

An Introduction To Modular Robots

- Introduction
- Morphology and Classification
- Locomotion
- Applications
- Challenges

Introduction

- Definition (Robot)

A robot is an artificial, intelligent, autonomous system with a physical electro-mechanical platform. It is a combined device with enough perception, manipulation capability or mobility to implement typical tasks. Its purpose is to release human beings of laborious tasks, and of working in a critical environment, or to provide services to improve our living standard. [H Zhang]

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- Definition (Modular Robot)

Modular self-reconfiguring robotic systems are autonomous kinematical machines with variable morphology. Beyond conventional actuation, sensing and control typically found in fixed-morphology robots, self-reconfiguring robots are also able to deliberately change their own shape by rearranging the connectivity of their parts, in order to adapt to new circumstances, perform new tasks, or recover from damage.[Wikipedia]

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Introduction

- Structure
 - Few types of building blocks w/ uniform IF:
 - Mechanical forces
 - Electrical power
 - Communication

Introduction

- Structure
 - Few types of building blocks w/ uniform IF:
 - Mechanical forces
 - Electrical power
 - Communication
 - Some primary structured blocks:
 - Gripper
 - Feet, Wheel
 - Sensor, e.g. Camera
 - Energy storage, payload

Introduction

- Motivation And Inspiration
 - Functional Advantage
 - Potentially more robust
 - Morphological adaptive
 - Self-repair (intra + inter robot)
 - Economic Advantage
 - Lower overall costs by making complex robots out of few mass produced modules

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Morphology and Classification

- General Classification
 - Chain topology
 - Lattice topology
 - Hybrid or Self-Reconfigurable

Morphology and Classification

- General Classification
 - Chain topology
 - Connected in a string or tree topology
 - Can fold up to become 3D
 - Strict serial architecture
 - Very versatile but computationally difficult to represent and analyze
 - Lattice topology
 - Hybrid or Self-Reconfigurable

Morphology and Classification

- General Classification
 - Chain topology
 - Lattice topology
 - Connected in space filling 3D pattern
 - Control + Motion executed in parallel
 - Computational simpler
 - Scalable to complex systems
 - Hybrid or Self-Reconfigurable

Morphology and Classification

- General Classification
 - Chain topology
 - Lattice topology
 - Hybrid or Self-Reconfigurable
 - Chain + Lattice Topology
 - Adaptive to environment

Morphology And Classification

- Chain Topology
 - Pros
 - Easy to generate motion
 - Few actuators needed
 - Cons
 - Few connection possibility
 - Hard to self-reconfiguration

Morphology And Classification

- Lattice Topology
 - Pros
 - Easy self-reconfiguration
 - Possible to connect in different directions
 - Cons
 - Difficult to generate motion
 - Need of many actuators

Morphology And Classification

- Examples
 - PolyBot from Mark Yim
 - Chain self-reconfiguration system
 - Each module is roughly cubic shaped, with about 50 mm of edge length, and
 - has one rotational degree of freedom (DOF)
 - Features demonstrated many modes of locomotion
 - CKbotnew version with force torque sensors, whisker touch sensors, and
 - Infrared proximity sensors. [DEMO](#)

Morphology And Classification

- Examples (cont'd)
 - M-TRAN from Satoshi Murata et.al.
 - Two blocks (active/passive) and a link
 - Two parallel axes and six connectable surfaces
 - Both blocks have 90 degrees rotation
 - Mechanical connectors in active block
 - 4 CPUs in a Master/Slave-Architecture
 - Master CPU: Algorithm computation and communication
 - Slave CPUs: Motor/Connection control and sensor data
 - Virtual shared memory for inter-module communication
 - DEMO

