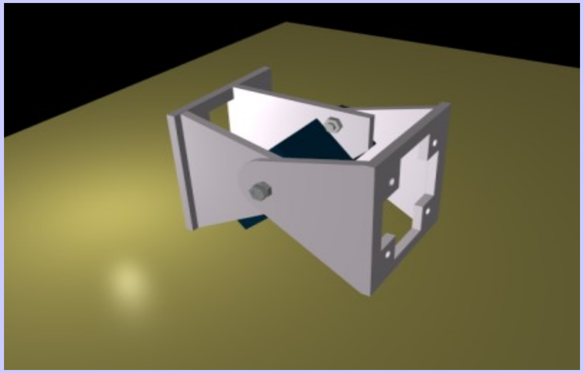
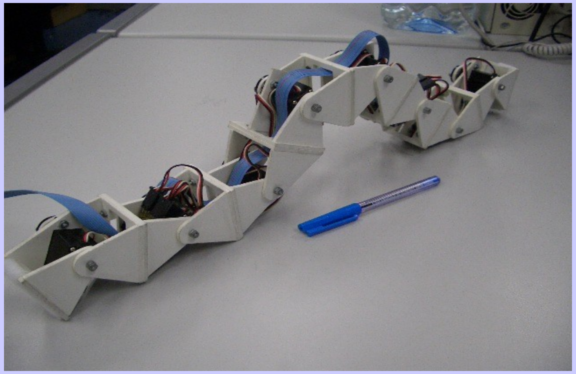
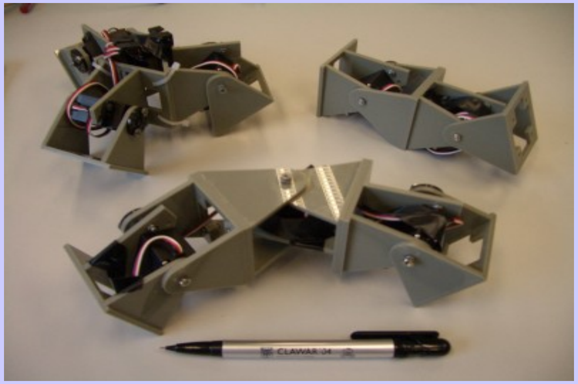
Modular robotics and locomotion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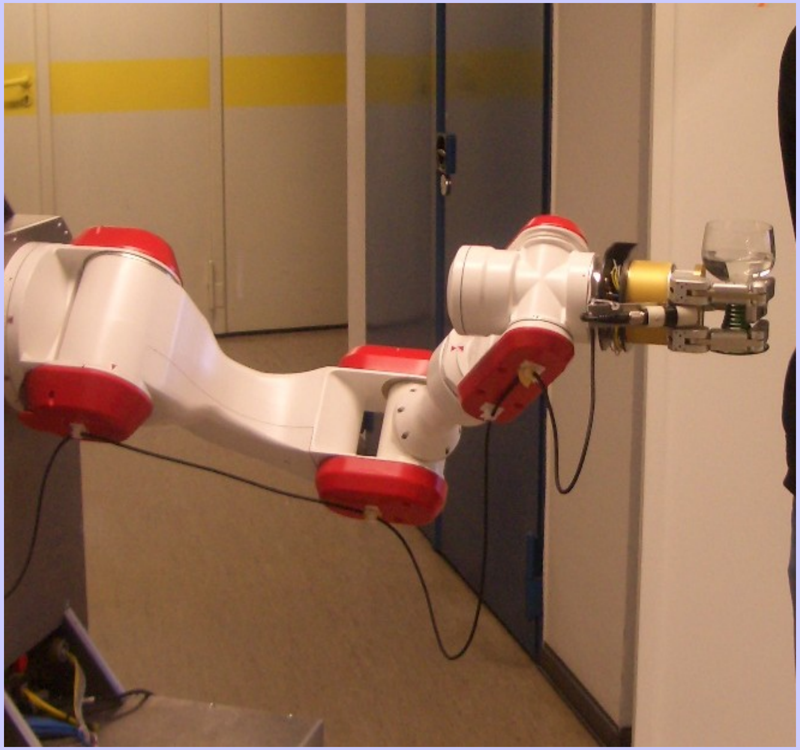
Contents

Introduction to robotics

Main areas of robotics

- **Manipulation:** Robots that are able to grasp and manipulate objects

- **Locomotion**: Capability of the robots to move from one point to another

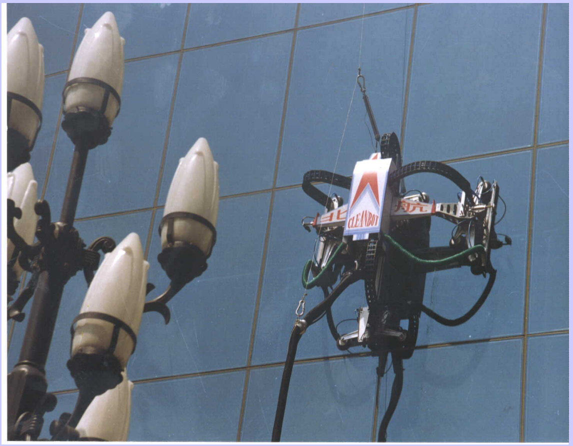


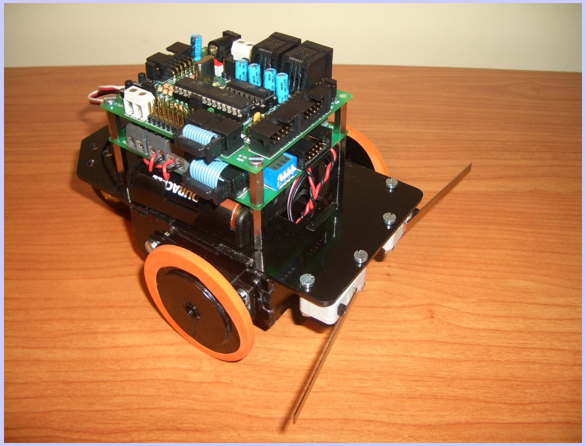
Industrial robots
Service Robots

Mobile robots

Locomotion: Classification of mobile robots (I)

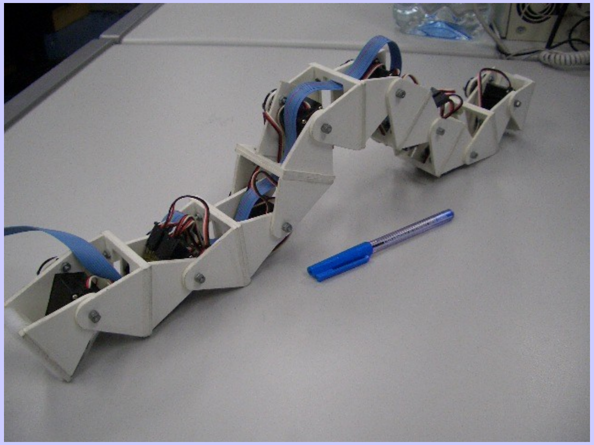
- **Mobile robots can be classified according to environment in which they move:**
  - **Air**. Flying robots: robotics planes, helicopters, insects...
  - **Water**. Swimming robots: fish, snakes
  - **Earth**. Terrestrial robots: Move on a surface
    - Horizontal surface: Locomotion on the ground
    - Vertical surface: **Climbing robots**.

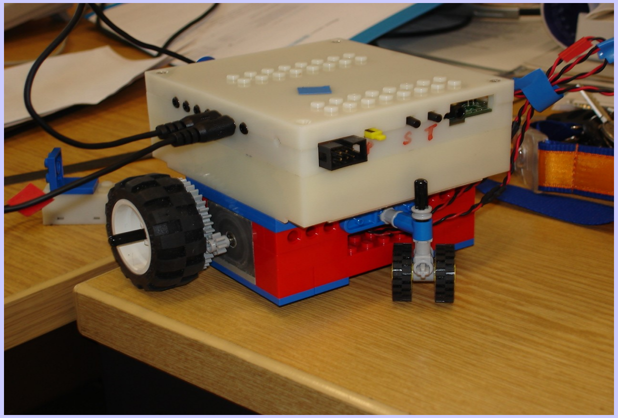


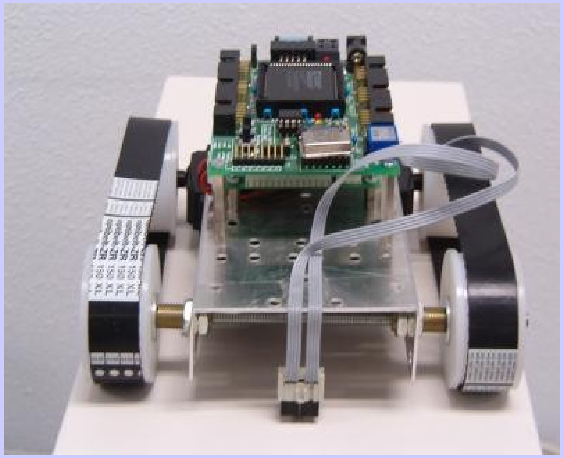


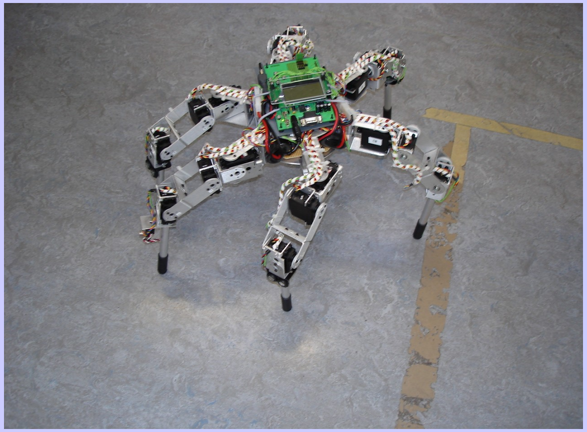
Locomotion: Classification of mobile robots (II)

- **Mobile robots can be classified according to the elements used to perform the locomotion:**
  - Wheeled robots
  - tracked robots
  - Legged robots
  - Body-motion robots







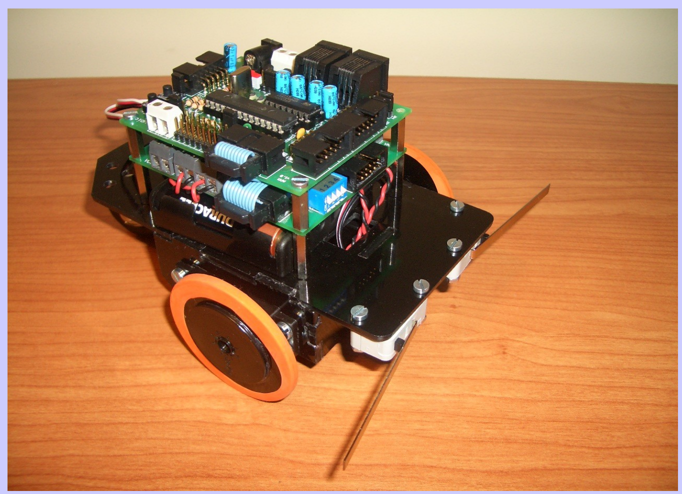


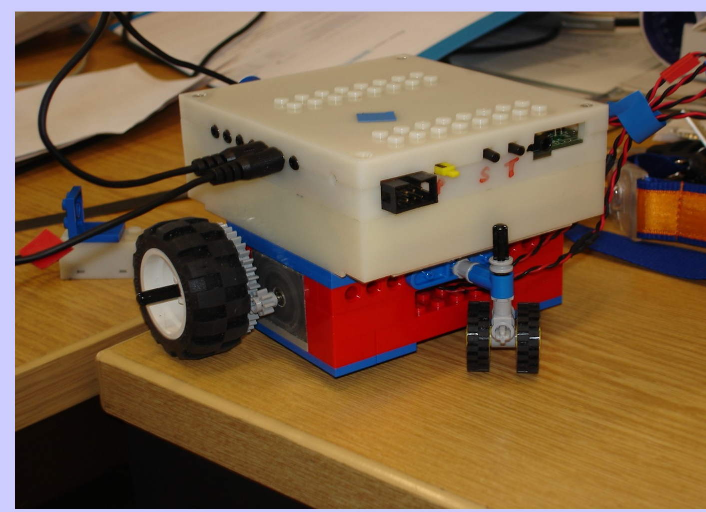
Wheeled robots

- Locomotion is easy to achieve
- They are very efficient
- Mechanics is very well known

DISADVANTAGE:

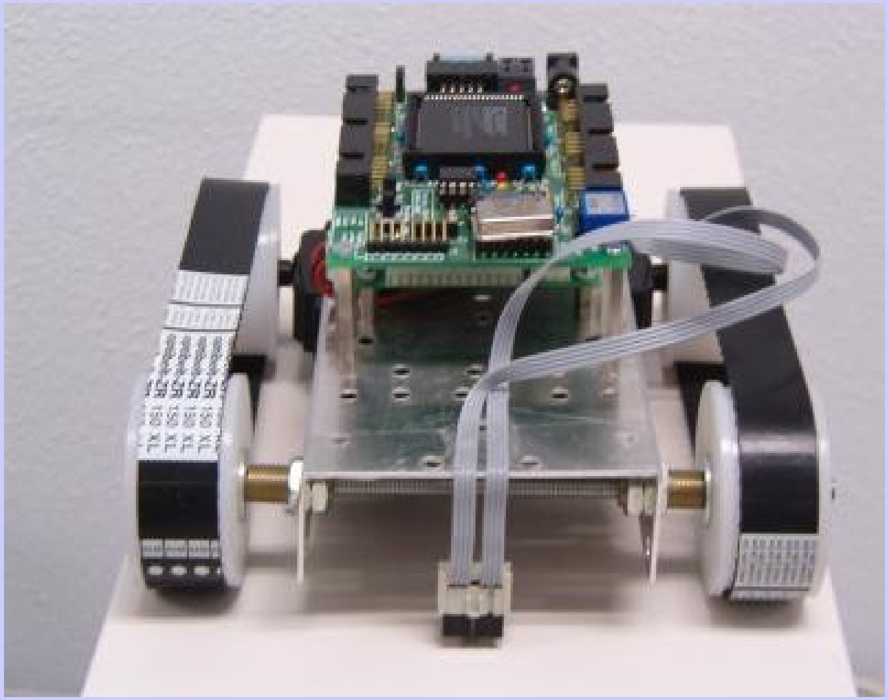
- They can only move on special surfaces

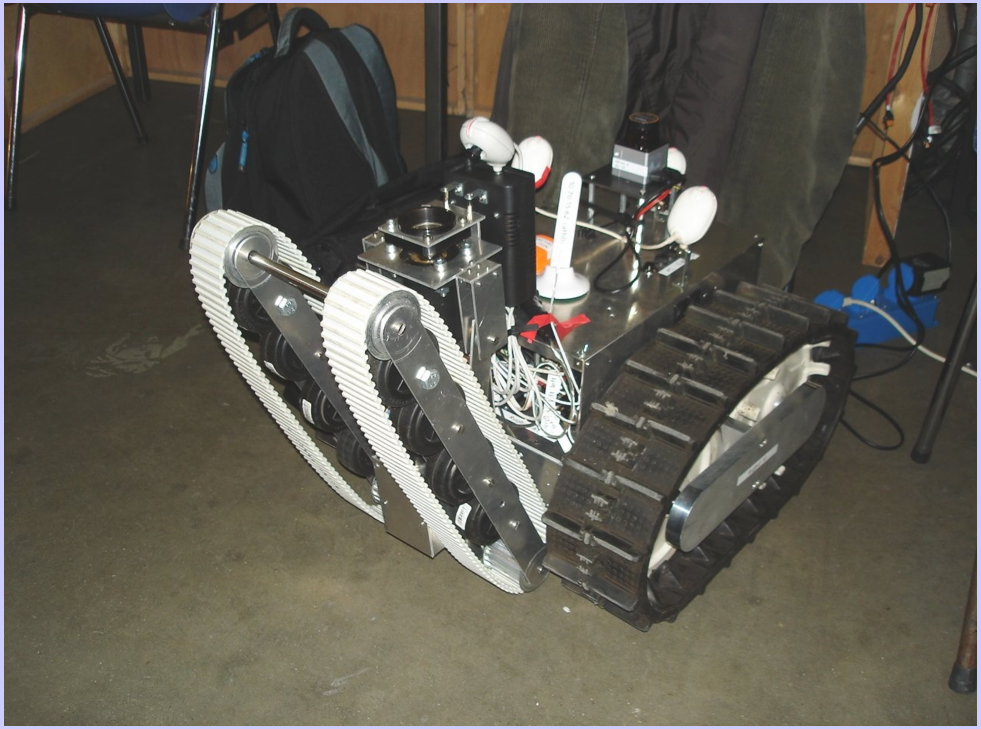




Tracked robots

- Very similar to wheeled robot
- They can move better in a rough terrain



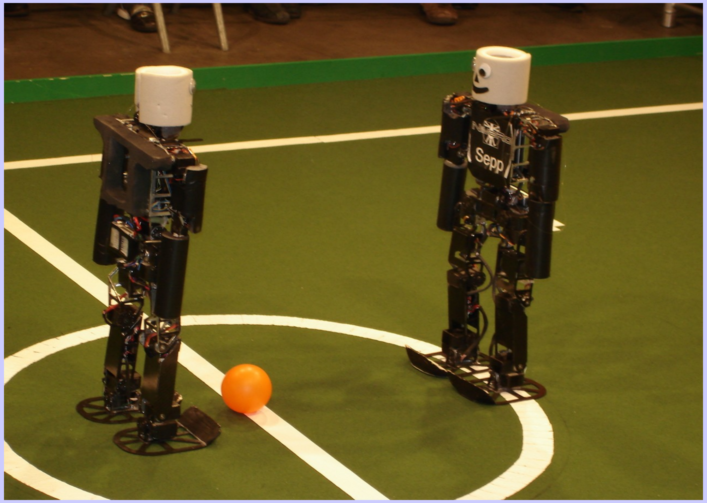


Legged robots

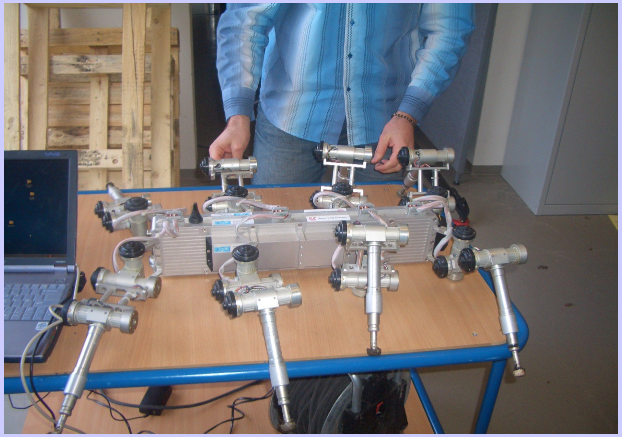
- **Higher power consumption**
- **More complex**
- **Coordination problem**

Why there are so many legged animals in the nature?

