

# A REPRODUCIBLE FRAMEWORK FOR EVALUATING AUTONOMIC SWARM RECRUITMENT

*ENHANCING MEGASWARM WITH SYSTEMATIC METRICS, VISUALIZATION, AND  
PERFORMANCE ANALYSIS*

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AI MSc graduate with bachelor's in Electrical & Electronics Engineering. I combine data-driven thinking with hands-on engineering skills.

My recent project involved building an advanced swarm robotics simulation with recruitment algorithms, pheromone communication, and large-scale evaluation tools.

Open to roles in AI/ML, Data, Software, Electrical and Electronics Engineering.



# INTRODUCTION

Swarm Robotics = Many simple robots working together, inspired by ants & bees.

Why Swarms? They are scalable, fault-tolerant and adaptive. SWARM stands for "Smart War-Fighting Array of Reconfigured Modules"

## Applications:

- Disaster response (searching collapsed buildings)
- Environmental monitoring (pollution, wildfire detection)
- Space exploration (NASA concepts for planetary swarms)

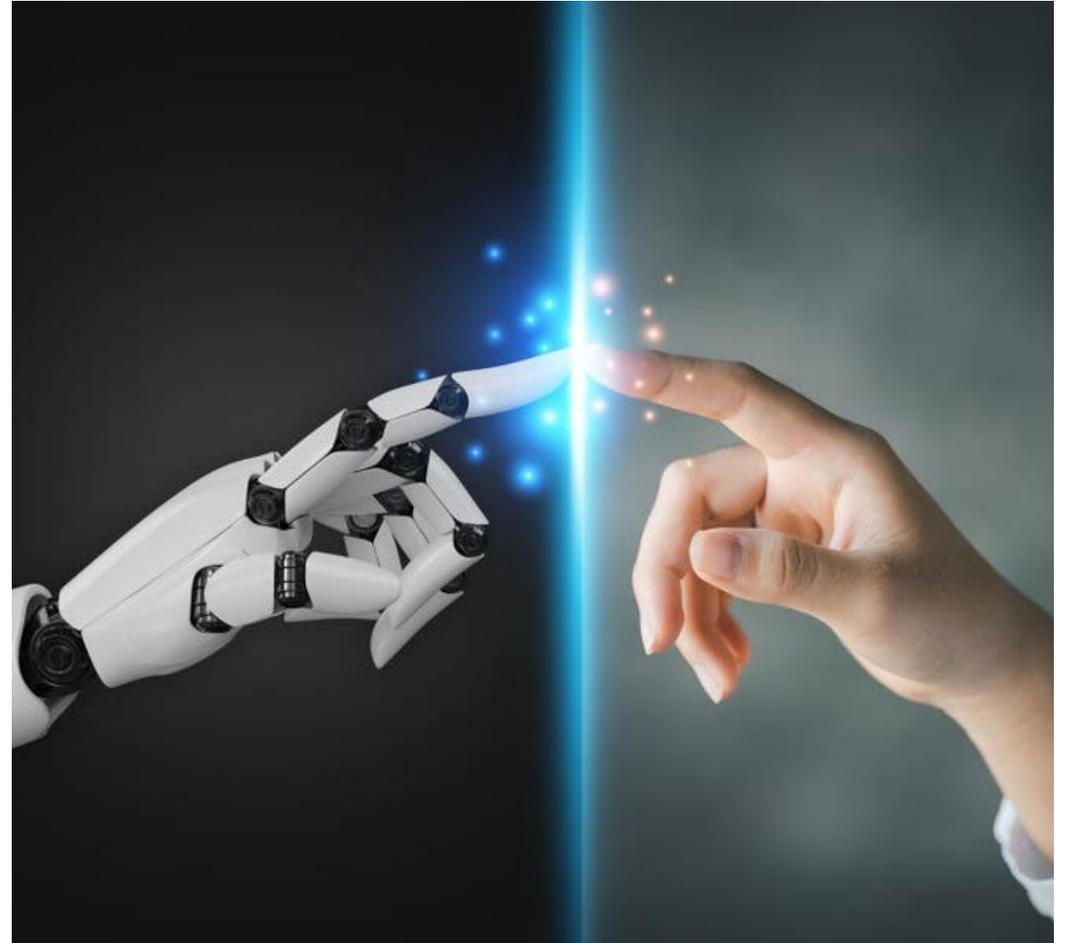
# MOTIVATION

## Problem in prototypes:

- **Early simulators (SwarmSim2, MegaSwarm prototype) lacked reproducibility.**
- **Robots often cluster at one site → wasted energy.**
- **Coverage is incomplete → many sites left unvisited.**

