Distributed Self-reconfiguration Control of an M-TRAN System

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Contents

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- Modular Robot
  - Modular robot as a DARS
  - Problem of self-reconfiguration
- M-TRAN
  - Hardware
  - Software
- Experiment
- Conclusion

M-TRANs

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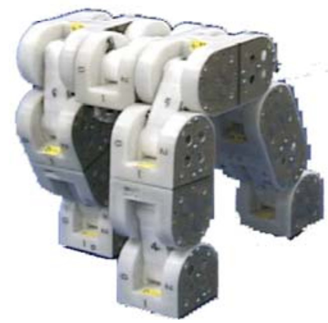
I	II	III
1998	2002	2005
66 mm 440 g	60 mm 400 g	65 mm 420 g



I Basic Experiments (centralized)

II Locomotion by Distributed Control

III Self-reconfiguration
by Distributed Control

Self-reconfiguration (metamorphosis)

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Fractum

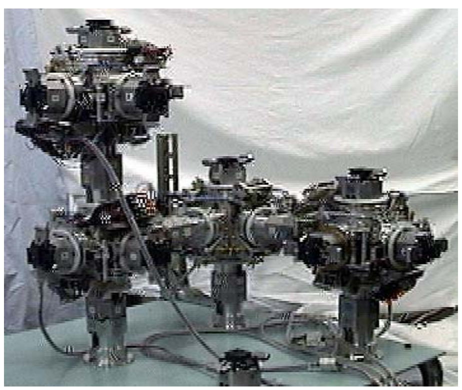
<u>2-dimensional system</u> (Fracta 1992)

Self-reconfiguration by distributed autonomous method was successful

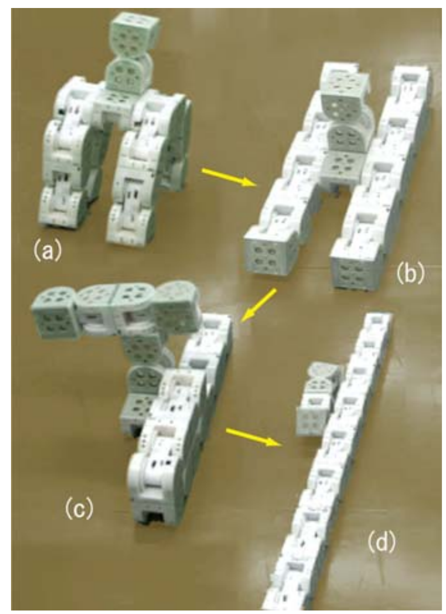
(Decentralized, asynchronous, neighbor-to-neighbor communication)

<u>3-dimensional system</u>

Small scale self-reconfiguration by centralized or globally synchronous controller



3-D module



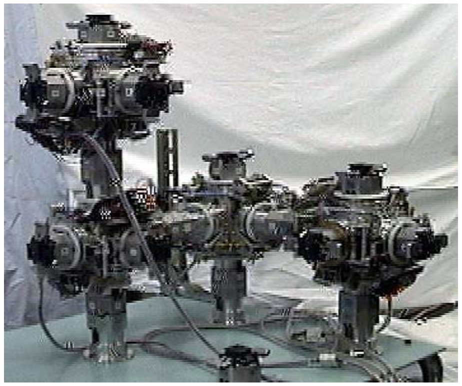
M-TRAN

Key factors for self-reconfiguration experiments

•Basic design of a module is important.
There is no optimal design.
M-TRAN is a one candidate.

•Hardware design & performance :
speed
power consumption
reliability

•Cost is important for mass production.
100 ATRON
50 M-TRAN III
...
1000 ???



7 Kg / module

^

ATRON (U.S.Denmark)

Experiments in the past

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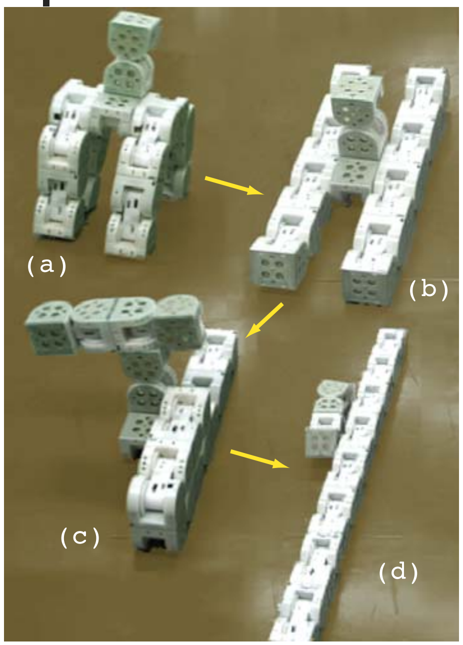
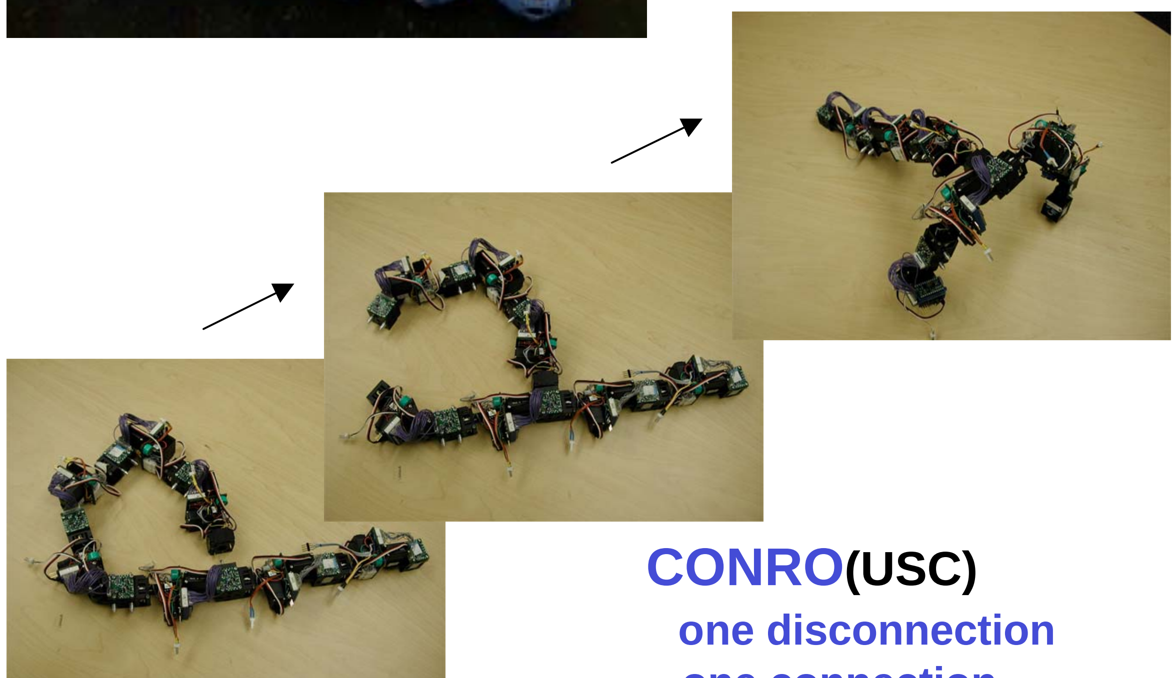


M-TRAN II
10 modules
(20 modules produced)
# of connection changes
1 or 2 times／module
8 min.

ATRON (USD)
35 modules
(100 in total)
# of connection changes
<10 times（2module）



CONRO(USC)
one disconnection
one connection

Distributed Metamorphosis Control

- Module design :
  Symmetric omnipotent module : too heavy
  Fewer DOF, fewer symmetry :
  Complicated motion for self-reconfiguration

→ Simple design (M-TRAN)
→ Regular structure and repetitive self-reconfiguration
(suitable for parallel control)

- Hardware performance :
  speed, power consumption, reliability
  especially of connection mechanism

- Small production : cost, ...