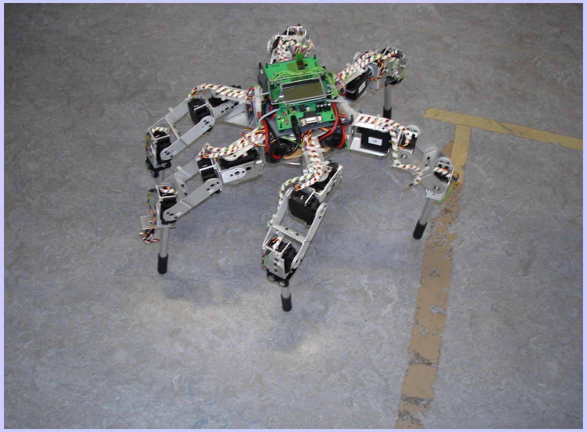
2 legs



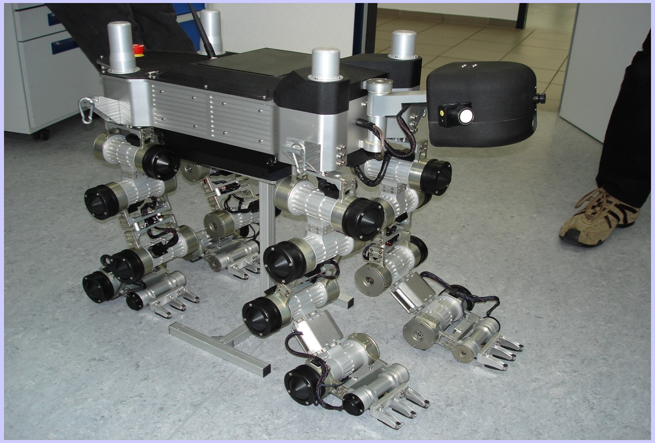
8 legs



6 legs

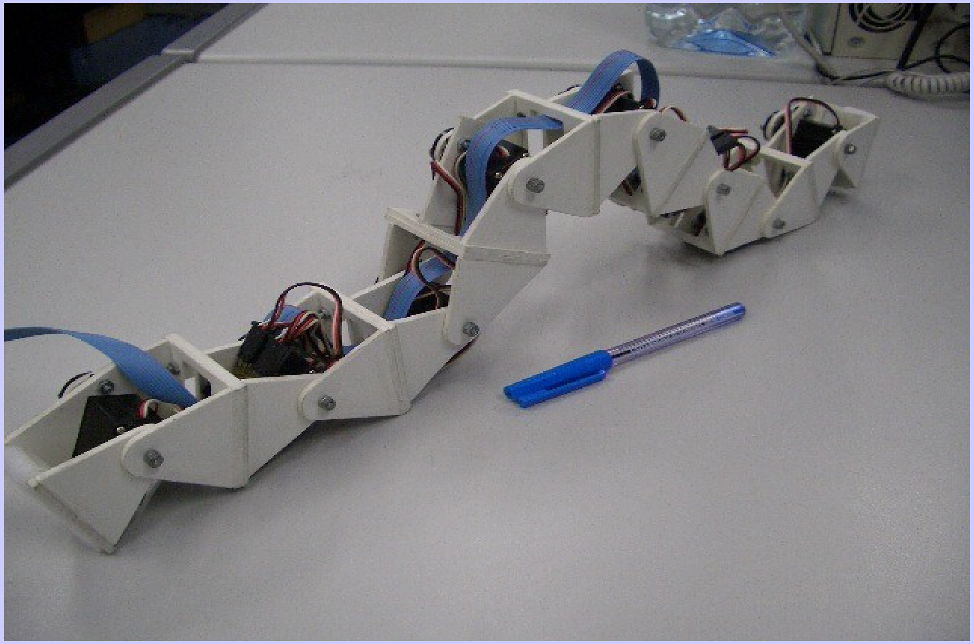


4 legs



Body-motion robots

- The locomotion is based on the movements of the body
- Examples: snakes, worms...

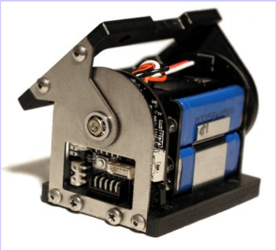


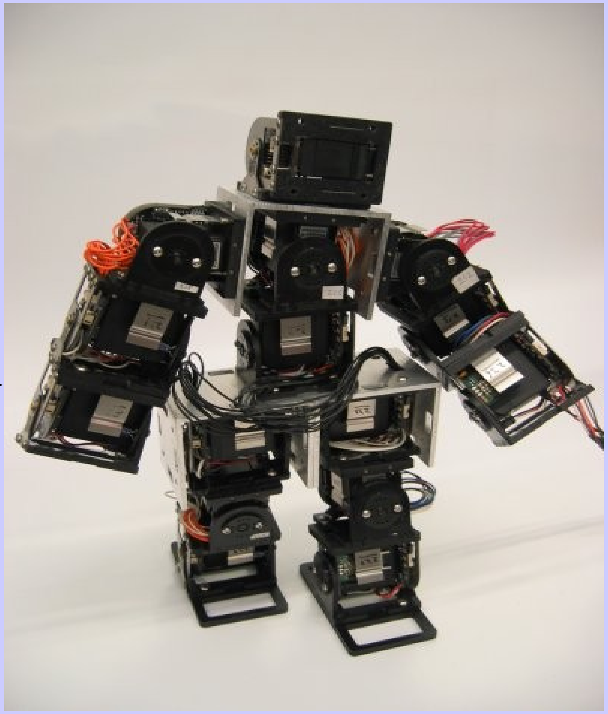
Classification according the structure

- **Specific design**
- **Modular design**

Video

Specific design of an Humanoid



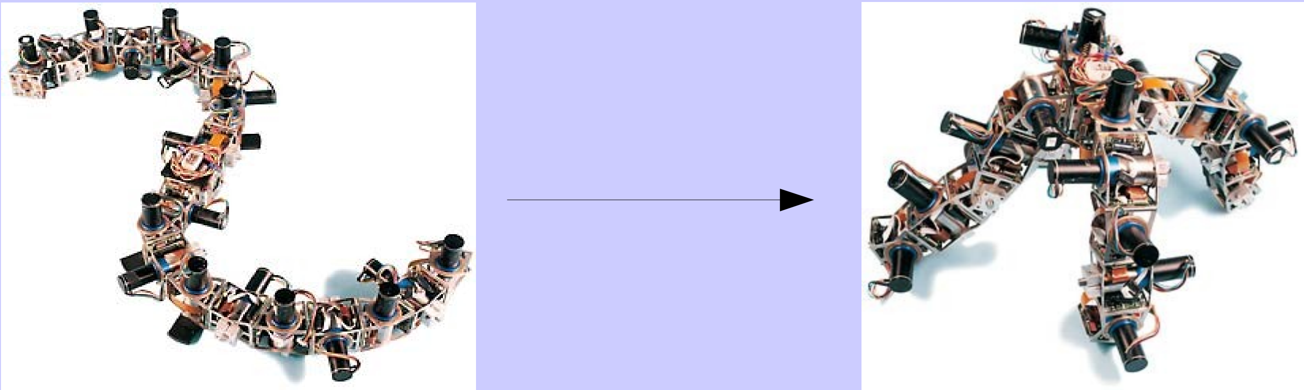


Modular approach

Modular robotics

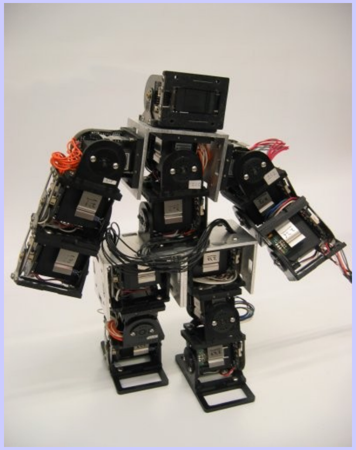
Introduction to Modular Robotics (I)

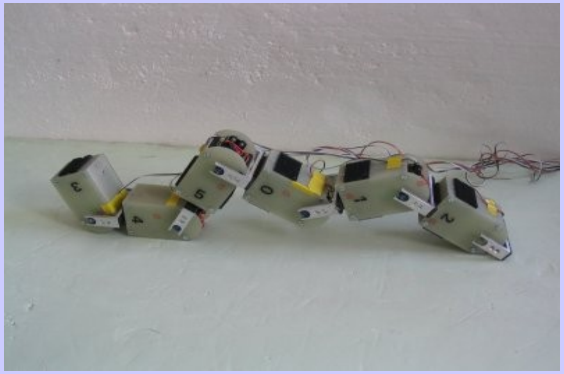
- Main idea: Building robots composed of **modules**
- The design is focused in the module, not in a particular robot
- The different combinations of modules are called **configurations**
- There are two kinds of modular robots:
  - **Manually reconfigurable robots**
  - **Self-reconfigurable robots**



Introduction to Modular Robotics (II)

- The idea of modular robotics was introduced by **Mark Yim**, in 1994
- There are many groups working on this topic in the world.
- The most avanced robots are:
  - **POLYBOT** (USA). Palo Alto Research Center (**PARC**)
  - **M-TRAN** (JAPAN). Advance Industrial Science Technology (**AIST**)
  - **YAMOR** (Swiss). Ecole Polytechnique Federale de Lausanne (**EPFL**)

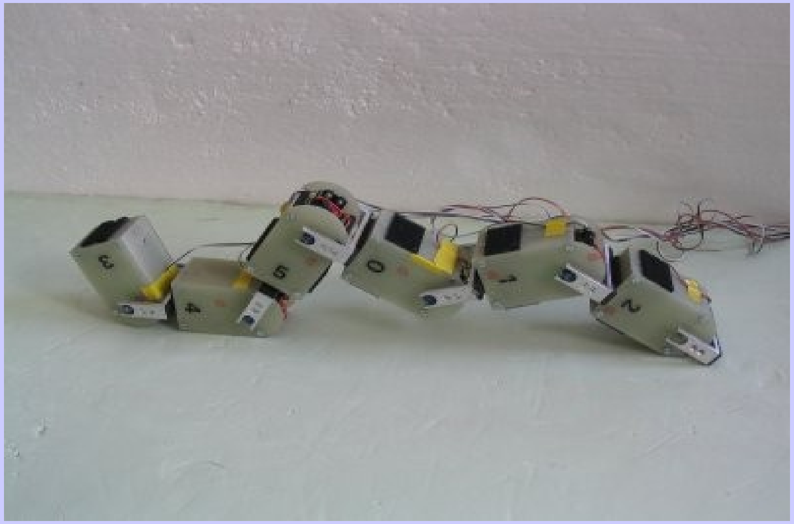


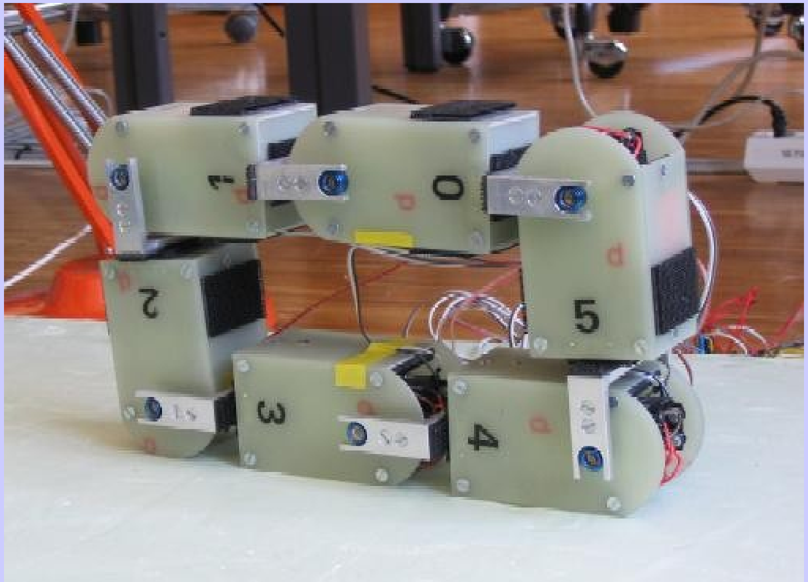


Introduction to Modular Robotics (V)

YAMOR

- The modules have 1 **DOF**
- Manually reconfigurable
- Control: ARM and FPGA
- Communication via bluetooth
- Connection using velcro





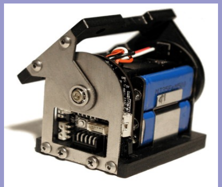
Introduction to Modular Robotics (III)

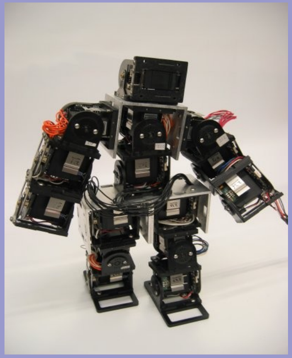
POLYBOT

- All the modules have 1 DOF
- 3 generations of modules

Generation 1

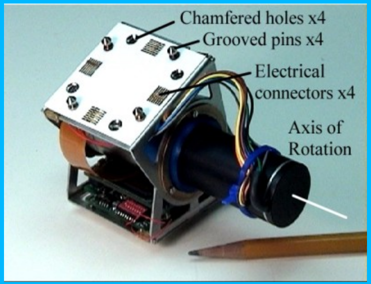
- Manually reconfigurable
- Many versions





Generation 2

- 11x7x6 cm
- Power PC 555
- 1MB Ram
- Can Bus
- Infrared emitters and detectors



Generation 3

- 5x5x5cm
- Maxon motor
- Similar electronics than G2

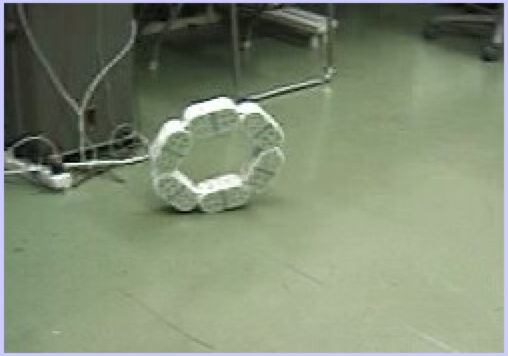
Introduction to Modular Robotics (IV)

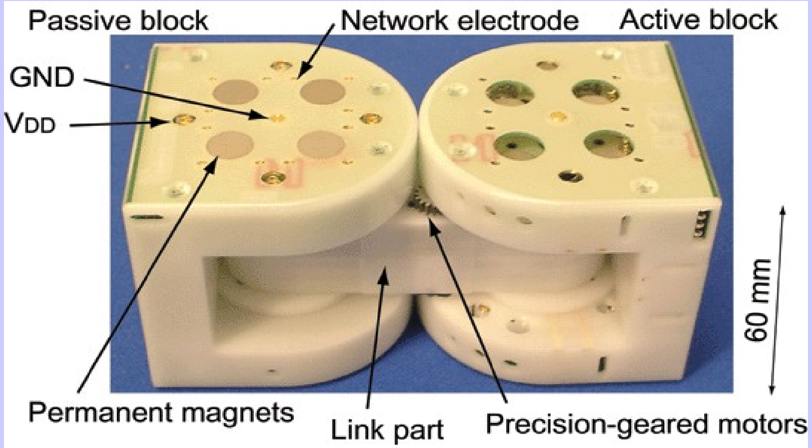
M-TRAN

4 Legged

- All the modules have **2 DOF**
- 6x12x6 cm
- CPU: 1 Neuron Chip and 3 PICs
- Acceleration sensor

Wheel

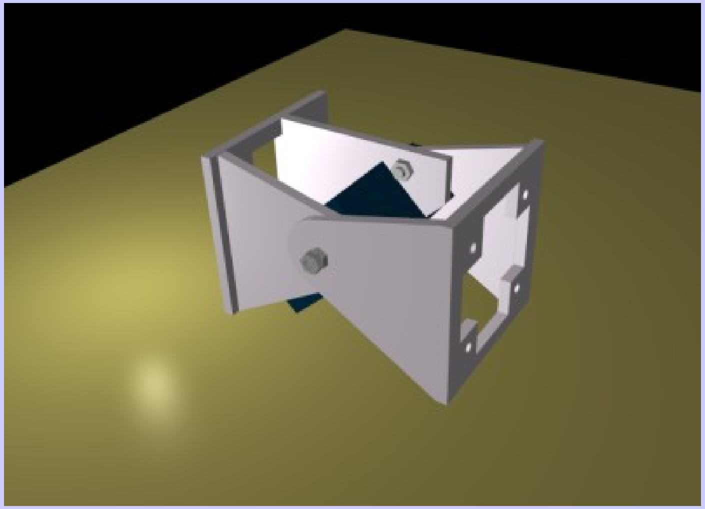


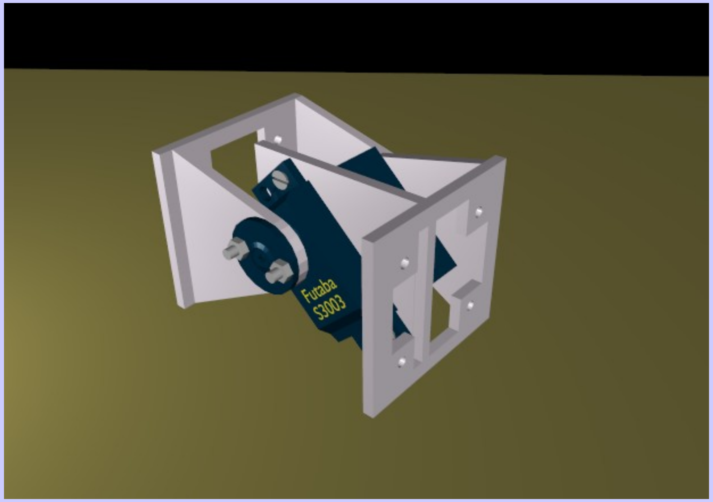


Snake

Video

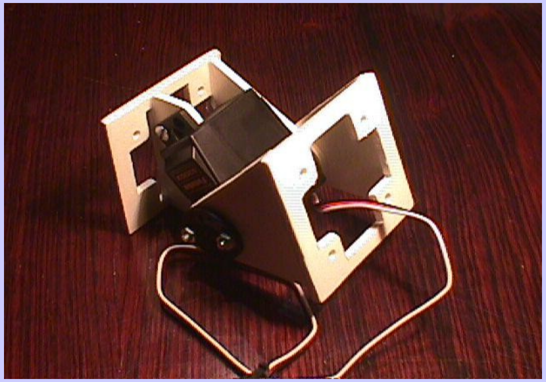
Starting platform:
Y1 Modules

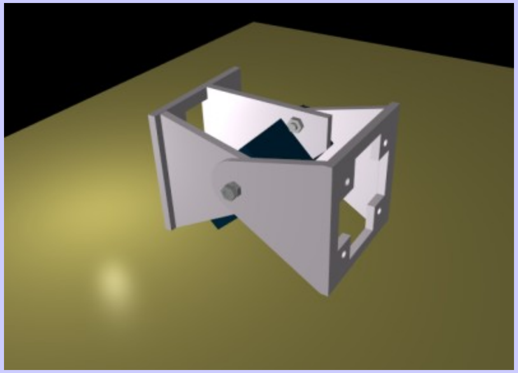




Y1 Modules: Introduction

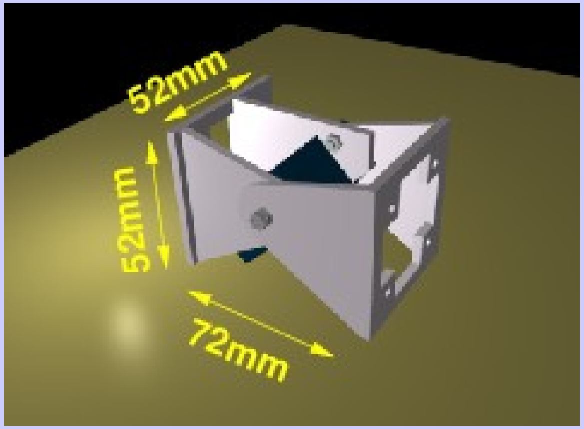
- We needed a cheap and easy-to-build platform to research on modular robotics
- It was not possible to buy the modules developed by the other groups
- **Y1 Modules** is the first generation
  - Fast prototyping
  - Manually reconfigurable robots
  - Students can build them very easily