## Aim of Project:

- **Extend MegaSwarm into a research-grade framework.**
- **Implement complete recruitment (Off, One, Multi, Blackboard).**
- **Integrate pheromone stigmergy + adaptive control.**
- **Automate sweeps with reproducible outputs (metrics, charts, heatmaps)**



# LITERATURE REVIEW

Ref	Author(s) & Year	Contribution / Relevance
[1]	M. Rubenstein, A. Cornejo, and R. Nagpal (2014)	1000-robot self-assembly → proved <b>scalability</b> of swarm systems
[2]	C. Saunders, R. Sterritt, and G. Wilkie (2016)	Introduced <b>message-board recruitment</b> → basis for our Blackboard extension
[3]	G. O. Akowanu (2015)	Outlined <b>challenges and future trends</b> → scalability, comms, fault-tolerance
[4]	Liam McGuigan (2023)	<b>Autonomic Pulse Comms (APC)</b> → inspired the <b>Adaptive Control</b>
[5]	Z. Zheng, Y. Zhou, Y. Xiang, X. Lei, and X. Peng (2024)	<b>Selective interaction</b> model → improved efficiency, reduced comm load

# BASELINE SIMULATOR OUTPUTS

- ❑ Early prototypes used Help, Board, No Coop strategies.
- ❑ Useful for demonstration, but not reproducible.
- ❑ No pheromone stigmergy or MAPE-K control.



# EXTENDED RESEARCH-GRADE FRAMEWORK

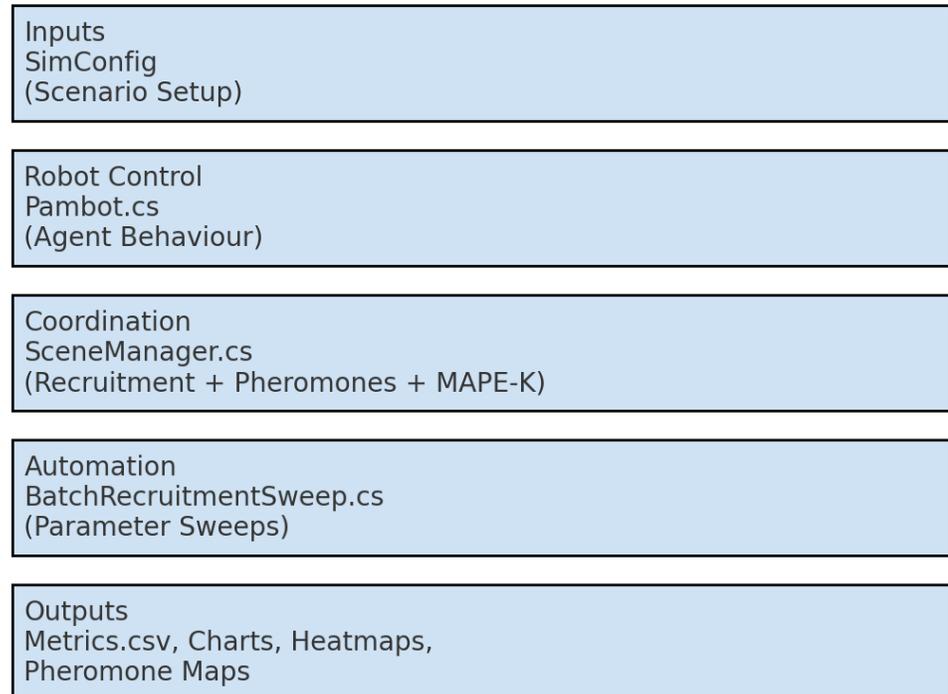
Implemented recruitment strategies: Off, One, Multi, Blackboard

- Added Pheromone Stigmergy + MAPE-K adaptation

- Automated factorial sweeps (BatchRecruitmentSweep.cs)

- Standardized reproducible exports: metrics, charts, heatmaps, pheromone

## Layered Architecture of Extended MegaSwarm Framework



# IMPLEMENTATION: SCENEMANAGER.CS

- Recruitment Board struct
- Probabilistic join ( $P_{\text{join}}$ )

