Pheromander: Real-time Strategy with Digital Pheromones

Simon Kerler, Johannes Vilsmeier, Sarah Edenhofer and Sebastian von Mammen
Organic Computing Group
Augsburg University
simon_kerler@web.de, johannes.alexander.vilsmeier@student.uni-augsburg.de,
{sarah.edenhofer, sebastian.von.mammen}@informatik.uni-augsburg.de

***Abstract*—Human-swarm interaction is a recent research topic on how human operators can support a swarm of semi-autonomous agents fulfilling certain tasks, like foraging or combat missions. In this paper, a serious game simulating a swarm of 50-250 ant-like agents is presented which have to collect resources and fight enemies. Digital pheromones (virtual chemical signals that diffuse over time) are used for their indirect communication. A mouse-based human-swarm interface is presented which allows players to interact with its agents by placing pheromones by clicking on the map. Wrapping the interface into a game allowed to develop and test it without requiring actual swarm hardware, to engage and motivate the user as well as to provide objective usability measures (e.g. awarding points for collected resources). The goal of the game is to convey the functioning of pheromone based swarms (e.g. temporal and spatial emergence) and to train players in using the human-swarm interface efficiently. Being a complex topic, the visualisation of the simulation and the GUI have been designed with usability and user experience in mind.**

A user study has been performed to evaluate the effectiveness of the simulation as well as usability and user experience. The results revealed that the users efficiency increased over time, proving that the presented pheromone based interface can be used to instruct swarms, and its usage can be conveyed by the presented application.

***Index Terms*—human-swarm interaction, digital pheromones, swarms, multi-agent systems, interactive simulation**

I. Introduction

In human-swarm interaction, a human operator is in control of a swarm of agents (robots, drones, etc.). These agents semi-autonomously perform certain tasks, e.g. foraging information [1] or combat missions [2]. One real world example for such systems are ants. They are able to coordinate foraging solely based on local information, without direct communication between each other and without centralised control [2]–[4]. Instead, ants guide fellow individuals in the direction of food locations by emitting pheromones (chemical signals that diffuse over time) and thus typical ant trails emerge.

In contrast to human-robot interaction where a human controls only a single agent, controlling a swarm is considerably more complicated. Therefore, new ways of interaction and representing the system status (so called human-swarm interfaces) have to be developed [1]. But it is not only necessary to develop these methodologies but also to convey them to the user. For this reason, this paper presents a serious game called *Pheromander*[1] which has been implemented in Unity3D. It simulates a colony of 50-250 ant-like agents the user is in charge of. The game mechanics follow those of real-time strategy (RTS) games like "Age of Empires": The player has to collect resources, create new agents and fight against enemies. To focus on the aspect of pheromones, these concepts have been reduced to the essential: there is only one type of resource and there are no human or AI competitors. The player is motivated to rerun the simulation trying to collect more resources. Most RTS games have direct controls to command units. In contrast, the interaction methodology of Pheromander consists of a mouse-based human-swarm interface using a vocabulary of digital pheromones to which agents react. A set of agent and pheromone parameters are exposed to the user as well so he can experiment with different configurations and understand how they influence agent performance. Wrapping the human-swarm interface into a game allowed to develop and test it without requiring actual swarm hardware, to engage and motivate the user as well as to provide objective usability measures (e.g. awarding points for collected resources). The intention of the simulation is to convey how pheromone based swarms work, teach spatial and temporal effects of pheromones and to train players in using the human-swarm interface efficiently. Being mainly an educational application, great care has been taken when designing the user interface and graphical representation of the simulation attempting to increase usability and user experience.

The remainder of this paper is structured as follows. Section II states related work about pheromone based simulations as well as human-swarm interaction. Section III explains the simulation and its models whereas Section IV covers user interaction. Measures to achieve good usability and user experience are discussed in Section V. A user study has been performed to reveal whether all of the aforementioned goals have been achieved. It confirmed that the user interface for human-swarm interaction introduced by Pheromander works and players can successfully utilise digital pheromones to guide swarms. The results are discussed in detail in Section VI. The paper is concluded by discussing the simulation and outlining future work in Section VII.

[1] https://pheromander.github.io

II. Related Work

There are many publications targeting the implementation of pheromone based agent systems. Some of the ideas integrated into the simulation are component based agents [4], [5], pheromone vocabularies and potential fields formed by pheromones [2]. The ant-like behaviour of the agents was inspired by [2]–[4], [6].

SimAnt [7] is a video game simulating an ant colony with direct user control. The user can select any of his ants, instruct it to move to a specific location and order it to deposit pheromones to which other members of his colony.

NetLogo Ants [8] also simulates an ant colony. Instead of direct control, the user can change the population size as well as diffusion and evaporation of pheromones. Pheromander follows the same basic principles but includes additional interaction possibilities like manually placing pheromones or influencing pheromone perception of agents.

