Live modular Robots!

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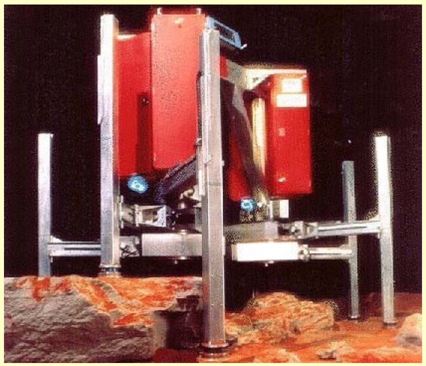
Outline

1. **Introduction**
2. Locomotion in 1D
3. Locomotion in 2D
4. Minimal configurations
5. Cube-M modules
6. Conclusions and current work

The Locomotion Problem

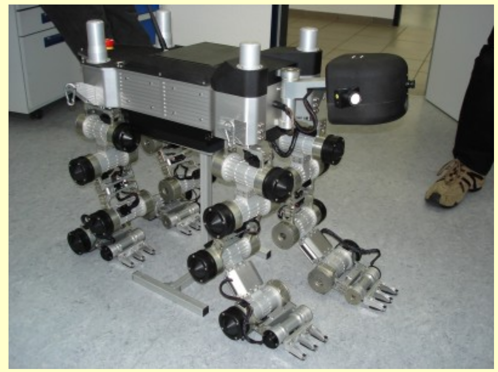
Classic approach



CMU Ambler

Dante II

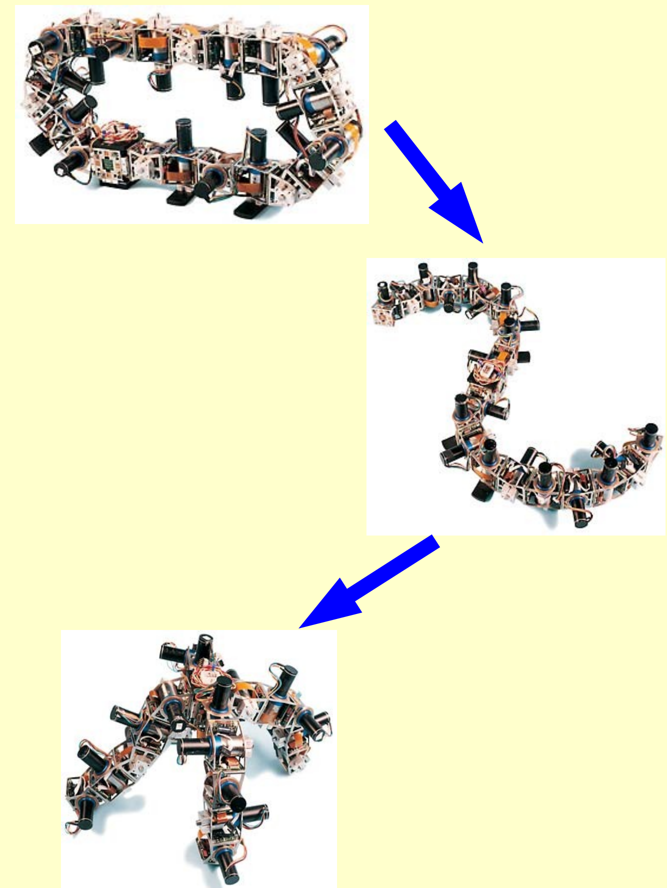
Bio-inspired approach



Aramies

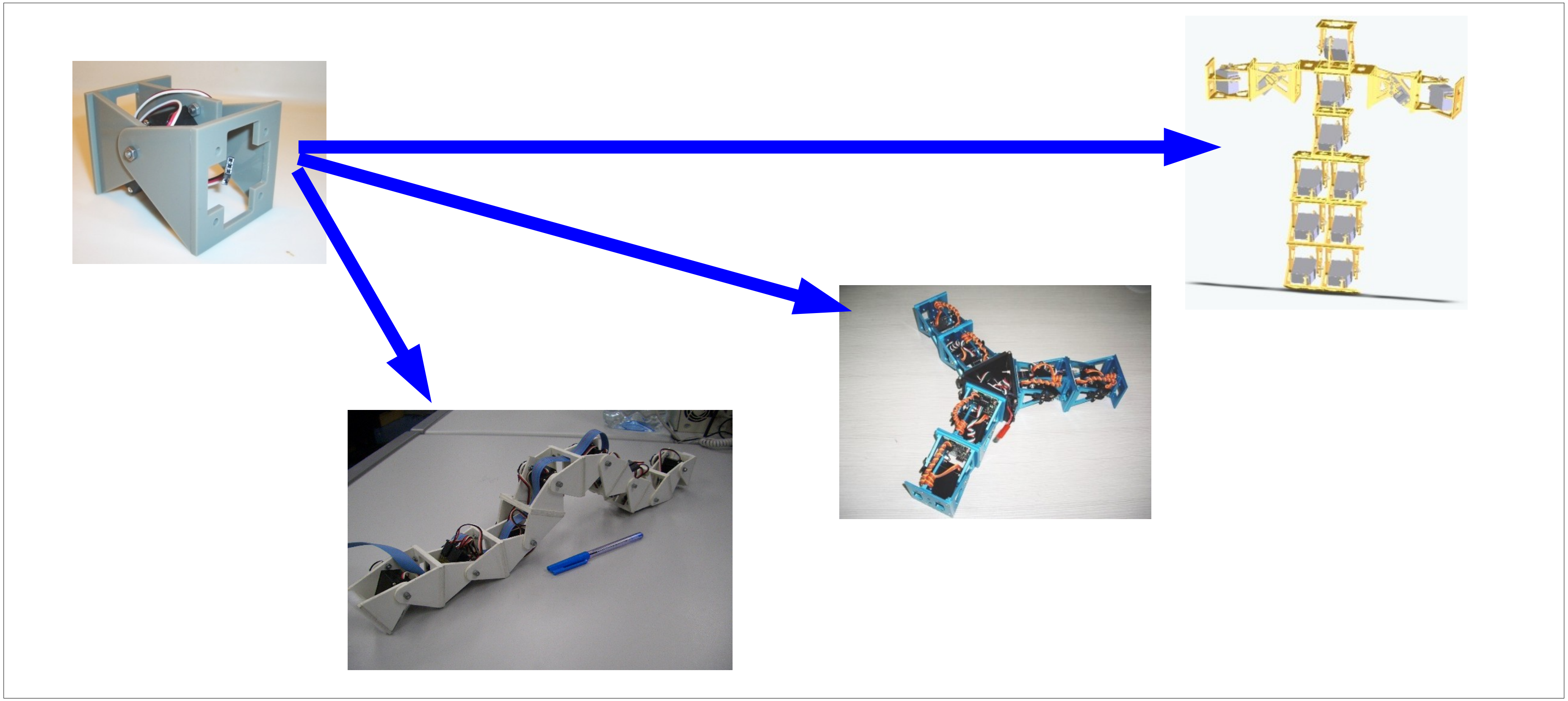
Big Dog

Modular approach



Polybot

Modular Robotics

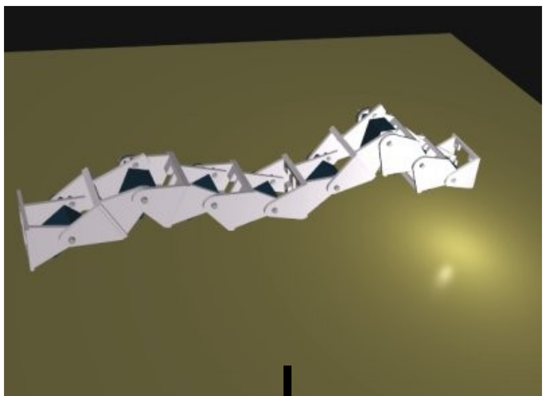


- Two important aspects:
    - **Robot morphology**
    - **Controller**

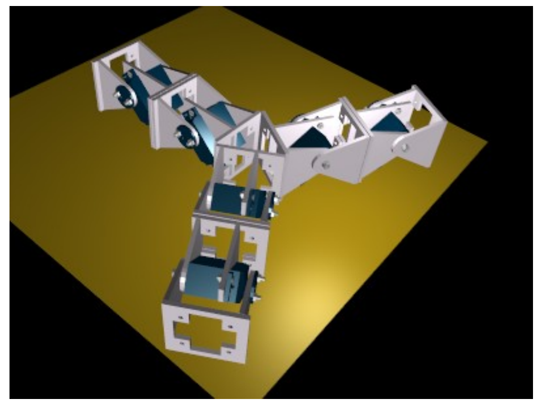
Morphology

Modular Robot classification

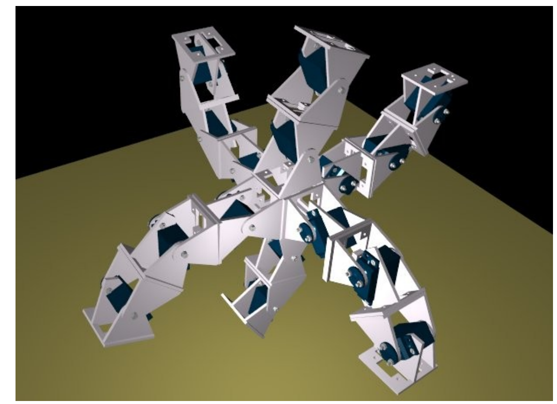
1D Topology



2D Topology

