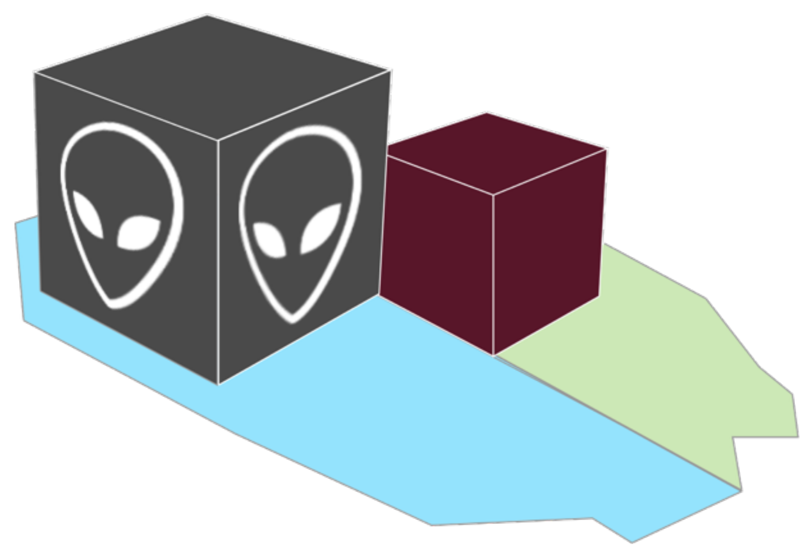
Extended stigmergy

in collective construction



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How to program an artificial swarm to build a given structure?


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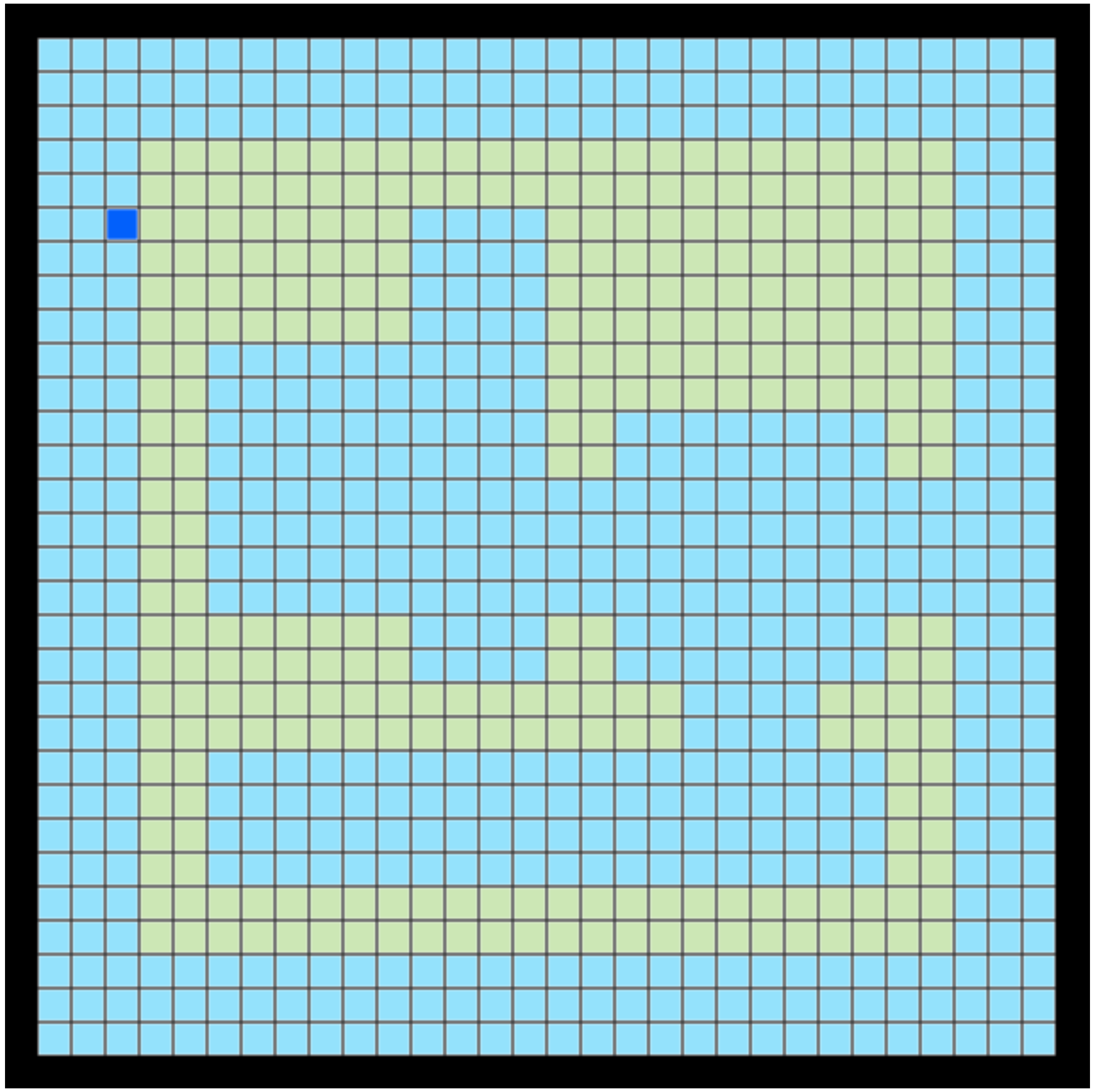
indirect coordination between agents, where the trace left in the environment by an action stimulates the performance of a subsequent action.

