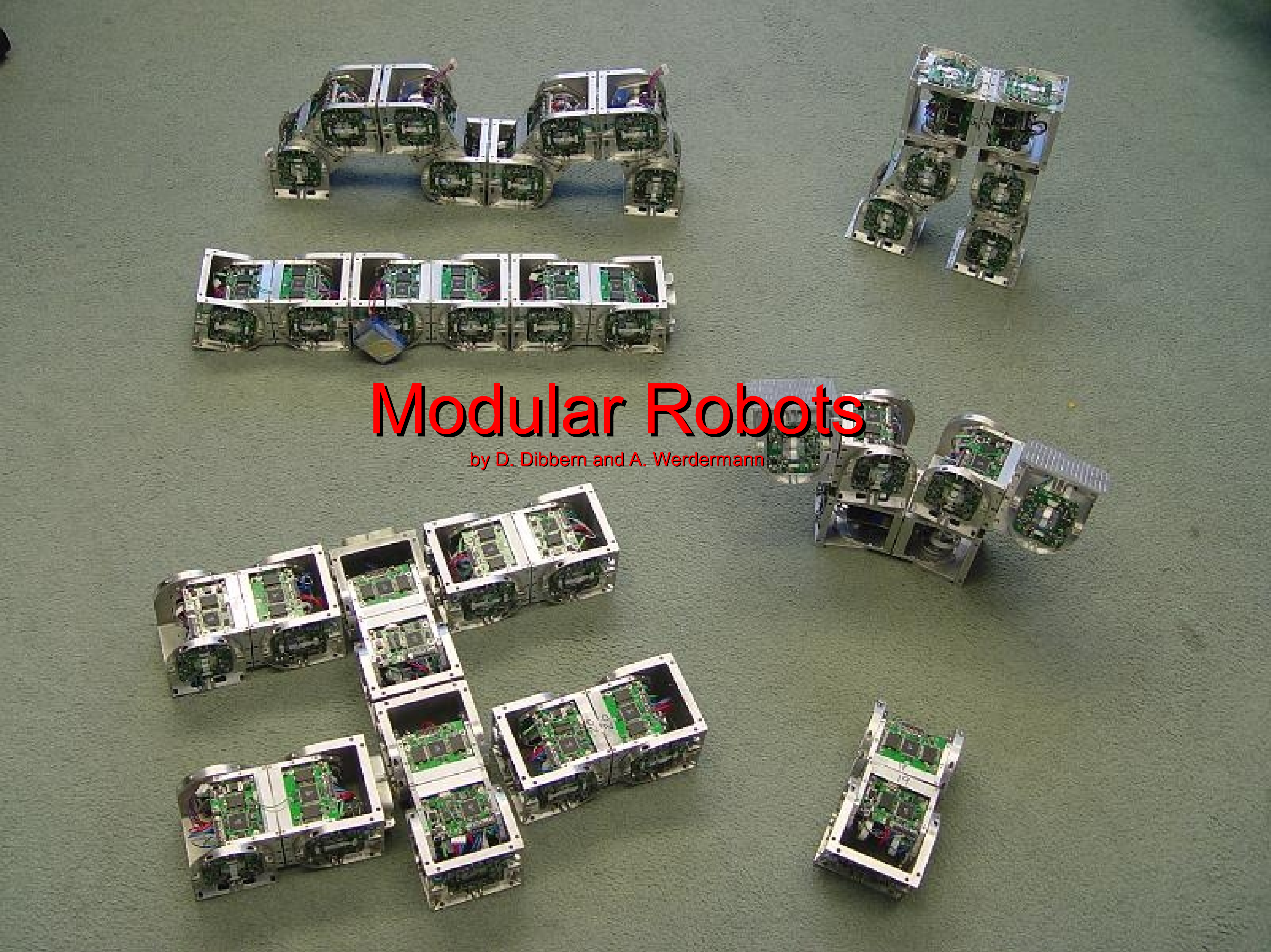
Modular Robots

by D. Dibbern and A. Werdermann



Introduction to modular robots

- Introduction
- Definition
- History
- General
- Research Challenges
- Future

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Wikipedia Definition

- Modular self-reconfiguring robotic systems or self-reconfigurable modular robots are autonomous kinematic 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.