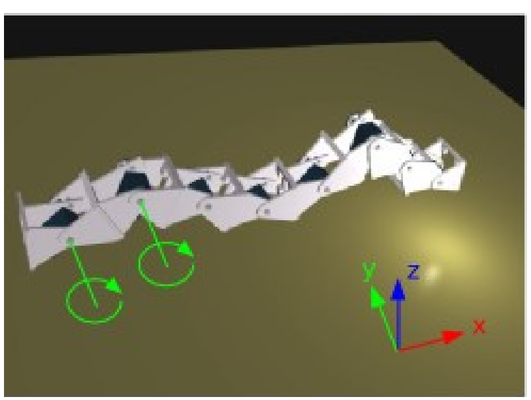


3D Topology

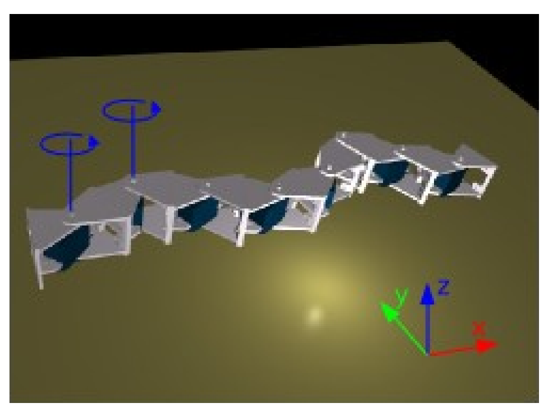


1D topology sub-classification

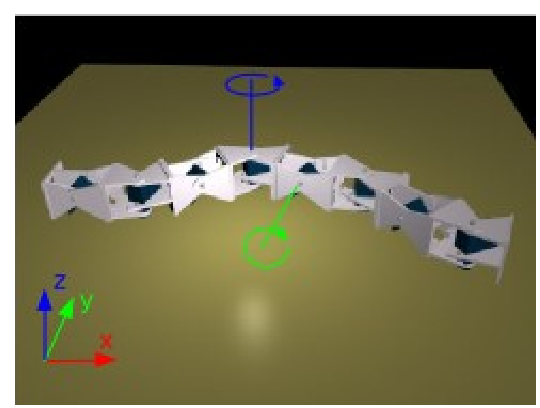
Pitch-Pitch



Yaw-yaw



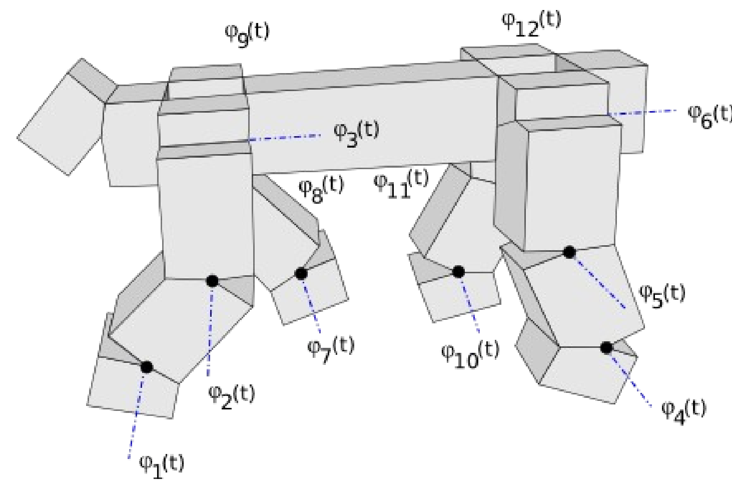
Pitch-yaw



Controller

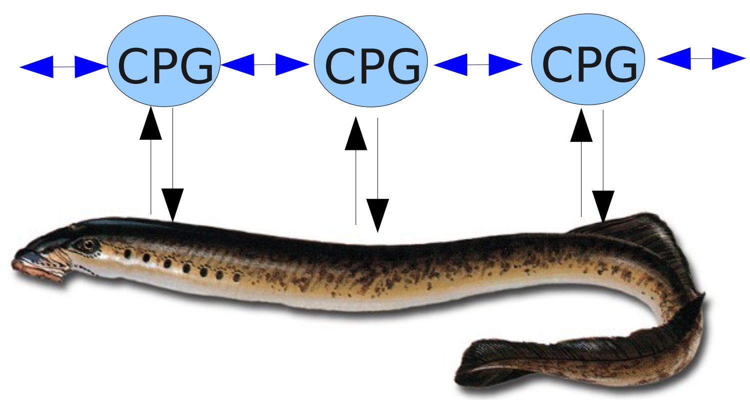
- **Coordination problem**:

> Calculation of the joint's angles to realize a gait: $\varphi_i(t)$



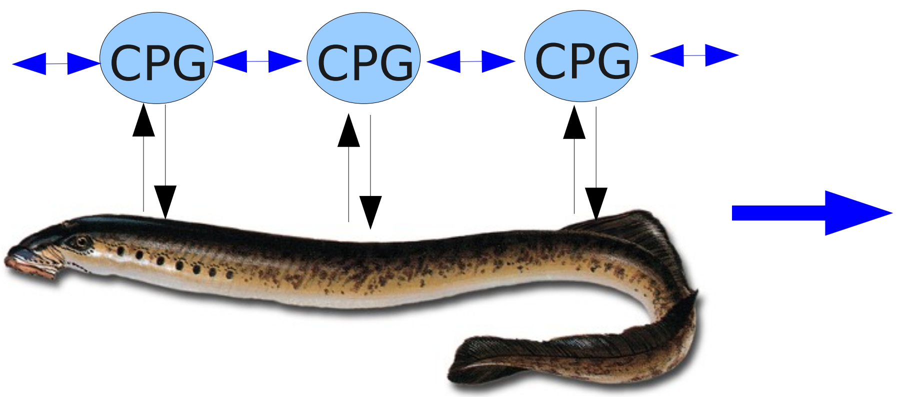
- **Classic approach**: Mathematical modeling
  - Calculation by inverse kinematics
  - Disadvantages: The equations are only valid for an specific morphology

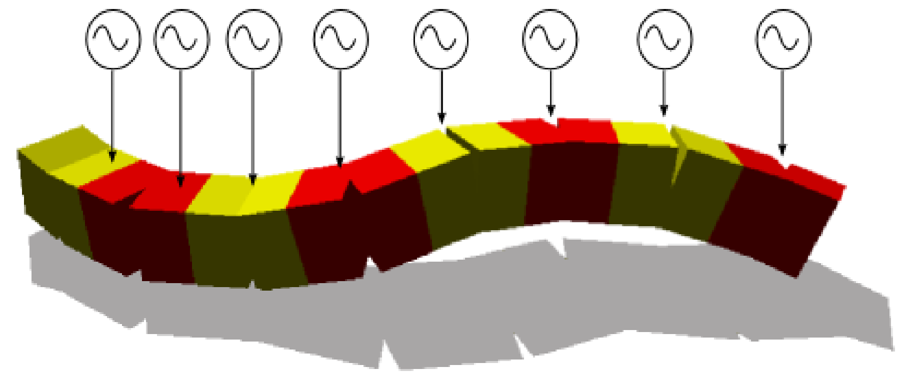
- **Bio-inspired controllers**: CPGs
  - Central Pattern Generators
  - CPGs control the rhythmic activities
  - Ej. The locomotion of the lamprey