Framework: the world

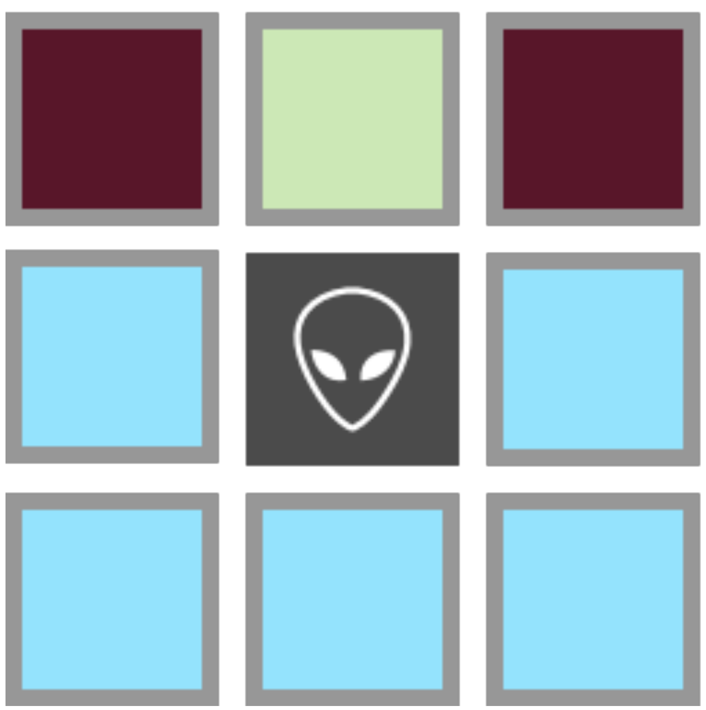
- 2D buildings with square blocks
- no interference from the environment
- every concavity in the structure must be at least two blocks wide



Framework: agents

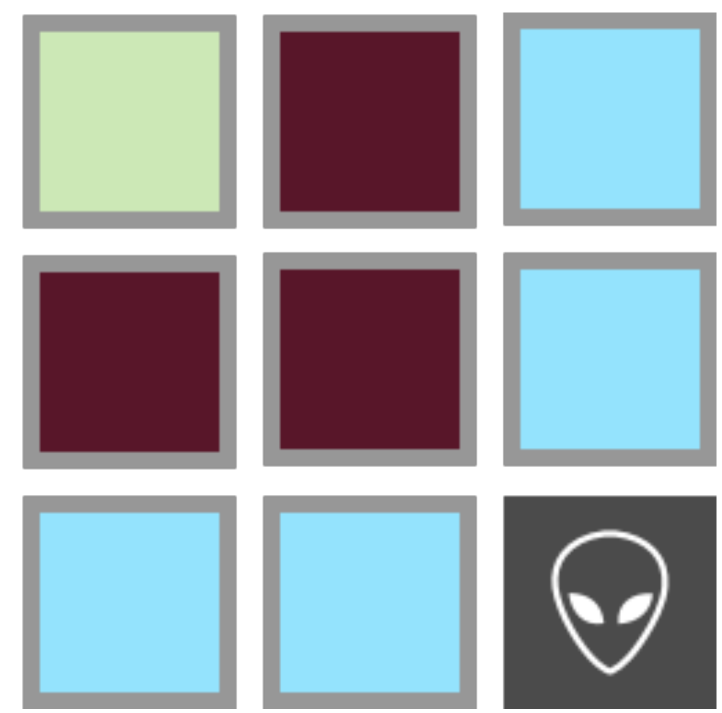
- unspecified number of agents
- robustness w.r.t. agent failures
- no explicit communication between agents
- agents do not know a priori their absolute position w.r.t. the building

