Toward a 2D Modular and Self-Reconfigurable Robot for Conveying Microparts

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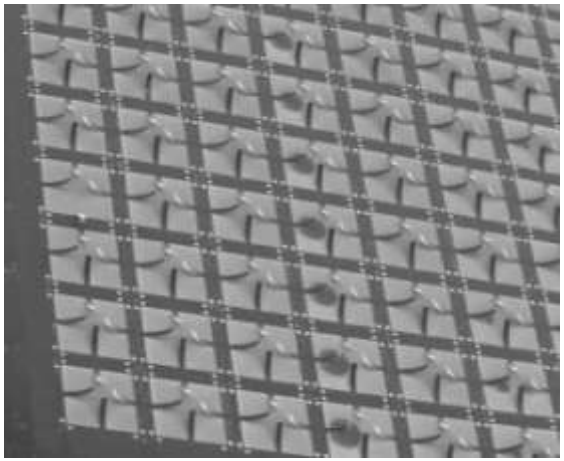
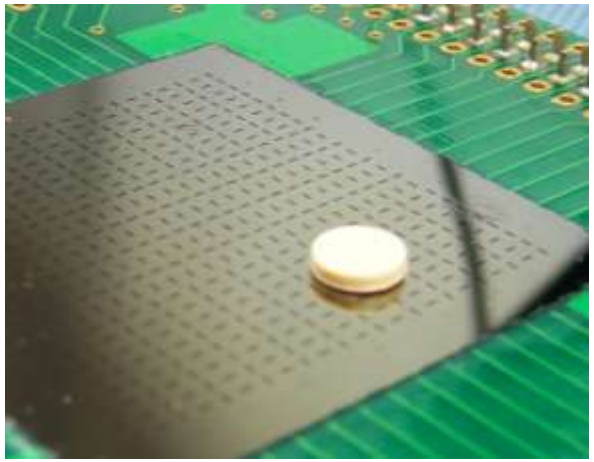
femto-st
sciences & technologies

Smart surfaces

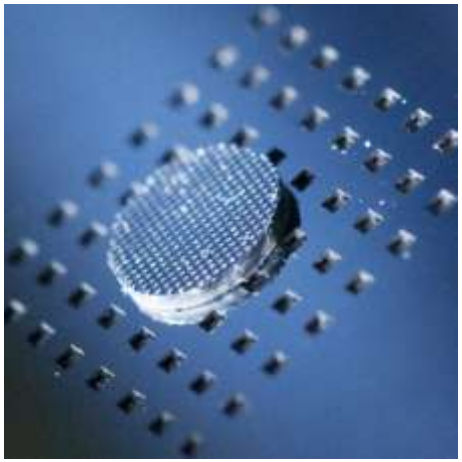
- **Distributed manipulation**
- **Up to 3 degrees of freedom**
- **Pneumatic => fast transport**
- **Ciliary actuators => high precision**



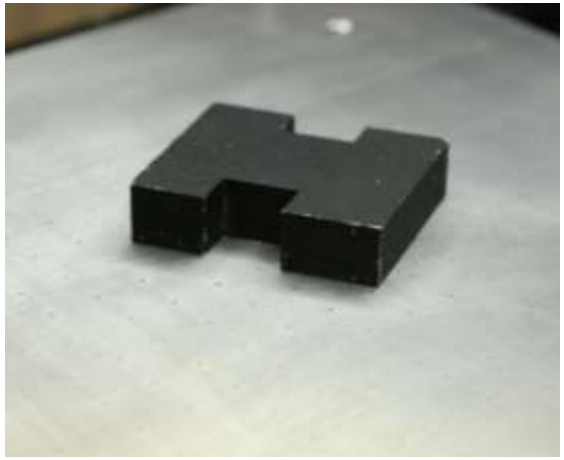
Ciliary actuator array
Ataka 2009, CIRMM/LIMMS, IIS



Active air-jet surface
Fukuta 2006, CIRMM/LIMMS, IIS

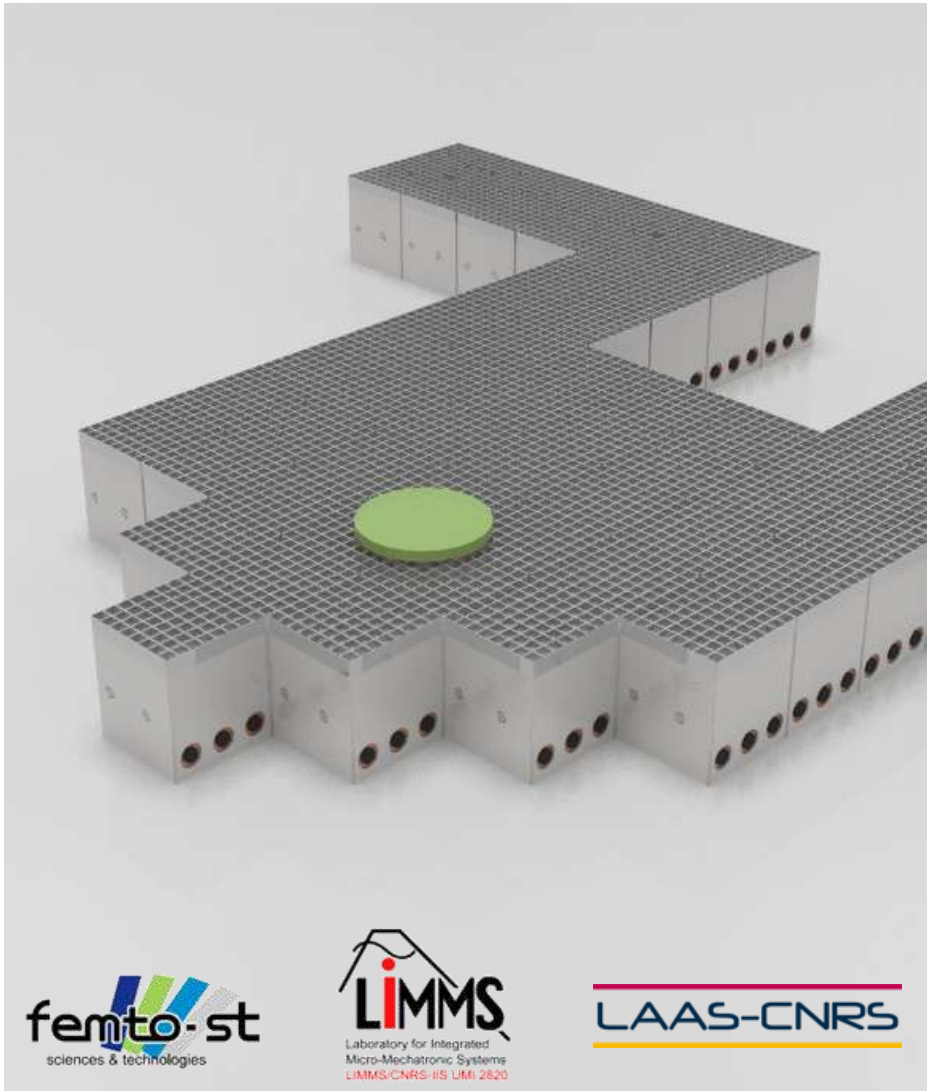


Passive air-jet surface
Zeggari 2010, FEMTO-ST

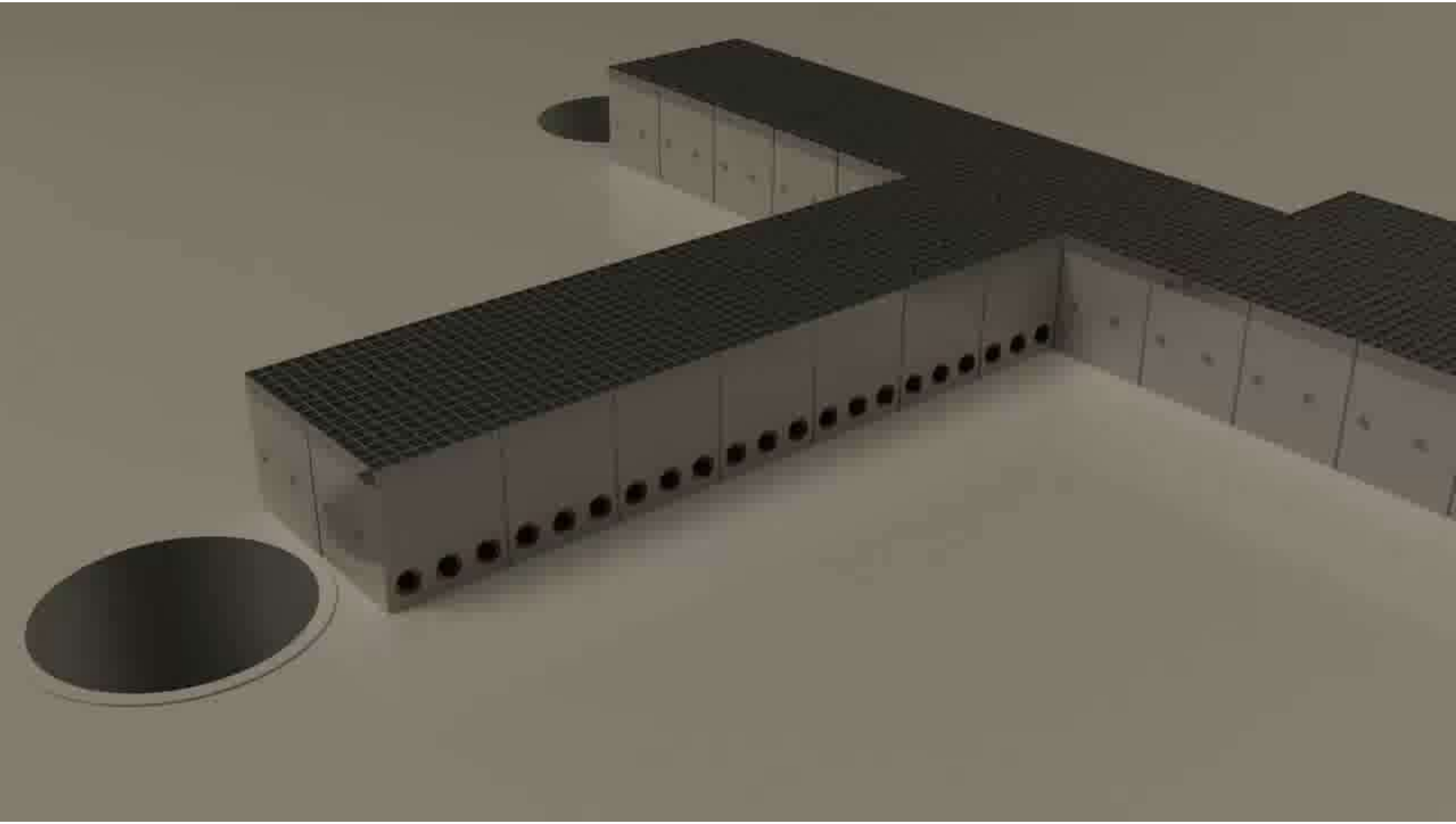


Potential air-flow surface
Delettre 2011, FEMTO-ST

- **Smart Blocks project**
  - Self-reconfigurable modular system
    - Moving
    - Processing
    - Communicating
  - Able to transport and sort small objects
    - Sensors/Actuators on the top.
  - Dynamically reactive to events
    - Create a new conveying path,
    - Replace a faulty block.



Example of application



Objectives of this paper

- **Presenting two aspects of the Smart Blocks project**
- **Multidisciplinary work**
  - FEMTO-ST/AS2M and FEMTO-ST/DISC
- **Actuation/locking system of the blocks**
  - 2 functions in one hardware
  - Use of electro-permanent magnets
- **Reconfiguration algorithm**
  - Distributed
  - Scalable
  - Based on the sliding actuation

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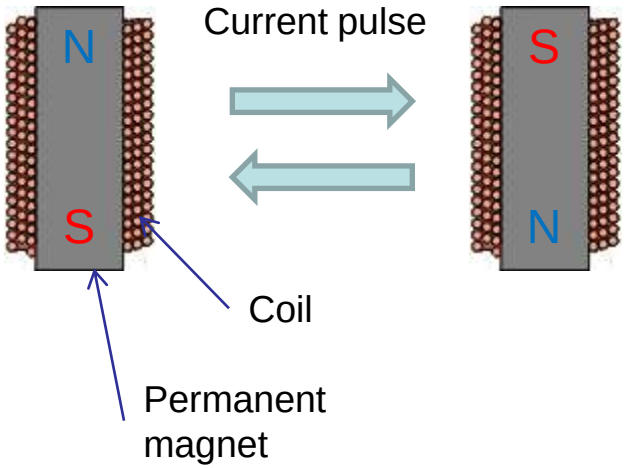
Block actuation