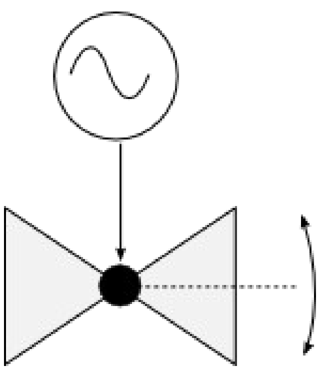
Hypothesis: Sinusoidal oscillators

- CPGs are replaced by a **Simplified model**





- Sinusoidal oscillators:



$$\varphi_i(t)=A_i \sin\left(\frac{2\pi}{T}+\psi_i\right)+O_i$$

- **Advantages**:
  - Few resources required

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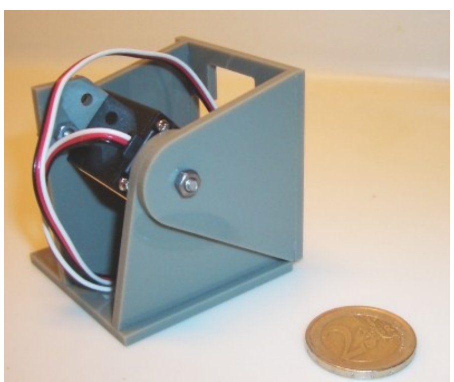
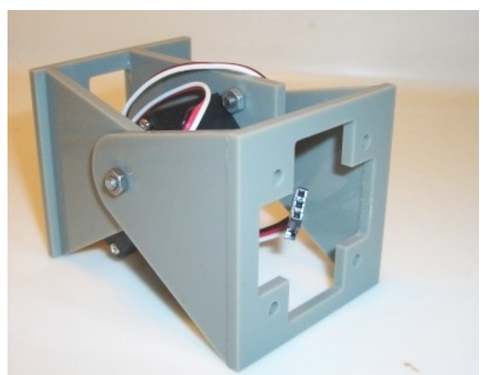
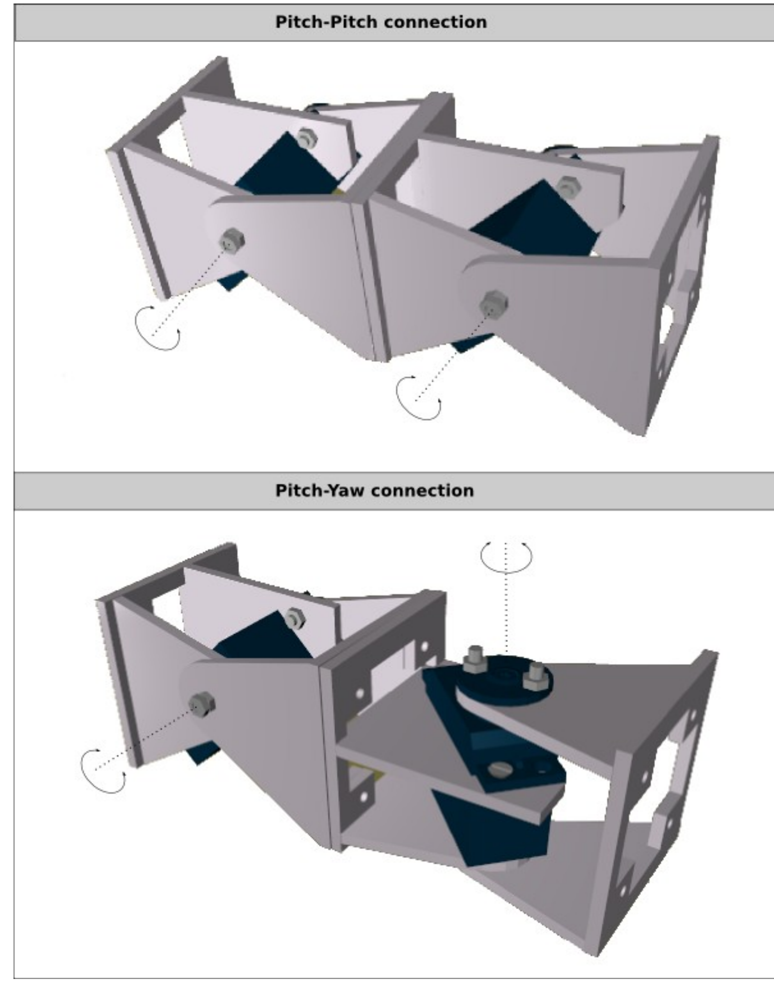
Y1 Modules

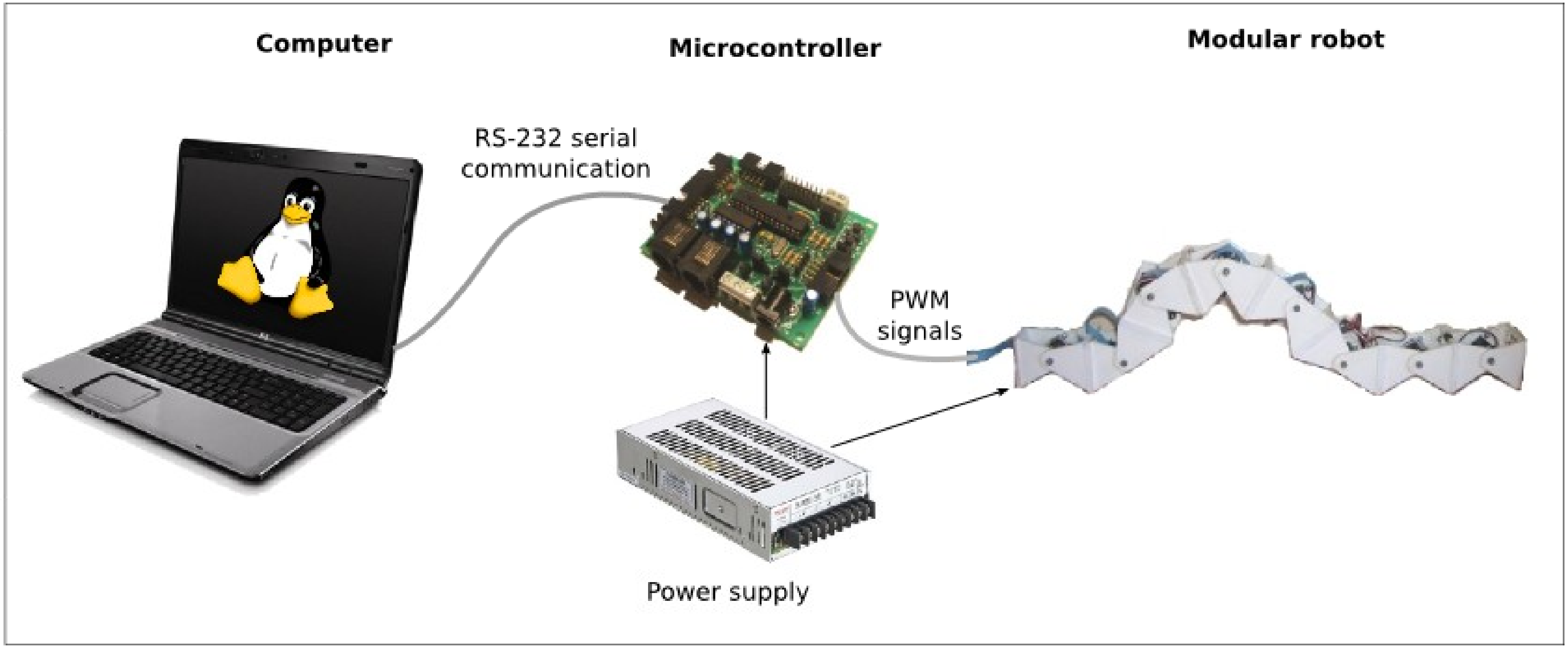
- One degree of freedom
- Easy to build
- Cheap
- Open and “Free”







Electronics & control

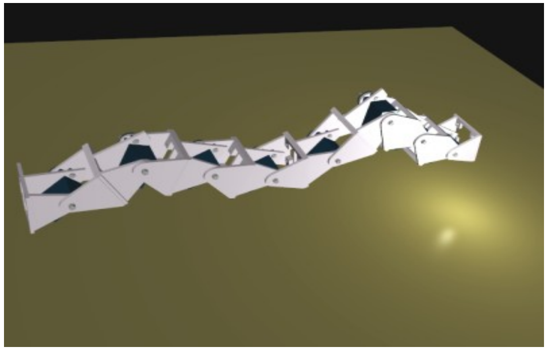


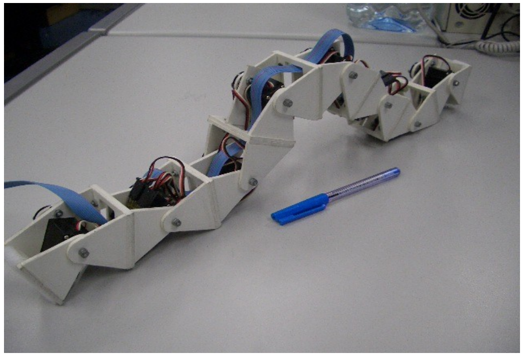
Cube Revolutions (I)

