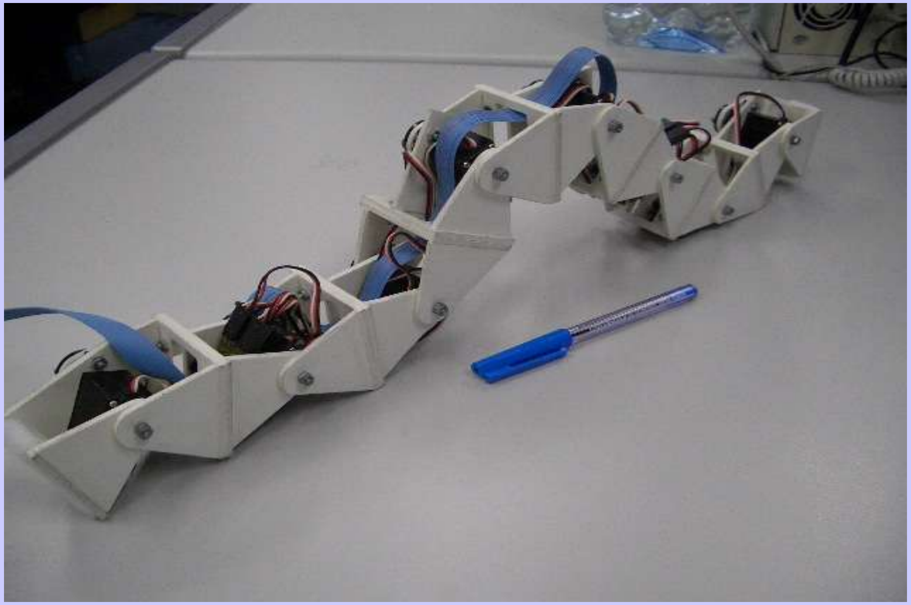
Locomotion of a Modular Worm-like Robot using a FPGA-based embedded MicroBlaze Soft-processor



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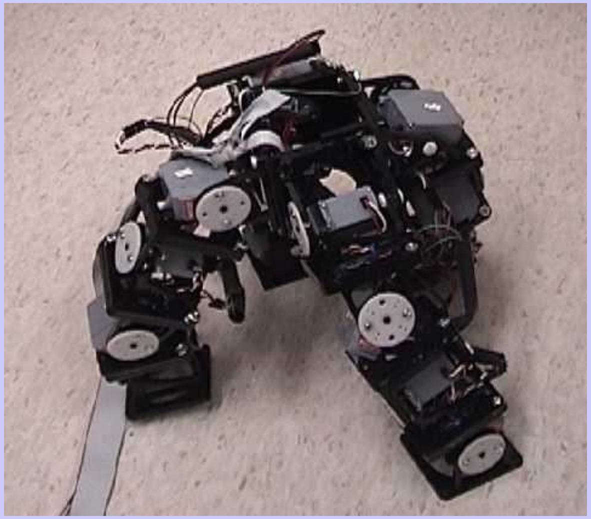
Introduction (I): Modular reconfigurable Robotics

- Started in 1994 by Mark Yim
- It concentrate on the construction of robots composed of modules
- The design is focused on the modules, not the whole robot
- Modules are capable of attach and detach one to each other
- Therefore, the shape of the robot changes



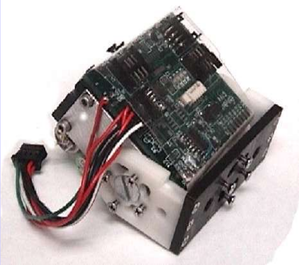
Introduction (II): Polybot

- One of the most advanced systems
- Designed at Palo Alto Research Center (PARC)
- Now working on the third generation of modules

G1

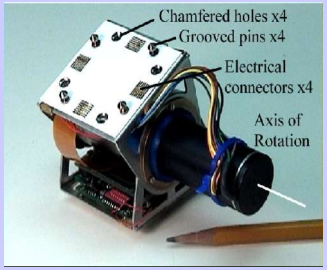
- No sensors
- Electronic and power outside
- Servo
- No self-reconfigurables

G1.4



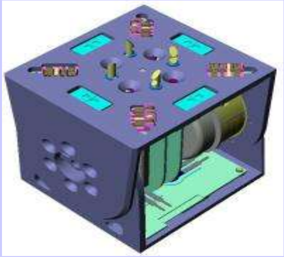
- **Electronic and power inside**
- 8-bit microcontroller
- Servo
- No self-reconfigurables

