An Hybrid Algorithm to Simulate Mice Following Residential Walls

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Abstract: Commensal rodents such as mice that live in the proximity of human are well-known pests that can transmit diseases to man. An agent-based model is presented to formalize the spread of rodents in human habitations. We focus in this paper on the specific behaviour of mice consisting in walking along the walls (thigmotaxis). In order to simulate this behaviour we combine a cognitive architecture with an algorithm simulating rodents' moves following residential walls. The cognitive model and the 'wall following' algorithm developed are successively described. Simulation configurations are tested to evaluate the robustness of the 'wall following' algorithm alone. In a data poor context this simple combined algorithm, using a discrete space, fulfils the basic needs to simulate a plausible mouse activity, towards a detailed representation of mice moves within a fluctuating environment.

1 INTRODUCTION

Commensal rodents that live in proximity to humans are most often reservoirs of bacteria and viruses that can be transmitted and cause epidemics. In epidemiology, new approaches known as Eco-Health (Lisitza and Wolbring, 2018) or One-Health (Mencke, 2013) suggest considering the whole set of factors likely to facilitate the transmission of diseases to humans. Among these factors, the risk of human-to-rodent contact is a key to the possible triggering or not of a zoonotic epidemic. However, data are not or are scarcely available about the details of rodent fine behaviour in human habitats. In this context, simulation tools may help providing a first image of what could really be ongoing in the field.
Commensal rodents like domestic mice live in human-inhabited areas where access to shelter and food is ensured. This preference however leads them to live in very dynamic and at the same time dangerous environments. Commensal rodents have thus developed survival behaviours such as staying close to their nest, move in covered areas, avoid empty spaces, increase their activity during calm hours and, particularly, walk along the walls.

This way of moving along vertical surfaces and avoid open habitats keep them in a relatively comfortable area with lower predation risk (Jensen, 2003). For this purpose they use their whiskers as tactile sensors which enable them to stay permanently in contact with walls (Meyer *et al*, 2005), an ability known as thigmotaxis (Reid, 2005).

This study is a first step to simulate mice movements in a complex residential environment. It aims to account in a simple way for this foraging or wandering particular behaviour by combining in simulated agents a reactive "wall following" algorithm with a cognitive search behaviour. The latter is used to make mice agents interact with items of interest such as food, relatives, predators, shelter, etc.

This article is first devoted to the presentation of existing methods that could be used to implement a "wall following" behaviour in a simulation context as well as the perspectives offered by using hybrid modelling. We then describe the general model of cognitive behaviour along with the reactive "wall following" algorithm plugged in this model. The robustness of the algorithm is then tested using different space configurations. The results obtained and the validity of the model are finally discussed in the light of existing knowledge.

2 RELATED WORKS

2.1 Wall Following Algorithms

Exploring an unknown environment, avoiding ob-

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stacles met in a path or reaching targeted point objectives are common problems in simulation modelling of agents living in an unknown environment. According to Mishra and Bande (2008), wall following algorithm is one of several navigating algorithm that simplifies the issue of autonomous movement of agents in their environment. In this field Lin *et al.* (2018) proposed a behaviour-based fuzzy controller (BFC) to implement mobile robot wall-following control. To detect the corners and edges Nepali *et al* (2014) proposed a wall-following algorithm using laser range finder. Purbarani *et al.* (2015) also proposed a wall following algorithm on fire-fighting robot using V-Rep ultrasonic sensors. To achieve an adaptive controller for wall following mode, (Lin *et al.*, 2017) proposed an efficient recurrent fuzzy cerebellar model articulation controller based on dynamic group artificial bee colony. Agiriga (2011) also proposed a simple and efficient model to avoid wall obstacles using Finite State Machine logic (Gill, 1962). In the bio-inspired robotics domain, thagmotaxis has been also explored in depth during the building of the psikharpat robot (Meyer *et al.*, 2005). This model provides a sophisticated behaviour using for example strategies meta-controllers of several navigation routes (Caluwaerts *et al.*, 2012) established by the robot. The latter shows the importance of using various strategies for a rat robot operating in a complex environment.

2.2 Hybrid Architectures

Agent-based model architectures are commonly based on either a *(i)* reactive, a *(ii)* cognitive approach (Ferber 1999) or *(iii)* a combination of both to formalize agents' actions.