Videos

- **Morphology:**

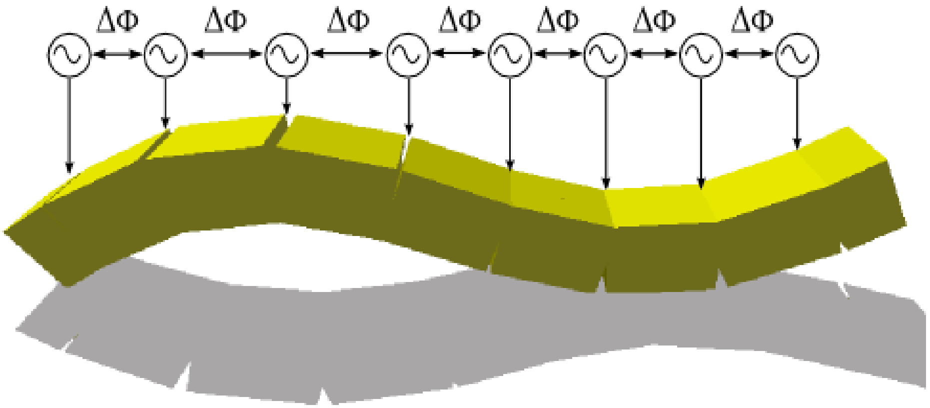
  8 modules with pitch-pitch connection



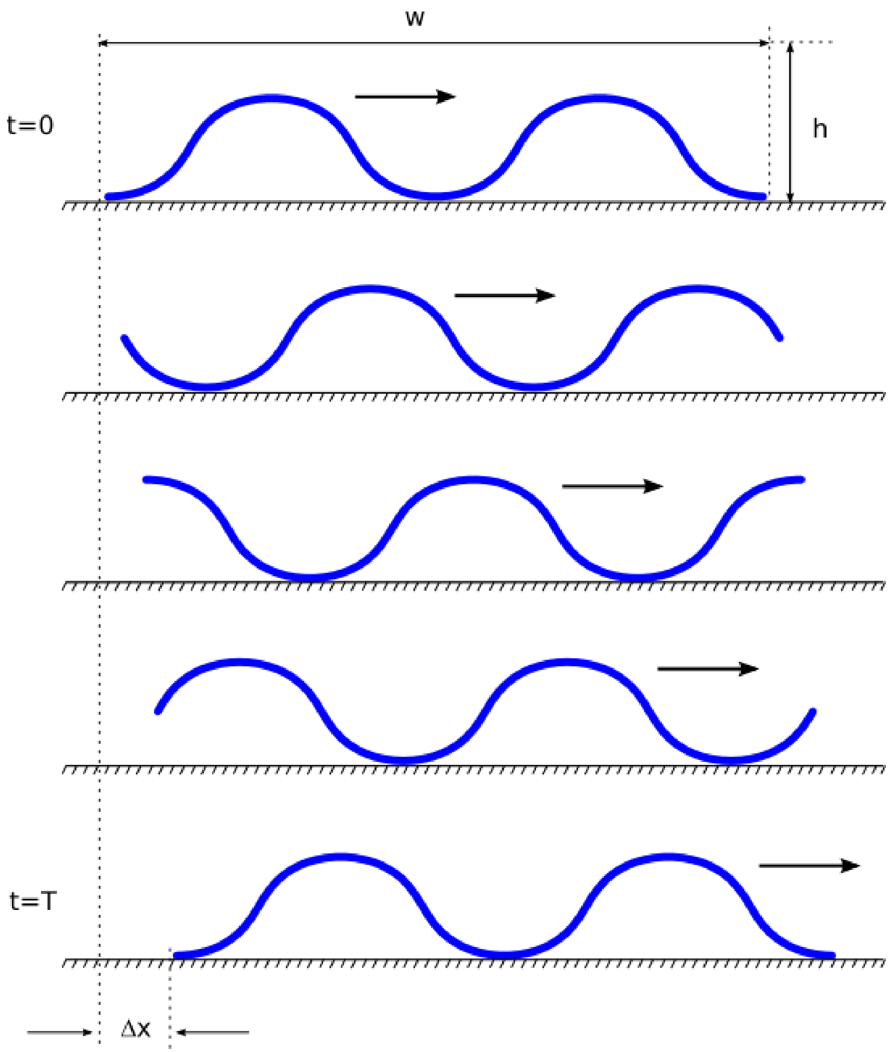


- **Controller:**
  - 8 equal oscillators
  - Parameters:

$$A, \Delta\Phi, T$$



Locomotion mechanism



- Locomotion performed by the body wave propagation
- Step: Δx
- Mean Speed: $V = \frac{\Delta x}{T}$
- **Serpenoid curve**
- Step calculation:

$$\Delta x = \frac{l}{k} - \int_0^{\frac{l}{k}} \cos\left(\alpha \cos\left(\frac{2\pi k}{l} s\right)\right) ds$$

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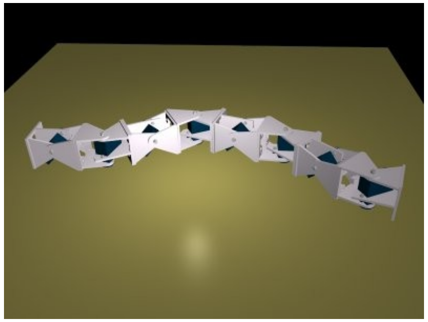
Hypercube (I)

