Void Reduction in Self-Healing Swarms

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Video

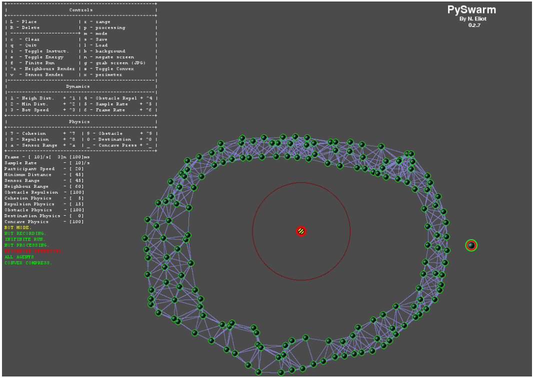


Figure: Simulator

https://www.youtube.com/watch?v=iyMSpj10elk

Introduction

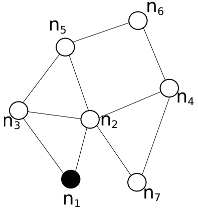
1. Set the Ground Rules!
2. Communications and/or Sensing
3. Void Reduction
4. Simulated Results

Swarm Rules

- Swarms consist of many agents (mobile robots or drones) that interact according to a simple set of rules.
- We consider swarms of agents that:
  - are capable of detecting their neighbours (proximity detection).
  - do not require any another form of communication.
- Swarms can be static or goal-based (directional).

Why no communications?

- Communication propagation protocol demands computing overhead.
  - $n_1 \rightarrow n_3$
  - $n_1 \rightarrow n_2$
  - $n_3 \rightarrow n_2$ (decision!)
- Message propagation takes time which limits swarm size.



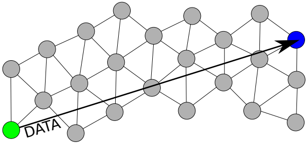


Figure: Swarm Communications

Proximity Sensing

- No communication is necessary apart from proximity detection.
- Arbitrary sized swarms are possible.
- Agent attributes include various ranges as shown in figure.

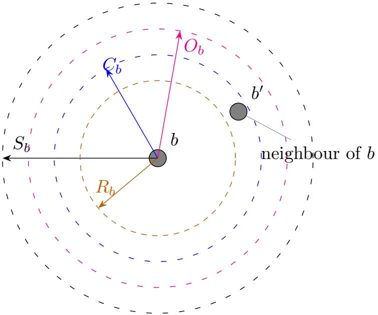


Figure: Ranges: S_b = sensing, O_b = obstacles avoidance, R_b = repulsion, C_b = cohesion.

Agent Movement

- Movement of agent b is computed as the weighted sum of 4 vectors, as shown in equation 1

$$v(b) = k_c v_c(b) + k_r v_r(b) + k_d v_d(b) + k_o v_o(b) \quad (1)$$

- $v_c(b)$: cohesion term ensures agents remain part of the swarm.
- $v_r(b)$: repulsion term ensures agents do not collide.
- $v_d(b)$: destination vector for goal based swarms.
- $v_o(b)$: obstacle avoidance vector.
- Numerical weights k_c, k_r, k_d, k_o to allow tuning of relative effects.

Swarm Structures

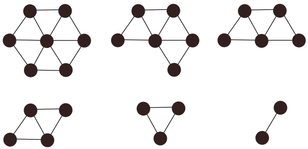


Figure: Stable Structures

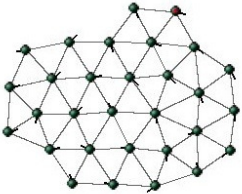


Figure: The Swarm - (Simulator)

Perimeter Detection

NOTE

Perimeter detection is used as part of the *void reduction* process. This will be discussed later.

- Perimeter detection allows for directional coordination with reduced resource usage.
  - ‘Internal’ agents don’t need to use their GPS.
- Reduces computational overhead in agents.

What is a Perimeter?