M-TRAN module (lattice-oriented design)

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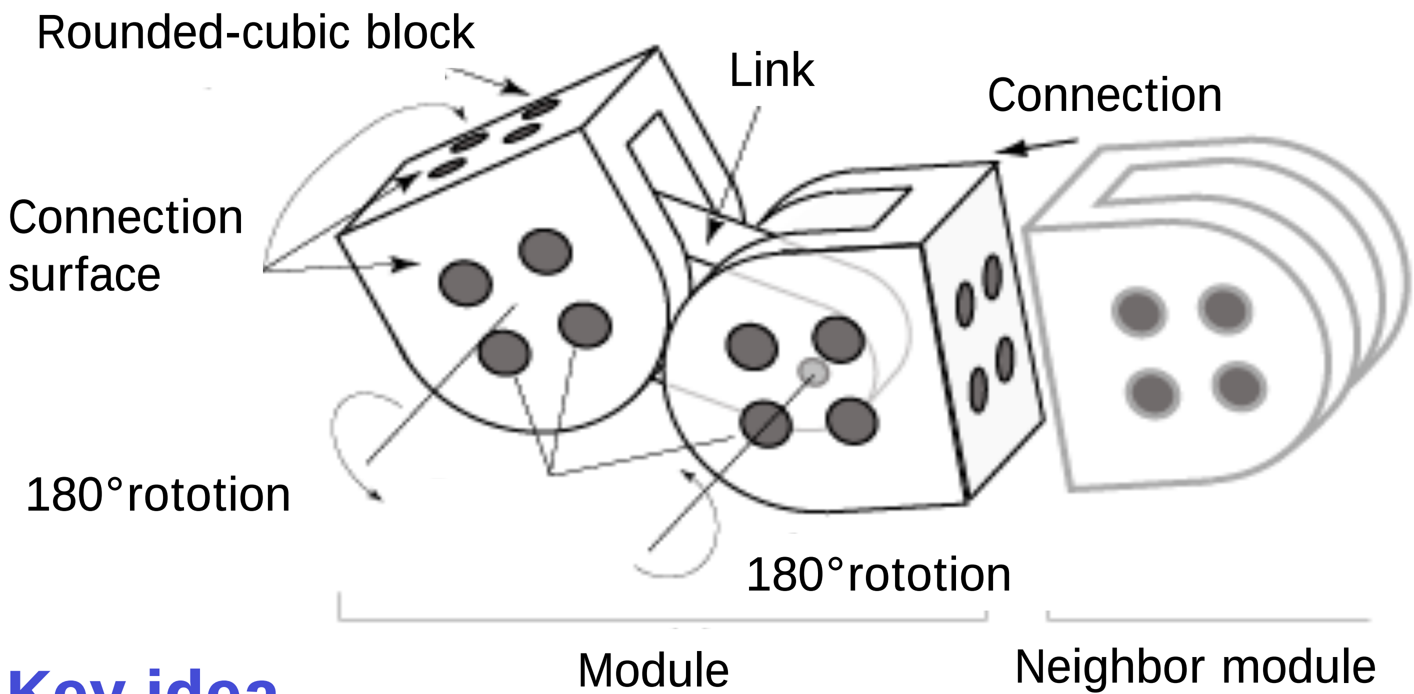
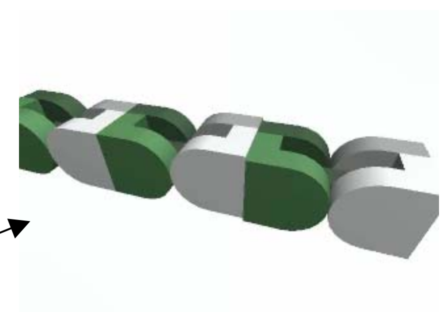


Key idea

Positioned in cubic lattice by angle=0, ±90º
Stackable in a cubic lattice
Large surface for connection
Avoid collision (parallel axes)



Distributed Metamorphosis Control

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- Module design :

- Hardware performance :
  speed, power consumption, reliability
  especially of connection mechanism

→ New mechanism for M-TRAN (Fast, low power consuming, reliable)

- Small production : cost, ...

New M-TRAN Hardware

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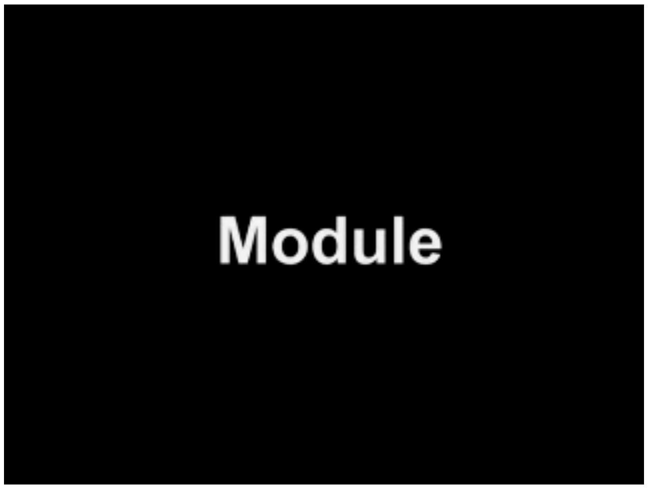
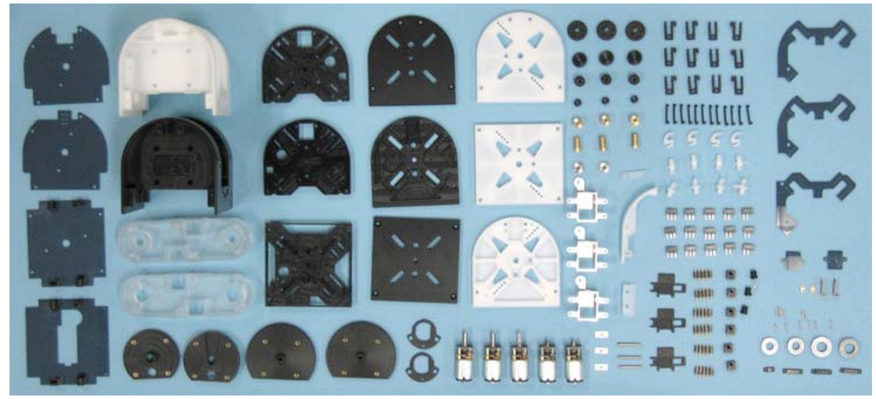
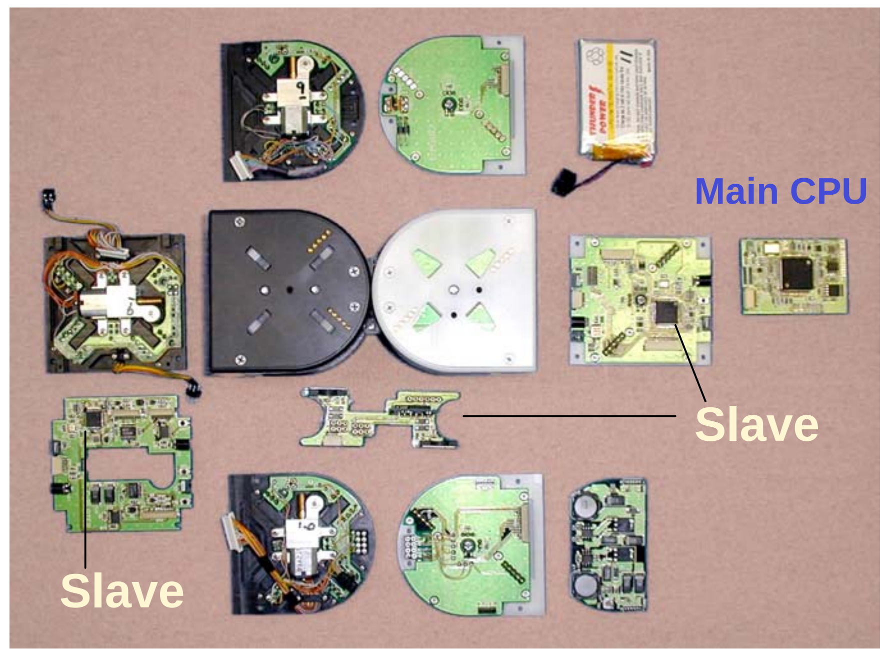


