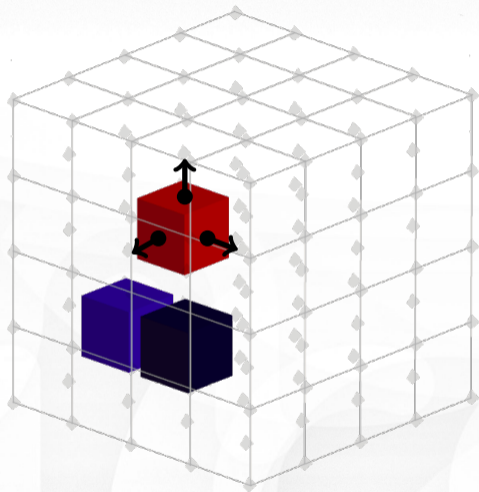


77 NUANCES DE COULEURS

1 Juin 2026

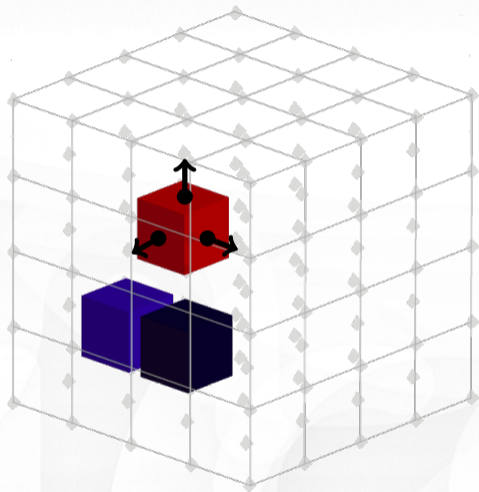
QUENTIN BRAMAS STÉPHANE DEVISMES ANAÏS DURAND
PASCAL LAFOURCADE ANISSA LAMANI

Perpetual Exploration with a Swarm of Luminous Robots

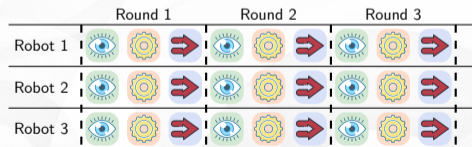


- ▶ Discrete moves in the **3D grid**
- ▶ Communications through **lights** of colors
- ▶ Limited visibility range
- ▶ No memory of previous actions
- ▶ No other communications

Perpetual Exploration with a Swarm of Luminous Robots



- ▶ Discrete moves in the **3D** grid
- ▶ Communications through **lights** of colors
- ▶ Limited visibility range
- ▶ No memory of previous actions
- ▶ No other communications
- ▶ **Synchronous** Look-Compute-Move cycles



[FUN'22]

Beedroids: How Luminous Autonomous Swarms of UAVs Can Save the World?

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— Abstract —

Bee extinction is a great risk for humanity. To circumvent this ineluctable disaster, we propose to develop beedroids, *i.e.*, small UAVs mimicking the behaviors of real bees. Those beedroids are endowed with very weak capabilities (short-range visibility sensors, no GPS, light with a few colors, ...). Like real bees, they have to self-organize together into swarms. Beedroid swarms will be deployed in cuboid-shaped greenhouse. Each beedroid swarm will have to indefinitely search for flowers to pollinate in its greenhouse. We model this problem as a perpetual exploration of a 3D grid by a swarm of beedroids. In this paper, we propose two optimal solutions to solve this problem and so to save humanity.

In the Previous Episode

[FUN'22]

Beedroids: How Luminous Autonomous UAVs Can Save the World

Quentin R...

