.0	1.26	30
timeHorizon	4.3	0.90	23.0
timeHorizonObst	3.0	0.63	10.0
radius	4.2	1.24	2.3
maxSpeed	3.5	1.74	2.0
affectNeighbor	2.9	1.22	3

We perform this process to each agent a in set of agents A. Goal vector V_{goal} can get by current position $P(a)$ subtracting from goal position $G(a)$. When difference between goal position and current position is bigger then 1, recalculate PV_a. By doing this, agents can go to their goal position. And it perturbs preferred velocity a little with little angle $angle$ and little distance $dist$ perturb to avoid deadlocks due to perfect symmetry (Alg 1).

Algorithm 2 shows how to set moving state of agent as true. First, classify agents into three groups into public self-consciousness, private self-consciousness and default. Set affective neighbor of agents into affect neighbor N_{affect} according to classification of agents. When random value $sample$ correspond to escape probability, then set moving state of agent as true. Also if moving state N_{moving} of neighbors is bigger than affect neighbor N_{affect} then set moving state of agent as true.

Table 5.2: Hand tuning parameters depend on self-consciousness element in the bystand scene.

(a) Hand-tuing parameters for Public self-consicousness

Parameter	Mean(mapped value)	Std dev
neighborDist	19.8	10.30
maxNeighbors	424	14.18
timeHorizon	15.8	8.28
timeHorizonObst	12.5	7.04
radius	2.1	0.58
maxSpeed	1.7	0.35
affectNeighbor	5	3.19

(b) Hand-tuing parameters for Private self-consicousness

Parameter	Mean(mapped value)	Std dev
neighborDist	9.9	5.27
maxNeighbors	7	6.57
timeHorizon	9.6	4.12
timeHorizonObst	8.3	1.31
radius	1.3	0.66
maxSpeed	1.8	0.43
affectNeighbor	2	1.11

(c) Hand-tuing parameters for Social anxiety

Parameter	Mean(mapped value)	Std dev
neighborDist	29.8	13.07
maxNeighbors	37	13.70
timeHorizon	21.5	7.10
timeHorizonObst	16.0	9.24
radius	2.7	0.38
maxSpeed	1.9	0.31
affectNeighbor	6	2.4

Algorithm 1: CALCULATE PREFERRED VELOCITY

Input: *Agent*, a set of agents

Output: PV_{agent}, preferred velocities

for ***each*** $a \in A$ *// per each agent* **do**

  if $IsTrueAgentMovingState(a)$ **then**

    $V_{goal} \leftarrow G(a) - P(a)$

    if $AbsSq(V_{goal} > 1.0f)$ **then**

      $PV_a \leftarrow SetAgentPrefVelocity(a, V_{goal})$

    $angle \leftarrow CalculateAngle()$

    $dist \leftarrow CalculateDist()$

    $PV_a \leftarrow SetAgentPrefVelocity(a, PreVelocity(a) + dist * Vector2(cos(angle), sin(angle)))$

return PV_a

Algorithm 2: SET MOVING STATE OF AGENT

Input: $Agent$, a set of agents, $flag$, flag of each agent

Output: MS_{agent}, moving states of agents

$sample \leftarrow GenerateRandom()$
$N_{moving} \leftarrow 0$
$N_{affect} \leftarrow 0$
if $FlagIsPublic$ **then**
    $N_{affect} \leftarrow N_{affect_public}$
    if $EscapeProbabilityofPublic(sample)$ **then**
        $MS_a \leftarrow true$
if $FlagIsPrivate()$ **then**
    $N_{affect} \leftarrow N_{affect_private}$
    if $EscapeProbabilityofPrivate(sample)$ **then**
        $MS_a \leftarrow true$
if $FlagIsDefault()$ **then**
    $N_{affect} \leftarrow N_{affect_default}$
    if $EscapeProbabilityofDefault(sample)$ **then**
        $MS_a \leftarrow true$
for ***each*** $a \in A$ *// per each agent* **do**
    if $IsTrueMovingState(a)$ **then**
        $N_{moving} \leftarrow N_{moving} + 1$
if $N_{moving} <= N_{affect}$ **then**
    $MS_a \leftarrow true$
return MS_a