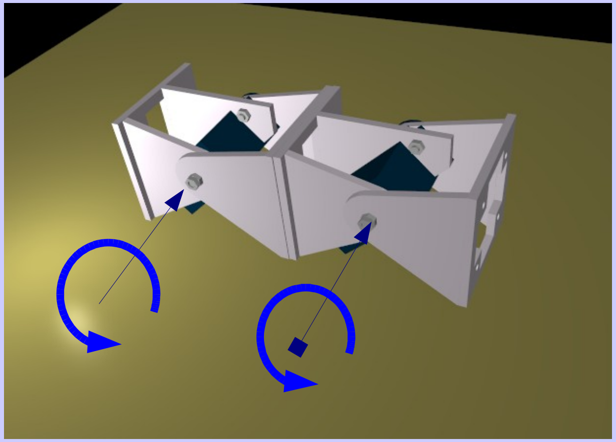


Y1 module: Characteristics

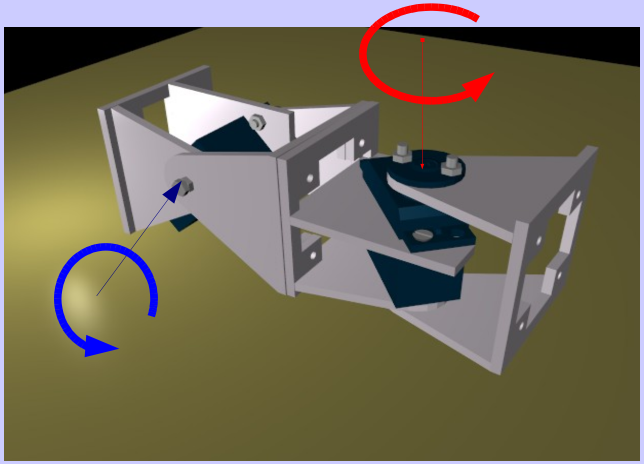
- **Material**: 3mm Plastic
- **Servo:** Futaba 3003
- **Dimension**: 52x52x72mm
- **Range**: 180 degrees
- Two types of connection:



Same orientation

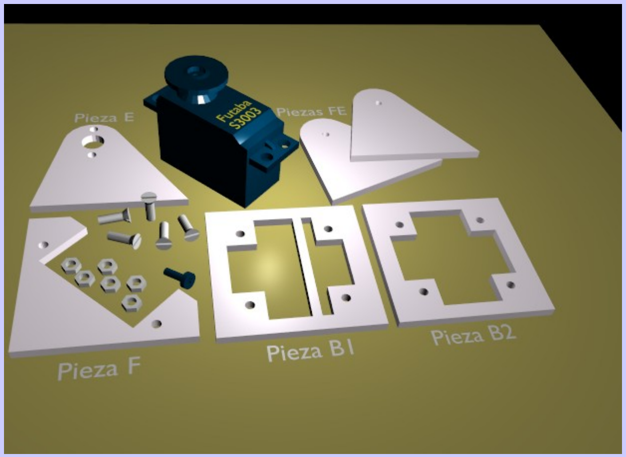


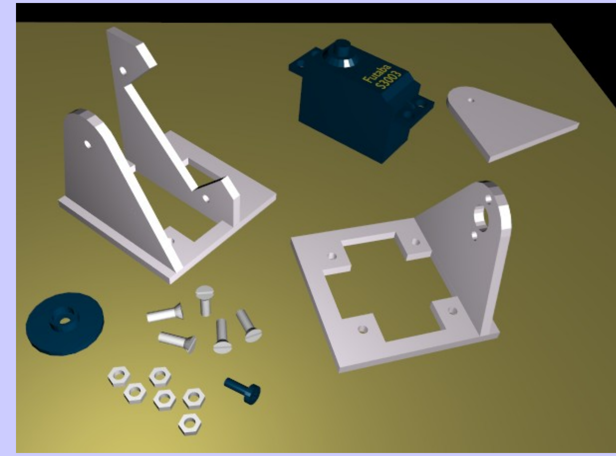
90 degrees rotation

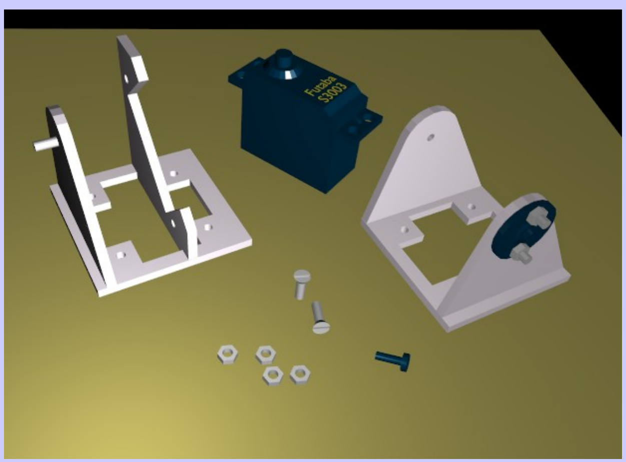


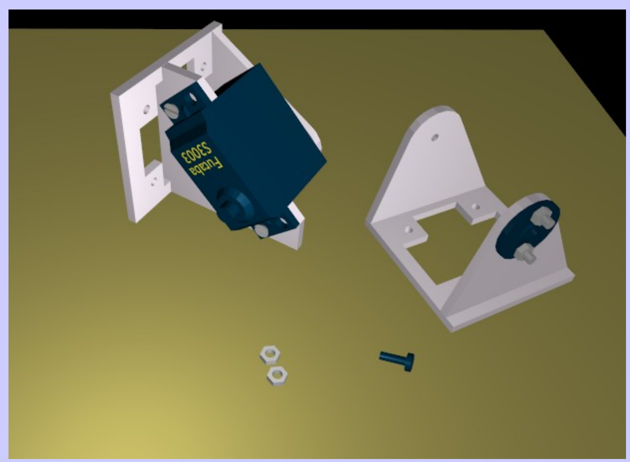
Video

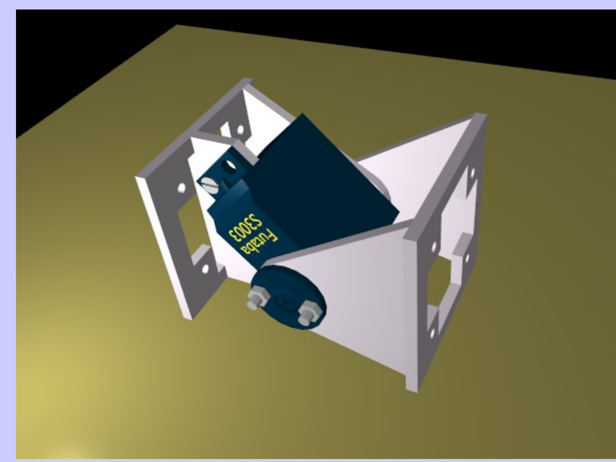
Y1 modules:
Building in 6 steps





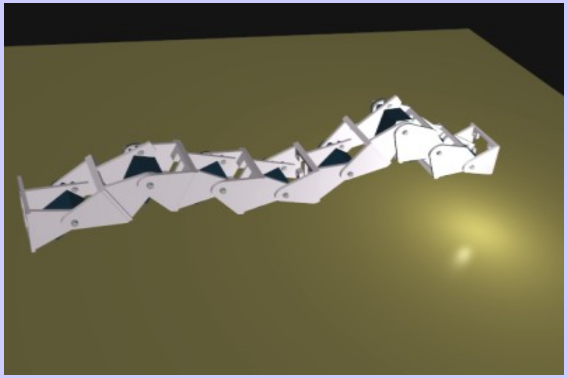


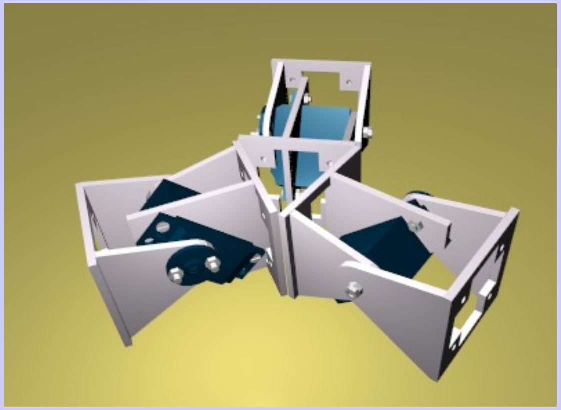




Y1 modules: Topology

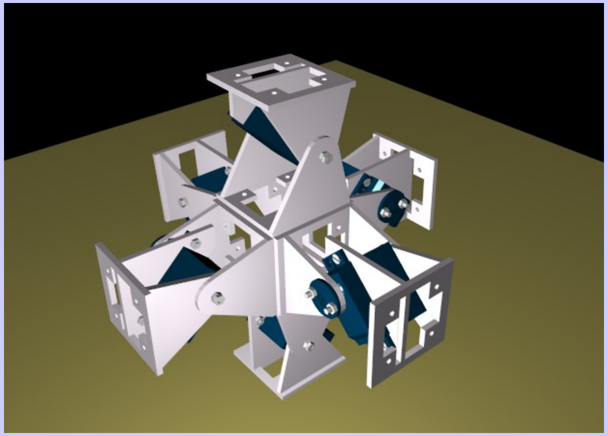
1D: Chain robots
(Worms, snakes)





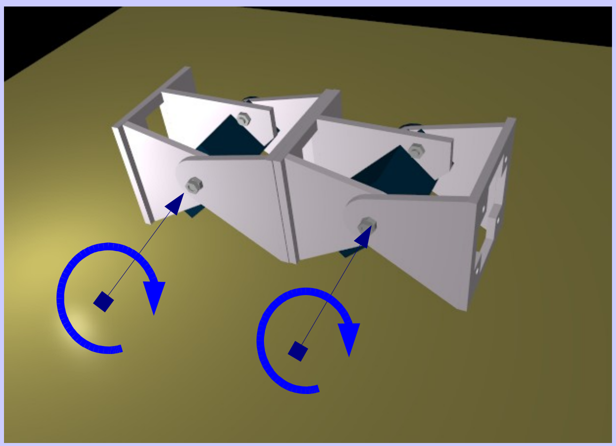
2D structures

3D structures

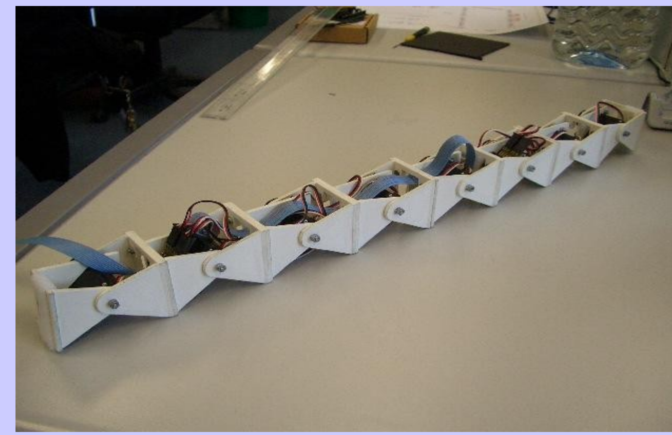


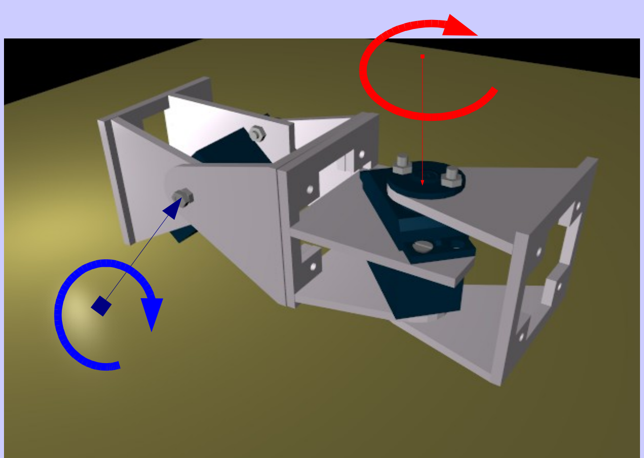
Y1 Modules:
1D Structures (Chain robots)

- Two different type of robots:



Same orientation →

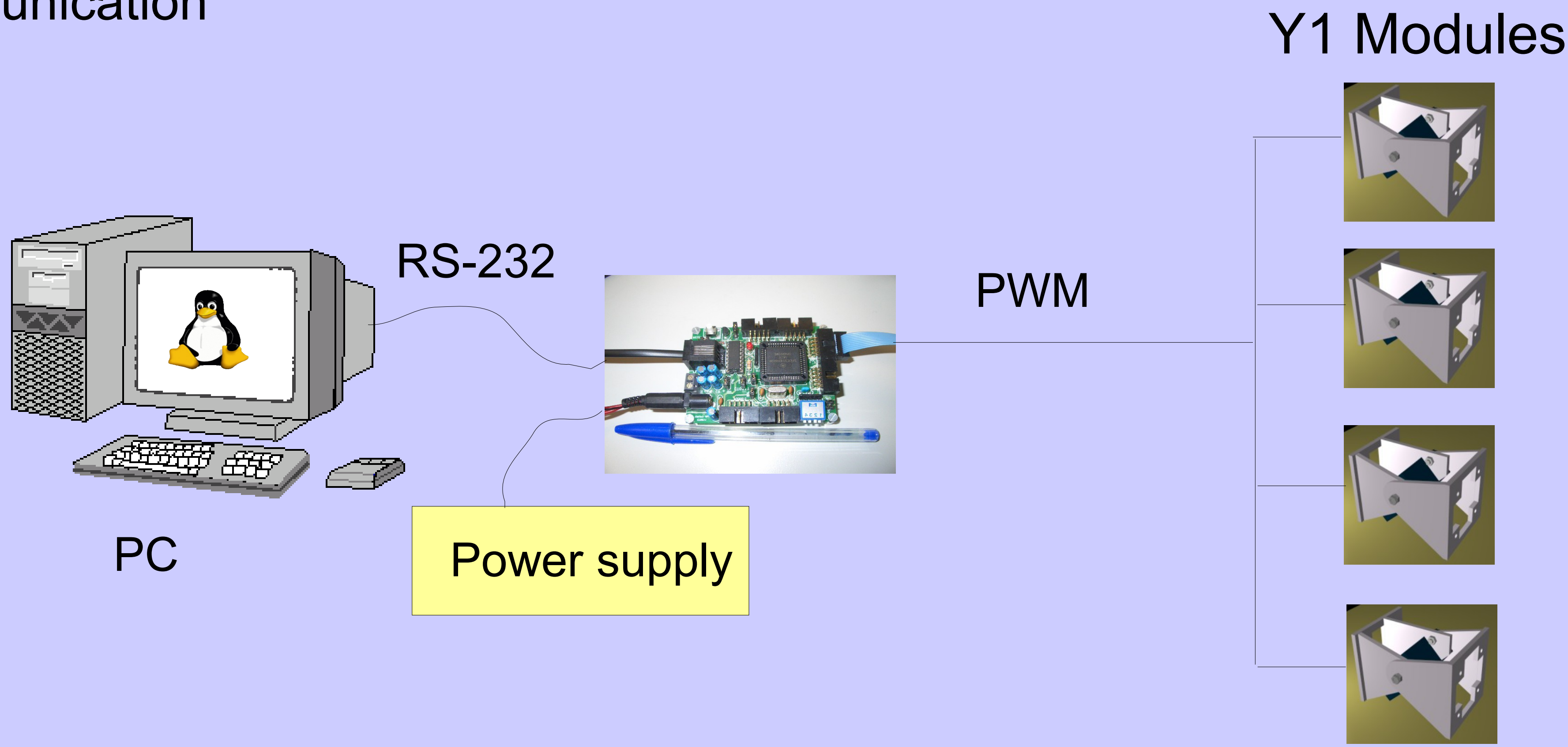




90 degrees rotation →

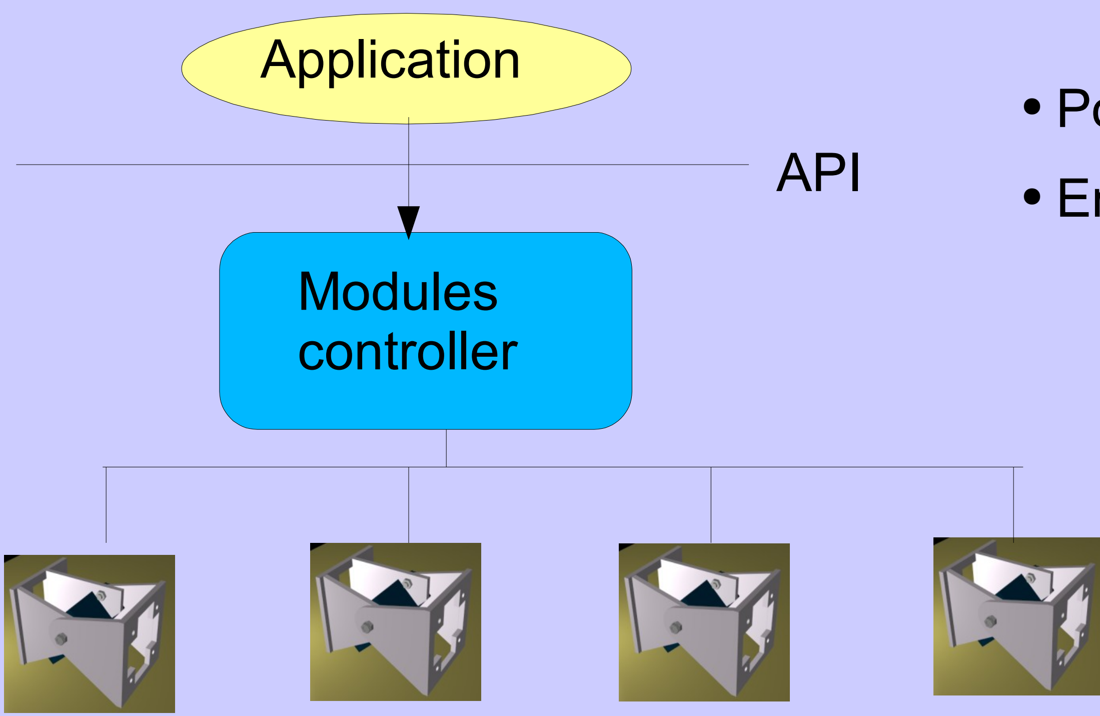
Y1 modules: Electronics

- The electronic and power supply are located outside the module
- An 8 bits micro-controller is used for the generation of the PWM signal that position the servos
- The software running in the PC send the position to the servos by serial communication