Model

$$P_{\text{join}} = B + G \cdot D \cdot \rho \cdot \beta \cdot P$$

**B**: base chance (minimum responsiveness).

**G**: gain (how strongly to recruit).

**D**: distance term (nearer robots more likely;  $\sim 1$  near,  $\rightarrow 0$  far).

**$\rho$  (rho)**: anti-crowding ( $\approx 1/(1+\text{localDensity})$ ).

**$\beta$  (beta)**: backlog/urgency ( $\uparrow$  when site is under-staffed / many tasks remain)

- Pheromone API

# IMPLEMENTATION: PAMBOT.CS

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Recruitment +  
pheromone in  
search loop

Separation  
force

Heatmap  
updates

# IMPLEMENTATION: BATCHRECRUITMENTSWEEP.CS

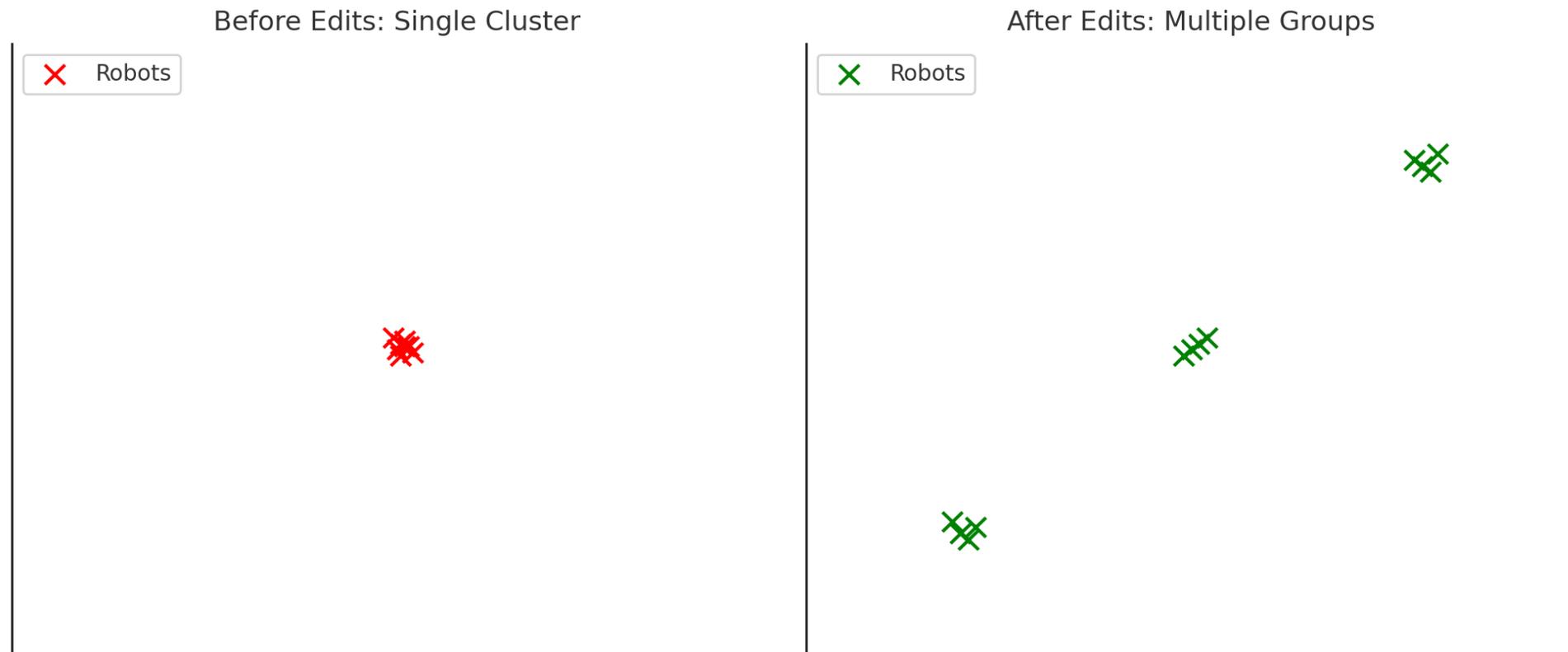
Parameter arrays  
(Strategy × Need ×  
TTL × Gains × Pull)

