WESTANTS: Exploring the design space of competing ant colonies

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Abstract

WESTANTS is a game-style implementation of exploring the modeling of similar ant colonies competing for sparse resources. It seeks to answer questions around the differences in modeling both a single agent and the environment from previous research. In order to assess the option space, our design challenge focuses on two colonies with the ability to locate and return resources to their nest and toggle characteristics like seeking/avoiding conflict, spawning faster/slower, increasing the strength (thus, duration) of pheromones, etc. This allowed us to run a series of tests to compare our results against both previous simulated work of single colonies and real-world capturing of ant warfare (thanks to YouTube). Based on our design space decisions and combined analysis of scenarios, our findings ended up being quite intuitive, thus validating our general approach and design. Three takeaways can be gleaned from this work. First, a complex path from nest to resource will damper colony performance, especially if the competing colony has a significantly shorter, less complex path to the same resource. Second, if a colony seeks conflict, they should have the "right to win" - i.e., if the opposing colony is the same, the only advantage of competition is expanding the resource pool to include using the dead opposing ant as a resource. And last, the ultimate best strategy: bring more ants. Population size and colony aggression were our biggest drivers of success in all measurable outcomes. A larger, aggressive colony not only comes with more ants to proceed in combat, but also has advantages like improved foraging and home pheromone strengthening when the colony is also conflict seeking and dedicating resources to combat.

1 Introduction

In this simulation-based project, we expanded upon ant colony foraging and stigmergy models to understand the changes to the design space when there are two competing colonies. In particular, we explored the potential implications of different foraging strategies when it comes to competition and which strategies lead to optimized results for the colonies. Our analysis focused on two design space implications:

1. How will changes in the environment and size/location of colonies, nests, and food sources affect outcomes?
2. How should a single agent be modeled in the presence of a competing colony?

Our research is demonstrated through simulation of pitting colonies with different or similar attributes against one another to see which colonies end up with the most resources in a finite time frame. The implications of identifying such an optimal competitive strategy can have impacts on multiple arenas and practical applications, ranging from video game artificial intelligence to autonomous robots that are optimizing the hauling and distribution of materials.

The simulations were conducted utilizing a video game engine called GameMaker Studio 2. Video game engines have the added benefit of rapid prototyping of the simulation environment, built in path finding algorithms and collision detection, easy to use scoring systems, and aesthetically pleasing visuals. Because this is formatted as a "game", we are excited to not only demonstrate the implications of adding competition to the design space but also provide the opportunity for our readers and audience to see the dramatic competition and how it unfolds. Our game, Westants, is available and hosted on itch.io (https://wruths.itch.io/westant).

2 Related Work

Previous work has been conducted in modeling stigmergy found in foraging ants to recreate the ability for colonies to find the optimal route to a resource. We utilized the findings and general approaches from the following papers as a source of inspiration and to help us create a baseline for our simulation:

2.1 *Swarm Smarts* by Eric Bonabeau and Guy Théraulaz

This paper demonstrated a variety of practical applications of swarm intelligence and provided context for the idea that, "dumb parts, properly connected into a swarm, yield smart results". We will be utilizing the concepts introduced in this paper, such as virtual foraging and path finding via pheromones to help define the essential components of our design space. We will be utilizing pheromones to help guide ants toward resources and will be building upon these pheromone trails with additional pheromones that also show the presence of threats.

2.2 *Self-organized Shortcuts in the Argentine Ant* by S. Goss, S. Aron, J. L. Deneubourg, and J. M. Pasteels

This paper utilized path systems from an ant colony to a source of food with various paths/path lengths. The results showed the ants were able to consistently converge to primarily using the shortest path using three key methods: amplification from positive feedback, repeated action from population, and leaving notes in the environment (stigmergy). We will build upon these techniques in our implementation by building like-functions for each agent in the simulation. Although we might not utilize this for routing, the core capability of amplification and stigmergy in large, competing populations.