Y1 modules: Software

- The modules are controlled by the PC
- The software can set the position of every module
- There is an simple API

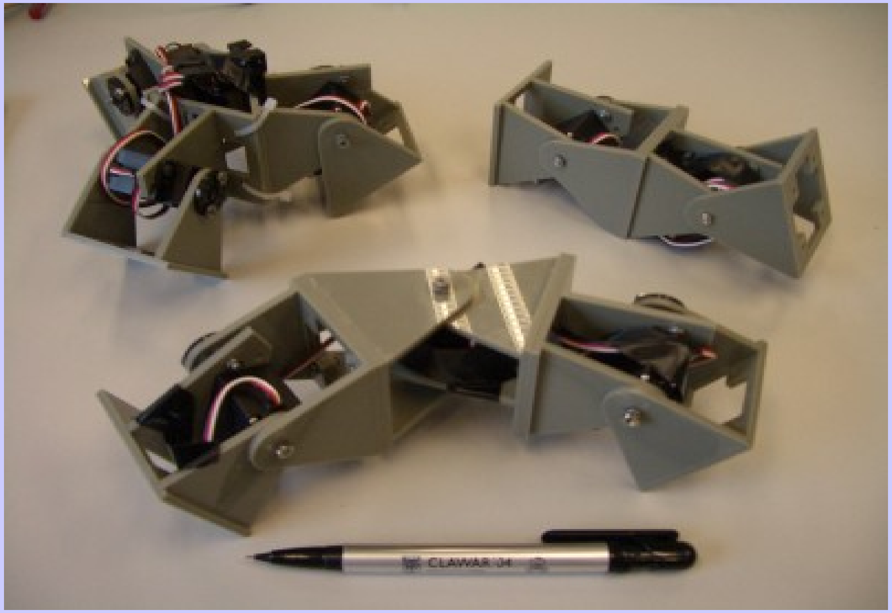


- Position each module
- Enable/disable each module

Demo

- Let's see some code...
- Let's move one module...

Locomotion of minimal configurations



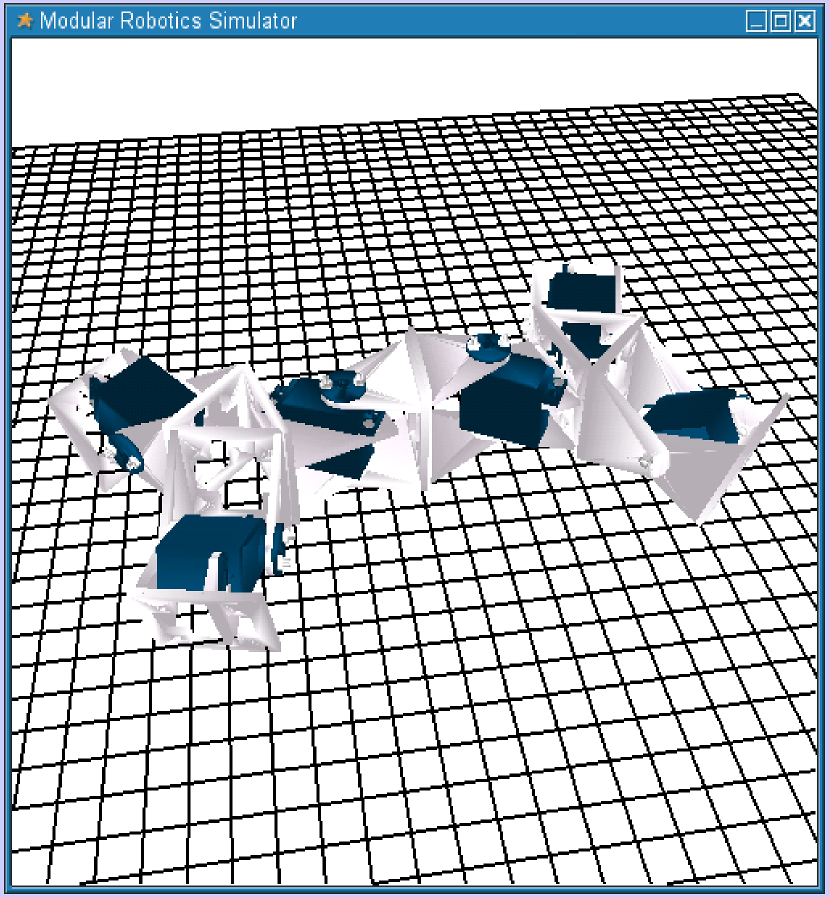
Introduction

• Complex robots can be constructed by attaching these modules

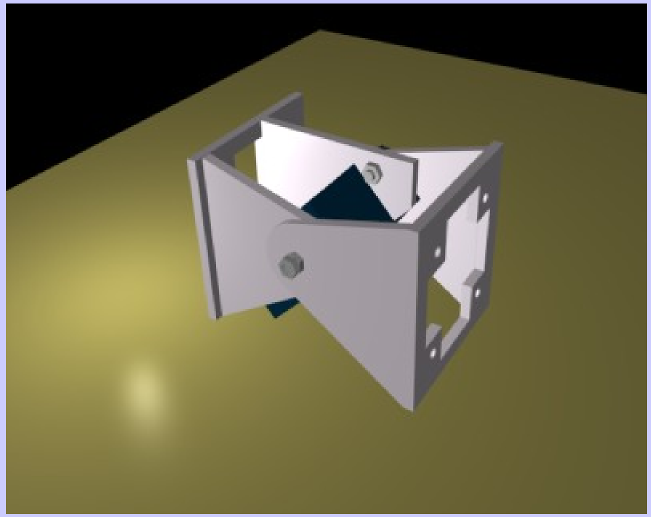
• But, what we wonder is:

What is the minimum number of modules needed to achieve locomotion in 1D and 2D?

How do these modules have to be coordinated to achieve the locomotion?



Configuration with one module (II)



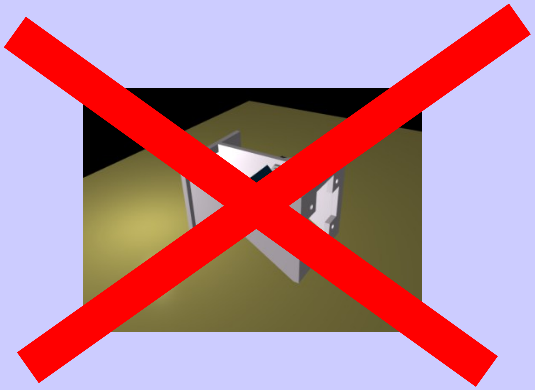
- Can one module move from one point to another??
- How can we test it?

????

Test

- Let's move one module...

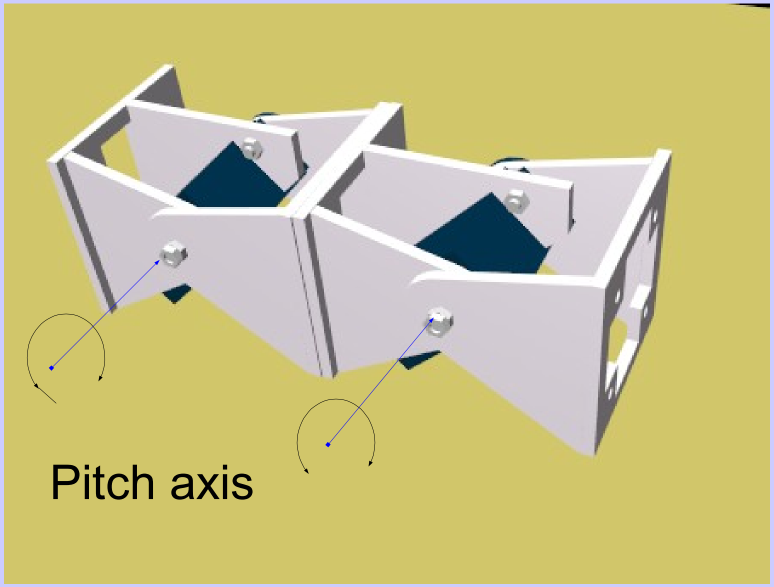
Configuration with one module

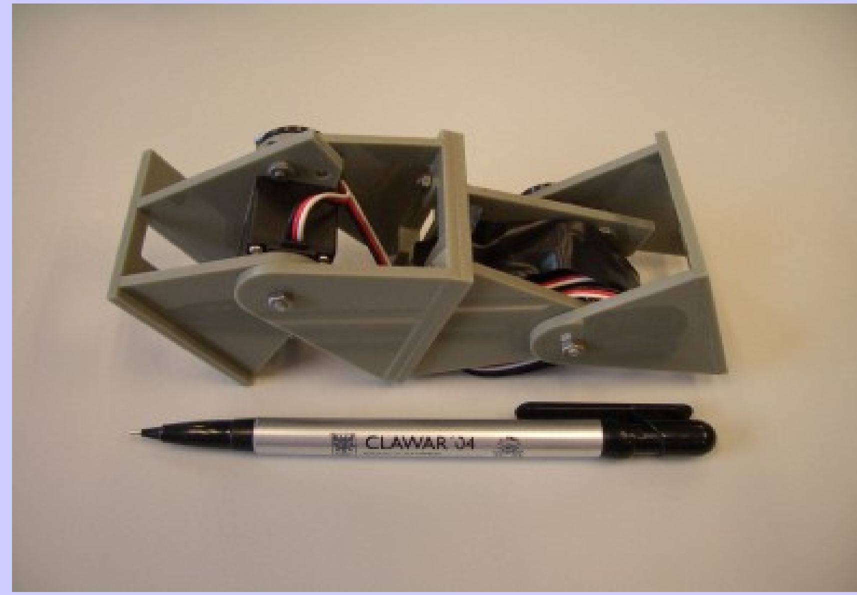


Answer: no locomotion

- Let's try with two modules...

Configuration with two modules: Pitch-Pitch





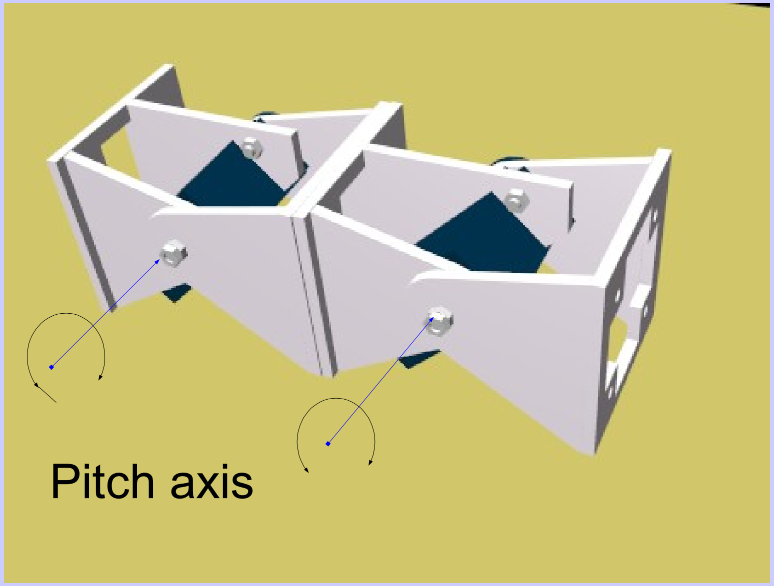
- Can this robot move from one point to another?
- if so ... How do we have to coordinate the articulations?

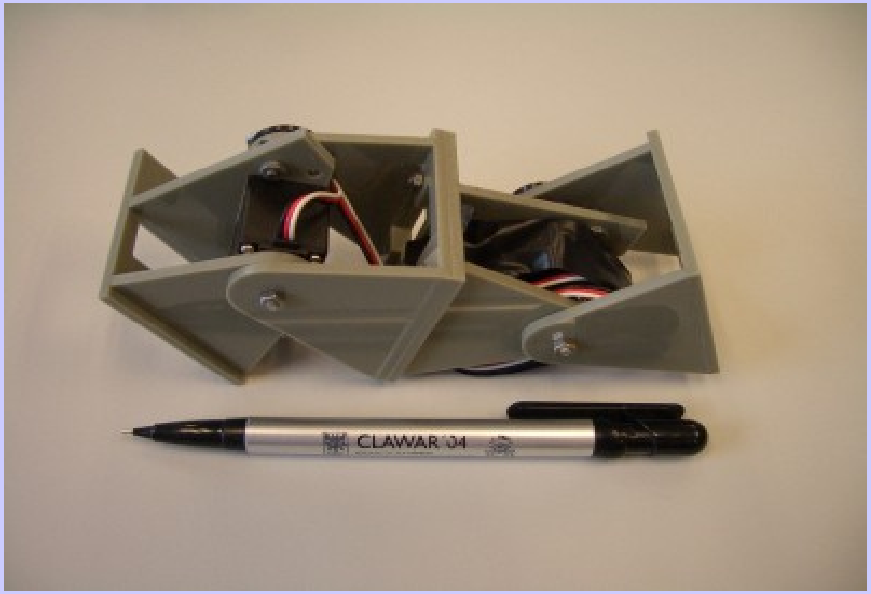
????

Test

- Let's move two modules...

Configuration with two modules:
Pitch-Pitch

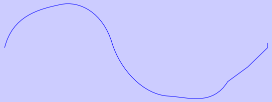




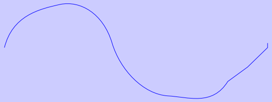
Answer: yes!!

- only two modules is enough for locomotion in 1D
- The robot can move forward and backward
- Let's try to study what happened...

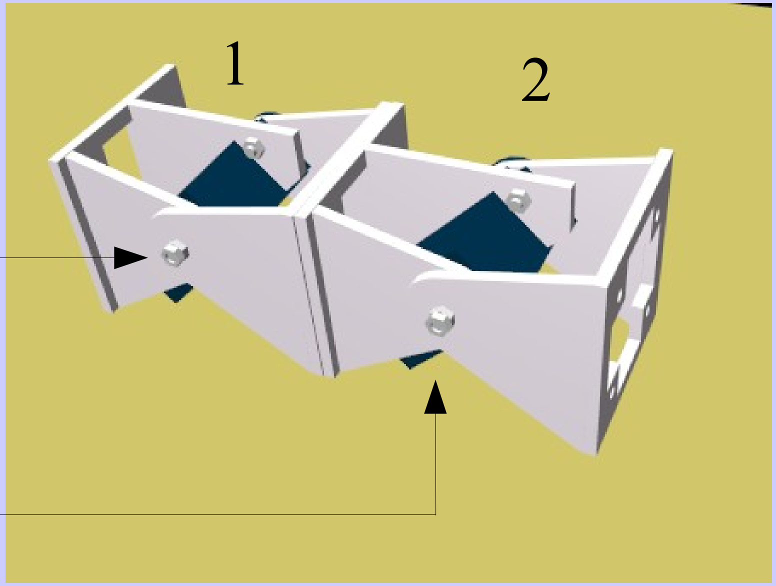
Configuration Pitch-Pitch: Coordination



$$\varphi_1 = A\sin(\frac{2\pi}{T}t)$$

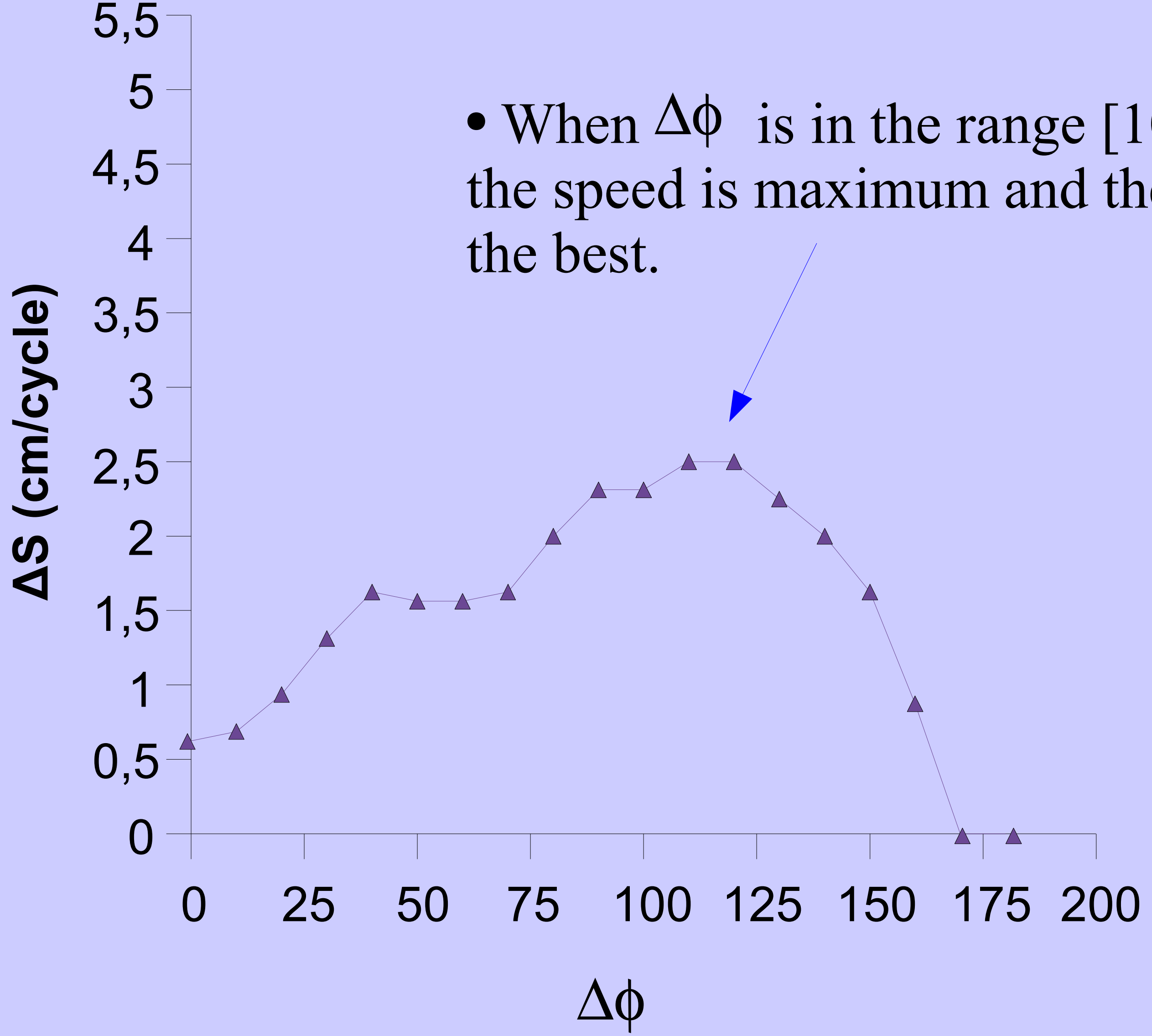


$$\varphi_2 = A\sin(\frac{2\pi}{T}t + \Delta\phi)$$



- Two sinusoidal waves are applied to each articulation
- These waves only differ on the phase ($\Delta\phi$)
- $\Delta\phi$ determines the coordination of the movement

Configuration I (Pitch-Pitch) Results



- When $\Delta\phi$ is in the range [100, 130] degrees, the speed is maximum and the coordination is the best.