Block actuation

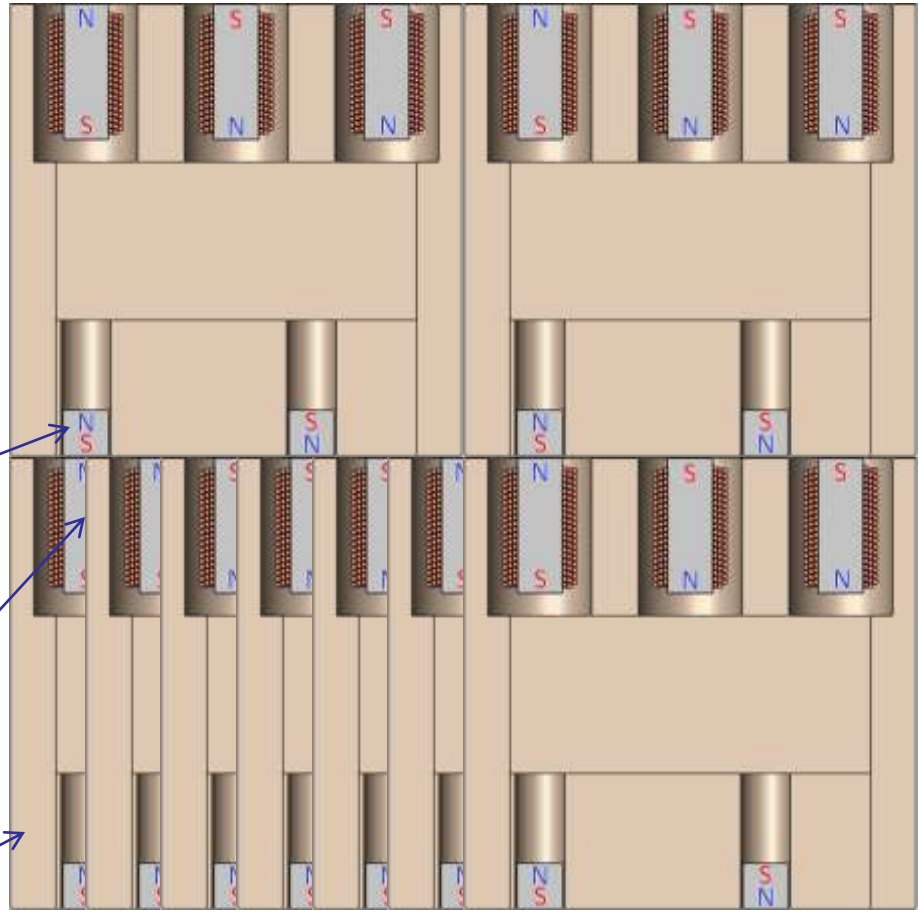
- **Electro-permanent magnets**
  - Permanent magnet + Coil
- **Permanent magnet = AlNiCo**
  - Aluminium, Nickel, Cobalt
  - High remanence
  - Weak coercive field
  - Changeable polarity



- **Features**
  - Core : 1 mm in diameter, 2 mm in length
  - Coil : 60 turns
  - Switching current : 15 A (reach by discharging a capacitor)

Block actuation

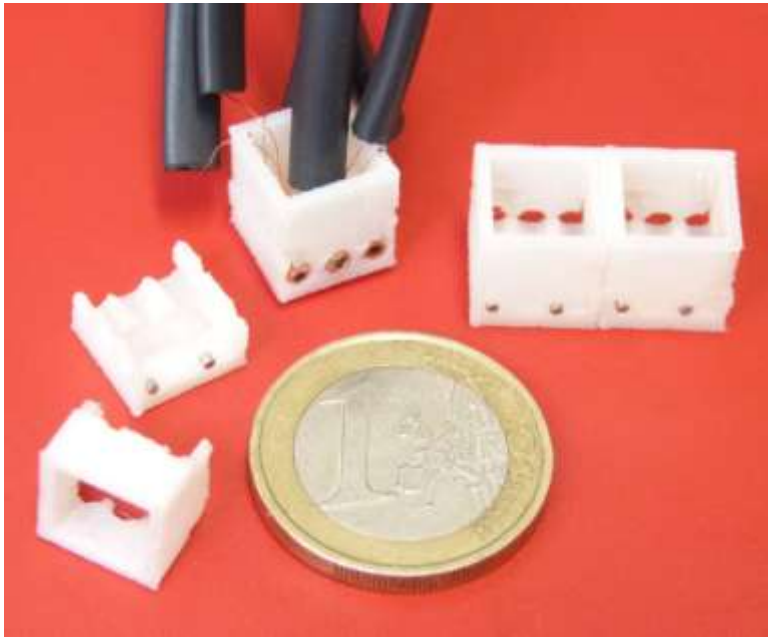
- **Linear motor principle**
  - One cycle = one move from one block to another = 6 states
- **Driving electronic**
  - dsPIC microcontroller
  - 100µF capacitor
  - H-bridges using MOSFETs

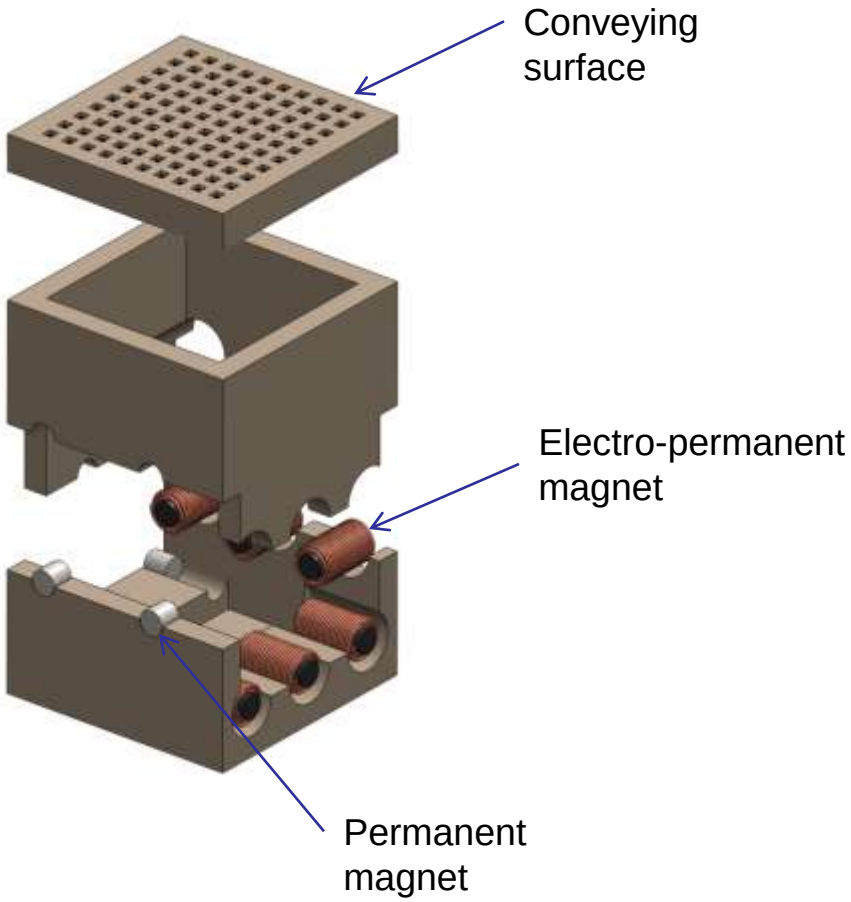


Top view of three blocks

Block design

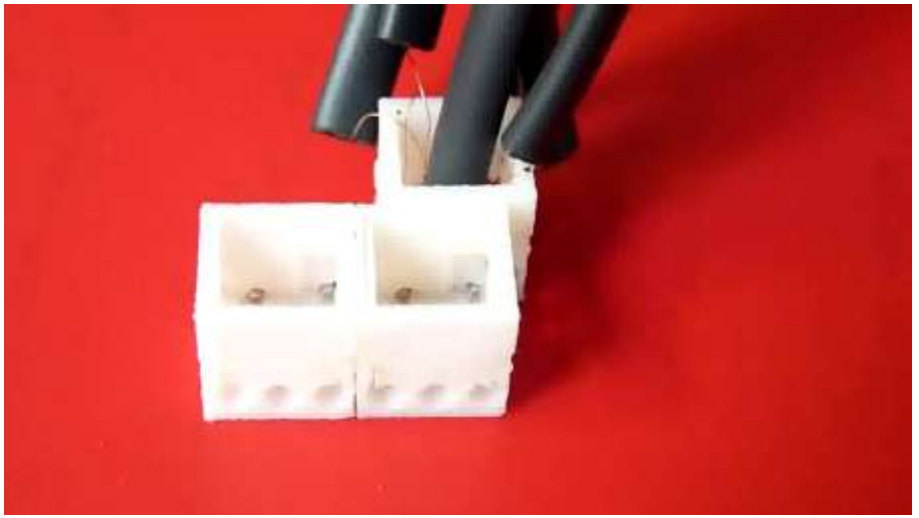
- 10x10x10 mm cube
- Two linear motors
- Rapid prototyping machine

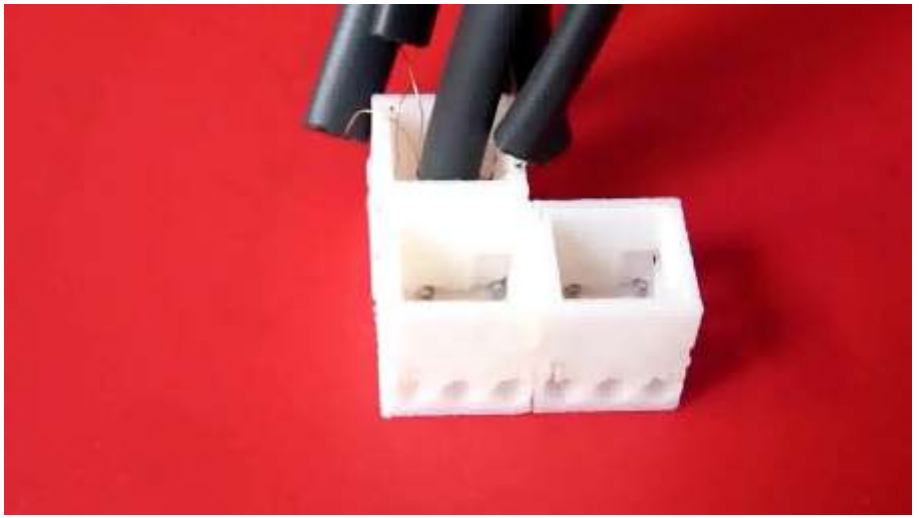




Experimental results

- Mean speed : 14 mm/s
- Holding force (power off) : 40 mN
- Pulse duration : 25 µs is sufficient
- Voltage : 15 V is sufficient





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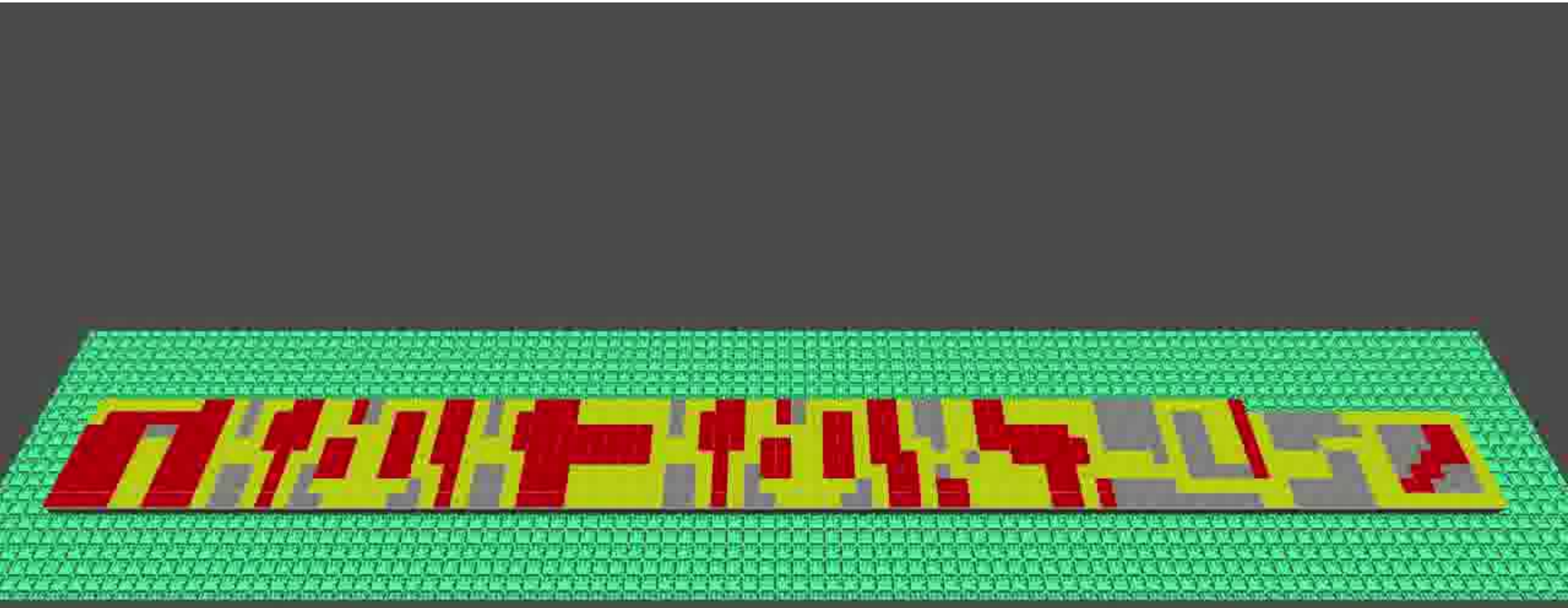
Block reconfiguration algorithm

Block reconfiguration algorithm

- **Goal of the reconfiguration process**
  - Blocks are placed in an initial configuration.
  - They have to move to a desired configuration.
- **Operating principle of the blocks**
  - Each block runs the same code.
  - Each block has local information only
    - State variables,
    - Neighbor blocks,
    - Local map of the final configuration.
  - Each block is connected to 1 to 4 other blocks.
    - Exchange messages
- **The Master Block**
  - A block is selected to manage the stages of the algorithm.
  - A the beginning of the process, it has the map of the goal configuration of blocks.

