Towards an Interactionist Model of Cognizant Architecture

A sentient maze built with swarm intelligence

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Cognizant Architecture is a term used to define sentient and smart structures broadly. In this paper, an `Interactionist' model of cognizant architecture is proposed as a method of investigating the development process by inverting the conventional concept of maze design. The proposed `Cognizant Maze' aims to achieve user-architecture micro-interactions through delighting the users, presenting a physical activity equally attractive to kids and adults alike, and activating mind-enticing visual effects. Like many previous innovations, nature is what inspires us in the maze-making process. In modelling the cognizant maze, we develop the concept and workflow of prototyping a form of swarm intelligence. We are particularly interested in exploring how simulated behaviours of swarm intelligence can be manifested in a maze environment for micro-interactions to take place. Combining parametric modelling and Arduino-based physical computing, our current interactive prototyping shows how the maze and its users can `think, act and play' with each other, hence achieving an interactionist model of cognizant architecture. We reflect that the lessons learned from the Cognizant Maze experiment may lead to further development of cognizant architecture as a propagation of swarm intelligence through multi-layered micro-interactions.

Keywords: *swarm intelligence, maze design, Micro-interactions, interactive prototyping, cognizant architecture*

INTRODUCTION

Cognizant Architecture is an endeavour of designing and realising built structures that can 'think and act' for themselves. The recent technological advancements have opened up many avenues to transform architecture into sentient systems. Given this, the traditional concept of maze design is challenged in this paper by programming an interactionist model that acts in response to human movements and activities. The interactionist model introduced a new dimension to the design of labyrinths that have evolved over 4,000 years (Wilson, 2018). The social life of people nowadays consists primarily of electronically mediated relationships. Instilling any curiosity in the minds deeply linked to the digital world can only be achieved by challenging it with structures that they think for themselves (Scheer, David R. 2014).

Labyrinth generation is a process of constructing the layout of passages and walls within a maze. As an interactive puzzle, maze contains every branch of a tree in graph theory, which stands for a route out to perplex the human intellect and psyche. Since long, mazes have acted like places where players could have fun by unravelling puzzles. However, the problem lies in the fact that once solved, the interest element of a typical maze decreases to virtually zero. To conquer this flaw, the project has been developed in a way that uses a unit panel model and unites it with Artificial Intelligence (AI) techniques to create a maze that retains entertainment value like a game of chess.The challenge in achieving this design is developing a configurable system that would detect the player's movements through the maze and deploy offensive strategies to counterattack their decisions. This paper shows the three steps involved in the formation of the cognizant maze.

- Designing a simple modular labyrinth system for ease of production.
- Programming motions for various units based on swarm intelligence techniques.
- Making the entire system intelligent using Arduino techniques.

SWARM INTELLIGENCE

Joanna Kwiecie (2018) in her article describes a swarm intelligence system as: "A coordination system of a group of individuals, being a decentralised system, composed of autonomous units, is responsible for the organisation of tasks required for resolving a specific problem." This concept has been widely employed in work on artificial intelligence. The expression was introduced earlier by Gerardo Beni and Jing Wang in 1989; in the context of cellular robotic systems.

In general, swarm intelligence describes the ability of the individual members to perceive their surroundings to the overall flock behaviour. To date, substantial research on modelling swarm intelligence has been carried out, and several computational design strategies have been developed (Sebastian, W., 2016). These studies were based on replicating the collective behaviours of a group of birds, or insects or a herd of mammals working together to achieve a common objective. As shown in Figure 1, the best example of these actions is seen in the flock's evasion from a predator.

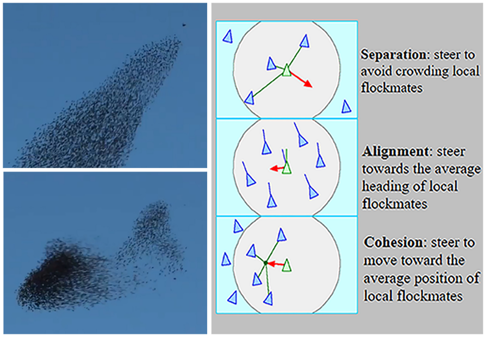


Figure 1
Behaviour of a starling swarm when a predator approaches and it's analysis.