G2



- DC Motor
- **CPU: Power PC**
- 1MB RAM
- CAN Bus
- **Self-reconfigurable**

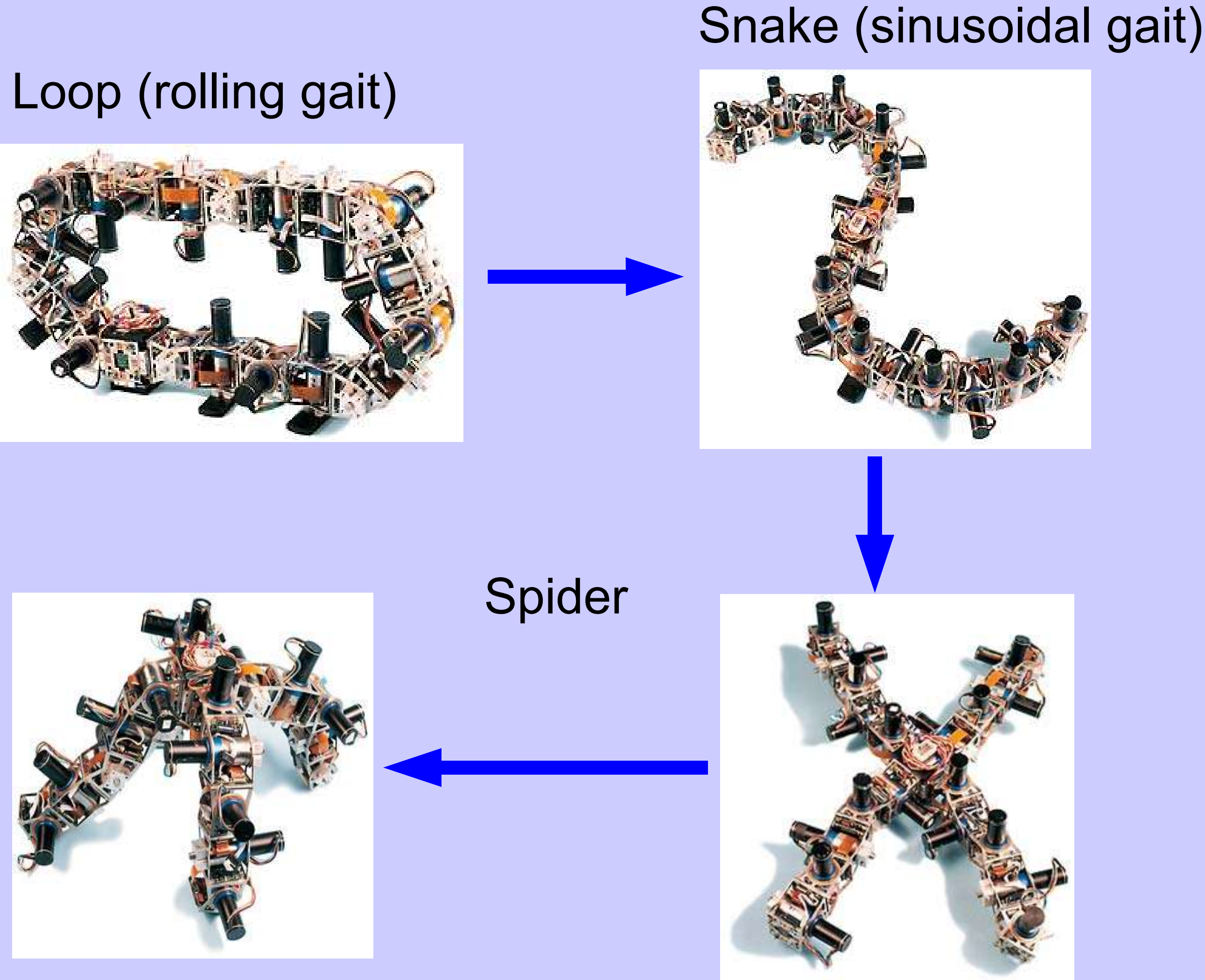
G3



- **In development**
- More sensors
- **5x5x4.5mm**

Introduction (III): Modular reconfigurable Robotics

- An example of reconfiguration (Polybot)



Loop (rolling gait)

Snake (sinusoidal gait)

Spider

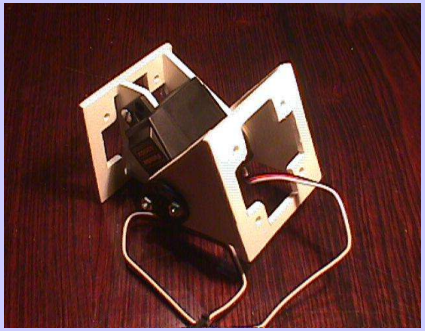
Introduction (IV): Main objetives

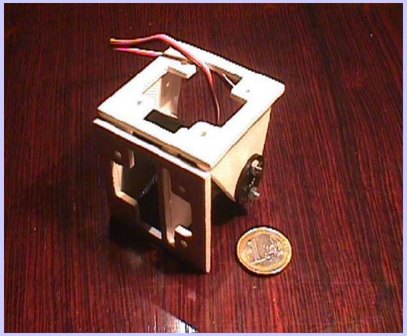
- ...An additional step on modularity is the use of FPGA technology instead of a conventional microprocessor chip.