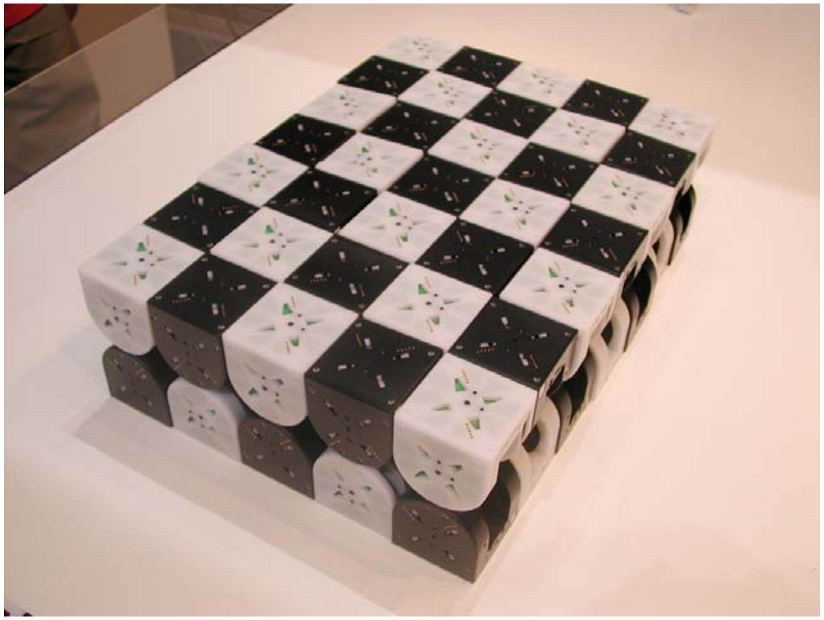


Motion DOF 2
Connection : male 3, female 3
CPU 1 main / 3 slave
10 IR proximity sensor
Gravity sensor
Global communication by CAN bus
Bluetooth modem
Battery in each module



Mass production :

50 M-TRAN III modules were produced for EXPO 2005



Target procedures for experiments

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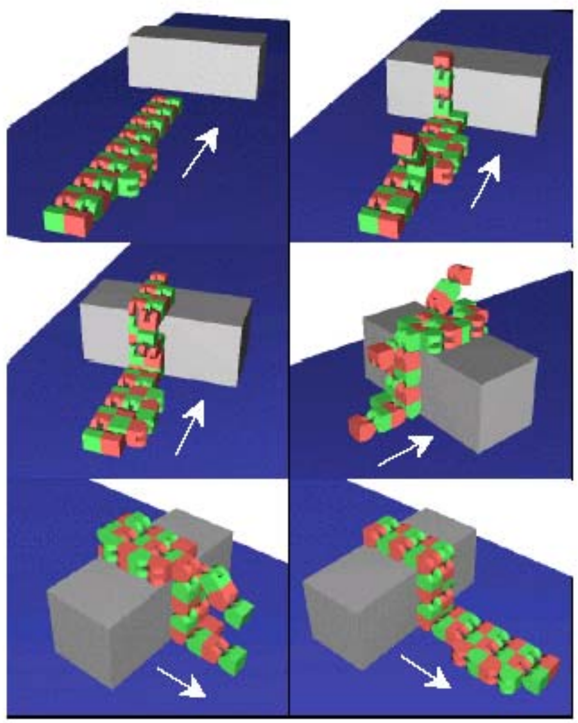
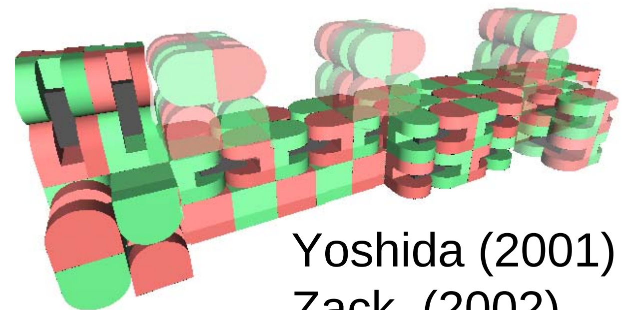
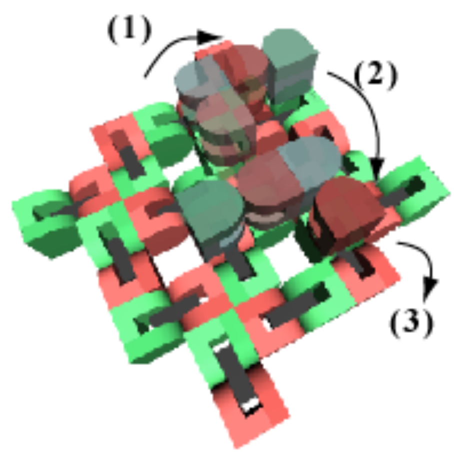
- Regular structure by meta-modules and repetitive self-reconfiguration



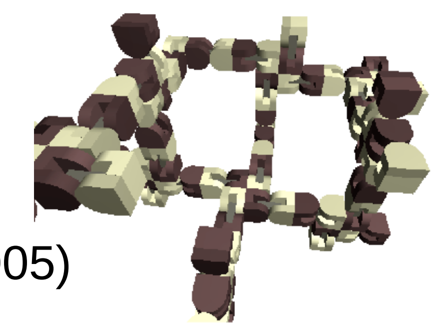
Tomita (2000)
Ostergaard (DARS 2004)



Yoshida (2001)
Zack (2002)
Lund (2003)



Kurokawa (2004)



Kurokawa (2005)

Distributed self-reconfiguration Control

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- Advanced module design & self-reconfiguration design
- Improved hardware performance :
- 50 modules

<u>Research Objective</u>

⇨ **Experimental verification of**

- **Decentralized and asynchronous parallel control**
- **Self-reconfiguration by large number of modules (>20)**

Software development

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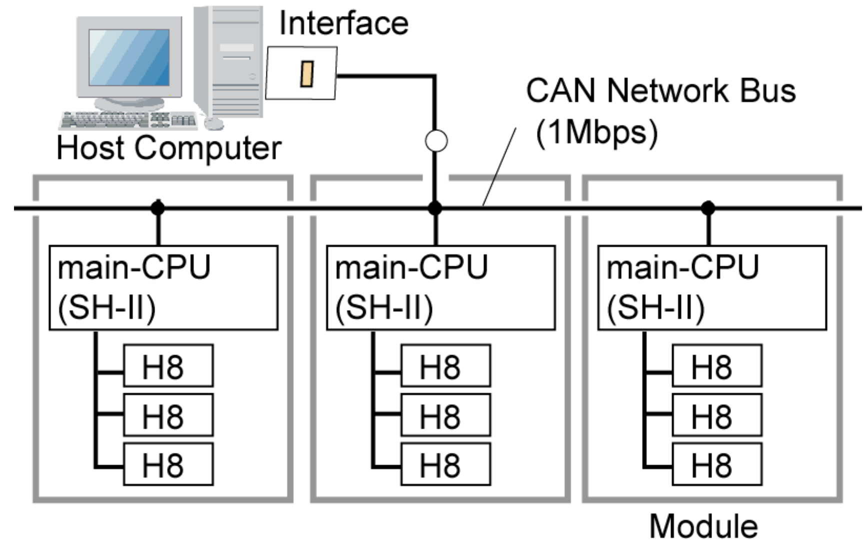
- Onboard controllers

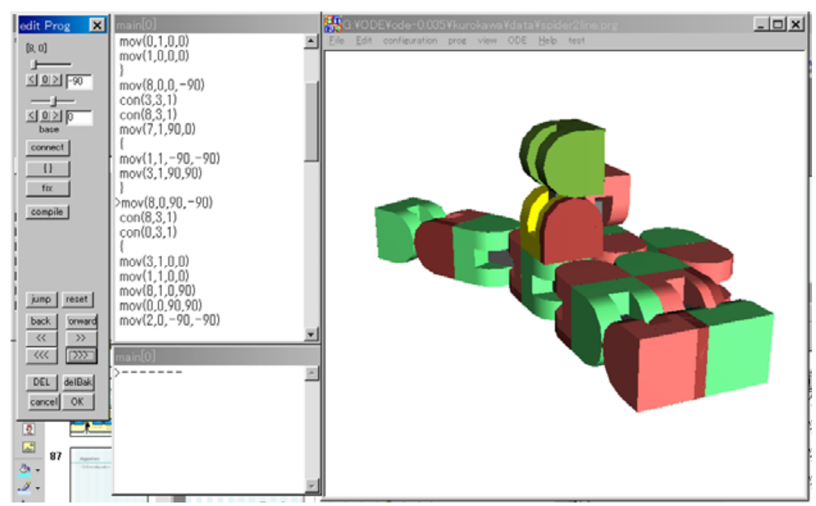
  Master CPU + 3 slave CPUs

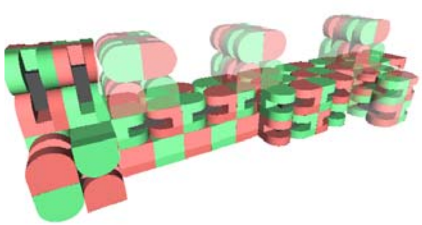


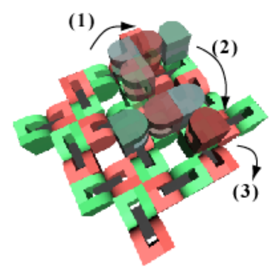
- M-TRAN simulator
  - Design of self-reconfiguration procedure