Demo

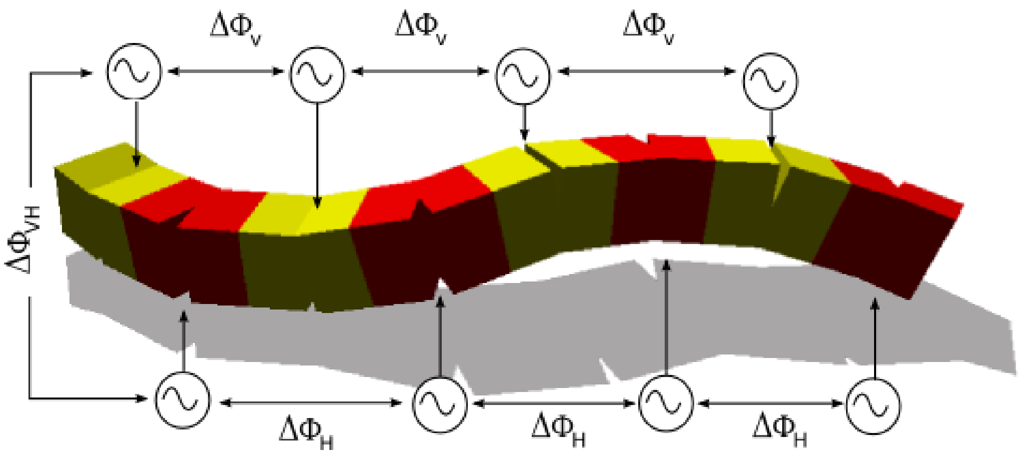
- **Morphology**

  8 modules with pitch-yaw connection

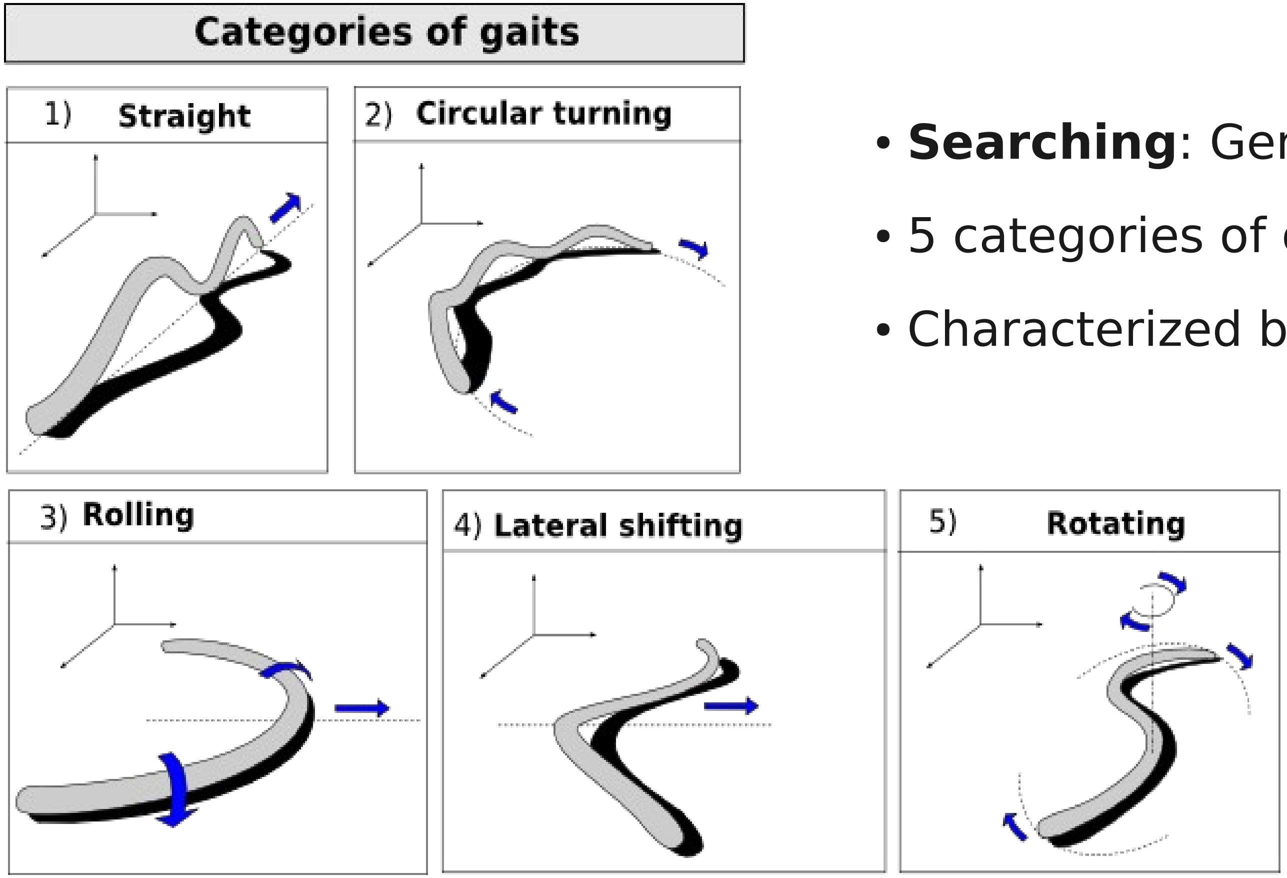


- **Controller:**
  - 4 vertical oscillators
  - 4 horizontal oscillators
  - Parameters:

$$A_h, A_v, \Delta\Phi_h, \Delta\Phi_v, \Delta\Phi_{vh}, T$$



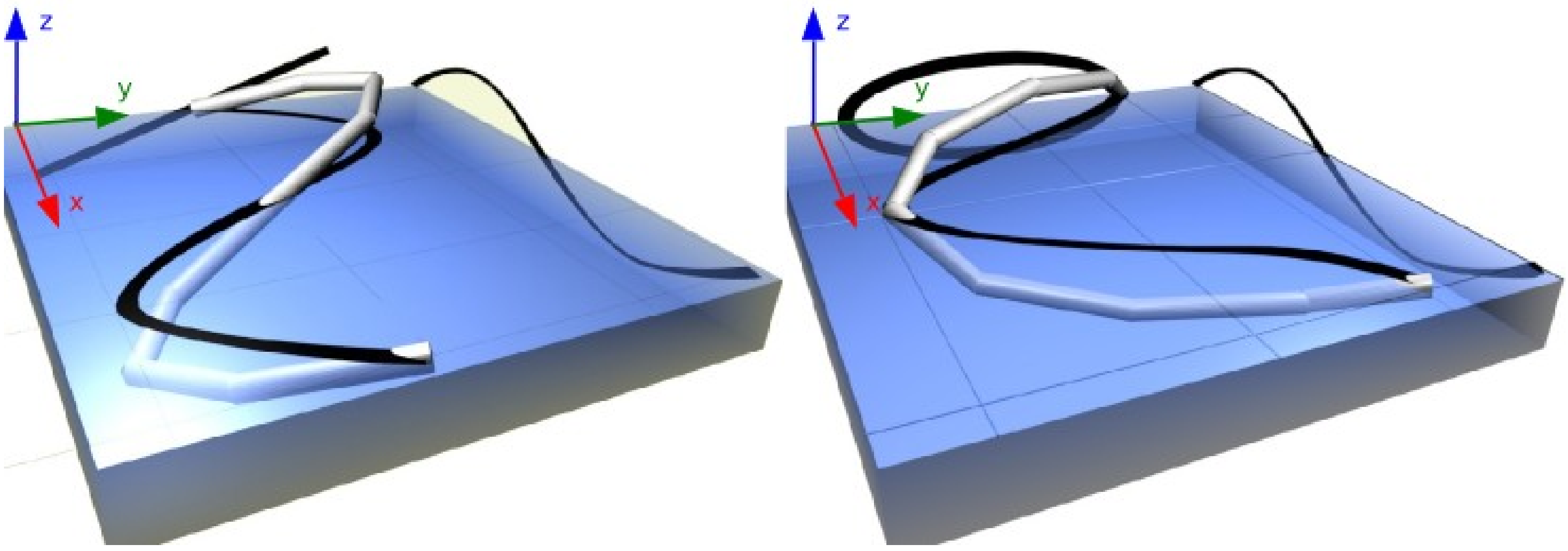
Locomotion gaits



- **Searching**: Genetic algorithms
- 5 categories of gaits
- Characterized by the 3D body wave

Locomotion mechanism

- 3D Body wave propagation
- Linear Step: Δr
- Angular Step: $\Delta\gamma$
- Dimensions: width (w) x length (lx) x heigth (h)



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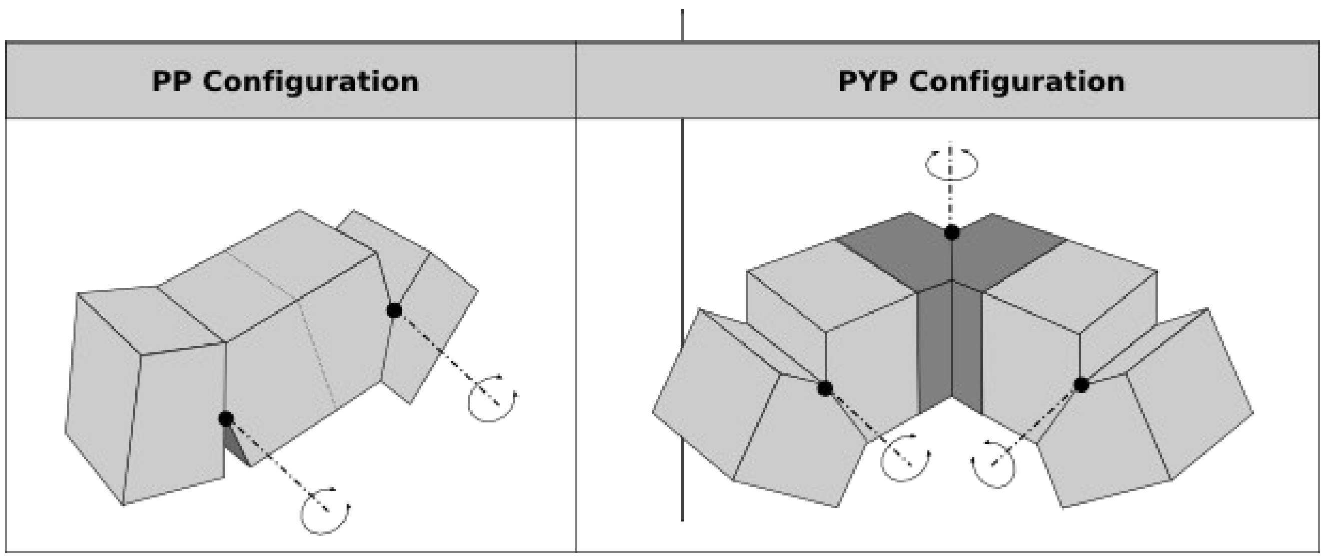
Minimal configurations

