

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 scalability of swarm systems
[2]	C. Saunders, R. Sterritt, and G. Wilkie (2016)	Introduced message-board recruitment → basis for our Blackboard extension
[3]	G. O. Akowanu (2015)	Outlined challenges and future trends → scalability, comms, fault-tolerance
[4]	Liam McGuigan (2023)	Autonomic Pulse Comms (APC) → inspired the Adaptive Control
[5]	Z. Zheng, Y. Zhou, Y. Xiang, X. Lei, and X. Peng (2024)	Selective interaction 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

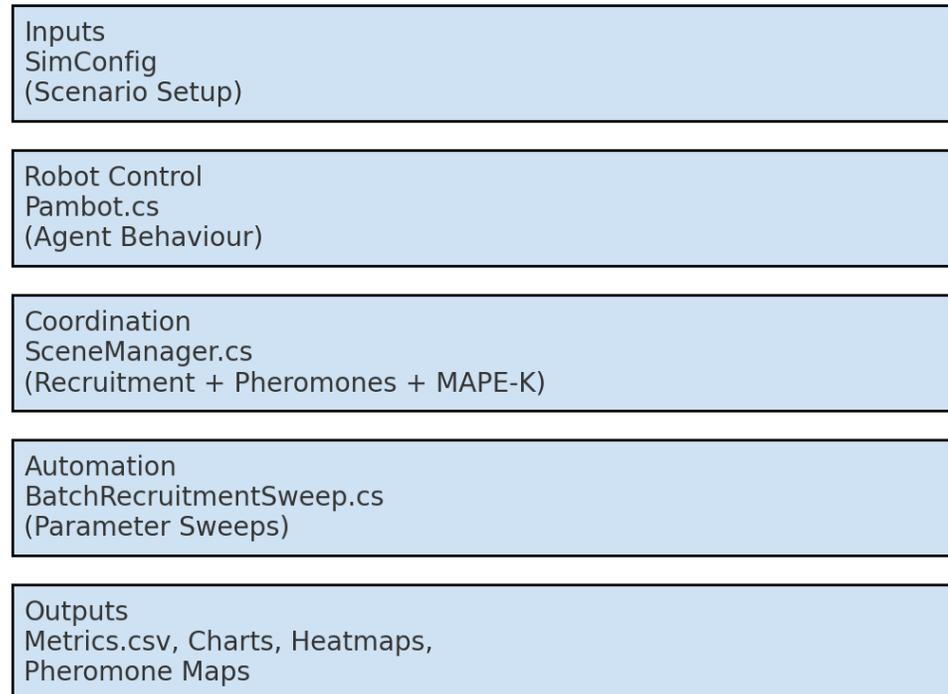
Implemented recruitment strategies: Off, One, Multi, Blackboard

- 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_{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; ~ 1 near, $\rightarrow 0$ far).