    (multi-thread, step synchronous)
  - Kinematics & Dynamics Simulation

    (Vortex & ODE)







Software

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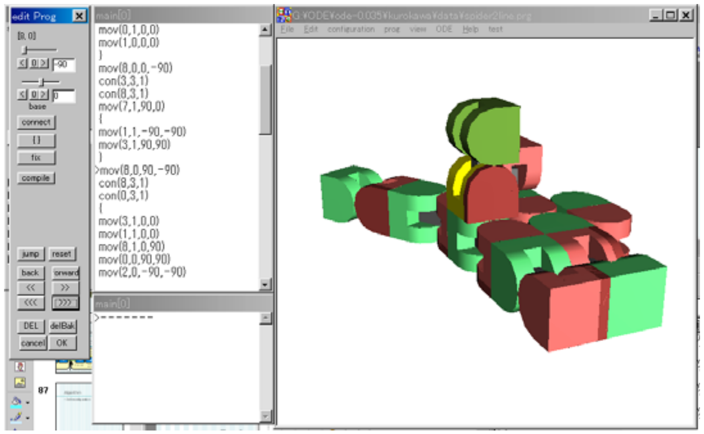
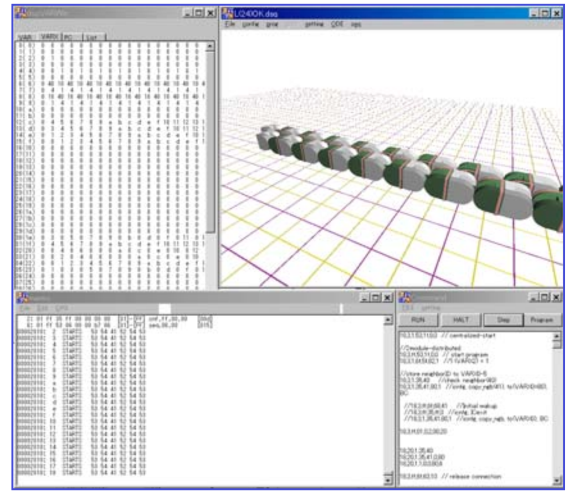


M-TRAN simulator
•Step synchronization
•Script conversion

Centralized control by Host PC（M−TRAN I）
Global event synchronization（M-TRAN II）

past



Emulator for distributed controller

Onboard Controller

Asynchronous decentralized control
(M-TRAN III)

Onboard Controller System

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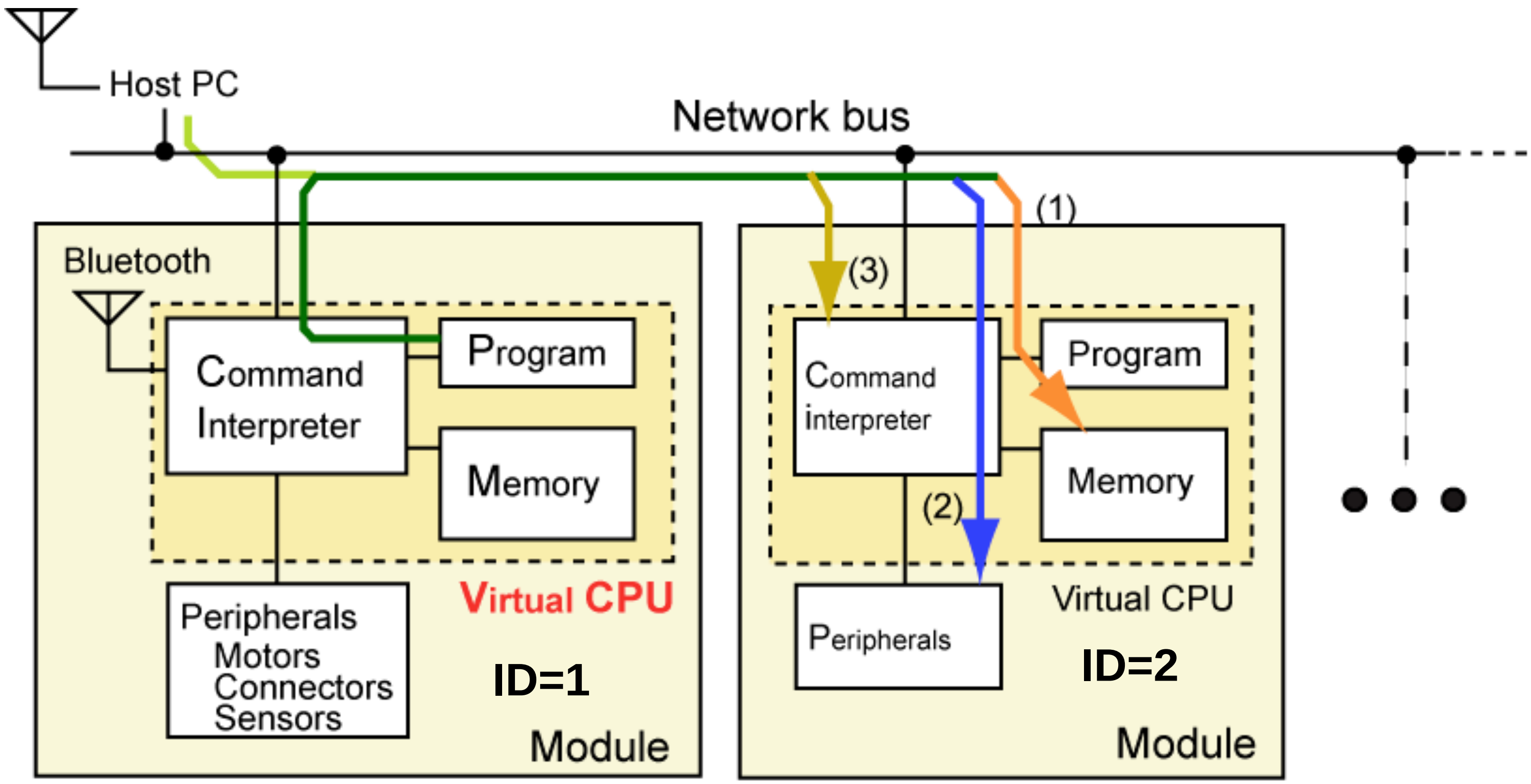
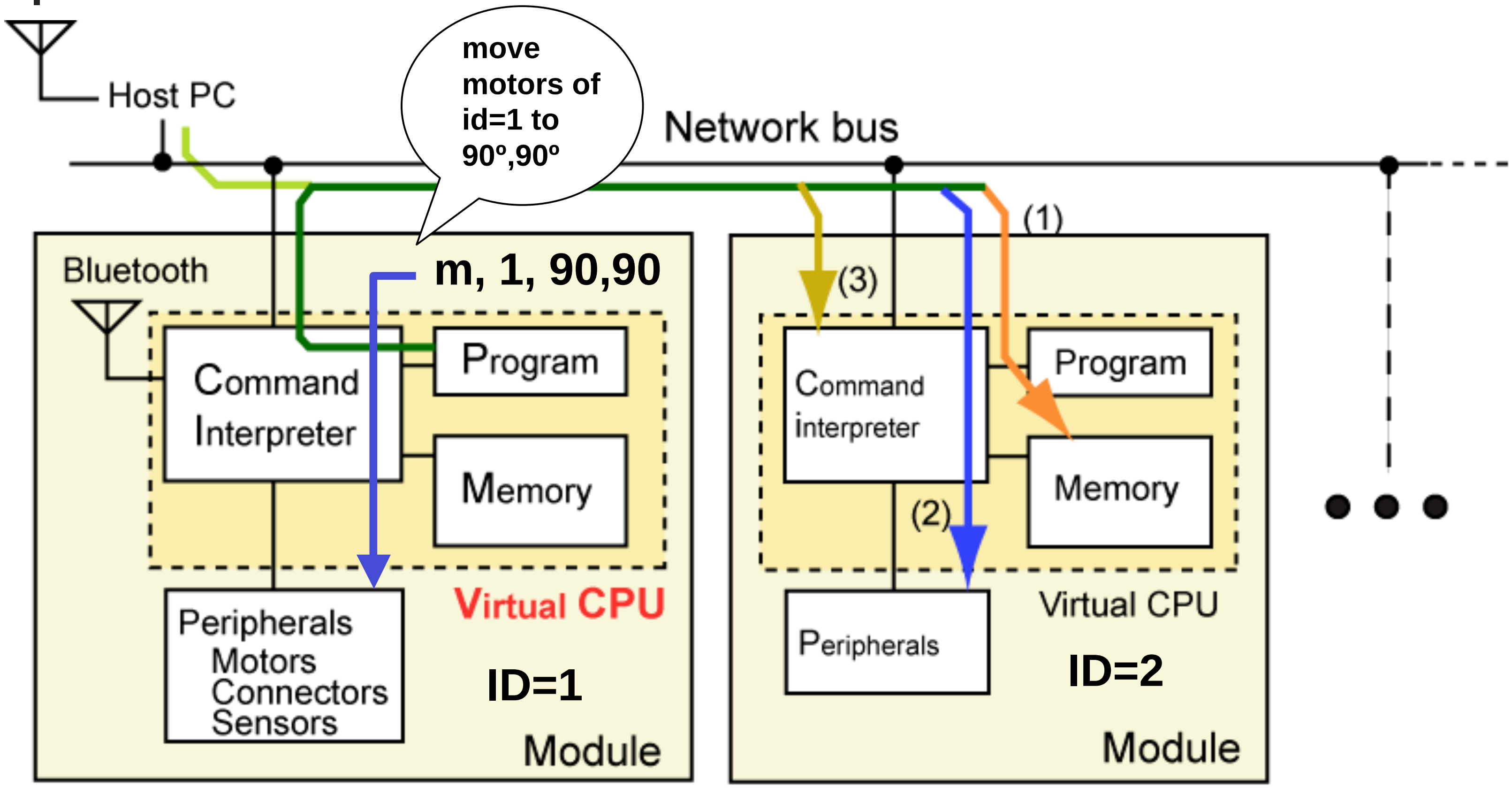