In the first one, agents react in response to internal or external influence following simple "Stimulus - Response" schemes. Reactive architectures possess several advantages such as simplicity, computational tractability, robustness against failure (Komma, 2011). However, in this type of architecture agents cannot learn from their experience to improve their performance over time nor select the appropriate reaction when stimuli are diverse. Cognitive architectures however allow agents to elaborate adapted decision based on their relationships with a composite environment (Ye, 2018). These architectures permit to describe world objects, their state and properties, elements of know-how, or meta-knowledge (Müller, 2002). On the other side, the cognitive approach aims to break down complex problems into sub-problems, in order to reduce their complexity, to treat them separately and combine their results. However like the reactive architecture, it presents some disadvantages such as complexity and heaviness of algorithms needed to face the unforeseen of real world but also the simplicity of some problems.

To tackle with these issues several works used hybrid architecture for implementing their models. Faghihi (2011) propose a Conscious Emotional Learning Tutoring System (CELTS) for introduction of transfer learning and memory with analogical information. The Simulation of the Mental Apparatus and Applications (SiMA) in (Schaat *et al*, 2015), tends to create plausible and reasonable motivation in human decision and behaviour. Connectionist Learning with Adaptive Rule Induction Online (CLARION) in (Sun *et al.*, 1999) is a popular hybrid architecture that aims to incorporate most cognitive aspects that distinguishes abstract and concrete knowledge, where concrete knowledge is easier to obtain and gets more attention than the abstract one.

To formalize a realistic overall behaviour of mice wandering in habitations we therefore investigated and developed an agent-based hybrid architecture mixing reactive and cognitive behaviours and focusing on the ability of these commensal rodents to simultaneously *(i)* follow wall and *(ii)* interact with things of interest perceived around them (partner, food, children, shelter, etc.).

3 MODEL DESCRIPTION

The 'wall following' algorithm is integrated within a general model described in Le Fur *et al.* (2017) and coded in Java using the Repast Simphony Platform (North *et al,* 2005).

Within this section we first present concepts and modelling considerations required to formalize the world of commensal rodent foraging using cognitive interaction with relatives and their passive environment. We then describe the rodent agents reacting to wall obstacles using the wall following algorithm.

3.1 General Cognitive Model

In this section we follow a simplified version of the Overview, Design concept and Details (ODD) protocol proposed by Grimm *et al* (2006) for describing agent-based models. According to this scheme, an overview is first presented, explaining the purpose of the model, the state variables and scales and finally its process scheduling; the design concepts are then described.

3.1.1 Purpose

This simulation model aims to explore commensal rodent spread within an urban habitat. It particularly focuses on the behaviour ability of rodents to forage and explore habitations using cognitive search behaviour to interact with items of interest whether attractive (*e.g.,* food, nests, relatives) or repulsive (*e.g.,* cats, humans) in their surroundings.

3.1.2 State Variables and Scales

Two categories of object classes are defined in the model: one formalizing the simulated world topology and one describing the commensal rodent. A supplementary class describing the biological characteristics of the species is also implemented.

Habitat Units: city or village habitat is formalized using two types of space, connected by conversion factors. The first is a continuous Euclidian two-dimensional space coded in meter units. It is used to locate agents, express perception of their surroundings and precisely compute their moves. In the second type of space, the simulated domain is discretized using a matrix of square soil cells (raster space). Each cell is characterized by a value describing its nature and the degree of affinity of a rodent for this type of cell (wall, room, shop, enclosure, etc.). Cells can support several rodents and things (*e.g.,* humans, cats, vehicles, nests, etc.).

In the model's implementation presented, the simulated domain is discretized into a matrix of soil cells of 1m × 1m sizes that is compatible with the rodents perception and action scale.

The temporal scale is configurable in seconds, minutes or hours even during the simulation (Le Fur and Sall, 2018).

Rodent Agents: Each rodent agent of the model is characterized with a unique ID, sex, birth date; its location in the grid, perception radius of surroundings without obstacle, mean daily speed, mortality risk, age at sexual maturity (different for males and females), mating period, litter size, gestation length, anoestrus duration and genetic profile (value of the allele at each gene locus). It also has characteristics that vary over time, such as age, physiological status (maturity, pregnancy, and readiness to mate) and geographic location. Rodent agents are mobile; they can move in the landscape and therefore have to account for a changing surrounding.

3.1.3 Process Overview and Scheduling

Commensal rodent agents are created either at initialization or when a pregnant female spawns. They are placed in the model' context and thus connected with other objects and agents.

Time is formalized as discrete steps. Rodent agents are triggered asynchronously at each time step in an order defined by their internal ID numbers following the scheme described on Figure 1.