Chapter 6. Simulation result

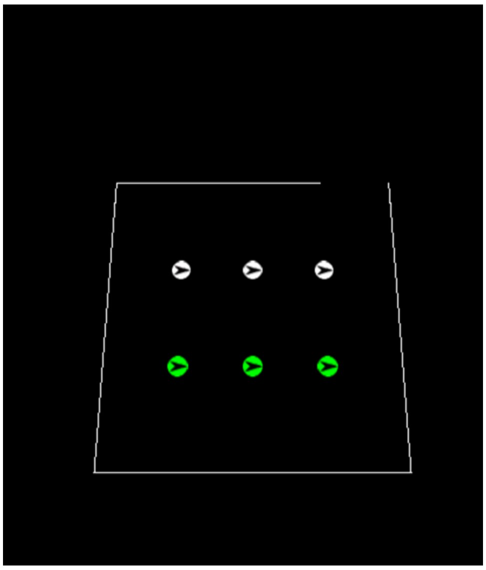
We present simulation results for the two kinds of scenes. One is the escape of smoking room scene to see the reaction of the agents. The other scene has still bystanders are in the middle. We used intuition mapped data for simulation result. We did validation survey between intuition data and hand-tuning data. And most of participants responded intuitive mapping scene is better.

The first figure 6.1 and Figure 6.2 shows the results of the public self-conscious agents and private self-conscious agents of escape scene. In previous works, all agents start to escape at the same time and they focused on how quickly escape in emergency situation [2, 21]. But in our research, we simulate agents that are more realistic with real people who reads others' countenance. Public self-conscious agents start to move following several moving default agents (Figure 6.1). By contrast, private self-conscious agents escape fast and default agents responded to escape following them (Figure 6.2).

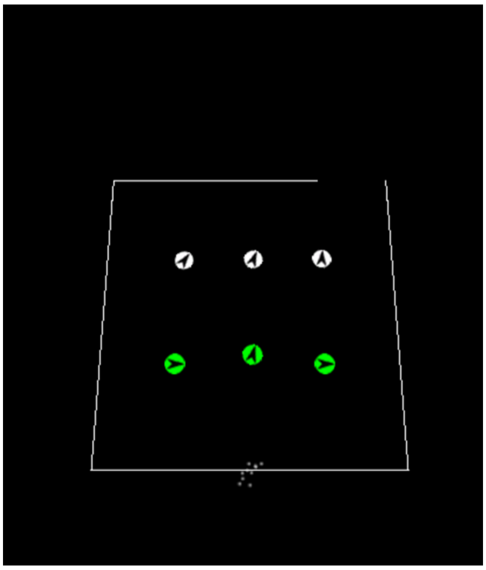
Figure 6.3 shows escape time of mixed public self-conscious agents and defaults agents and escape time of mixed private self-conscious agents and default agents. Escape time is the simulation time after appearance of smoke. Pause+Escape time is simulation time of whole escape scene (waiting time before appearance of smoke and escape time after apperance of smoke). If there are multiple agents at the scene, then private self-consciousness agents escape faster then public self-consciousness agents. But the interesting thing is that when a public agent and private agent is alone, escape time is similar. This is because no other agents around so it is not self-conscious.

The other scene is bystander scene. It has still a group of agents in the middle of it, and the agents of the four groups are in the four corners moving diagonally. As the agents had united in the middle of a scene and scattered to their goal positions. Figure 6.4 shows sequence of scenes for self-consciousness modeling. White agents are default agents, green ones are public self-consciousness agents, purple ones are private self-consciousness agents, and red one are social anxiety agents. We compare our model to PEN modelwhich is simulated at [4]. One of well arranged trait theory is PEN model by Eysenck [22]. This model divide trait of people into three categories : Psychoticism, Extraversion, and Neuroticism. Psychoticism can be thought as aggressive and impulsive, Extraversion is similar with Assertive and Active, and Neuroticism is similar with shy and tense [4]. Figure 6.5 shows sequence of scenes for PEN model.

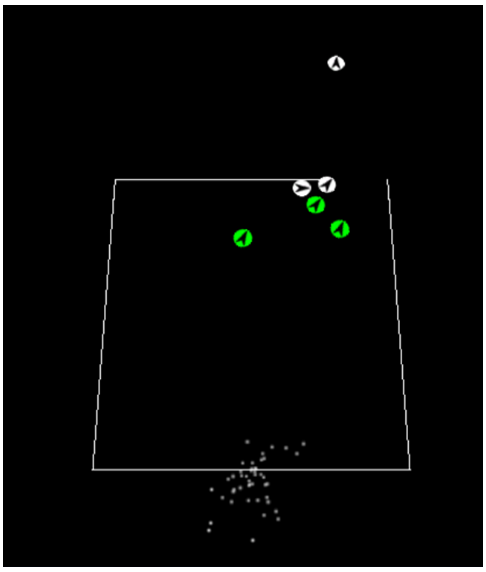
White agents are default agents, yellow ones are P agents, sky blue ones are E agents, and blue ones are N agents. Our model works seamlessly with a similar radius with default agent.