(1) Shared memory (2) Remote control (3) Message for synchronization

Parallel Controller System



(1) Shared memory (2) Remote control (3) Message for synchronization

Parallel Controller System

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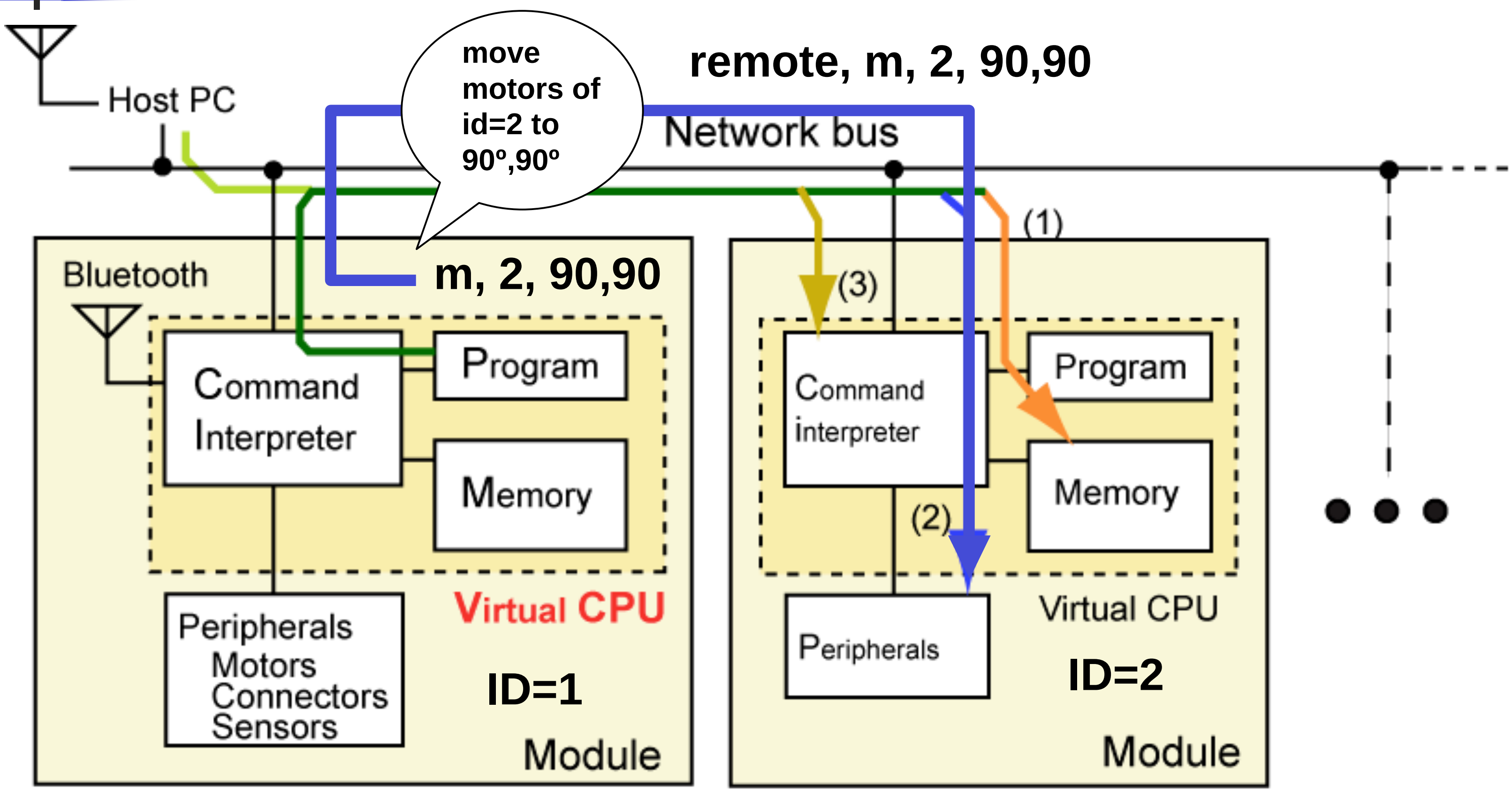
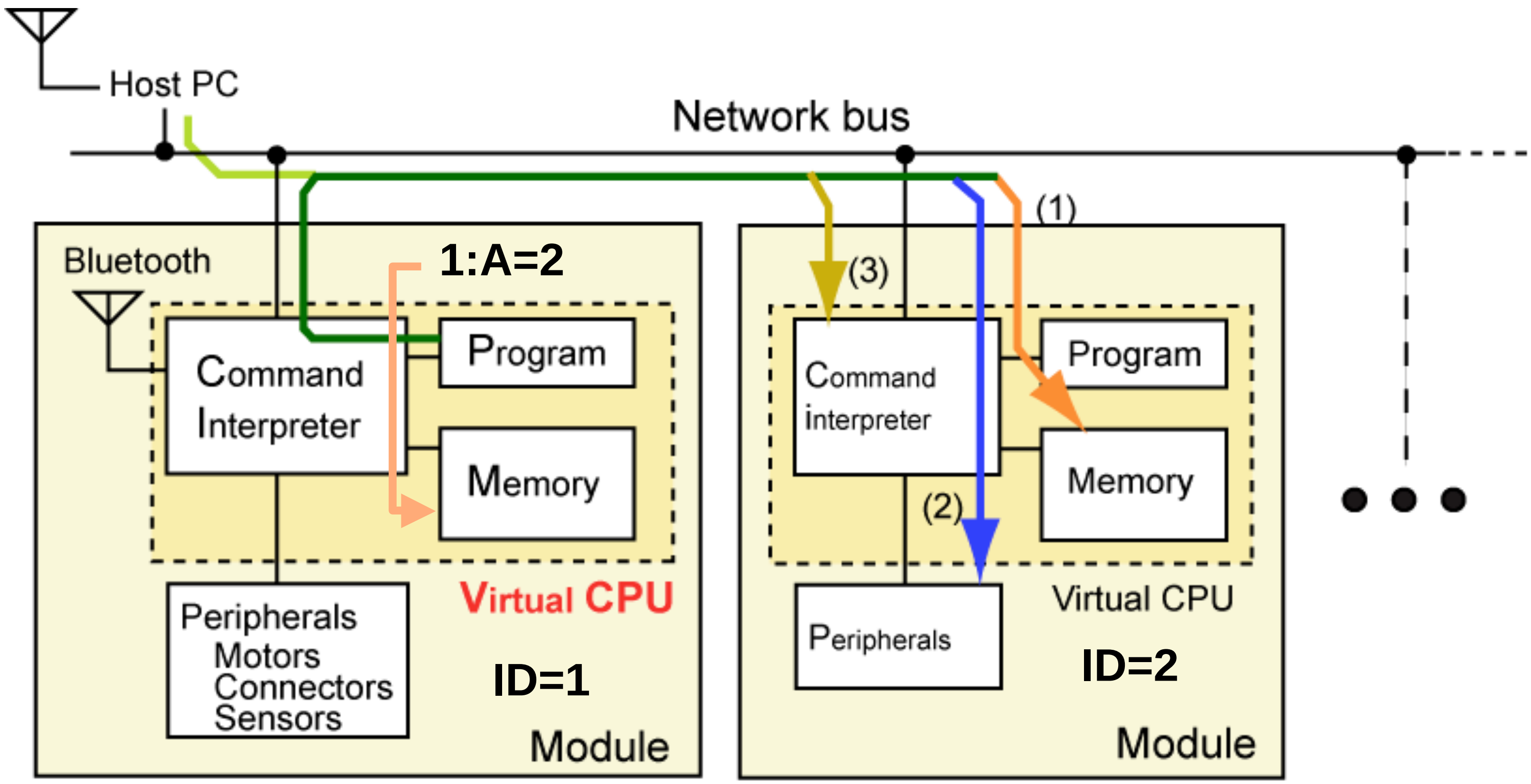