Our Own Definition

- A modular robot is a compound of several modules with the intention of solving a particular task that it was designed for. The robot only exist for as long as his current structure is able to solve his tasks. Otherwise it may change its structure to be able to solve a different task or simply disband and create one or more new robots or be part of a larger robot.

History Overview

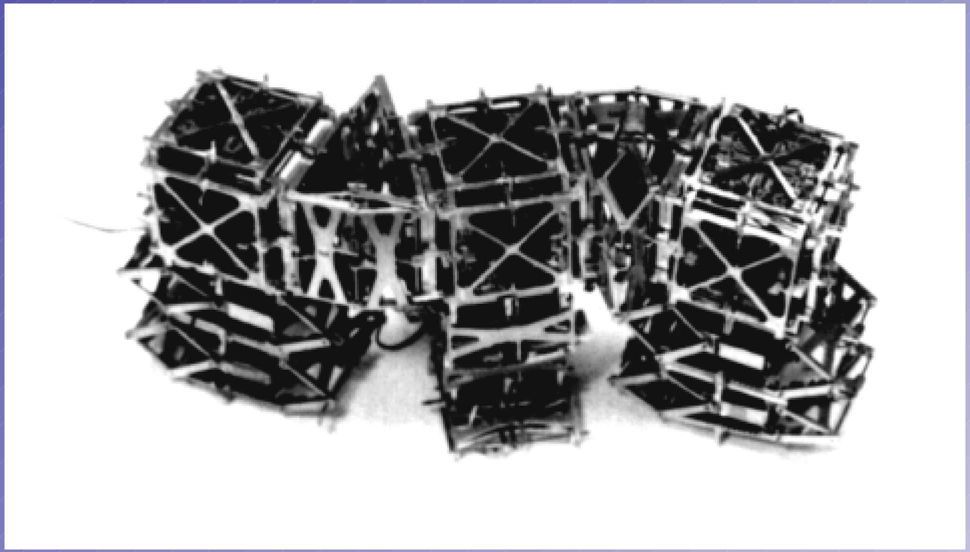
- CEBOT (1988, Tsukuba)
- PolyPod (1993, Stanford)
- Molecule (1998, Dartmouth)
- Telecube (1998, PARC)
- Crystal (1999, Dartmouth)
- PolyBot G2 (2001 and earlier, PARC)
- ATRON (2003, Denmark)
- M-TRAN Series (2005 and earlier, AIST)
- SUPERBOT (2004, USC)
- GZ-I (2006, Hamburg)

CEBOT (1988, Tsukuba)

- First modular robot
- Designed by Fukuda et.al.

PolyPod (1993, Stanford)