Concerning different swarm interaction methodologies, [1] evaluates selection and beacon based interaction where agents can be instructed directly by a marquee or by placing beacons with limited range influencing all agents within its radius. In [9], control mechanisms for swarms of unmanned aerial vehicles (UAVs) are evaluated. UAVs communicate with each other via pheromones, whereas the human operator instruct them directly by selection or by influencing their decision making. In contrast, users of Pheromander control agents by placing pheromones or adjusting agent/pheormone configurations. Additionally, [9] states some issues related to representing the state of a swarm. Pheromander has been designed with these problems in mind.

III. Simulation and Models

The simulation takes place on a spatially limited map populated by gameplay objects depicted in Figure 1. The last element which is not included in this figure are pheromones.

Fig. 1: Gameplay elements encountered on the map. From top left to bottom right: The base, an agent, a resource and an enemy.

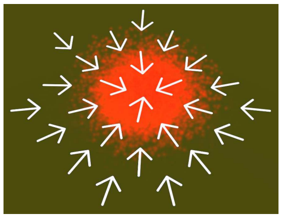
Each pheromone has a set of parameters, most notably its type (harvest, combat and repellent), initial intensity, diffusion rate and minimum concentration (similar to [10]). The latter three can be modified by the user. The area in which the scent can be perceived is modelled by a sphere (in contrast to discrete environments [2]). Diffusion has been implemented by scaling this sphere depending on the diffusion rate and elapsed time. The current concentration within the diffusion sphere is periodically recalculated to match the diffusion of real pheromones. If the current concentration falls below a threshold, this pheromone has evaporated and is removed from the simulation. For visualisation, pheromones are rendered as particle systems occupying the diffusion sphere. Colours are used to show the type of pheromone: green (harvest), red (combat) and blue (repellent). Another way to visualize pheromones is the gradient field visualiser inspired by [2], [4] which displays arrows pointing towards the area of highest pheromone concentration (see Figure 2(a)).

The base is located at the center of the map and is the place where agents spawn and resources are stored. Agents can have one out of two different tasks indicated by the colour of their "snout": harvest resources (green) and combat enemies (red). Trying to fulfil their duties, they move around randomly. If a pheromone matching the agent's task is perceived, it starts to move along the odour trail. By differentiating the reaction to pheromones based on their tasks, the user has more fine-grained control over his agents. Independent of its task, if an agent scents repellent pheromones, it tries to back off and not cross the line. Agents have a pheromone preception limited in range and angle which are both configurable by the user. A user can click on an agent to get additional information like pheromone perception details or attack range (see Figure 2(b)). After finding a resource, harvesting agents start to collect them and take them home. Similar to some ant species which orient themselves by the sun, agents always know the location of their base. On their way back, harvest pheromones are emitted to guide fellow harvesters towards the resource. Resources have only a limited capacity and are removed from the simulation when this number reaches zero. If a combating agent comes across an enemy, it attacks the foe while calling for support by emitting combat pheromones. Enemies are stationary entities without sophisticated AI. Instead they simply attack agents and try to kill them when they are within attack range.

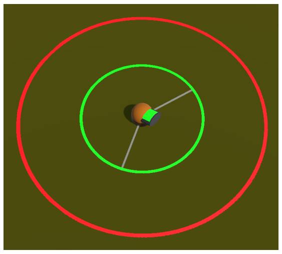
IV. User Interaction

There are three game modes available: tutorial, challenge and simulation. The tutorial provides beginners with an introduction on how to play. In challenge mode, the user has to collect as many resources as possible within a five minute period. For each resource deposited by an agent at the base, a point is awarded. The resulting score quantifies the agents' and thus the player's performance. Simulation mode focuses on experimentation and provides the user with additional tools which allow to create new resource spots and deploy new enemies so users can test different scenarios.