Episode  
management

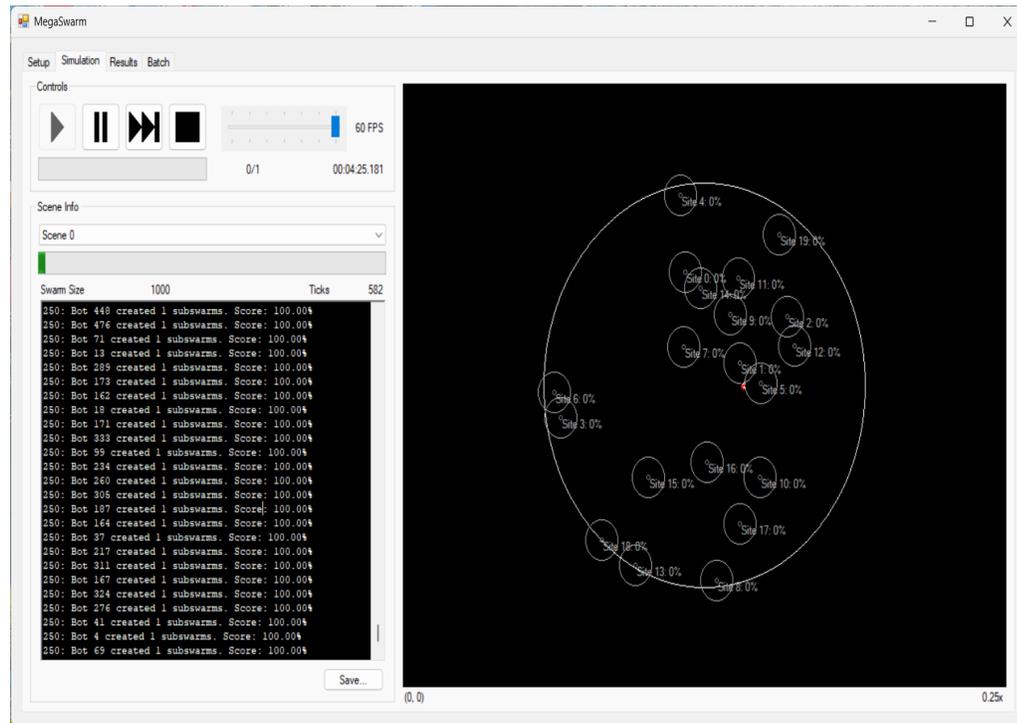
Exports Automation

# OBSERVED BEHAVIOUR (BEFORE VS AFTER)

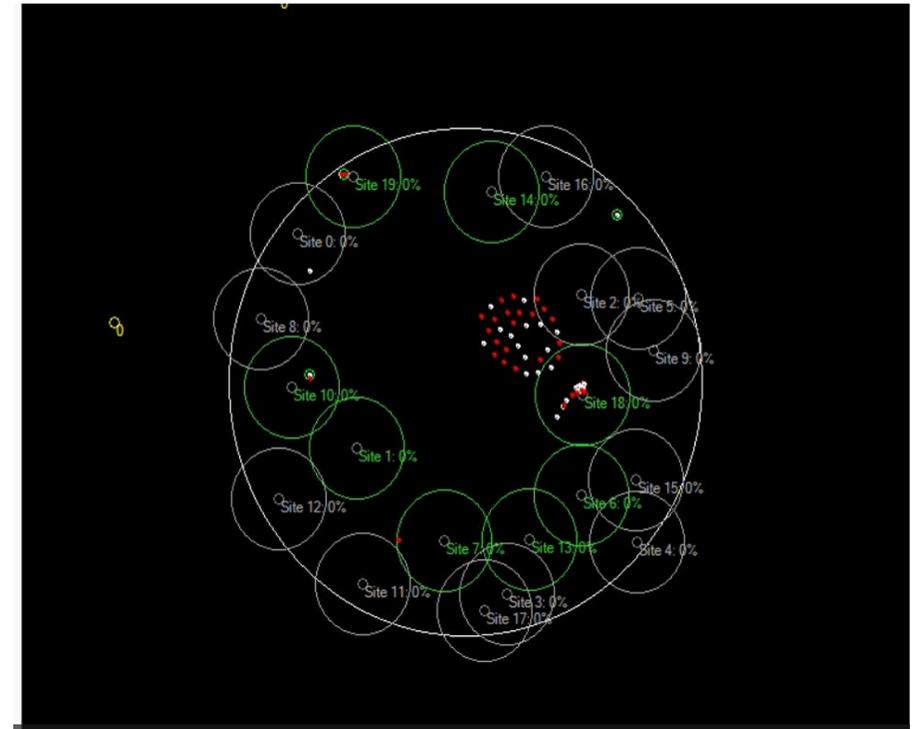