Framework: problems

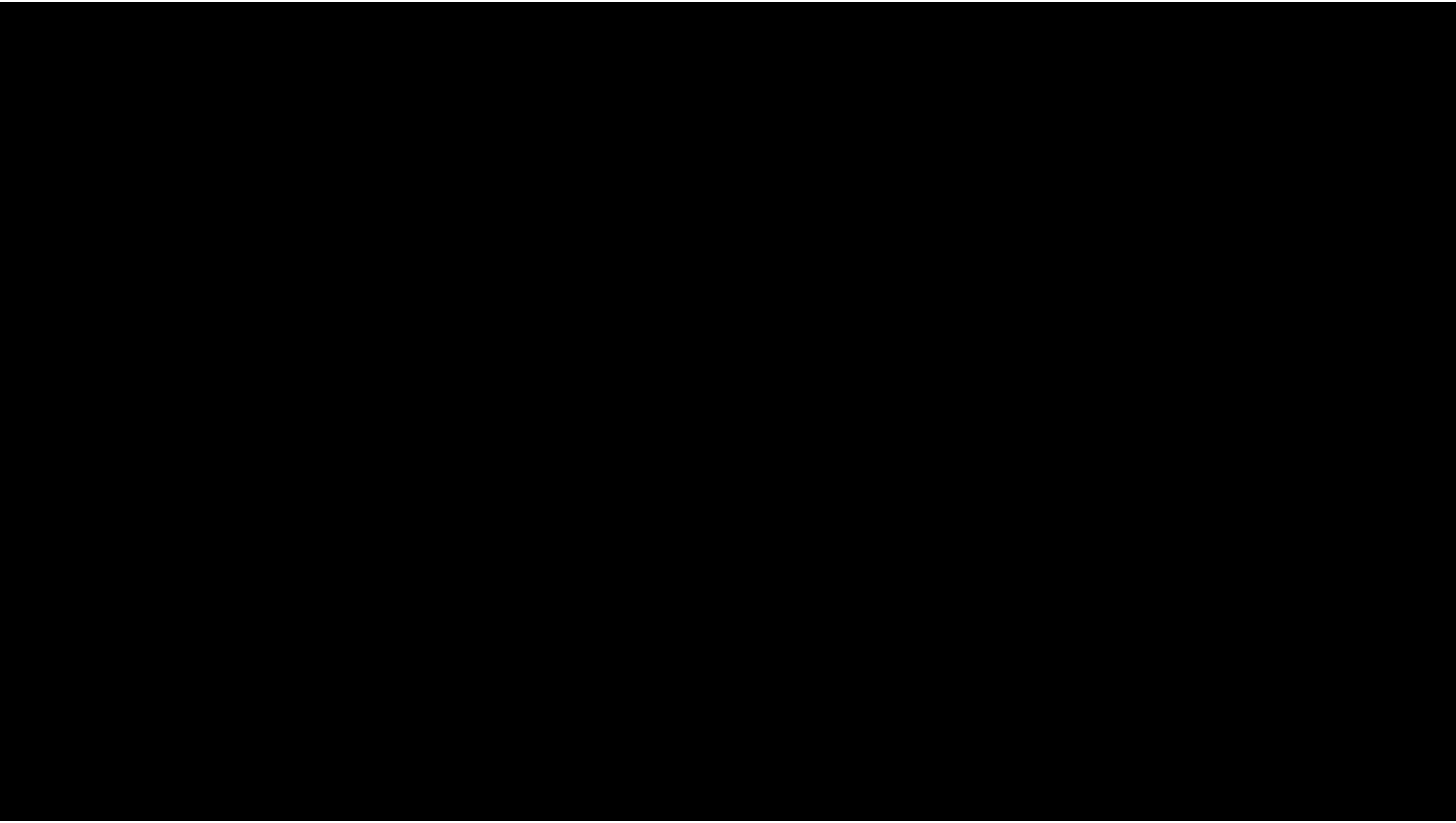


Separated blocks

Prisoner

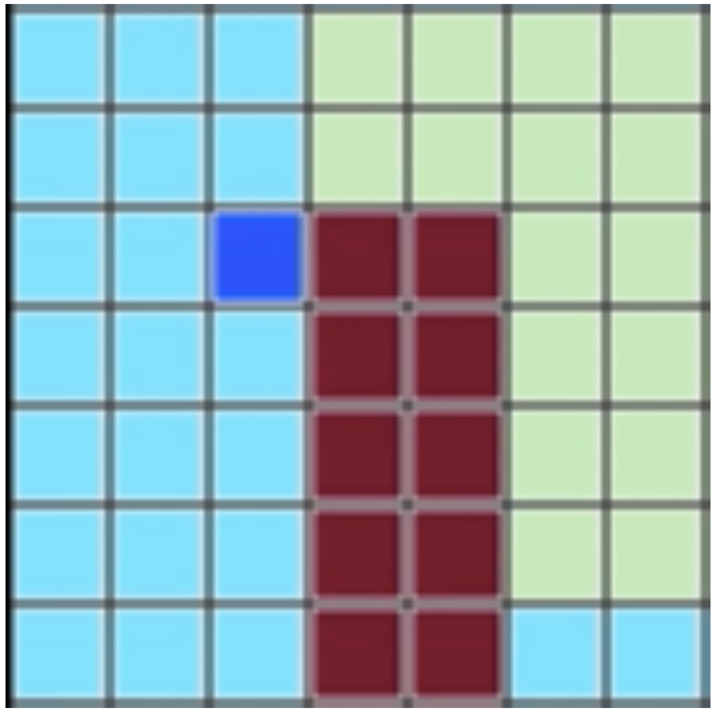


Dead-ends

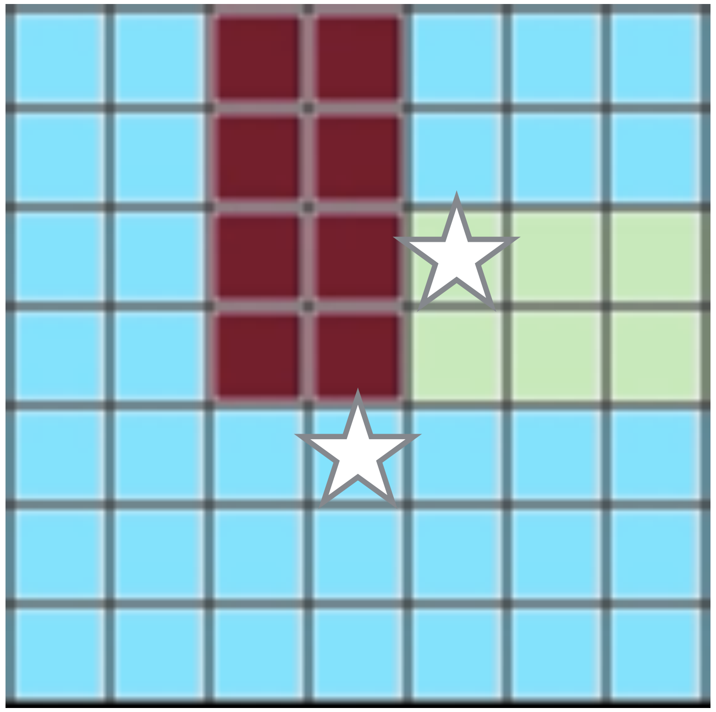


https://youtu.be/Qa-ephtt7eI

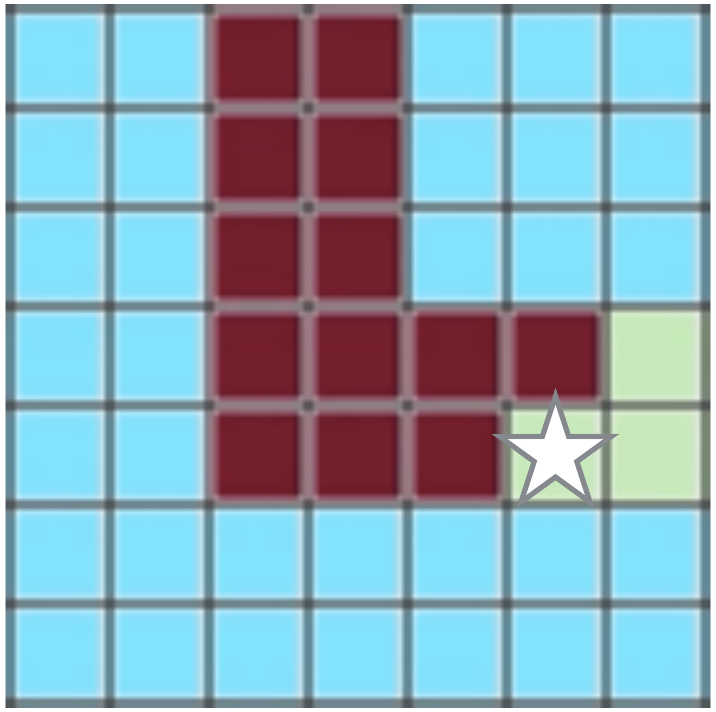
Terminology



Landmark

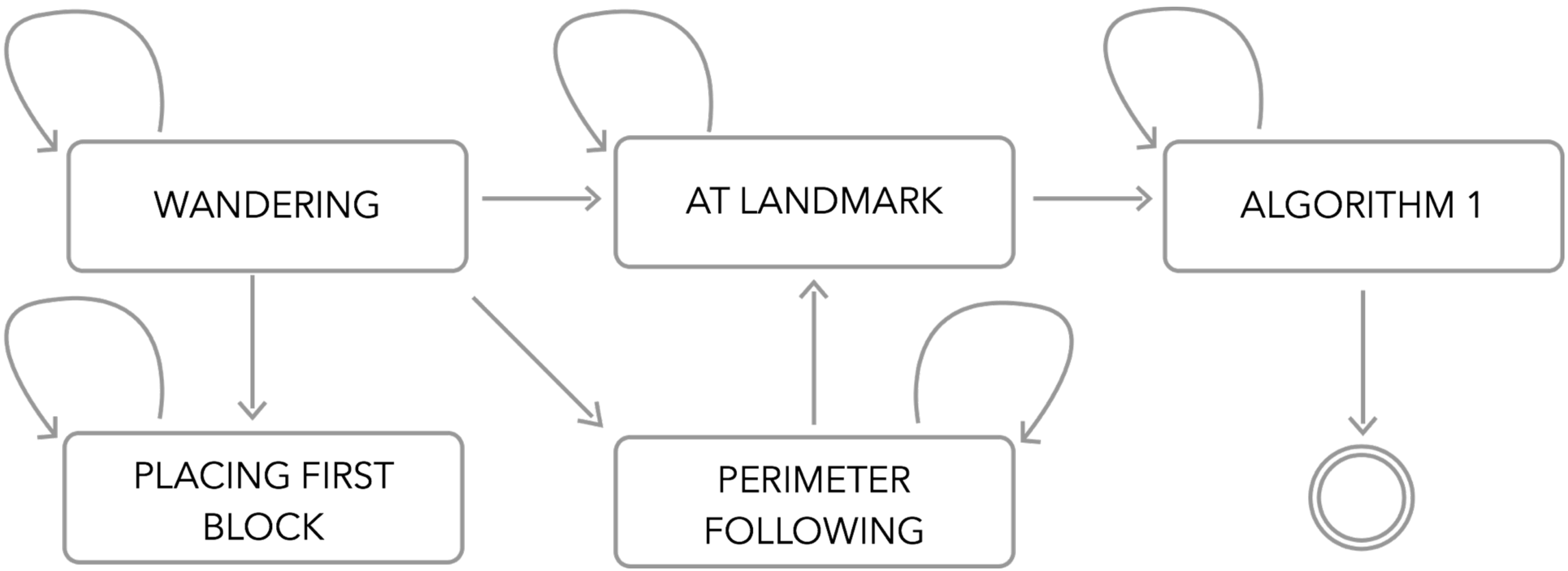


End of row



Inside corner

Agent FSM


WANDERING
AT LANDMARK
ALGORITHM 1
PLACING FIRST BLOCK
PERIMETER FOLLOWING

Algorithm

```
seen-row-start <-- false
while still holding block do
  if (site should have a block) and
  ((at inside corner) or
  (seen-row-start and (at end-of-row))) then
    attach block here
    write coordinates to block
  else
    if at end-of-row then
      seen-row-start <-- true
    end if
    follow perimeter counterclockwise
  end if
end while
```

https://youtu.be/eheLjRLky2o

Proof (hypothesis)

Suppose the algorithm can get stuck

(that is, it can reach a stage of construction where no further blocks can be attached, but at least one empty site is still supposed to be occupied)

It can’t be due to an unfillable gap

(the algorithm naturally avoids this situation)

Along the incomplete structure’s perimeter, one of the following must be true:

Blocks are supposed to occupy all sites

or

At least one site is supposed to be left empty

Proof (contradiction 1)

In the first case,

consider a robot moving **counterclockwise** along the perimeter of any closed shape drawn only with right angles.

It must come to a point where it has to take two left turns sequentially → The second left turn is an end-of-row site that can be occupied

Proof (contradiction 2)

In the second case,

there can be no inside corners where blocks are supposed to be attached, or the algorithm could attach them there.