Demo

Locomotion in 2D

- Now we want to build the minimal configuration capable of moving in 2D

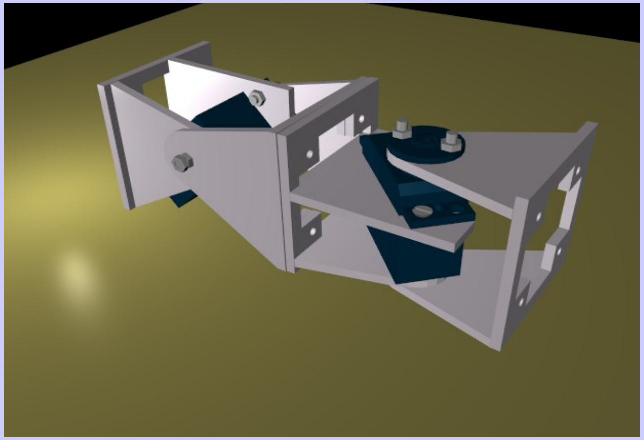
- How many modules are necessary?
- What is the coordination?

- One module is not enough...
- Two modules?
- Three modules?

????

Locomotion in 2D

- Let's try this configuration...



- Can this robot move from one point to another?

Test

- Let's move two modules...

Locomotion in 2D

- ANSWER: NO

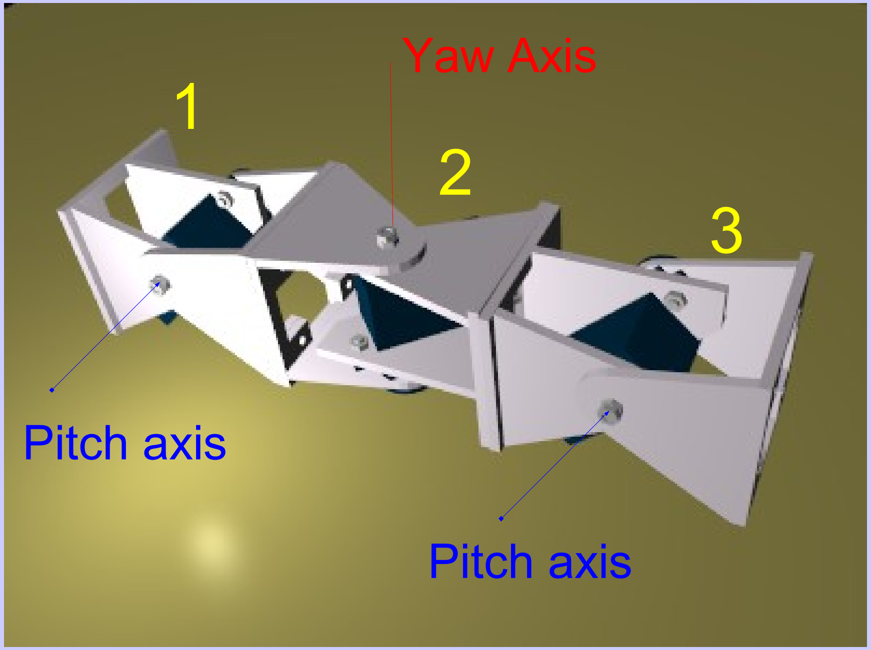
- Let's try with three modules...

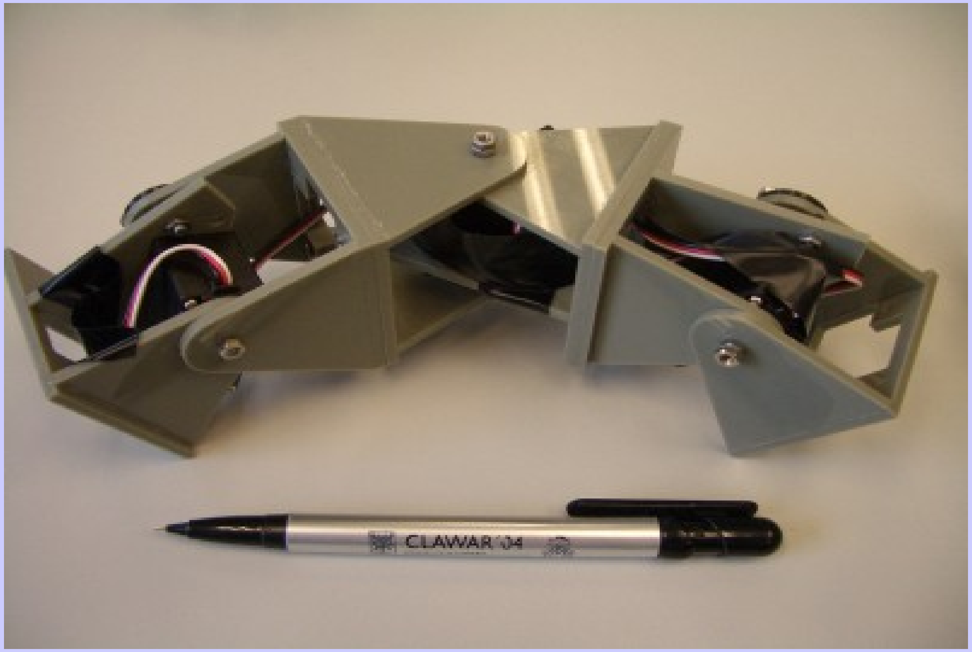
- How can we connect the modules?
- Are three modules enough for moving in 2D?
- How are the modules coordinates?

Test

- Let's move three modules...

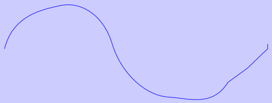
Configuration II (Pitch-Yaw-Pitch) Description





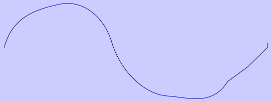
- Three modules: two rotating in the pitch axis and one in the yaw
- We call it Pitch-Yaw-Pitch configuration (PYP)
- 1D and 2D sinusoidal gait
- Lateral shift gait
- Lateral rolling gait

Configuration II (Pitch-Yaw-Pitch)
1D sinusoidal gait

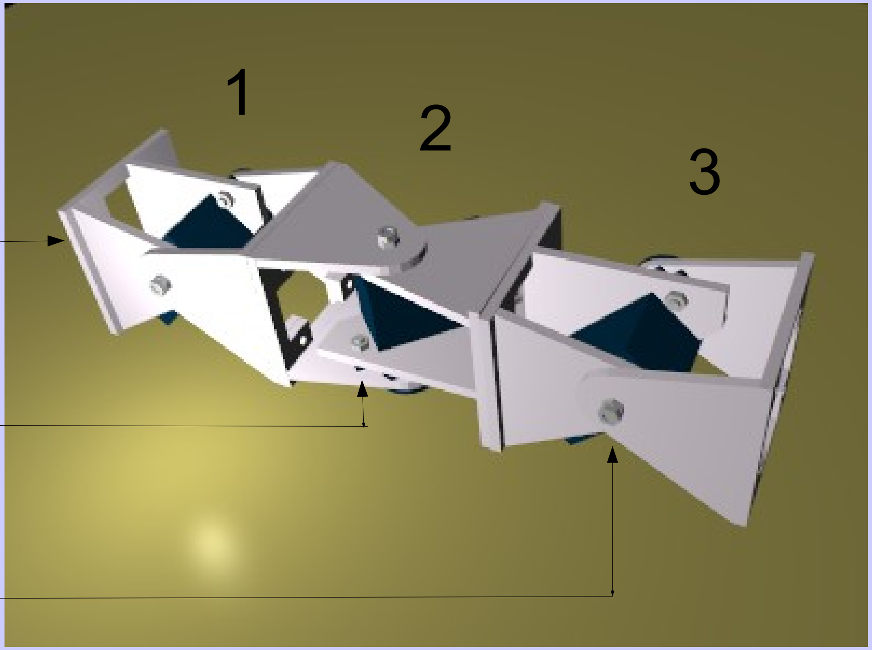


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

$$\varphi_2 = 0$$

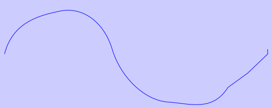


$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



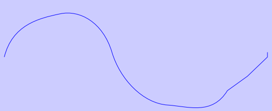
- The angle of articulation 2 fixed to 0 degrees
- Articulations 1 and 3 coordinated in the same way that in the PP configuration
- Sames results as in configuration PP

Configuration II (Pitch-Yaw-Pitch)
2D sinusoidal gait

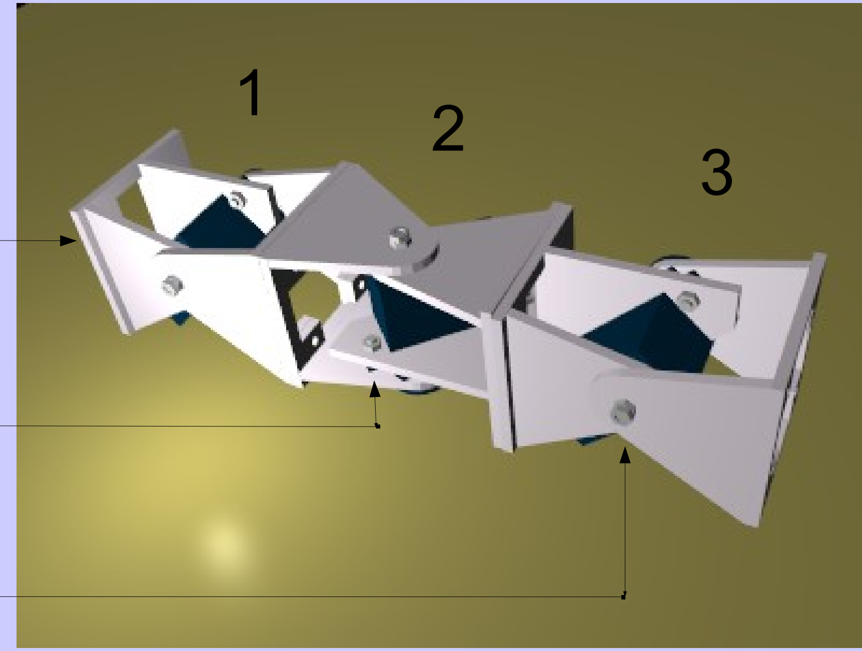


$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

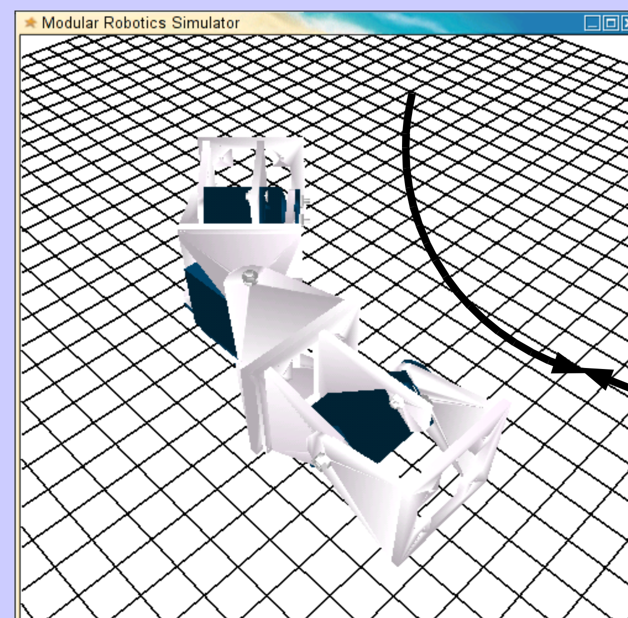
$$\varphi_2 \neq 0$$



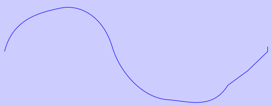
$$\varphi_3 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi\right)$$



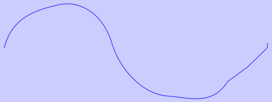
- The same as in 1D sinusoidal gait, but the angle of articulation 2 different from 0 degrees
- The trajectory of the robot is an arc



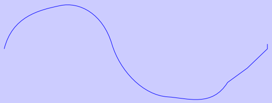
Configuration II (Pitch-Yaw-Pitch)
Lateral shift gait



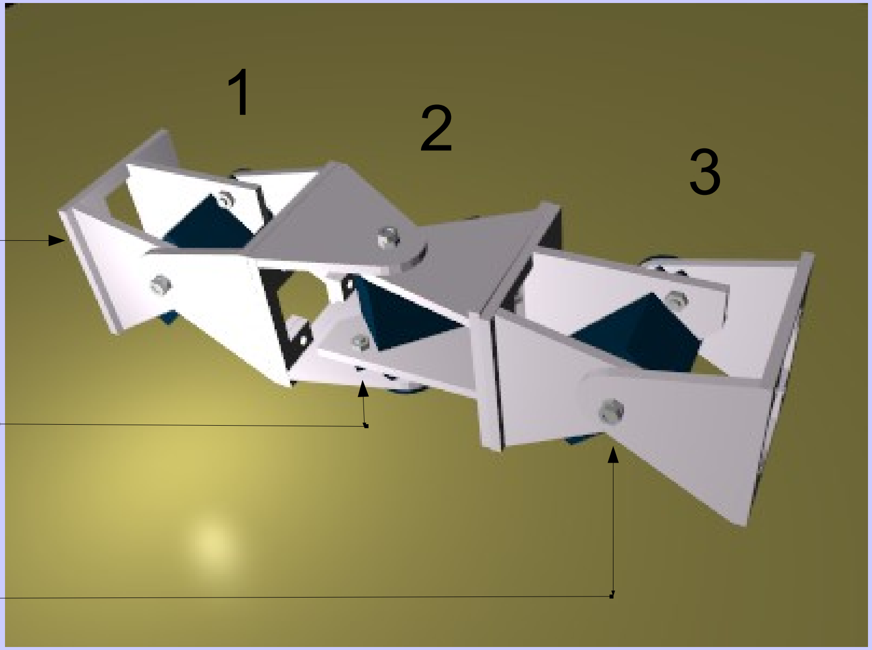
$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t\right)$$

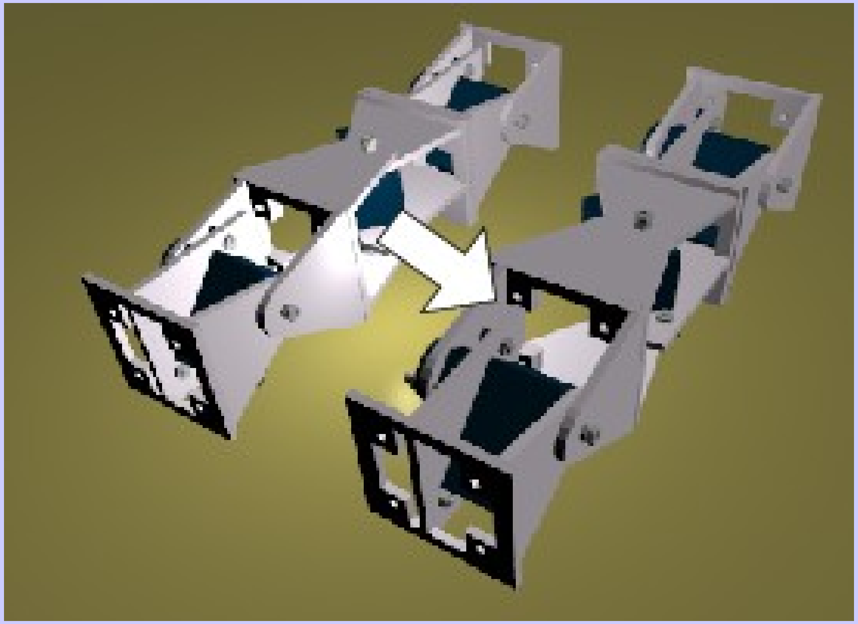


$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \frac{\pi}{2}\right)$$



$$\varphi_3 = \varphi_1$$

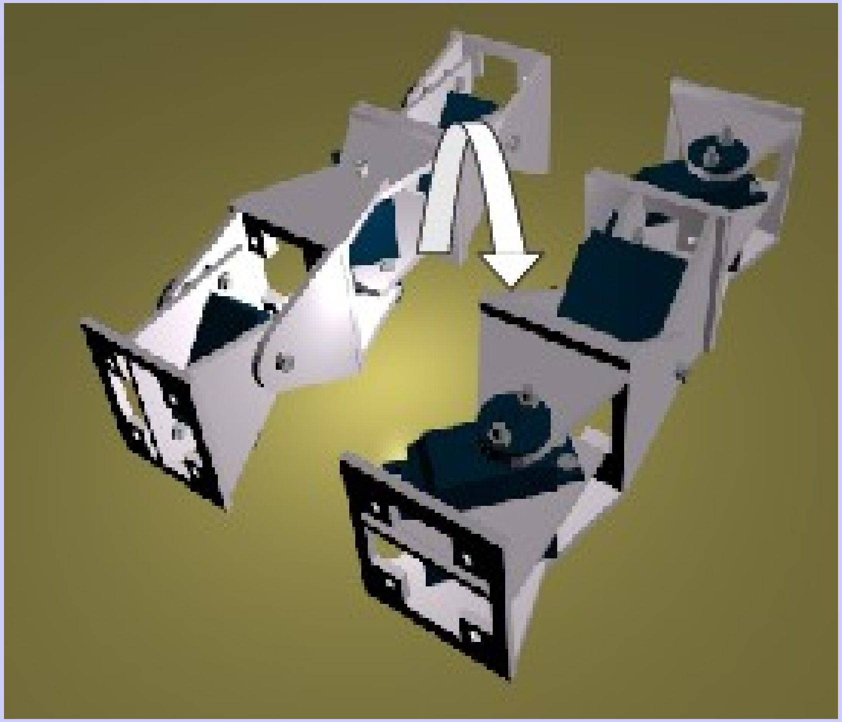




- **A<=40**
- Module 1 and 3 are in phase
- Module 2 is 90 degrees out of phase
- The robot moves parallel to its body axis

Configuration II (Pitch-Yaw-Pitch)
Lateral rolling gait

- The same coordination as in the lateral shift gait, but using and amplitude **A>60** degrees.
- The sense of rolling can also be controlled by changing the sign of the difference of phase
- The robot rolls about its body axis



Minimal configuration in 2D

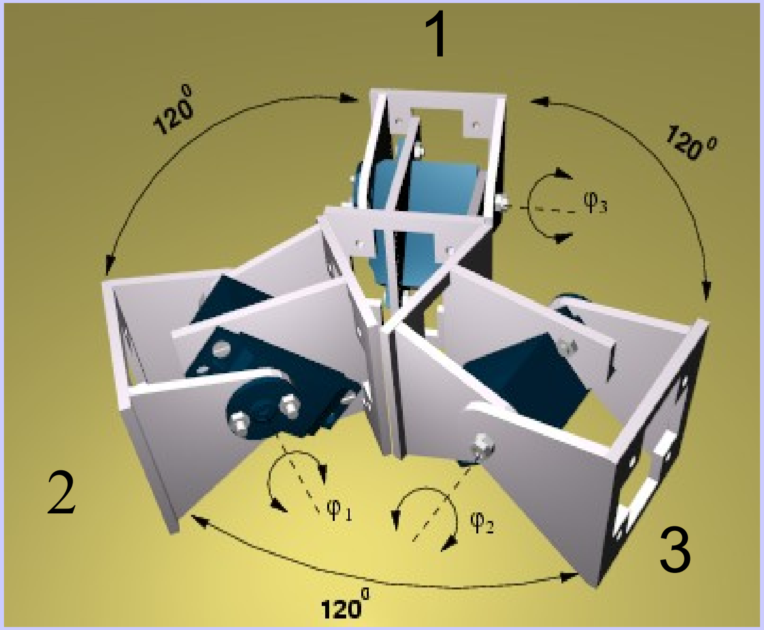
- Which is the minimal configuration in 2D that can move from one point to another?
- How do we have to coordinate the modules?