Example of reconfiguration

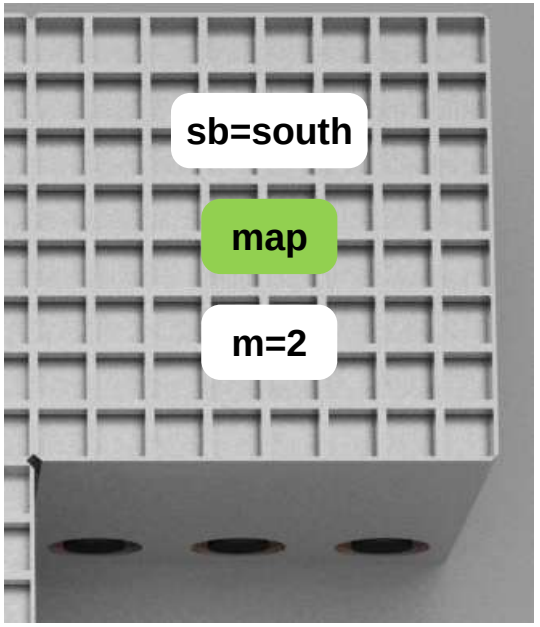


Block reconfiguration algorithm

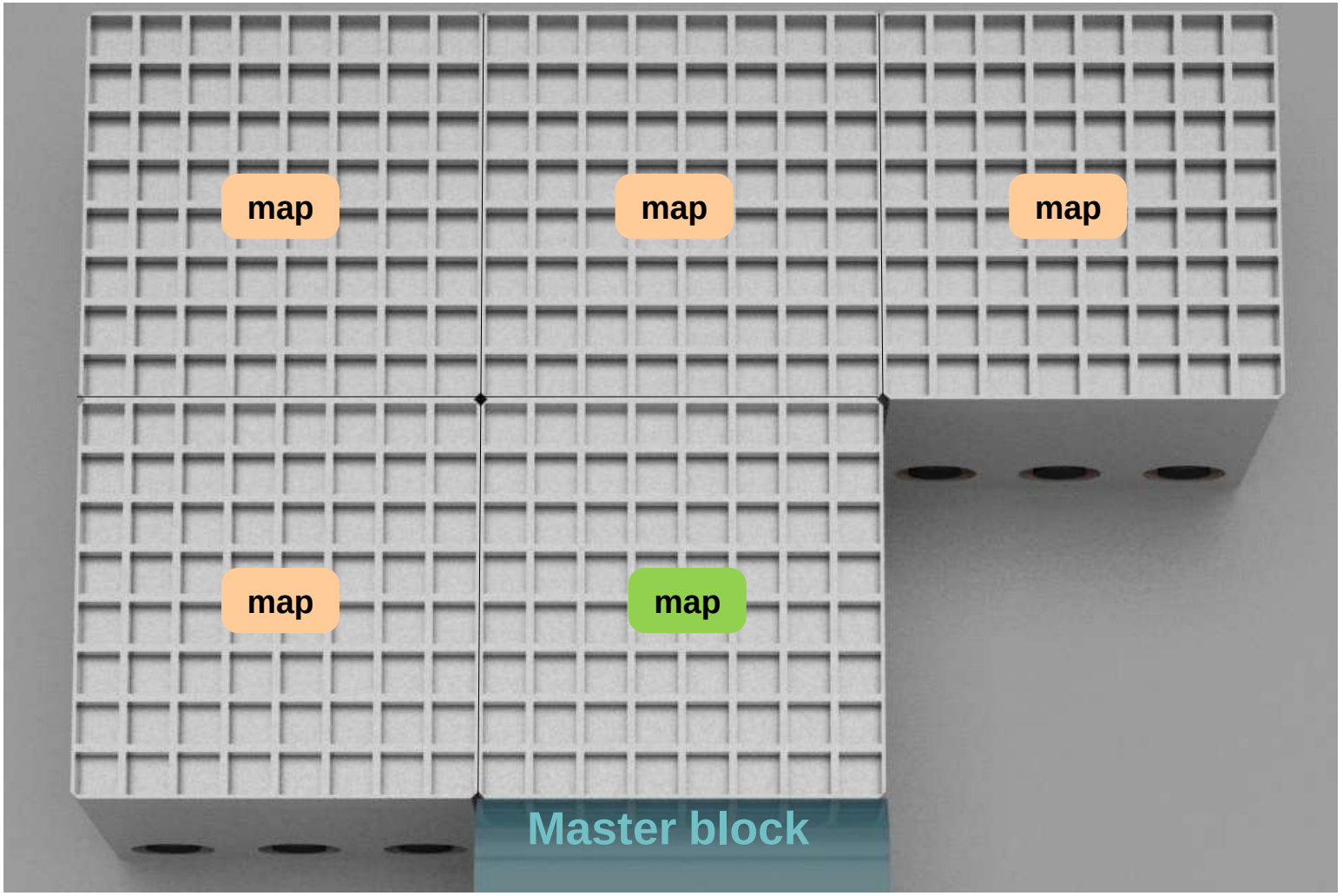
- **The 4 major stages of the algorithm**
  1. Preliminary step : sending the goal map to each block
     - To give the locations of free places to all blocks
  2. Calculation of the shortest distance between each block and a free place
  3. Determination of the direction of movement of each block
     - Many blocks may move at the same time
  4. Organize the motions of mobile blocks.
     - Without collision
- **If the goal is not reached, repeat from step 2**

1 : Sending the map to each block

- **Sending the map to each block**
  - The master block sends the map
    - to its *m=n* neighbors
    - using a MAP message
    - Message containing the map data.
  - When a block receives a MAP message
    - If it already gets the map, it sends an ACQ message
    - else
      - It copies the map in its local memory
      - It memorizes the sender in *sb*
      - and sends a MAP message to its *m =n-1* other neighbors
  - When a block receives an ACQ message
    - It decrements *m,*
    - If all neighbors have answered (*m ==0*), it sends an ACQ message to *sb*.



Sending the map to each block



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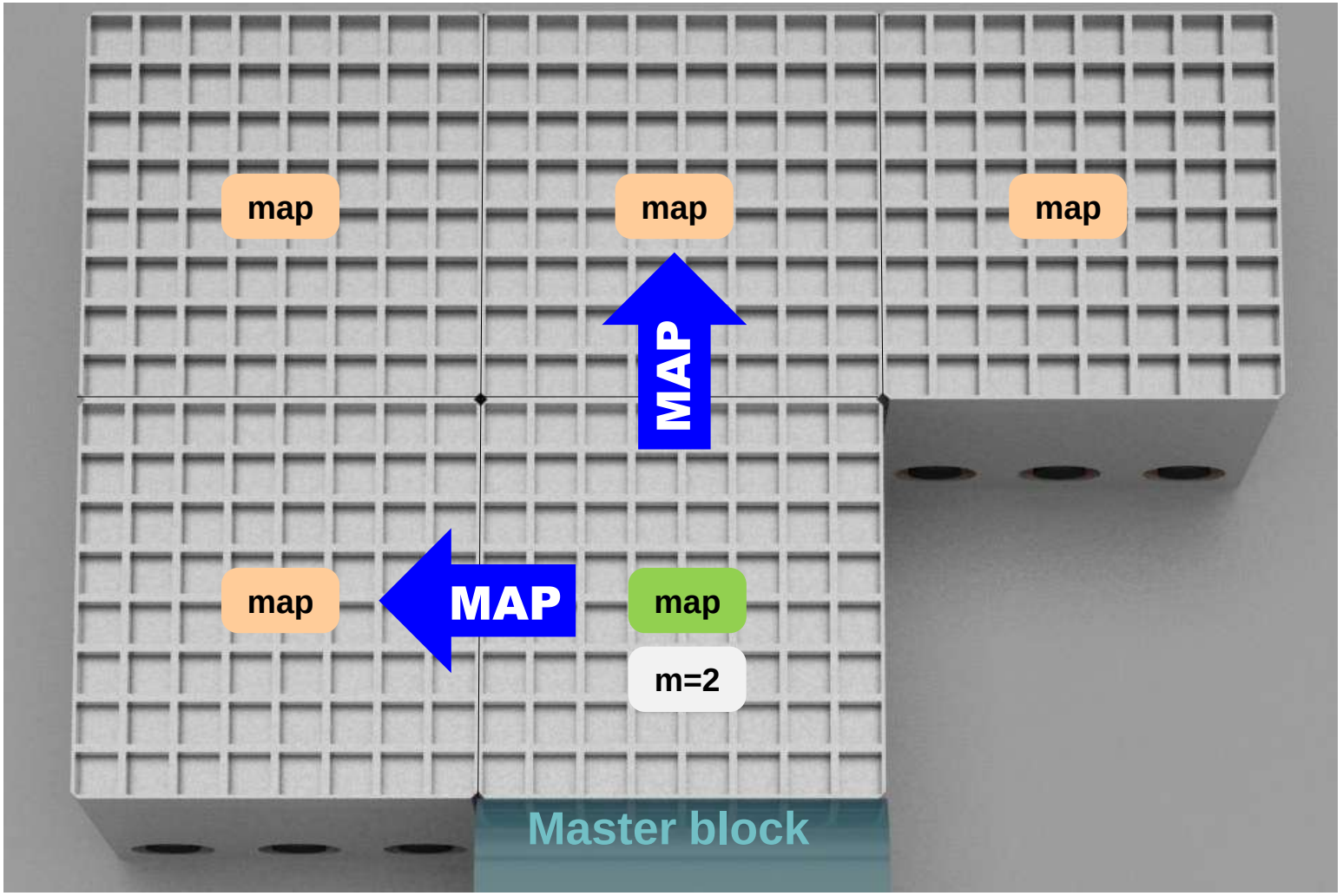

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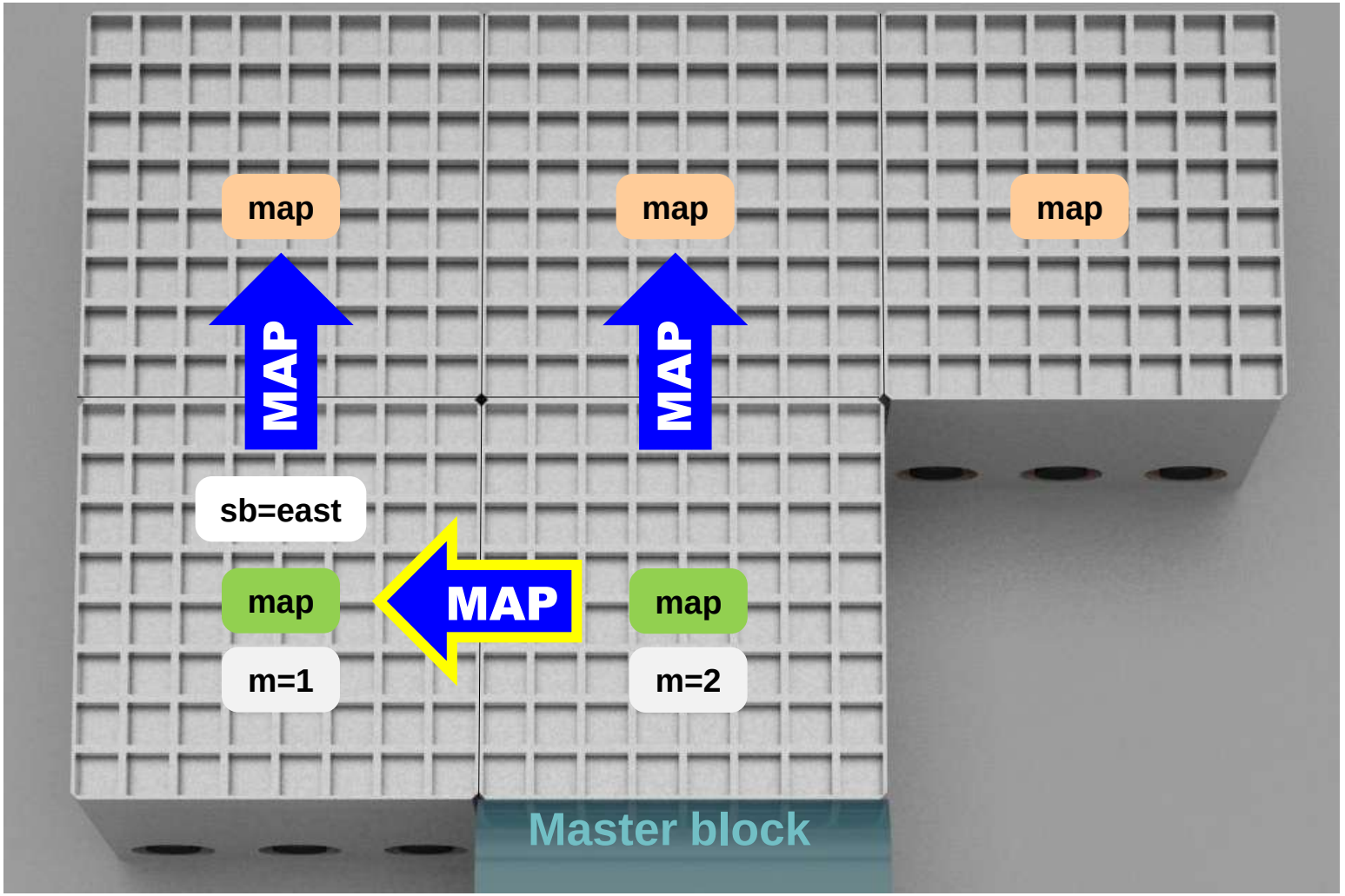

