Brief Announcement: Infinite Grid Exploration by Disoriented Robots*

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Abstract. We deal with a set of autonomous robots moving on an infinite grid. Those robots are opaque, have limited visibility capabilities, and run using synchronous Look-Compute-Move cycles. They all agree on a common chirality, but have no global compass. Finally, they may use lights of different colors, but except from that, robots have neither persistent memories, nor communication mean. We consider the *infinite grid exploration* (IGE) problem. We first show that two robots are not sufficient in our settings to solve the problem, even when robots have a common coordinate system. We then show that if the robots' coordinate systems are not self-consistent, three or four robots are not sufficient to solve the problem neither. Finally, we present three algorithms that solve the IGE problem in various settings. The first algorithm uses six robots with constant colors and a visibility range of one. The second one uses the minimum number of robots, *i.e.*, five, as well as five modifiable colors, still under visibility one. The last algorithm requires seven oblivious anonymous robots, yet assuming visibility two. Notice that the two last algorithms also achieve exclusiveness.

1 Context and Motivation

We deal with a swarm of mobile robots having low computation and communication capabilities. The robots we consider are opaque (*i.e.*, a robot is able to see another robot if and only if no other robot lies in the line segment joining them) and run in synchronous Look-Compute-Move cycles, where they can sense their surroundings within a limited visibility range. All robots agree on a common chirality (*i.e.*, when a robot is located on an axis of symmetry in its surroundings, it is able to distinguish its two sides one from another), but have no global compass (they agree neither on a North-South, nor a East-West direction). However, they may use lights of different colors [13,18]. These lights can be seen by robots in their surroundings. However, except from those lights, robots have neither persistent memories nor communication capabilities.

We are interested in coordinating such weak robots, endowed with both typically small visibility range (*i.e.*, one or two) and few light colors (only a constant number of them), to solve an infinite task in an infinite discrete environment. As an attempt to tackle this general problem, we consider the exploration of an infinite grid, where nodes

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represent locations that can be sensed by robots and edges represent the possibility for a robot to move from one location to another. Precisely, the exploration task consists in ensuring that each node of the infinite grid is visited within finite time by at least one robot. We refer to this problem as the *Infinite Grid Exploration* (IGE) problem.

2 Contribution

We present both negative and positive results. On the negative side, we show that if robots have a common chirality but a bounded visibility range, then the IGE problem is not solvable with:

- two robots, even if those robots agree on common North (the proof is essentially the adaptation to our context of the impossibility proof given in [14]);
- three or four robots with self-inconsistent compass (*i.e.*, the compass may change throughout the execution).

On the positive side, we provide three algorithms for solving the IGE problem using opaque robots equipped with self-inconsistent compass, yet agreeing on a common chirality. Two of them also satisfy *exclusiveness* [2], which requires any two robots to never simultaneously occupy the same position nor traverse the same edge. The first one requires the minimum number of robots, *i.e.*, five, and ensures exclusiveness. The robots use modifiable lights with only five states, and have a visibility range restricted to one. The second algorithm solves the problem with six robots and only three non-modifiable colors, still assuming visibility range one. The last algorithm requires seven identical robots without any light (*i.e.*, seven oblivious[4] anonymous robots) and ensures exclusiveness, yet assuming visibility range two. Our contributions are summarized below.

visibility range	# of robots	# of colors	modifiable colors?	exclusiveness?
1	5 **(opt)**	5	yes	yes
1	6	3	no	no
2	7	1	N/A	yes

In order to help the reader, animations, for each algorithm, are available online [6]. Our algorithms and their proofs of correctness can be found in a technical report online [5].

3 Related Work

The model of robots with lights have been proposed by Peleg in [13,18]. In [8], the authors use robots with lights and compare the computational power of such robots with respect to the three main execution model: fully-synchronous, semi-synchronous, and asynchronous. Solutions for dedicated problems such as *weak gathering* or *mutual visibility* have been respectively investigated in [16] and [17].

Mobile robot computing in infinite environments has been first studied in the continuous two-dimensional Euclidean space. In this context, studied problems are mostly *terminating* tasks, such as *pattern formation* [11] and *gathering* [15], *i.e.*, problems where robots aim at eventually stopping in a particular configuration specified by their

[4] *Oblivious* means that robots cannot remember the past.

relative positions. A notable exception is the *flocking* problem [19], *i.e.*, the infinite task consisting of forming a desired pattern with the robots and make them moving together while maintaining that formation.

When considering a discrete environment, space is defined as a graph, where the nodes represent the possible locations that a robot can take and the edges the possibility for a robot to move from one location to another. In this setting, researchers have first considered finite graphs and two variants of the exploration problem, respectively called the *terminating* and *perpetual* exploration. The terminating exploration requires every possible location to be eventually visited by at least one robot, with the additional constraint that all robots stop moving after task completion. In contrast, the perpetual exploration requires each location to be visited infinitely often by all or a part of robots. In [9], authors solve terminating exploration of any finite grid using few asynchronous anonymous oblivious robots, yet assuming unbounded visibility range. The exclusive perpetual exploration of a finite grid is considered in the same model in [3].

Various terminating problems have been investigated in infinite grids such as *arbitrary pattern formation* [4], *mutual visibility* [1], and *gathering* [10,12]. The possibly closest related work is that of Emek *et al.* [14]. In this paper, authors consider a treasure search problem, which is roughly equivalent to the IGE problem, in an infinite grid. They consider robots that operate in two models: the semi-synchronous and synchronous ones. However, they do not impose the exclusivity at all since their robots can only sense the states of the robots located at the same node (in that sense, the visibility range is zero). The main difference with our settings is that they assume all robots agree on a *global compass*, *i.e.*, they all agree on the same directions North-South and East-West; while we only assume here a *common chirality*. This difference makes their model stronger, indeed they propose two algorithms that respectively need three synchronous and four asynchronous robots, while in our settings the IGE problem (even in its non-exclusive variant) requires at least five robots. They also exclude solutions for two robots. Brandt *et al.* [7] extend the impossibility result of Emek *et al.* Indeed, they show the impossibility of exploring an infinite grid with three semi-synchronous deterministic robots that agree on a common coordinate system. Although proven using similar techniques, this result is not correlated to ours. Indeed, the lower bound of Brandt *et al.* holds for robots that are weaker in terms of synchrony assumption (semi-synchronous *vs.* fully synchronous in our case), but stronger in terms of coordination capabilities (common coordinate system *vs.* self-inconsistent compass in our case). In other words, our impossibility results does not (even indirectly) follows from those of Brandt *et al.* since in our model difficulties arise from the lack of coordination capabilities and not the level asynchrony. As a matter of facts, based on the results of Emek *et al.* [14], four (asynchronous) robots are actually necessary and sufficient in their settings, while in our context five robots are required.

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