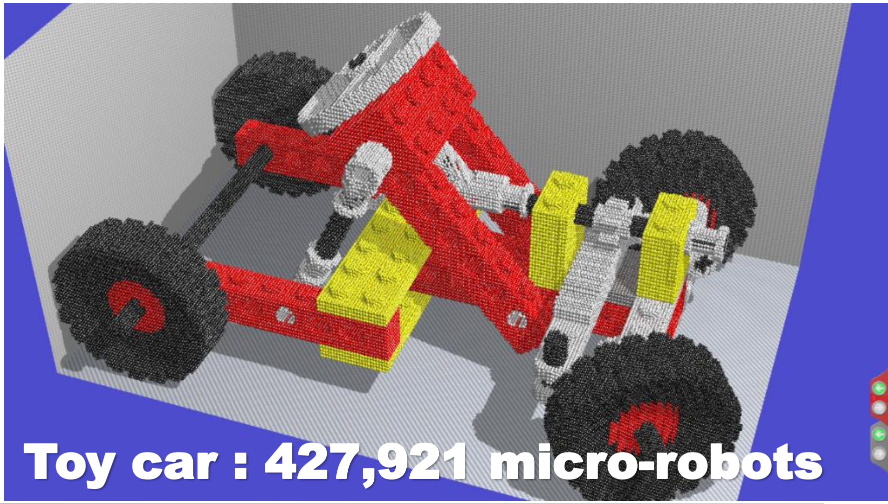
Design of Quasi-Spherical Modules for Building Programmable Matter

Dr. Benoit PIRANDA, Pr. Julien BOURGEOIS

DARS 2016,
13th International Symposium on Distributed Autonomous Robotic Systems
London

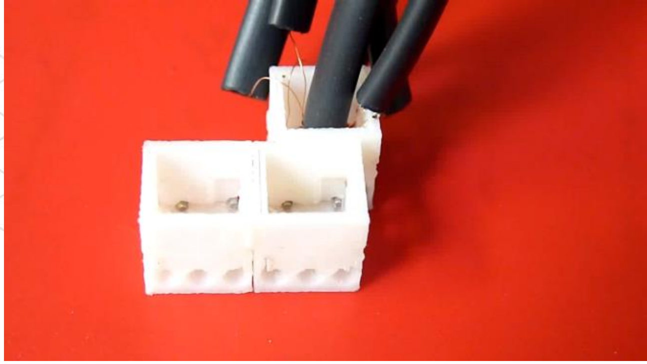
Recalls on Programmable Matter?

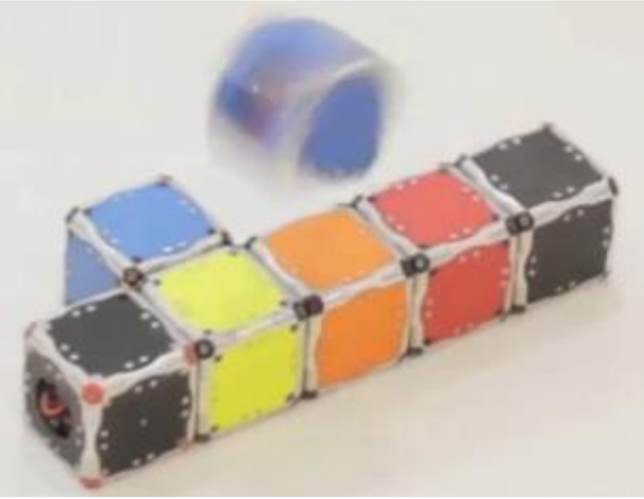
- We consider that Programmable Matter is composed of micro-robots.
- Micro-robot
  - Has computation capabilities
  - Can interact with its environment
    - Sensors
    - Actuators
  - Is placed in a regular grid.
  - Exchanges data with its neighbors
  - Move from one position to another

