Introduction to the Locomotion of limbless modular robots

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Outline

1. **Introduction**
2. Modules
3. Oscillators
4. Locomotion in 1D
5. Locomotion in 2D
6. Simulation
7. Conclusions and current work

The Locomotion Problem (I)

• Development of a very versatile robot with the full capability of moving on different terrains.

Robot architecture

Higher level

- *Environment perception*
- *Path planning*
- *Navigation*
- *Making decision*

Lower level

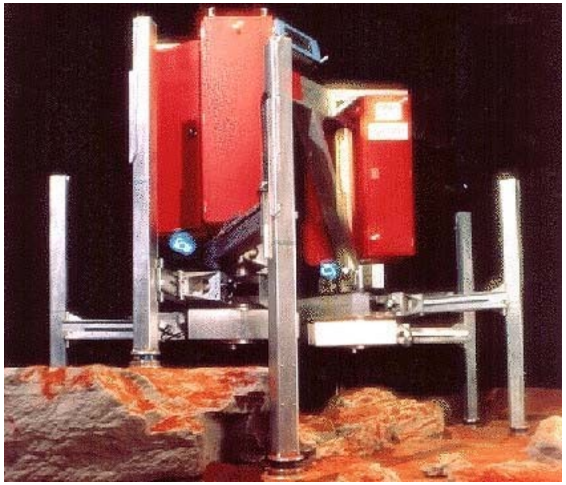
- *Coordination of the joints*
- *Robot morphology*
- *Gaits*

Locomotion problem (II)

Classic approach:

- Study the terrain
- Design the mechanics
- Gait realization

- NASA interested in this problem
- Planet exploration
- Ex. Ambler and Dante II Robots



*(**Ambler**, Krotkov et al, 1989)*

*(**Dante II**, Bares et al, 1994)*

Locomotion problem (III)

Videos: 1,2

Bio-inspired approach:

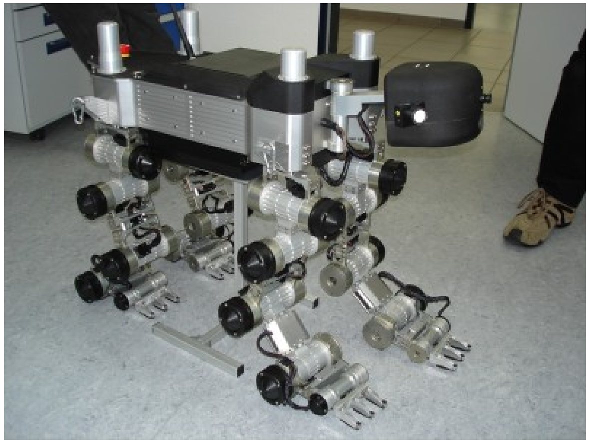
- Copying the animals in nature

Boston Dynamics

*(**BigDog**, Raibert et al. 2008)*

Robotic Lab at DFKI Bremen

*(**Scorpio**, Dirk et al. 2007)*



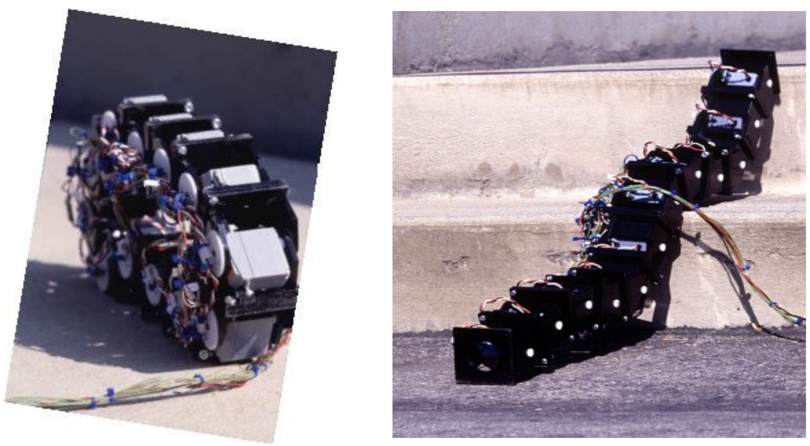
*(**Aramies**, Sastra. 2008)*

Locomotion problem (IV)

Modular self-reconfigurable approach:

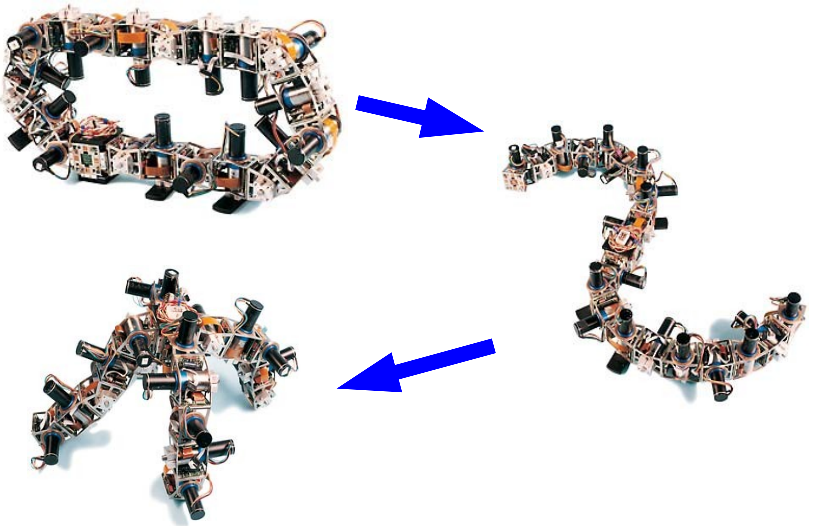
- The robots change their morphology to adapt to the terrain

Simple reconfiguration with Polybot G1. From wheel to snake



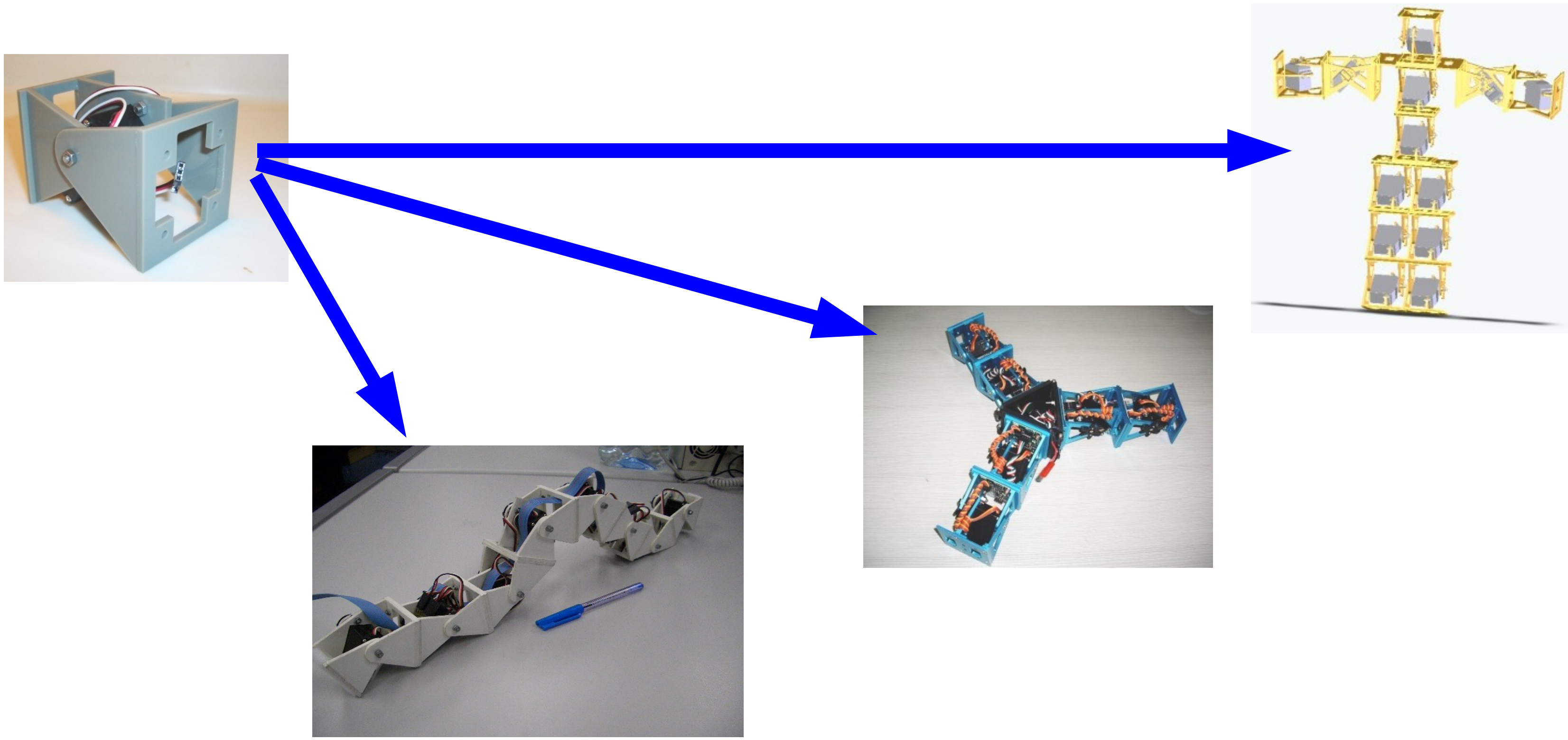
*(**Polybot G1**, Yim et al. 1997)*

Complex reconfiguration with Polybot G2. From wheel to a snake and finally to a 4-legged robot



*(**Polybot G2**, Yim et al. 2000)*

Modular Robotics



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

Morphology (I)

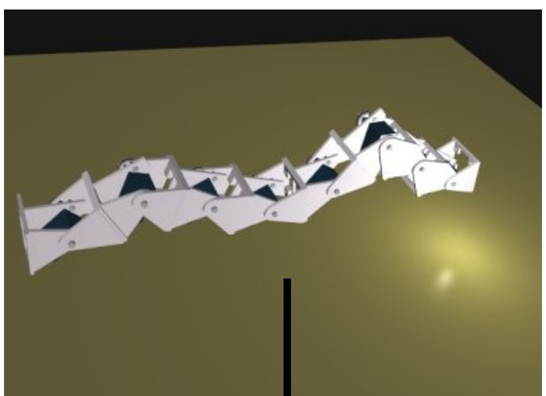
• Each morphology has its own locomotion capabilities