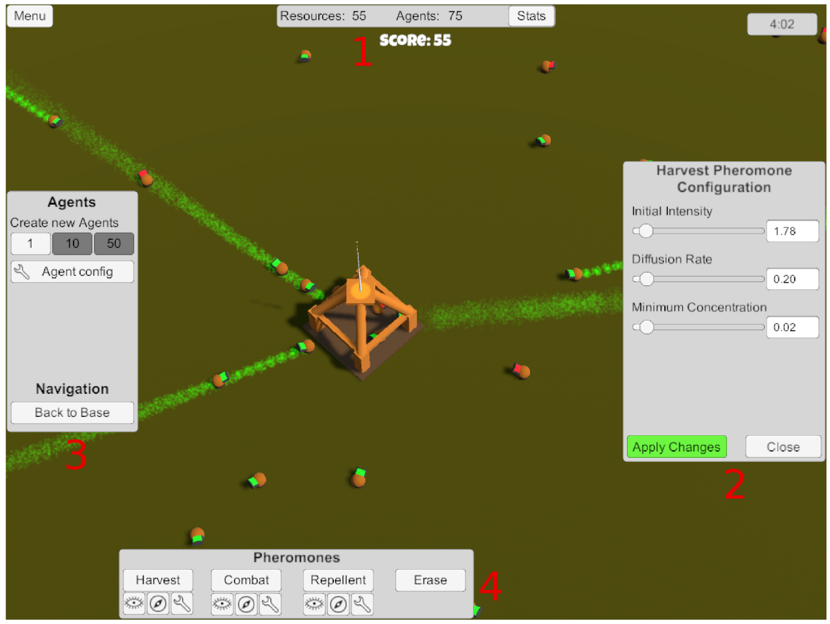
Figure 2(c) depicts the ingame view presented to the user. It consists of a visualisation of the simulation's system status framed by the GUI. The top bar (1) shows the amount of collected resources and the size of the current agent population. By clicking the "Stats" button, simulation statistics are shown in the panel on the right (2). These include the number of resources harvested per minute, how many agents died, how many enemies were killed etc., so the player can determine how to improve his play style. The context sensitive sidebar also includes views for details of selected agents, resources



(a) Gradient field visualiser: Arrows point towards highest pheromone concentration.



(b) Agent's pheromone perception range (green) and angle (gray lines) and maximum attack range (red)



(c) Ingame screenshot of the simulation with GUI and models. Green particles are harvest pheromones. (Red numbers are only references and not part of the GUI.)

Fig. 2: Screenshots depicting visualisations of the simulation.

and enemies as well as configuration dialogues for agents and pheromones. The bar on the left (3) contains a set of distinct functions. Here, the user can create new agents by spending a certain number of collected resources. Note that spending resources does not decrease the player's score in challenge mode. Clicking the "Agent config" button reveals the agent configuration dialogue in the sidebar in which the pheromone perception range and angle as well as pheromone emission rate can be changed. The last button in the left bar resets the camera to the base.

Pheromone related controls are located in the bottom bar (4). Enabling one of the labelled buttons, the player can place according pheromones by pressing the left mouse button on the map and dragging the mouse. Pheromones are placed under the cursor in a fixed rate resulting in a pheromone trail being drawn. Similarly, existing ones are removed when the "Erase" button is activated. The three buttons below the pheromones' names allow to (a) toggle its respective visibility, (b) show its gradient field around the mouse pointer, and (c) configure its properties. For the latter, a configuration dialogue appears in the sidebar in which the initial intensity, diffusion rate and minimum concentration threshold can be altered. It is also possible to reassign an agent's task by holding the "shift" key and clicking the agent while either harvest or combat pheromones are activated.

V. Usability and User Experience

To achieve good usability, it was attempted to design the user interaction in a clean way that can be understood easily. Concerning the GUI, Gestalt Laws and icons have been used where possible trying to make it more intuitive. Being a complex topic, it is important to provide good interaction guidance. For this reason, tool tips have been added to almost all GUI components so the user always knows which functionality is hidden behind an unknown button. Most vital for very beginners is the tutorial which introduces the most important gameplay elements and interaction possibilities.

The user has to be motivated to interact with the simulation to try different strategies and to experiment with different configurations. One important aspect is a clear representation of the simulation state and its world [9]. For this reason, abstract models have been created for all gameplay elements. This helps the user to concentrate more on understanding pheromone based systems than a concrete simulation of, for example, an ant colony could achieve. By providing constant feedback via the statistics menu or the score display in challenge mode, the player is motivated to rerun the simulation trying different strategies and configurations to achieve better results (gamification). The indirect control mechanism using pheromones is a variation to many strategy games leading to a unique user experience. Enemies are used to increase the difficulty of the simulation and to challenge the user.

VI. User Study

An anonymous user study among 20 persons (recruited via personal e-mails) has been performed to validate whether Pheromander can be used to (a) convey the concept of pheromone based systems, (b) train the user to interact with those systems and (c) measure whether the game realises a high degree usability and provides a positive user experience. The user study involved the following steps for each user which they performed at home (i.e. without supervision by the authors): (1) Download the binary of the game, (2) play the tutorial, (3) play the challenge mode three times and (4) fill out an online questionnaire. During challenge mode a set of parameters is logged for each run, most notably the time and the player's score which is calculated as explained at the beginning of Section IV. The log file was appended to the questionnaire. The questionnaire itself covered 20 questions consisting of eight five-level Likert items, two yes/no questions and ten open questions for feedback in written form. Note that discussing all open questions in detail is out of scope of this paper and only the most important information are stated where necessary.