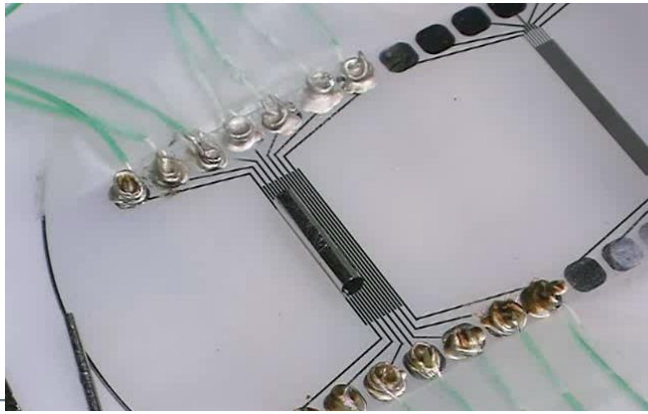


Existing solutions

- Sliding cubes
  - Smart blocks Project
  - 1 centimeter cube
  - Electro-permanent Magnets
- Rotating/Jumping cubes
  - M-Blocks (MIT)
  - 5 centimeter cube
  - High speed flywheel and Magnets
- Rotating cylinders
  - 2D Catoms, Claytronics Project
  - 1mm diameter / 5mm long
  - Electrostatic actuators





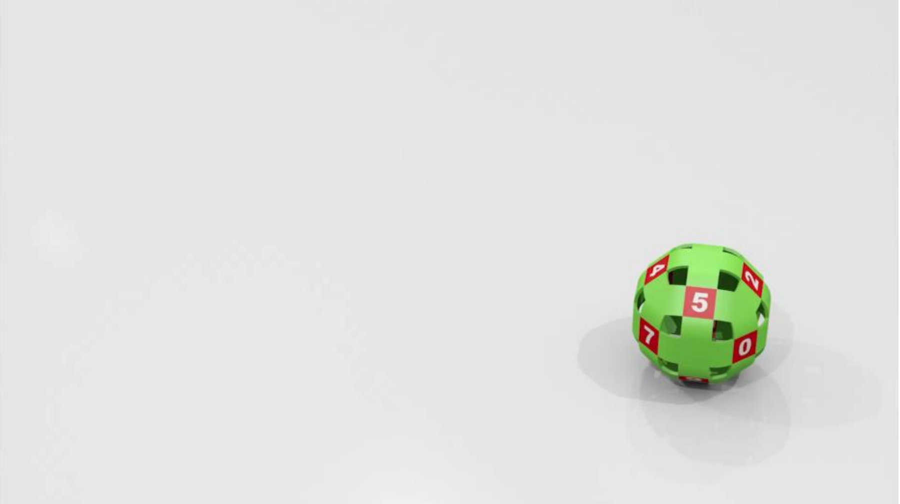


Constraints in micro-robot geometry

1. **Be combined in order to regularly fill a 3D space (predefined grid),**
2. **Have a large surface of contact for latching, communication, contact sensors and power transfer.**
3. **Be free to move from one position of the grid to a neighboring free one.**
4. **After a motion, a module must be oriented in order to place each of its connectors in front of one connector of its neighbor modules.**
5. Be physically connected to many neighbors, in order to allow power transfer and P2P communication,
6. Have a finite number of connectors that are always in the same place on the surface of the module.
7. **Be fabricated from a deformation of a flat shape.**