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

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

- Pheromone API

IMPLEMENTATION: PAMBOT.CS

Recruitment +
pheromone in
search loop

Separation
force

Heatmap
updates

IMPLEMENTATION: BATCHRECRUITMENTSWEEP.CS

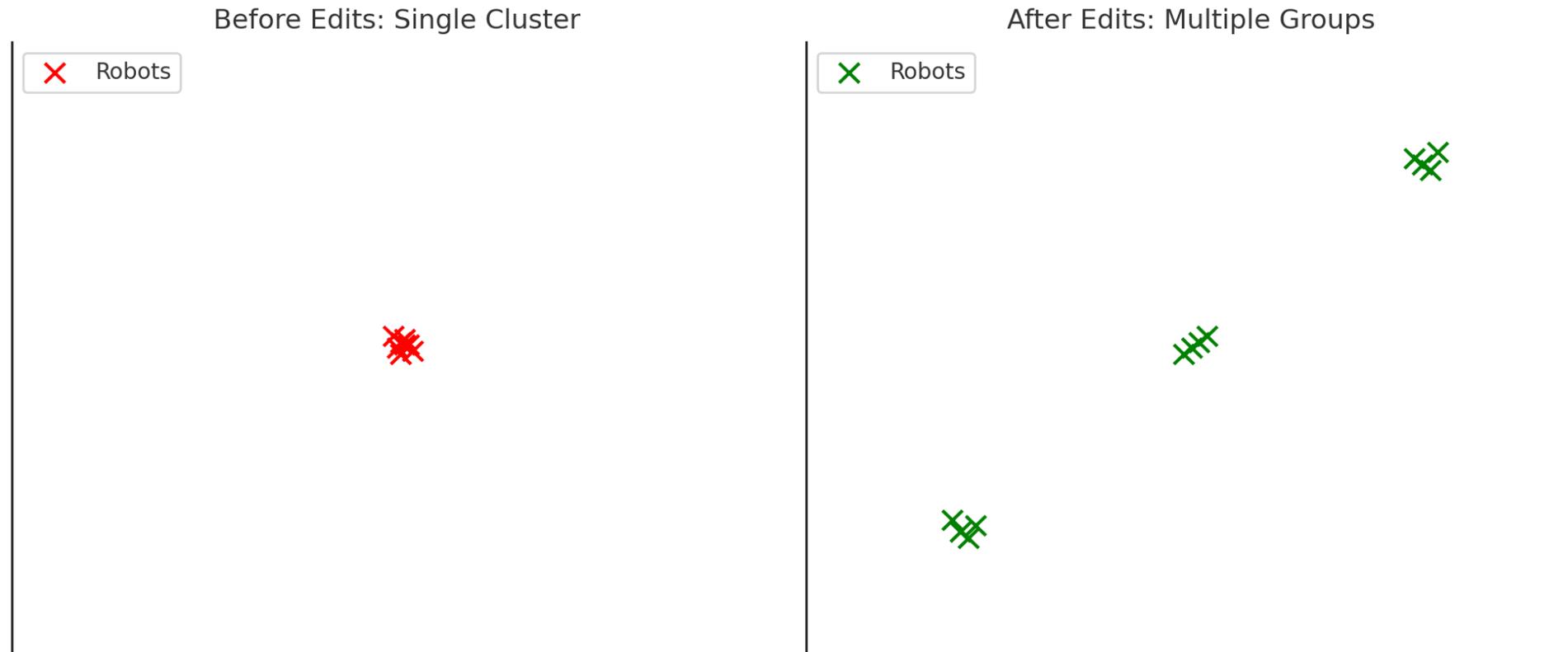
Parameter arrays
(Strategy × Need ×
TTL × Gains × Pull)

Episode
management

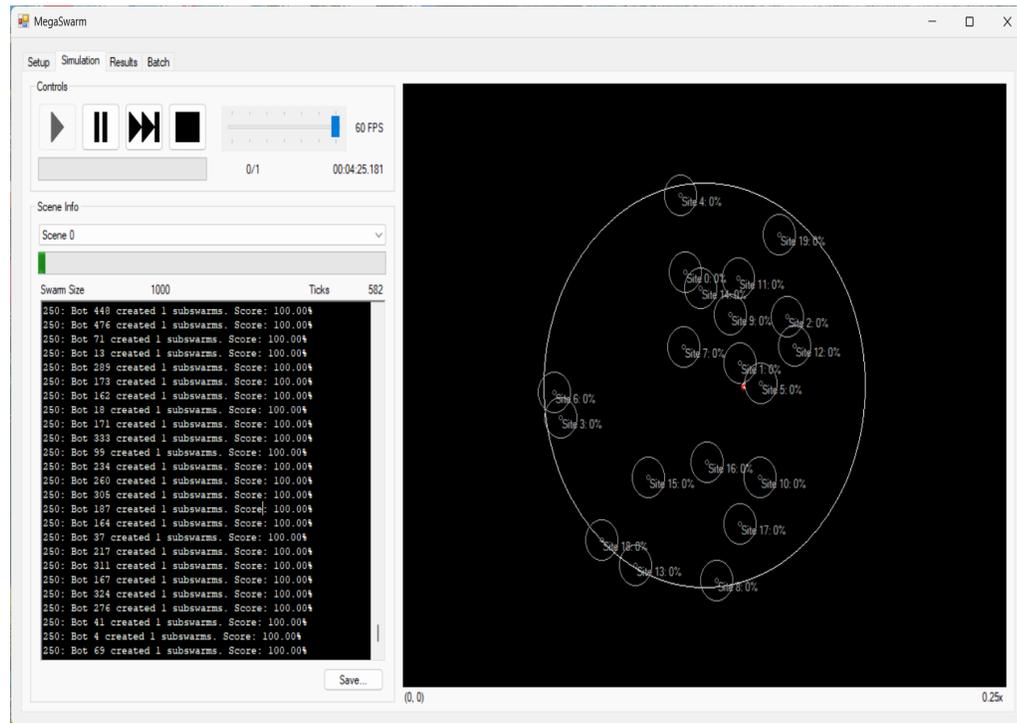
Exports Automation

OBSERVED BEHAVIOUR (BEFORE VS AFTER)