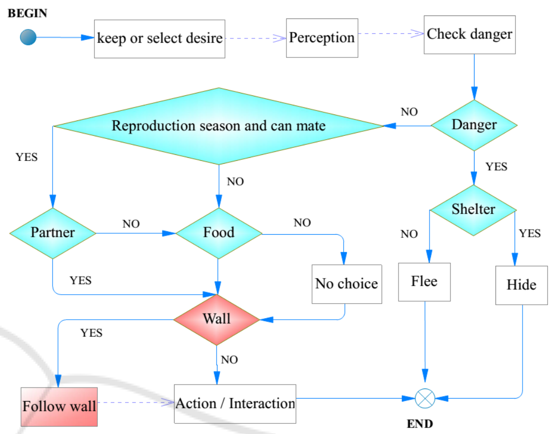

Figure 1: Simplified diagram of rodent agent activity at each step. The nature of the Action/Interaction process depends on the desire and target selected. Red shapes correspond to the reactive architecture added to the general model and describe in section 3.2.

3.1.4 Design Concepts

Basic Principle: Cognitive agents operate within their environment using a scheme derived from *(i)* PDE (perception / deliberation / execution; *e.g.,* Macia Perez *et al.*, 2014) and *(ii)* BDI (Belief/Desire/Intention'; *e.g.,* Caillou *et al.*, 2015) behavioural schemes (Le Fur and Sall, 2018).

Current desire ('reproduction', 'suckling', 'spawning', 'foraging', 'none') is first selected by the agent depending on its physiological status. It then proceeds to perception of its environment. Desire can here change into 'flee' or 'hide' if danger is detected. Then, given the selected desire, the agent chooses the most appropriate environment item to interact with (deliberation) among the alternatives corresponding to its desire. Once selected, the choice is converted into a target (decision) and the next move is computed (action).

Sensing: Rodent agents have a perception area encompassing object or agent within a circle defined by a parameterized radius. The perception area moves with the agent and is calculated precisely from the continuous space coordinates.

<u>Fitness</u>: Rodent agents' activity is driven by three basic needs. The first is feeding, which is modelled on the basis of optimal foraging in a patchy environment (MacArthur and Pianka, 1966). The second driving force is the need to maximize reproduction rates which is formalized by systematic attempts at mating whenever a rodent encounters a receptive (in terms of reproduction season, maturity, etc.) individual of the opposite sex. The agent's third motivation is the need to remain as unnoticed as possible when wandering, which is a key to its survival. This led to the addition of the 'wall following' algorithm.

3.2 Wall Following Algorithm

In order to formalize this behaviour, we implemented an algorithm composed of three component parts: *(i)* modification of sensing to exclude perceived objects hidden by walls, *(ii)* a process for reaching the closest wall without entering in it and *(iii)* a process for following the chosen wall according to the direction (e.g., target position) selected by the agent.

3.2.1 Filtering Perceived Objects

In the general model, agent perceive object within its sensing disc area even if objects are beyond a wall. We therefore introduced a filtering procedure that scans all perceived objects and removes them from the perceived objects' list when a wall is detected between the agent and the target.

3.2.2 Reaching Closest Wall

When aiming to any target, mice agents are here also due to search for the closest wall and follow it to perform their moves. For this purpose they follow the general scheme described in Figure 2.

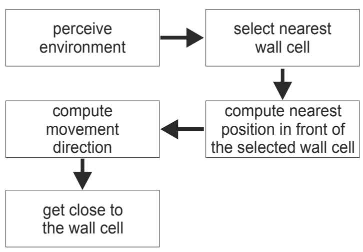

Figure 2: Sub-models involved in the process of reaching the nearest wall.

The sub-model **"compute nearest position"** is used by the agent to avoid positioning itself within the wall cell. To do so, agent selects the interest cell just before the selected wall cell.

In order to "**compute movement direction**", the agent records the vector formed by its position and the nearest position targeted in front of wall cell.

3.2.3 Wall Following

Once in front of the wall, the agent tries to skirt it by choosing to go on its right or left. The notation used for this computation is as described on Figure 3.

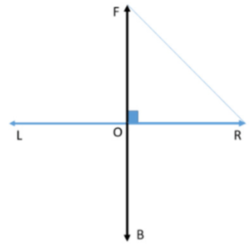

Figure 3: Representation of agent direction F(front), R(right), L(left), B(back) and O(its current position).