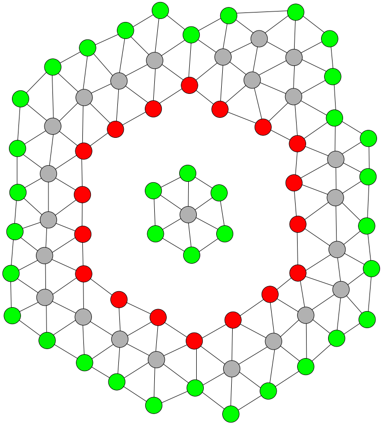


Figure: Internal (red) and external (green) perimeters

What is a Void?

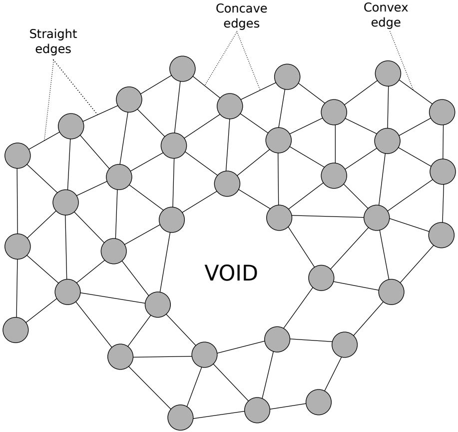


Figure: Concave components of a perimeter (voids)

Perimeter Detection (Concave)

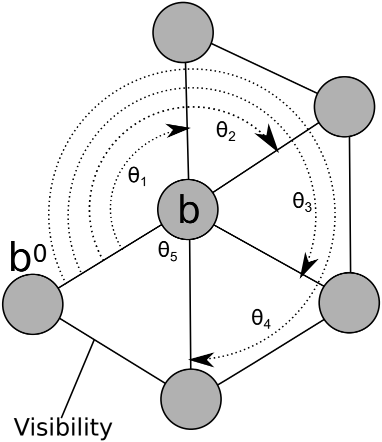


Figure: Concave gap (*Void Reduction*)

Perimeter Detection (Convex)

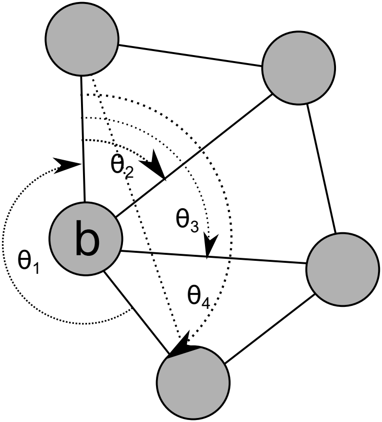


Figure: Convex gap

Void Reduction Movement

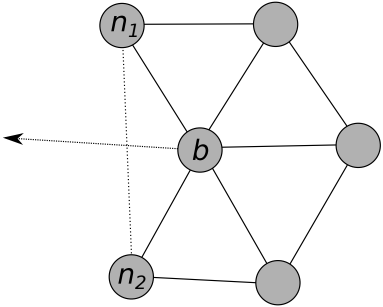


Figure: Concave detection

As part of the perimeter detection a pair $G_b = \{n_1, n_2\}$ of agents is generated. These are the first two agents identified as creating a 'gap' in agent b's neighbours. Equation 2 calculates the centroid of the identified 'gap'.

$$D_{pos}(b) = \frac{1}{2}(n_1 + n_2) \qquad (2)$$

(n_1, n_2 label agents and also denote their position vectors.)