- 2 types of modules
- Build for locomotion research



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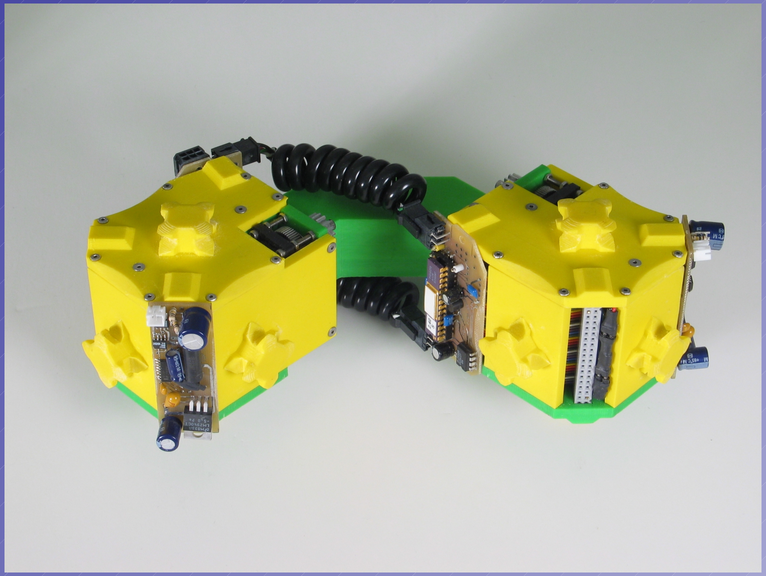
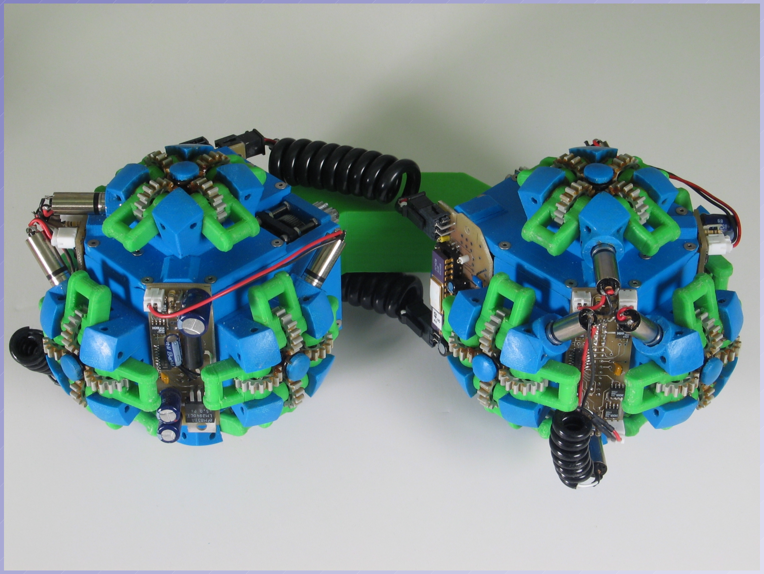
Molecule (1998, Dartmouth)

- 2 types of modules, male and female
- 2 atoms connected by a bond represent one module
- Locomotion by using self-reconfiguration





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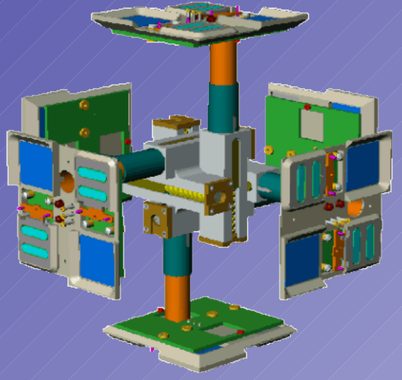
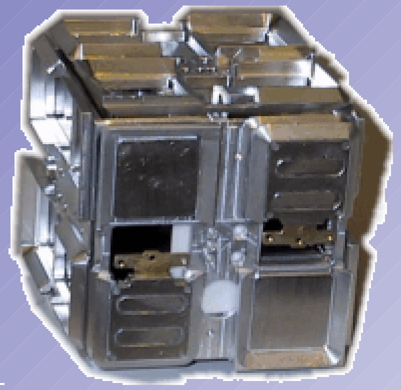
Telecube (1998, PARC)