• The number of configurations growth exponentially with the number of modules

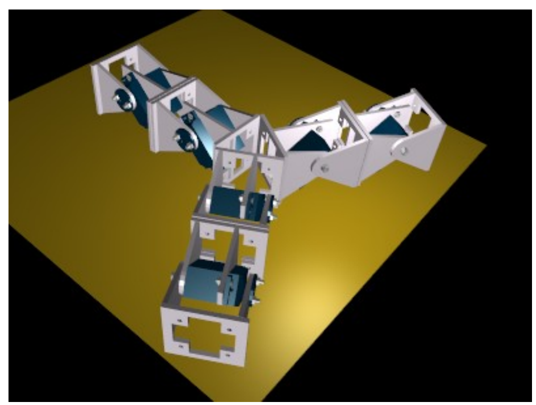
• A classification is needed

Modular Robot classification

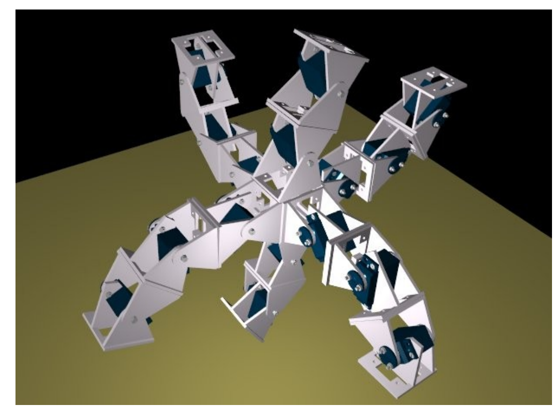
1D Topology



2D Topology



3D Topology

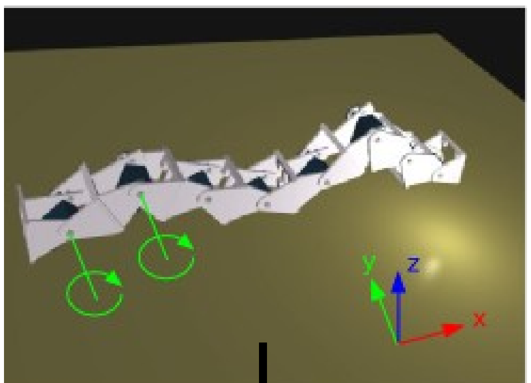


Snakes Robots

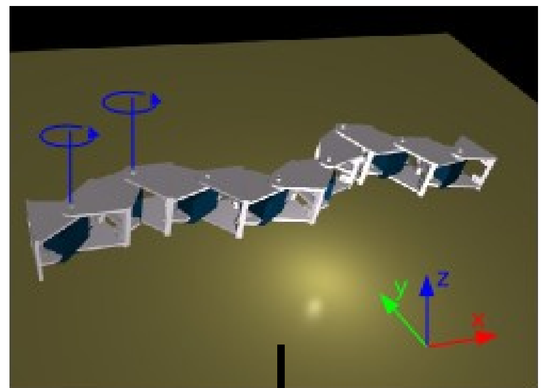
Morphology (II)

1D topology sub-classification (snakes robots)

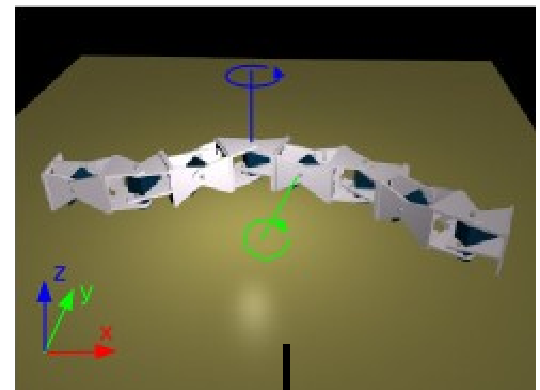
Pitch-Pitch



Yaw-yaw



Pitch-yaw

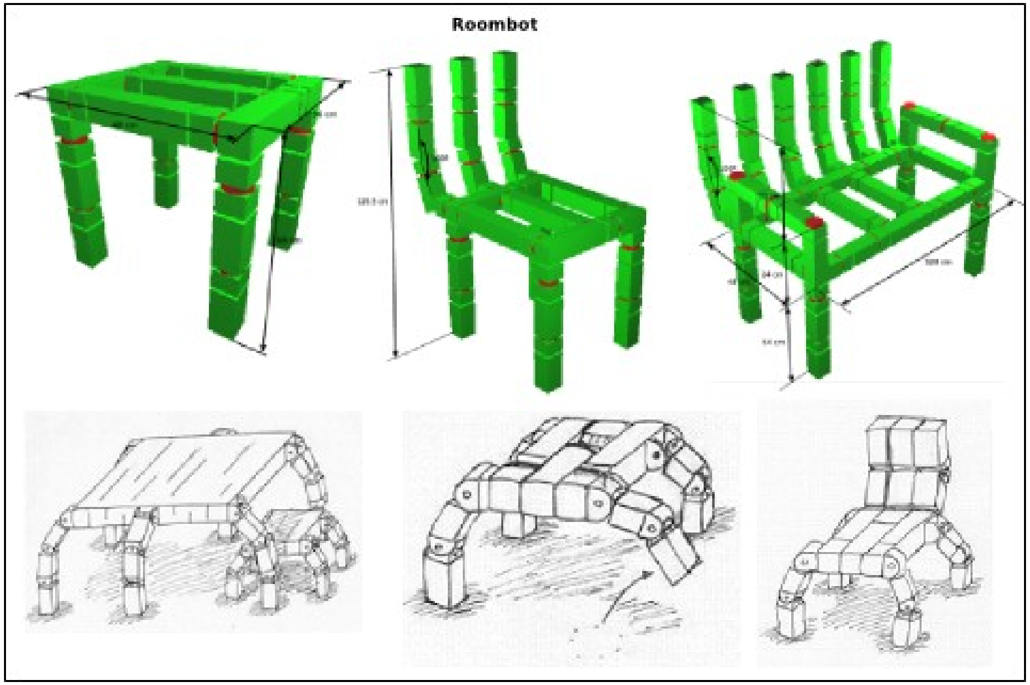


For studying the locomotion in 1D

This robots need a special skin or passive wheels to move

For studying the locomotion in 2D

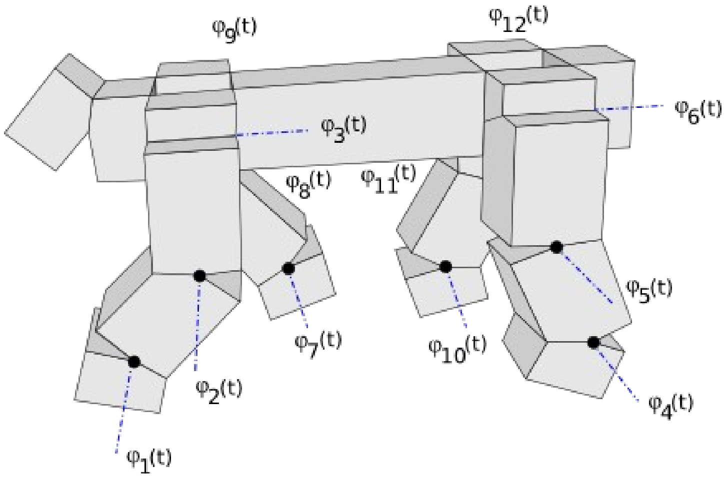
Modular robots and solid objects



- Building solids objects using modules
- Ej. **RoomBot**, (Arredondo et al.). Bioinspired Robotics Lab at EPFL
- Self reconfigurable Furnitures with locomotion capabilities :-)

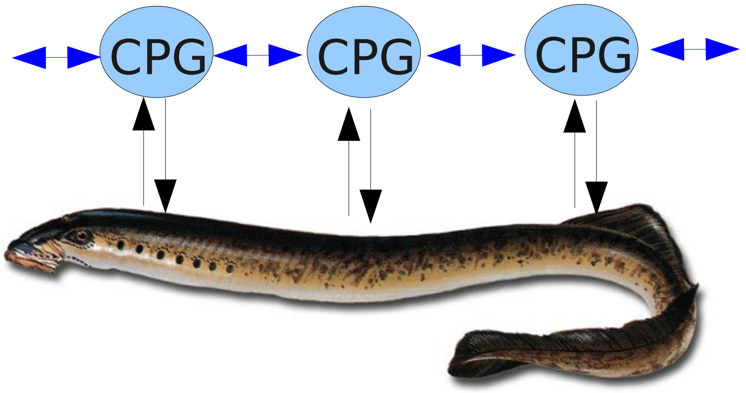
Controllers

- **Coordination problem**:



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

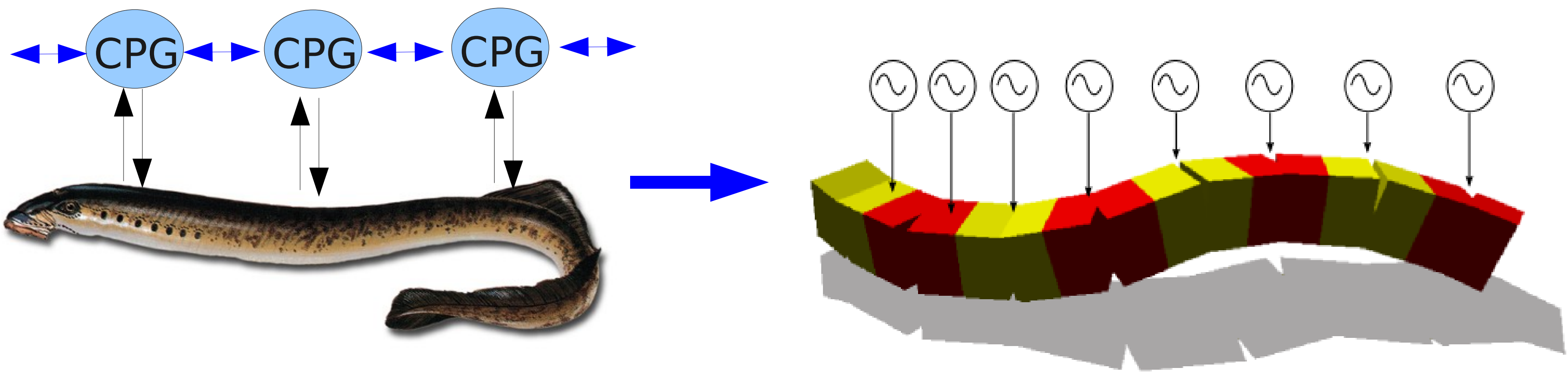
- **Classic approach**: Mathematical modeling
  - Calculation by inverse kinematics
  - Disadvantages: The equations are only valid for an specific morphology



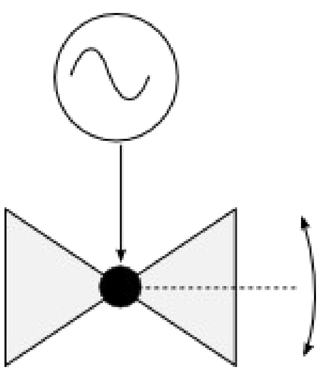
- **Bio-inspired controllers**: CPGs
  - Central Pattern Generators
  - CPGs control the rhythmic activities
  - Ej. The locomotion of the lamprey

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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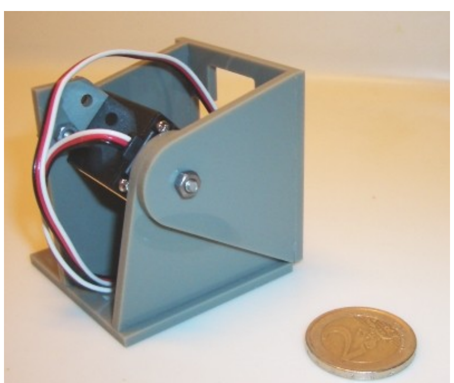
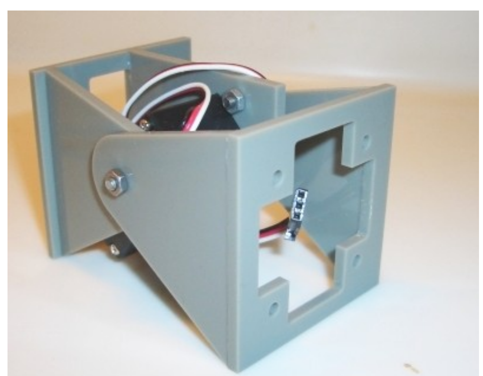
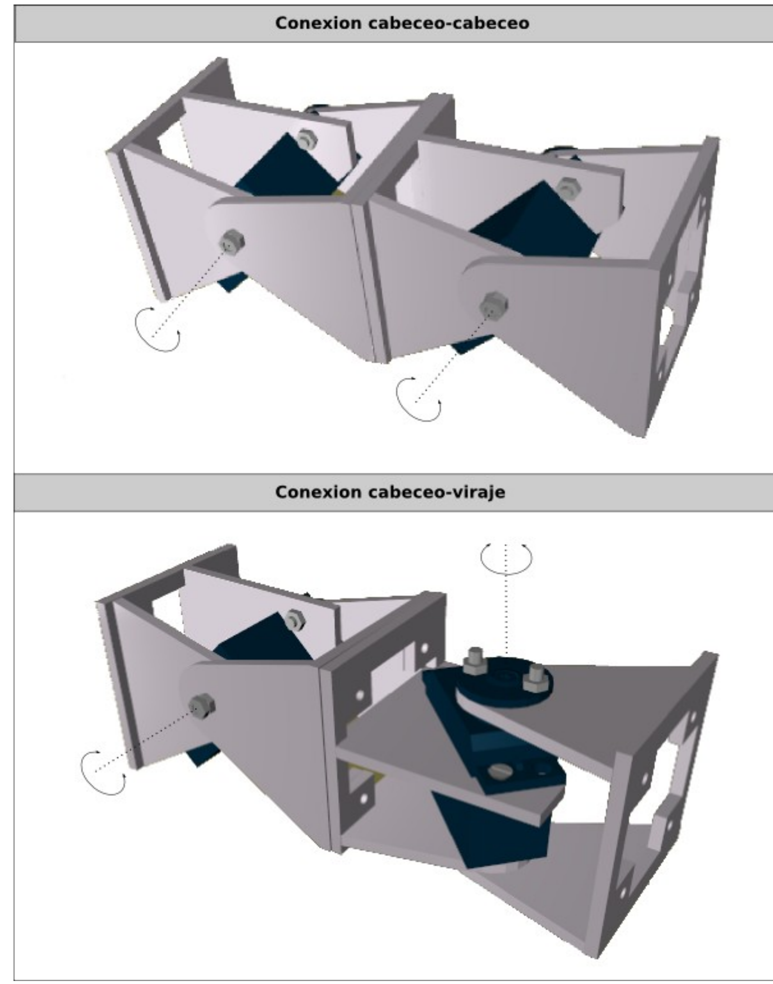
First generation: Y1 modules