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Locomotion

- Controlling Method

- Sinusoidal generators produce smooth movements
- Making the controller much simpler:

$$y_i = A_i \cdot \sin\left(\frac{2\pi}{T}t + \phi_i\right) + O_i$$

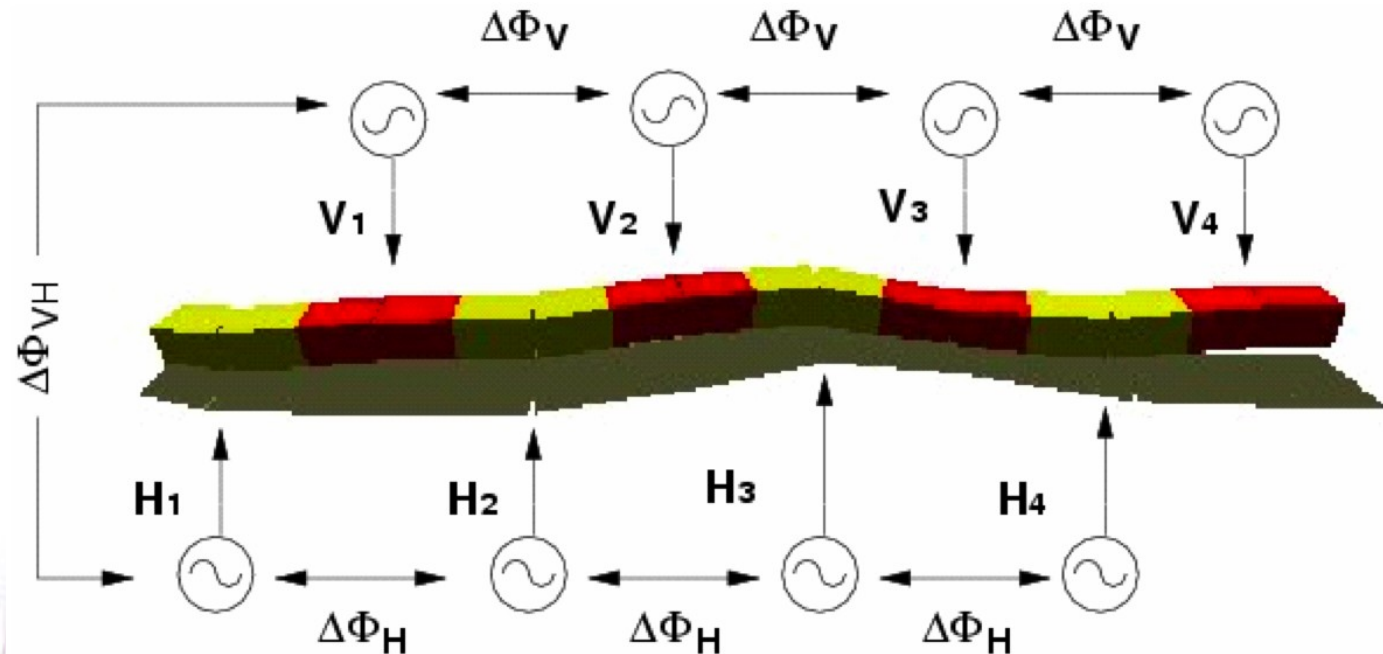
- y_i : Rotation angle of corresponding joint
- A_i : Amplitude
- T : Control period
- t : time
- ϕ_i : Phase
- O_i : Initial offset.

DEMO1 DEMO2 DEMO3

Locomotion

- Controlling Method (cont'd)

- Horizontal +vertical groups (H_i and V_i)
- $\Delta\Phi_V$: Phase difference between two adjacent vertical modules
- $\Delta\Phi_H$: Phase difference between two adjacent horizontal modules
- $\Delta\Phi_{HV}$: Phase difference between two adjacent horizontal and vertical modules