A finite shape can't have inside corners indefinitely $\longrightarrow$ Again contradiction

Communication vs Common Knowledge

Common knowledge

Pros

- Less failure points
- Cheaper technology

Cons

- Less parallelism
- Not very robust to position errors (miscounting, external factors)
- Need all the way to find the landmark

Communication

Pros

- High parallelism
- Faster block positioning
- Simpler agents

Cons

- Higher cost
- Higher number of failure points

Writable blocks

Passive noncommunicating block (trough RFID)

They don't communicate between each other but can store values that can be read by the approaching agents

Store nonlocal information

Robots understand their position reading from previously placed blocks

Share position information

When placing a block the robot marks it with its coordinates to make it available for other incoming agents

Communicating blocks

Processors embedded in each block

Communication

Blocks have a physical connection to their immediate neighbors, forming the basis for a data line

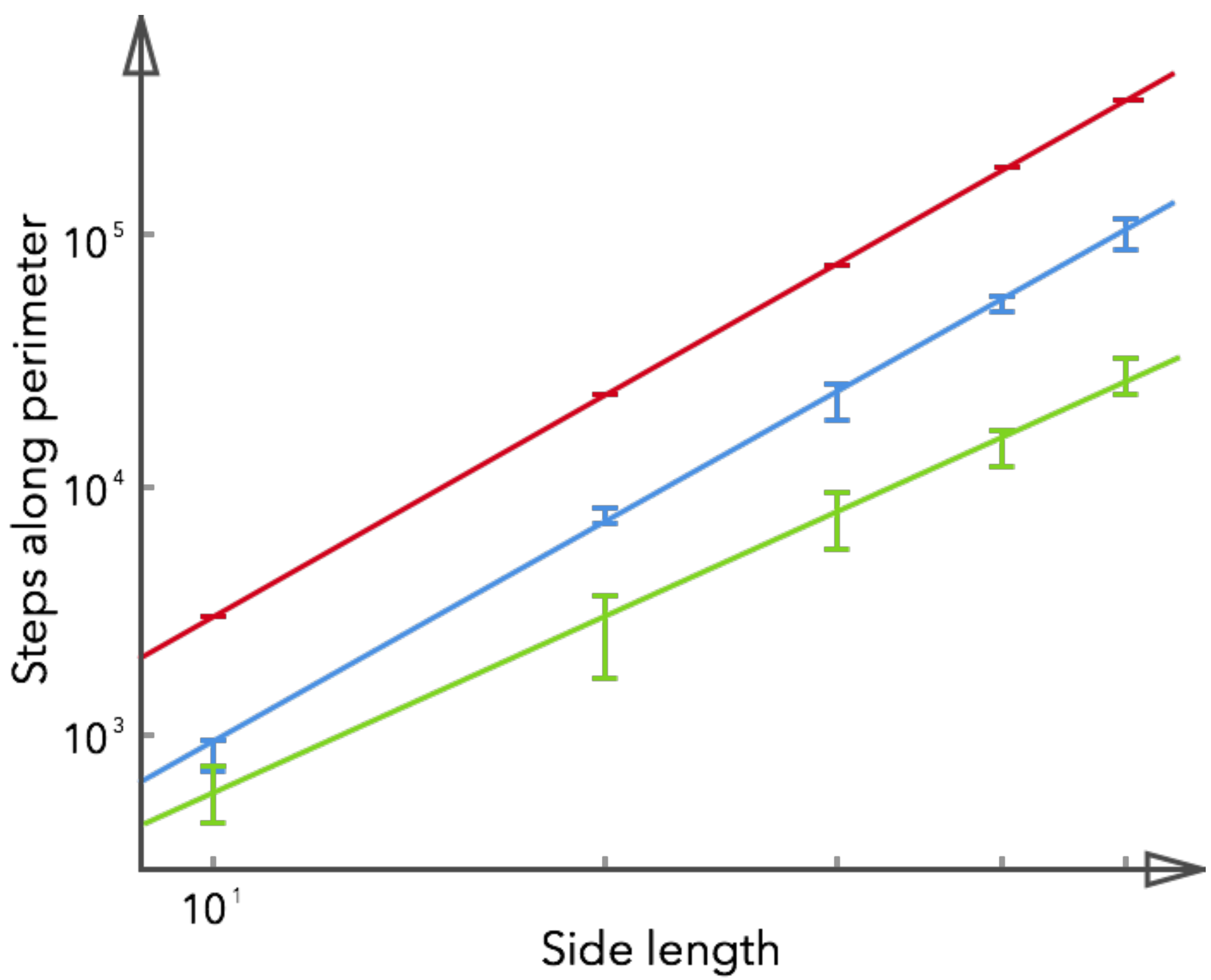
The structure ensures constraints

Blocks indicate to robots passing along their perimeter whether they allow attachment