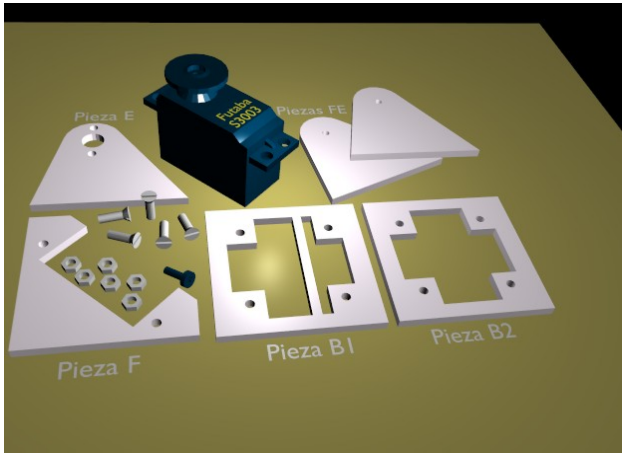
- One degree of freedom
- Easy to build
- Cheap
- Servo: Futaba 3003
- Material: Plastic 3mm width
- Size: 52x52x72mm
- Open and “Free”

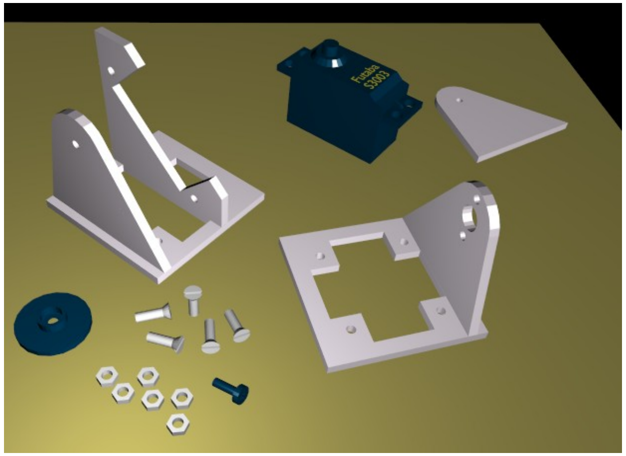


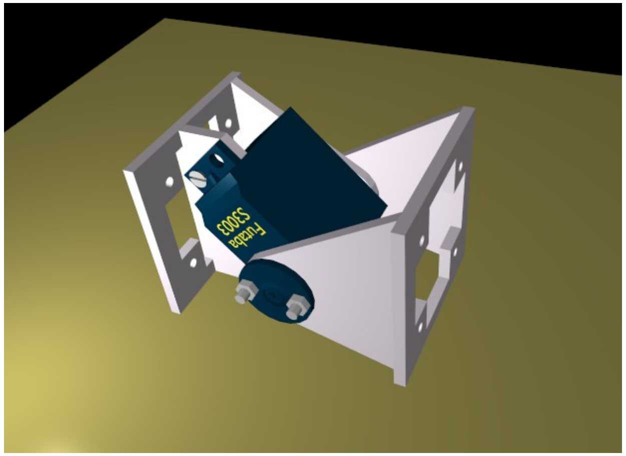




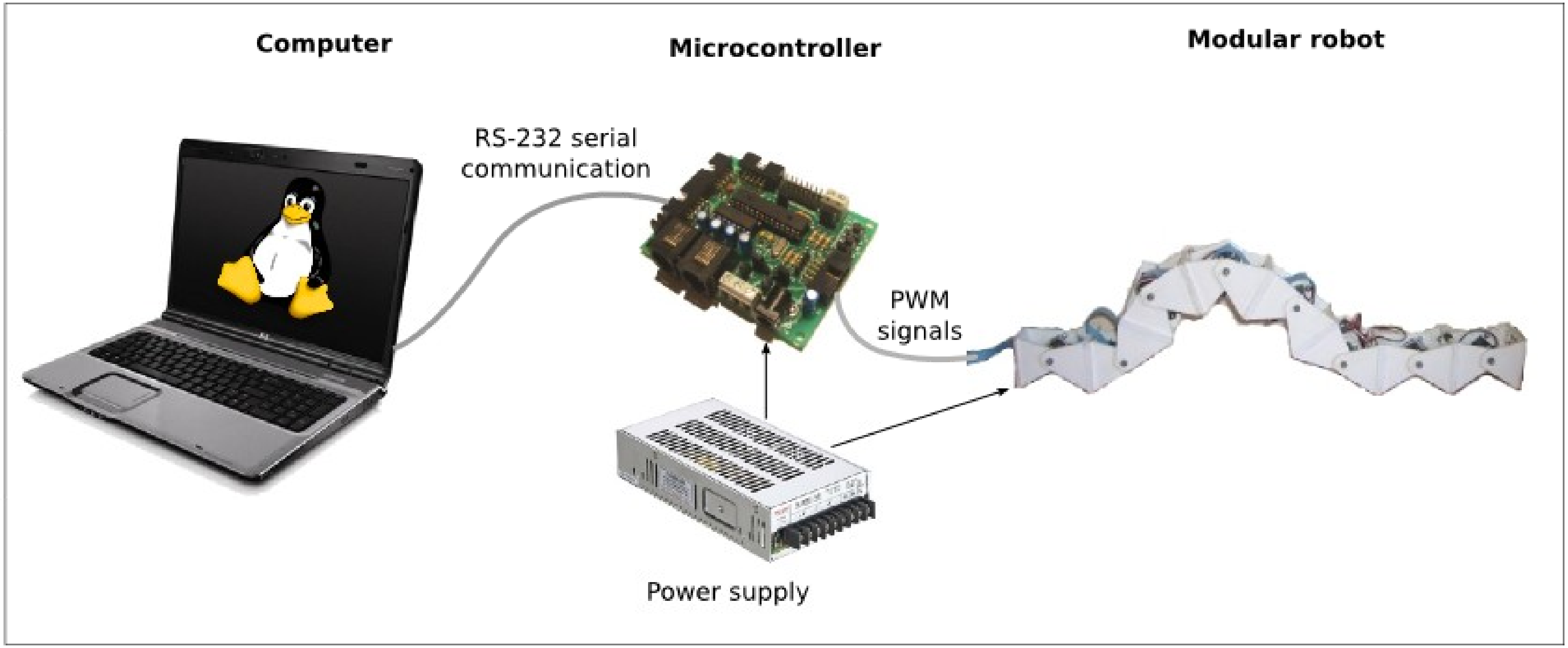
Building the Y1 modules





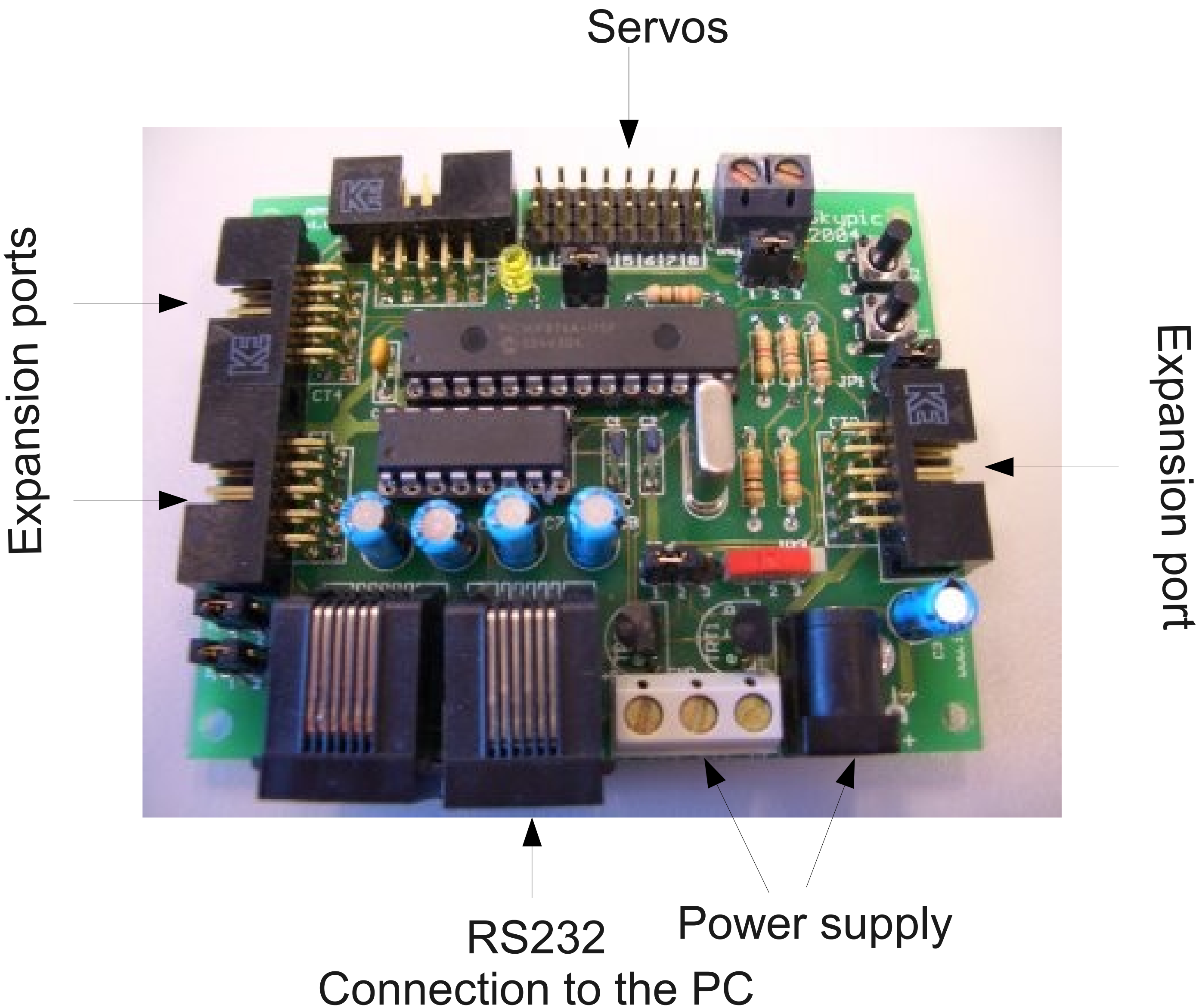


Electronics & control



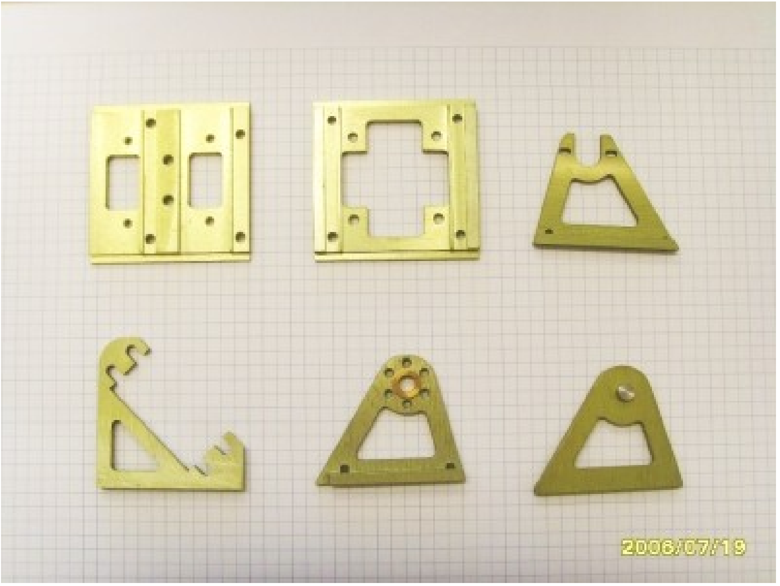
Electronics

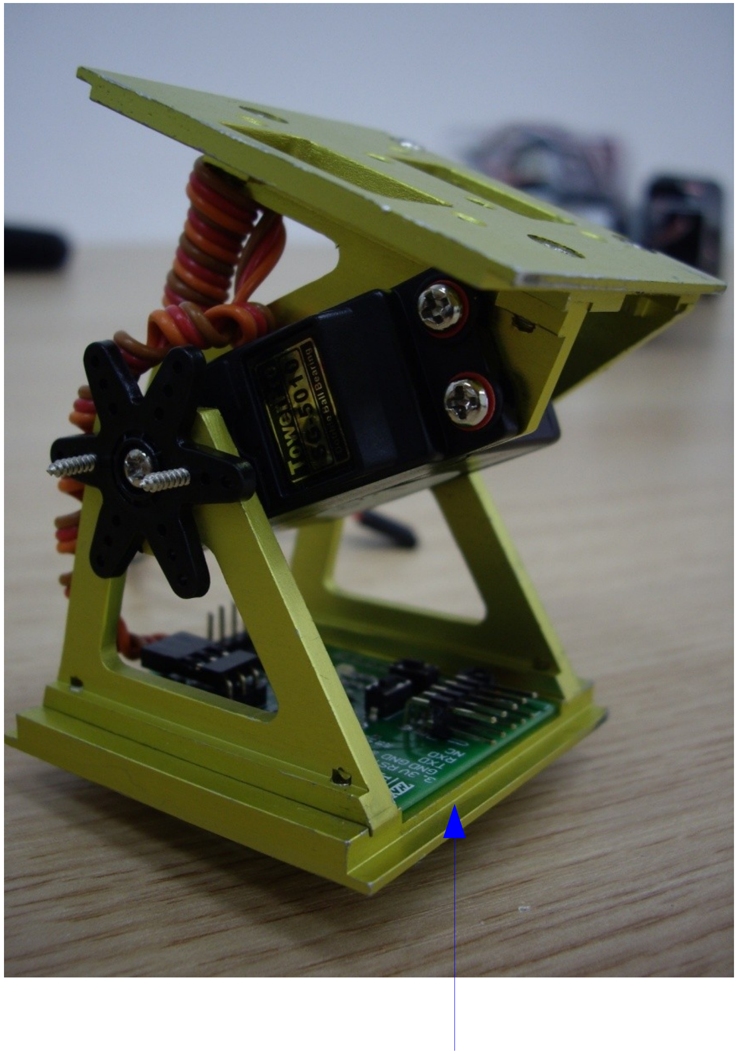
- 8-bit microcontroller (**PIC16F876A** from Microchip)



Cube-M module(I)

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

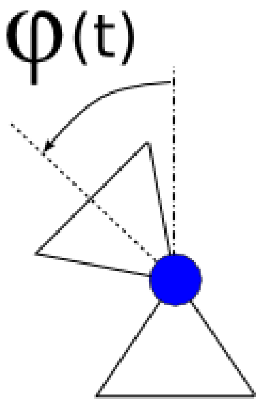




Outline

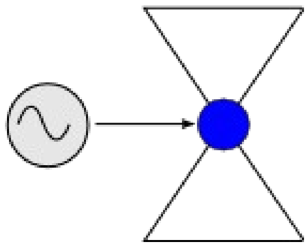
One Oscillator (I)