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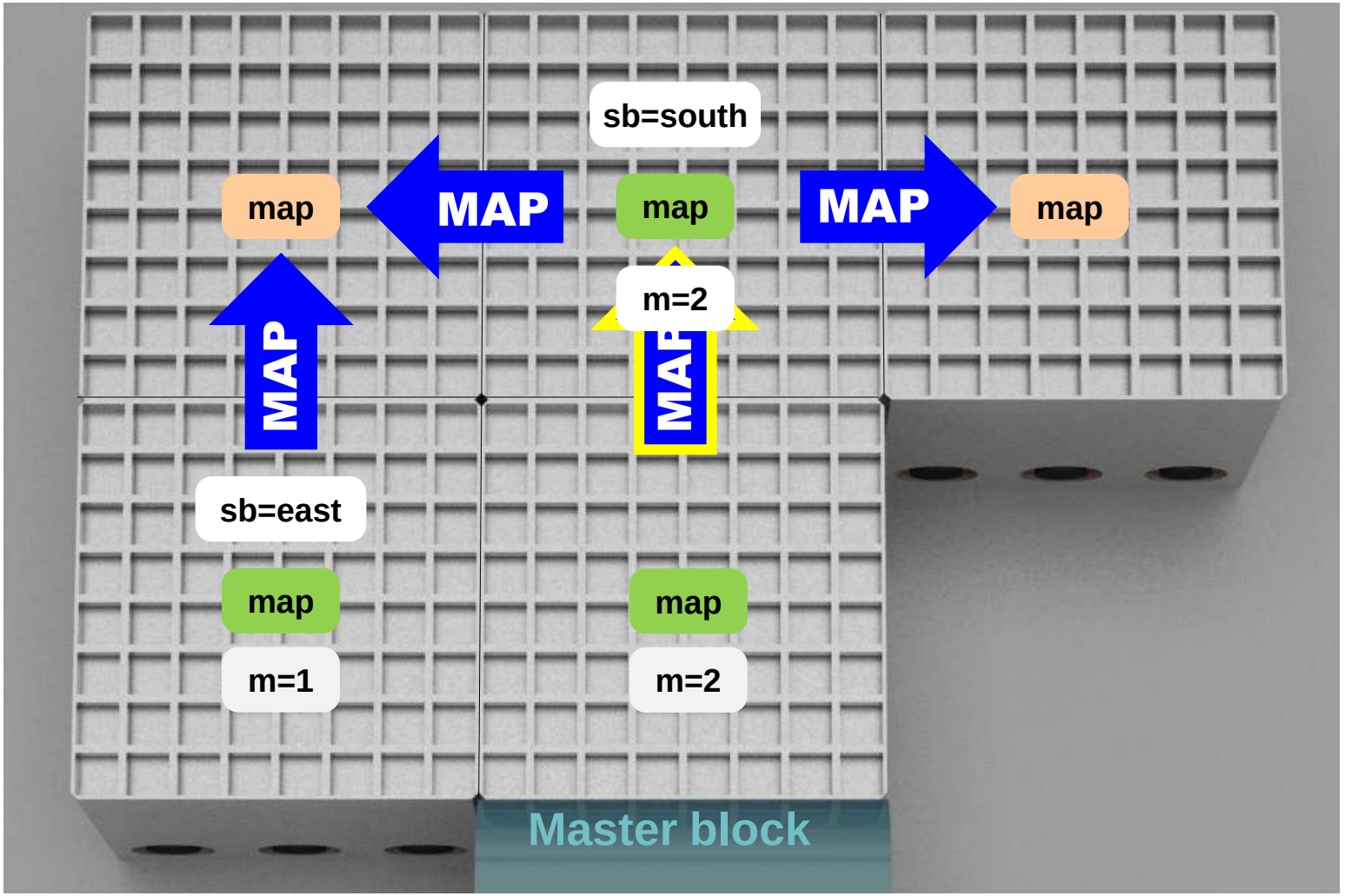

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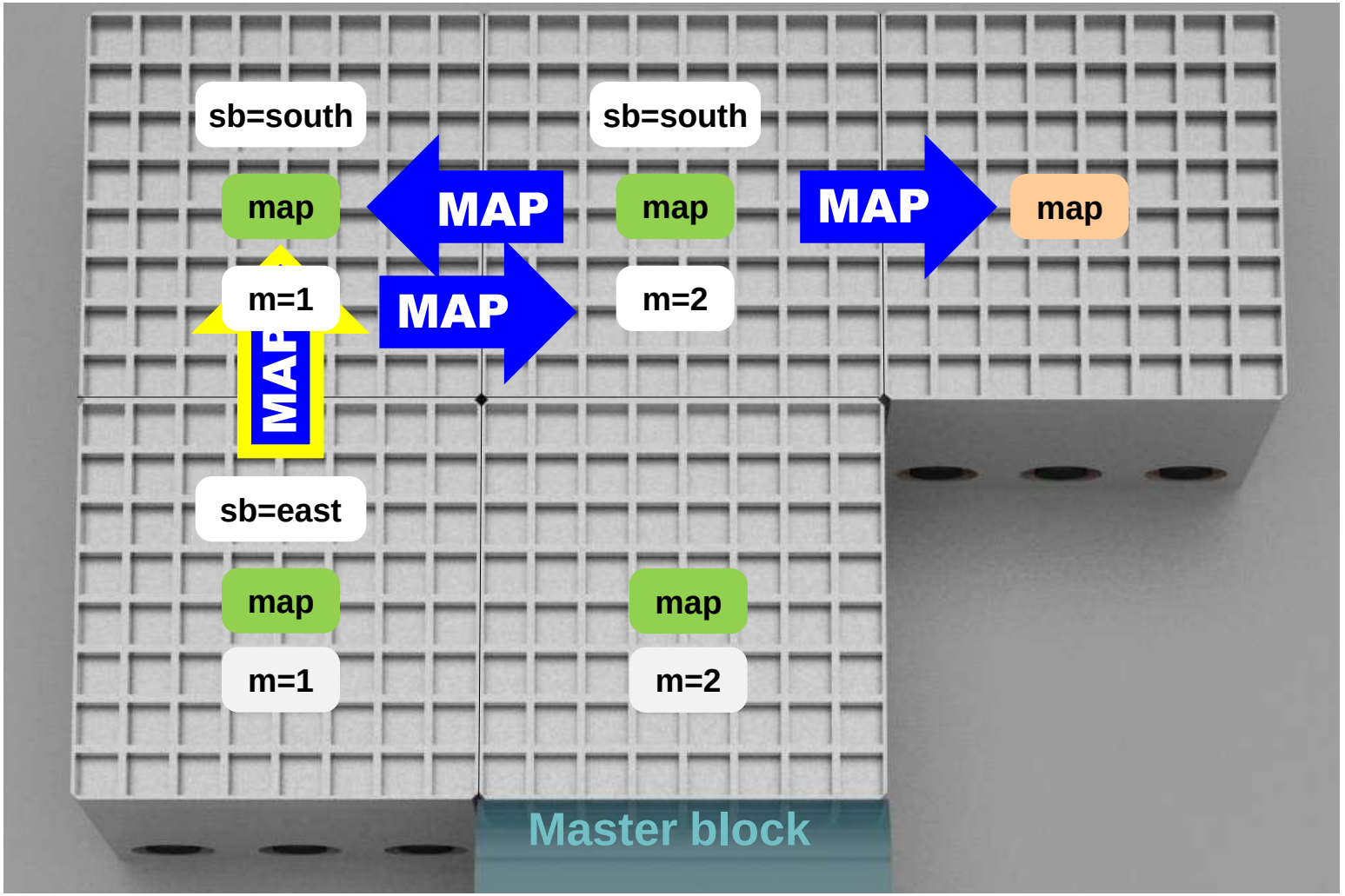

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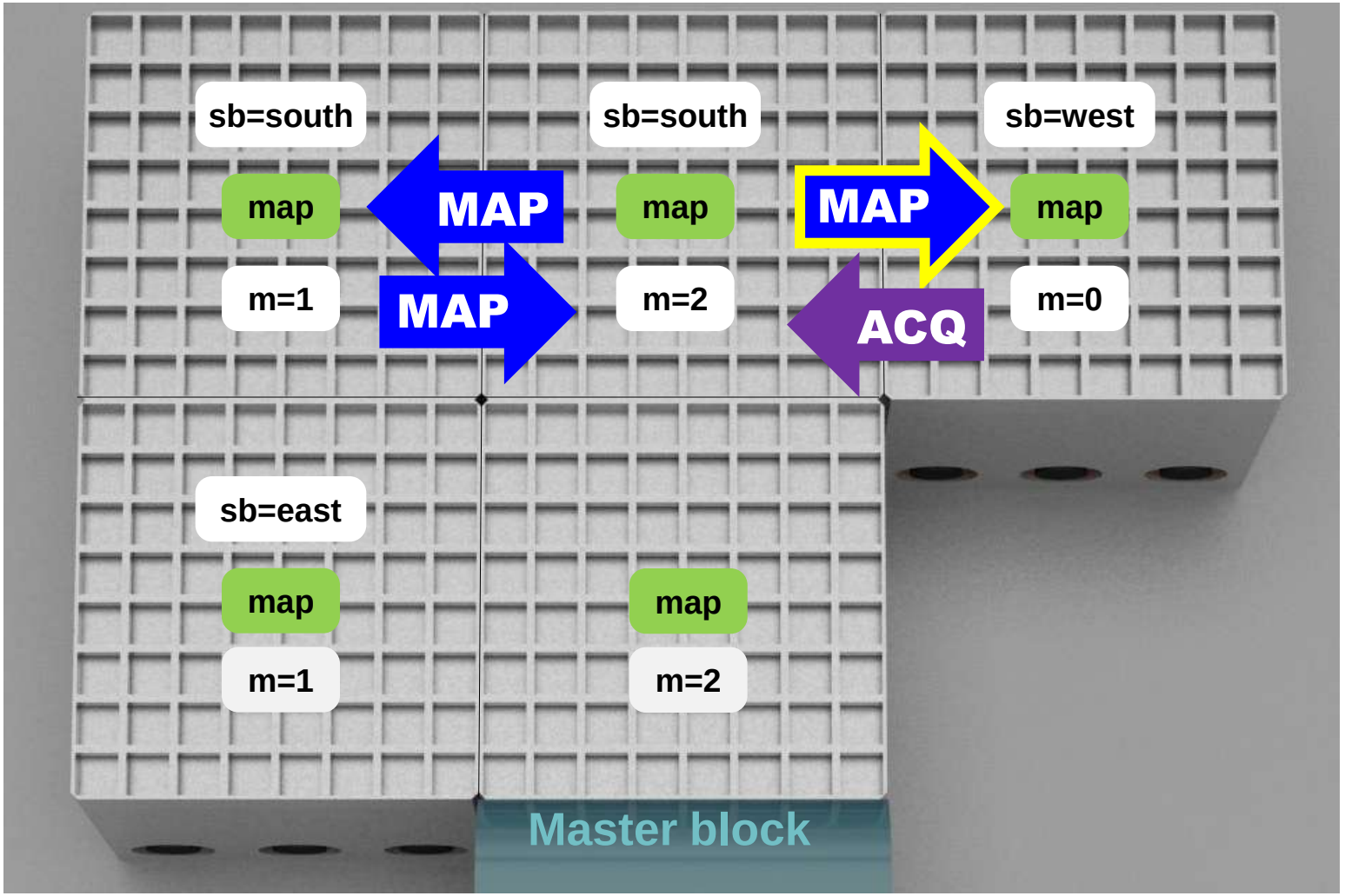

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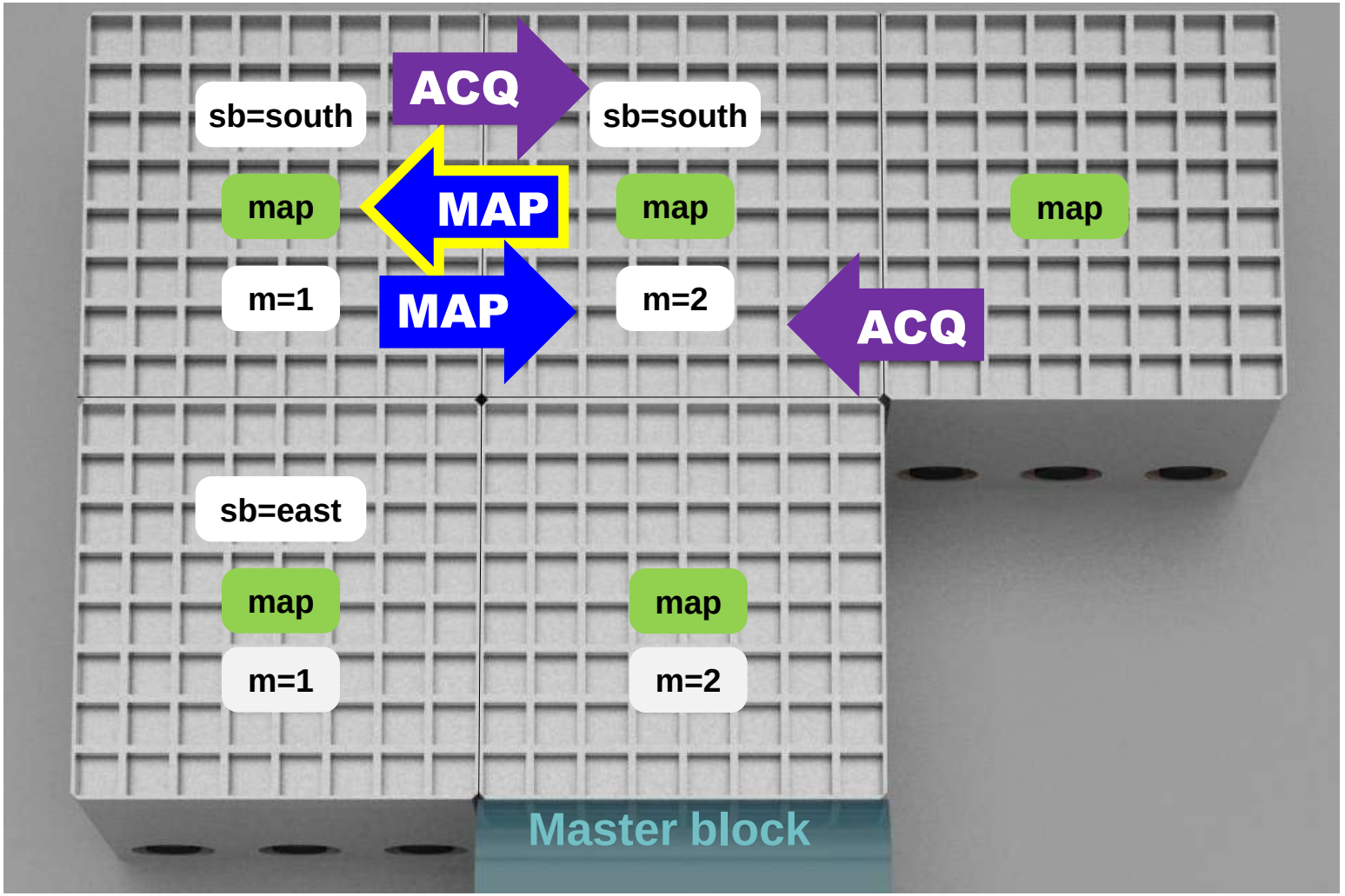