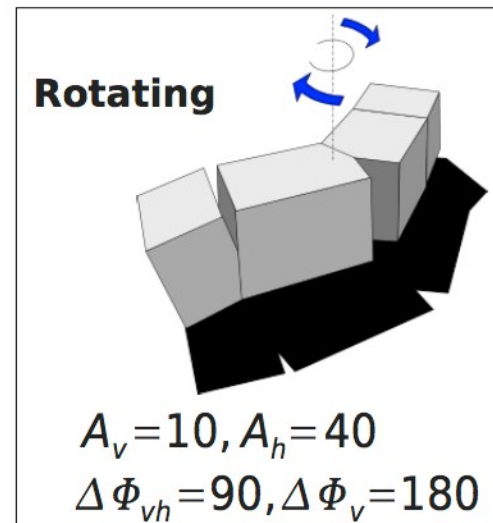
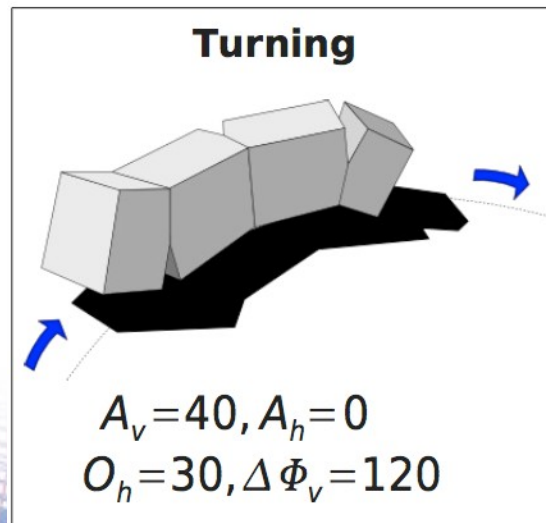
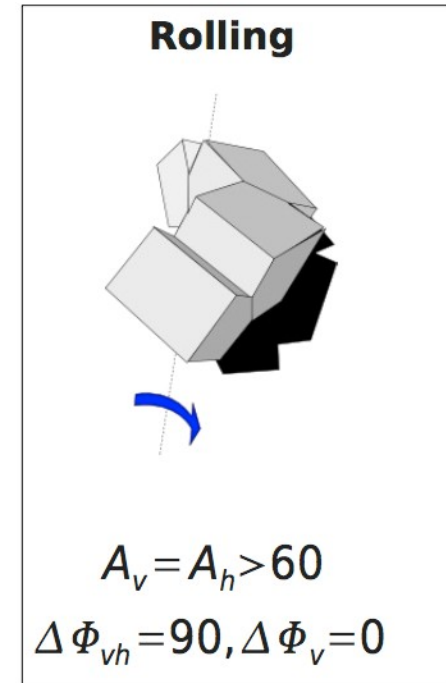
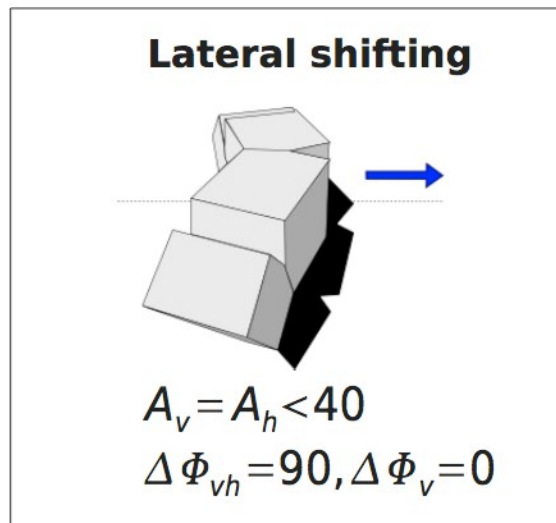
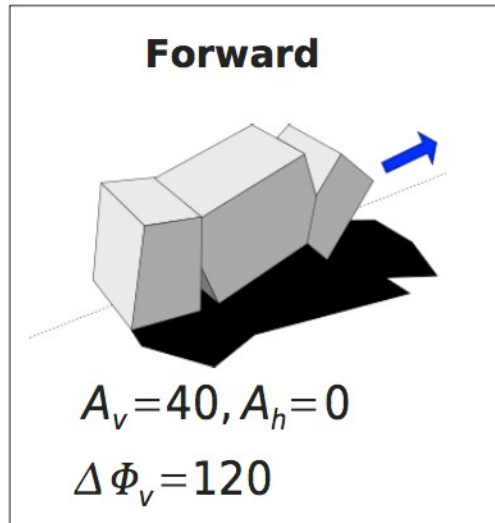
Locomotion