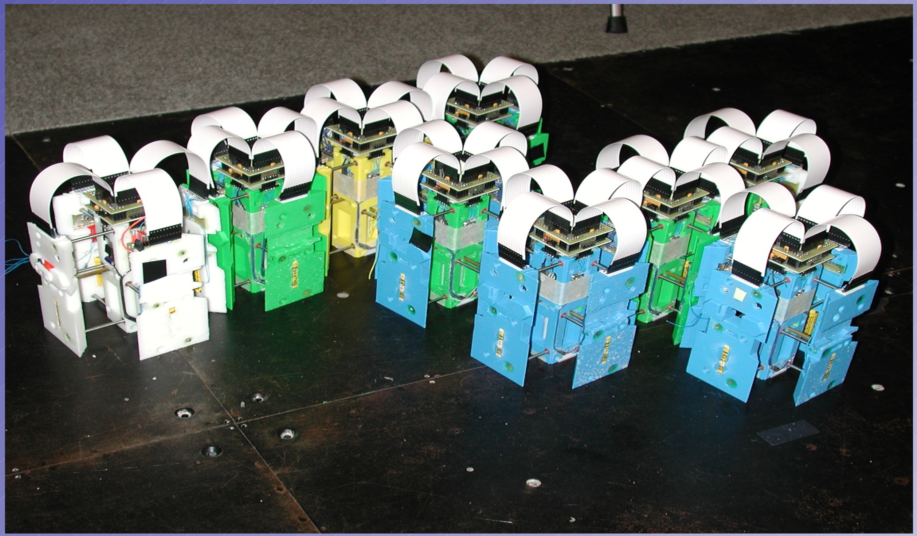
- 1 type of modules
- Cube-design
- Surfaces can be extended in 3D to transform into other shapes





Crystal (1999, Dartmouth)

- 1 type of modules
- Surfaces can be extended in 2D to transform into other shapes



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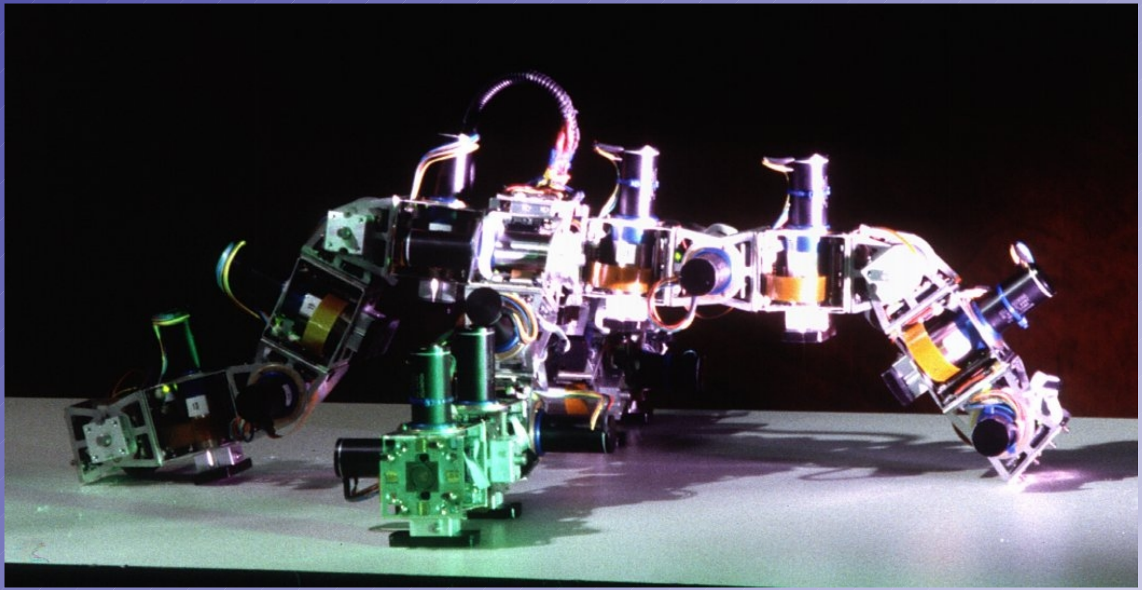
PolyBot G2 (2001 and earlier, PARC)

- 1 type of modules
- autonomous attachment to other modules
- Embedded processor



ATRON (2003, Denmark)