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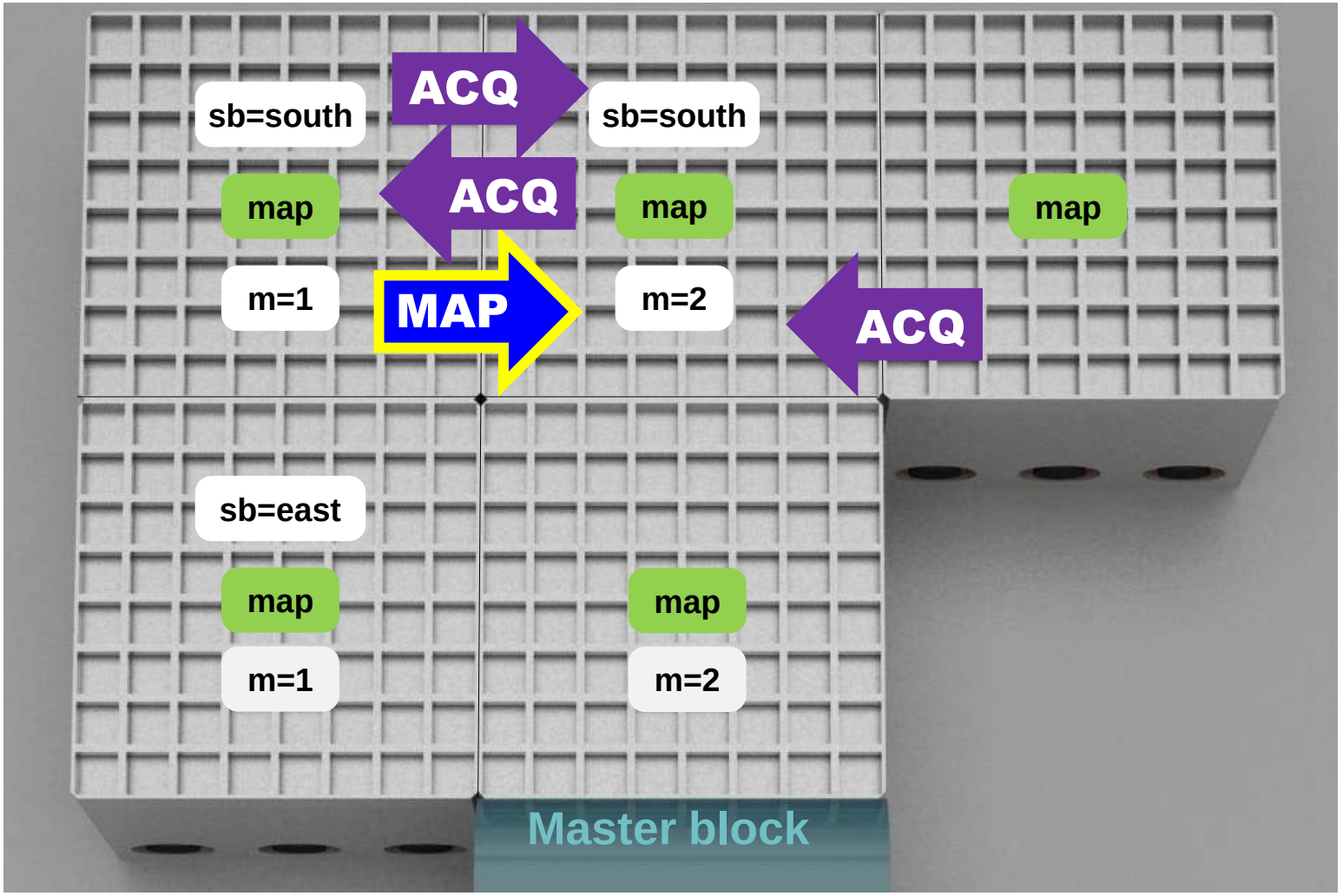

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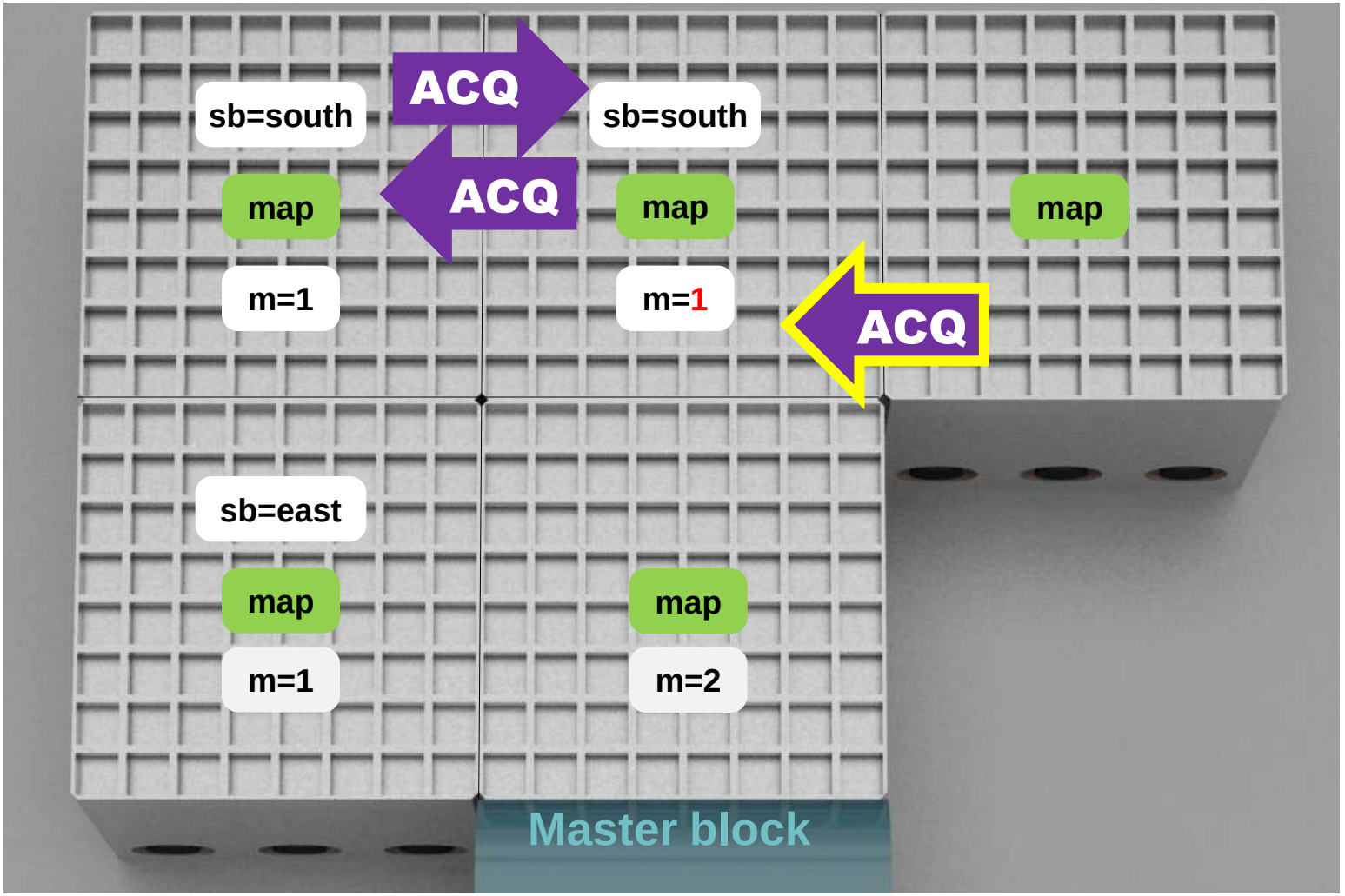

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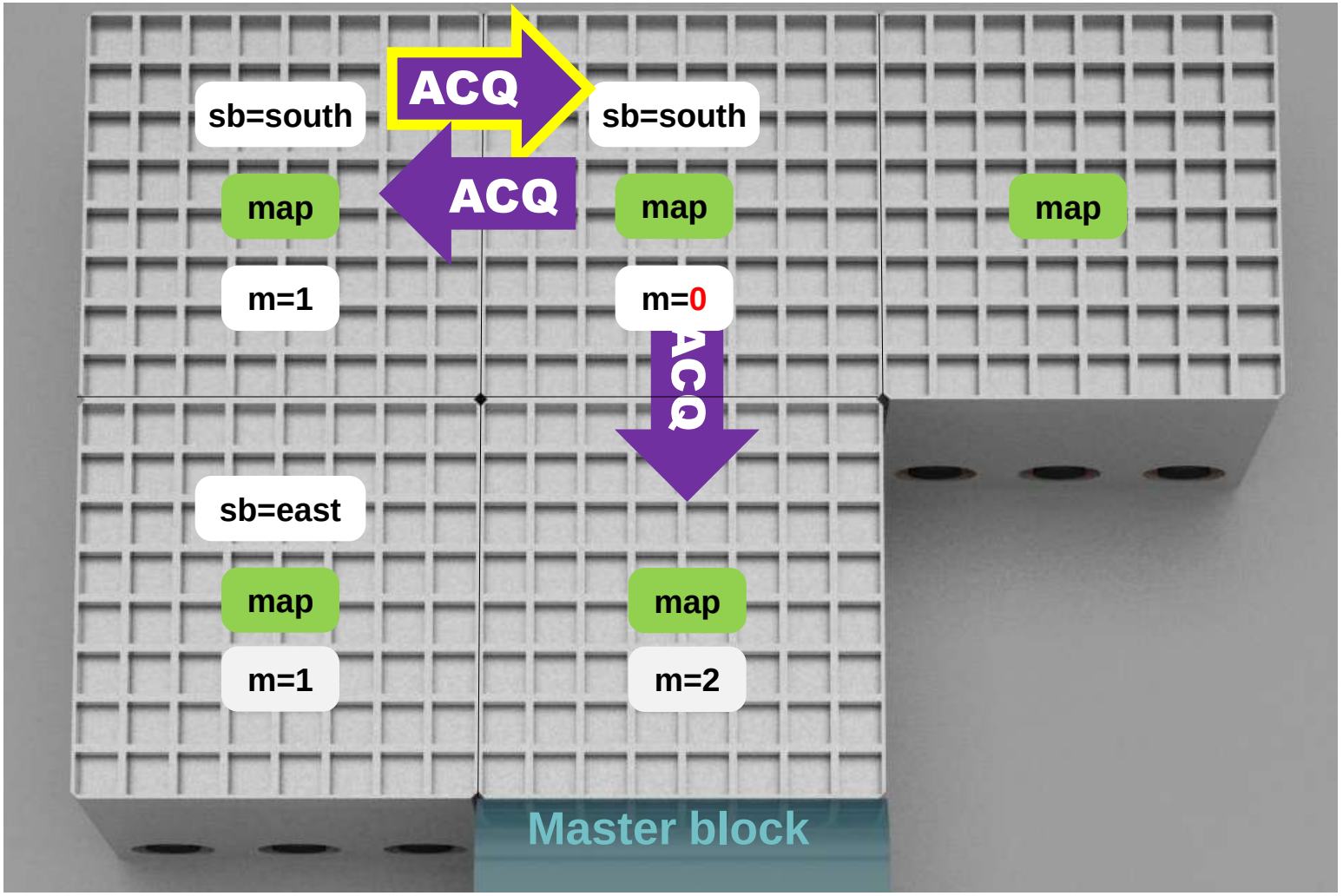