## Swarm Behavior: Before vs After



# OBSERVED BEHAVIOUR (BEFORE VS AFTER)



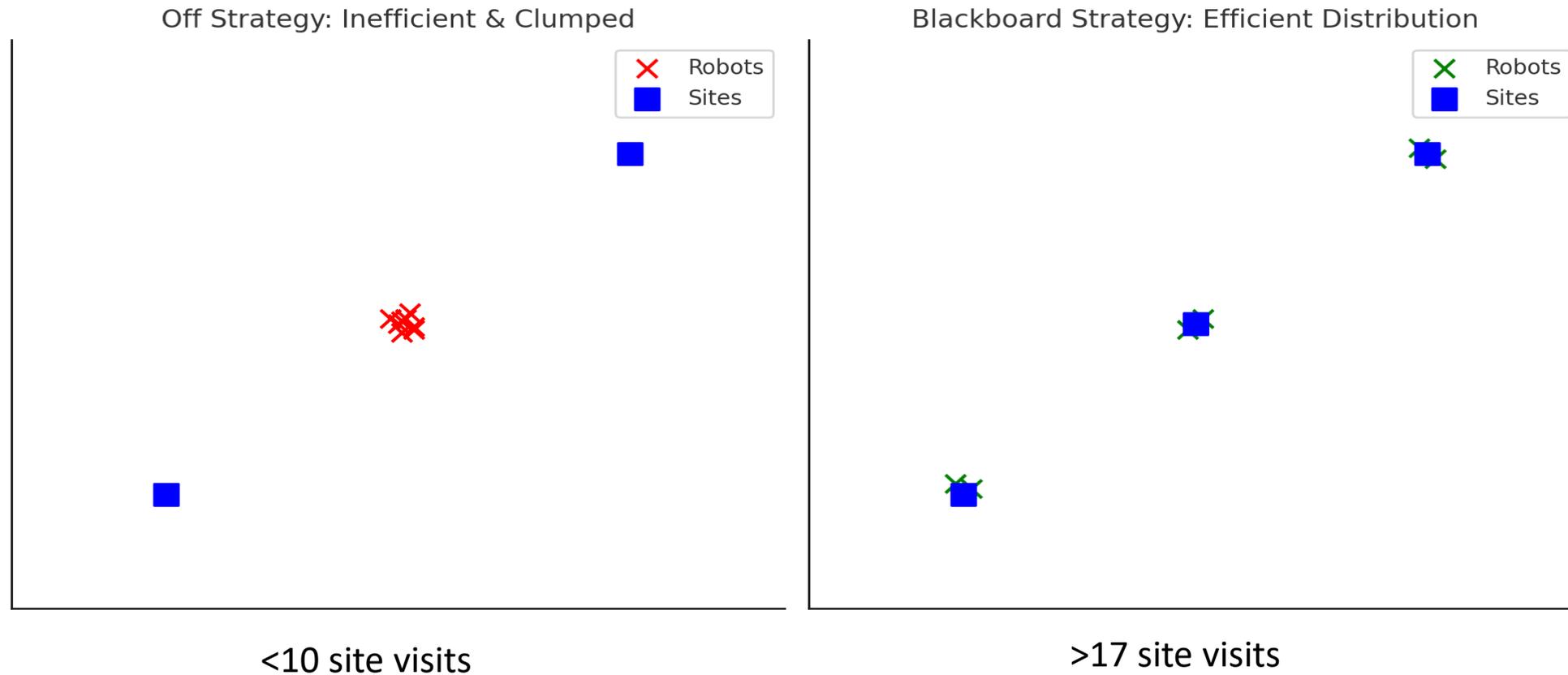
Robots in one big cluster, very few sites visited