- **Bending angle:**



It is the angle between the two parts of the module

- **Sinusoidal oscillator:**



The bending angle is changed following this equation:

$$\varphi(t) = A \sin\left(\frac{2\pi}{T} + \Phi_0\right)$$

Bending angle

$\varphi(t) \in [-90, 90]$

Degrees

Amplitude

$A \in [0, 90]$

Degrees

Period

Seconds

Initial phase

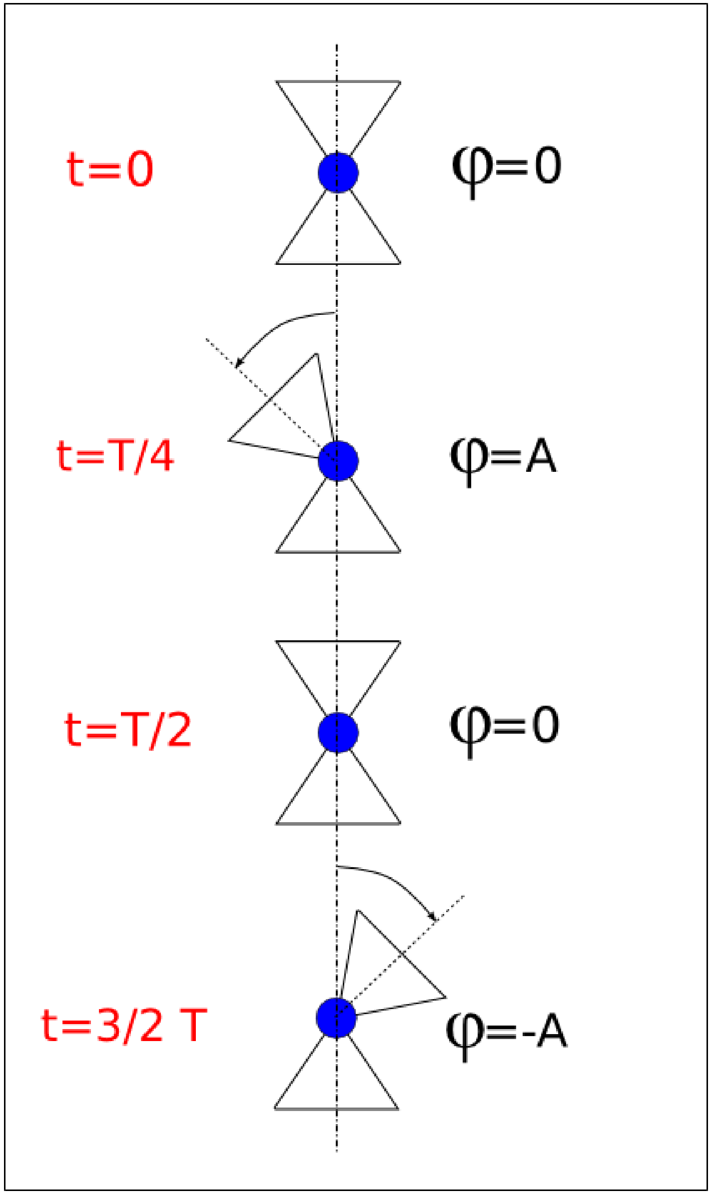
$\Phi_0 \in [-180, 180]$

Degrees

The initial phase determines the bending angle in the begining.

One Oscillator (II)

Demo



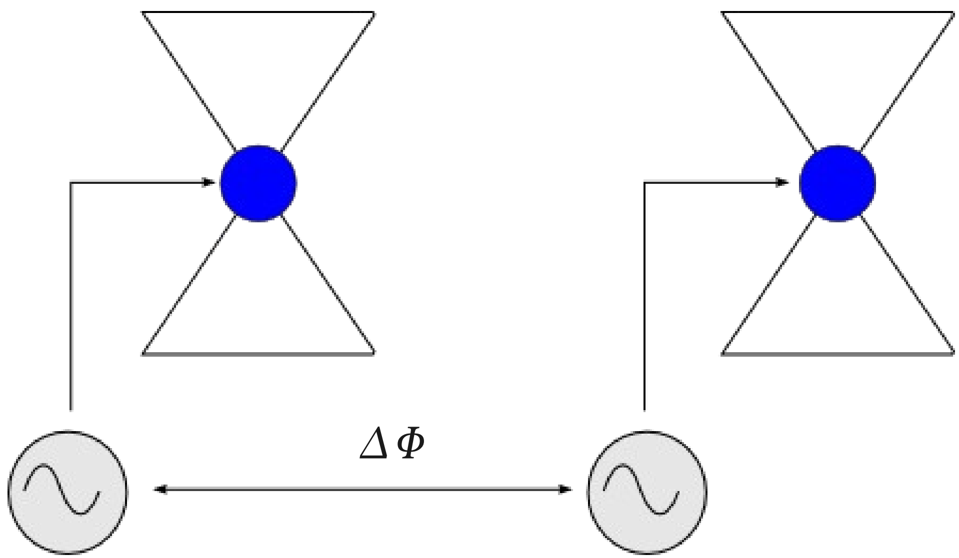
Example:

- A=45 degrees
- $\Phi_0 = 0$

Two oscillators (I)

$$\varphi_1(t) = A\sin(\frac{2\pi}{T} + \Phi_0) \qquad \varphi_2(t) = A\sin(\frac{2\pi}{T} + \Delta\Phi + \Phi_0)$$