- Locomotion Capabilities
 - Linear gait
 - Forward and backward movement
 - Turning gait
 - Turn left and right; or the robot moves along an arc
 - Rolling gait
 - The robot rolls around its body axis
 - Lateral shift
 - The robot moves parallel
 - Rotation
 - The robot rotates around its body axis

DEMO

Locomotion

- Locomotion Capabilities - Summary



Locomotion

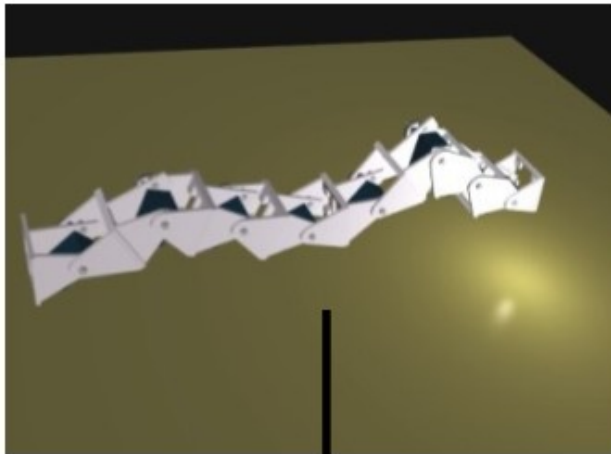
- Locomotion and Reconfiguration
 - Adaptive, M-TRAN II+III DEMO
 - Superbot DEMO
 - PolyBot turn'n'roll DEMO