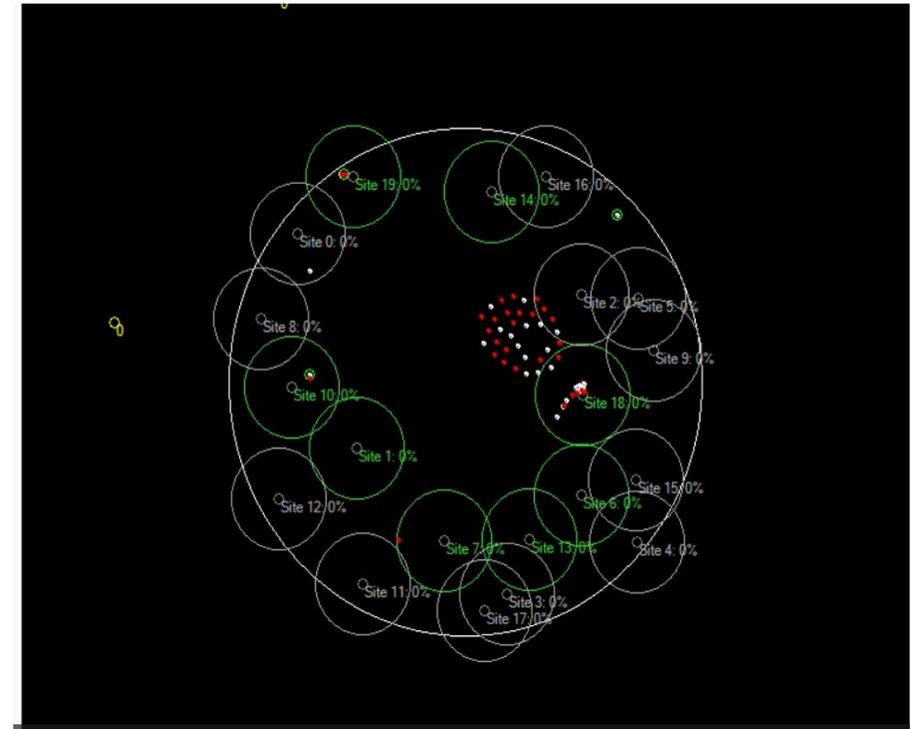
Swarm Behavior: Before vs After



OBSERVED BEHAVIOUR (BEFORE VS AFTER)