Local Agent Movement

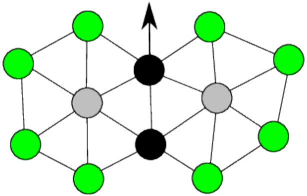


Figure: Initial positions

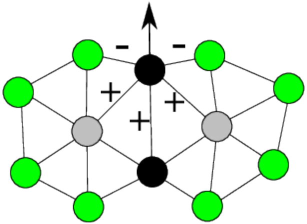


Figure: Agent movement

Global Agent Movement

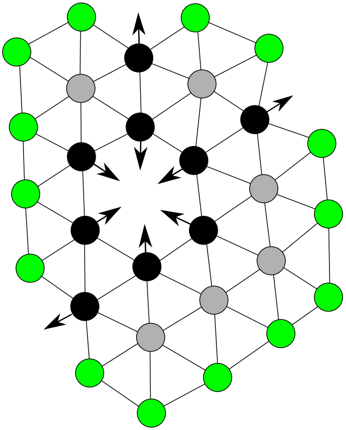


Figure: Initial positions

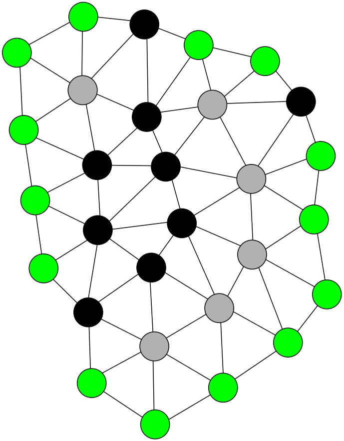


Figure: Agent movement

Scenario 1

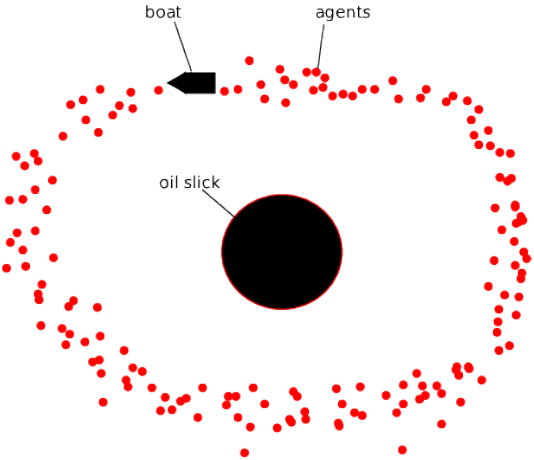


Figure: Oil Slick Encapsulation

Scenario 1

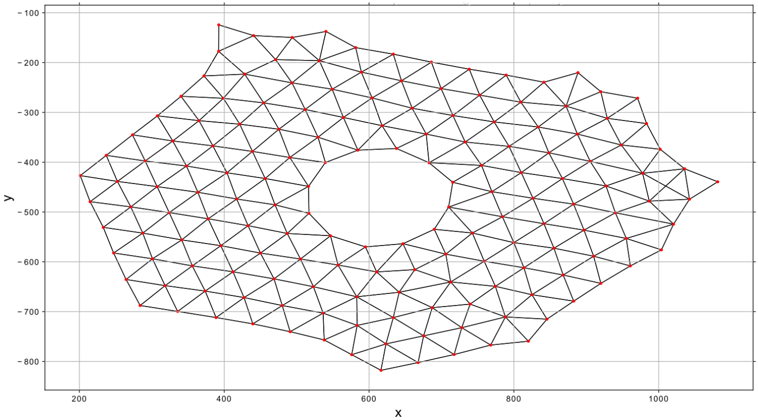


Figure: Oil Slick Encapsulation

Scenario 2

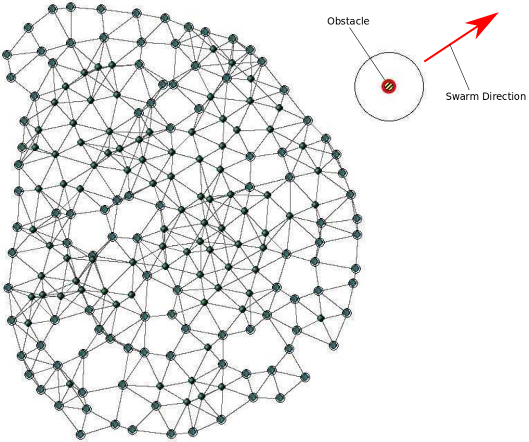


Figure: Mobile Swarm

Scenario 2

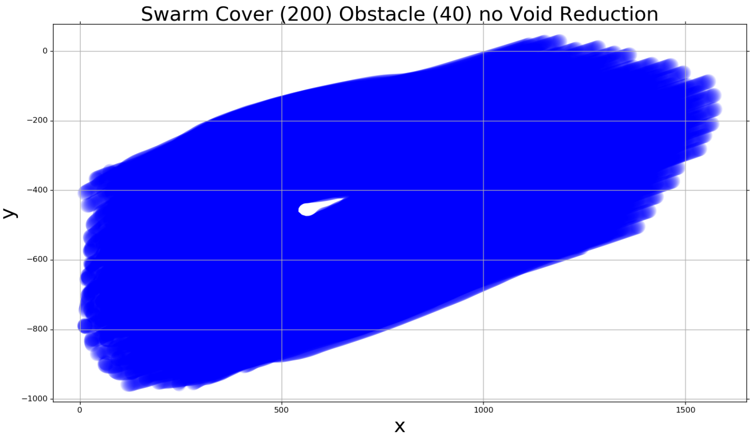


Figure: No void reduction - path plot

Scenario 2

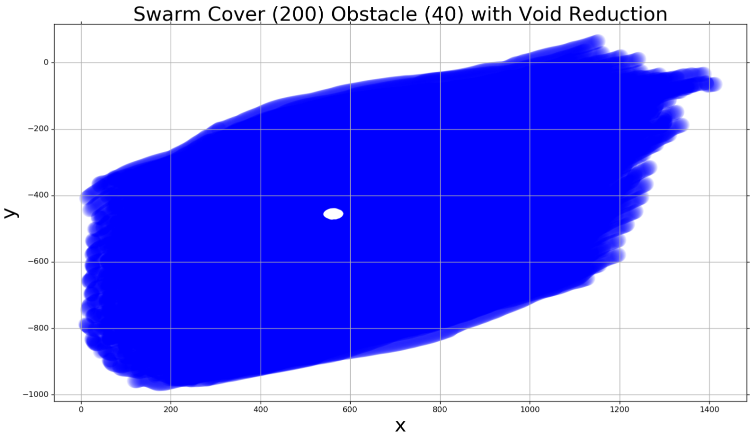


Figure: Void reduction - path plot

Summary

- Void reduction has a local effect creating a global emergent behaviour that improves the shape and structure of a swarm.
- Void reduction removes anomalies on internal and external perimeters.
- Void reduction can be applied to both static swarms and directional swarms.

Thank You

THANK YOU!
QUESTIONS?

Agent Movement

Here are the equations defining the movement vectors for cohesion and repulsion.
b, b' denote agents and also (inside the $\sum$s), their position vectors.
$\mathcal{R}_b$ is the set of agents within agent b's repulsion range; $\mathcal{C}_b$ is the set of agents within its cohesion range.

$$v_r(b) = \frac{1}{|\mathcal{R}_b|}\left(\sum_{b' \in \mathcal{R}_b}\left(1 - \frac{|b'|}{R_b}\right)b'\right) \tag{3}$$

$$v_c(b) = \frac{-1}{|\mathcal{C}_b|}\left(\sum_{b' \in \mathcal{C}_b} b'\right) \tag{4}$$

Agent Movement

$$v_d(b) = d \tag{5}$$

d is a constant vector which points to a destination.

$$v_o(b) = O_b \left(\sum_{o \in \mathcal{O}_b} \hat{o} \right)^{\wedge} \tag{6}$$

O_b is b's detection detection range; $\mathcal{O}_b$ is the set of obstacles within this range.
o denotes an obstacle and (within the $\sum$) its position vector. The caret $\hat{}$ denotes normalisation of a vector to unit length.