Phase difference



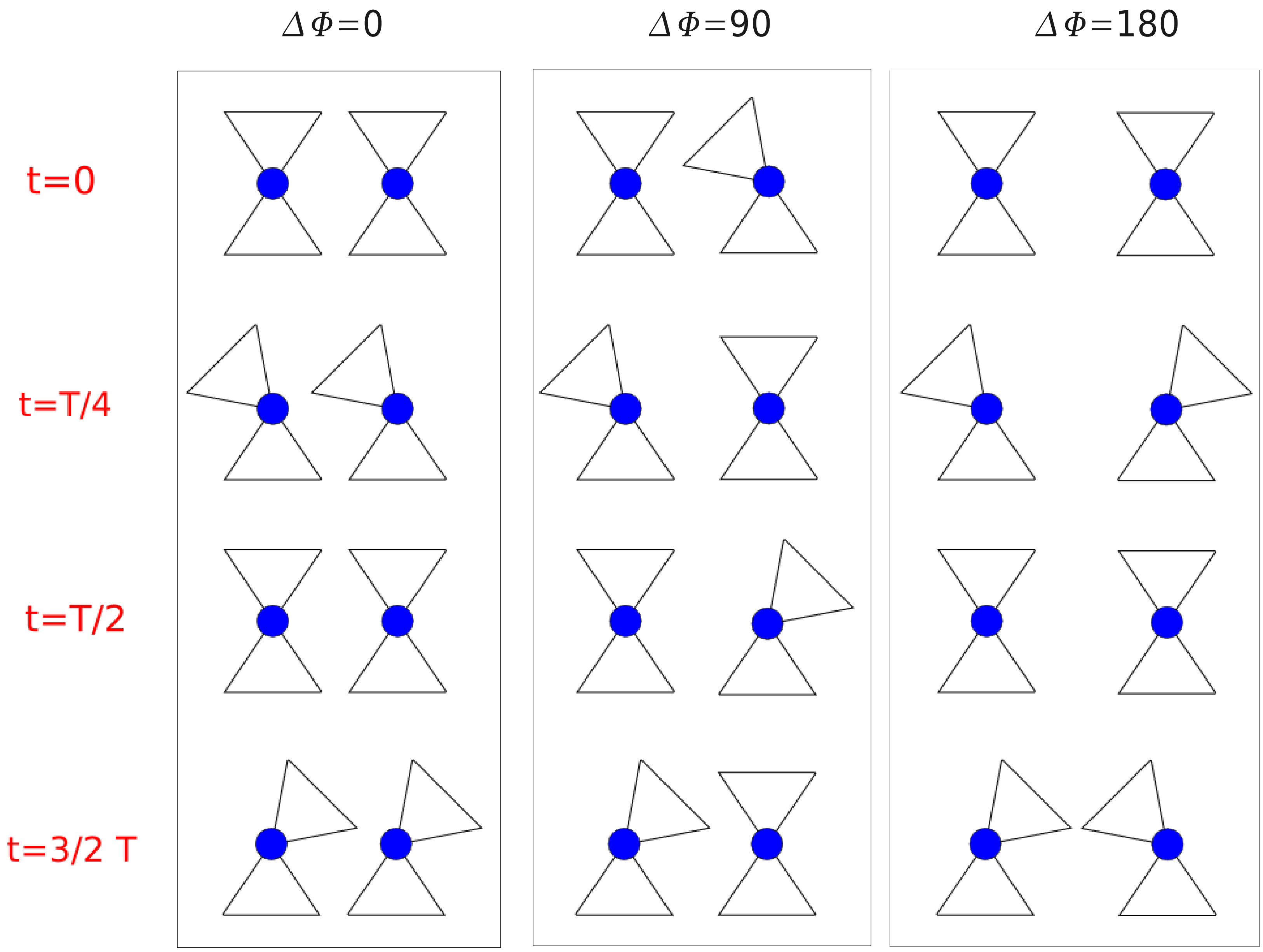
New parameter:

- Phase difference: $\Delta\Phi \in [-180, 180]$

It determines the oscillation of one module relative to the other

Two oscillators (II)

Demo



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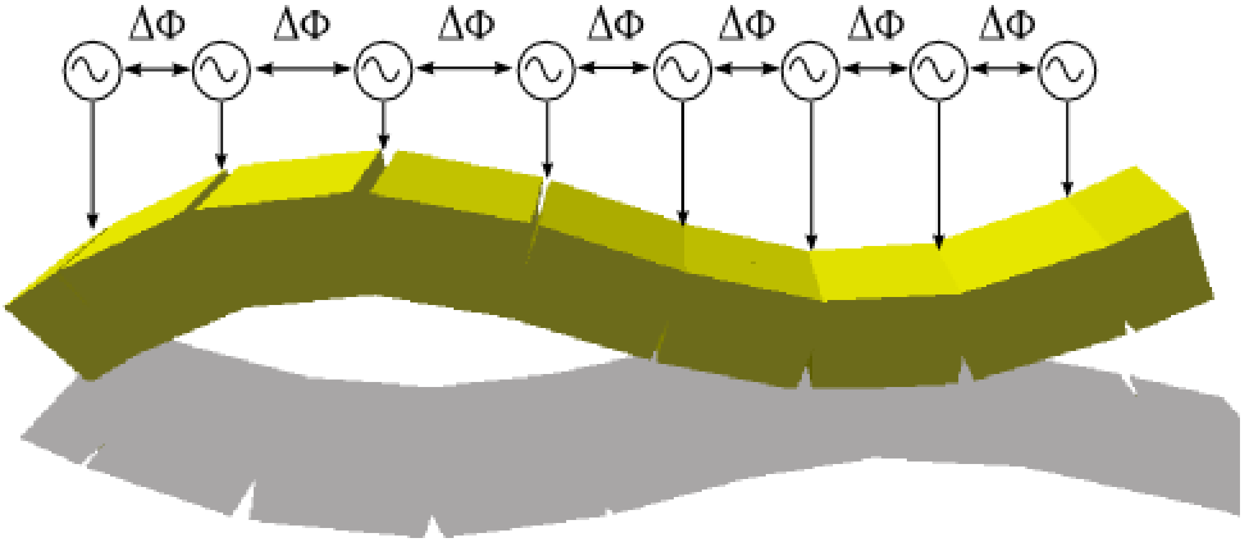
Locomotion in 1D

Control scheme:



Questions:

Is this control scheme valid?

How does the oscillators parameters affect the locomotion?

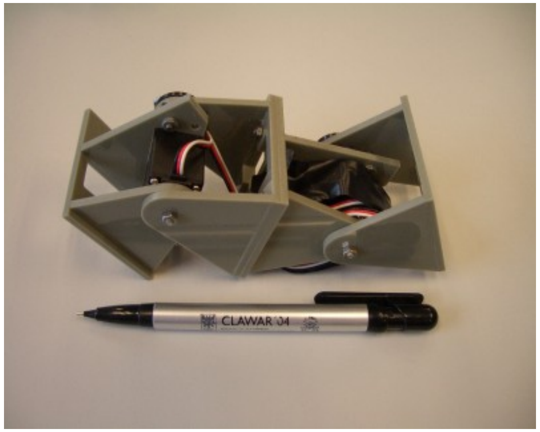
How many modules are needed at least to achieve locomotion?

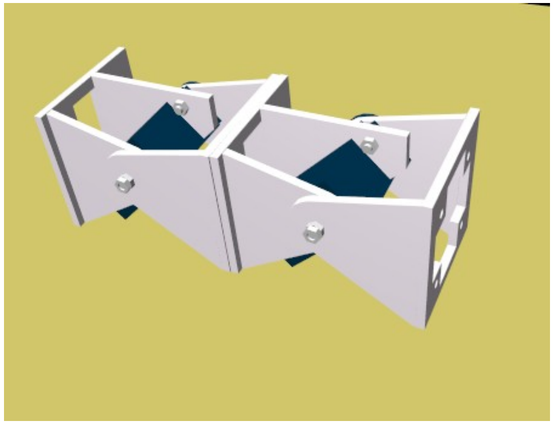
Minicube-I

Demo

- **Morphology**

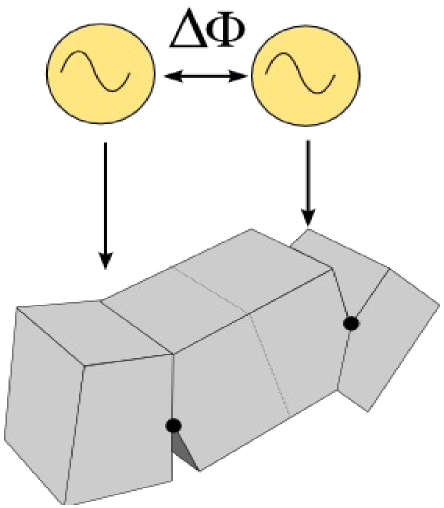
  2 modules with a Pitch-pitch connection





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

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



Minicube-I (I)

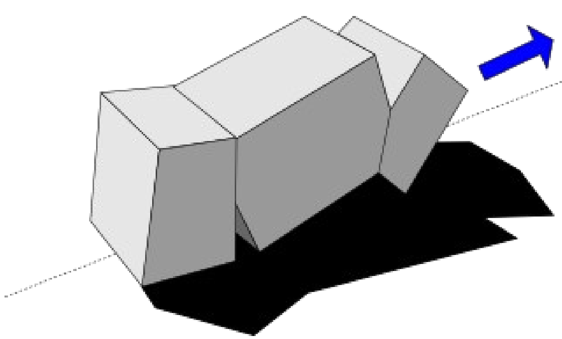
Oscillators and locomotion

- **Period** --> Velocity
- **Amplitud** --> Step
- **Phase difference** --> Coordination

Control space

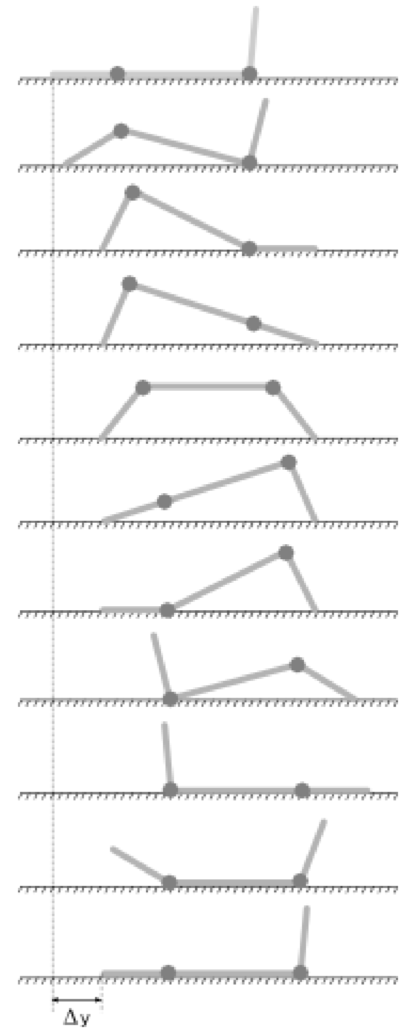
- Two dimensions: $A, \Delta\Phi$
- Period is a constant

Typical values for locomotion:



$A=40, \Delta\Phi=120$

Wired model

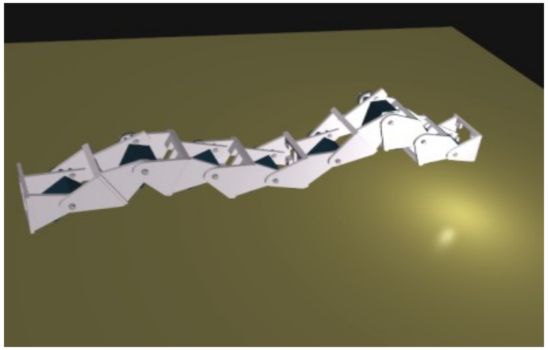


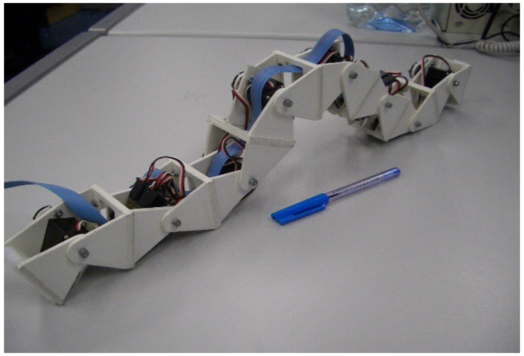
Cube Revolutions (I)