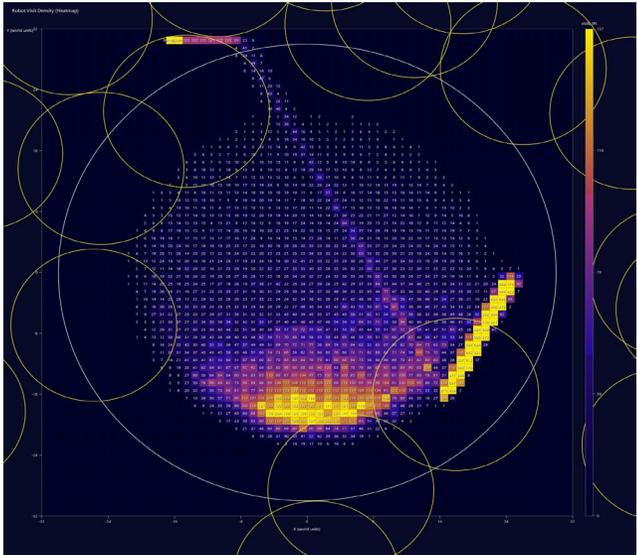
robots split into multiple groups, more sites visited

# OBSERVED BEHAVIOUR (BEFORE VS AFTER)

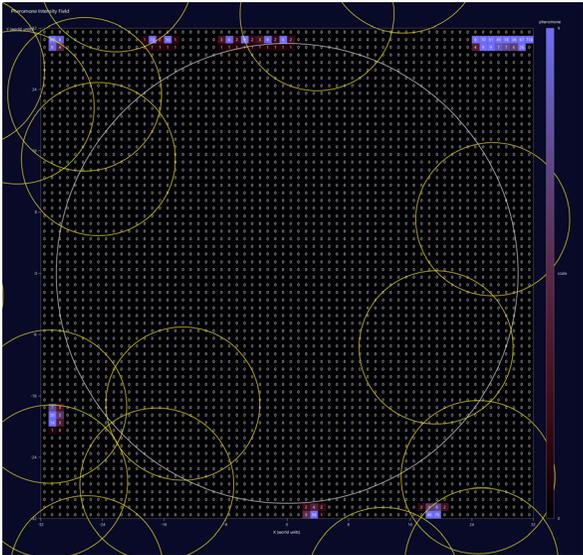
## Swarm Results: Off vs Blackboard Strategies