- 1 type of modules
- Sphere-shape
- Only one connector

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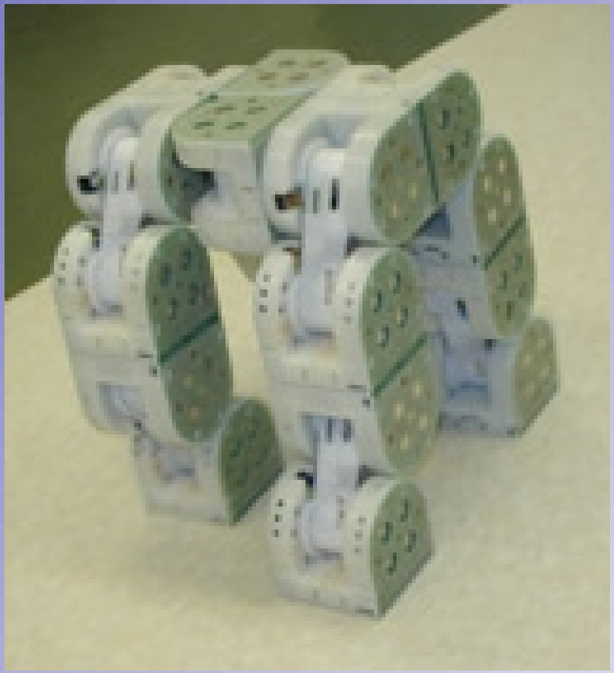
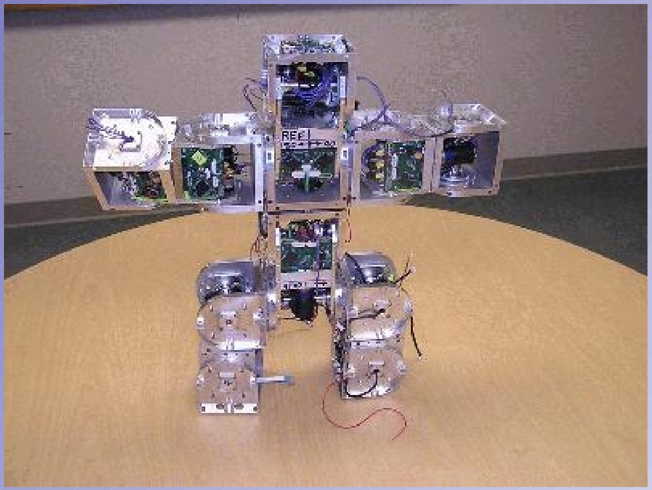
M-TRAN (2005 and earlier, AIST)

- 1 type of modules
- Autonomous self-reconfiguration
- Hybrid design allows high usability



SUPERBOT (2004, USC)

- 1 type of modules
- Based on CONRO (1998) and M-TRAN
- 6 connectors to dock with other modules
- Connectors also used for high-level communication



GZ-I (2006, Hamburg)

- 1 type of modules
- Fast and easy building
- Low-cost to be usable by large group of people

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Consumer Scenario

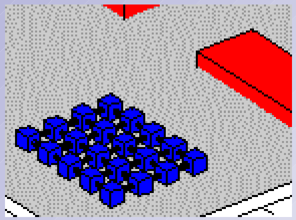
- vision of a future consumer having a container of self-reconfigurable modules
- when the need arises, the consumer calls forth the robot to achieve a task
- the robot may then assume the shape best suited for the task ahead

Taxonomy of Architectures

- Lattice architecture
- Chain/tree architecture
- Mobile architecture
- Deterministic reconfiguration
- Stochastic reconfiguration

Lattice Architecture

- arranged in regular 3d pattern
- control and motion executed parallel
- simpler reconfiguration
- discrete set of neighboring locations
- easily scaled to more complex systems