Videos

- **Morphology:**

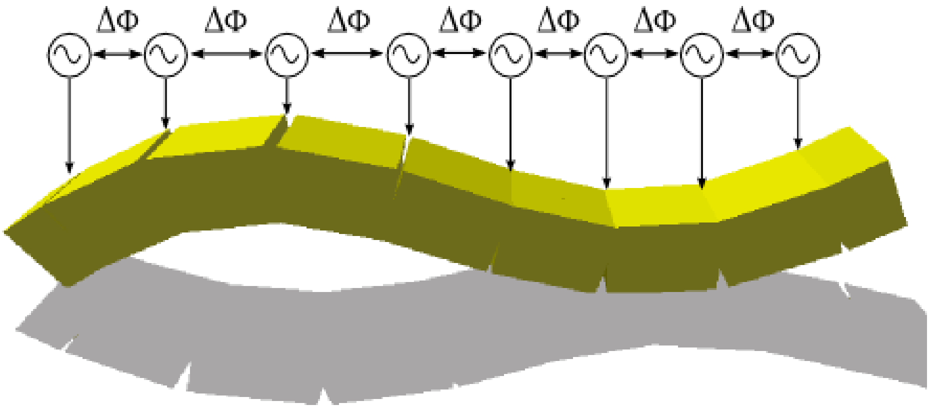
  8 modules with pitch-pitch connection



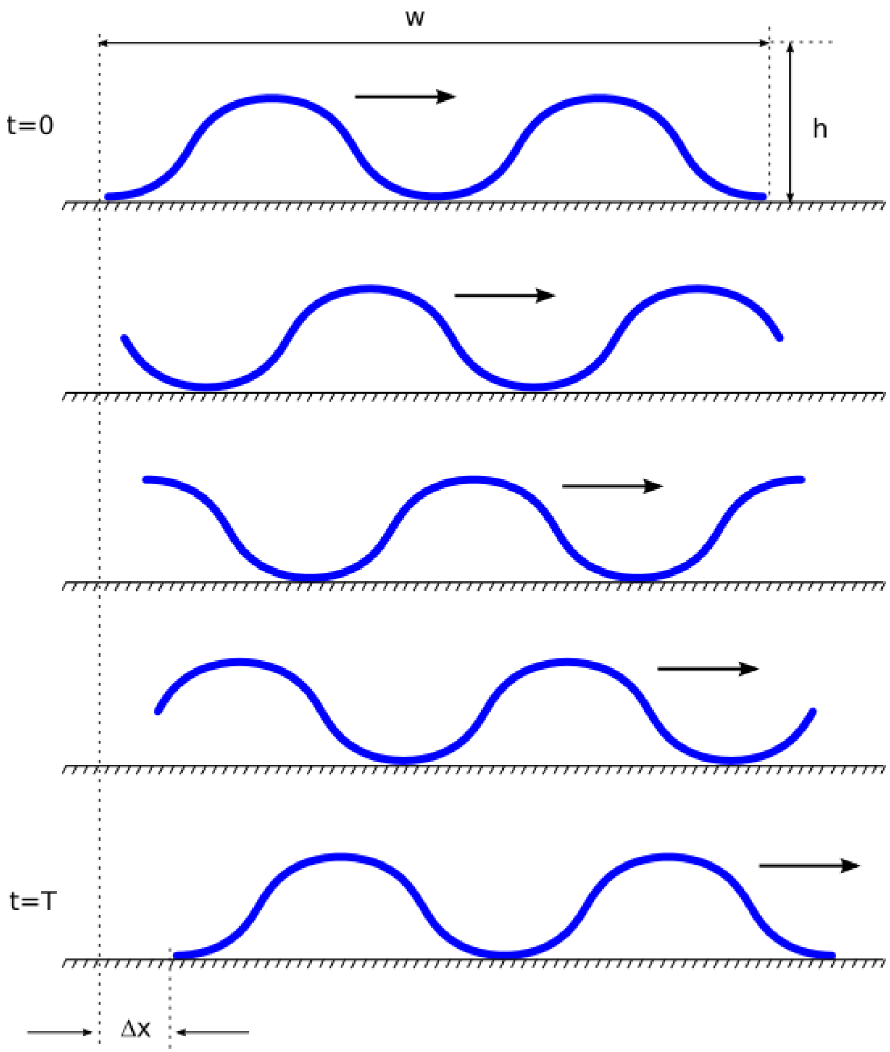


- **Controller:**
  - 8 equal oscillators
  - Parameters:

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



Locomotion mechanism



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

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

3 Modules caterpillar

Demo

Most effiency when:

- A=40 degrees
- $\Delta\Phi = 125$

- Application of modular robots to caterpillar-like locomotion research

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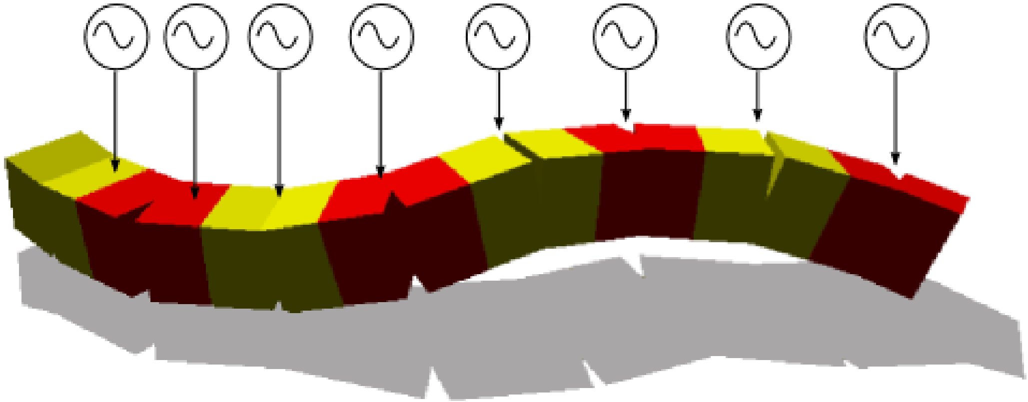
Locomotion in 2D

Control scheme:



Questions:

Is this model feasible?

How many locomotion gaits can be achieved?

What is the relationship between the oscillators and the gaits?

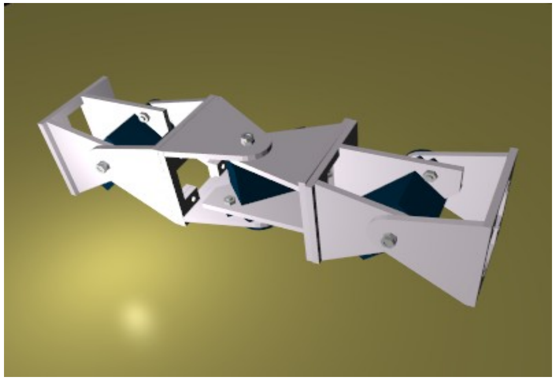
How many modules are needed for achieving locomotion in 2D?

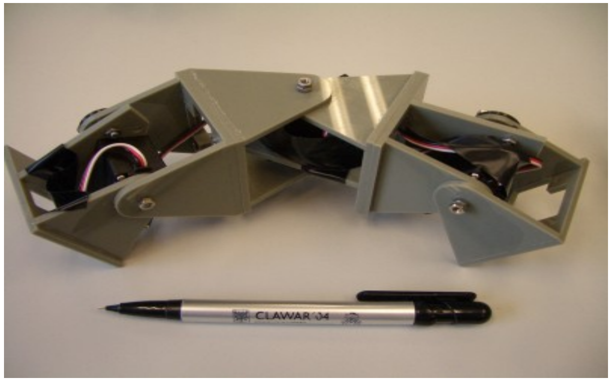
Minicube-II

Demo

- **Morphology:**

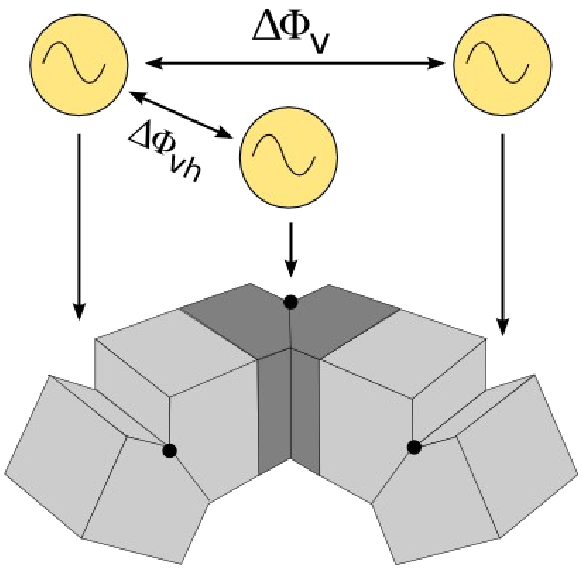
  3 modules with Pitch-yaw-pitch connection





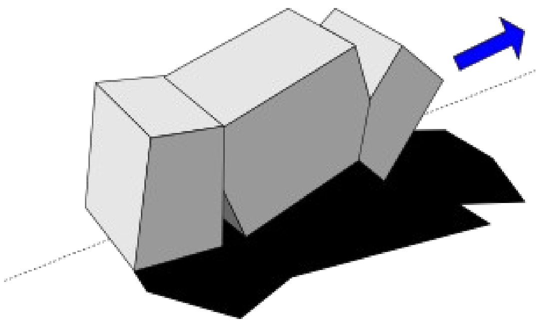
- **Controller:**
  - 3 oscillators
  - Parameters:

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



Locomotion gaits

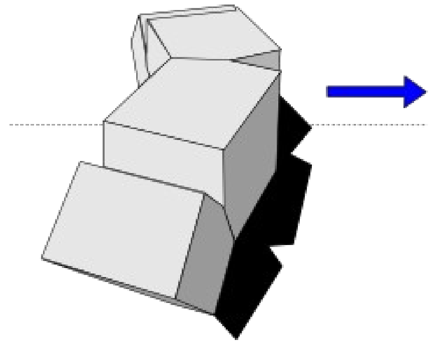
Forward



$A_v=40, A_h=0$

$\Delta\Phi_v=120$

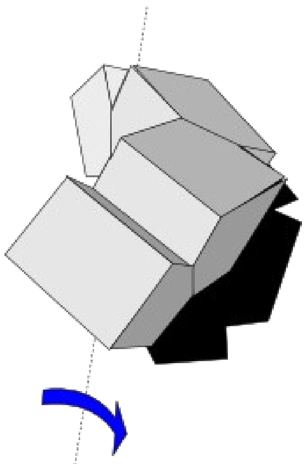
Lateral shifting



$A_v=A_h<40$

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

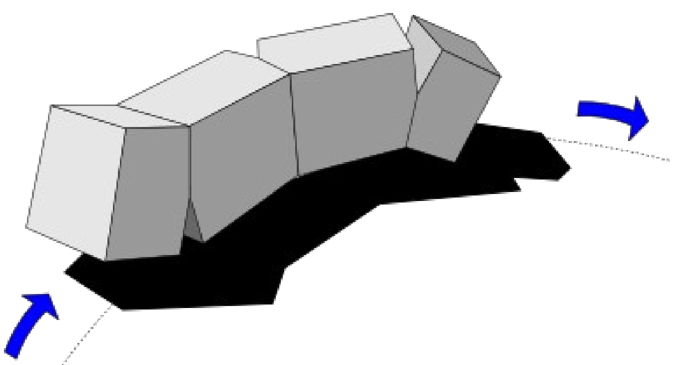
Rolling



$A_v=A_h>60$

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

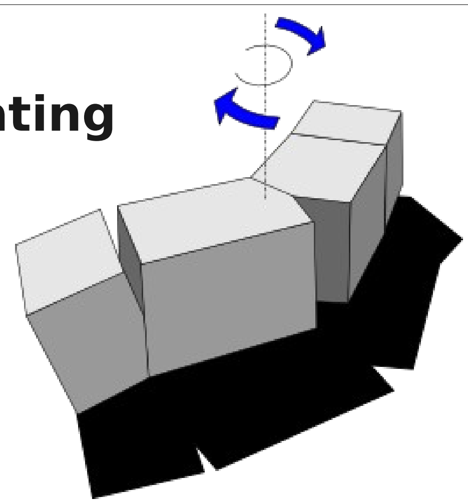
Turning



$A_v=40, A_h=0$

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

Rotating



$A_v=10, A_h=40$

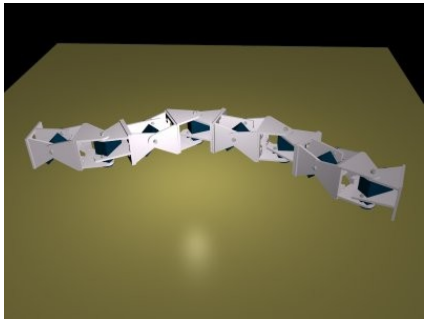
$\Delta\Phi_{vh}=90, \Delta\Phi_v=180$

Hypercube (I)