2.3 *Ant System: Optimization by a Colony of Cooperating Agents* by Marco Dorigo, Vittorio Maniezzo, and Alberto Colorni

Dorigo et al tested optimization techniques using ant-like distributed systems ("Ant Systems" or AS). The game they initiated was a simulation of solving the classic traveling salesman problem. The two key inspirations we'll build upon are the use of positive feedback in system design so each colony will reach a consensus approach as well as the construction of a greedy heuristic so the simulated agents have a catalyst to build a competitive baseline from the start. If there is future work based on our design decisions, it would be interesting to build with their parting thoughts of developing a system for distributed communication, on top of stigmergy, to optimize for conflict or resource redirection.

2.4 *Ant Foraging Revisited* by Liviu Panait and Sean Luke

Panait and Luke provide a framework for a simple mechanism of ant path planning using pheromones. We'll use their algorithms as our primary baselines for agent decisions and adjustments. This will replace our need for a complicated nest-discovery device. If that proves to be unsuccessful, we can hard-code the nest location in an easily-discoverable place and build upon only their adjustment capabilities to have an avoidance/retreating mechanism when an agent encounters an enemy along their own path.

3 Design

Our design space was built with the expectations and necessity to have the ability to explore the following colony strategies:

1. Conflict Avoidance; Resource Identification Pheromones.
2. Conflict Avoidance; Resource Identification and Enemy Identification Pheromones
3. Conflict Seeking; Resource Identification Pheromones
4. Conflict Seeking; Resource Identification Pheromones and Enemy Identification Pheromones

Each of these strategies was represented by a different colony's initial settings in our simulation. We placed these simulated colonies into competition with each other and recorded the results via the number of resources (or grains of rice) that each colony collects.

We explored the following two competitive dynamics:

1. Competition only over resources with no violence between agents
2. Competition for resources with violence allowed between agents

These two competitive dynamics will also allow us to see the implications of our models and strategies in different practical scenarios. In a video game or in real-life wargaming, conflict between agents is likely and should be considered when choosing the optimum strategy. However, in the case of a robot swarm that is allocating resources, there would likely not be violence involved. By modeling both dynamics our results will have a broader swath of practical application.

3.1 Scenario and Environment Design

We first had to make the decision of how a colony is able to "win" a round of foraging. While we could explore many creative options here, we started with the most simple application of a colony scoring a point each time an ant successfully forages one unit of food and returns that food back to their home. This is representative of real-life ant colonies and places meaningful bounds on the gameplay dynamic. It also is a meaningful goal to promote colonies with higher-performing optimization of stigmergic paths. Next we explored path complexity. While there were many options here, we narrowed in on static nest locations with obstacles in the environment which left us with the most flexibility to alter and study the validity of a single ant's choices and effects on colony performance. In order to iterate through map designs with intention so that they would simulate real life ant dynamics, we turned to the glorious YouTube, specifically the AntsCanada channel. In his video "I Filmed Ants Going to War," he demonstrates two fire ant colonies in conflict over a single resource in their mutual environment. A few takeaways we believe are important to model is the concept of harmony until competition and how a colony's distance from an obstacle affects its incentive to engage in battle. Although both colonies in the video were alike, the colony with the shorter path from the resource to their nest were more ruthless. They would attempt to kill, outcompete, and displace the opposing colony, but conflict occurred at the resource rather than attacking an opposing nest. Additionally, in "Weaver Ants vs. Fire Ants," colonies with sufficiently large resources near their nest will live in harmony until that resource is expended. At that point, the colony seeks their next closest resource, which is the catalyst for conflict. With both of these in mind, we decided to control the location and size of resources alongside creating more complex (i.e., longer) paths to the resources dropped. We also created initial obstacles with multiple "exits" within a few steps from the spawn location. This was primarily an aesthetic choice to demonstrate the naturally stochastic behavior of each Westant's path finding. In a similar vein, we imbued the direction of the home nest in each ant for the sake of obstacle avoidance leading towards "forward" progress when foraging, as seen in Exhibit 1.

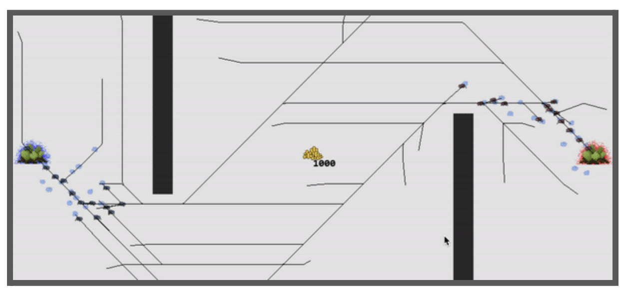

Exhibit 1: Westant environment displaying all agent paths during gameplay.