NOTE:

To prevent communication delays from causing separated blocks attachments, blocks lock a row from additional attachment before giving permission to any robot to attach

Performance comparison 1



Steps along perimeter

Inert blocks

Best case is approching at landmark.
Worst case is approaching immediately after. In both case O(n3)

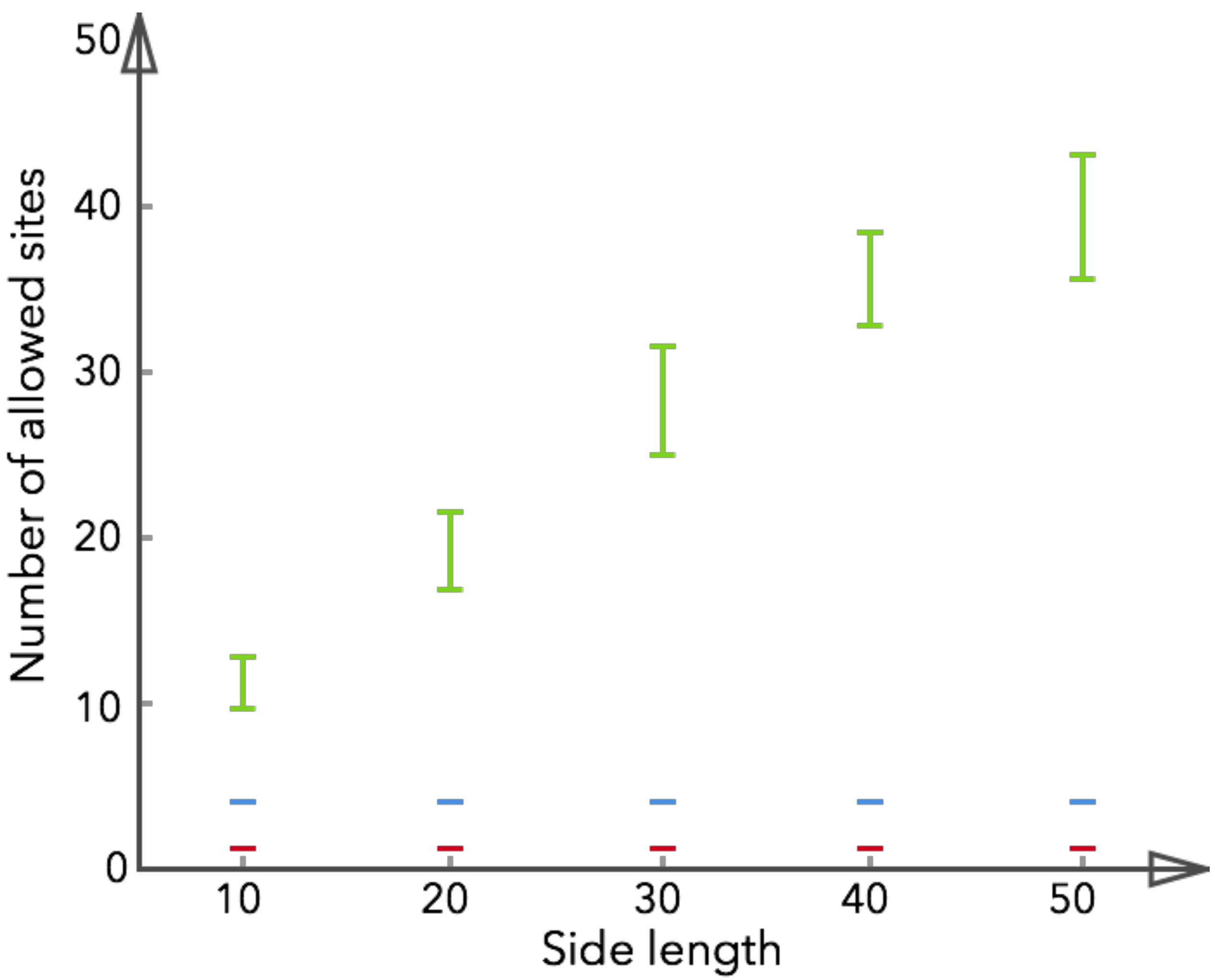
Writable blocks

Best case for is O(n2)
(n new rows with length O(n) to check emptyness)
Worst case is O(n3)

Communicating blocks

the best case is 0, the worst case is O(n3)