For this purpose, the agent computes its new right and left position using the perpendicular vectors

$$\overrightarrow{OR}\binom{xR-xO}{yR-yO} \text{ and } \overrightarrow{OF}\binom{xF-xO}{yF-yO}.$$

The Pythagorean Theorem and vector product leads to:

$$\begin{cases} RF^2 = OR^2 + OF^2 \\ \overrightarrow{OR}.\overrightarrow{OF} = ||\overrightarrow{OR}||.||\overrightarrow{OF}||.\cos(\widehat{\overrightarrow{OR},\overrightarrow{OF}}) \end{cases}$$

The right point R is then given by:

$$\begin{cases} xR = yO + \dfrac{N2}{N1}(xF - xO) \\ yR = xO - \dfrac{N2}{N1}(yF - yO) \end{cases}$$

and the left point L with :

$$\begin{cases} xL = yO - \dfrac{N2}{N1}(xF - xO) \\ yL = xO + \dfrac{N2}{N1}(yF - yO) \end{cases}$$

using N1 norm of the $\overrightarrow{OF}$ and N2 norm of $\overrightarrow{OR}$.
The agent then starts to follow the wall according to the scheme described in Figure 4.

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If wall position is forward then
Flag = random choose left or right
If Flag equals right then
If **can go right** then: **select right aim**
Else If **can go back** then: **select back aim**
Else **select left aim**
Else If **can go left** then: **select left aim**
Else If **can go back** then: **select back aim**
Else **select right aim**
Else If wall position is right then
If **can go forward** then: **select forward aim**
Else If **can go left** then: **select left aim**
Else **select back aim**
Else If wall position is left then
If **can go forward** then: **select forward aim**
Else If **can go right** then: **select right aim**
Else **select back aim**

Figure 4: Pseudo code for agent following the wall according to its current direction (bold: sub-models not detailed here).

At each step agent records its chosen aim and recompute the new left, right, front and back according to its new position.

4 RESULTS

We present in this section the simulation results of *(i)* mice reactive behaviour in wall following algorithm and *(ii)* the combination of this behaviour with cognitive behaviour.

4.1 'Wall Following' Algorithm Robustness

To test the robustness of the 'wall following' algorithm alone we used it in various space configurations as presented on Figure 5. Using the algorithm, agents proved able to enter and come out of a dead end corridor without traversing walls or entering wall cells. The second configuration confirmed that the scheme described in Figure 5 was also efficient to deal with the grid limits where one out of the four directions is set to null. Finally a simulated maze provided an overall satisfactory displacement of agents whatever the walls configuration.

4.2 Reactive and Cognitive Behaviours Combination

A second series of simulations was performed to evaluate the realism of the hybrid algorithm. To this end, we simulated an experimental concrete enclosure and let agents evolve there. Only one cognitive behaviour was selected for the test that is the encounter and mating process between relatives. These simulation results were then presented to a biologist specialized in these rodents (Granjon, L., pers. comm. 2019). In the sequence (Figure 6) figured to the expert: *a)* female slides along the upper wall while male turn around a concrete block, *b)* male perceives its relatives and aims toward it, *c)* mating