Locomotion

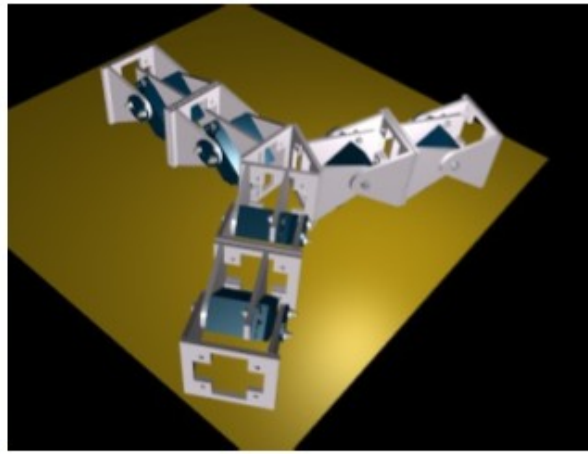
- Topology

Modular Robot classification

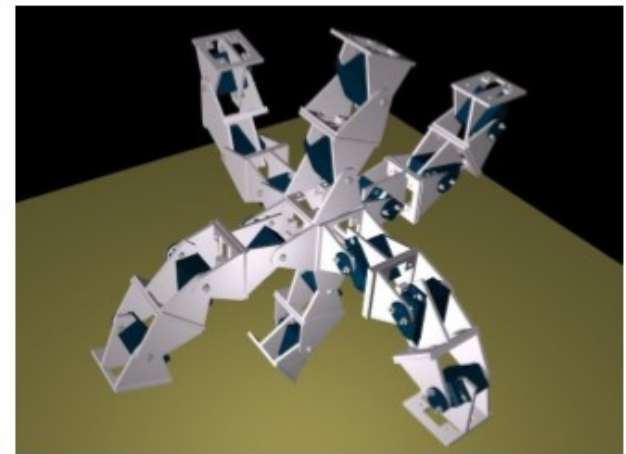
1D Topology



2D Topology



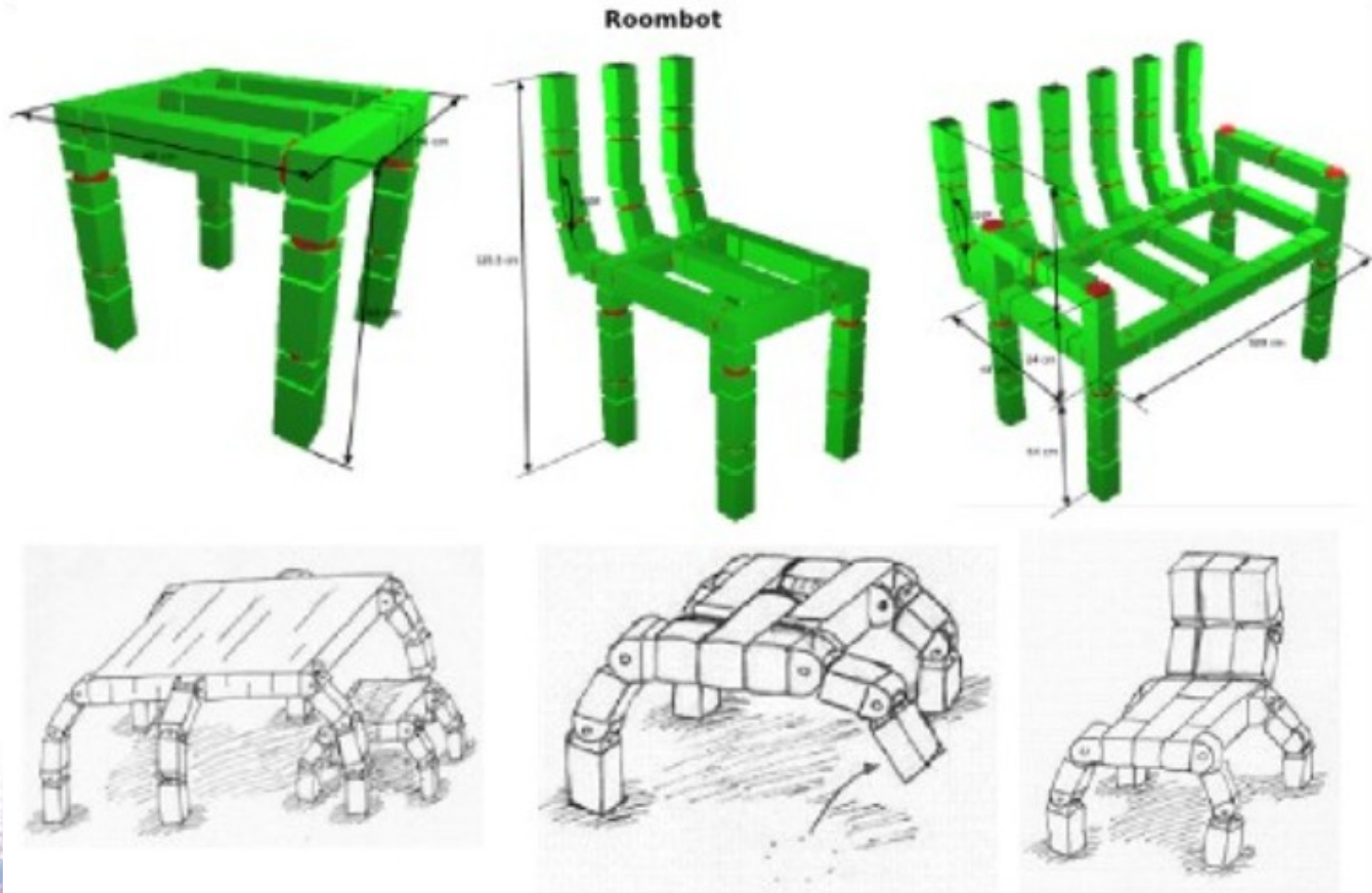
3D Topology



↓
Snakes Robots

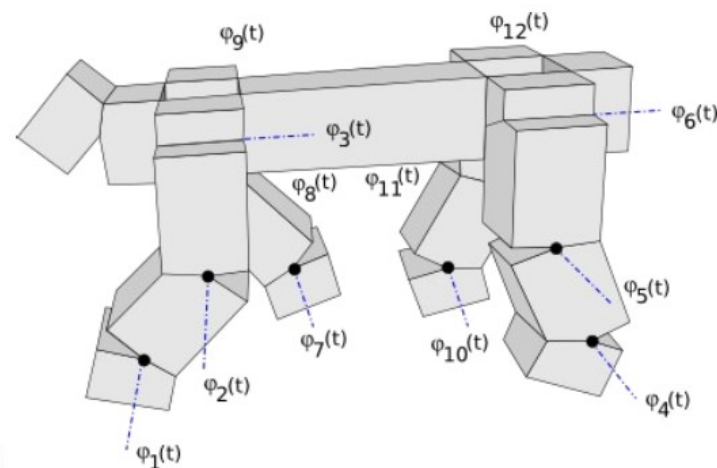
Locomotion

- Example