Again, according to Kwiecie, "Most often, swarm intelligence is used to resolve the issues relating to optimisations, finding best routes, assignments, developing work schedules, task arrangement or object grouping. However, the complete natural systems seem to be reliable and fitted with the capability of adaptation to environmental changes." For this project, relationships developed during the movements have been studied, and principles learned form a baseline for the concept development. Gathering information from the immediate surrounding and transferring a stimulus based on the information through the entire flock is the simple principle used by these entities [Figure 2: Zaleshina, (2019)]. The whole phenomenon can be broken down into four simple rules:

- Following neighbor's direction of movement
- Remaining close while maintain distance from neighbor
- Acting as individual entities
- Transmitting signals in case of need.

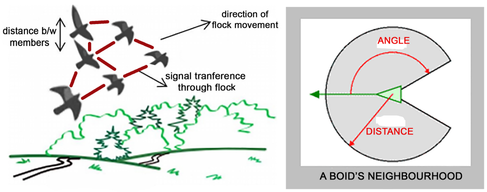


Figure 2
Boid's distances and rules.

AN INTERACTIONIST MODEL

To contextualise swarm intelligence in architecture, we adopt an Interactionist approach to modelling human-microenvironment interactions. Symbolic architectural interaction is an offshoot of architecture sociology that gives us a frame for designing a physical environment intertwined with human persons, with one potentially influencing and finding expression in the other (Ronald W. Smith, 2001). Involving computer programming in the design of spaces that interact with users is not new. In 1967, Nicholas Negroponte founded the Architecture Machine Group at MIT, a lab and a think tank whose members studied new approaches to human-computer interaction (Tristan, 2005). In the sections below, we present steps of prototyping a cognizant architecture that interacts with the player, using maze design as a testing ground.

PROTOTYPING A COGNIZANT MAZE (STEP I): PARAMETRIC MODELLING

Concept

Unlike a typical hedge maze in a park, for this sentient game, we propose a parametrically designed installation [Figure 3]. The model comprises of three main components, the support posts, the blades, and the horizontal bars that attach the blades to posts. Each blade is treated as a boid programmed to follow swarm intelligence behaviour. It not only acts independently but also assembles to execute the required objective. These blade components mimic birds that horde together like a flock, generating panels. The base form for the installation is two concentric spirals. These spirals are divided in a manner that the unit size of the blade remains constant. The number of modules in each panel depends on the height of the support posts. The panels are then divided into groups depending on the type of motion they would perform. Finally, each panel group is coded to conduct their movements. By acting in reaction to the decisions made by the person (player), the maze provides a personalised experience for each player.

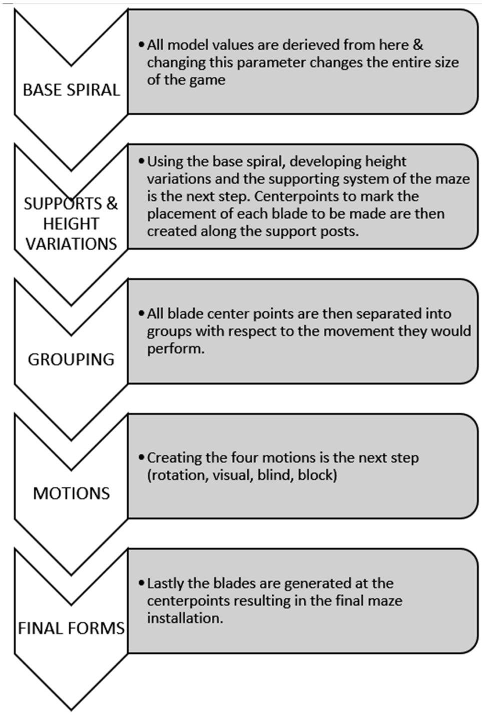


Figure 3
The parametric modular development process of the maze design.