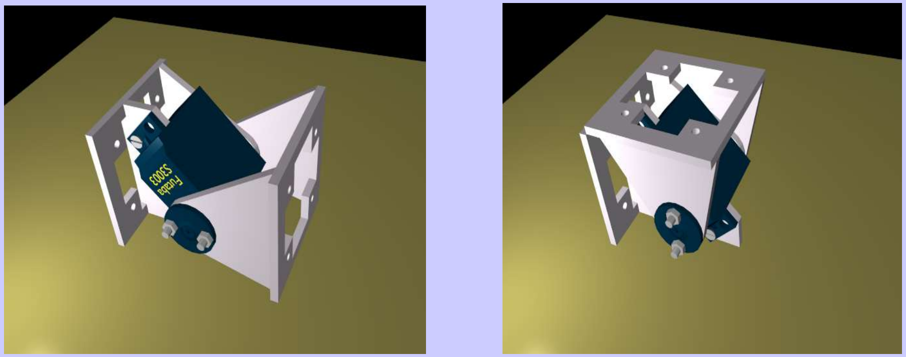
- It gives the designer the possibility of implementing new architectures, faster control algorithms or dinamically modify the hardware to adapt it to a new environment

- We are just starting to research on this area
- We have designed the simplest kind of modular robot, composed of 8 equals linked modules
- The control system is centralized
- The locomotion controller is embedded into an FPGA

Mechanical description







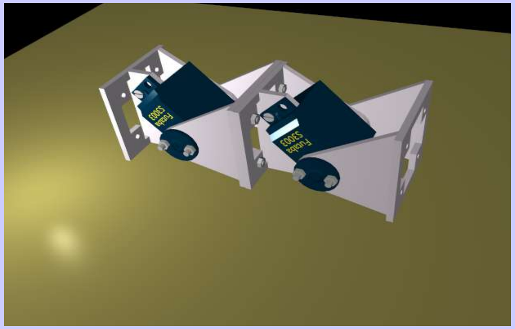
CAD rendering

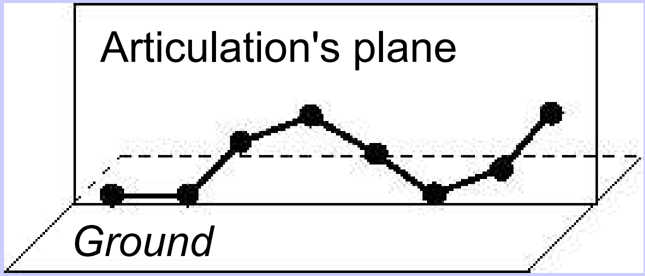
- Y1 Modules
- Based on G1 Polybot modules
- Simple and cheap
- No sensors
- One degree of freedom, actuated by a servo

Material: PVC
Dimensions: 52x52x72mm
Weight: 50gr
Rotation Range: 180 degrees

Mechanical description(II)

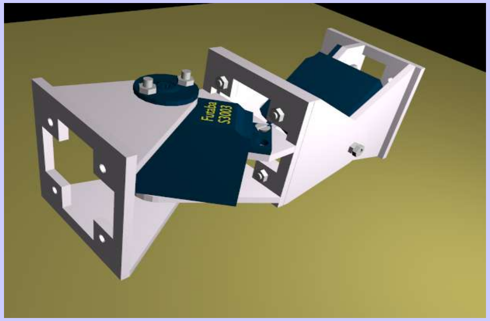
- Y1 Modules can be connected in two different ways:
  - Connection in phase