Idea : quasi-spherical module

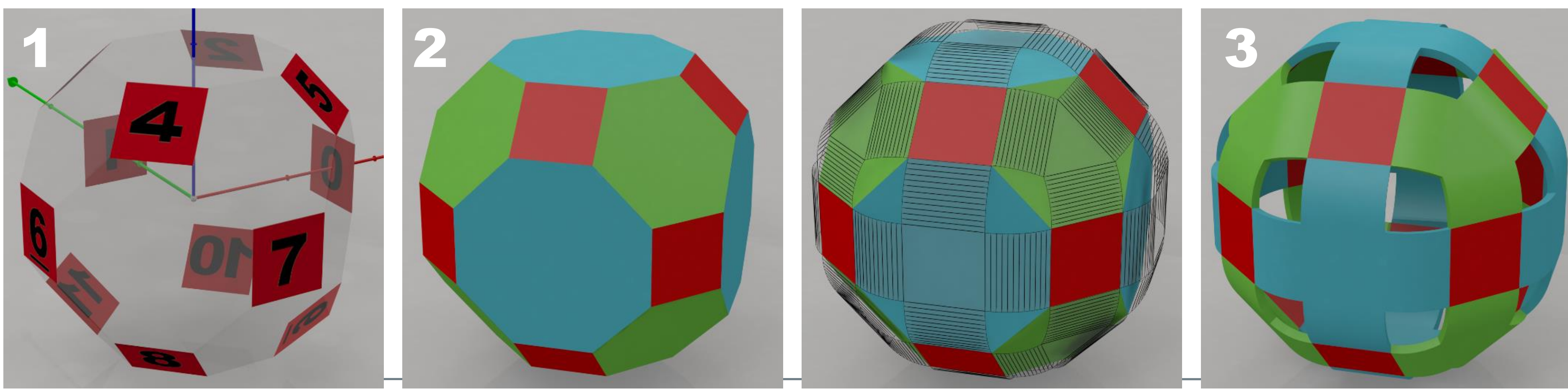
- Rotation of sphere need less energy than sliding of cubes!
- Compact organization of spheres (Face-Centered Cubic lattice)
  - Each sphere admits 12 neighbors
  - Odd floors: regular square grid,
  - Even floors: staggered regular square grid
- Sphere contacts reduced to a point
  - We propose to find a geometry that enlarge these contact areas.
  - We propose to place a square surface at each contact point.