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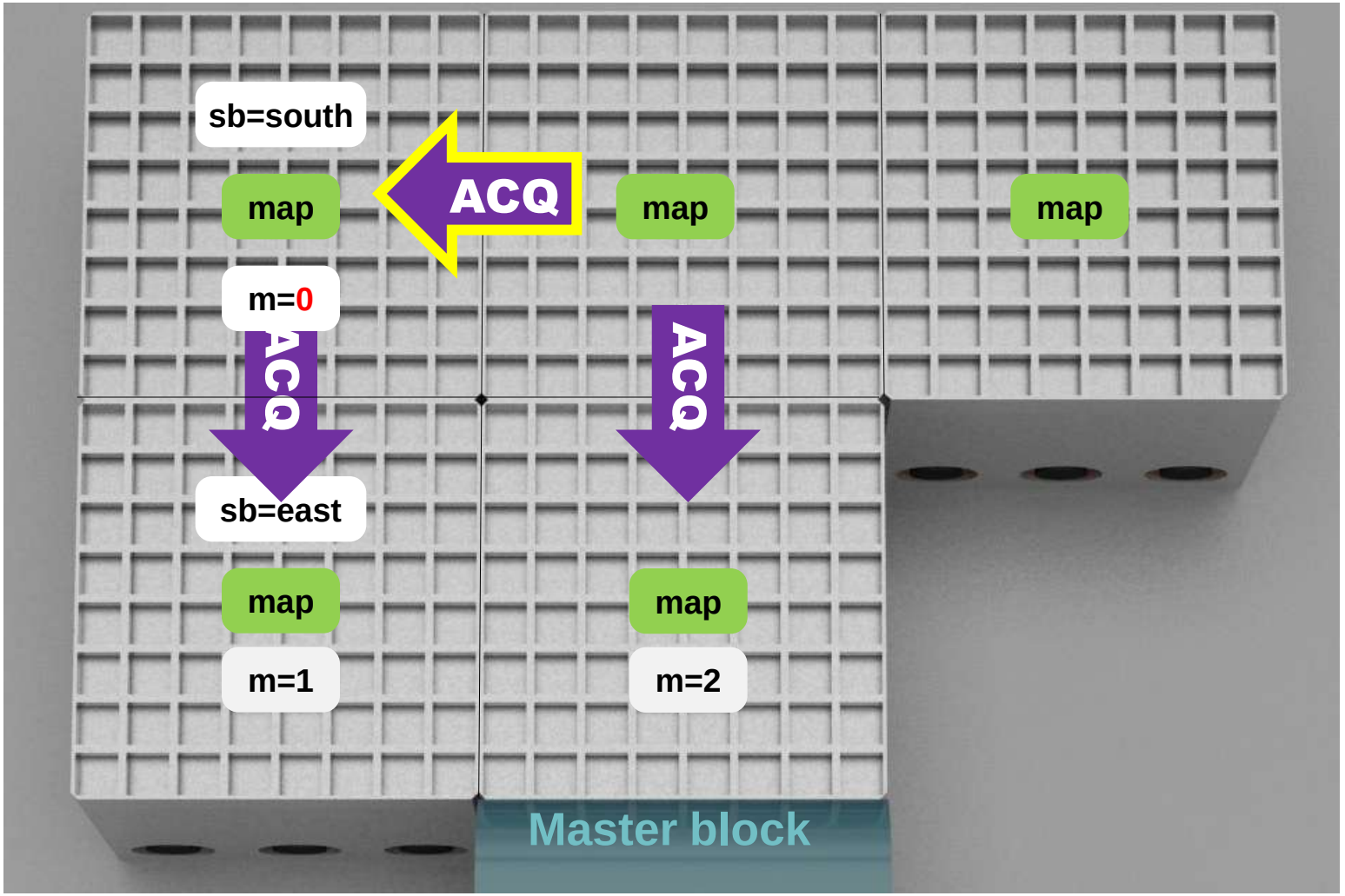

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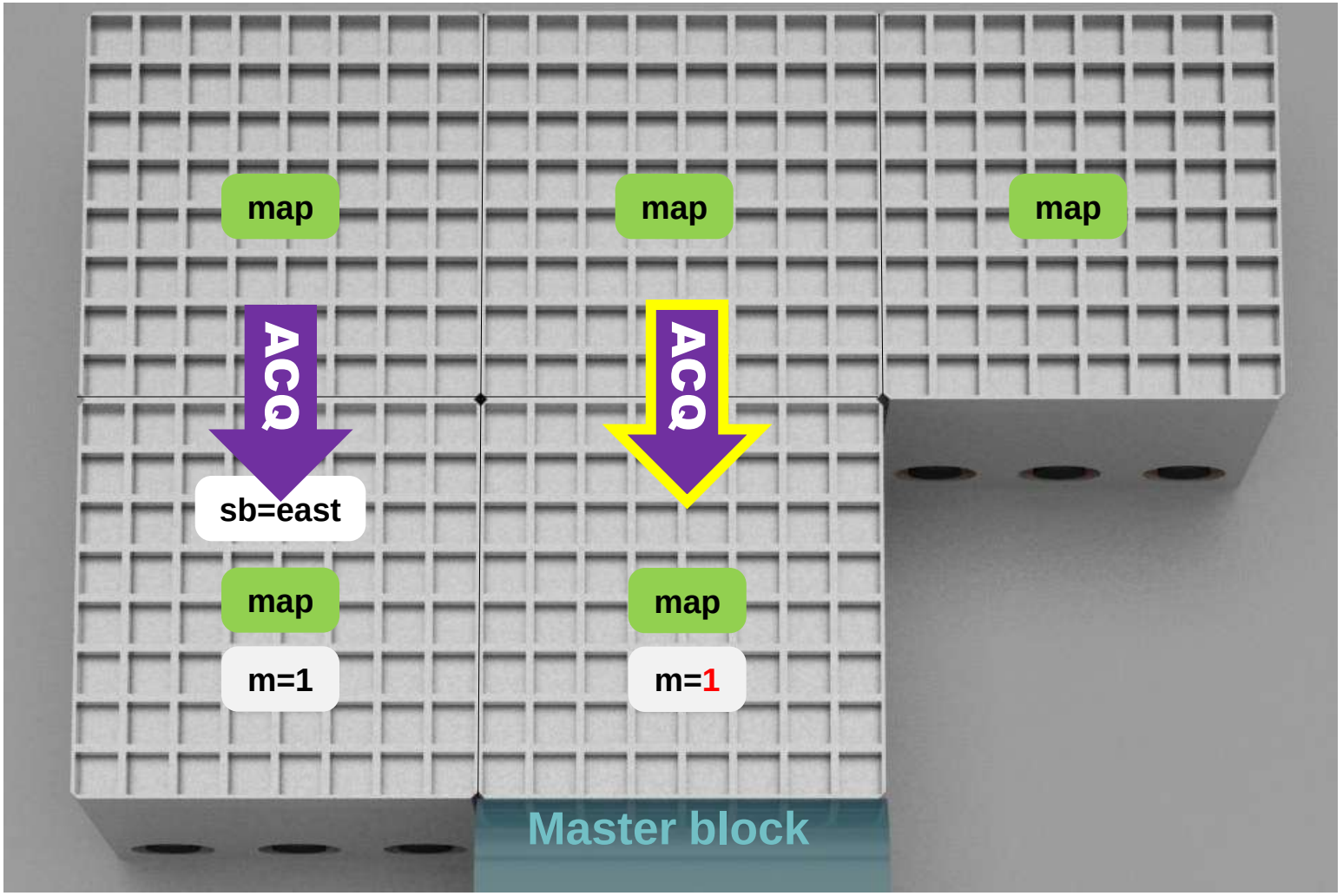

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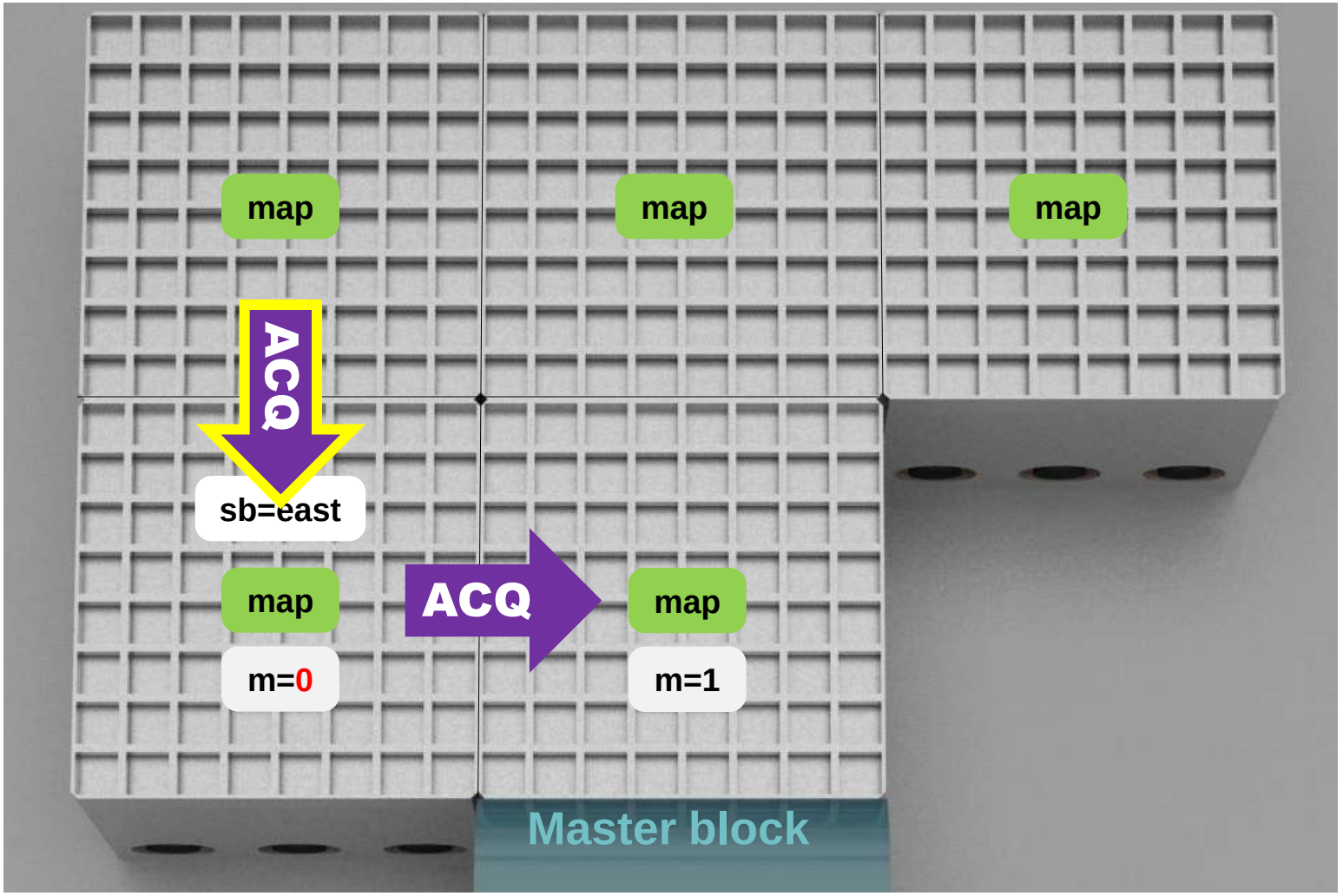