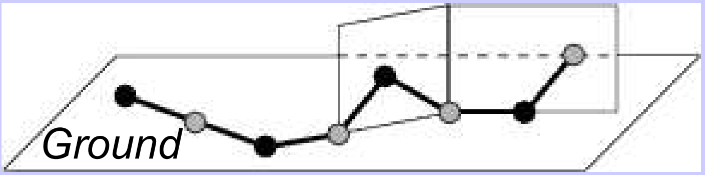




Articulations rotate on the same plane, perpendicular to the ground

  - Connection out of phase

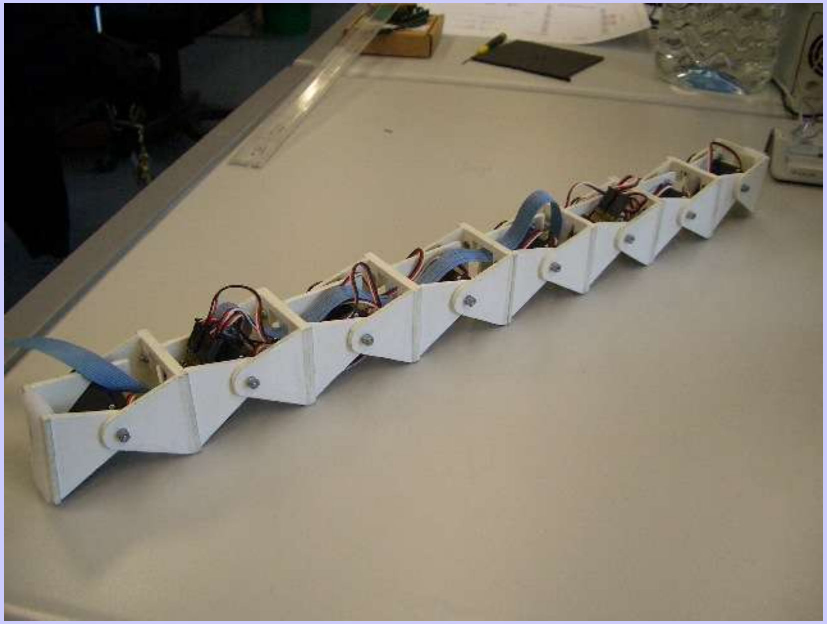


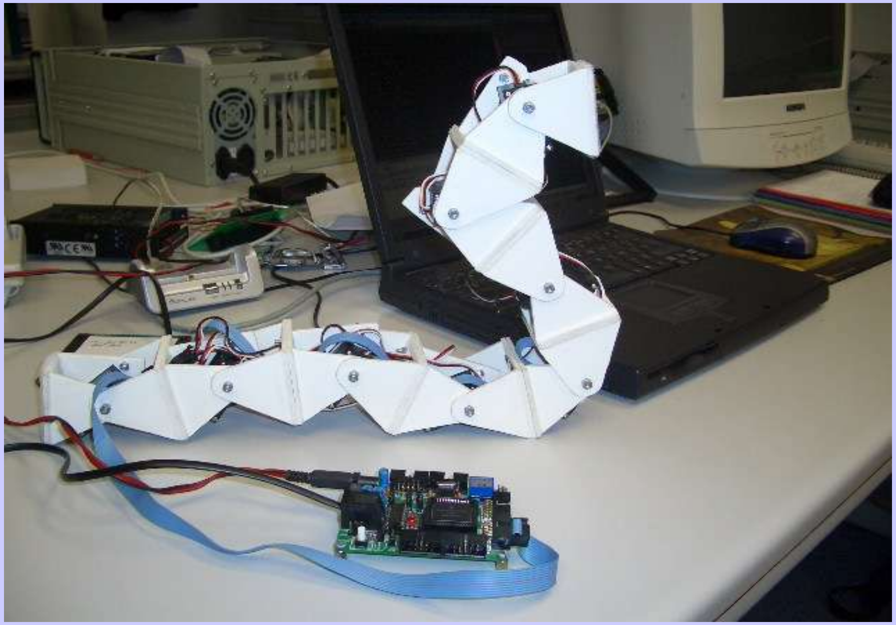


Articulations rotate on different planes

Mechanical description(III)

- The robot designed consist of 8 Y1 modules connected in phase



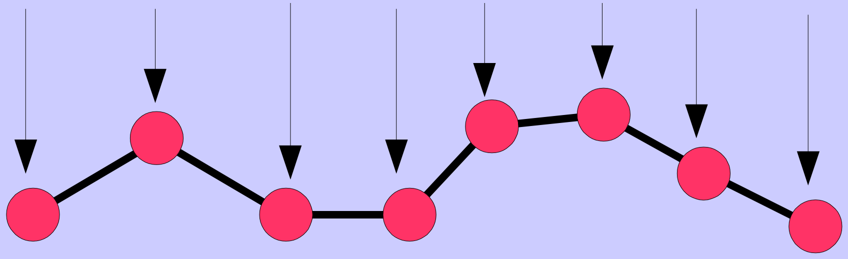


- It is very chep and easy to construct
- Electronic and power supply are off-board
- Locomotion is restricted to a straight line

Locomotion(I)

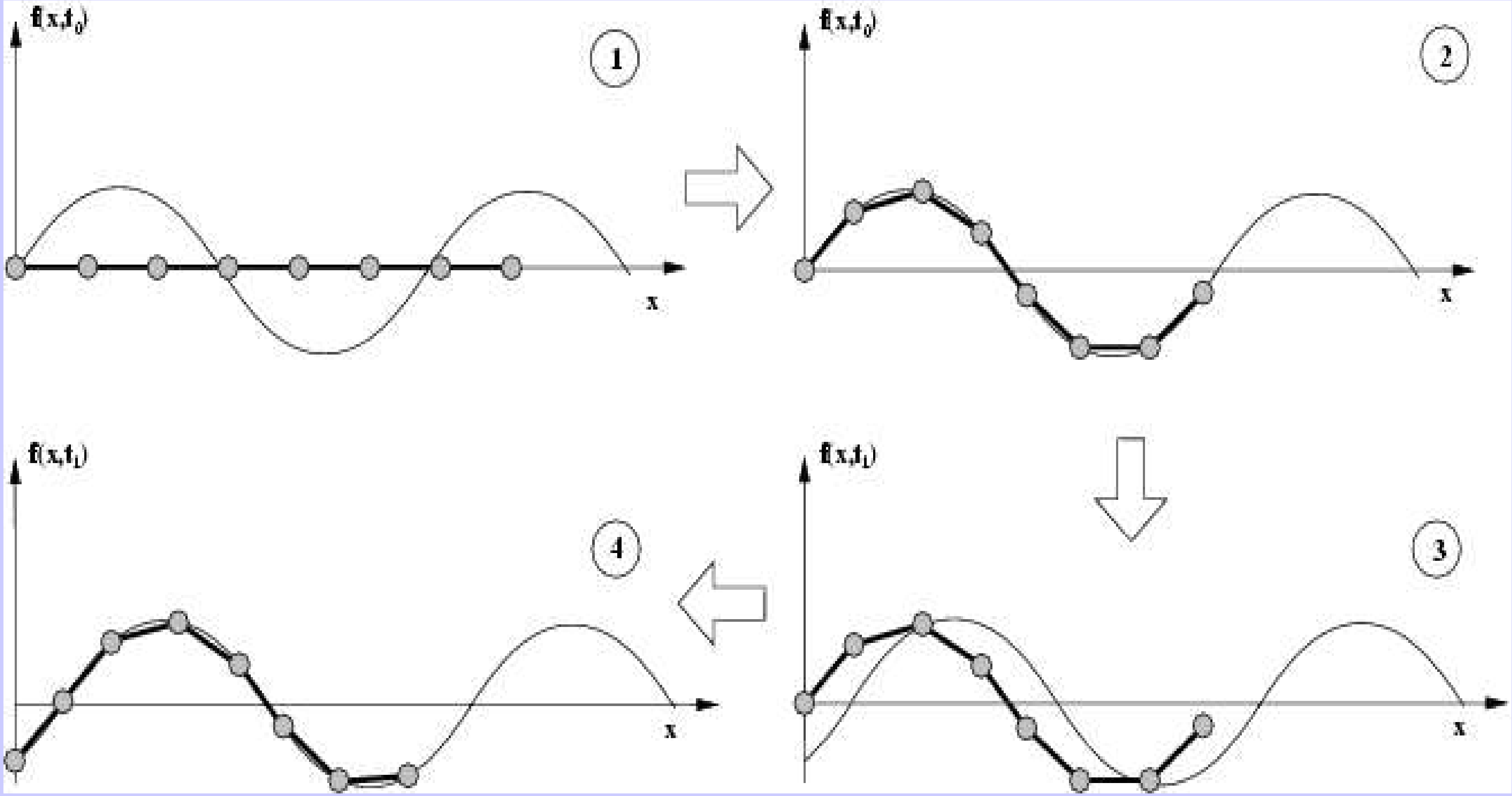
- Locomotion is achieved by the propagation of waves that traverse the worm, from the tail to the head
- Gait control tables are used
- Each row defines the position of the articulations at an instant