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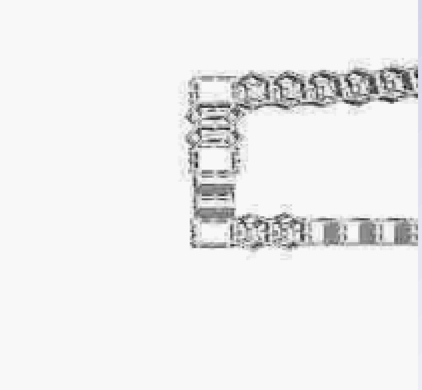
Chain/Tree Architecture

- units connected in a string/tree topology
- may fold up to become more space filling
- underlying architecture is serial
- can potentially reach any point or orientation in space through articulation
- more versatile, but computationally more difficult



Mobile Architecture

- units use the environment to maneuver around
- can hook up to form complex chains/lattices
- may form a number of smaller robots that execute coordinated movements and form a larger "virtual" network

Deterministic Reconfiguration

- relies on units moving or being directly manipulated
- exact location of each unit is known at all times
- or can be discovered and calculated at run time
- reconfiguration times can be guaranteed
- feedback control is often necessary for precise manipulation
- macro scale systems are usually deterministic

Stochastic Reconfiguration

- relies on units moving around using statistical processes
- exact location of each unit only known when connected to main structure, but may take unknown paths to move between locations
- more favorable for micro scale systems
- environment provides much of the energy for transportation

Standard Gaits

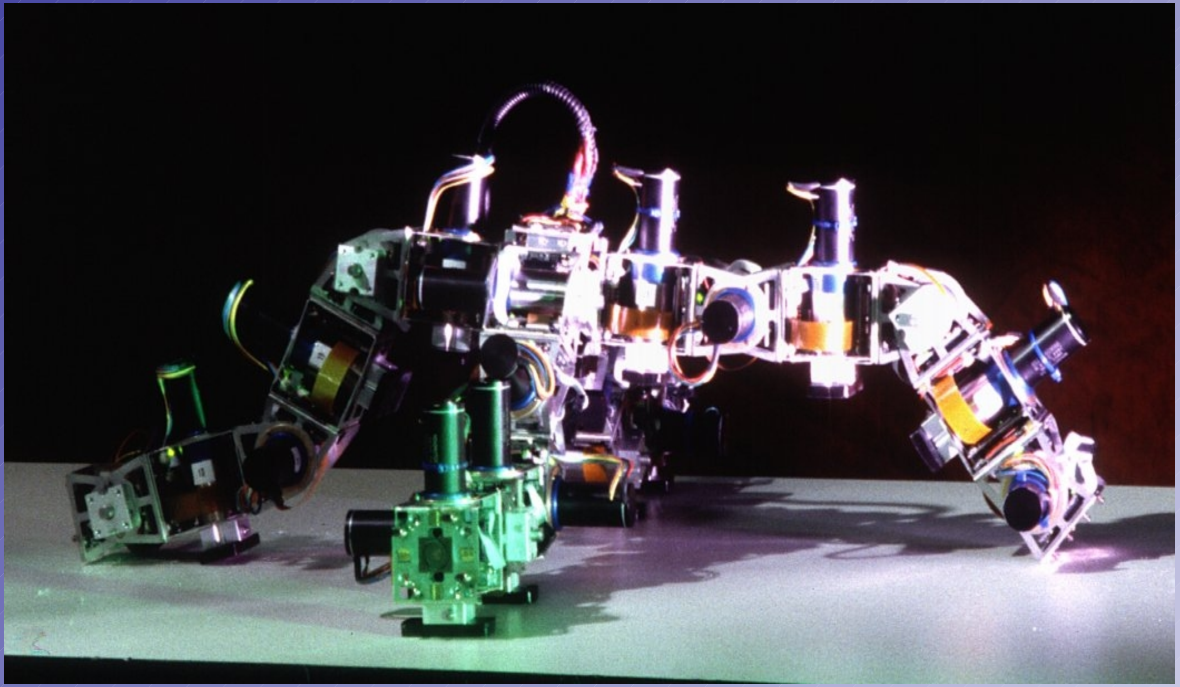
- Linear Gait
  - Forward and backward
- Turning Gait
  - Left and right
- Rolling Gait
  - Rolling around axis
- Lateral Shift
  - Parallel movement