 - Self reconfigurable Furnitures with locomotion capabilities



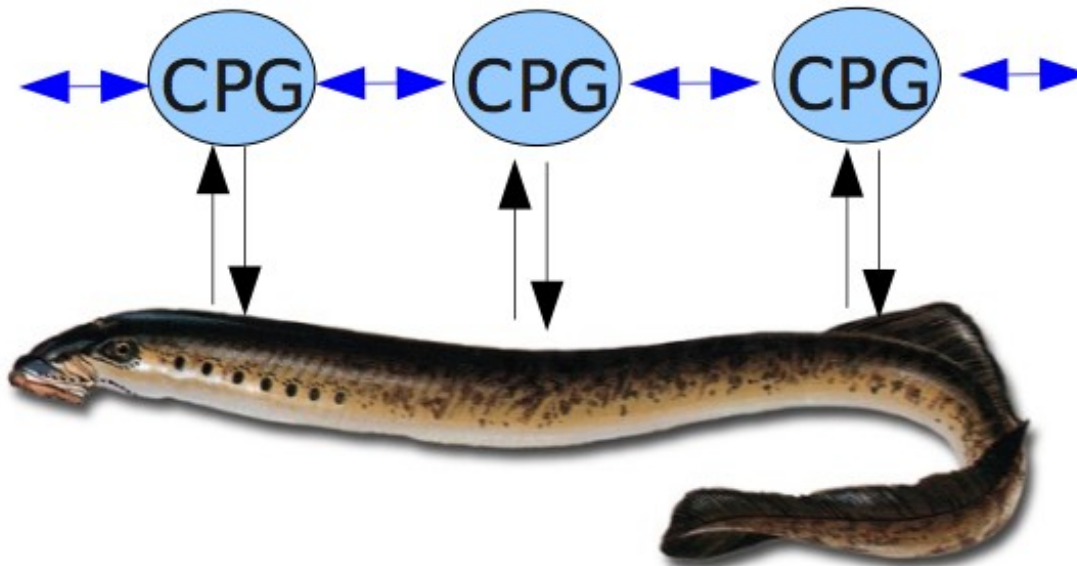
Locomotion

- Controller: Classic Approach
 - Calculation of the joint's angle to realize a gait $\varphi_i(t)$
 - Mathematical modeling
 - Con: Equations are only valid for specific morphology