1	2	3	4	5	6	7	8	
[-19	-9	24	-4	-22	17	12	-18]	→ Instant t1
[-17	-14	21	4	-25	11	19	-15]	→ Instant t2
[-12	-20	18	11	-25	3	23	-7]	→ Instant t2
			.					.
			.					.
								.
[21	0	-23	12	17	-21	-6	22]	
[19	9	-24	4	22	-17	-12	18]	→ Instant tn



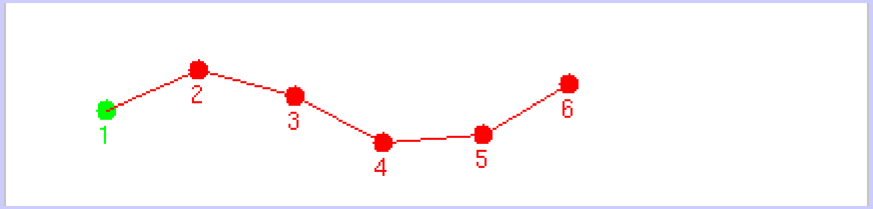
Locomotion(II)

- Algorithm for automatic generation of control tables:



Locomotion(III)

- **RESULT: We obtain a control table that makes the robot move**
- An example sequence follows:

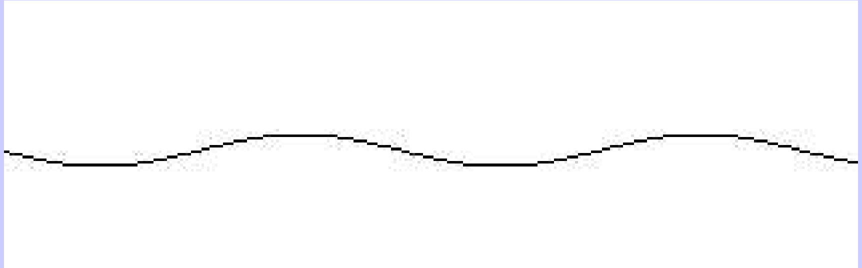


- we can generate movements based only on the wave parameters

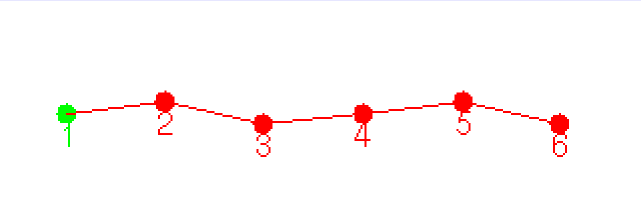
Changing the kind of wave and its parameters, different locomotion movement are achieved

Locomotion(IV)