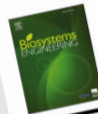
17-18

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Review

A review of strategic enhancement of pollination with smart agriculture to counteract the decline of natural pollinators

Wantong Zhang, Fa Song, Jiyu Sun 
Key Laboratory of Bionic Engineering (Ministry of Education, China), Jilin University, Changchun, 130022, China

ARTICLE INFO

Keywords:

UAV

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Artificial pollination

Intelligent technologies

ABSTRACT

The population of animal pollinators has been steadily declining due to human activities, disrupting the balance of agricultural ecosystems. In response, UAV pollination technology has emerged as a promising option to mitigate the shortage of natural pollination services. This paper reviews the background of the development of UAV pollination technology, summarises and evaluates current UAV pollination technology and the intelligent technologies involved therein, highlighting the current state and development limitations. Finally, based on this analysis and the prevailing conditions of crop pollination and agricultural environments, the integration of intelligent technologies is proposed, particularly UAV-based systems, to improve the efficiency of pollination.



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In the Previous Episode

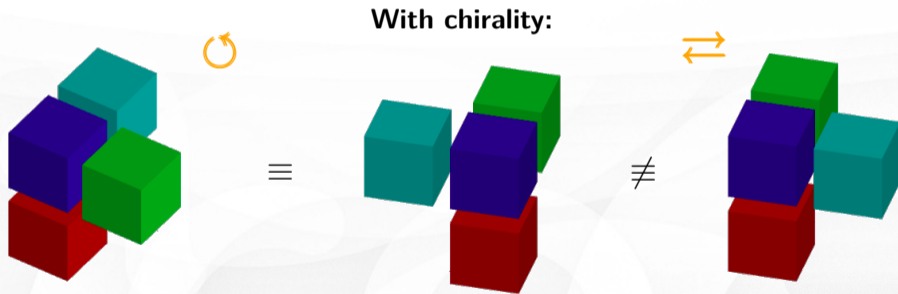
- ▶ [FUN'22]: Perpetual exploration of a 3D grid with disoriented luminous robots
 - ▷ With 3 robots, 5 colors, and visibility range 1
 - ▷ With 5 oblivious robots and visibility range 2

In the Previous Episode

- ▶ [FUN'22]: Perpetual exploration of a 3D grid with disoriented luminous robots **with chirality**
 - ▷ With 3 robots, 5 colors, and visibility range 1
 - ▷ With 5 oblivious robots and visibility range 2

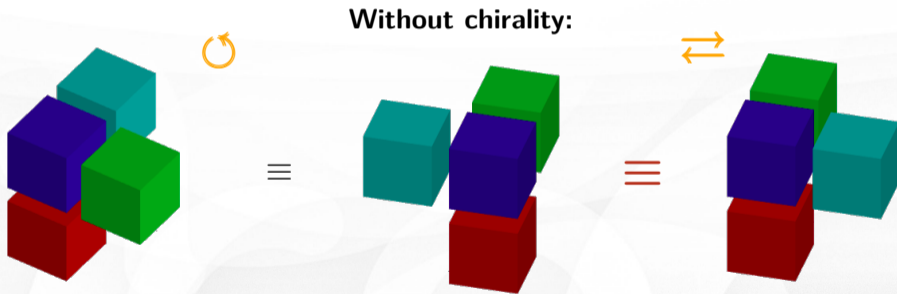
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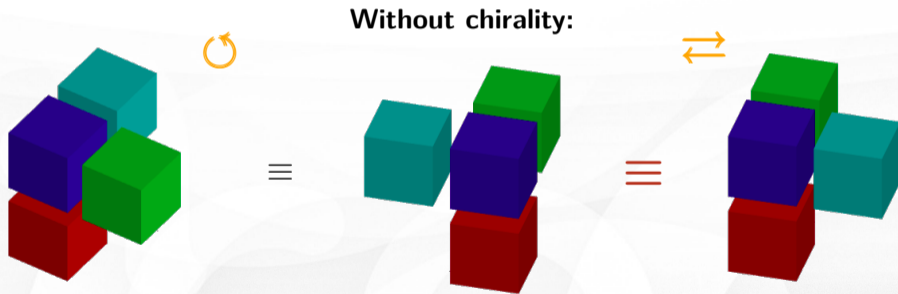
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⇒ Perpetual exploration of a 3D grid without chirality?