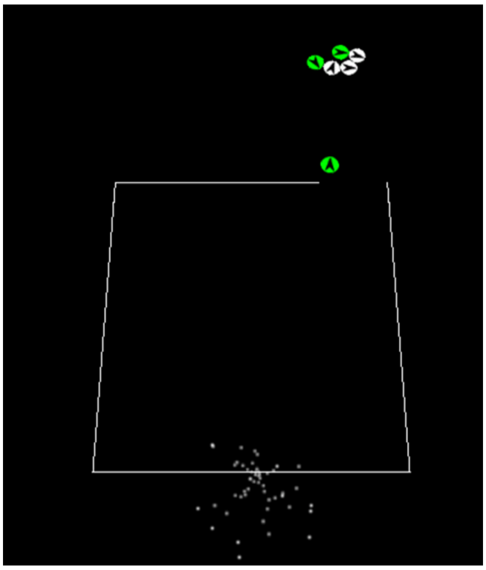
(a) Start to move



(b) Default agents moving start

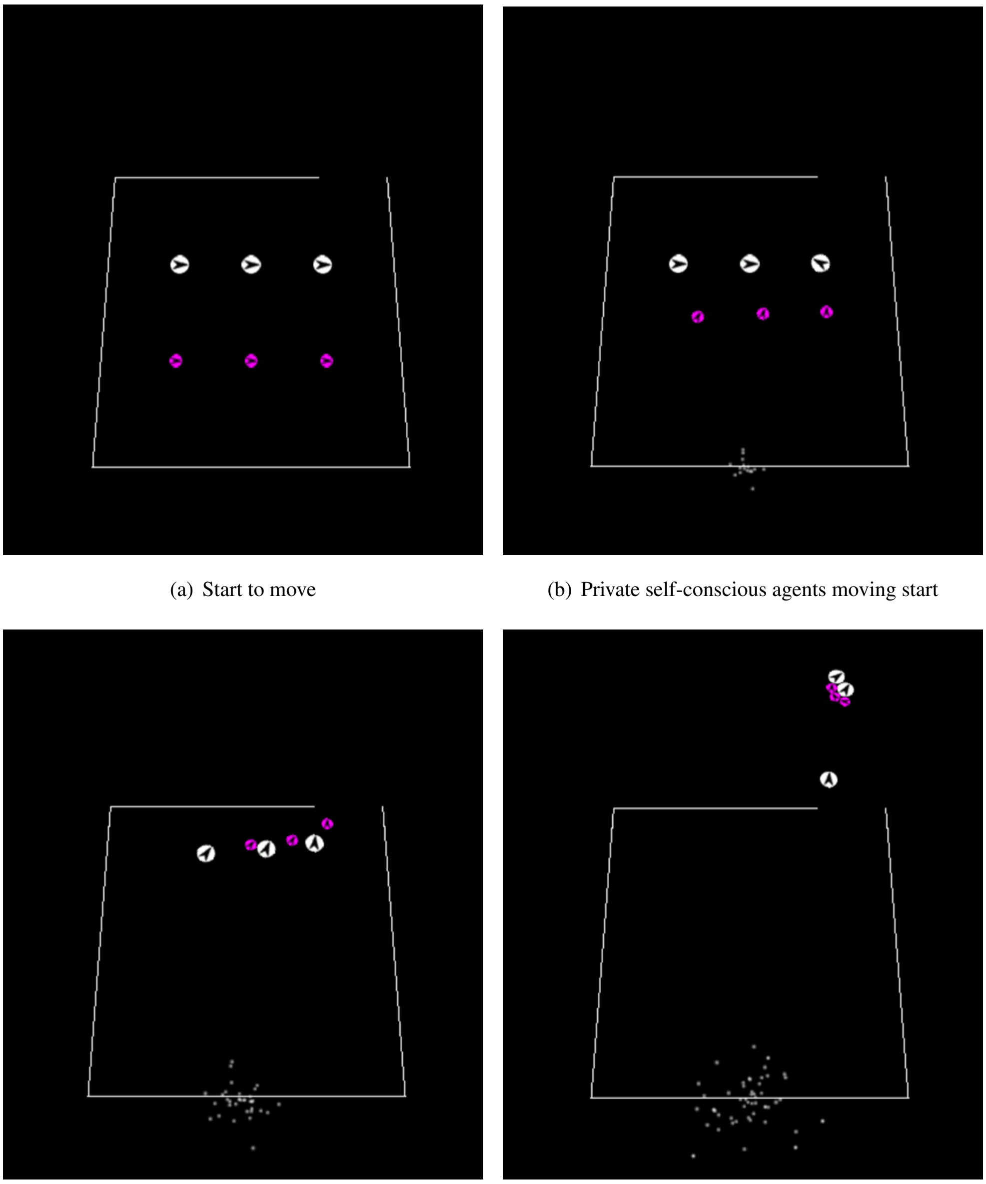


(c) Following public self-conscious agents



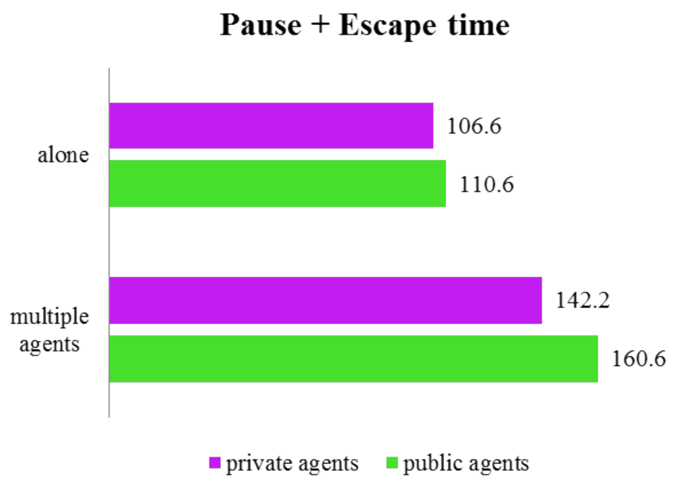
(d) End of escape

Figure 6.1: This figure shows sequence of moving public self-concsious agents in the escape scene. White agents are default agents and green ones are public self-consciousness agents.