To begin with, participants were asked how much they felt they knew about pheromones and the extent of conveyed information about pheromones during the game. The answers revealed, that 45% of the users knew at most "little" about pheromones. 30% of the users stated their knowledge at least with "good" and 25% answered with "moderate". When asked about the game's success in conveying knowledge about pheromones, 10% answered with "moderate", 60% with "good" and 30% with "very good". From these results it is inferred that the users had the impression that the game fulfils requirement (a), i.e. Pheromander conveys knowledge about pheromones.

In order to determine whether the simulation achieved goal (b) and was able to train the users in utilising a pheromone based human-swarm interface, the users' performances during challenge mode trials were evaluated. Note that some users did not play the challenge mode three times as requested, but two or four times. To this end, the achieved scores after the first and the last trial in challenge mode were compared. The mean value of the achieved scores after the first run was 458.7, after the last run 513.8, with a standard deviation of 115.6 and 118.4 respectively. A paired t-test with two-sided null hypothesis is significant with $\alpha = 2.5\%$.

Finally, in order to investigate about usability and user experience, users were asked about their understanding of their agents' behaviours. 27% answered "very good", 41% "good", 18% "moderate" and 14% "bad". The next question asked how good users could understand how they influenced their agents. Users had a "very good" (50%), "good" (18%) or "moderate" (27%) grasp of their actions' effects on the agents. Only one person (5%) had a "bad" understanding of the effects of his/her actions. Most users (75%) rated the appearance of the models with at least "good" and 78% considered the UI at least "good". Asked how the tutorial succeeds in introducing new users to the simulation, 45% said "very good", 41% "good", 9% "moderate". Only one person (5%) rated the tutorial "bad".

Concerning gamification, 86% said that they were encouraged by the score system to improve their performances. 68% had "much" or "very much" pleasure playing and just as many said that they would like to play again. The main reason for degraded fun is a drop in performance caused by the sphere-based pheromone implementation explained in Section III. Further possibilities of improvement revealed by the survey are stated as future work in the next section. All in all, point (c) from above is considered as achieved.

VII. Summary & Future Work

Pheromander is an interactive simulation designed to convey the basics of pheromone based swarm interaction and train the usage of a pheromone based interface to command large numbers of units. The user study shows that both goals have been achieved alongside of good usability and user experience.

For future work, the survey revealed possibilities of improvement like an increasing camera zoom speed/range, the display of health bars or increasing pheromone placement speed. The main point of criticism are performance issues which have to be solved by improving the pheromone model of the simulation. Furthermore, different approaches like the agent-based pheromone discretisation explained in [2] or using "breadcrumbs" instead of pheromones [5] could be added to the simulation. This allows to convey that there are multiple solutions which work equally well or which are better suited for certain situations.

References

[1] A. Kolling, K. Sycara, S. Nunnally, and M. Lewis, "Human swarm interaction: an experimental study of two types of interaction with foraging swarms," *Journal of Human-Robot Interaction*, vol. 2, no. 2, pp. 103–128, Jun. 2013.

[2] H. V. D. Parunak, S. A. Brueckner, and J. Sauter, "Digital pheromones for coordination of unmanned vehicles," in *International Conference on Autonomous Agents and Multi-Agent Systems*, 2002.

[3] M. Dorigo and C. Blum, "Ant colony optimization theory: a survey," *Theoretical Computer Science*, 2005.

[4] A. Drogoul, B. Corbara, and S. Lalande, "Manta: new experimental results on the emergence of (artificial) ant societies," in. UCL Press, 1995, ch. MANTA.

[5] L. Steels, "Towards a theory of emergent functionality," in *Proceedings of the First International Conference on Simulation of Adaptive Behavior on From Animals to Animats*, 1990.

[6] F. Kluegl. (2008). Swarm intelligence: from natural to artificial systems. Book review, [Online]. Available: http://jasss.soc.surrey.ac.uk/4/1/reviews/kluegl.html (visited on 01/09/2016).

[7] *SimAnt*, 1991. [Online]. Available: https://archive.org/details/msdos_SimAnt_-_The_Electronic_Ant_Colony_1991 (visited on 01/09/2016).

[8] U. Wilensky. (1997). NetLogo Ants model, CCL, Northwestern University, Evanston, IL, [Online]. Available: http://ccl.northwestern.edu/netlogo/models/Ants (visited on 01/09/2016).

[9] G. Coppin and F. Legras, "Autonomy spectrum and pheromoneserformance perception issues in swarm supervisory control," *Proceedings of the IEEE*, vol. 100, no. 3, pp. 590–603, Mar. 2012.

[10] G. Beurier, O. Simonin, and J. Ferber, "Model and simulation of multi-level emergence," in *2nd IEEE International Symposium on Signal Processing*, 2002.