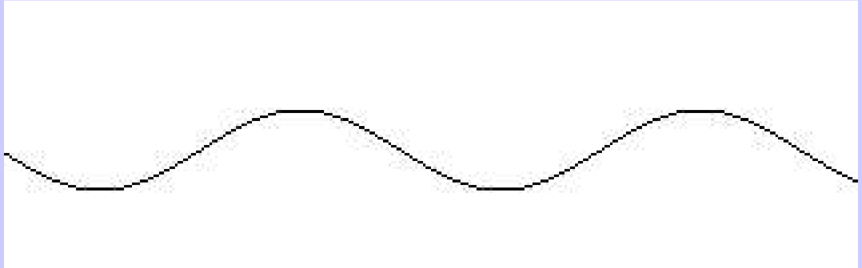
Low amplitud wave



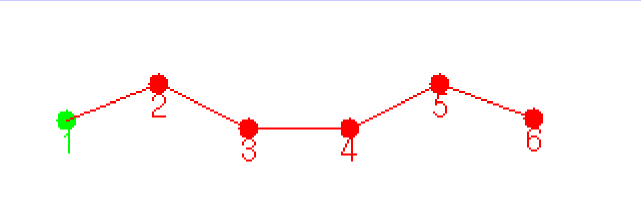
Ex. Crawling through a tube



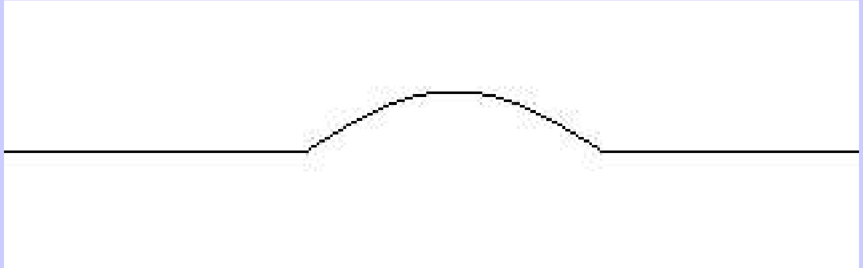
Higer amplitud wave



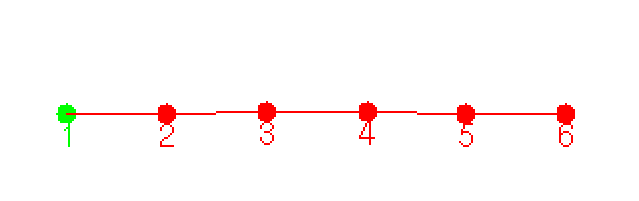
Ex: crossing over an obstacuble



semi-sinusoidal wave



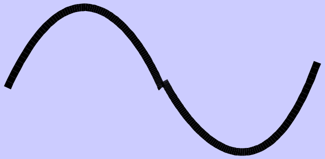
Ex: caterpillar locomotion

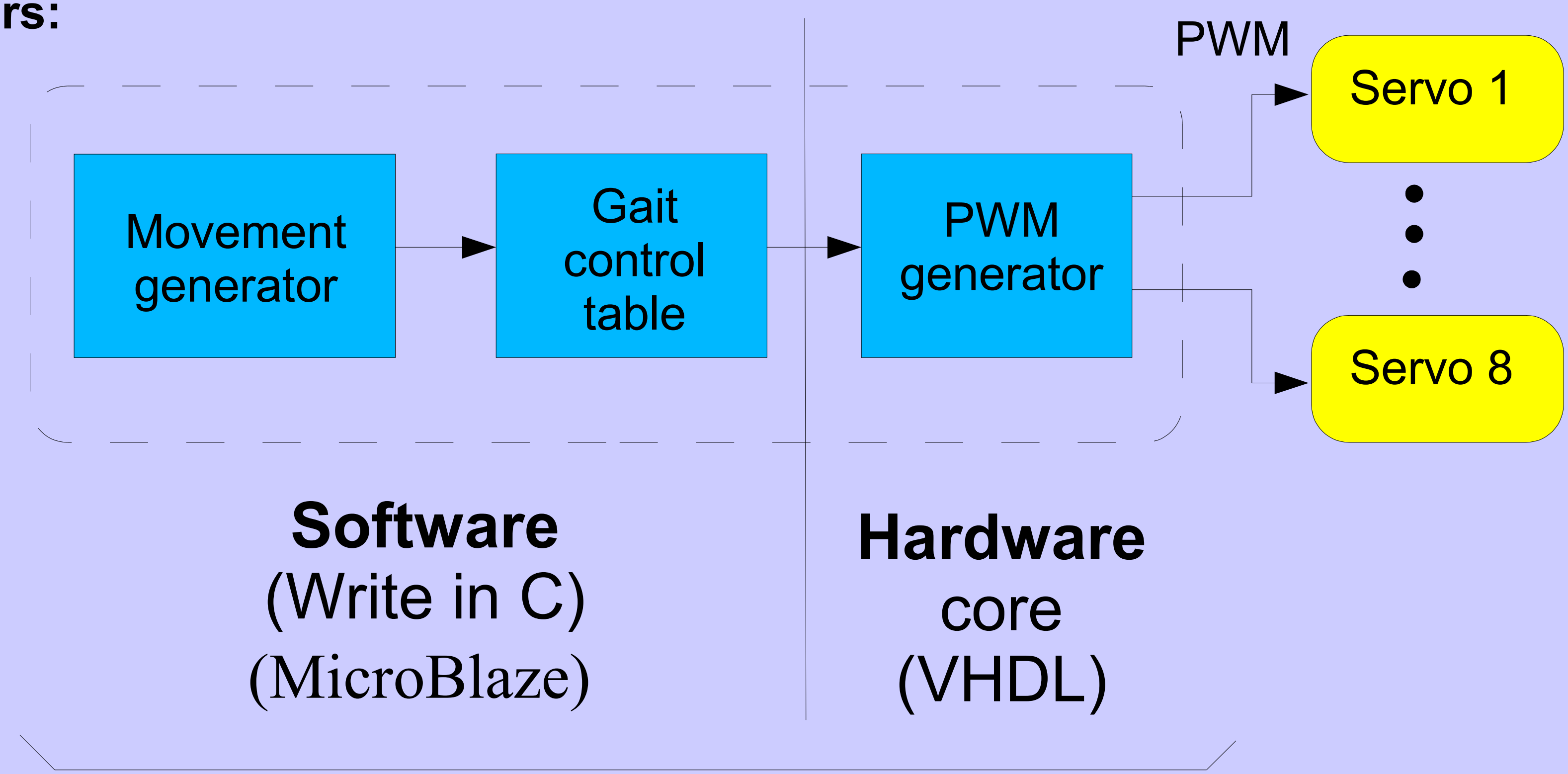


Locomotion controller(I)

Wave parameters:

- Wavaform
- Amplitude
- Wavelength





PWM

Movement generator

Gait control table

PWM generator

Servo 1

Servo 8

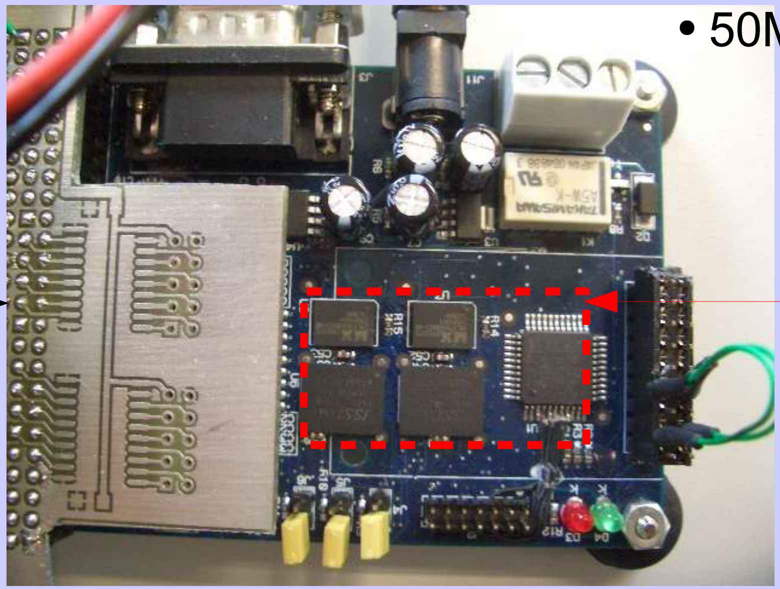
Software
(Write in C)
(MicroBlaze)

Hardware
core
(VHDL)

Spartan IIE400

Locomotion controller(II)

- **MicroBlaze**
  - 32 bit soft-processor, created by Xilinx
  - Soft-processors are written in VHDL. You can design your own hardware cores and connect them to the processor.
  - Follows the IBM Core Connect standard Bus, for the connection of peripherals
- **A comercial board is used:**



RS-232
(Software downloading)

Power Supply
5(v)

Expansion
board
(servo conection)

- FPGA: SpartanIIE400
- 2MB RAM
- 4MB Flash
- 50Mhz Clock

Implementation results

Implementations results for the synthesis of the locomotion controller into an **Spartan IIE400** Xilinx FPGA:

	Total	**Used**	**Available**
BRAM	14	8	43%
Slices (Area)	2352	1312	44%
I/O pins	146	10	93%

- The Microblaze and the pwm core occupy the 56% of the FPGA resources.
- **44%** of the resource of the FPGA **are avaiblable** for future improvements
- The Software is loaded into external RAM

Conclusions

- A modular worm-like robot has been constructed, capable of moving on a straight line
- Locomotion controller is based on gait control tables, generated automatically from the parameters of the wave applied
- The controller has been implemented on a FPGA

A versatile working platform has been developed for further research on Modular reconfigurable robotics in general and Worm-like locomotion in particular

FPGA makes Modular robots even more versatile. New architectures can be designed and new topics are introduced:

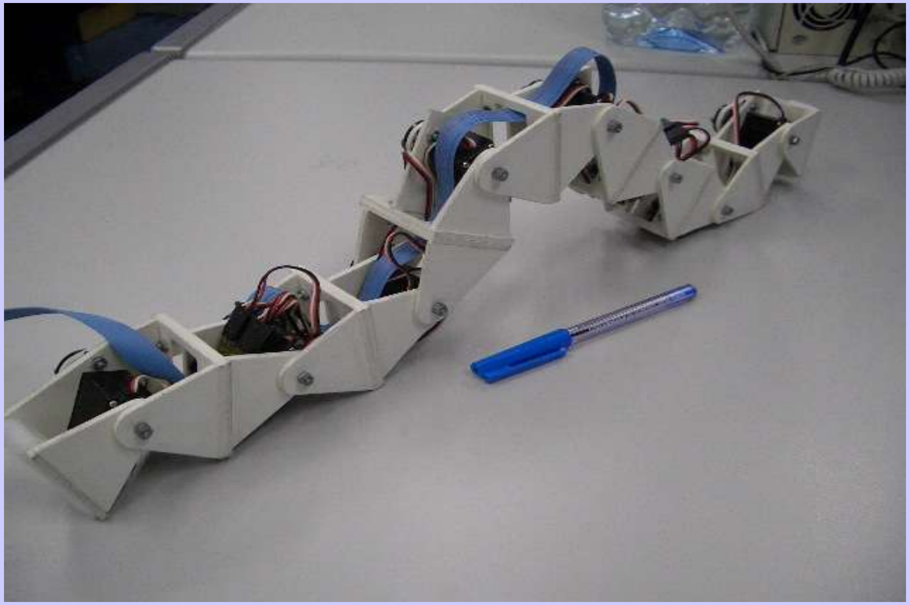
- Hardware/software codesign
- Dynamic Hardware reconfiguration

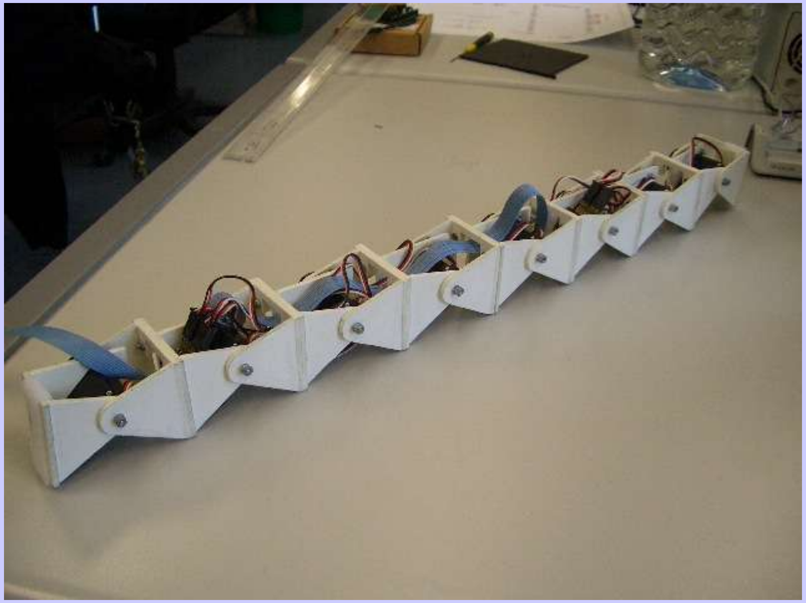
Future work

Currently, we have two research areas opened:

- **Modular reconfigurable Robotics:**
  - The design of a new generation of modules, with embedded FPGAs
  - The construction of new more complex robots, not just worm-like
- **Work-like robots locomotion**
  - Generation of Gait control tables using genetic algorithms, in order to determinate the optimal table that minimize the power consumption and maximize the stability and speed.
  - Locomotion on a plane, not just on a straight line

THANK you for your attention





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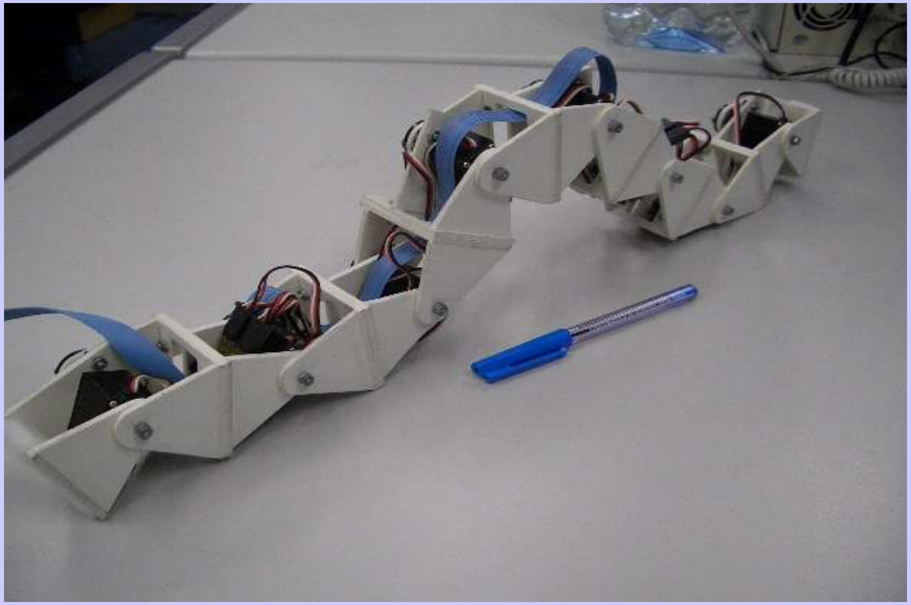

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Agenda

1. Introduction
2. Mechanical description
3. Locomotion algorithms
4. Locomotion Controller
5. Implementation results on FPGA
6. Conclusion and future work