Performance comparison 2



Allowed sites

Inert blocks

Only one site is ever admissible for attachment at a time

Writable blocks

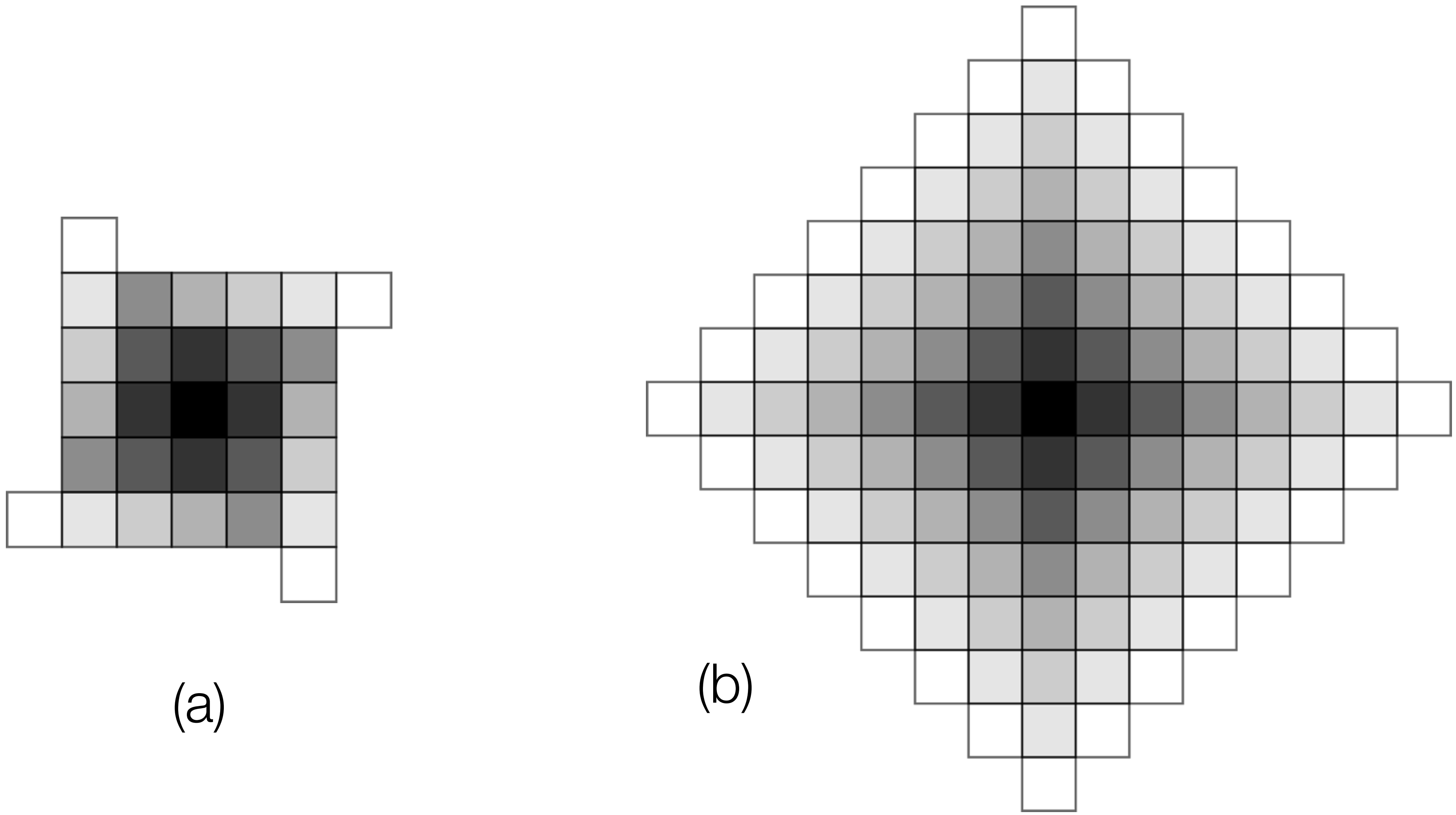
Lets robots work on all four sides of the structure at once

Communicating blocks

Many more allowed sites

(Availability scales up with structure size)

Performance comparison 3



Blocks placed after 8 steps assuming that the number of robots N is arbitrarily large for writable block **(a)** and communicating block **(b)**

Personal impressions

Due to its **current limitations**,

robotic collective construction is useful in either in dangerous situations or where human intervention is not possible

As a consequence:

- Using inert blocks is less prone to failures and more feasible
- The use of writable or communicative blocks makes it difficult to manufacture on site
- Costs, especially for communicative blocks, don't scale well with growing structure dimensions