(1) Shared memory (2) Remote control (3) Message for synchronization

Parallel Controller System



(1) Shared memory (2) Remote control (3) Message for synchronization

Parallel Controller System

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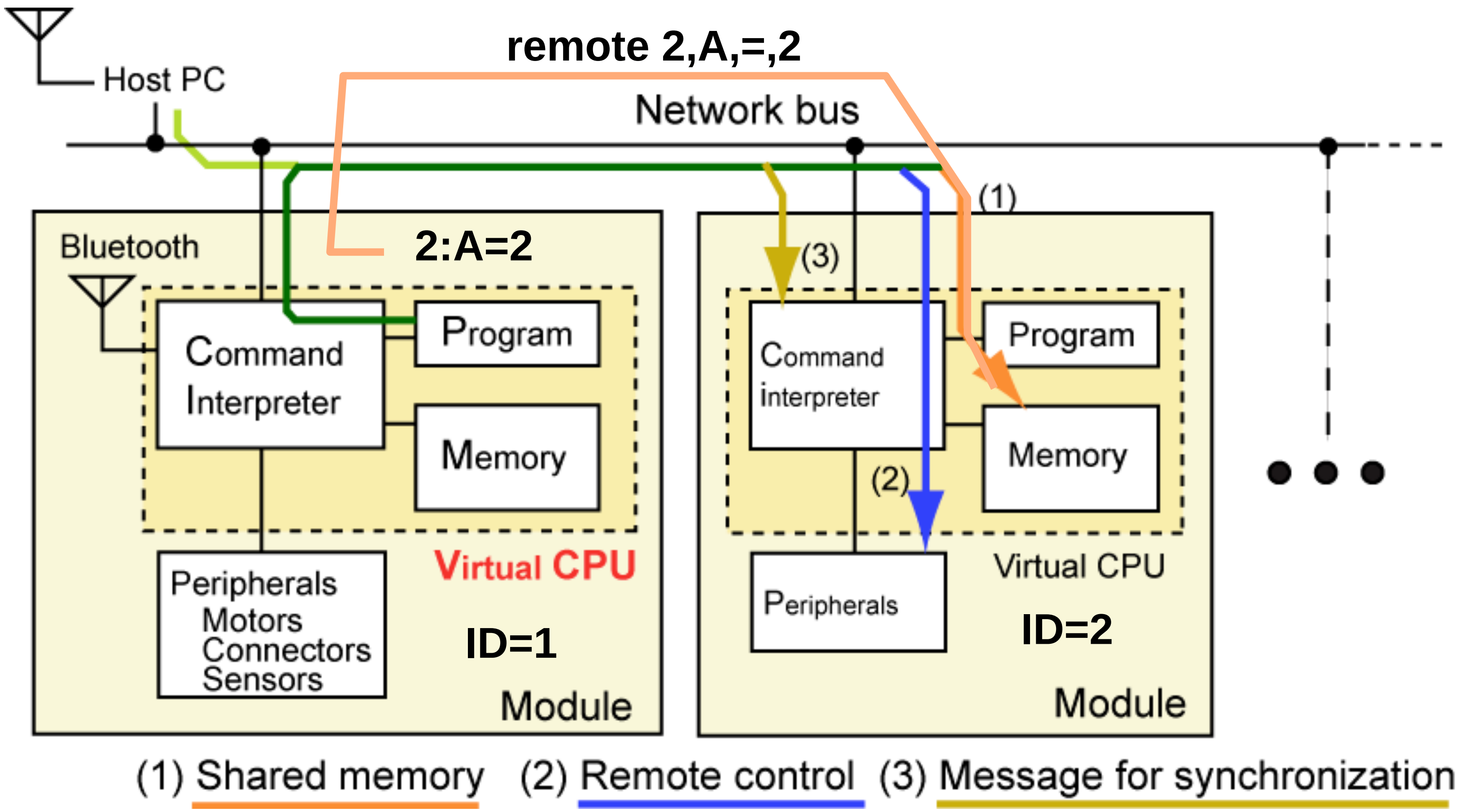

Parallel Controller System

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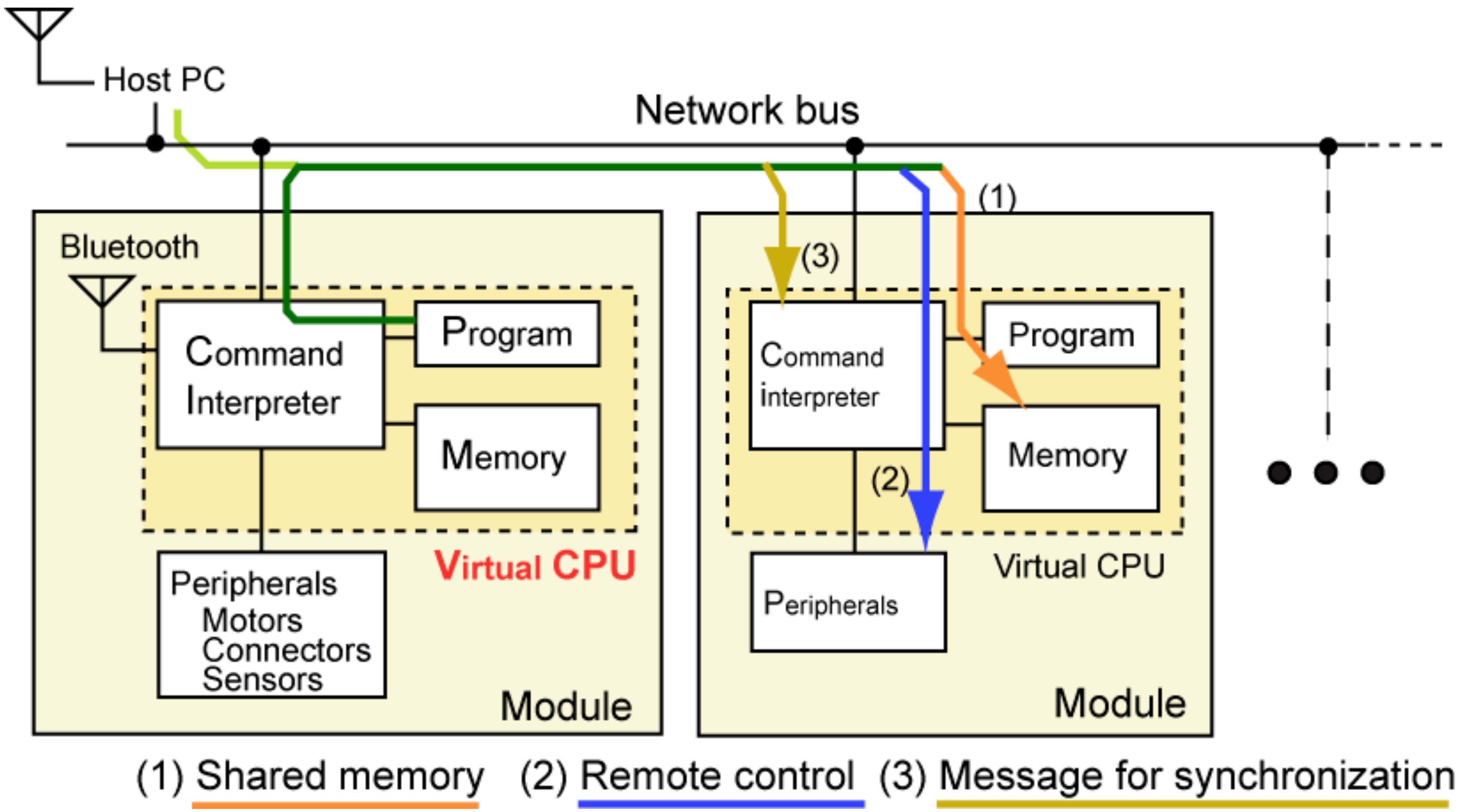