3.2 Ant Design

Our single-agent ant design, a "Westant", is based primarily on Panait and Luke's methods but with necessary changes and additions due to the multi colony architecture and game engine design, as outlined in sections 3.2.3 and 3.2.4 below. At the highest level, a Westant has a few modes: resource hunting (*AntFindFoodSource*), home seeking (*AntReturnToNest*), or direct ant-to-ant conflict (*AntConflict*).

The process of resource gathering and returning to nest is heavily built on the key concepts of stigmergy, population density, and amplification. While we expected this implementation to be straightforward when considering multiple colonies, it was anything but. Westants leave differentiated pheromones in the environment for both their path to a resource and their path home, which are amplified scaled on the population of a colony. However, because of the naturally greedy nature of an individual colony, we were forced to generate colony-specific pheromones for both foraging and homebound.

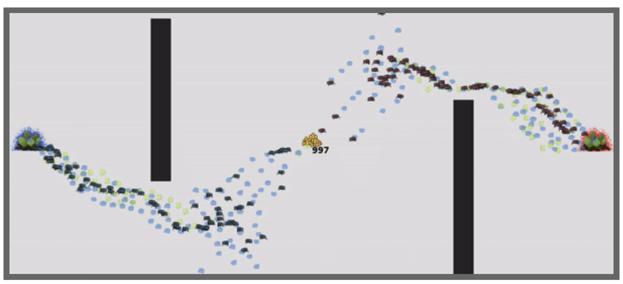

Exhibit 2: Opposing colonies converging towards fully optimized foraging and home pheromone placement and amplification.

The resulting scenario led to a multi-variable optimization problem between pheromone evaporation and update/strengthening rates, ant spawn frequency, and colony size. We had to place upper and lower bounds on the size of each for a colony to both converge on optimal resource/home paths and maintain convergence in the face of conflict. This was exacerbated in our early design phase when all ant-to-ant interactions resulted in conflict because home pheromones would evaporate in the time it took for an agent to win in conflict and restart their journey home. Additionally, as more conflict occurred, all ants would eventually end up at the largest resource on the map if the spawn rate wasn't slow enough to leave some ants still in seeking mode. This time delay would also leave the few Westants that make it back to their nest with no optimized path back to the resource. After placing constraints on these variables, we were able to proceed with continuing down the design space of considering the concepts of conflict, enemy pheromones, and amplification.

We first approached conflict as "two ants intersect on the graph; they fight; one wins, one dies." We believed this would then let us explore strategies around seeking or avoiding conflict. However, after one run we realized we needed a reframe. If a Westant wants to locate an enemy, rather than needing to lay and follow enemy seeking/identifying pheromones, find the next closest resource! Our early experiments could be summed up by the phrase "battle royale" as they would always end up as a random-chance ultimate battle surrounding the resource, as seen in Exhibit 3.

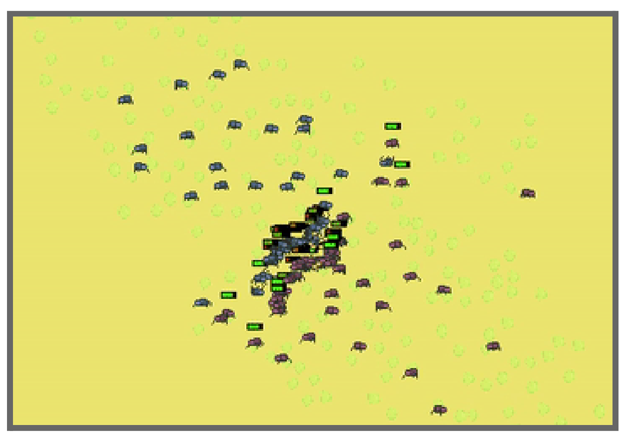

Exhibit 3: Both colonies ultimately converging to conflict and losing both foraging and home pheromone optimized paths.