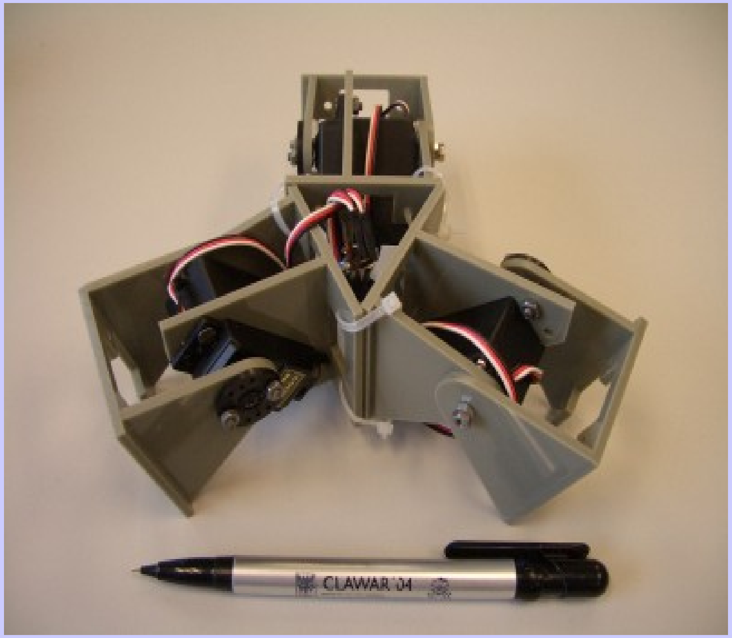
- At least, we need three modules...

????

Test

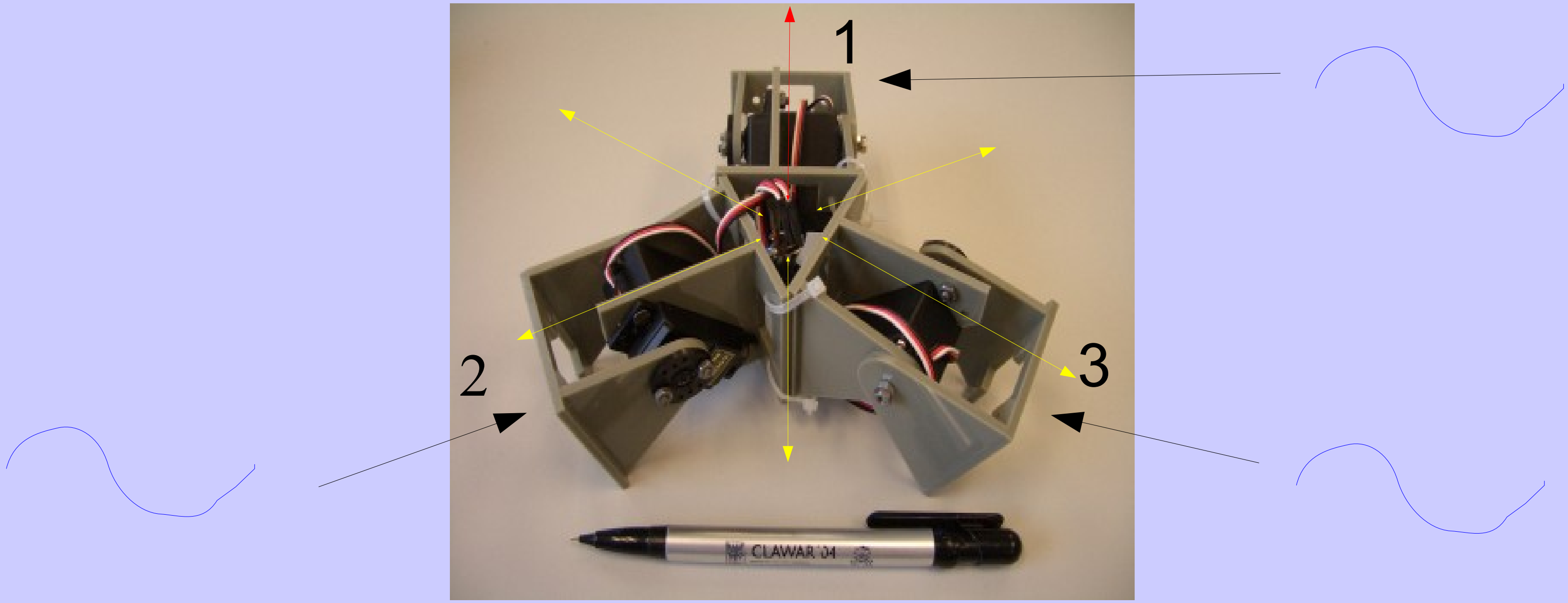
Configuration III: three-modules star
Description





- Three modules in the same plane, moving about its pitch axis
- The angle between the modules is 120 degrees (connected in a three-points-star form)
- 1D sinusoidal gait along six different directions
- Rotation about the robot's yaw axis

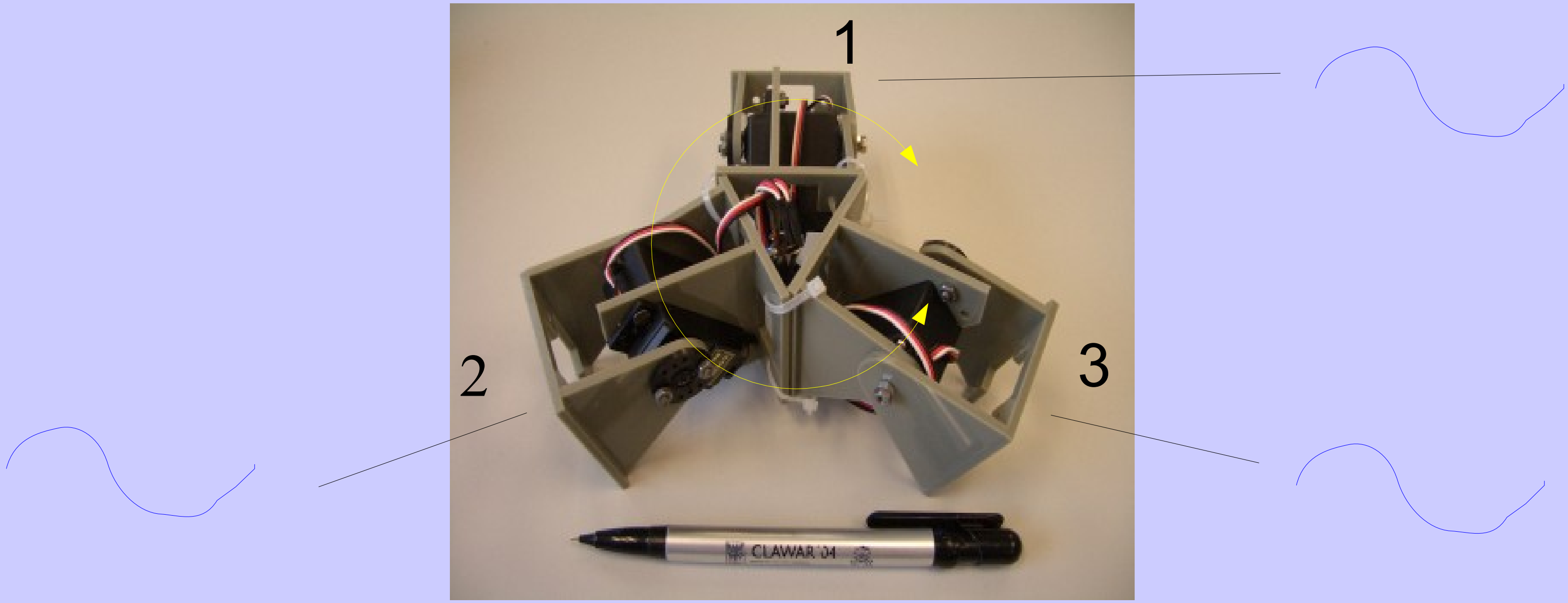
Configuration III: three-modules star
1D sinusoidal gait



- The robot can move along six different directions
- Three sinusoidal waves are applied
- Example: In order to move along the red direction:

$$\varphi_2 = \varphi_3 = A\sin\left(\frac{2\pi}{T}\right) \qquad \varphi_1 = A\sin\left(\frac{2\pi}{T} + \Delta\phi\right) \qquad 100 < \Delta\phi < 130$$

Configuration III: three-modules star
Rotation about its yaw axis



- Rotation about the robot yaw axis
- Three sinusoidal waves are applied

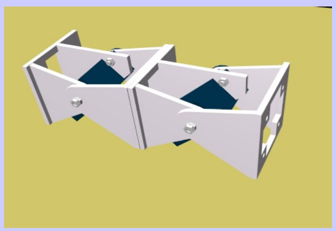
$$\varphi_1 = A\sin\left(\frac{2\pi}{T}\right) \qquad \varphi_2 = A\sin\left(\frac{2\pi}{T} + \frac{2\pi}{3}\right) \qquad \varphi_3 = A\sin\left(\frac{2\pi}{T} + \frac{4\pi}{3}\right)$$

Video

Conclusions...

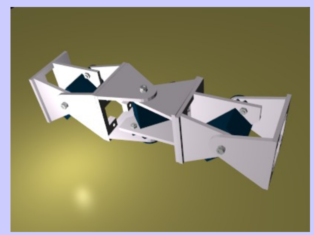
- We have found three minimal configurations:

1D Structure



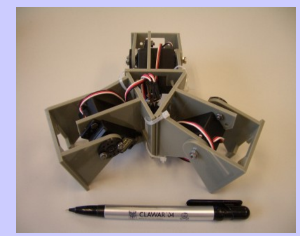
Locomotion in 1D

1D Structure



Locomotion in 2D
Rolling

2D Structure



Locomotion in 2D
Rotating

- All of these robots are controlled using sinusoidal signals
- The phase difference determines the coordination between the modules

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

A: Amplitude

T: Period

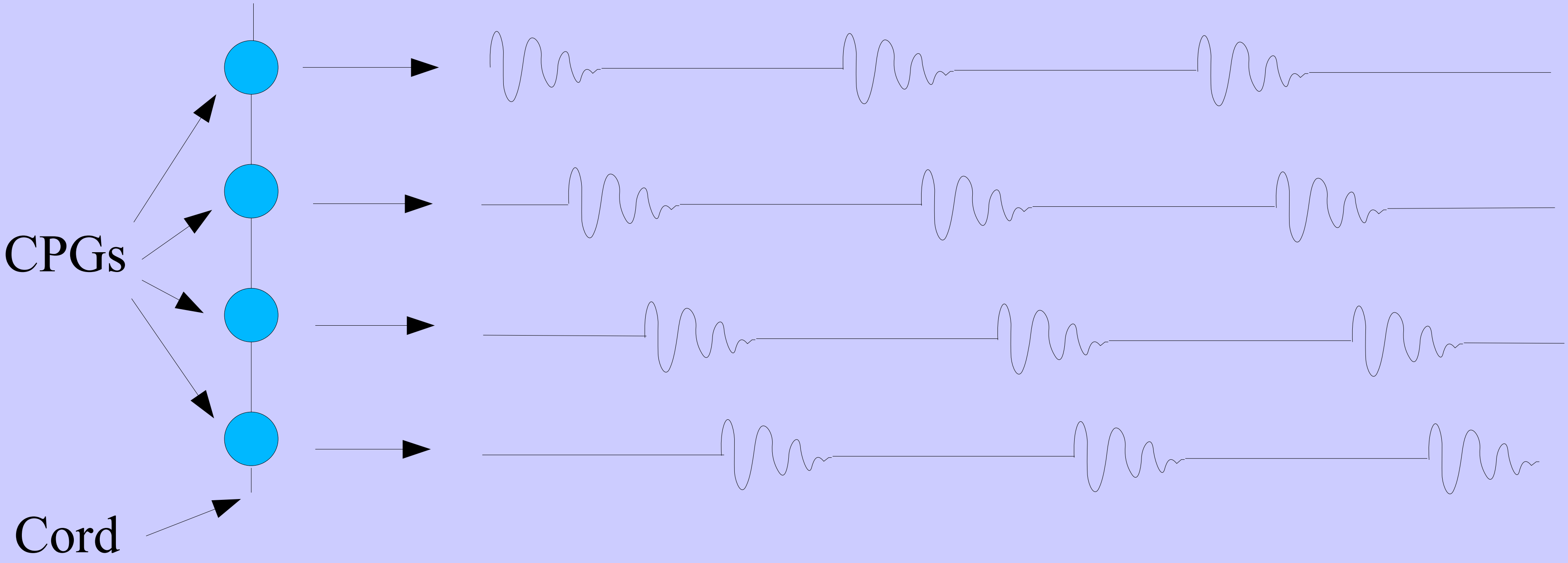
ϕ : Phase

Conclusions...

- We have discover the basic coordination method that is found in nature.

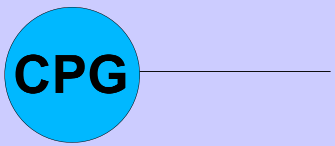
- All the vertebrates have central pattern generators (**CPGs**) in the Cord.

- CPG are oscillators that generate periodic signals that are applied to the muscles, making the animal move.



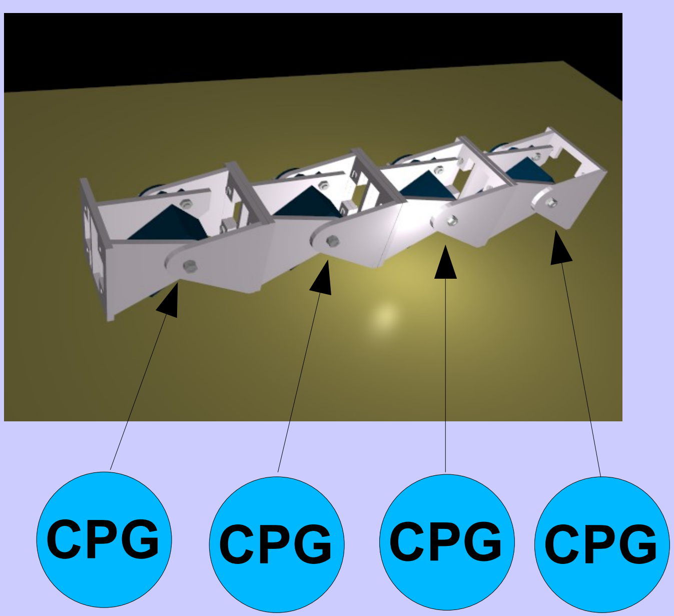
Conclusions...