Online video: https://youtu.be/lZh-5p1dbKk

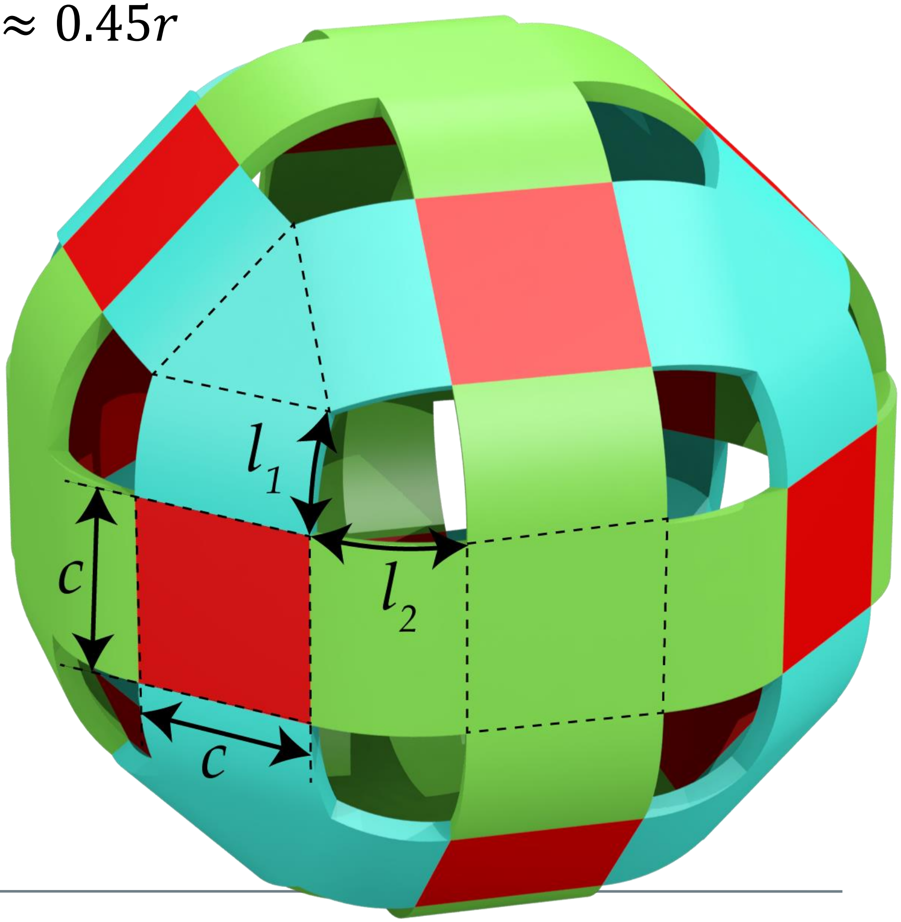
Geometrical basics

1. We replace connection points by 12 square connectors.
2. Then we can place 8 hexagons and 6 octagons.
   - Truncated cuboctahedron
3. Electrostatic actuators make catoms turning around neighbors.
   - We place curved surface over hexagonal and octagonal faces.
   - These curves are part of cylinders and planes in order to obtain continuous surfaces



