Distributed Computing by Oblivious Mobile Robots

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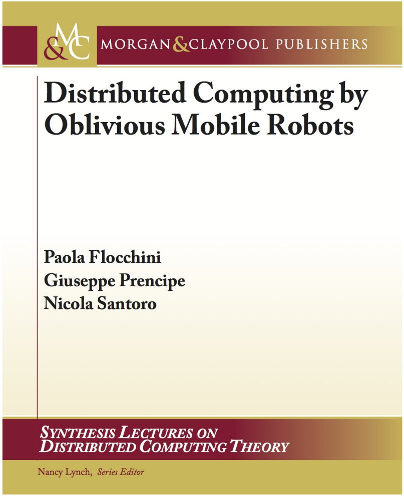
Disclaimer

- This is not my research area
- I've read a book and some papers
- I find this exciting
- I think this is very relevant for things we want to do

A nice book


MORGAN & CLAYPOOL PUBLISHERS
Distributed Computing by Oblivious Mobile Robots
Paola Flocchini
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SYNTHESIS LECTURES ON DISTRIBUTED COMPUTING THEORY
Nancy Lynch, Series Editor

Summary

- Lots of research in the theory of distributed robotics.
- Very much related to the theory of distributed systems.
- Focus on autonomous simple robots with limited communication capabilities.
- Nice theoretical results, but few things have been done in practice.

Robot models

- Networks of mobile robots which are
  - anonymous: they all run the same algorithm
  - oblivious: they keep no memory of prior computations
  - distributed: there is no central control
  - with implicit communication (typically through light)
- Sometimes, "oblivious" is relaxed to "finite memory".
- Generally, freedom from failures is assumed; few works on robots with crash faults or Byzantine faults
- Generally, robots are assumed to
  - be dimensionless: points in space; few works on solid or fat robots
  - have infinite precision; few works on inaccurate robots
  - have no notion of real time

Robots have layers (like onions or cakes)

Two-layer control model:

- Layer 1: control of individual robots
- Layer 2: control of the network

(For Layer 1, another nice book.)

Veni vidi vici

- The Look-Compute-Move cycle:
  1. Look around and gather positions of other robots and obstacles
     - sometimes, limited visibility is assumed
  2. Compute your next move
     - with or without knowledge of previous positions or moves
  3. Move to the computed new position
     - or stay put if you wish
- No looking or computing during the Move phase!
- No real-time model: can't say how long the phases will be

Network models

- fully synchronous (FSYNC): all LCM cycles in lockstep
- semi-synchronous (SSYNC): all LCM cycles in lockstep, but in every round only a subset of robots participates
- asynchronous (ASYNC): most interesting (and difficult!)

Theorem

ASYNC $\subsetneq$ *SSYNC* $\subsetneq$ *FSYNC*

Theorem

ASYNC + *5-colored lights* $\supsetneq$ *SSYNC*

Theorem

ASYNC + *3-colored lights* + *one-snapshot memory* $\supsetneq$ *FSYNC*

Gathering and convergence

- Convergence: make robots meet in one point.
- Gathering: make robots meet in one point in a finite number of rounds.

Theorem

Gathering is solvable in FSYNC, even with restricted mobility.
Convergence is solvable in ASYNC, even with restricted mobility.

Proof.

Move to center of gravity. □

Theorem

Gathering is impossible in SSYNC (and hence in ASYNC).

Proof.

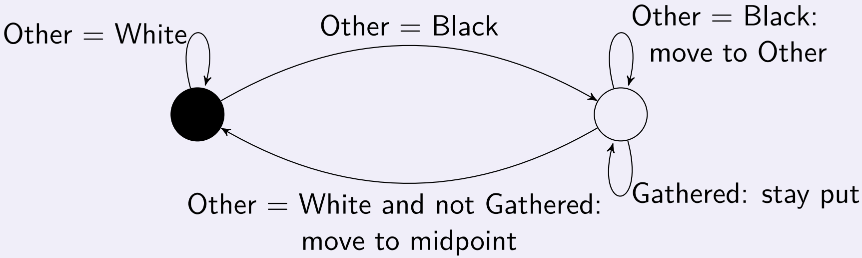
Move-to-CoG does not work; neither does anything else. □

Gathering with lights

Theorem (Heriban (COMASIC!), Défago, Tixeuil 2018)

Gathering 2 robots is solvable in ASYNC with 2-colored lights.

Proof.



□

Gathering solid robots

- Fail-stop collisions: if a robot collides with another during Move, it stops.
- Gathering: make robots form a connected configuration (in a finite number of rounds).

Theorem

Gathering is solvable in ASYNC for 2, 3 or 4 solid robots, in $\mathbb{R}^2$, assuming common unit distance and fail-stop collisions.

Proof.

(It's complicated.) □

(Nothing more seems to be known.)

Convergence with limited visibility

- Same visibility range for all robots.
- Visibility graph: points = robots; edge iff visible
- partial ASYNC: global time bound on LCM cycle duration

Theorem

Convergence is impossible in FSYNC if the initial visibility graph is disconnected.

Proof.

Trivial. □

Theorem

Convergence is solvable in partial ASYNC (and hence in SSYNC).

Proof.

Move towards center of circle which encloses all visible companions. □

Convergence with inaccuracies

- Distance imprecision ϵ: measurement $\subseteq [1-\epsilon, 1+\epsilon] \cdot$ distance
- Angular imprecision θ: $|$measurement $-$ angle$| \leq \theta$

Theorem

Gathering is impossible in FSYNC with distance imprecisions, even with memory and randomness.

Proof.

Partition the line into finitely many segments of length $\frac{1+\epsilon}{1-\epsilon}$ ... □

Theorem (Cohen-Peleg 2008)

Convergence is impossible in FSYNC if $\theta \geq 60^\circ$, even with unlimited memory.

Convergence with inaccuracies, contd.

- Distance imprecision ϵ: measurement $\subseteq [1-\epsilon, 1+\epsilon] \cdot$ distance
- Angular imprecision θ: $|$measurement $-$ angle$| \leq \theta$

Theorem (Cohen-Peleg 2008)

Convergence is solvable in FSYNC if $\sqrt{2(1+\epsilon)(1-\cos\theta)+\epsilon^2} < 0.2$.

Proof.

Move to center of gravity, but stay outside circle of possible error. □

Conjecture (Cohen-Peleg 2008)

Convergence is solvable in ASYNC for ϵ and θ sufficiently small.

Conclusion

- This is fun!
- Results also for pattern formation, covering, and flocking
- Also many results for robots on graphs
- It seems Luc wants to do moving circle formation in the Bay of Biscaya?

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SIEBEL ENERGY INSTITUTE Seed Grant Proposals

Distributed Robotics from Theory to Practice

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Ulrich (Uli) **Fahrenberg** holds a PhD in mathematics from Aalb
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Alexandre **Chapoutot**, ENSTA ParisTech ?