This led us to finding a new mechanism. Through trial and error, we landed on a three part framework to drive an individual's response to potential ant-to-ant conflict:

1. "Will we fight?"
2. "Who wins?"
3. "What does winning mean?"

Instead of immediately proceeding to conflict, when two ants intersect the graph, the first check is their probability of fleeing. We allowed this to be scaled for each colony per run as the main mechanism to control a colony's strategy. With this in place, the first check at interaction is this linear scale compared against a randomly generated number. If the comparison leads to engagement, the next step is determining who wins. To provide general variability, we randomly toggle the frequency each ant can strike the opponent through random delay. Before this was in place, we explored the concept of a colony having the "right to win," with particular attributes leading to a higher chance of winning in direct combat (think weaver ant vs fire ant). This ultimately would drive the outcome and we instead wanted more variability in results, like the AntsCanada videos. Because we thought it best to compare like-to-like colonies as our general approach, the random delay attack added a sense of fairness to the decision of the outcome of the battle. Last, after witnessing ants using dead ants as structural resources, AntsCanada inspired us to reward a win through the dead ant becoming a single unit resource to the victor (after the return it to the nest, of course).

3.2.1 Ant PathFinding Algorithm

Foraging ants execute the *AntForage* procedure at each time step. When moving, the ants were imbued with an understanding of their environment and would path find around any obstacles between themselves and their destination using an A* algorithm implemented by the GameMaker Engine. Nearby pheromones or objects were constituted as "nearby" when they were in a 100 pixel range of the ant. The pseudocode is shown next:

```
AntForage
If HasFoodItem
   AntReturnToNest
Else
   AntFindFoodSource

AntReturnToNest
If Friendly Home Pheromone is Nearby
   Move to this Pheromone
Else If Nest is Nearby
   Move to the Nest and Deposit Food
   Ant Colony Score + 1
Else
   Move to a Random Point

Lay Down Food Pheromone

AntFindFoodSource
If Friendly Food Pheromone is Nearby
   Move to this Pheromone
Else If FoodItem is Nearby
   Move to the FoodItem & Pick Up Food
Else
   Move to a Random Point

Lay Down Home Pheromone
```

3.2.2 Ant Conflict Algorithm

Ants that collide with each other execute the *AntConflict* procedure. The pseudocode is shown next:

<u>*AntConflict*</u>
If Collided Object is Enemy Ant
    If Random_Num <= Ant's Prob Flee
        Ant Runs Away
    Else
        Stop Moving
        X ←Random Number
        Attack in X Time Steps
Else
    AntForage

<u>*Attack*</u>
Enemy Ant Health - 1
If Enemy Ant Health <= 0
    Enemy Ant is Dead
    Enemy Ant becomes FoodItem
    Enemy Colony Death Count + 1
    AntForage
Else
    X ←Random Number
    Attack in X Time Steps

4 Evaluation

Our evaluation and testing methodologies were to utilize our simulation to run a series of experiments demonstrating the impacts of our design decisions. Our simulation is hosted here: https://wruths.itch.io/westant.

The questions we wanted to answer were as follows:

1. Does our algorithm replicate real life ant competition dynamics, such as path convergence and conflict over resources?
2. What is the best strategy for an ant colony in regards to combat? Is it to engage in or flee combat?
3. How will changing the environment (obstacles, distance to food, and size of food piles) impact the ant colony's path convergence and their behaviors toward competing colonies?
4. What is the impact of population size on a colony's ability to out compete and displace another colony over a resource, even in circumstances where it might be at a positional disadvantage?

With these questions in mind we set up four simulation environments to answer each question and address our design space decisions. These simulations and their results are addressed as follows:

Test 1: Base Case

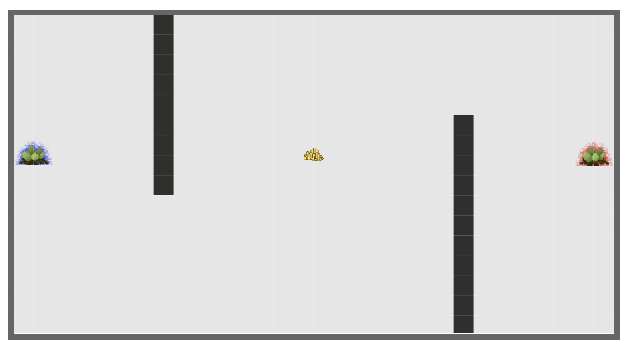

Exhibit 4: The Base Case Simulation Environment with Simple Obstacles and One Central Resource