Previous Results

► On 2D grids:

	Visibility	# Robots	# Colors
With chirality	*	1	*
	1	2	3
Without chirality	*	2	*
	1	3	3

[Bramas et al., ICDCN'21]

[Bramas et al., NETYS'21]

And many other results on 2D grids, infinite 2D grids, torus ...

Previous Results

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[Bramas et al., ICDCN'21]

[Bramas et al., NETYS'21]

And many other results on 2D grids, infinite 2D grids, torus ...

► On 3D grids:

	Visibility	# Robots	# Colors
With chirality	1	2	*
	1	3	5
Without chirality	?	?	?

[Bramas et al., FUN'22]

Impossibility Result

Impossible with 3 robots, no chirality, and visibility 1

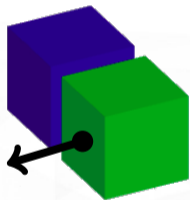
Impossibility Result

Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

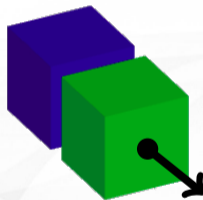
Impossibility Result

Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

Ambiguous Move?



Ambiguous

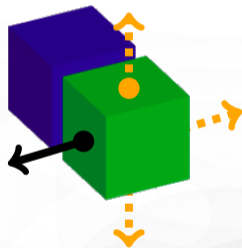


Not ambiguous

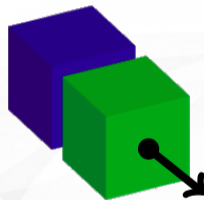
Impossibility Result

Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

Ambiguous Move?



Ambiguous



Not ambiguous

Impossibility Result: Some Intuition

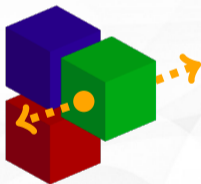
Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

- ▶ Isolated robot = cannot move
- ▶ Visibility 1 \Rightarrow the 3 robots are on a plane

Impossibility Result: Some Intuition

Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

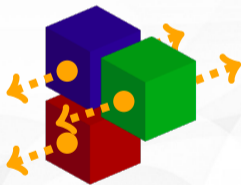
- ▶ Isolated robot = cannot move
- ▶ Visibility 1 \Rightarrow the 3 robots are on a plane
- ▶ Must leave the plane to explore the grid



Impossibility Result: Some Intuition

Impossible with 3 robots, no chirality, and visibility 1 **without ambiguous moves**

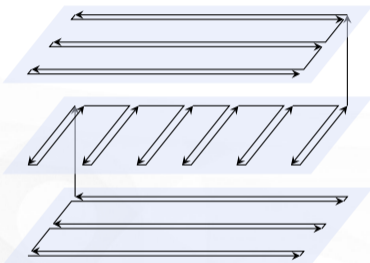
- ▶ Isolated robot = cannot move
- ▶ Visibility 1 \Rightarrow the 3 robots are on a plane
- ▶ Must leave the plane to explore the grid



- ▶ Both directions are indistinguishable \Rightarrow **Ambiguous move**

Algorithm 1: Visibility 2, 3 Robots, 5 Colors, no Ambiguous Moves

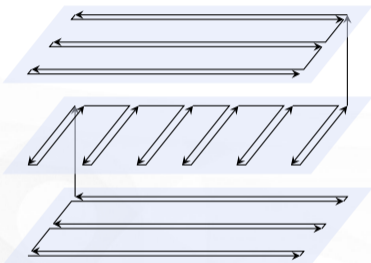
Exploration Path:



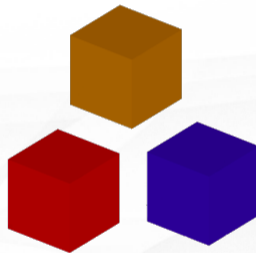
<https://y.uca.fr/fun26-algo1>

Algorithm 1: Visibility 2, 3 Robots, 5 Colors, no Ambiguous Moves

Exploration Path:



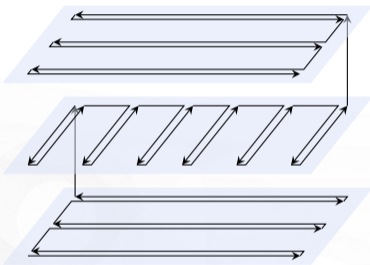
Relative Positions:



<https://y.uca.fr/fun26-algo1>

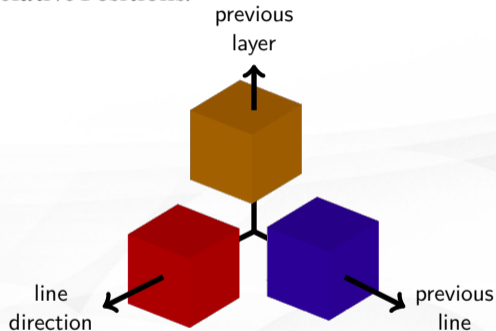
Algorithm 1: Visibility 2, 3 Robots, 5 Colors, no Ambiguous Moves

Exploration Path:



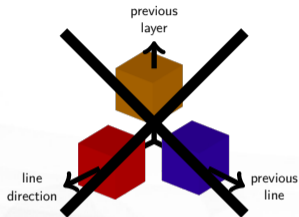
<https://y.uca.fr/fun26-algo1>

Relative Positions:



⇒ Build an orientation system

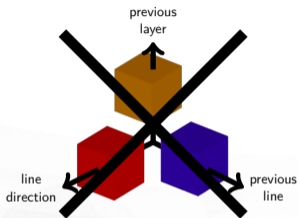
Algorithm 2: Visibility 1, 3 Robots, 77 Colors, Ambiguous Moves



<https://y.uca.fr/fun26-algo2>

Algorithm 2: Visibility 1, 3 Robots, 77 Colors, Ambiguous Moves

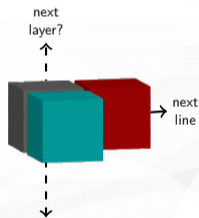
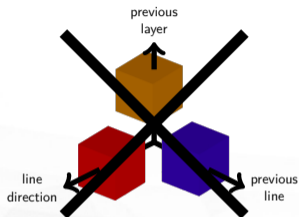
Encoding Directions at the Wall:



<https://y.uca.fr/fun26-algo2>

Algorithm 2: Visibility 1, 3 Robots, 77 Colors, Ambiguous Moves

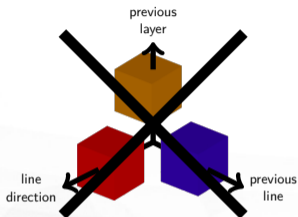
Encoding Directions at the Wall:



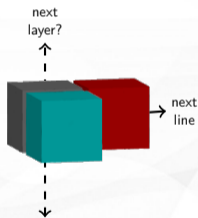
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Encoding Directions at the Wall:

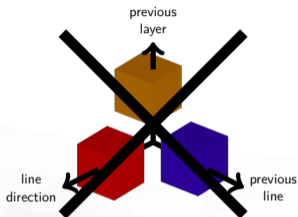


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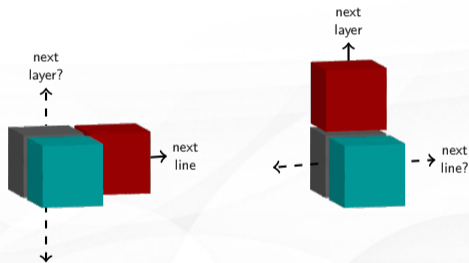