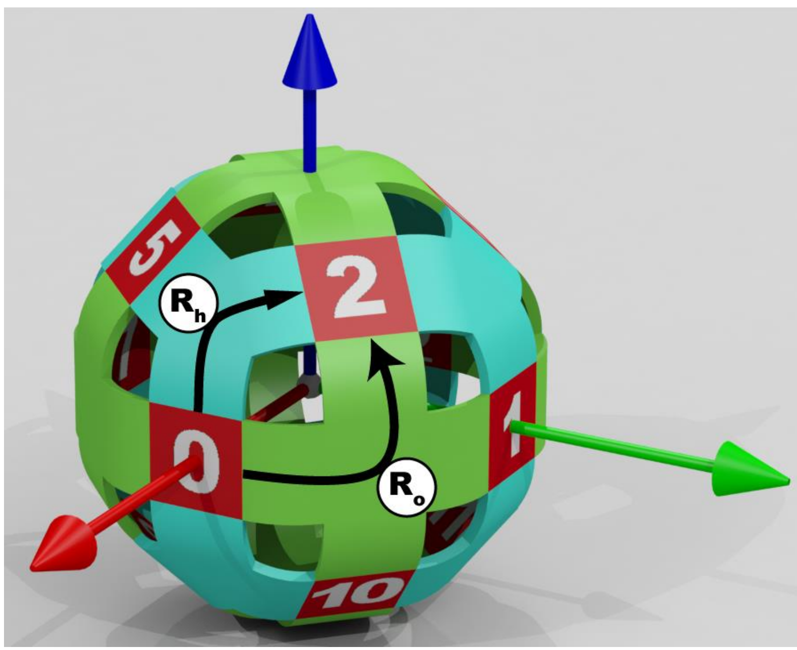
Dimensions of 3D catom

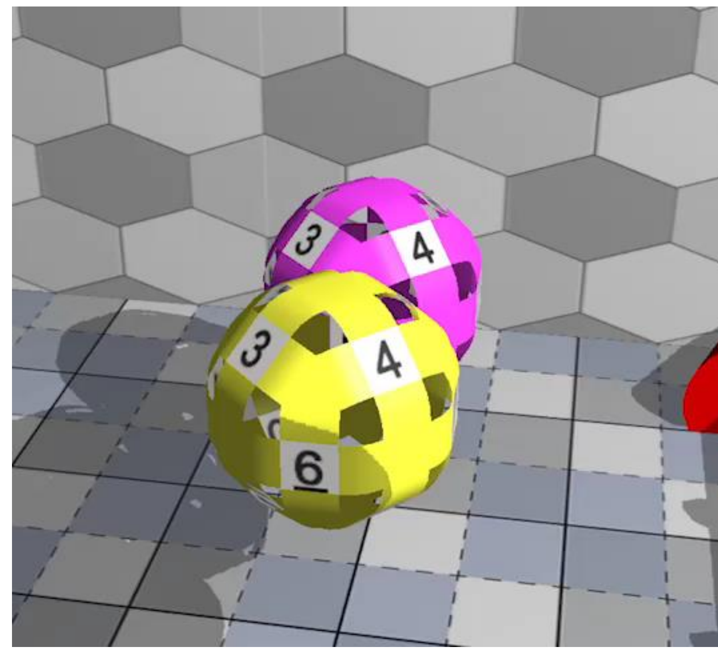
- At contact points
  - Square connectors of size $c = \frac{2r}{3+\sqrt{2}} \approx 0.45r$
- Actuator length (c large)
  - Hexagonal face:
    - $l_1 = 2 \times 0.287r$
  - Octagonal face:
    - $l_2 = 2 \times 0.356r$
- Dense packing in FCC lattice