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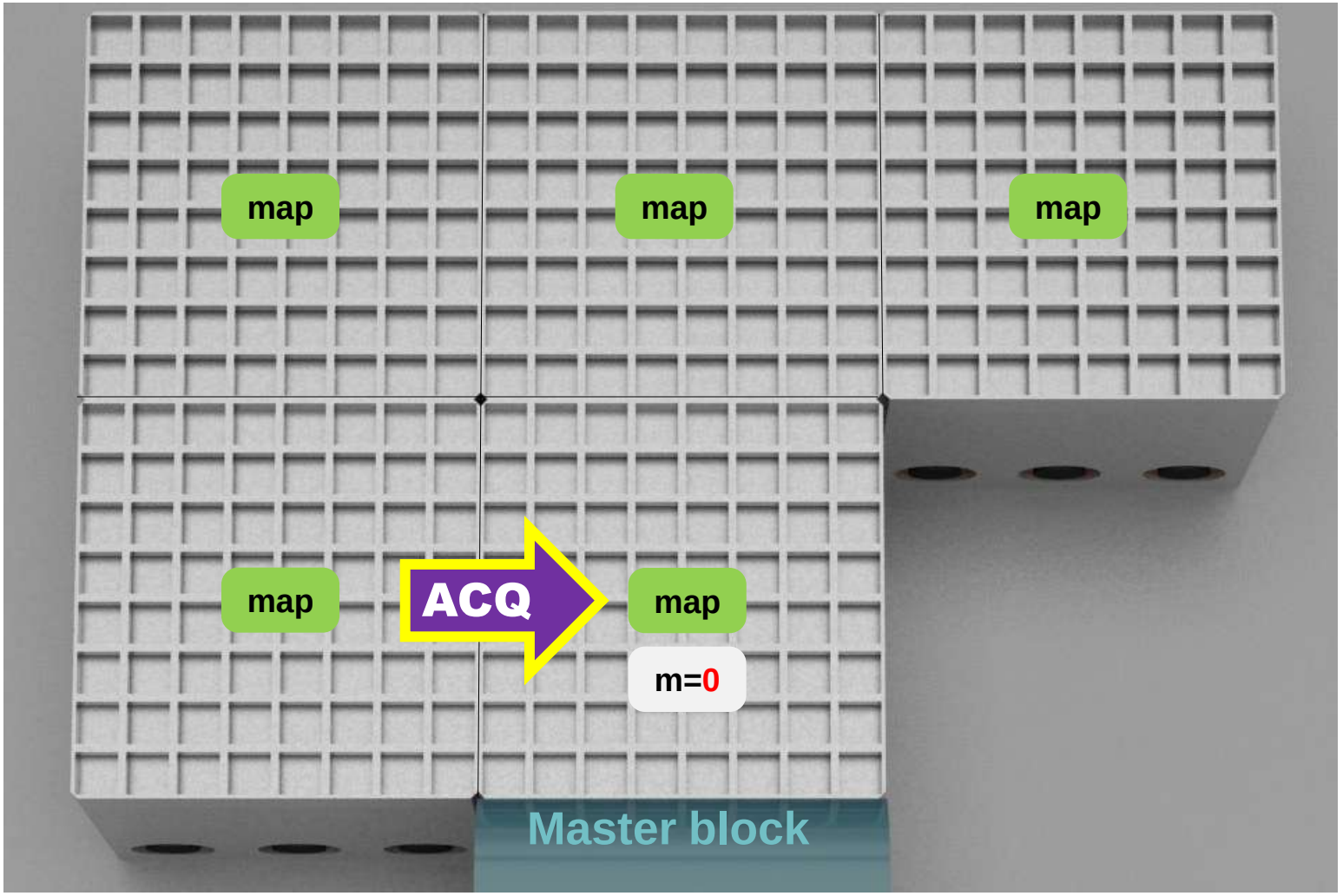
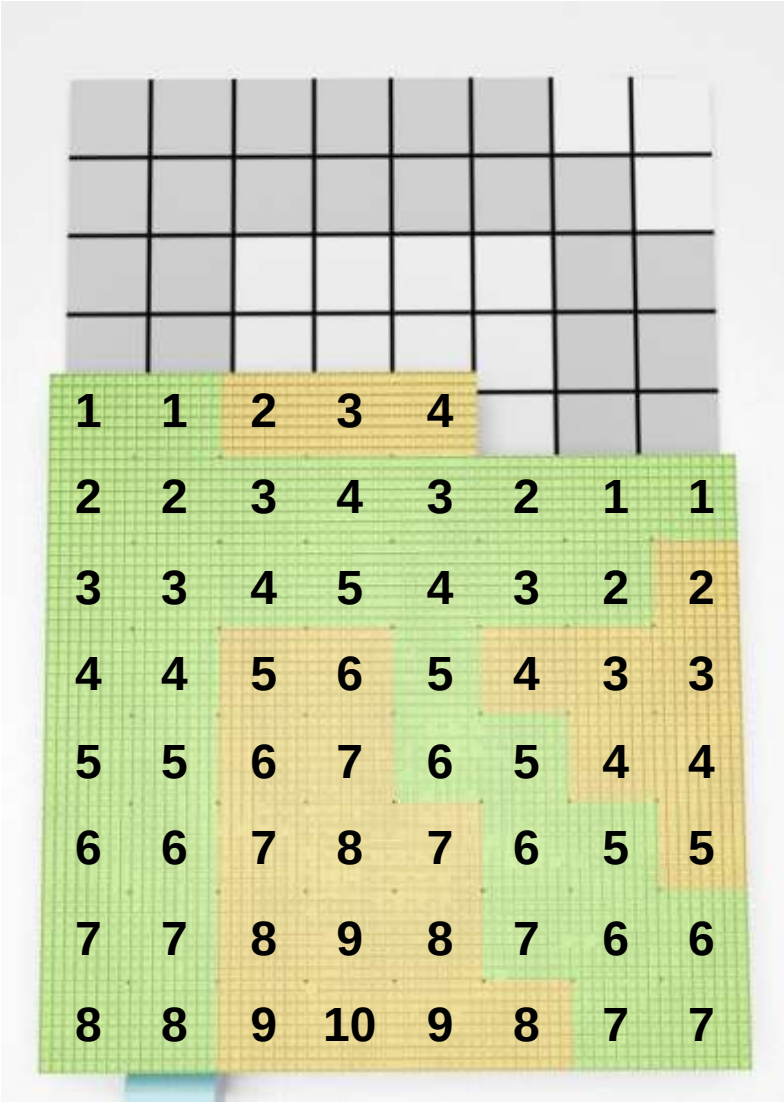


Calculating the shortest distance

- **Calculating the shortest distance to an empty area**
  - If a block has an empty place on one of its 4 sides, its distance is 1.
  - For each other block, its distance is the minimum distance of its neighbors plus 1.
- **Example of results of distance calculation**
  - The goal configuration forms the R letter.
  - Green blocks are well placed.
  - Orange blocks have to move.

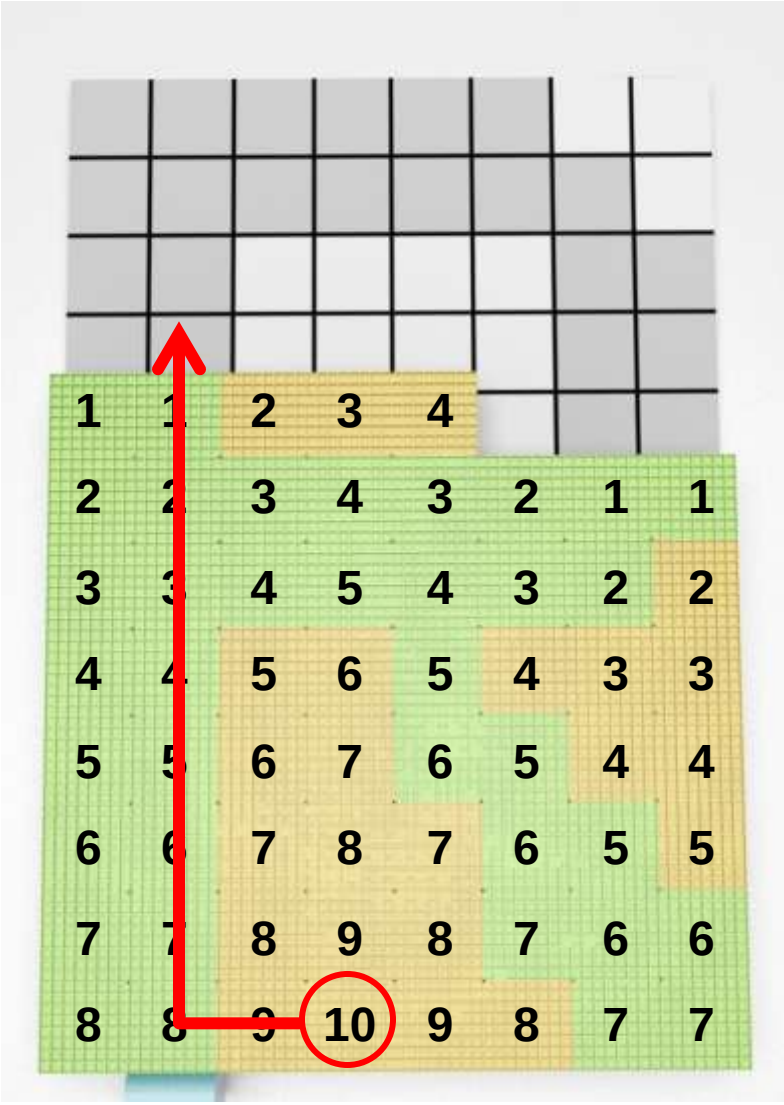


Calculating the shortest distance

- **Algorithm using messages**
  - The method is very similar to the previous one.
  - First, each block gets a distance parameter initialized to infinite.
  - The master block sends the distance requirement
    - to its *m=n* neighbors using a REQUIREMENT message.
  - When a block receives a REQUIREMENT message
    - If one of its sides touches a free place it writes 1 in the distance local variable and answers with a DISTANCE message
    - else
      - It memorizes the sender in *sb*
      - and sends a REQUIREMENT message to its $m = n-1$ other neighbors
  - When a block receives a DISTANCE message
    - It decrements m
    - It writes the minimum of its distance and the distance of the sender plus 1 in the distance variable
    - If all neighbors have answered ($m == 0$), it sends a DISTANCE message to *sb*.

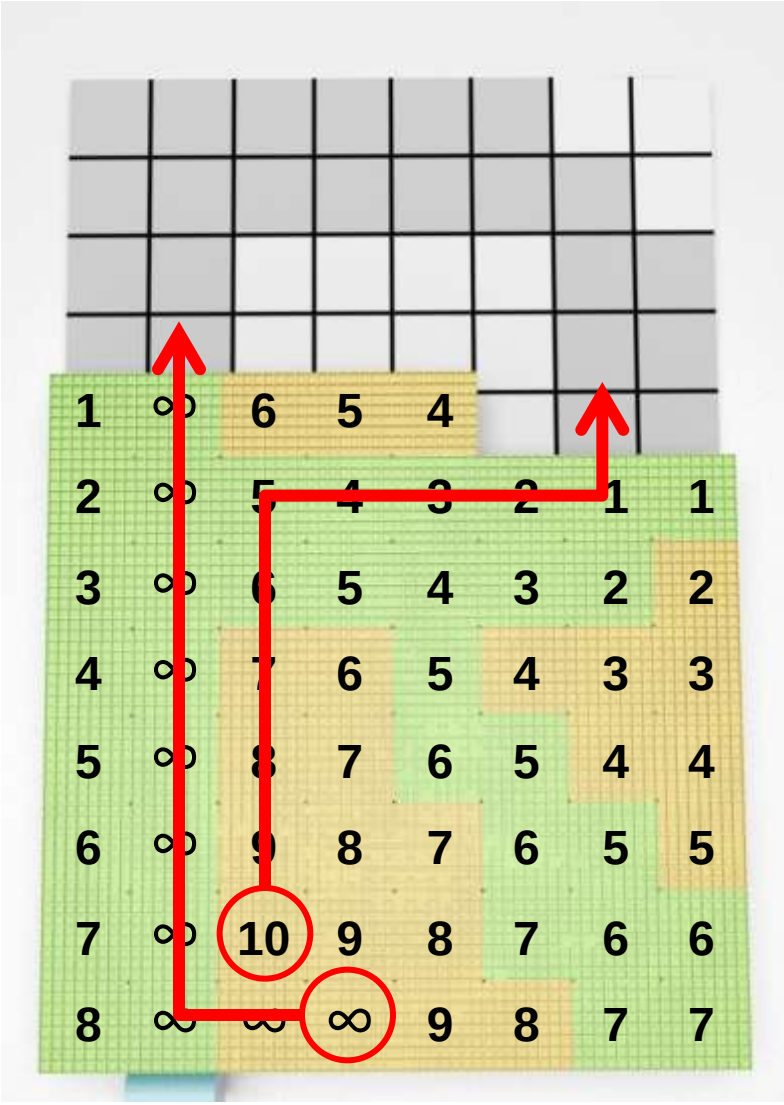
Moving blocks

- **Determining the moving blocks**
  - To reduce the global distance of blocks.
    - Converge to a solution
  - Find the block B_{max}
    - That admits the greatest distance value
    - And is in a place that must be emptied
  - Find a path from B_{max} to an empty place



Moving blocks

- **Repeat the two last steps :**
  - The distance of cells crossed by the paths is set to infinite
  - Recalculate the distance
  - Find a new path
- **Until all distances are infinite**



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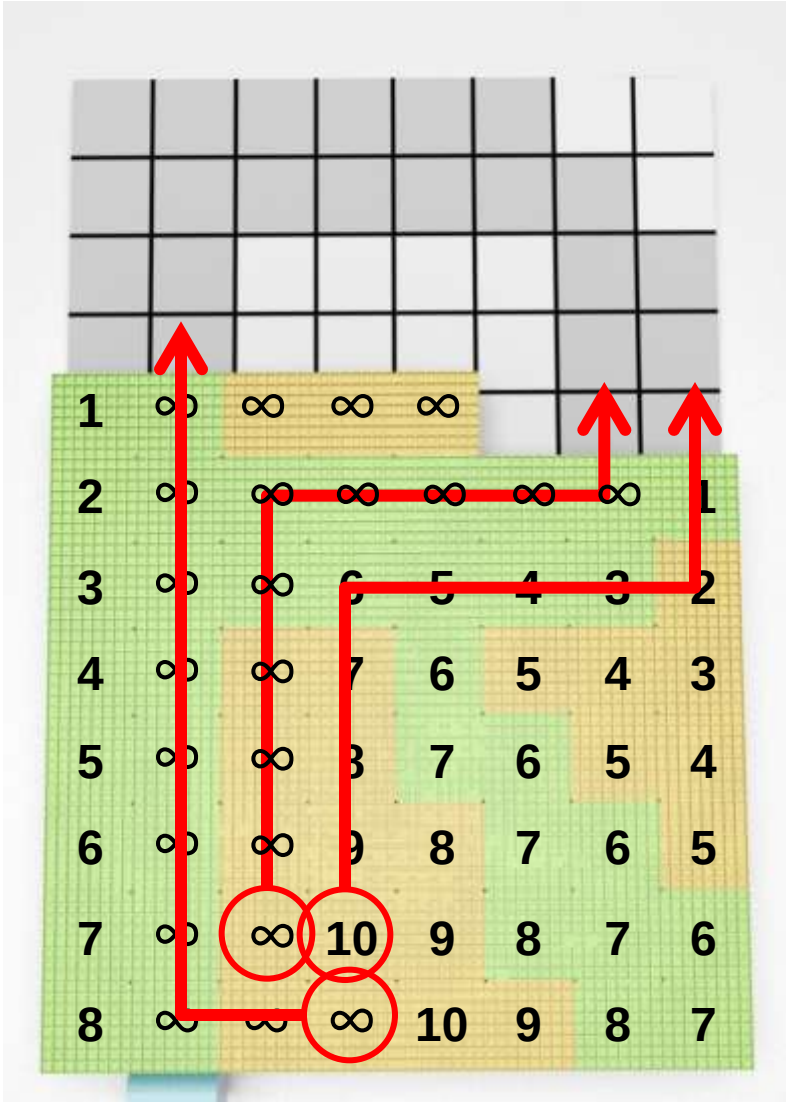