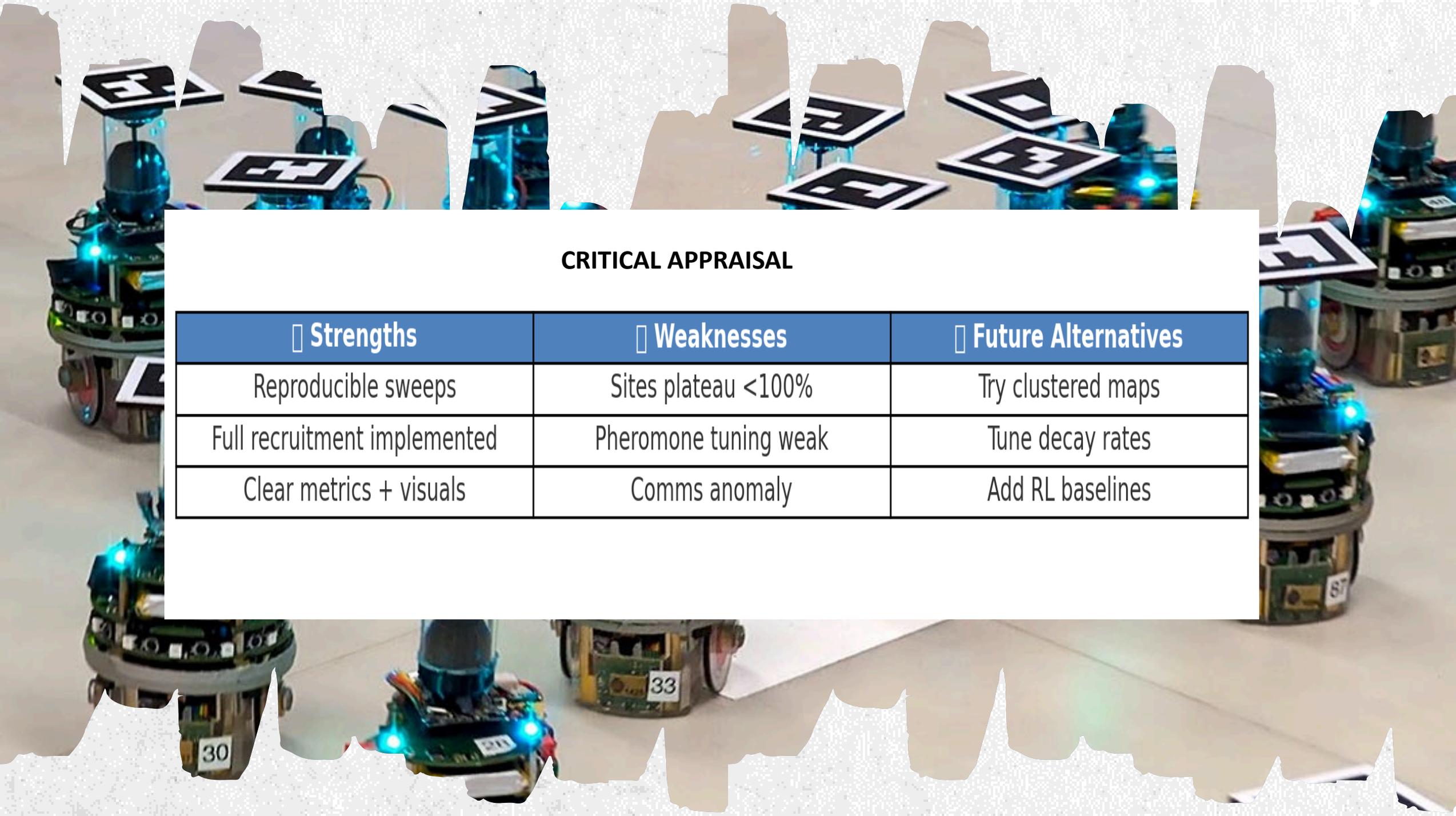
# OUTPUTS



HEATMAP



PHEROMONE FIELDS



### CRITICAL APPRAISAL

Strengths	Weaknesses	Future Alternatives
Reproducible sweeps	Sites plateau <100%	Try clustered maps
Full recruitment implemented	Pheromone tuning weak	Tune decay rates
Clear metrics + visuals	Comms anomaly	Add RL baselines

# CONCLUSION & FUTURE WORK

## Conclusion

- **Extended MegaSwarm into a research-grade, reproducible framework.**
- **Implemented complete recruitment strategies (Off, One, Multi, Blackboard).**
- **Added pheromone stigmergy + MAPE-K adaptation.**
- **Automated factorial sweeps with metrics, heatmaps, pheromone fields.**
- **Inspired by nature**



# CONCLUSION & FUTURE WORK

## Future Work

### Biological parallels:

- Explore bee-like recruitment (multi-directional communication, dance-style signals), Test termite-inspired clustering for building/constructive tasks, Add fish-schooling style avoidance for smoother group motion.

### Technical directions:

- Clustered/unbalanced maps & varied swarm sizes.
- Tune pheromone evaporation/reinforcement.
- Fault tolerance via Time Bomb modules.
- Hybrid swarms → combine stigmergy + reinforcement learning.
- Real-world validation → drones/ground robots in exploration tasks.



# REFERENCES

- [1] M. Rubenstein, A. Cornejo, and R. Nagpal, “Programmable Self Assembly in a Thousand-Robot Swarm,” *Science*, vol. 345, no. 6198, pp. 795–799, Aug. 2014.
- [2] C. Saunders, R. Sterritt, and G. Wilkie, “Autonomic Cooperation Strategies for Robot Swarms,” in *Proc. IARIA International Conference on Adaptive Systems*, pp. 20–27, 2016.
- [3] G. O. Akowanu, “Swarm Robotics: Challenges and Future Trends,” *International Journal of Advanced Research in Artificial Intelligence*, vol. 4, no. 3, pp. 45–52, 2015.
- [4] L. McGuigan, “Autonomic Pulse Communications for Adaptive Transmission Range and Data Transfer in Decentralised Robot Swarms”, PhD Thesis, Ulster University, 2023.
- [5] Z. Zheng, Y. Zhou, Y. Xiang, X. Lei, and X. Peng, “Emergence of collective behaviours for swarm robotics through visual attention-based selective interaction,” *IEEE Robotics and Automation Letters*, vol. 9, no. 11, pp. 9399–9406, Nov. 2024.



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