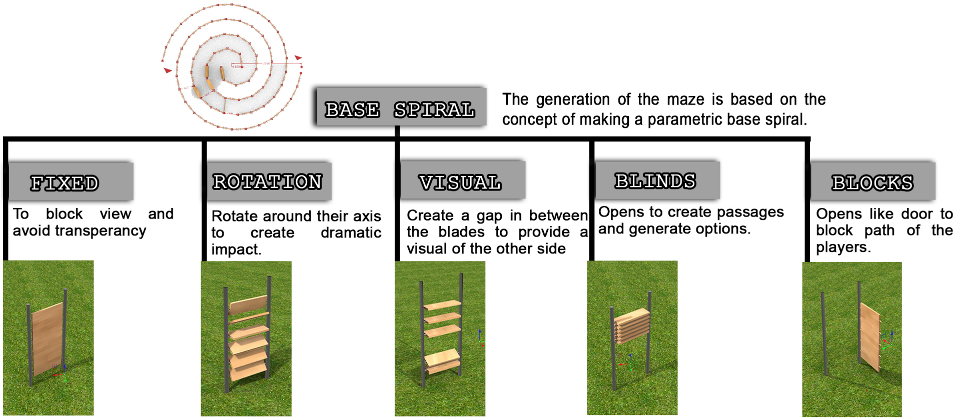


Figure 4
Implementation of five types of panels motions to the base spiral to manifest the impact of simulated swarm intelligence.

Since all blades of the labyrinth are configured with simulated swarm intelligence behaviours, each panel not only acts as a part of a stable wall to create isolation and but also senses the player's movements [Figure 4].

By calculating the individual's distances from the panels, the panel movements can be activated to operate in different ways to trap, make way or create diversions. The movements are captured by motion sensors, which are analysed to perform specific activations. As a result, the paths in the maze will be changing along with the different decisions made by each player, making it an interactive and intelligent installation.

Implementation

The movement generation in the panels is implemented by dividing into five different groups (fixed, rotation, visual, blinds and block panels) [Figure 4]. As shown in Figure 5, each group is programmed to perform a specific movement. Like birds in a flock, the panels can act independently (like the rotation, visual and fixed panels) or collaborate with others (like the blocks and the blinds). The fixed panels always stay still and maintain the mystery of the maze by creating visual blocks. The dramatic impact of swarm intelligence is created by the rotation panels when rotating randomly around their axes in response to sensed human motions. The visual panels, on the other hand, create a gap at eye level height by separating themselves into two different groups moving up and down along the vertical post. Blinds panels not only open as a door to create a new path when a player approaches them (generating options to confuse the player) but also pass the signal to the nearest block panel and activate it to block the player's path. With the five types of panels working together, the maze gains the ability to act cognitively and simulate human intelligence resulting in a dynamic and interactive game.

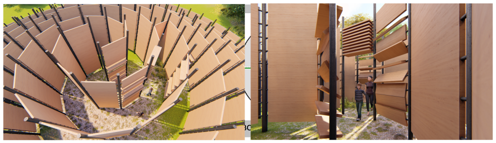


Figure 5
Panels composed of blades configured with simulated swarm intelligence behaviours reacting to people approaching.

PROTOTYPING A COGNIZANT MAZE (STEP II): VIRTUAL GAMING

Based on the parametric modelling in Step I, we develop a rule-based virtual gaming system for testing the maze's swarm intelligence behaviours. Much like evading a predator, the swarm of panels is programmed with a set of rules that lures people towards the centre of the maze using shortcuts. If the player's distance from each panel is less than the assigned value a stimulus is generated indicating the member to perform the necessary motion.

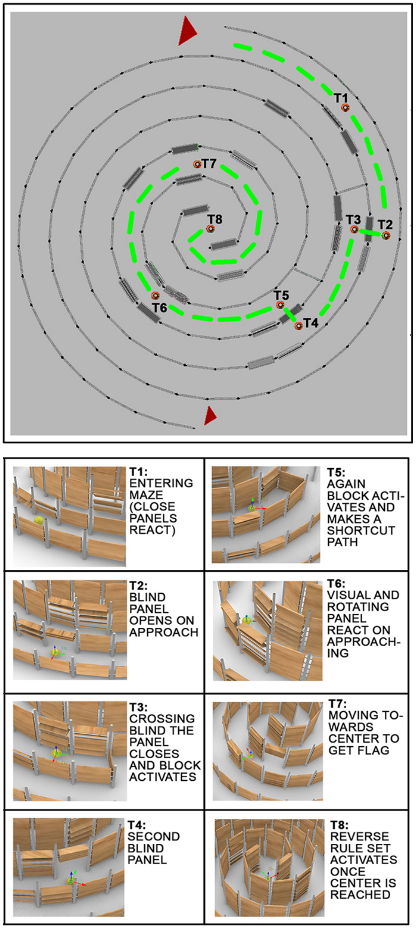


Figure 6
Shortest distance towards the center.