- Configurations with the minimal number of modules that are able to move
- Searching the control space using genetic algorithms



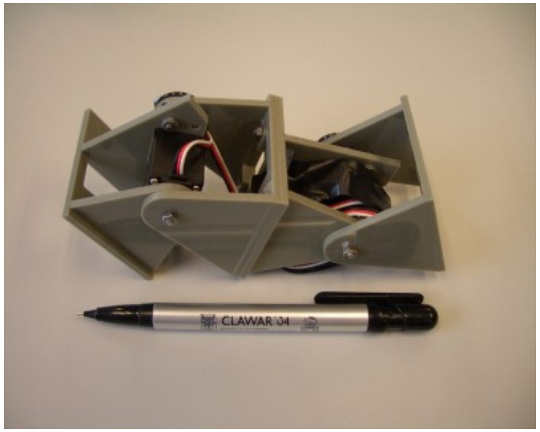
- Straight line
- 5 gaits

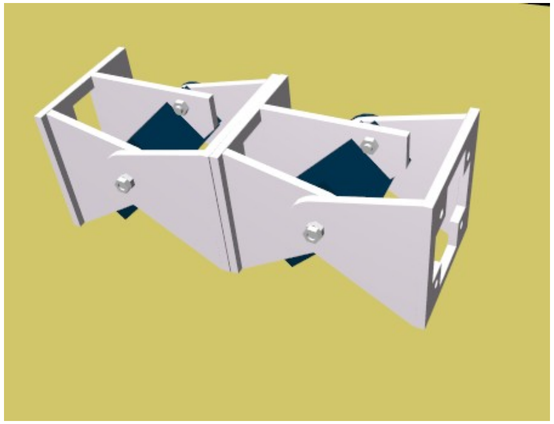
Minicube-I

Demo

- **Morphology**

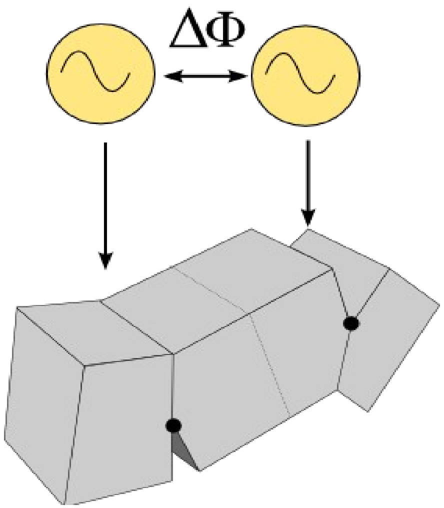
  2 modules with a Pitch-pitch connection





- **Controller:**
  - Two generators
  - Parameters:

$$A, \Delta\Phi, T$$

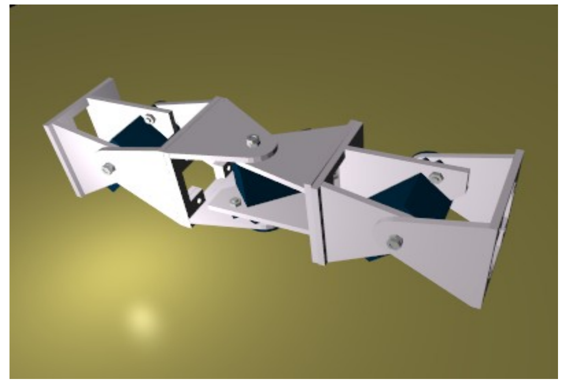


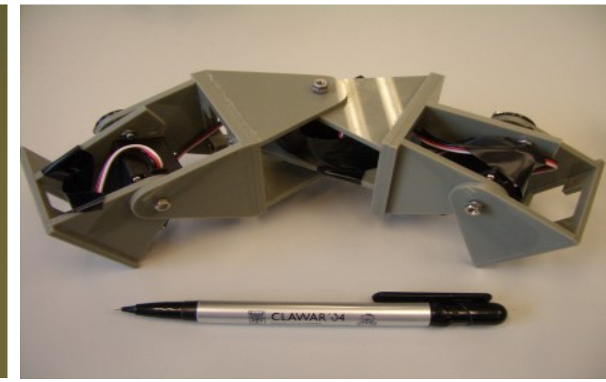
Minicube-II

Demo

- **Morphology:**

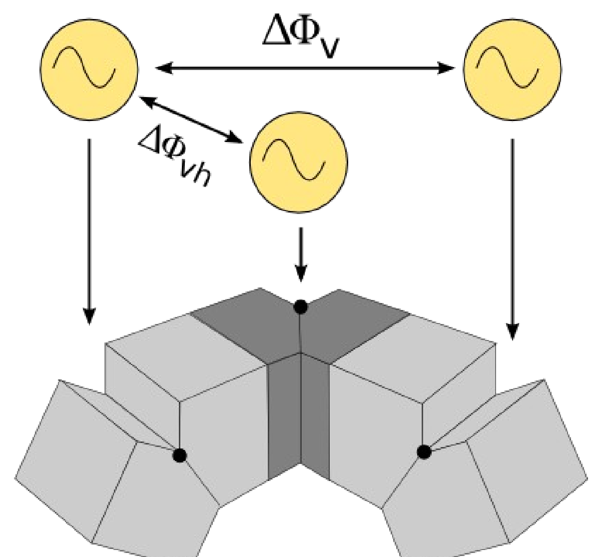
  3 modules with Pitch-yaw-pitch connection





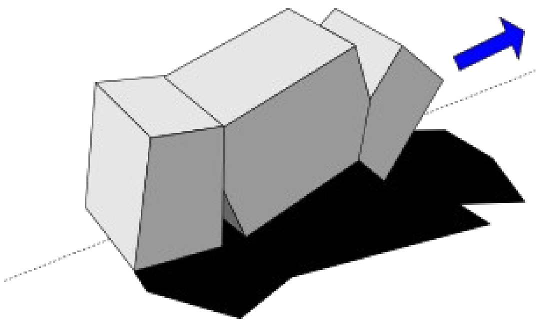
- **Controller:**
  - 3 oscillators
  - Parameters:

$$A_v, A_h, \Delta\Phi_v, \Delta\Phi_{vh}, T$$



Locomotion gaits

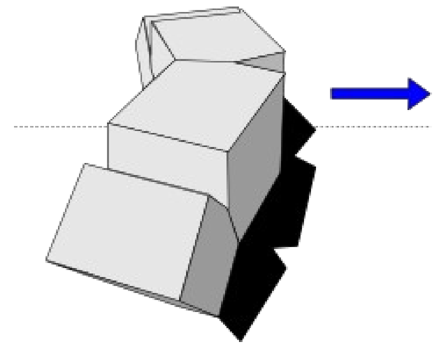
Forward



$A_v = 40, A_h = 0$

$\Delta\Phi_v = 120$

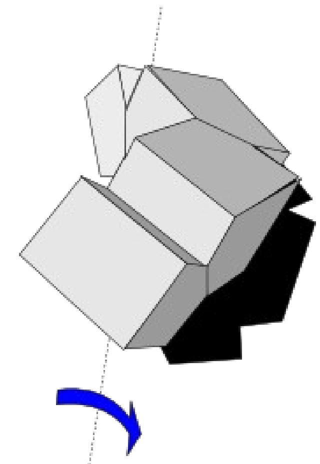
Lateral shifting



$A_v = A_h < 40$

$\Delta\Phi_{vh} = 90, \Delta\Phi_v = 0$

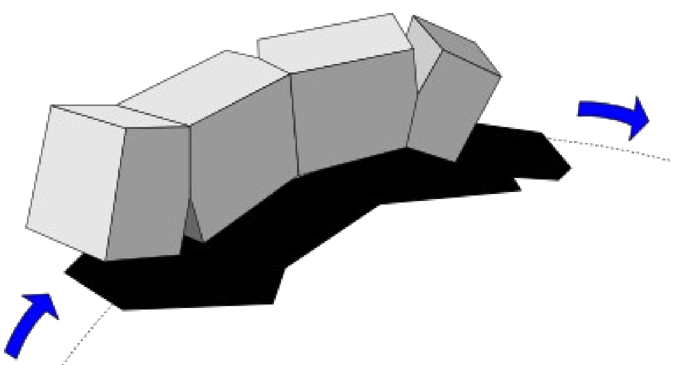
Rolling



$A_v = A_h > 60$

$\Delta\Phi_{vh} = 90, \Delta\Phi_v = 0$

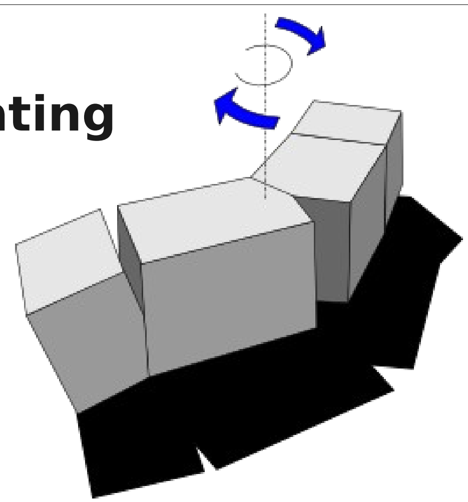
Turning



$A_v = 40, A_h = 0$

$O_h = 30, \Delta\Phi_v = 120$

Rotating



$A_v = 10, A_h = 40$

$\Delta\Phi_{vh} = 90, \Delta\Phi_v = 180$

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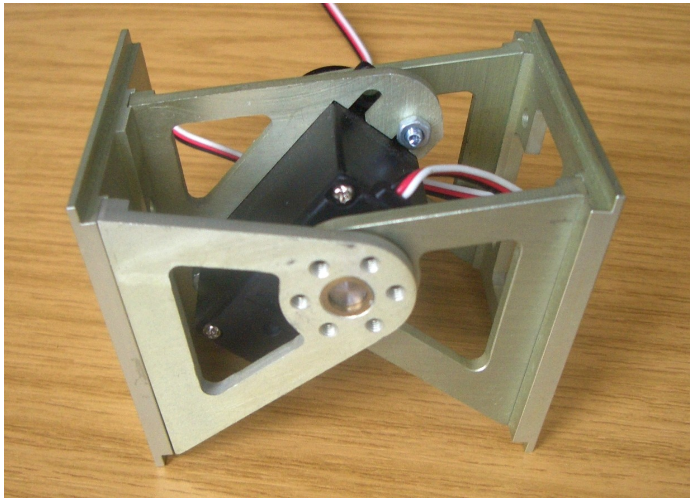
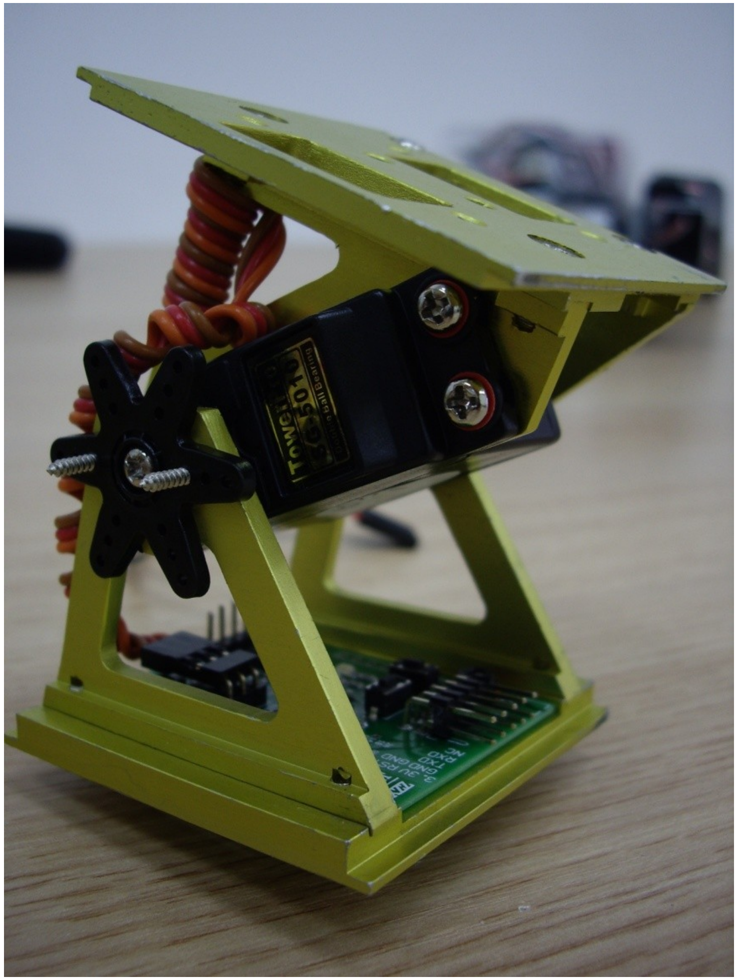
Cube-M module(I)

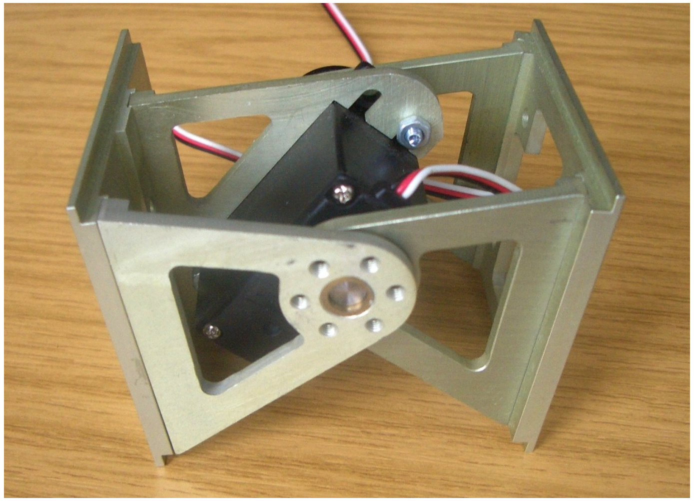
- Low cost mechanical design
- Simple robust modules assembling manually and int a quick-to-build, easy-to-handle design
- Onboard electronics and sensors

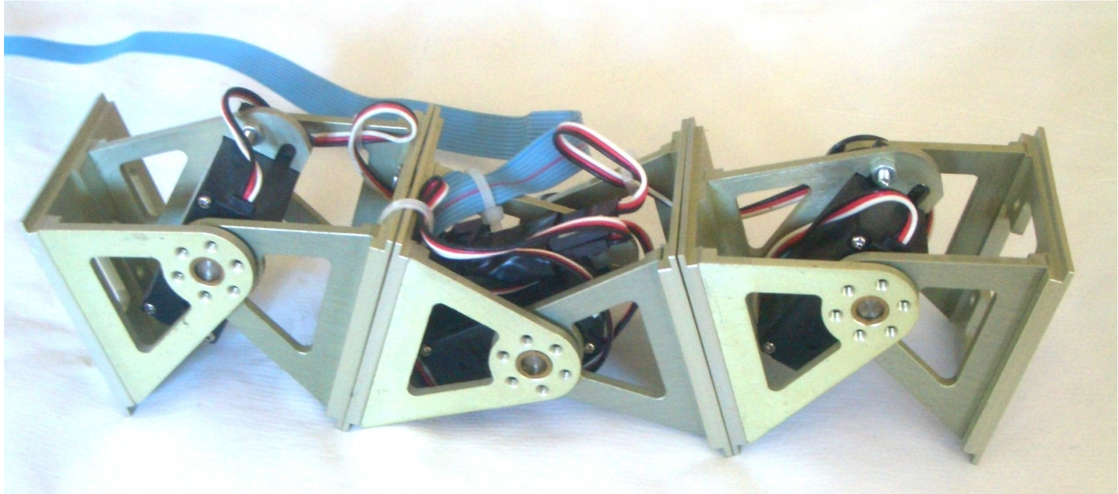


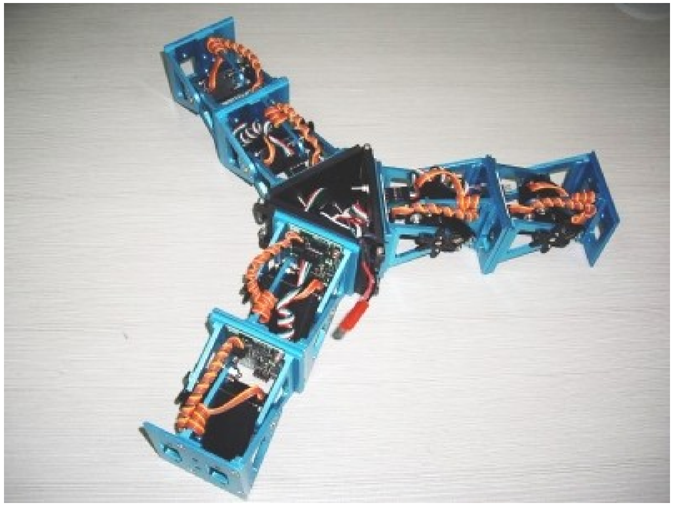


Cube-M module (II)