Algorithm 2: Visibility 1, 3 Robots, 77 Colors, Ambiguous Moves

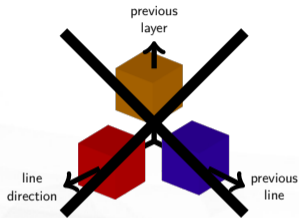
Encoding Directions at the Wall:



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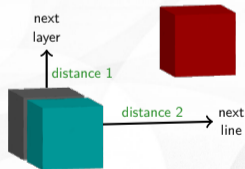
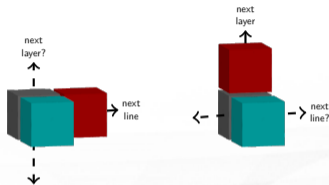


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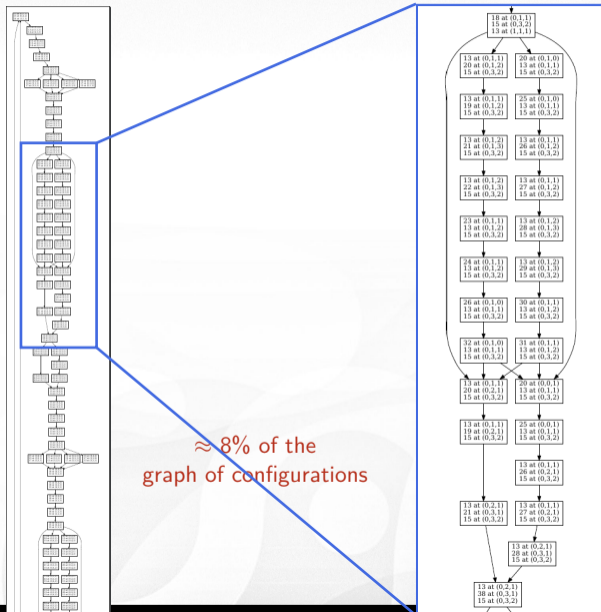


<https://y.uca.fr/fun26-algo2>

Encoding Directions at the Wall:



Algorithm 2: Visibility 1, 3 Robots, 77 Colors, Ambiguous Moves



≈ 8% of the graph of configurations

Our Contributions

Perpetual exploration of finite **3D** grids **without chirality**

- ▶ **Impossibility** with **3** robots and visibility **1** without **ambiguous moves**
- ▶ Algorithm **without ambiguous moves** in visibility **2**
optimal in number of robots & visibility (3 robots, 5 colors)
- ▶ Algorithm **with ambiguous moves** in visibility **1**
optimal in number of robots & visibility (3 robots, 77 colors)

Open Questions

- ▶ **Optimality** in number of **colors**?
 - ▷ With less than 5 colors and no ambiguous moves?
 - ▷ With less than 77 colors and ambiguous moves?

Open Questions

- ▶ **Optimality** in number of **colors**?
 - ▷ With less than 5 colors and no ambiguous moves?
 - ▷ With less than 77 colors and ambiguous moves?

- ▶ **Generalization** to any dimension?
 - ▷ Adding an extra robot not always necessary for superior dimension and/or removing chirality assumption.

Open Questions

- ▶ **Optimality** in number of **colors**?
 - ▷ With less than 5 colors and no ambiguous moves?
 - ▷ With less than 77 colors and ambiguous moves?

- ▶ **Generalization** to any dimension?
 - ▷ Adding an extra robot not always necessary for superior dimension and/or removing chirality assumption.

- ▶ What about **infinite** 3D grids?

THANK YOU!

Full paper:

77 Shades of Grey. Quentin Bramas,
Stéphane Devismes, Anaïs Durand,
Pascal Lafourcade, Anissa Lamani. FUN 2026

77 NUANCES
PLUS SOMBRES



Upcoming (maybe) ...