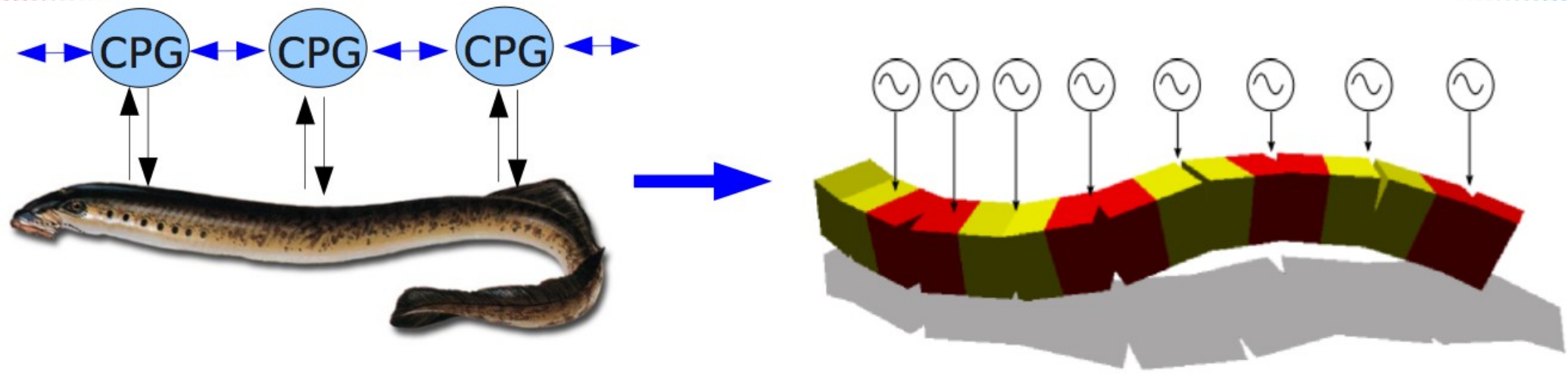
Locomotion

- Controller: Bio-inspired Approach
 - Central Pattern Generators (CPG)
 - Control rhythmic activities
 - e.g. lamprey, snake, earthworm



Locomotion

- Controller: Bio-inspired Approach (cont'd)
 - Sinusoidal oscillators
 - Pro: Few resources needed



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Applications

- Search and Rescue
 - Access dangerous areas
 - Access tight spaces
 - Exploration + Detection to support rescue mission

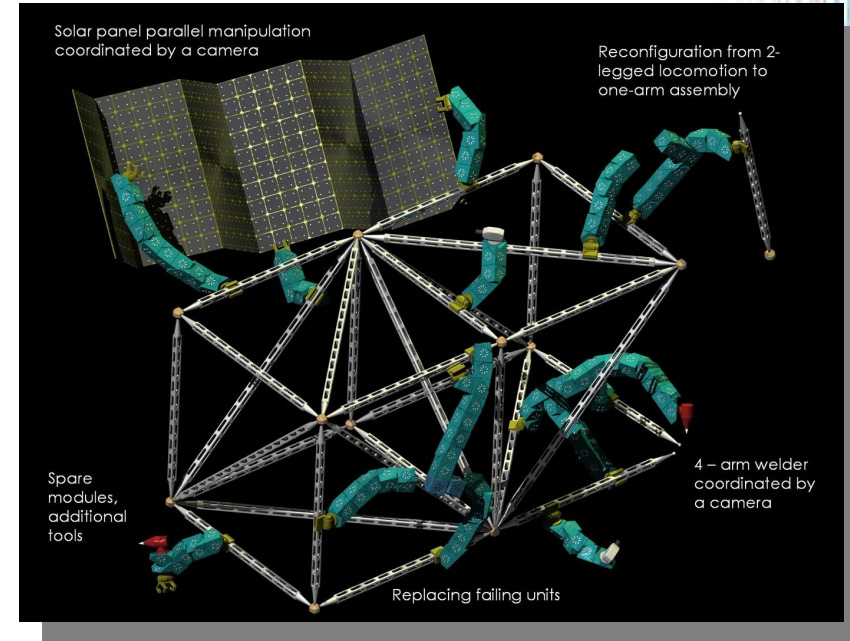
Applications

- Inspection of Tubes and Bridges
 - Narrow environment
 - Dirty environment
 - Flexible



Applications

- Space exploration
 - Long-term space missions
 - Self-sustainable + self-repair
 - Handle unknown tasks
 - highly volume and mass constrained
 - One type of robot for many tasks



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Challenges

- **Big Systems**

- Example: living cell as self-organizing modular system
- Today's systems: \ll 1000 modules
- Demonstration of such a system requires rethinking of key HW issues:
 - Binding mechanisms
 - Power distribution
 - Dynamics and vibrations
- New algorithms:
 - Account for noise,
 - Errors, failures
 - Changing connecting topologies

Challenges

- Self-Repairing Systems
 - Compromised system recovers from (serious) damage
 - Requires rethinking of algorithms + HW for:
 - Sensing + estimating global state
 - Reconfiguration from any initial state
 - Demonstrate self-assemble of (randomly) blown-up system or recover under certain percentage of faulty units DEMO

Challenges

- Self-replication and self-extension
 - Low-level modules or elementary components (raw material?) used to self-replicate
 - Improving system from environmental resources
 - Overcome complexity of machines building copies of themselves

References

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Thank You!