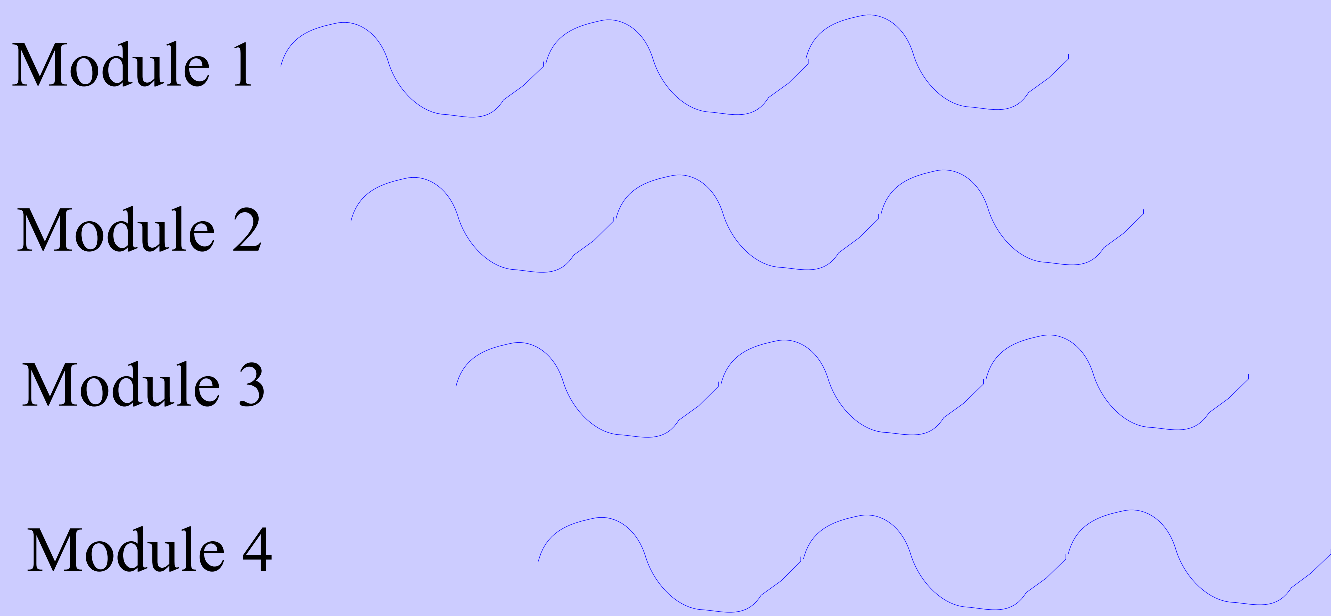
- We are applying the same model that in nature, but a little simplied



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

- There are one CPG per module:

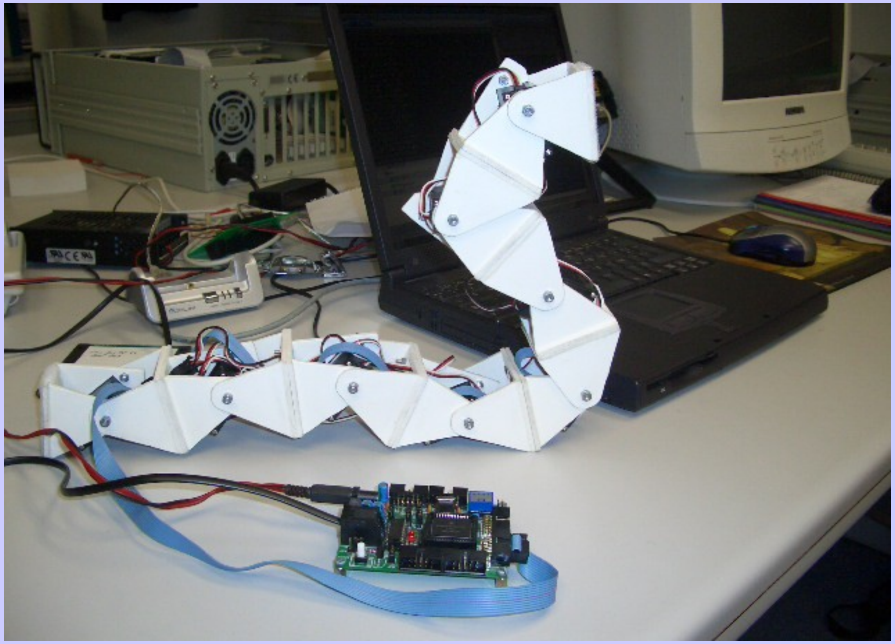




Conclusions...

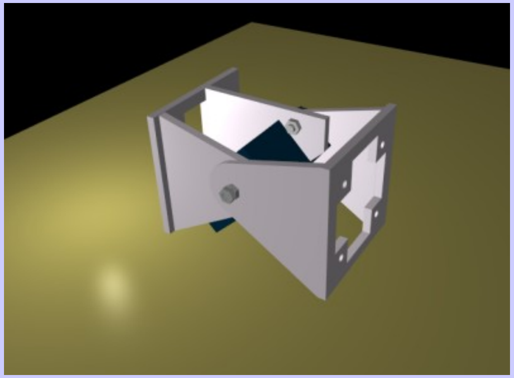
- We have found a general control method valid for all the configurations!!!
- We only have to find the different parameters of the CPG: Phase difference, Amplitude and period.

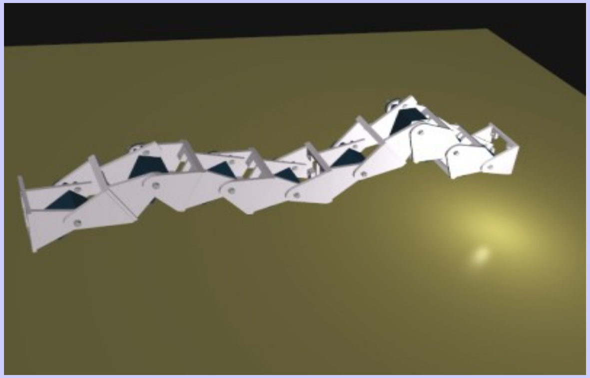
Locomotion of 1D worm-like robot



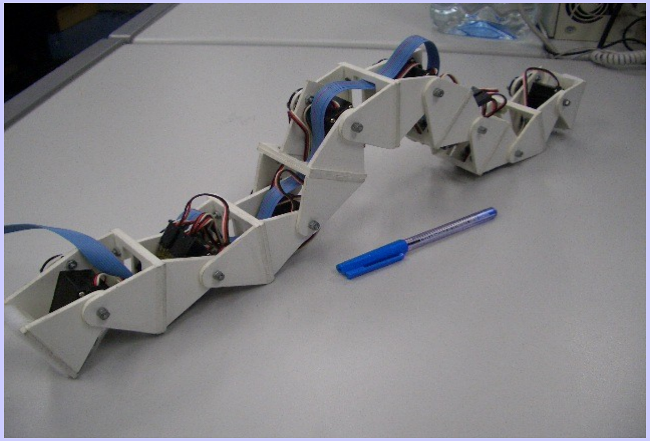
1D chain robot: Introduction

- **Configuration**: 8 Y1 modules in the same orientation



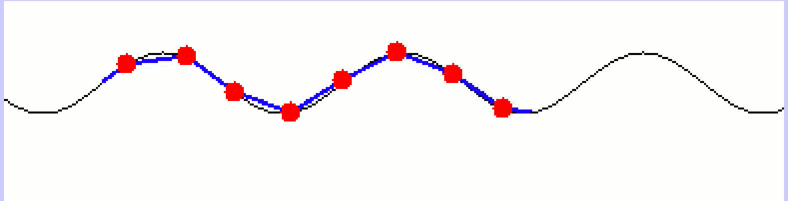


- **Dimensions:** 52x52x576mm:



1D Chain robot:
Locomotion approaches

- Two approaches can be used for the locomotion:
  - Using 8 CPGs
  - Using a global wave that travel through the robot, from the tail to the head

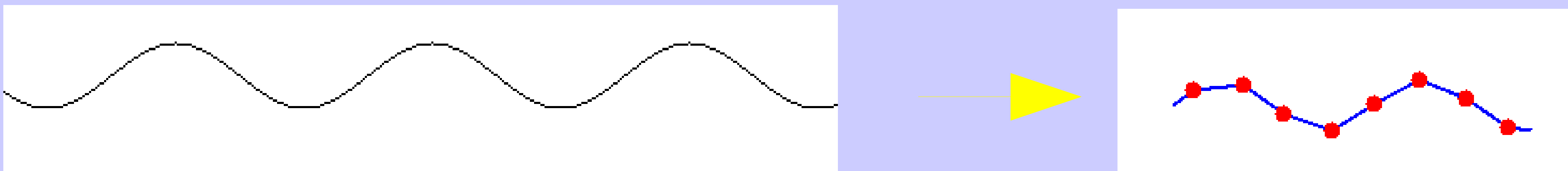


- For the second approach only 4 parameters have to be specified:
  - Waveform
  - Wavelength
  - Amplitude
  - Period

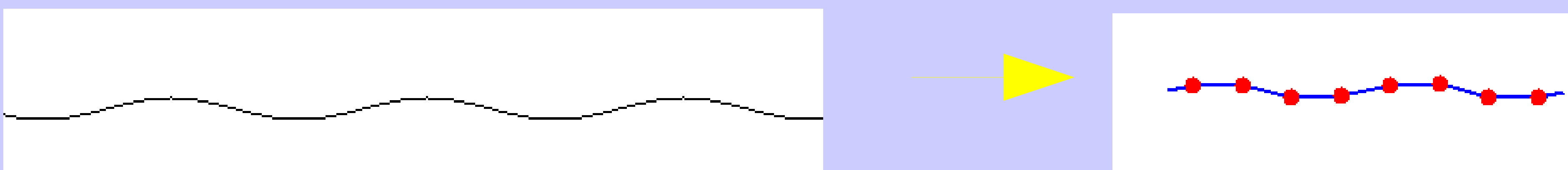
1D chain robots: Global waves

- The locomotion characteristics depend on the global wave used:

High amplitude: Crossing over obstacles



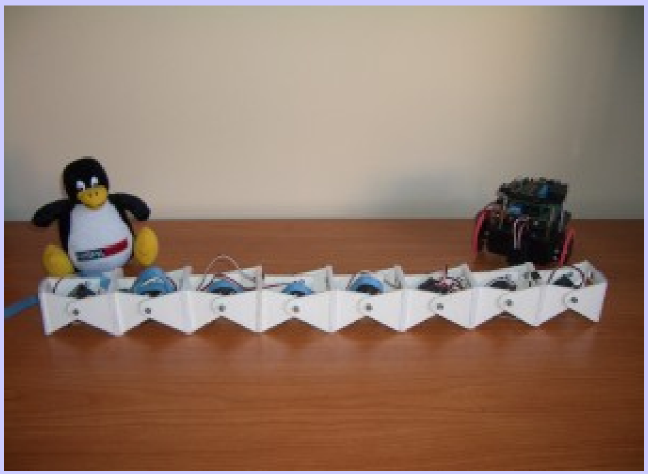
Low amplitude: Going inside a tube

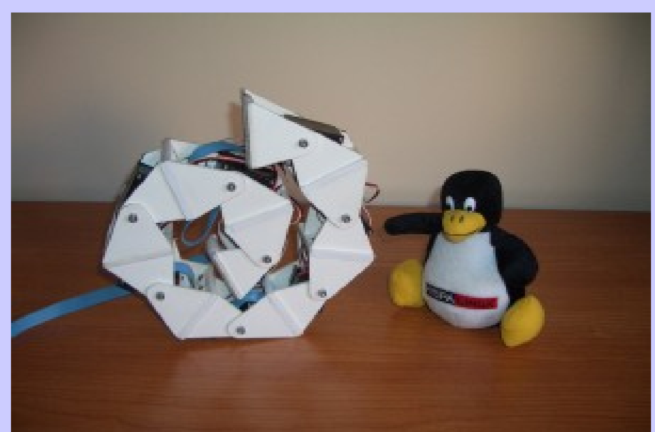


Semi-sine wave: Caterpillar locomotion

1D chain robots: Locomotion capabilities

- One feature of these robots is that they can change their shape:



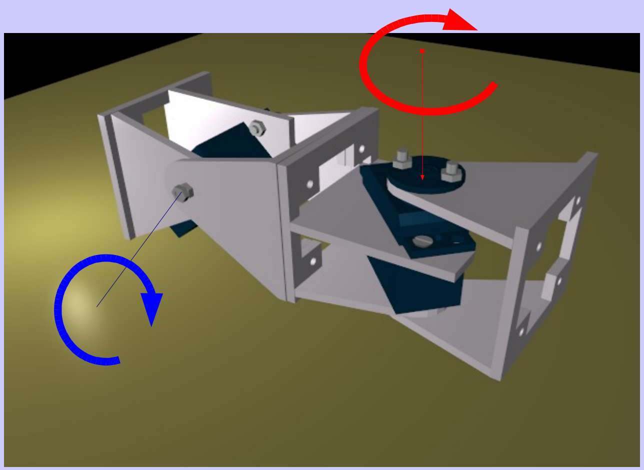


Video

Locomotion of 2D snake-robot

Chain robot 2D: Introduction

- Robot composed of 8 Y1 modules
- Two adjacent modules are 90 degrees rotated

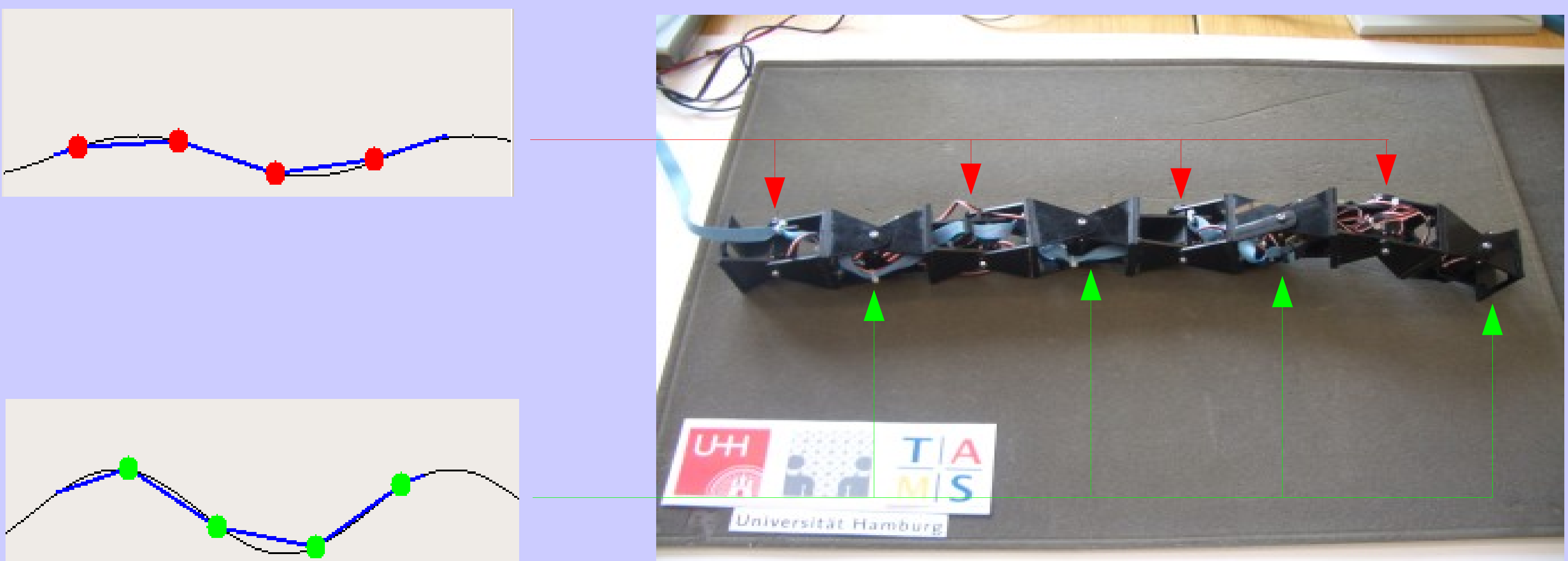


90 degrees rotation →

- This robot have the following locomotion capabilities:
  - 1D locomotion
  - 1D locomotion in an arc
  - Lateral shift
  - Rotating parallel to the ground
  - Lateral rolling

Chain robot 2D:
Control approaches

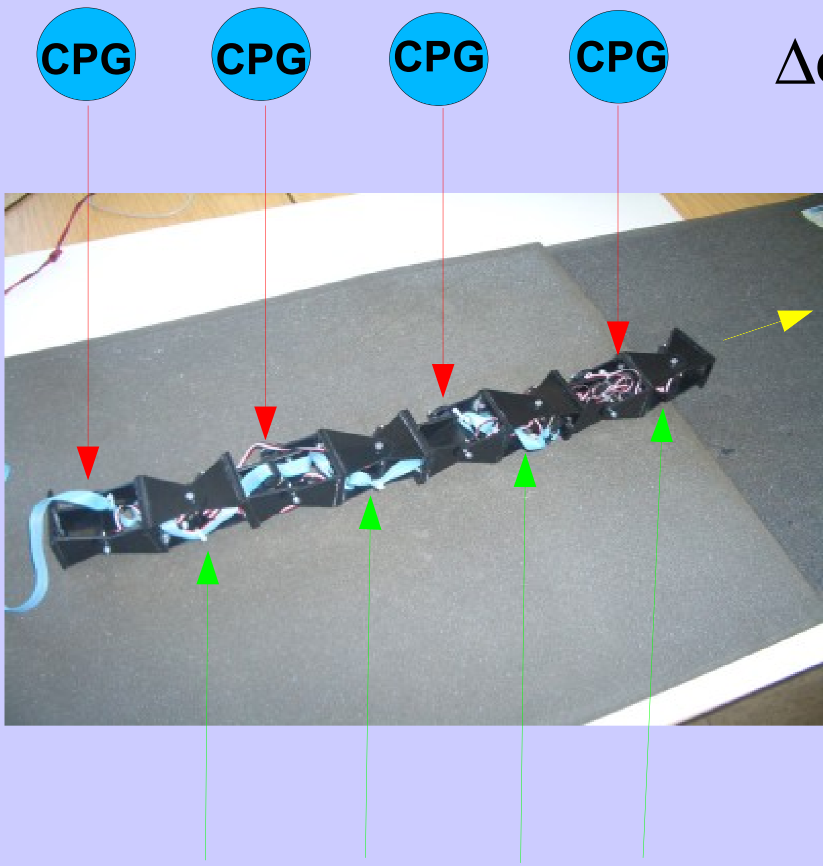
- Using 8 CPGs
- Using two global waves. One for the vertical modules and the other for the horizontal:



- Some gaits are easier to implement with the first approach and others with the second