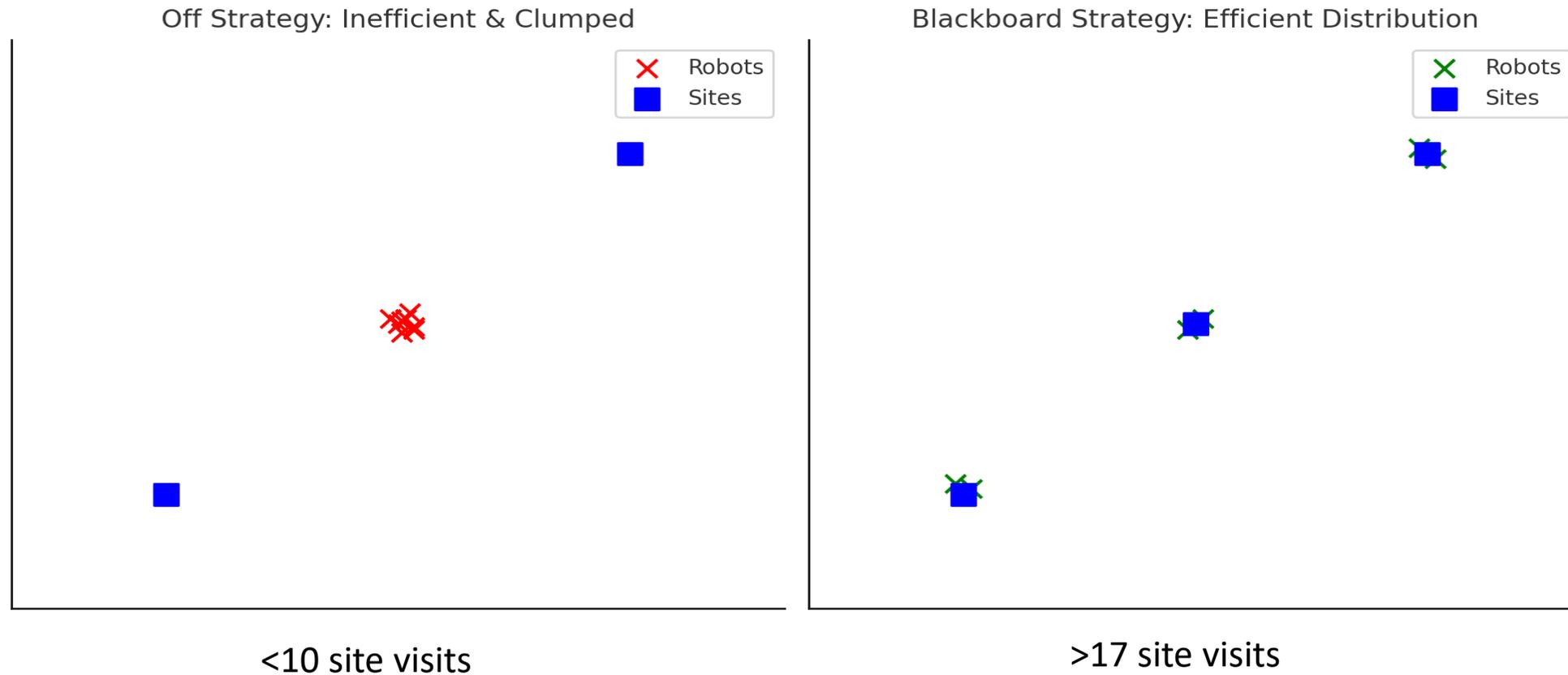
Robots in one big cluster, very few sites visited



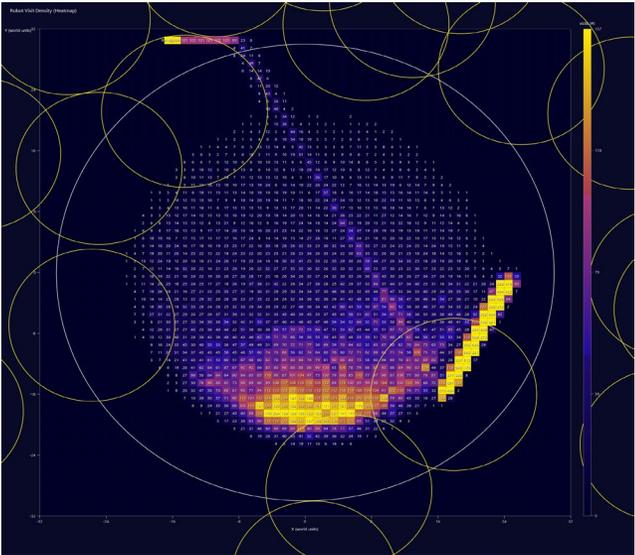
robots split into multiple groups, more sites visited

OBSERVED BEHAVIOUR (BEFORE VS AFTER)

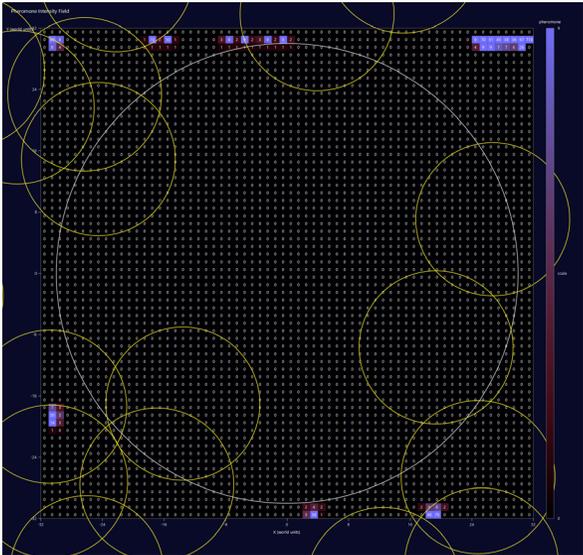
Swarm Results: Off vs Blackboard Strategies