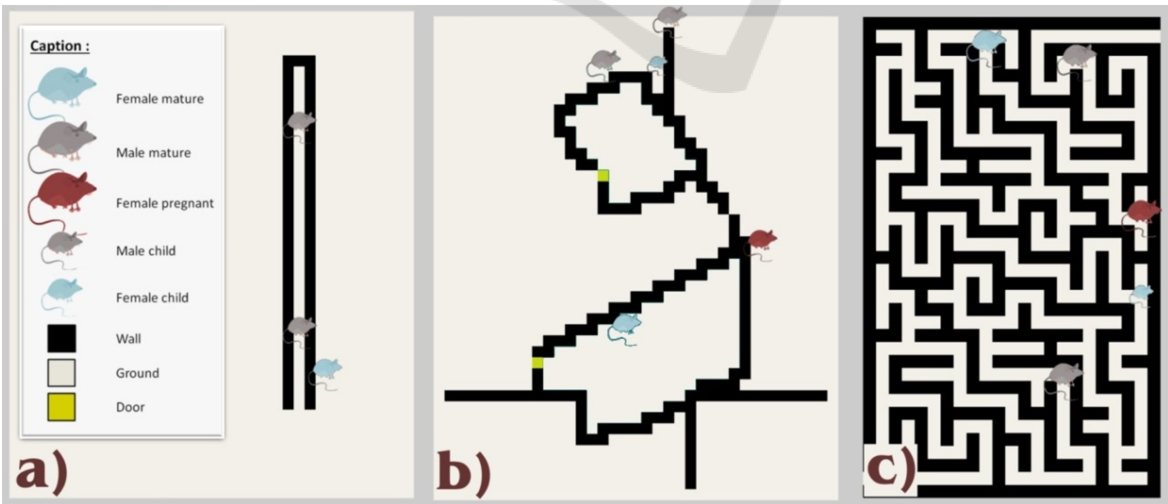

Figure 5: Three space configurations used to test the 'wall following' algorithm: *a)* dead end corridor. *b)* Domain extended in the four directions minus one cell at the grid limit. *c)* Agents moving about in a simulated maze. For better rendering, a dynamic representation of the simulation has been also uploaded on Youtube™ and is available at https://youtu.be/z5oS8elHD34.

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occurs then both agents switch back to wall following *d)* rodent agents follow separate routes.

The biologist concluded to an overall satisfactory rendering with the main characteristics to be taken into account effectively expressed in the simulation: basic foraging behaviour making use of thigmotaxis as well as correct transition to mating behaviour at the occurrence of a potential partner.

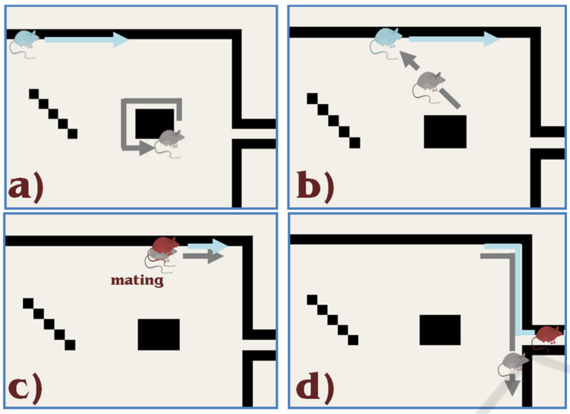

Figure 6: Simulation result (detail) of the combination of ‘wall following’ algorithm with the cognitive architecture using a simulated experimental enclosure (see text for sequence description). Same caption used as on Figure 5. The simulated space in its entirety is featured on the Youtube™ video. (*ibid.).*

5 DISCUSSION

The model developed here attempts to reproduce rough mice behaviour in a residential habitat taking into account their propensity to move along wall. Using the hybrid architecture proposed, mice agents are hence able to fulfil their three basic needs, *i.e.*, feeding, reproducing and discrete wandering along walls. Despite the mechanical computation used by the agents, the ‘wall following’ algorithm proposed cannot be considered as a genuine reactive architecture since the process described implies that rodents perceive the walls topology in their surroundings, that is a cognitive process. However, the ‘wall following’ algorithm enables rodent agents to explore their environment and follow walls without needing a target.

The formalism used to represent space raises the question of the grid resolution to be used. The cell size scale chosen (1x1m) is suitable to formalize and follow mice agents’ moves. However it may be inadequate to formalize some components of the environment (e.g., walls are at least one meter thick that is unrealistic).

Given its simplicity, the algorithm has to be overloaded with several patches to account for particular constraints:

1. To prevent agents from entering the walls, agents have to target free cells contiguous to wall cells.
2. To account for walls as obstacles for sensing, agents' perception has to be filtered from invisible items beyond walls
3. To account for the simulated grid limits for which one direction (left, right, front, back) is missing, conditional tests have to be included in the algorithm
4. To avoid infinite loops in which agents endlessly leave and return to the cell they just left, a direction of movement has to be included in the scheme.

The alternative modelling approaches described in section 2 appear accurate and adapted to their specific questions. They make use of various sophisticated sensors and mechanisms to formalize moves within a continuous environment. The method proposed in this work results however in a model based on a simple scheme mixing geometric calculations and directional orientation within a discrete space. It has been easily plugged with the general cognitive behaviour architecture.

In a 2-D grid representation as it is used here, the approach based on the concept of Finite State Machine applied in Agiriga (2011) model could also be used. This method allows rodents to easily follow a given direction and avoid vertical obstacles. However, this method may not be relevant in large study area like an entire city.

6 CONCLUSION

As a perspective, this algorithm can satisfactorily fulfil the needs for a plausible simulation of mice moves. It has to be embedded in a simulation model encompassing a richer context including cats’ moves, human activity rhythms, for more realistic simulations. Encapsulating this model into a more composite framework may there be straightforward, thanks to its parsimony or simplicity.

At this position of this work and within a data poor environment, the model can also be used as a simulation tool helping to prepare the design of accurate field protocols to tackle the question of mice wandering in actual households.

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