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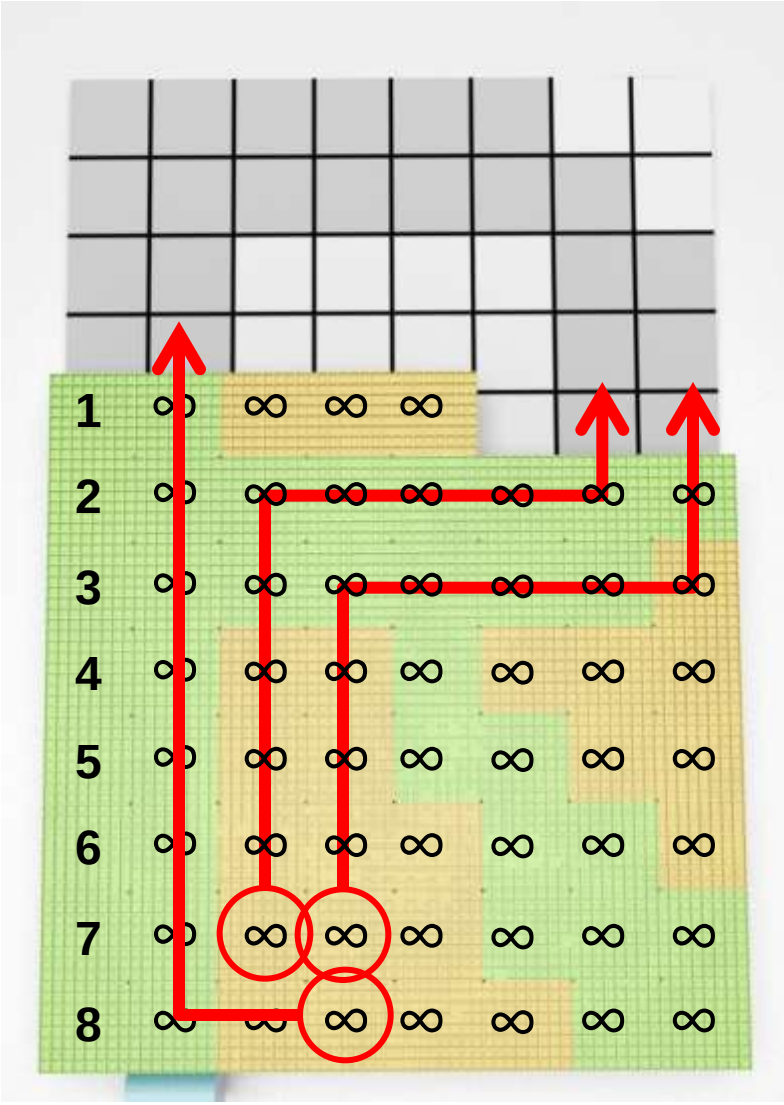
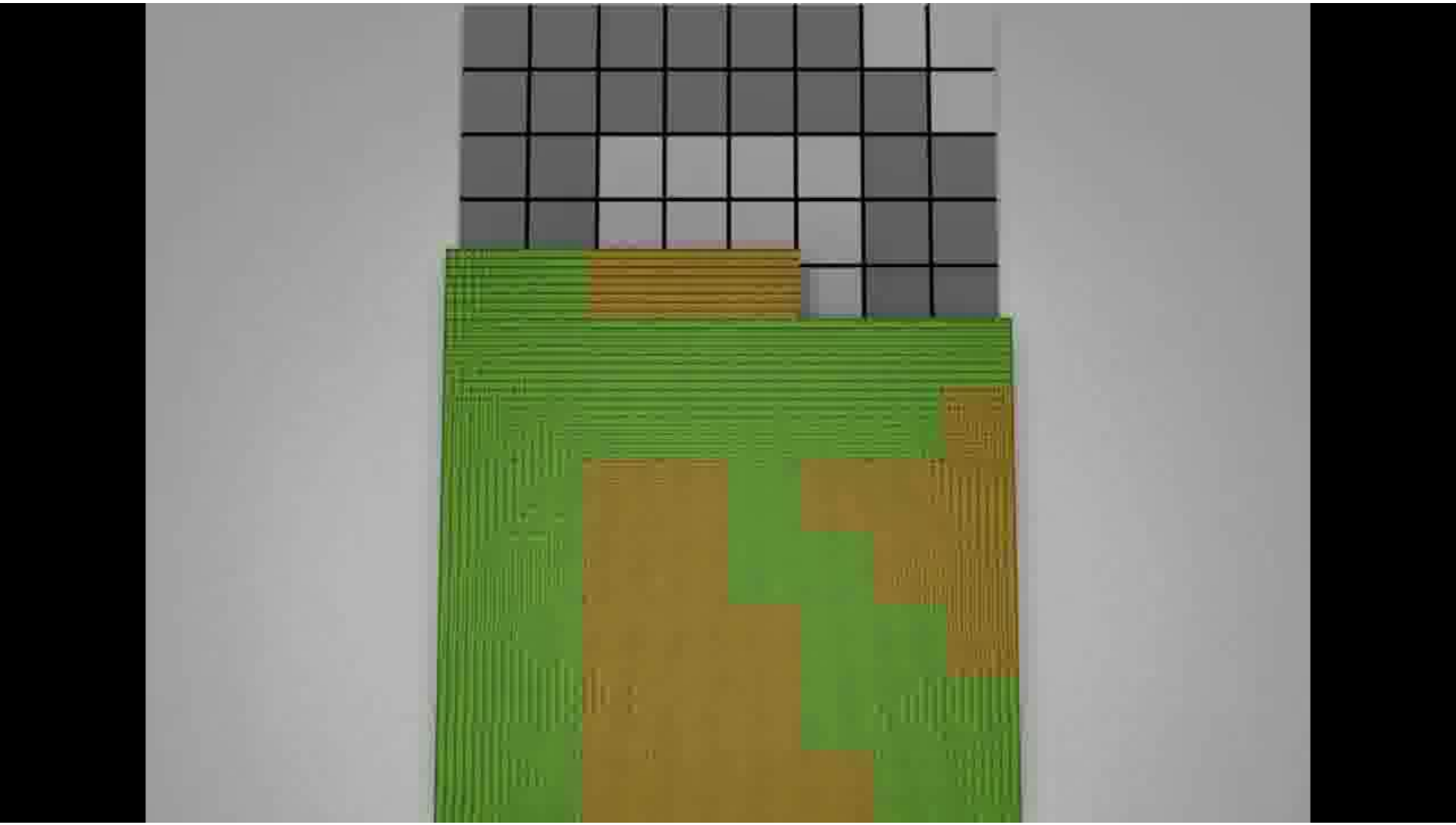


Motions of blocks



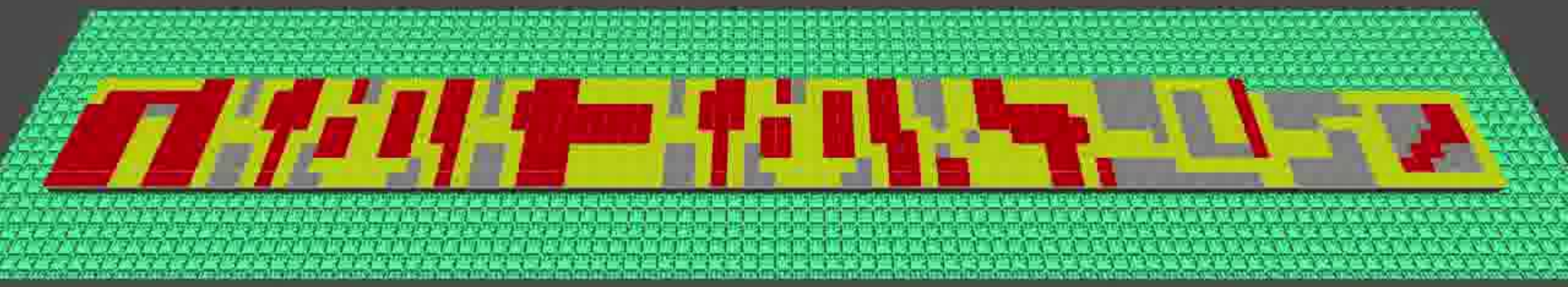
The real-time simulator

- **Discrete events simulator**
  - Deterministic
  - Is able to reproduce the exact same list of events.
- **Capabilities**
  - Blocks movements
  - Exchanges of messages between neighbor blocks.
- **Interface**
  - Free visualization of blocks
  - Selection of a block to get its state.
  - Colorization of blocks to show states of blocks

Example of reconfiguration

Initial configuration : horizontal line

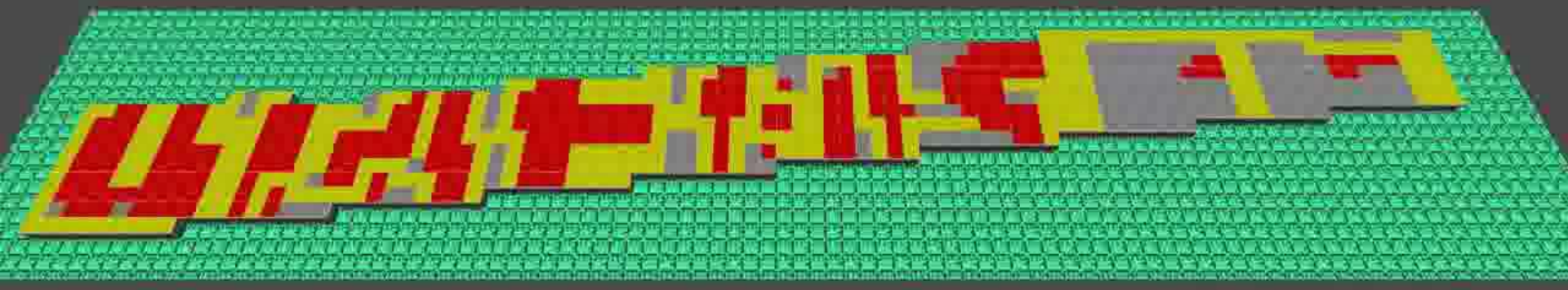
706 blocks / 66 steps



Example of reconfiguration

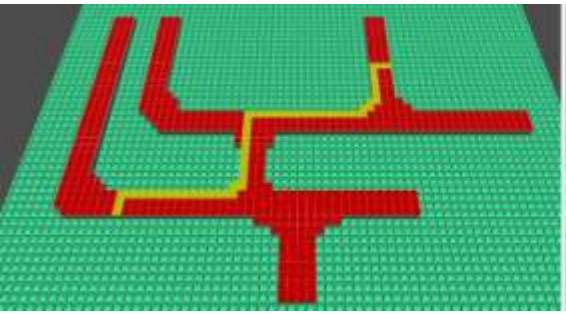
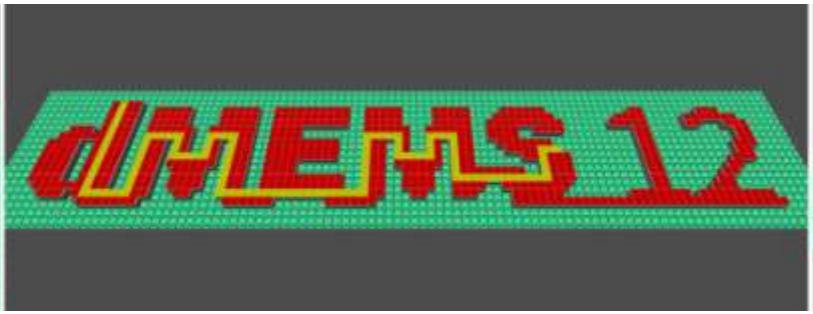
Initial configuration : diagonal line

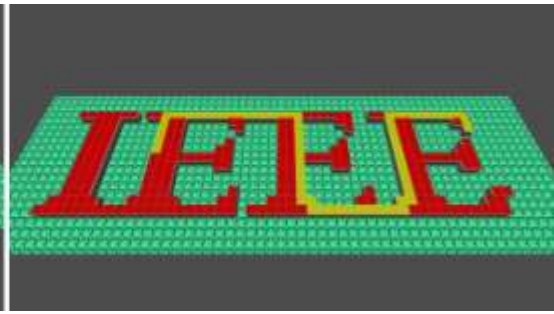
706 blocks / 65 steps



Some results

- **The speed of convergence of the algorithm to reach a configuration is highly dependent on the initial configuration.**



Initial configuration \ Final configuration	Conveyor (546 blocks)	dMEMS 12 (706 blocks)	IEEE (281 blocks)
Horizontal line	121	66	23
2 horizontal lines	136	64	18
Diagonal line	108	65	27
Sinusoïdal line	71	71	21
2 boxes	132	177	67

Future works

- **Block actuators**
  - Increase the size of blocks to 25 mm
    - Higher holding forces
    - More place for electronics.
  - Integrate conveyance actuators on the top
- **Algorithm**
  - Modifying the algorithm to better meet the constraints of lateral displacement of the blocks.
  - Defining a hierarchy of virtual levels
    - Software level over real blocks: agents.
    - Agents allowing to realize macro processing on a set of blocks.
- **Simulator**
  - Add physical simulation of
    - Air-jet forces
    - Micro-parts displacements
  - Add debugging and tracing tools

Questions ?