This base case simulation demonstrated that the colonies will converge to a path when a resource is found and that the colonies will engage in combat over a contested resource. This simulation also demonstrated that the use of additional pheromones, such as enemy pheromones, to indicate the presence of an enemy would not provide additional useful information to a colony as conflict always occurs around a resource.

Test 2: Assessment of Combat Strategy

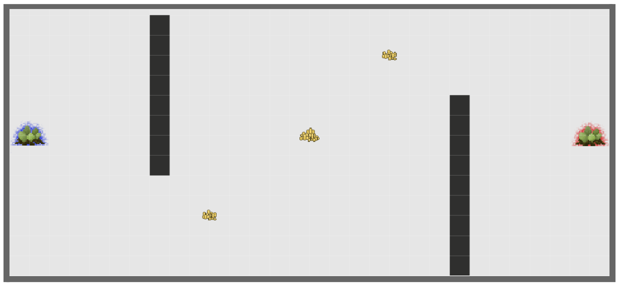

Exhibit 5: The Test 2 simulation environment placed two small resource deposits near the colonies with a large resource at the center

The objective of this simulation was to show which strategy is best: to fight or to flee. From our experiments we found that the best strategy was to engage in combat. Our results are presented in the graph below:

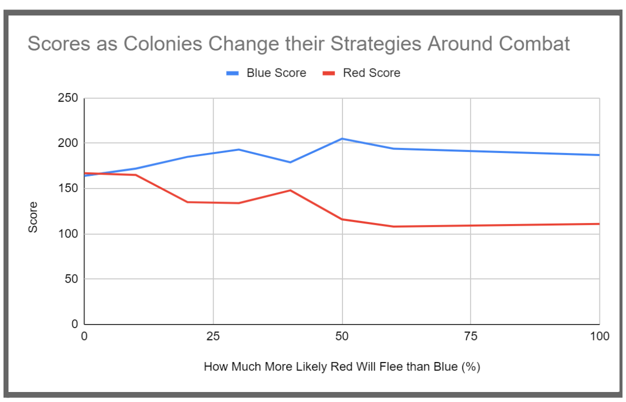

Exhibit 6: In these experiments the blue colony became more likely to engage in combat while the red colony became more likely to flee. Blue consistently outperformed red during the different trials.

Engaging in combat was the winning strategy because dead ants count as resources, and by engaging in combat an ant colony will kill more opposing ants and therefore have more resources available to them. Additionally, by being more aggressive, an ant colony is able to dominate a resource and prevent the other ant colony from freely accessing it.

An additional outcome from this particular map layout was that it demonstrated that ants would focus on the nearest fool pile before moving to other resource locations. This also demonstrated the robustness of the foraging algorithm as it showed that ant colonies were able to redirect once a resource was depleted.

Test 3: Ant Harmony

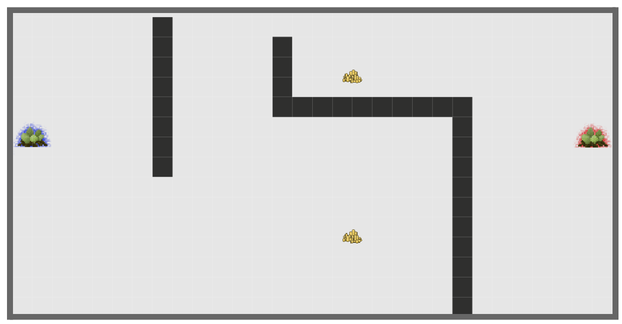

Exhibit 7: This simulation environment was set up so that there was little incentive for the ant's to fight over the same resources.

In this simulation, we set up an environment where the two colonies did not have a resource to compete over as they both had nearby large resources to feed off of. This simulation addressed our third question and demonstrated that two colonies would avoid conflict as long as there was a close resource that could satisfy the colony.