- **Single master control （Remote control)**
- **Parallel & locally synchronous control （Shared memory）**

Program development system

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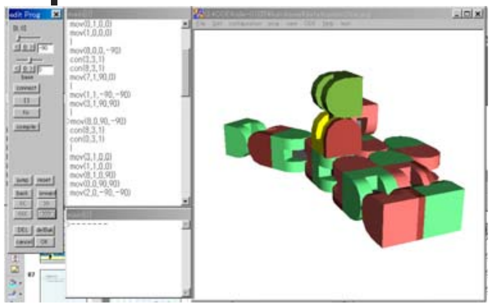
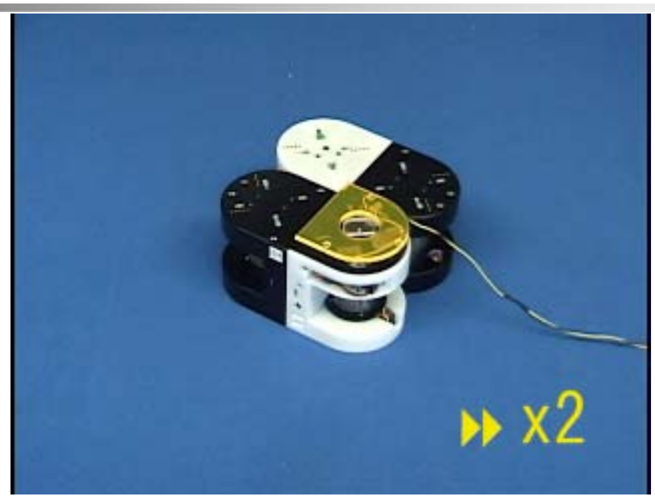


M-TRAN simulator

```
while (1) //loop
{
    mov(1, 1, 90, -90)
    mov(2, 0, 90, -90)
}
{
    mov(1, 0, 90, -90)
    mov(2, 1, 90, -90)
}
endwhile
```

Simulation Script

Auto conversion




```
L0:
 cnr 2, 2, 0 ;
 mvr 1, -90, 90
 mvr 2, 90, -90 ;
 cnr 2, 2, 1 ;
 cnr 1, 2, 0 ;
 mvr 1, 90, -90
 mvr 2, -90, 90 ;
 cnr 1, 2, 0
 jpr L0
```

Machine Program (Single master)

example of parallel control

```
load flag, 0
L0: switch flag, L0, L1, L2, L3
L1: load flag, 0
    con 2, 0 ;
    remote, next, load, flag, 3
    mov -90, 90 ;
    jpr L0
L2: load flag, 0
    con 2, 1 ;
    remote, next, load, flag, 1
    jpr L0 ;
L3: load flag, 0
    mov, 90, -90 ;
    remote, next, load, flag, 2
    jpr L0
```

Machine Program (parallel)

Emulation of parallel processing

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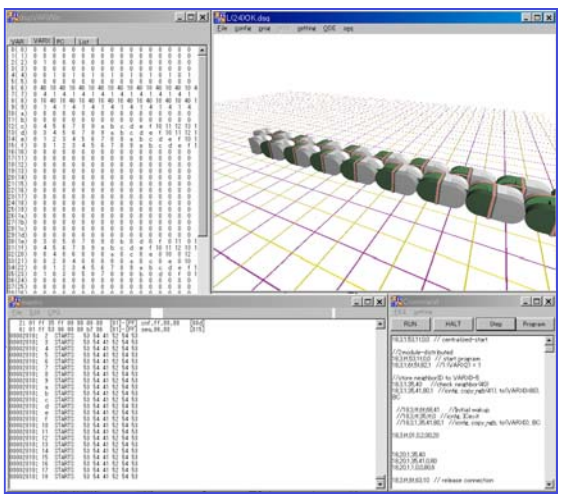
Emulator = M-TRAN Simulator (Kinematics & Dynamics)
+ multi-Controller Emulation

Source code compatible to the onboard controller



Network Bus

Virtual CPU
Command Interpreter & Memory

Slave CPU control
Link motor
connector
etc.

• • •

• • •

Multi-Controller Emulation

Experiments

- Locomotion
- Self-reconfiguration
  - Centralized & synchronous (Single master)
  - Decentralized & asynchronous (Parallel)

Experiment (single master)

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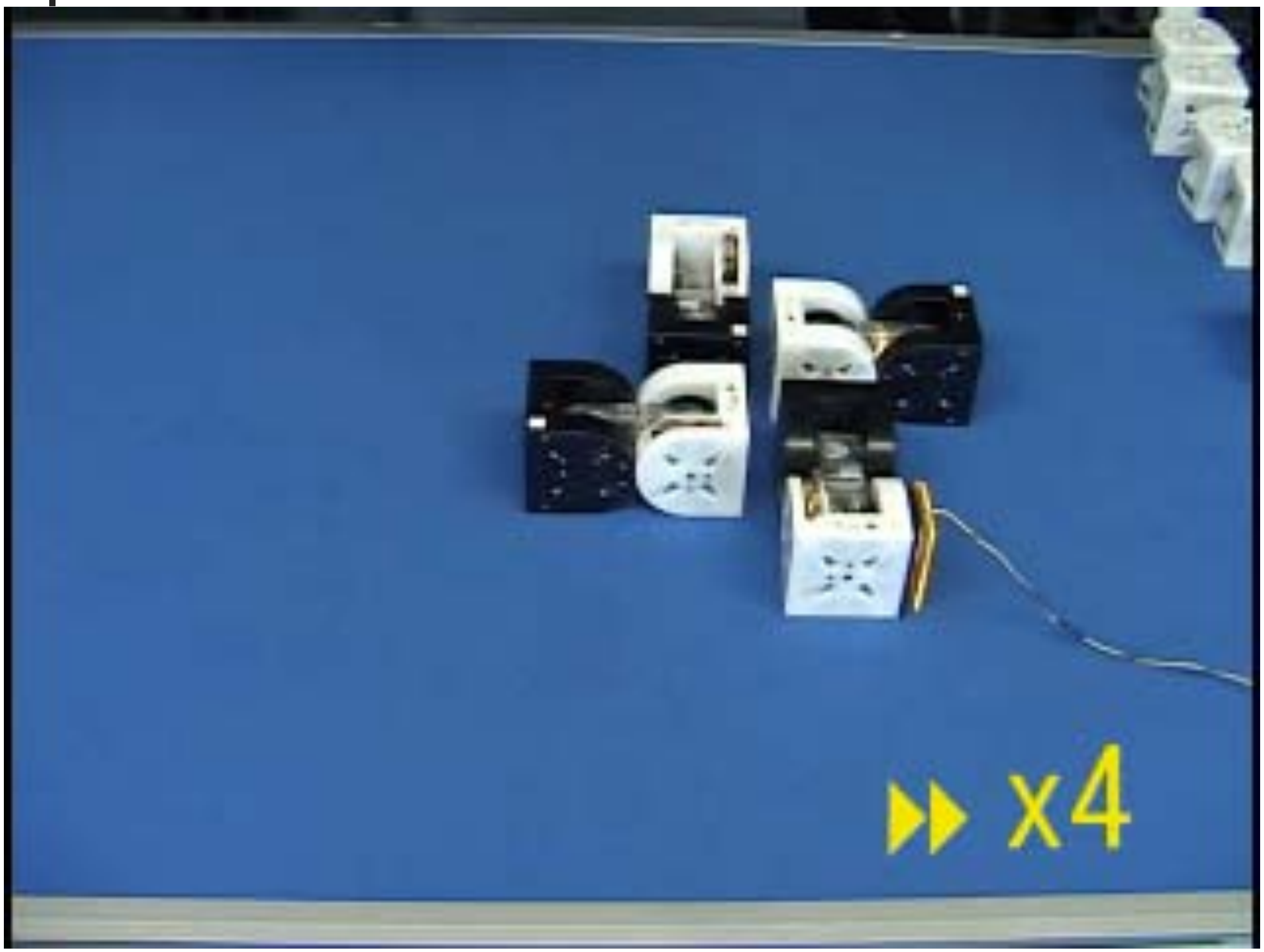

Demonstrated in EXPO 2005

Arbitrary 4 module

Master voting

Identification of configuration & role

Locomotion (clock sync.)