Demo

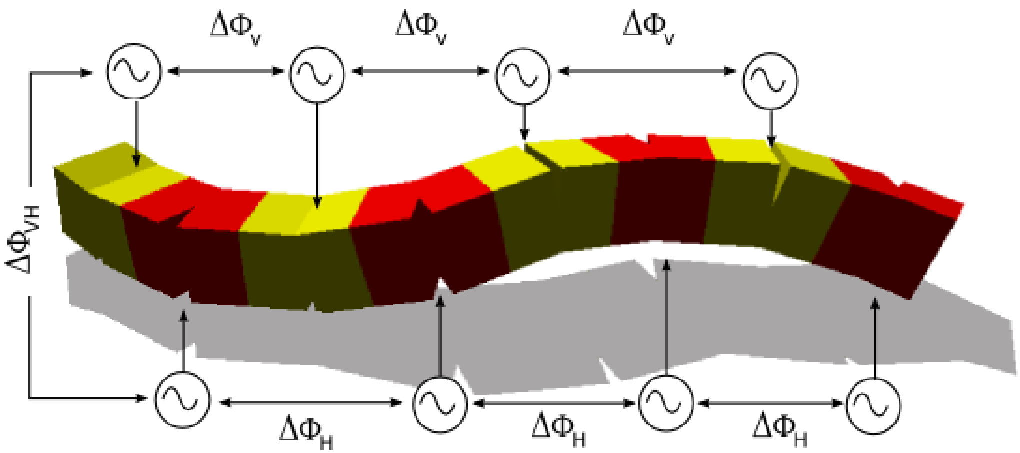
- **Morphology**

  8 modules with pitch-yaw connection

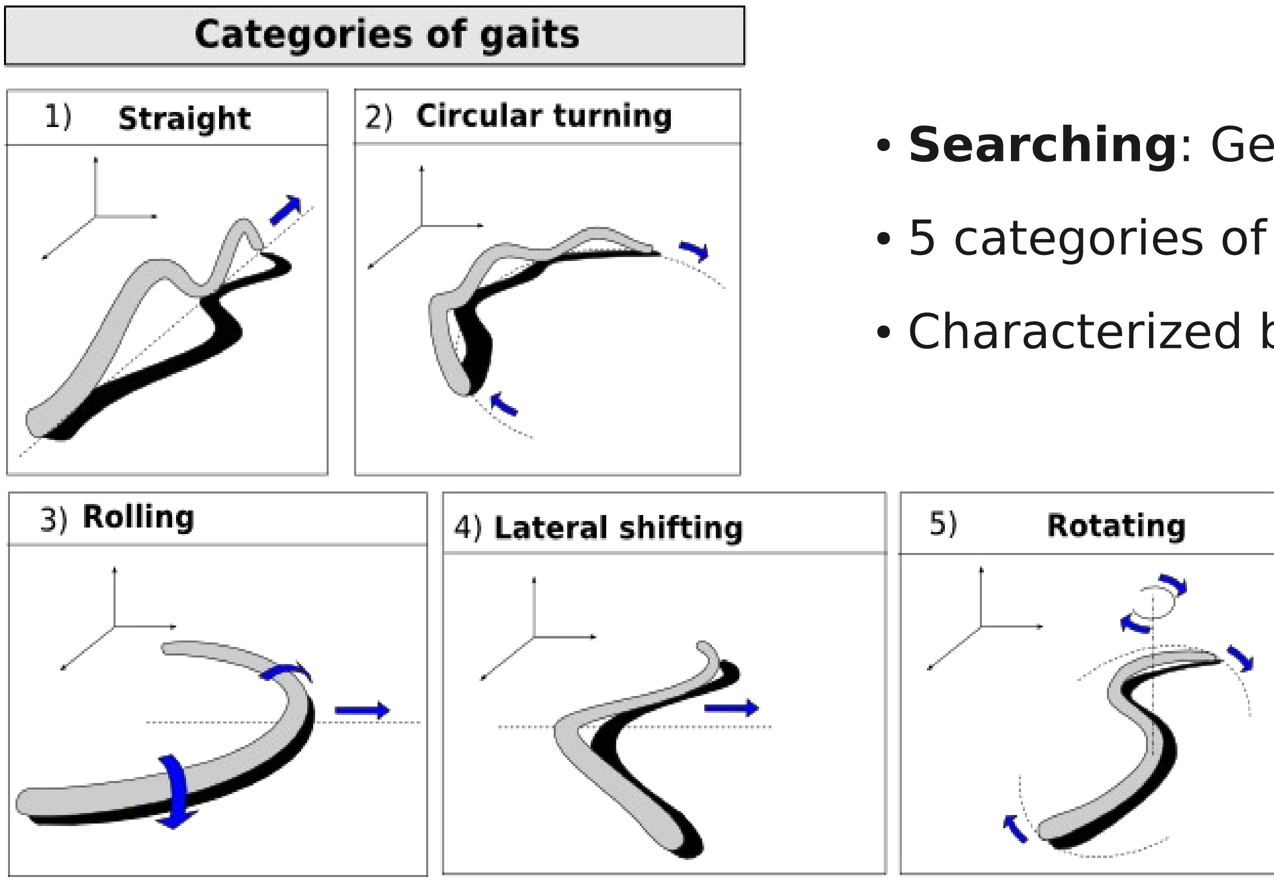


- **Controller:**
  - 4 vertical oscillators
  - 4 horizontal oscillators
  - Parameters:

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



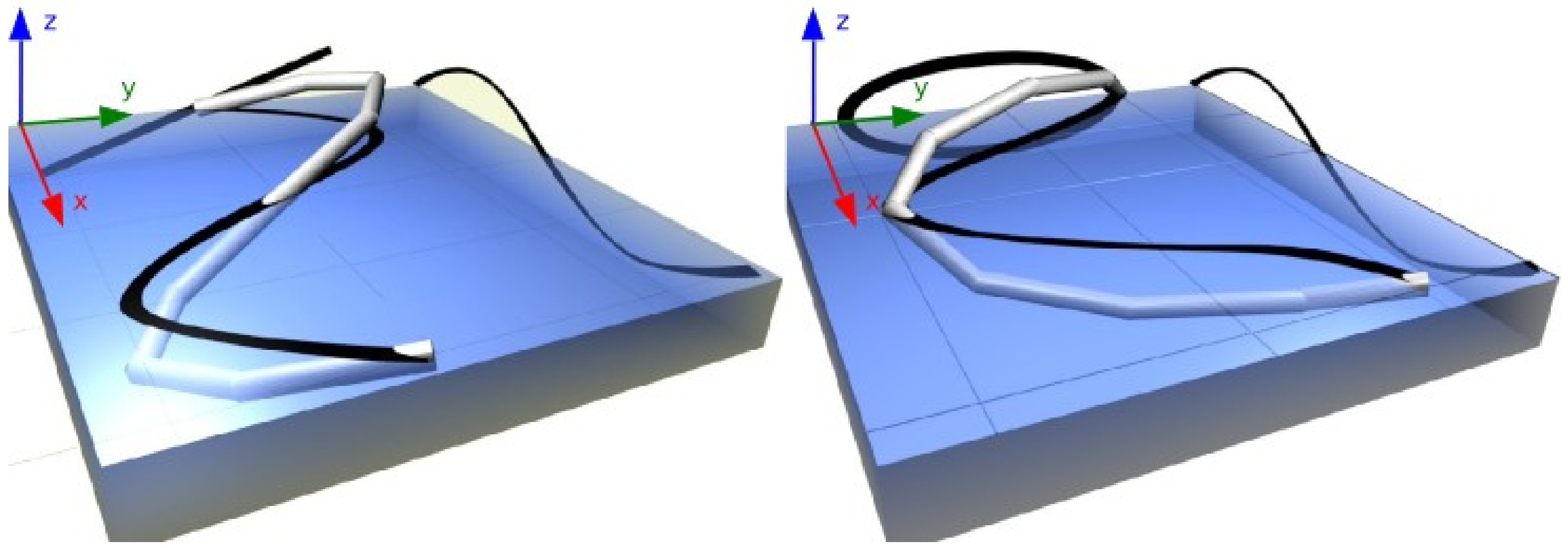
Locomotion gaits



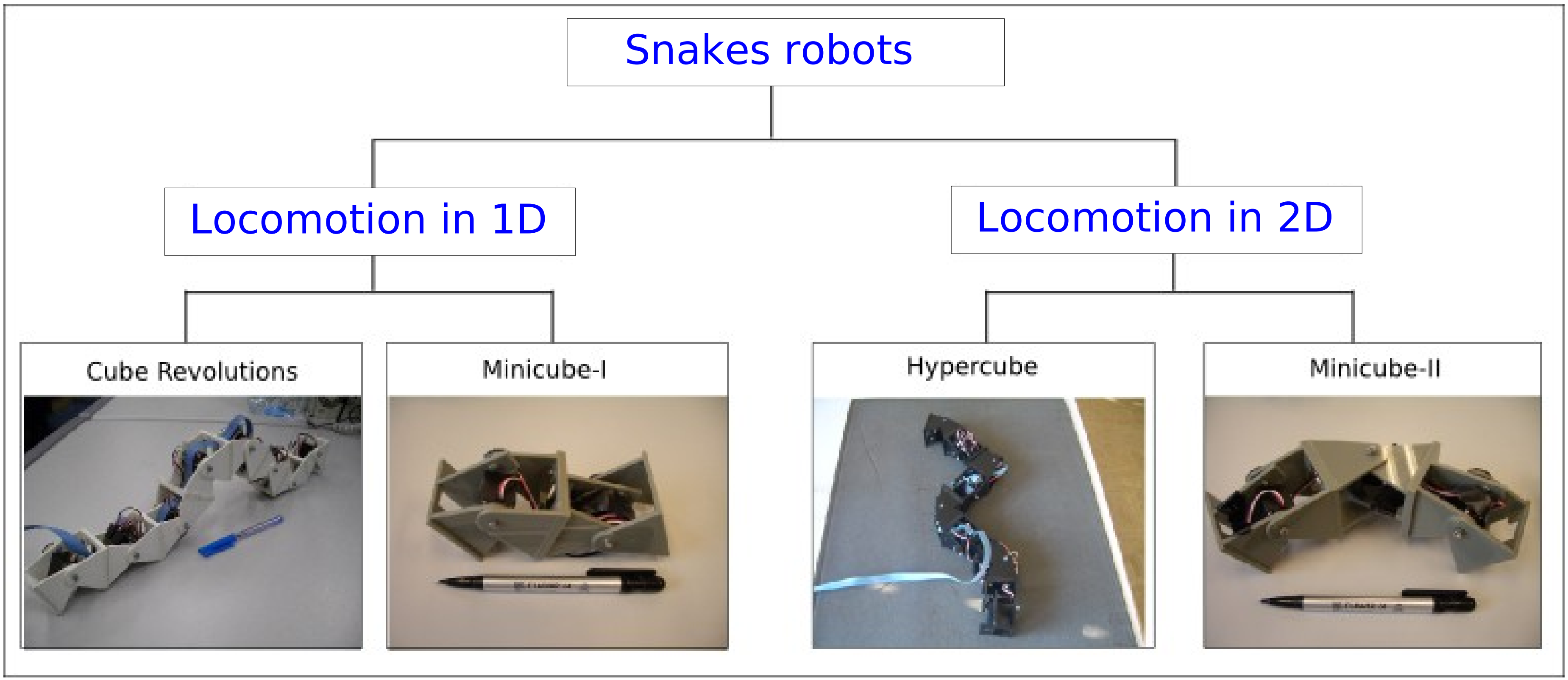
- **Searching**: Genetic algorithms
- 5 categories of gaits
- Characterized by the 3D body wave