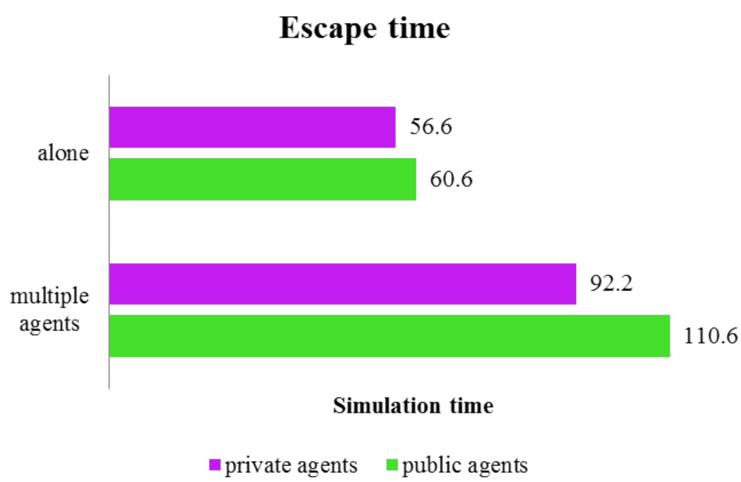


(a) Start to move
(b) Private self-conscious agents moving start
(c) Following default agents
(d) End of escape

Figure 6.2: This figure shows sequence of moving private self-concsious agents in the escape scene. White agents are default agents and purple ones are public self-consciousness agents.