  - $p_{catoms} \approx 0.83$
  - $p_{spheres} \approx 0.74$



Motions of catoms

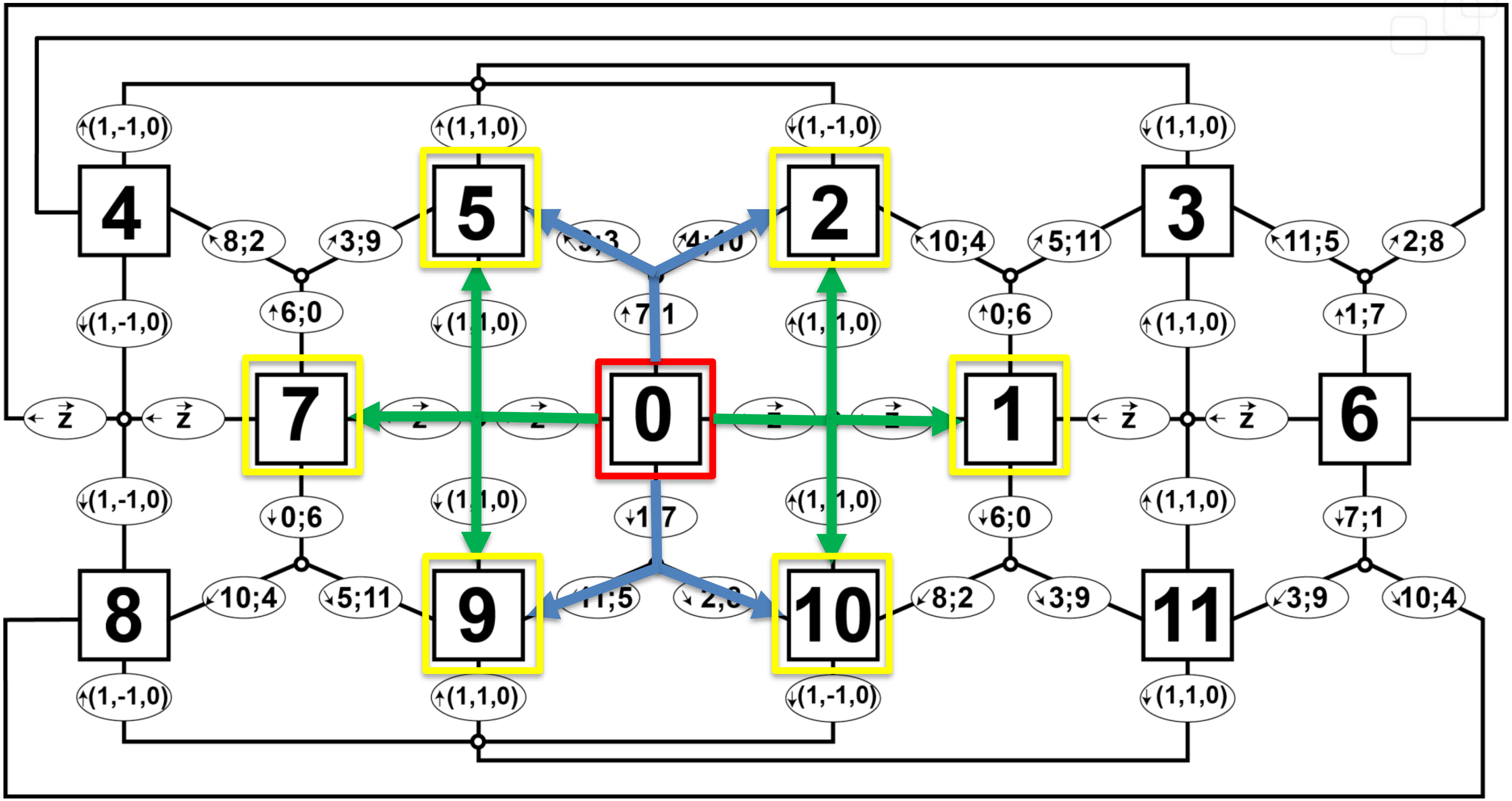
- From a connector position, 10 rotations are available
  - 3 rotations along each actuator placed over an octagonal face (R_o).
  - 2 rotations along an actuator placed over a hexagonal face (R_h).
- But only 6 different connectors can be directly reached.