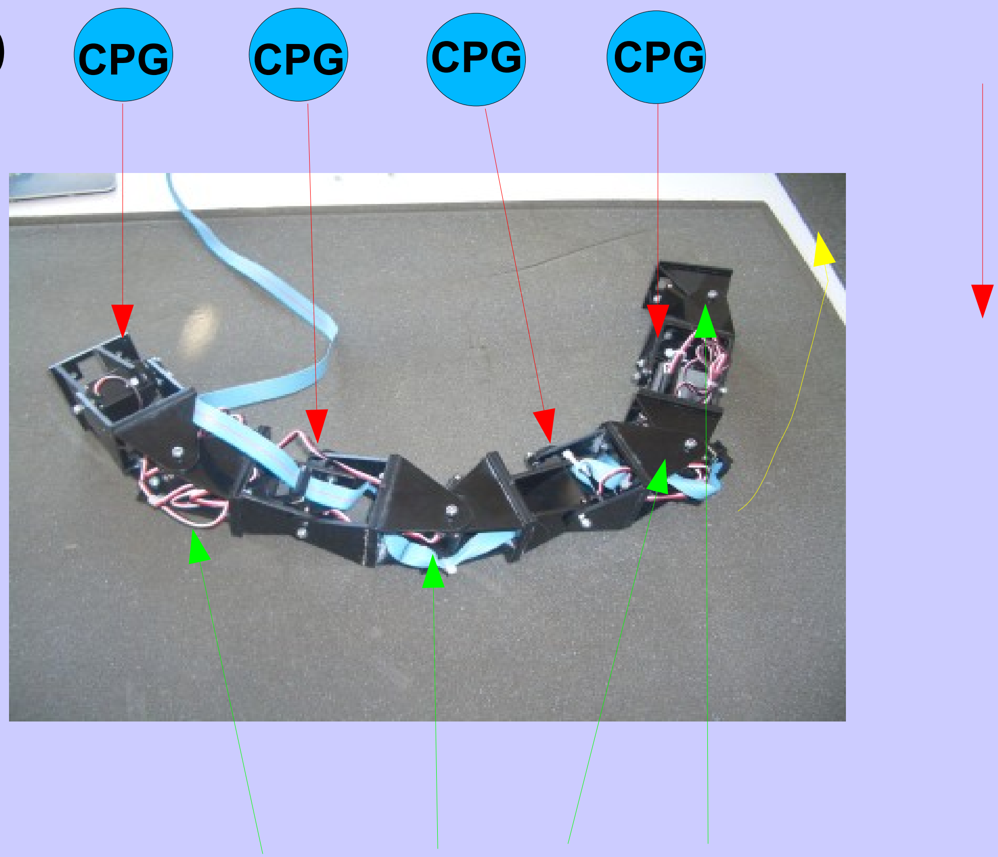
Chain robot 2D:
1D locomotion

- **Locomotion in 1D**: straight and arc trajectories



Fixed: 0 degrees

$\Delta\phi=120$

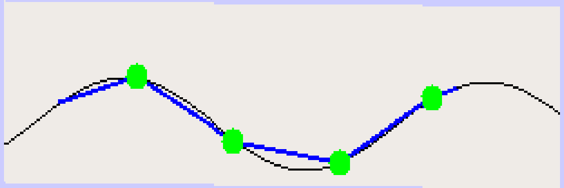


Fixed: 30 degrees

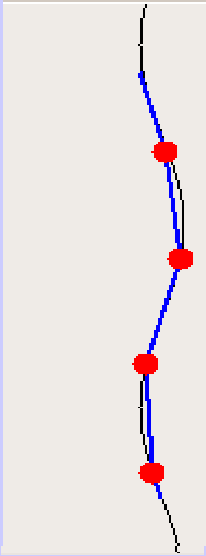
Chain robot 2D: 2D locomotion

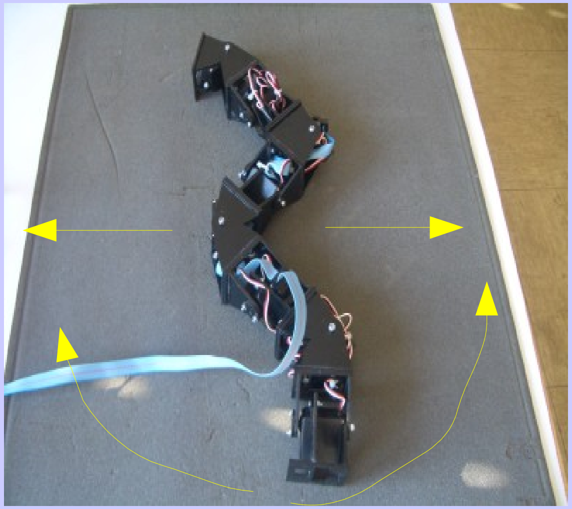
- **Locomotion in 2D**: Lateral shift and rotating

Horizontal wave



Vertical wave

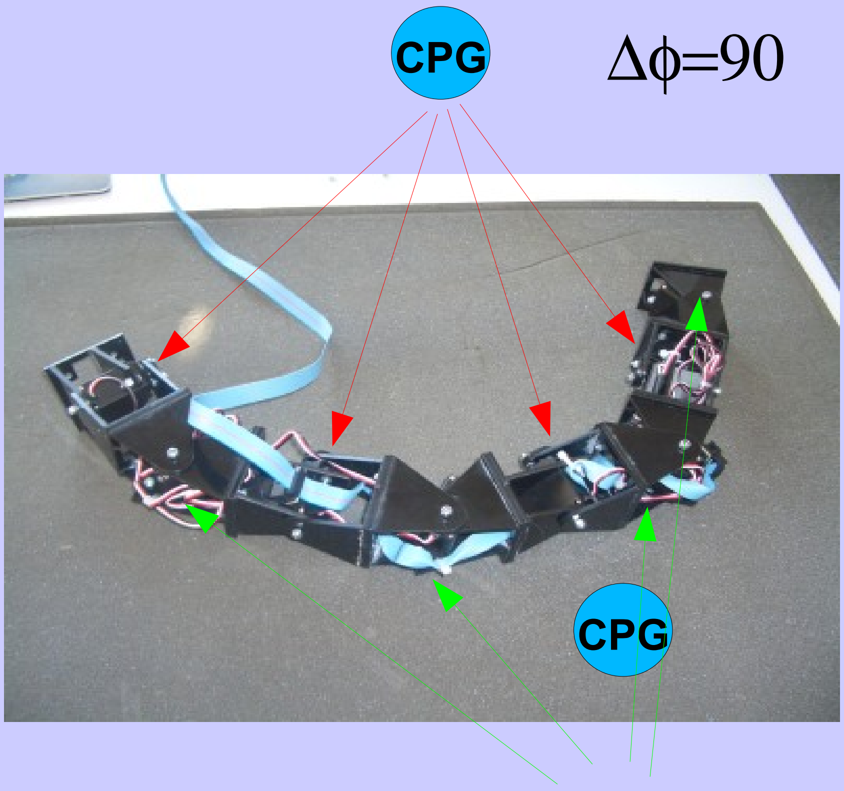




- $\Delta\phi=90$ → Shift right
- $\Delta\phi=-90$ → Shift left
- $\Delta\phi=0$ → Anti-clockwise rotation
- $\Delta\phi=180$ → Clockwise rotation

Chain robot 2D: Lateral rolling

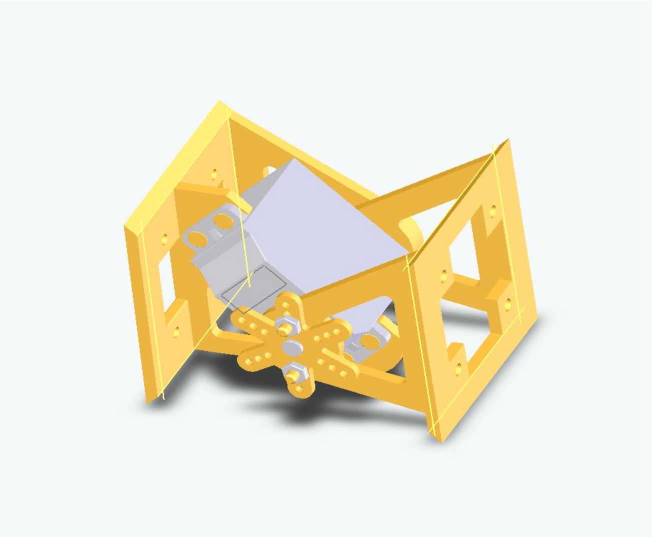
- Two CPGs are used for vertical and horizontal modules
- The phase difference between them is 90 degrees
- The robot rotates about its body axis

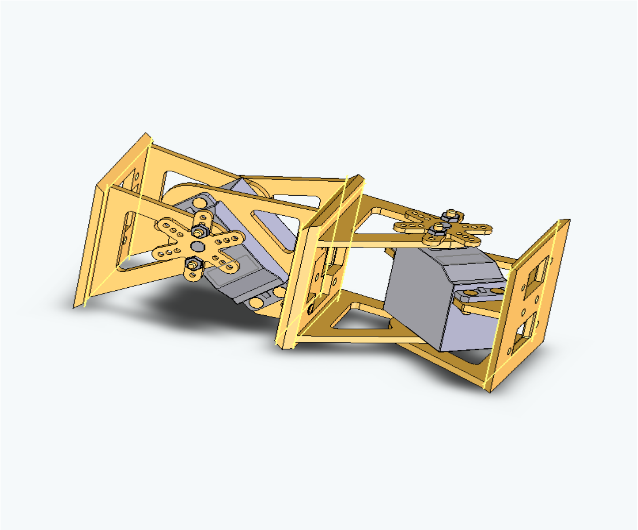


Demo

Future work (I)

- We are designing a new module (GZ2)

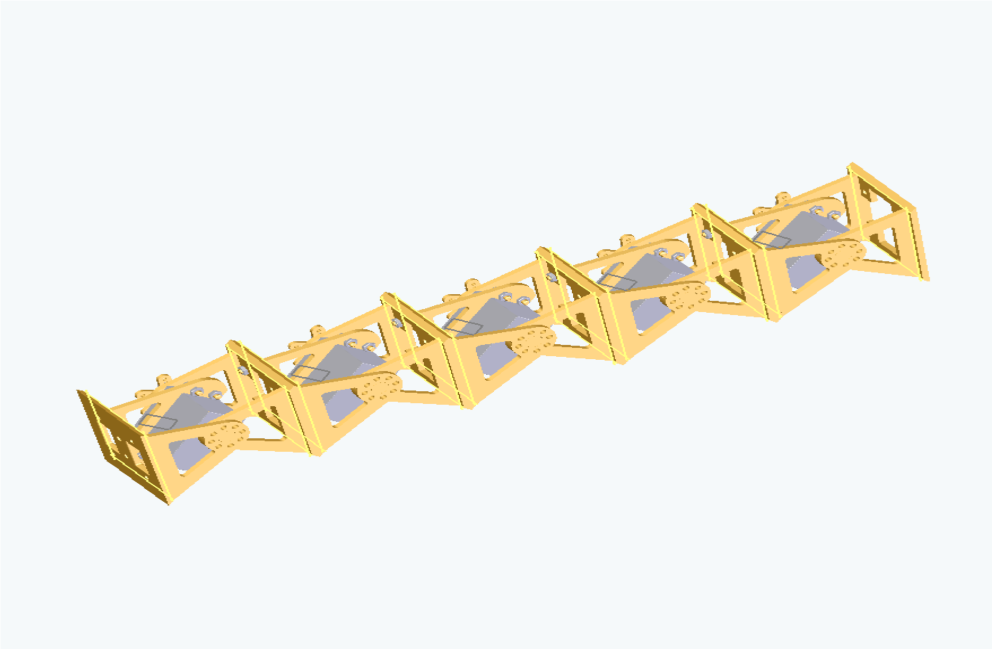




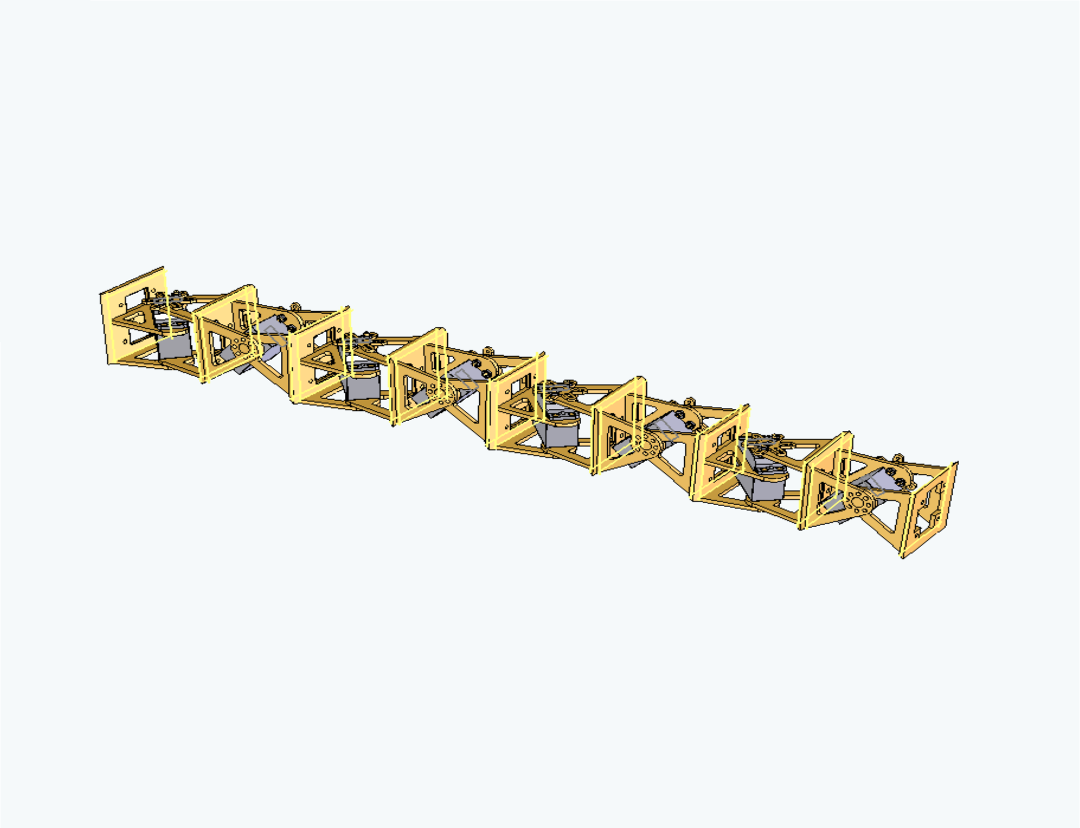
- The servo is more powerful
- It is stronger: made of aluminium
- It has four connection plates

Future work (II)

• **Caterpillar configuration:**



• **Snake configuration:**

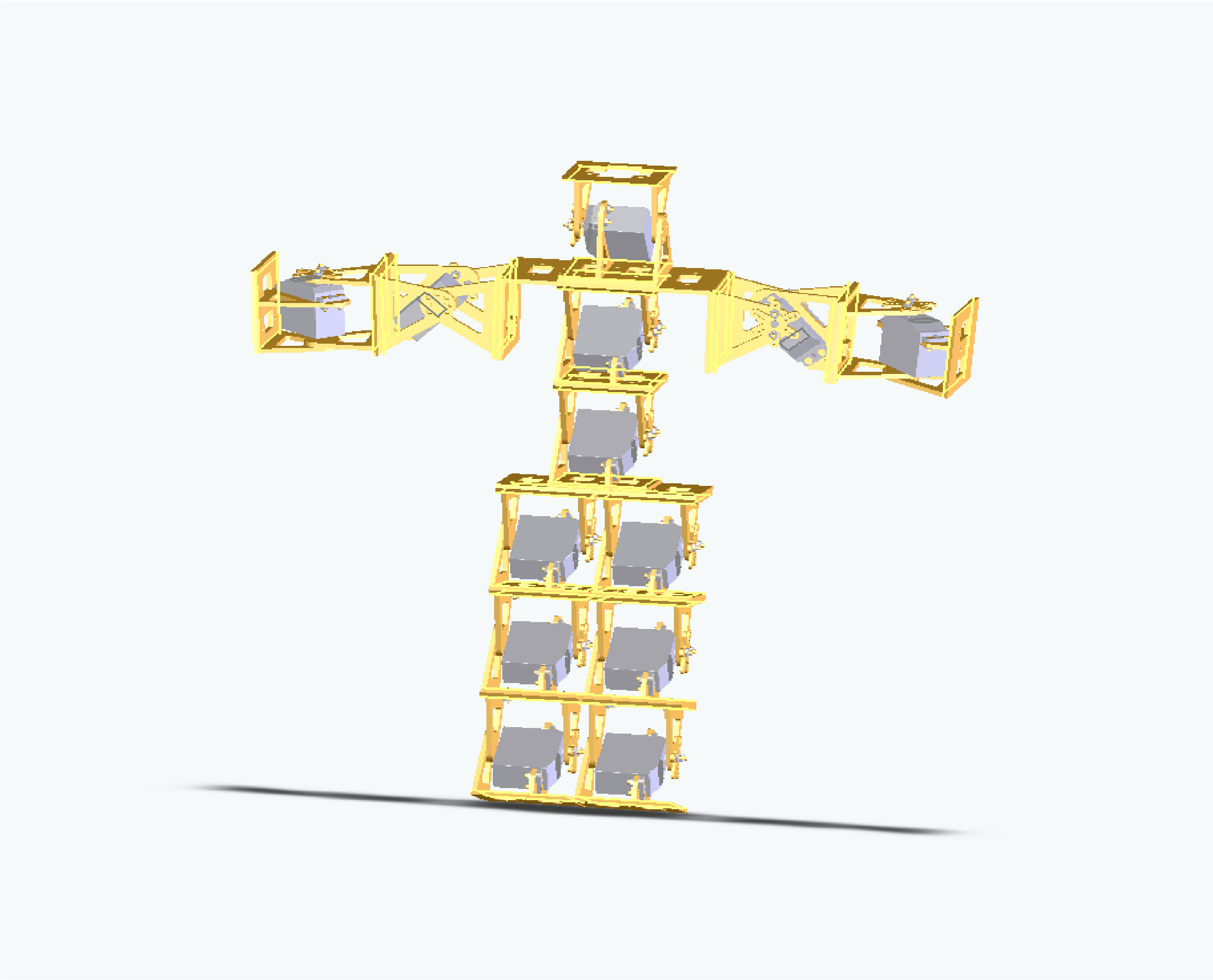


Future work

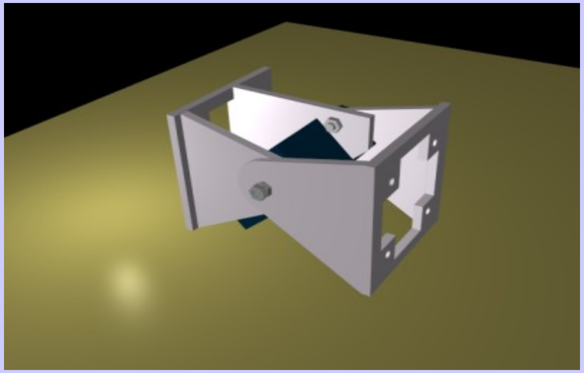
- 4 Leg configuration

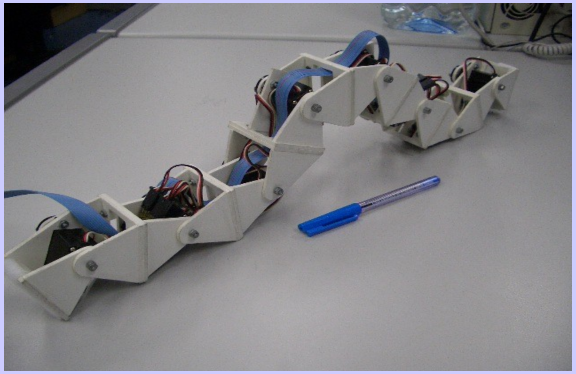
Future work

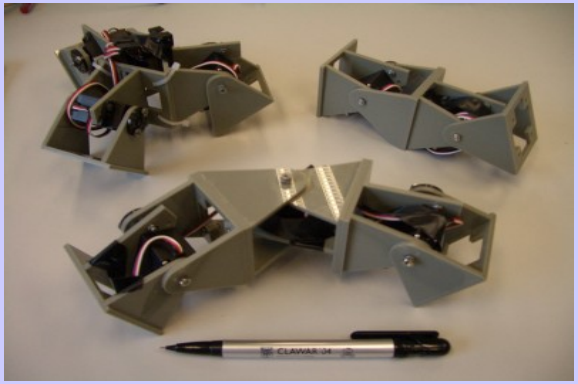
- **Humanoid configuration**



Modular robotics and locomotion







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