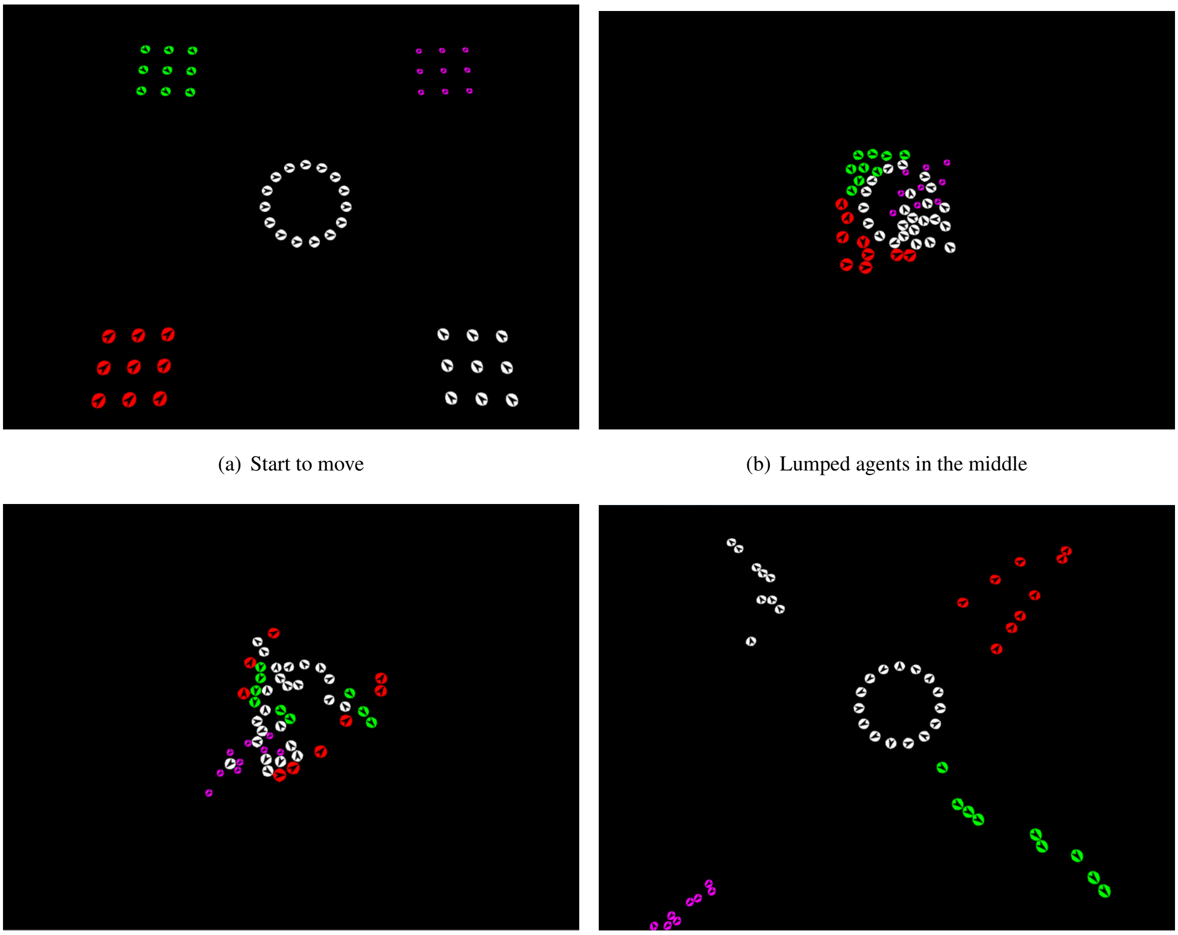


(a) Start to move



(b) Default agents moving start

Figure 6.3: This figure shows simulation time for escape.