Demo



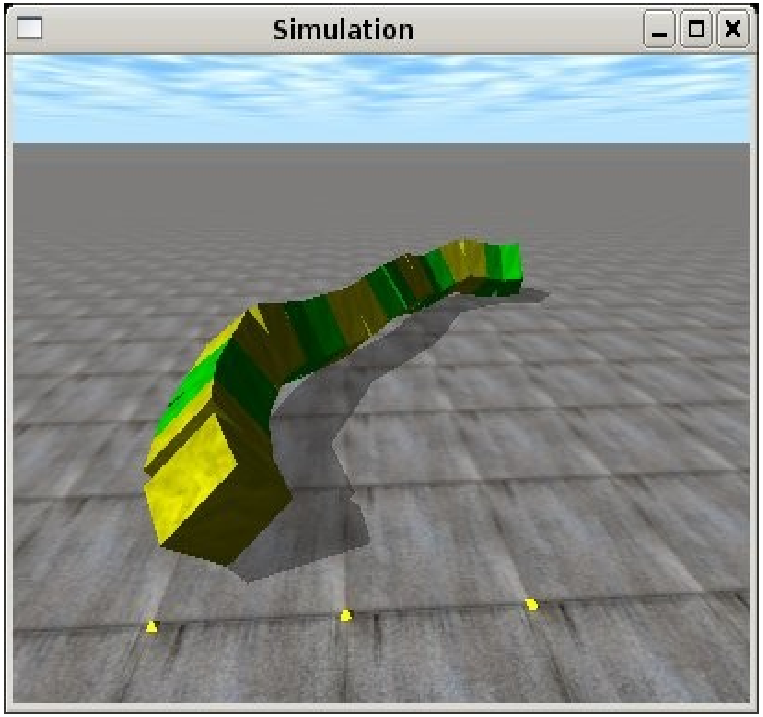


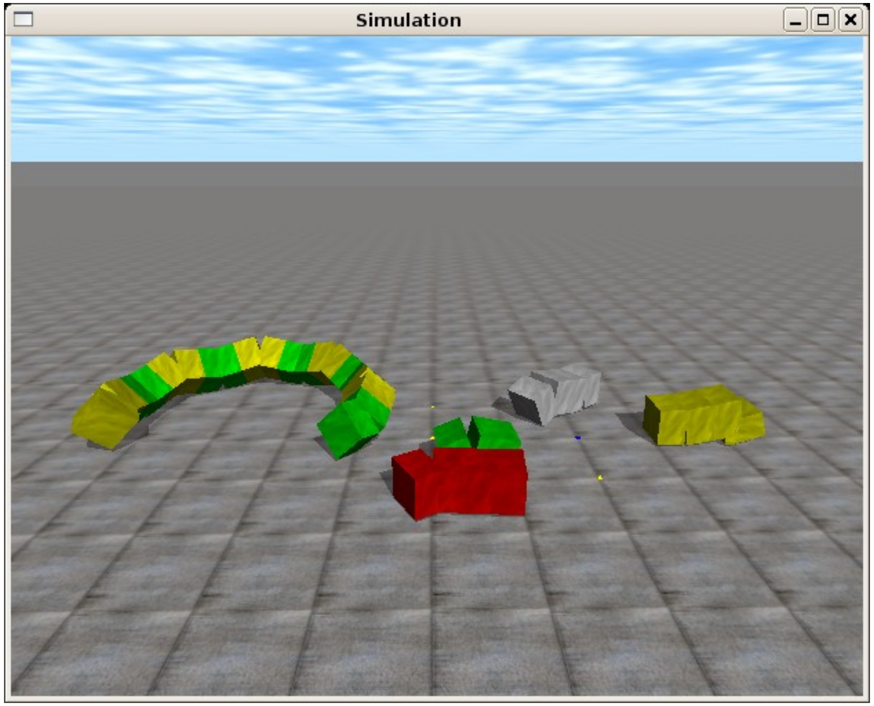


Software

Demo

- 1D topology **simulator** (Based on Open Dynamics Engine [ODE])
- Generics algorithms: PGAPack
- Mathematical models in Octave/Matlab





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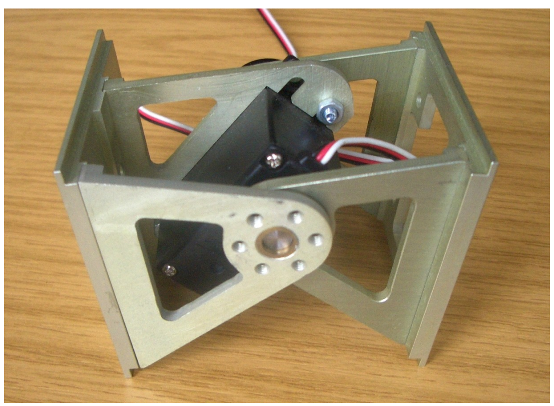
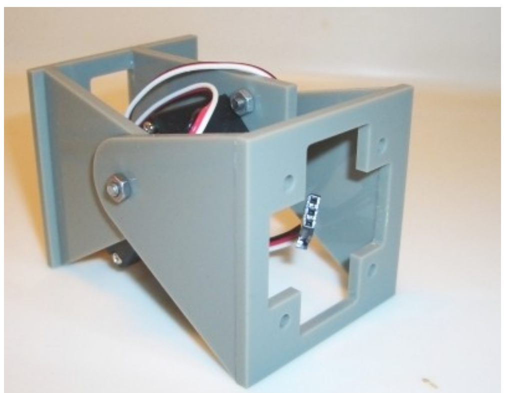
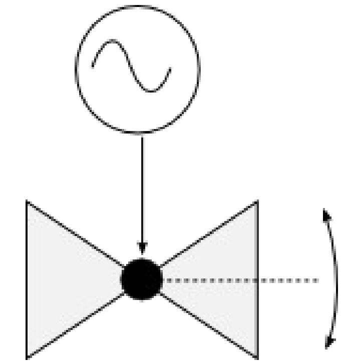
Conclusions

The controller based on sinusoidal oscillators is valid for the locomotion of the 1D-topology modular robots

- Very few resources are required for its implementation
- The locomotion gaits are very smooth and natural
- At least 5 different gaits can be achieved



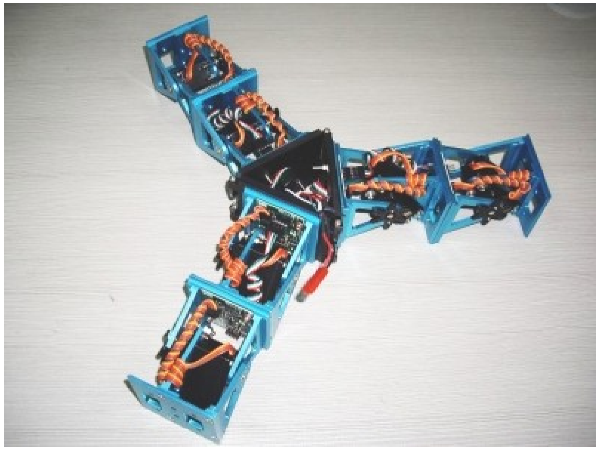




$$\varphi_i(t)=A_i \sin\left(\frac{2\pi}{T}+\psi_i\right)+O_i$$

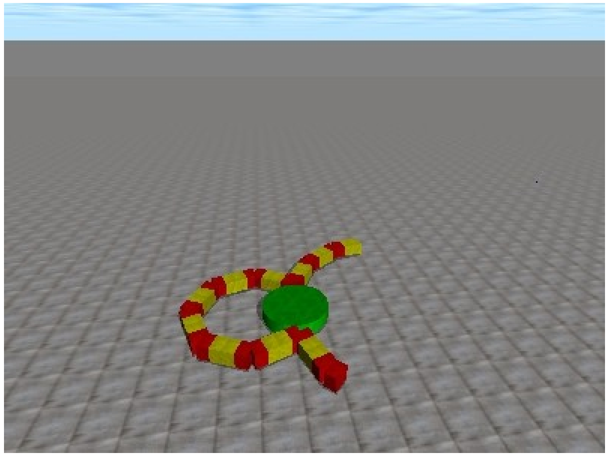
Current work

Locomotion of 2D
Topology modular robots



Climbing caterpillar

Modular grasping



New module design

Live modular Robots!

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