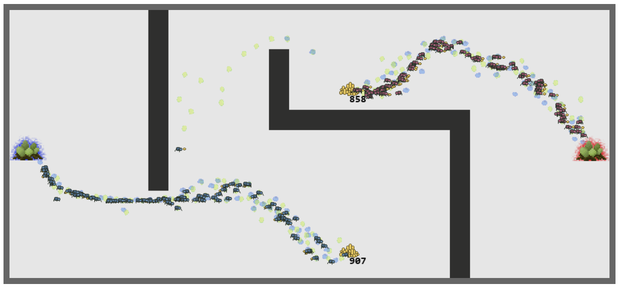

Exhibit 8: In this environment we see that the two colonies converge towards the resource that is closest and easiest to navigate to.

Additionally, this particular environment showed that not only distance but also obstacle layout plays a critical role in which food sources a colony pursues.

Test 4: Distance vs Population Tradeoffs

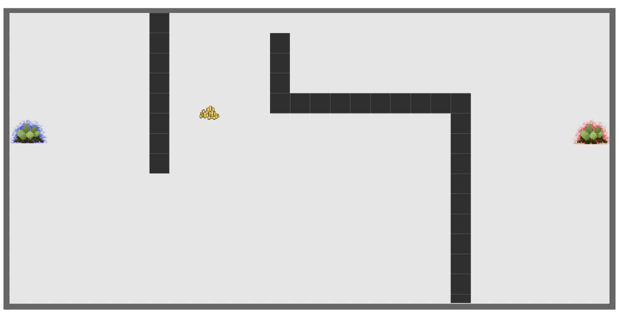

Exhibit 9: Similar environment to test 3 but now there is a central resource where the blue colony has a significant positional advantage.

This simulation environment demonstrated the tradeoff between distance between the nest and the resource, and the colony's population size. We conducted a series of experiments where we increased the gap in the population size between the red and the blue colonies to show that despite the red colonies disadvantage with its distance to the resource, that once its population grew large enough it was able to effectively compensate for this handicap. Below we see the results of these experiments:

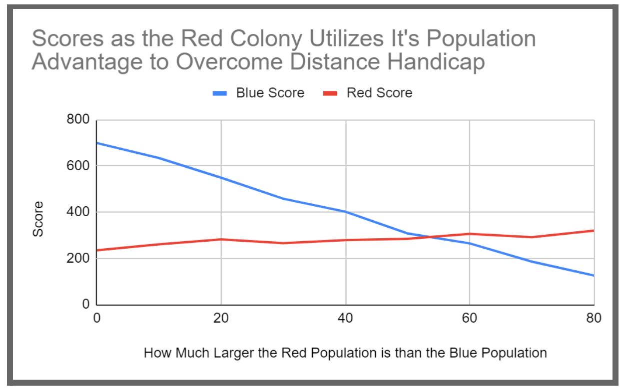

Exhibit 10: In these experiments the red colony becomes increasingly large in comparison to the blue colony. Eventually the positional disadvantage of red is overcome as the red exceeds blue in great enough size.

Looking at the graph above, we see that when the red colony is 50 ants larger in population than the blue colony, the red colony is able to overcome its distance disadvantage and score the same as the blue colony. Thereafter it continues to perform better than its competitor, showing that population does in fact play a critical role in determining winners in colony competition.

5 Future Work

There are multiple directions to take this work next. The simulation and algorithms in this paper could be further enhanced with future work around the following:

1. Parameter Tuning for Ant Combat Ability
2. Multi-Colony (2+) Simulations and Design Space Implications
3. Employment of Different Ant "Classes"

Parameter tuning for ant combat abilities would be focused on providing a lever for experiments that would let us calibrate the variable X as presented in the *AntConflict* algorithm. By adjusting X, or the attack rate of the ants, we are effectively enhancing or inhibiting the ability of the ant to kill other ants. This would let us simulate such circumstances as weaver ants vs army ants. By providing a way to adjust this, further experiments could be done on the best strategies for colonies given combat ability in conjunction with other colony and environmental parameters.