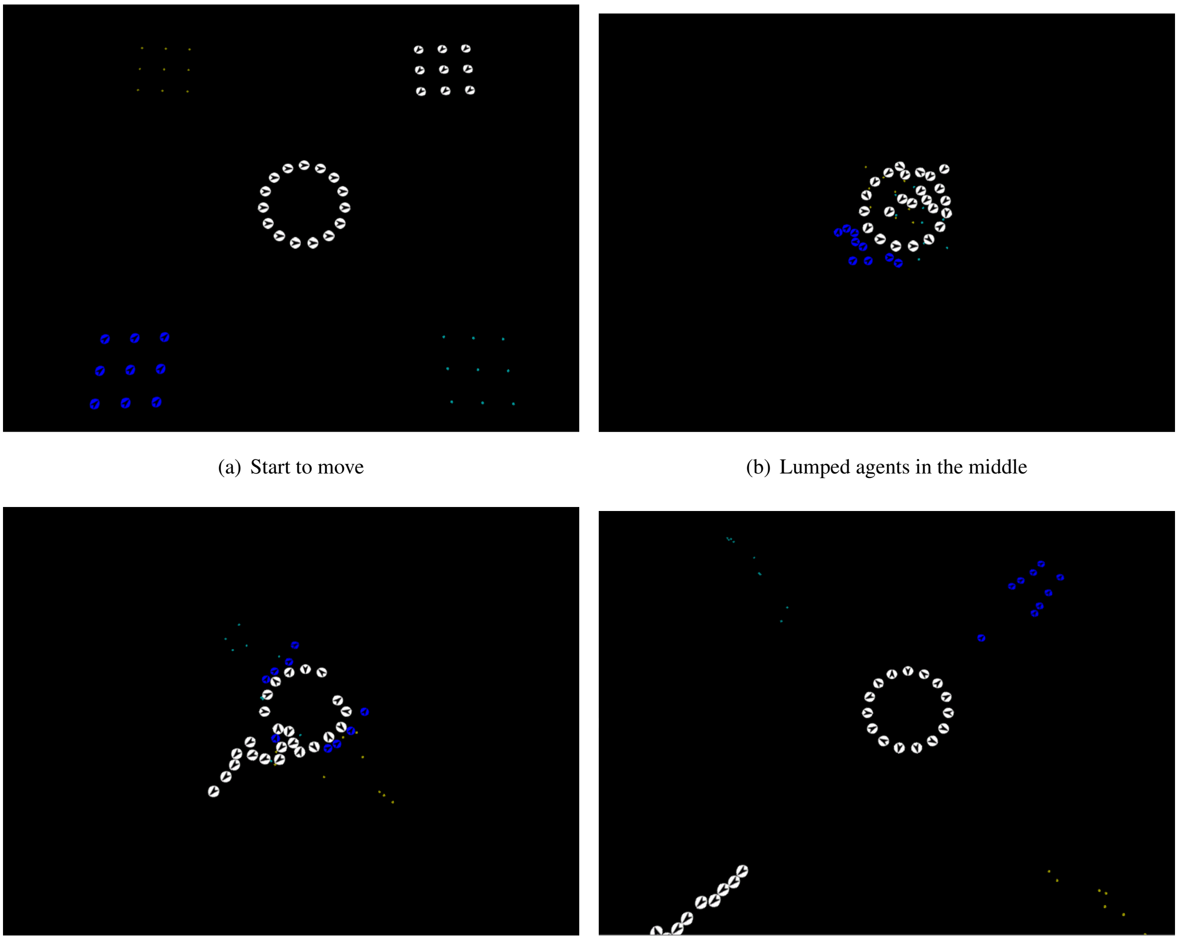
(a) Start to move

(b) Lumped agents in the middle

(c) Dispersive agents

(d) Agents near their goal position

Figure 6.4: This figure shows self-consciousness modeling agents in the bystander scene. White agents are default agents, green ones are public self-consciousness agents, purple ones are private self-consciousness agents, and red one are social anxiety agents.



(a) Start to move

(b) Lumped agents in the middle

(c) Dispersive agents

(d) Agents near their goal position

Figure 6.5: This figure shows PEN modeling agents in the bystander scene. White agents are default agents, yellow ones are P agents, sky blue ones are E agents, and blue ones are N agents.

Chapter 7. CONCLUSION

We mapped self-consciousness theory into crowd simulation. And we provide simulation result for two scenes. Whereas existing simulator begins to escape all the agents at the same time in the escape situation, in our simulator agents begin to escape at different times under the influence of agents nearby. In addition, the result of private self-consciousness and public self-consciousness is similar when they are alone and the result is different when there are neighbors, since self-consciousness is decided whether with neighbors or alone. We compare simulation results with the existing PEN model. Radii of the P and E model are too small compared to the default agent in PEN model, but we can simulate naturally with big enough radius of agent.

However, a limitation of our study is that psychological factors is hard to divide tendency of people into three categories. The factors that seem to be the opposite may be higher and lower both because three elements of this theory are not independent of each other. We consider only the elements that are most representative of simulation in the present study, we want to make a more detailed simulations that consider the agent with all three elements in future work.