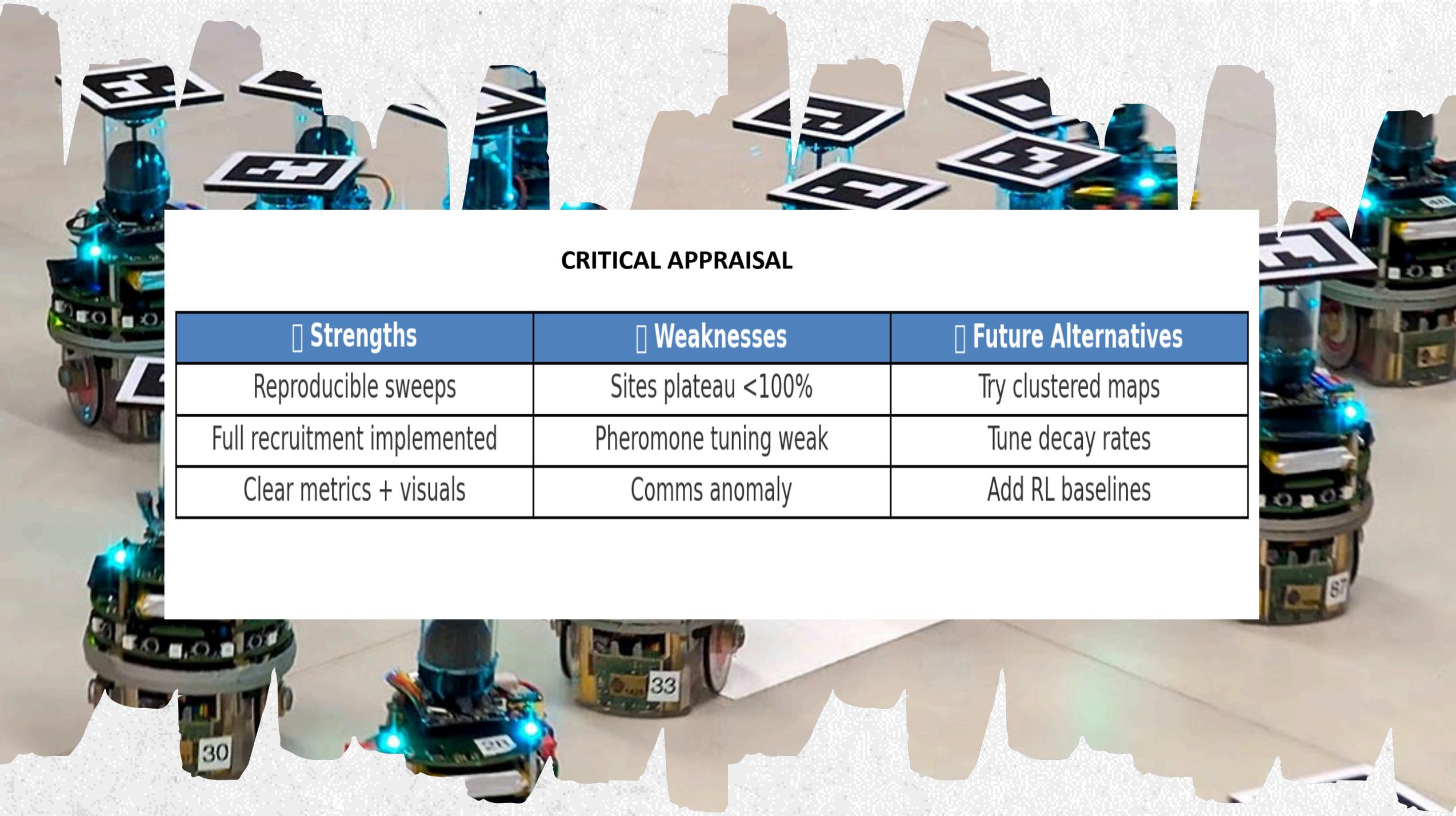
OUTPUTS



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.



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- [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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Thank You

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