In some instances, the components react to the other members in the swarm to block paths and compel players to move in the desired direction as depicted in the images in Figure 6. But once the player reaches the centre, the initial set of rules are changed. Now the maze will open up misdirecting shortcuts that will loop back to the centre, making it difficult to solve the puzzle (shown in the green path in Figure 7). In this case, the player has to figure out the right way while the panels keep reacting to the player's choices to fabricate hindrances along the path. Some of the blind panels are designed to remain open for a while to allow the person to rethink their decisions. One path could be to follow the spiral without interacting with the maze (but it might not be the fastest path).

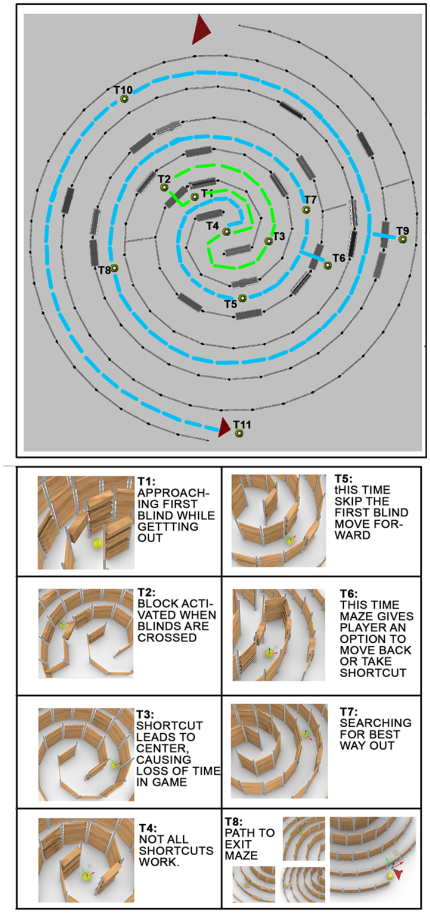


Figure 7
Looping back to center and creating misdirection when getting out of the maze.

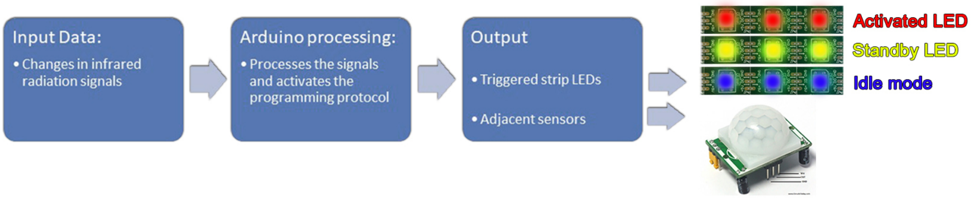


Figure 8
Arduino prototyping process and coding behaviours.

PROTOTYPING A COGNIZANT MAZE (STEP III): ARDUINO-BASED SIMULATION

Components

The third stage of the project resulted in making prototype simulation using digital design with Arduino sensor and actuator techniques to generate cognizant architecture behaviours.

To achieve this objective, we made the decision to use PIR (passive infrared) sensors in the project. Once the object in its view moves, it generates signals that can be taken as input parameters in Arduino. The PIR sensors are ideal for detecting movements. The second component used in the simulation is the programmable RGB LED strips. These are adaptable LED that can be linked to Arduino control boards to produce a wide range of colour variations. Each LED light on the strip represents one panel of the virtual maze game-[Figure 8].

Assembly & testing

The base for the prototype is a wooden disc with punctures at various points that open into the spaces below. The sensors are placed in these pits, and the depth provided helps to control the sensor's wide-angle view. This also helps to reduce the interference between adjacent PIRs. The plate is supported by the PIR cavity tunnels that have been punctured at places to allow convenient workings of the wiring connecting to the main Arduino board. The LED strips are then arranged in the form of two spirals, as shown in Figure 9.