Multi-Colony simulations would provide further opportunity to explore the design space implications of more than two competing colonies. Questions to explore could include: what is the best way to design a fair competitive environment? How do the impact of population parameters and combat strategies differ for multi-colony situations?

In terms of employment of different ant “classes”, this future work would be centered on employing ants with different algorithms and strengths. For example: a scout ant that focuses on finding new resources, a hauling ant that prioritizes moving food back to the nest, and soldier ants that focus on defending the colony and resources it claimed. These algorithms would help us to properly simulate the complexity of actual ant colonies and allow for further refinement of optimal colony strategies.

The next area for future work lies within the realm of practical applications. These simulations could end up being quite useful for defense simulations, warehouse worker optimization, and video game or movie simulations.

Westants and the discovered optimal strategies could prove quite useful for defense applications after proper refinement and parameter tuning. The defense industry is constantly in search of more predictive power within the warfighting domain and these simulations could help uncover some of the uncertainty and fog of war when it comes to anticipating enemy movement and strategies.

In a warehouse environment, robots or humans often pull from a shared pool of resources that resembles the competitive environment in our simulations. With further tweaking, our simulation could be used to show optimal warehouse resource allocation strategies.

Lastly, these life-like ant simulations found in this paper could help to realistically show colony behaviors in various forms of entertainment. Whether in video games or in movies, the entertainment industry is eager to utilize simulations to provide realistic, inexpensive, and exciting portrayals of the creative director’s vision. These simulations could end up being a useful tool in a production team’s arsenal.

6 Conclusion

Using prior research and real life scenarios, we have created a simulation that addresses the design space implications for two competing colonies. Our decision space decisions encompassed the following:

1. Ant Pathfinding Algorithm Decisions
    a. Use of home and resource pheromones (but no need for enemy pheromones). Parameter tuning of pheromone evaporation rates.
    b. Imbued knowledge of obstacles and the ant's nest location.
    c. No other knowledge of enemy ants or location of resources.
2. Ant Conflict Algorithm Decisions
    a. Parameter tuning for the probability that the ants in a colony will avoid conflict.
    b. Ants have a random attack delay which randomizes battles.
3. Colony Design Decisions
    a. Ants will spawn at a parameter set interval.
    b. Ant colony population size parameter tuning.
4. Environment Design Decisions
    a. Multiple different test environments to replicate different real world scenarios.
    b. Environments changed in obstacle placement, resource placement, and resource size.

With these design decisions we then evaluated our simulations across a series of experiments. We discovered the following:

1. Our simulation successfully replicates ant stigmergy and conflict over resources.
2. The optimal strategy for a colony is to be conflicting seeking.
3. When in separated environments with enough resources that are easily accessible, ant colonies will avoid combat.
4. With a large enough population, an ant colony can overcome a positional disadvantage.

With these results, we are confident in the robustness of Westant- a simple agent that utilizes stigmergy to create complex, competitive interactions utilizing simple rulesets to find resources and usurp control of them from competitors. We look forward to exploring future applications of the Westant- from predictive defense solutions to commercial operations to entertainment simulations.

7 References

[1] Bonabeau, E., & Théraulaz, G. (2000). Swarm smarts. *Scientific American*, *282*(3), 72–79. https://doi.org/10.1038/scientificamerican0300-72

[2] Dorigo, M., Maniezzo, V., & Colorni, A. (1996). Ant system: Optimization by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics)*, *26*(1), 29–41. https://doi.org/10.1109/3477.484436

[3] Goss, S., Aron, S., Deneubourg, J. L., & Pasteels, J. M. (1989). Self-organized shortcuts in the Argentine ant. *Naturwissenschaften*, *76*(12), 579–581. https://doi.org/10.1007/bf00462870

[4] Panait, L., & Luke, S. (2004). Ant foraging revisited. *Artificial Life IX*.

https://doi.org/10.7551/mitpress/1429.003.0096

[5] "I Filmed Ants Going to War - Youtube." *YouTube*, AntsCanada, 23 Jan. 2021, https://www.youtube.com/watch?v=uCr_v09Qpps.

[6] "Ant War: Weaver Ants vs. Fire Ants." *YouTube,* AntsCanada, 30 Jan. 2021, https://www.youtube.com/watch?v=XfpVBSD4zLs