Locomotion mechanism

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

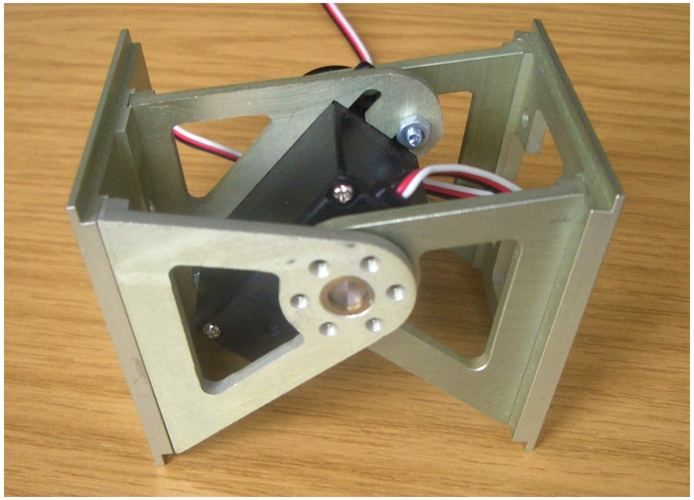


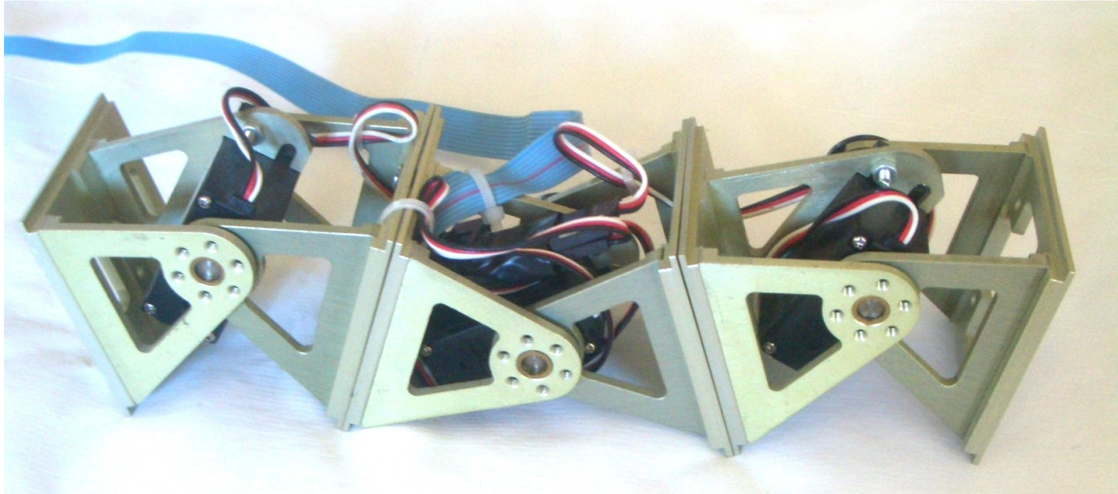
Summary of the robots

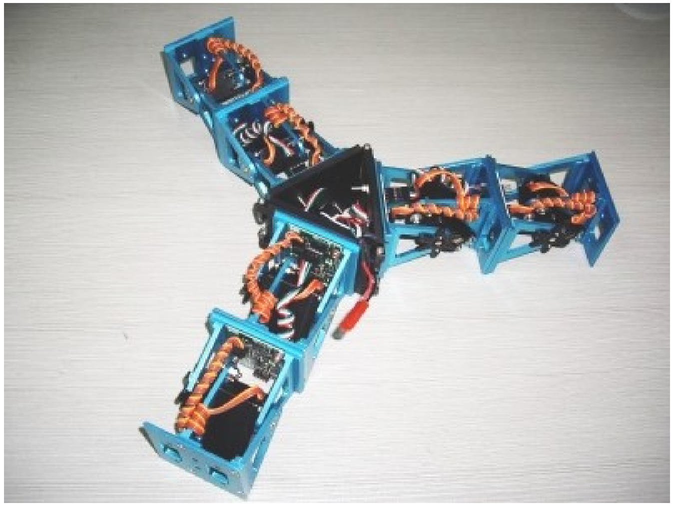


Cube-M module

Video





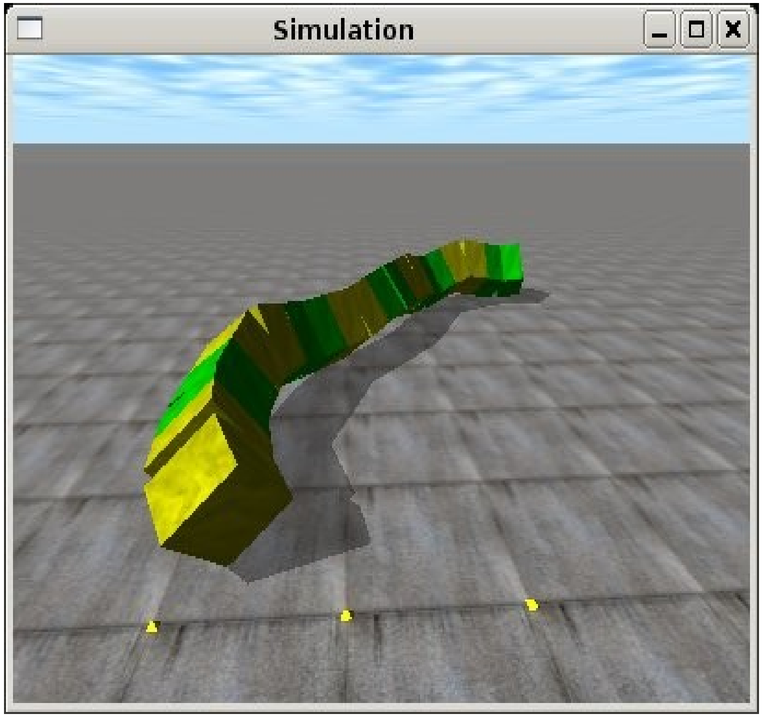


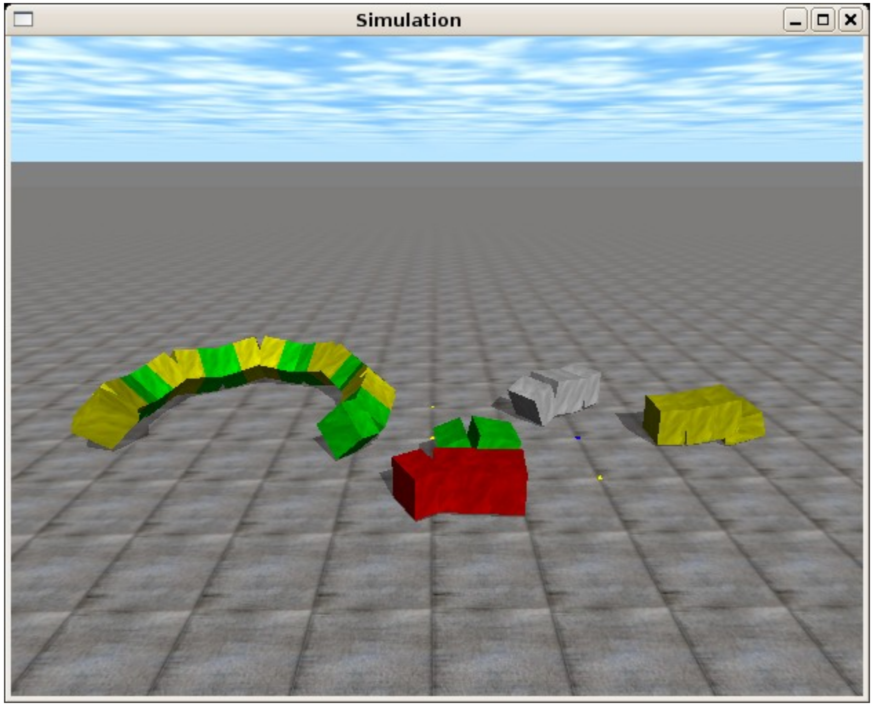
Outline

Software

Demo

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





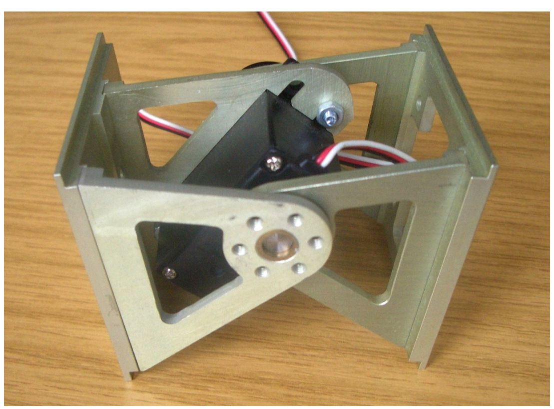
Outline

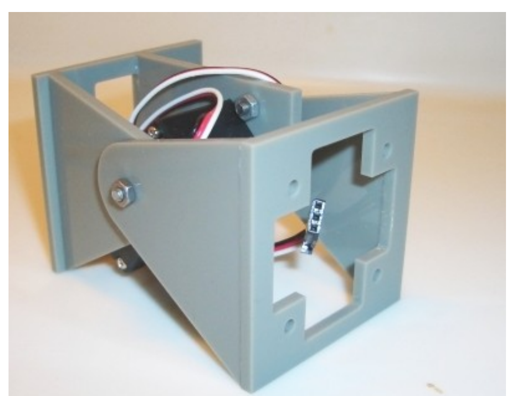
1. Introduction
2. Modules
3. Oscillators
4. Locomotion in 1D
5. Locomotion in 2D
6. Simulation
7. **Conclusions and current work**

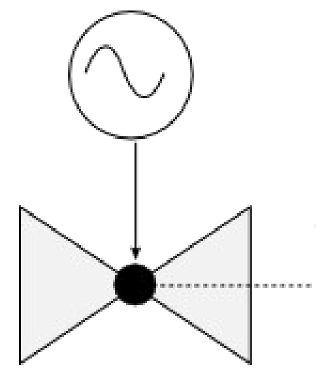
Conclusions

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



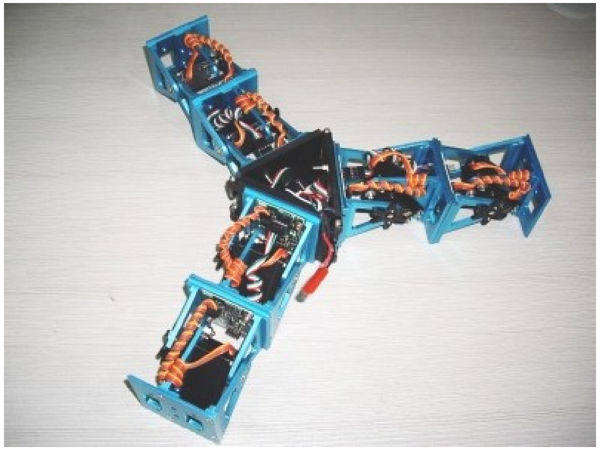




$$\varphi_i(t) = A_i \sin\left(\frac{2\pi}{T} + \psi_i\right) + O_i$$

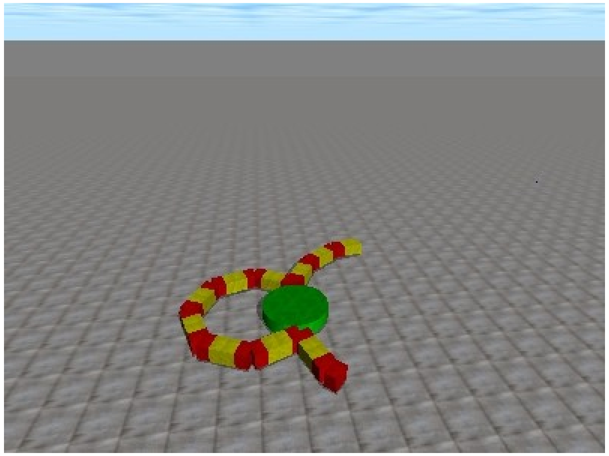
Current work

Locomotion of 2D
Topology modular robots



Climbing caterpillar

Modular grasping



New module design

Introduction to the Locomotion of limbless modular robots

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