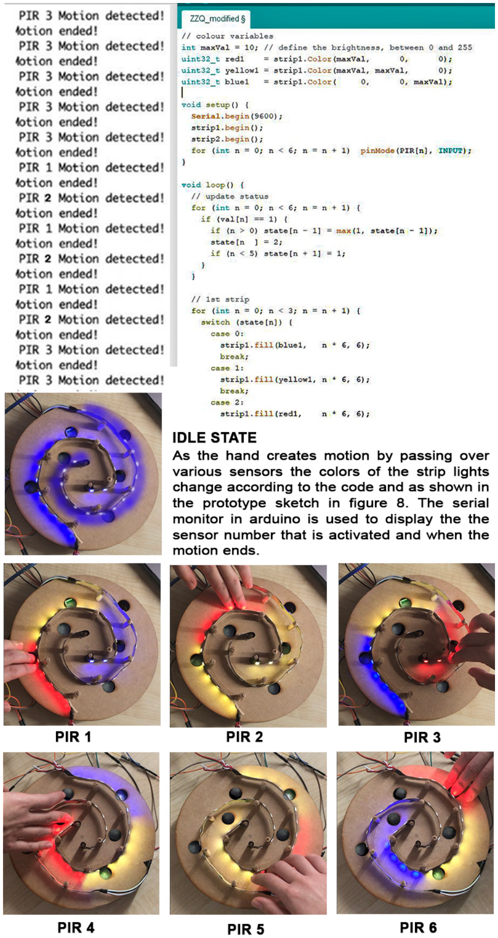
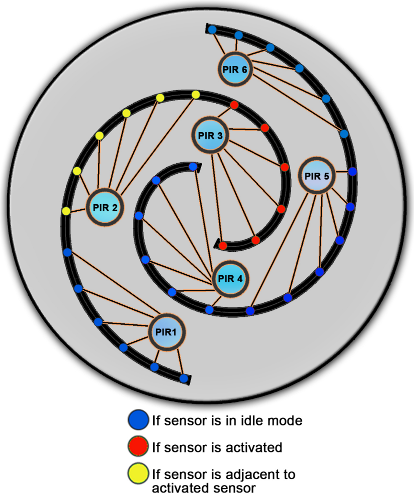


Figure 9
Assembled prototype model workings.

Figure 10
Simulation sketch.



Each motion detector is then connected to 6 RGB LED lights. Once a motion is detected by variations in infrared radiations, a signal is sent to be processed through the Arduino code [Figure 10]. It is here that the program sends signals to the 6 LEDs attached to the triggered PIR sensor to turn red (representing an activated state). Like the transference of stimulus through the body of a swarm of birds, a warning signal is sent to the neighbouring sensors. As a result, they trigger the lights attached to them to turn yellow (standby state). Through Arduino programming, the person's exact location in the maze can be pinpointed, and the panels closest to the person can react while the adjacent panels are also activated accordingly. In this way, the labyrinth reacts cognitively to the decisions made by the player.

CONCLUSION

In this paper, we have demonstrated how swarm intelligence observed in nature can be applied in the design of a cognizant maze that may delight the human psyche and intellect. The depth and complexity of a typical maze are enhanced by tracking the individual's movements and the cognizant ability of each Boid. We show a model of cognitive & responsive architectural components that can adapt to changing patterns of user decisions. The modular algorithm implemented allows maze design to produce a variety of sizes in the most simplified manner, as shown in the on-site rendering of a medium-sized maze in Figure 11 and 12.

The swarm of panels developed thus far interact with the players through their movements. Further progress in this direction would involve learning from the player's action and deploying responsive strategies accordingly. It should be noted that the design developed until now is based on a modular unit that can only perform one type of motion. But, the panel design can be evolved to perform the five different movements depending on the situation. By doing so, the maze's cognizant abilities can be significantly enhanced, resulting in more choices for each decision made by the player.

Based on the algorithms developed for the Cognizant Maze, it would be interesting to see real-time swarm intelligence in action. For example, generating a louvred facade system that makes use of weather sensors and the Internet of Thing (IoT) to intelligently maintain comfortable interiors, or creating efficient evacuation routes in a building by propagating detected stimulus through a swarm of opening/closing building components. There could be many other applications of this remarkable natural phenomenon.

Figure 11
Rendering of a medium-sized maze in a park setting.

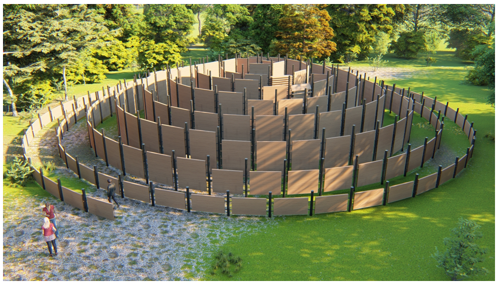


Figure 12
Eye-level view of the maze in the park setting.

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