Motivation and Inspiration

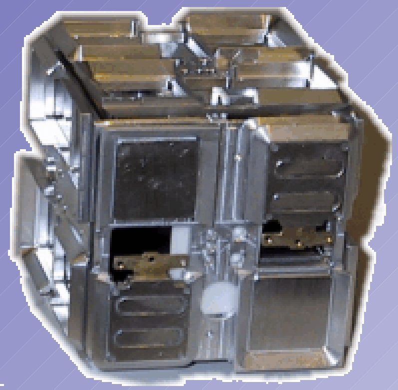
- Versatility
  - More adaptive than conventional systems
  - may change morphologies suited for new tasks
- Robustness
  - Parts are interchangeable leading to self-repair
- Low Cost
  - Because many copies of one (or relatively few) type of modules instead of a variety of parts

PARC Module Overview

- Telecube
- G1
- G1v4
- G2
- G3
- G1v5



Telecube G2 Module



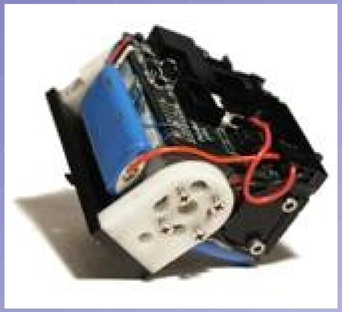
- cube shaped modules
- permanent switching magnet
- telescoping-tube linear actuator
- latching mechanism to attach or detach
- faces can extend out doubling the length of any dimension
- example for lattice architecture

G1 Module

- Two structural parts
- Plastic sheets
- Screwed together
- No self-reconfiguration
- Hobby RC Servos
- Power and computation off-board
- Design used by NASA snakebot

G1v4 Module

- Not self-reconfigurable
- Easy to manually reconfigure
- Hobby servo
- Computation on-board
- Power on-board (AAA NiMH Batteries)
- Cable attached for computation and power sharing between modules

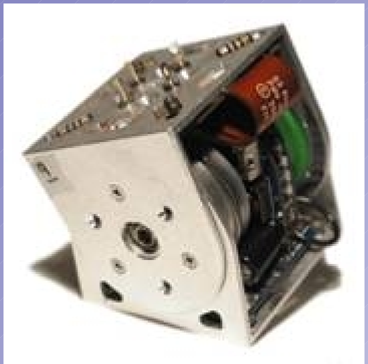


G2 Module

- On-board computing
- Motorola PowerPC 555 (1MB external RAM)
- Can reconfigure automatically
- Shape Memory Allocation
- Stainless steel sheet structure
- Communication over semi-global bus
- Motor 5x stronger than G1 modules

G3 Module

- Very similar to G2 Modules but...
- Smaller (5x5x4.5 cm)
- Integrated active brake
- Lower power than G2
- More sensors than G2
- Weighs only 200g instead of 450g
- Main drive weighs only 70g (compared to 300)



G1v5 Module

- Better G1 Module build after G2 & G3 Modules
- Robust screw together connections
- More reliable and robust
- Increased torque servos
- 36 volt bus with on-board DC-DC converters
- Allows chaining of up to 100 modules from a single power supply

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Research challenges

- Hardware challenges
- Software challenges
- Environment challenges
- Future challenges

Challenge on hardware design

- Robustness and strength on docking interfaces
- Motorpower, precision and energy efficiency
- Easy-to-use-hardware for running software
- Low-cost for high amount of modules

Challenge on software design

- Highly scalable software, handling 2 or 1000 modules
- tolerance on missing or not responding modules and unknown situations
- Determining configuration for solving problems
- Optimization of reconfiguration regarding to energy efficiency

Challenge on environment

- Space exploration
  - No gravity, no weight
- Sea exploration
  - Waterproof
- Search and rescue
  - Ability to cross every surface and obstacle