Online video: https://youtu.be/lBqdtqmzyoA

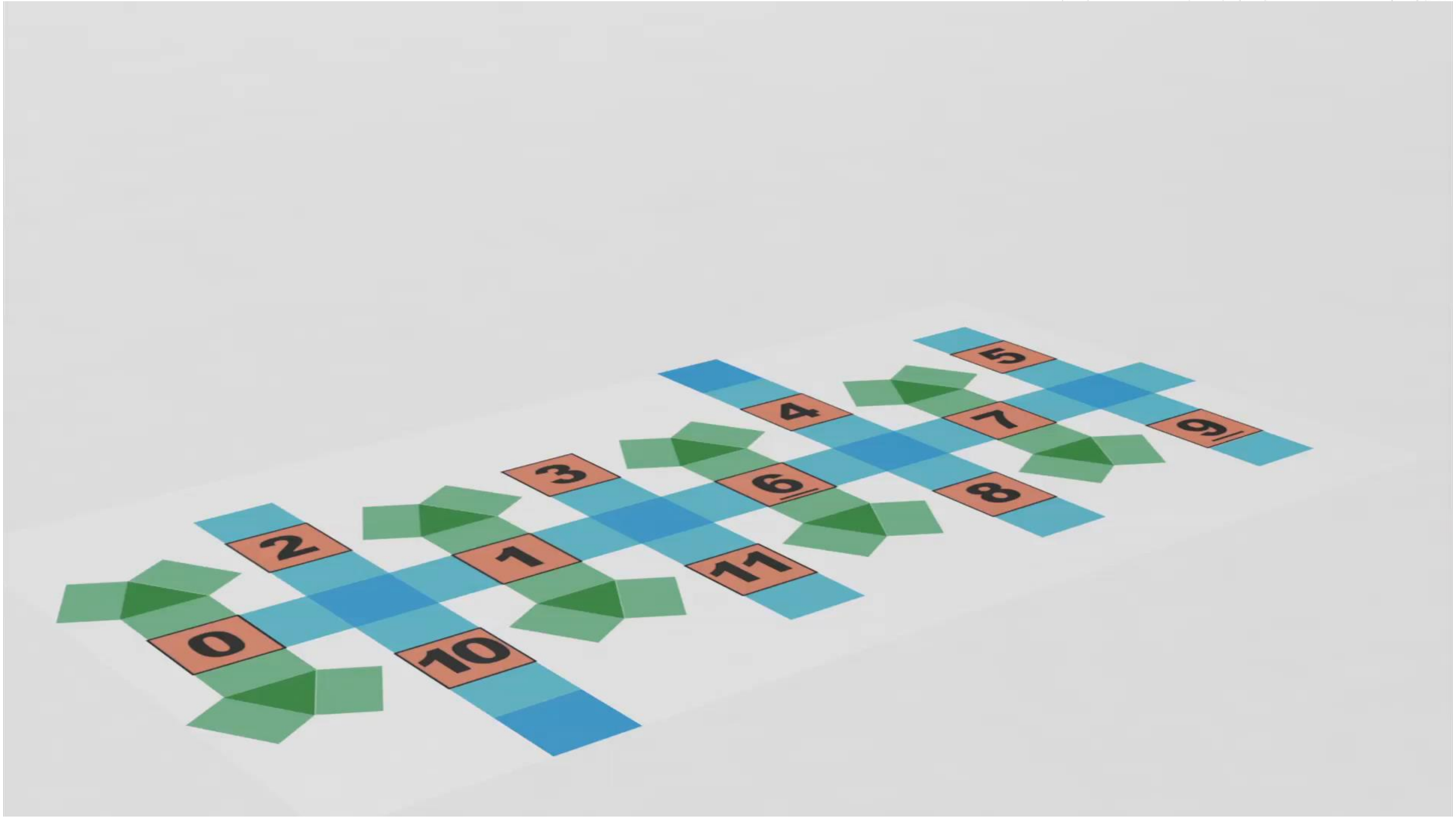
Graph of possible motions



Motion examples

Online video: https://youtu.be/IZh-5p1dbKk

Construction of a 3D Catom from an unfold



Online video: https://youtu.be/IZh-5p1dbKk

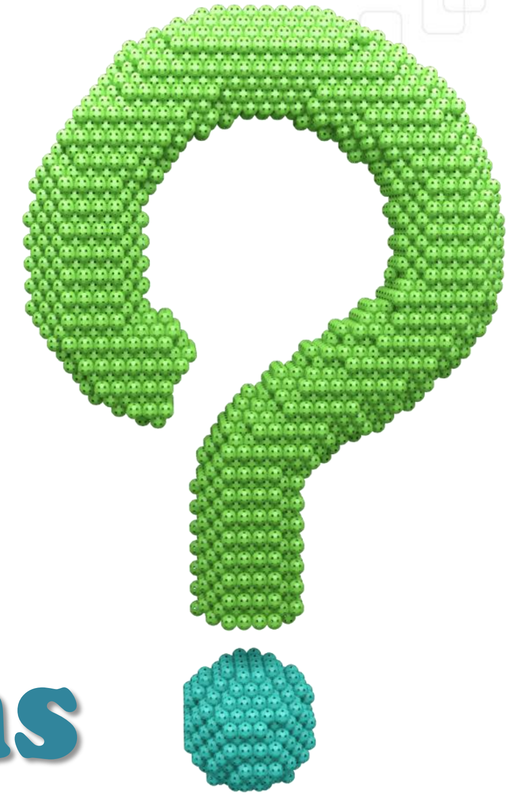
Conclusion and future works

- Conclusion
  - Geometrical solution for Quasi-Spherical micro-robots.
  - Gives large surface of latching between connected modules.
  - Allows motion capabilities for self-reconfiguration.
- Future Works
  - Realization of a catom prototype at two sizes: 1 inch and 2 mm of diameter (funded project ANR-16-CE33-0022-02)
  - Distributed self-reconfiguration algorithm using rotation of catoms over neighbors.

Thank you for your attention!

Follow us on Google:
OMNI Team (FEMTO-ST/DISC/OMNI)

Questions



Works funded by ANR and Labex ACTION program (contract ANR-11-LABX-01-01 and ANR-16-CE33-0022-02)