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Summary

Crowd Simulation based on Self-consciousness Theory

군중 시뮬레이션은 많은 수의, 서로 다른 특성을 가진 군중을 모델링하는 기법으로, 심리학, 로보틱스(Robotics), 가상현실, 영화, 게임 등에서 널리 사용된다. 기존의 군중 시뮬레이션은 목적지에 도달하기까지 길을 찾는 전반적인 길 찾기(global path finding)와 장애물, 다른 군중을 피하는 국소적인 플래닝(local planning)에 중점을 두고 연구가 진행되어 왔다. 하지만 요즘의 연구는 이런 물리적인 요소를 심리학적 분야와 결합시키는 데 더 집중하고 있다. 더 실제적인 군중을 흉내내기 위해 사람의 성격 요소와 물리적 특성을 결합하는 연구가 많이 진행되었다. 본 연구에서는 어떤 개인이 주위 사람의 존재 여부에 따라 그들을 얼마나 신경 쓰는지를 나타내는 척도인 자의식 이론을 군중 시뮬레이션에 적용한다. 자의식 이론과 군중 시뮬레이션을 결합하기 위해 우리는 유저 스터디를 하였다. 그 자료들에 의거해 사람을 공적 자기의식(Public self-consciousness)과 사적 자기의식(Private self-consciousness), 사회적 불안(Social Anxiety) 세 분류로 나누어 시뮬레이션 하였다. 이를 통해 자신의 정해진 특성에 따라 움직이던 기존의 군중과 달리 주변 이웃의 행동에 의해 영향을 받는 군중을 시뮬레이션 한다. 또한 혼자 있을 때와 주변 사람이 있을 때 행동이 달라지는 사람의 모습을 보인다. 기존의 군중 시뮬레이션은 탈출 장면에서 항상 모든 에이전트가 동시에 탈출을 시작한다. 하지만 우리의 결과는 서로의 '눈치를 보는' 군중을 시뮬레이션 할 수 있어, 주위의 이웃이 탈출하느냐 정지하느냐의 여부에 영향을 받는다. 또한 우리는 기존의 PEN 모델과 시뮬레이션 결과를 비교하였는데, PEN 모델은 에이전트의 크기(radius)가 디폴트 에이전트에 비해 너무 작은데 반해 우리는 비슷한 크기를 가지면서도 자연스러운 시뮬레이션 결과를 제공한다.

감 사 의 글

하나의 논문을 마무리 짓는 더딘 과정에서 인내를 가지고 저를 지켜봐주신 윤성의 교수님께 감사의 말씀을 전합니다. 대학원에 오면서 가장 오고 싶던 연구실에 오게 되어 기뻤는데, 교수님께서 연구적으로도 열심히 지도해 주셨고, 인격적으로도 뛰어난 모습을 많이 보여주셨습니다. 또한 제가 힘들어 할 때도 교수님께서 용기를 돋아 주셔서 제가 논문을 마무리 지을 수 있었습니다. 대단히 감사하게 생각합니다.

그리고 3년 가까이의 시간 동안 동고동락한 연구실 사람들을 돌아봅니다. 이 연구에 시작에 있어 많은 직관적인 도움을 주신 이정환 오빠, 항상 웃는 얼굴로 많은 가르침을 주신 김덕수 오빠, 그리고 연구의 막바지에 큰 도움을 주신 허재필 오빠, 옆자리에서 많은 도움을 줬던 Pio 오빠에게 감사를 드립니다. 지금은 영국 신사가 되어 있을 문보창오빠, 항상 바른 소리로 저를 일깨워 주신 김태준 오빠, 깊은 이야기를 많이 나누었던 김영현 오빠도 잘 지내시죠? 연구실 동기로는 같이 전산학과 탁구대회에 참여했던 김동혁군, 마음이 여리고 따뜻한 밍양이 있네요. 후배지만 같이 졸업하게 된 손명배군과 김수민양에게도 축하의 말을 전합니다. 특히 김수민 양은 마른 연구실 생활에 단비 같은 존재였습니다. 감사합니다. 앞으로 우리 연구실의 기둥으로 자라날 뛰어난 후배들도 열심히 하시길 바랍니다. 유저 스터디를 하면서 제 시뮬레이터의 문제점을 찾아준 최창민 오빠, 항상 동생들을 잘 챙기고 많은 도움을 주었던 윤웅직 오빠께 감사드립니다. 항상 저에게 어려운 서브를 주던 김태영군, 아들 삼고 싶은 권용선군, 연구실의 분위기 메이커 양현철군, 침착함과 유머러스함을 겸비한 이윤석군 모두 좋은 연구하시길 바랍니다.

끝으로 항상 기도해주시는 사랑하는 엄마, 아빠, 언니, 시부모님께 감사를 드리며 항상 의지가 되는 듬직한 김동민 남편에게 감사를 전합니다. 사랑합니다.

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