Future challenges

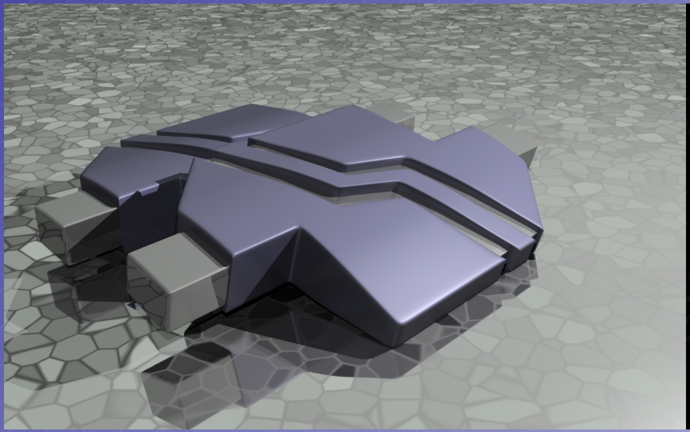
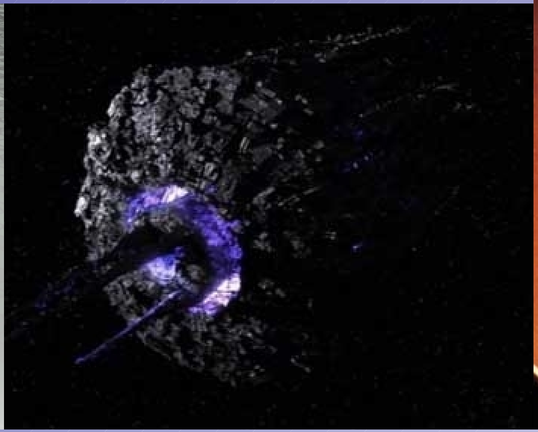
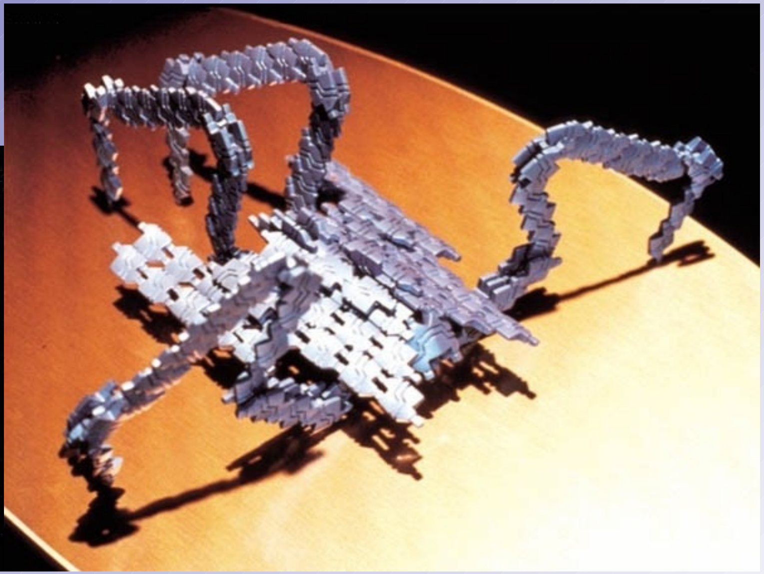
- High amount of modules working as one unit
- Self-replication
- Highly autonomous and advanced AI

Sci-Fi / far future

- Example
  - Replicator (Stargate SG-I)
  - T-1000 (Terminator 2)

Replicator (Stargate SG-I)

- Consist of modules
- Advanced artificial intelligence
- Strong connection between modules
- Able to create large robots
- Able to produce new modules

T-1000 (Terminator 2)

- Self-Healing
- Self-Reconfiguring
- Variable morphology
- Advanced AI
- Highly autonomous

Questions?

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