↓

Self-reconfiguration Single master

Parallel distributed control

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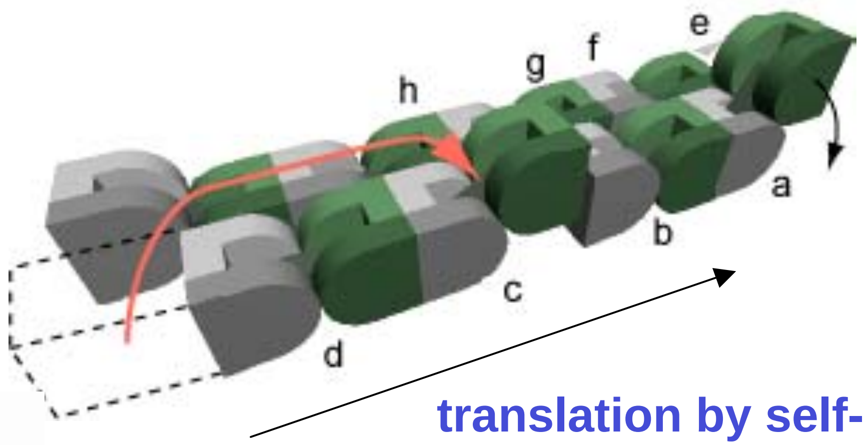
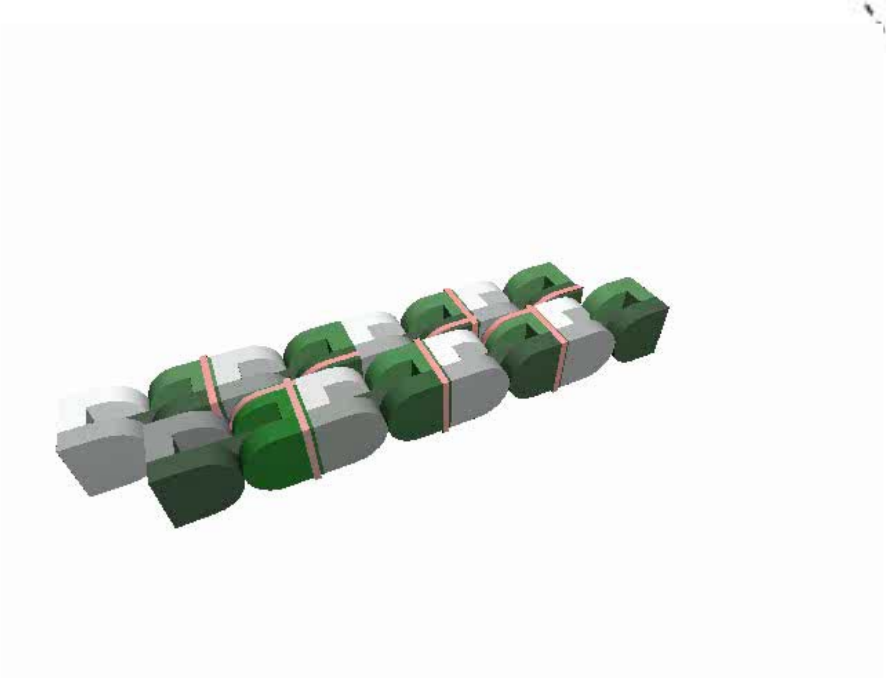
Algorithm

・Two modules cooperate
 (meta-module, cluster)

・Communication with 4 neighbors



translation by self-reconfiguration



Parallel distributed control

Parallel distributed control

# of modules : 4, 8, 12, 20

The same program for all the modules (code size 660 Byte)

Local synchronization

Parallel control

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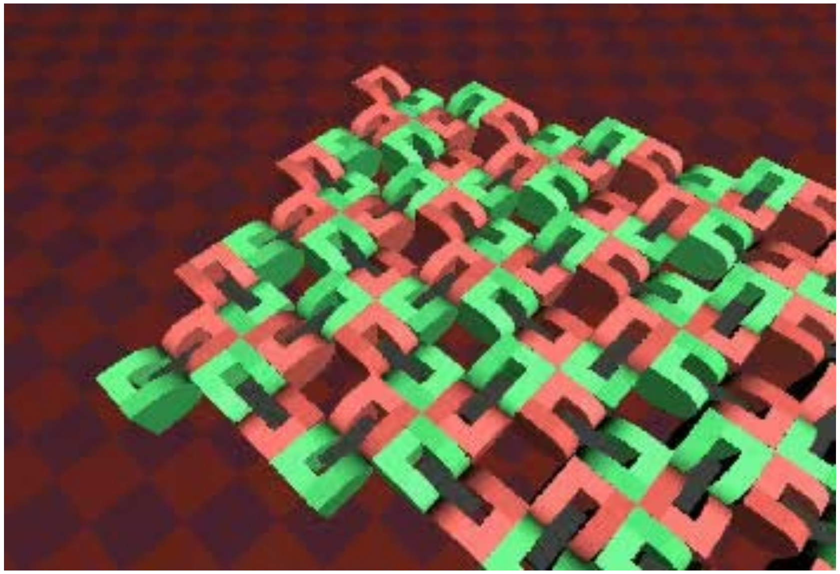

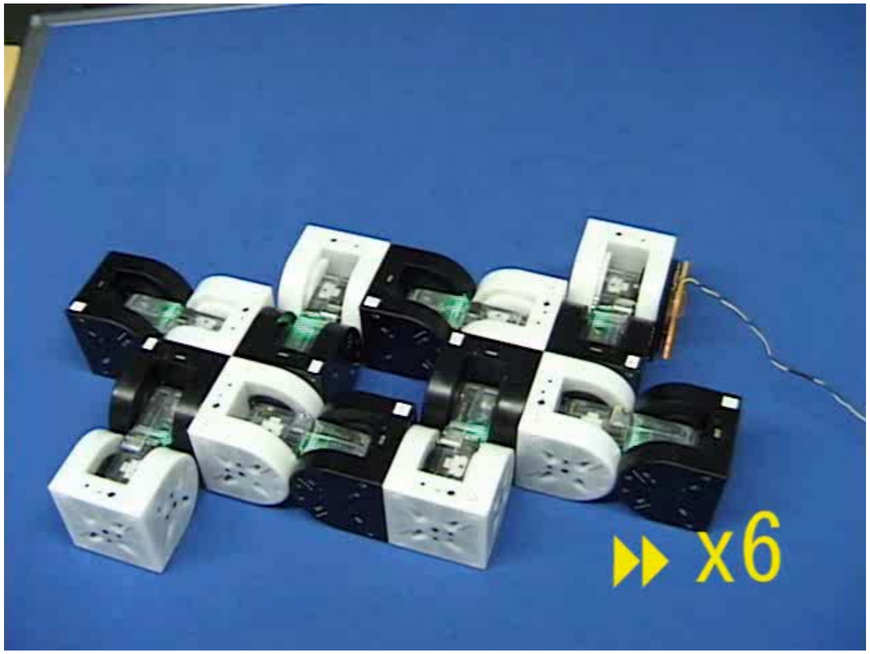

code size ≈ 1.5 KB

using long distance communication

Hardware problems

mechanical : alignment error →connection fails
communication : unreliable electric contact, ...

⇨ **Improvement**
retrial
reconnection

Parallel control (improved a little)

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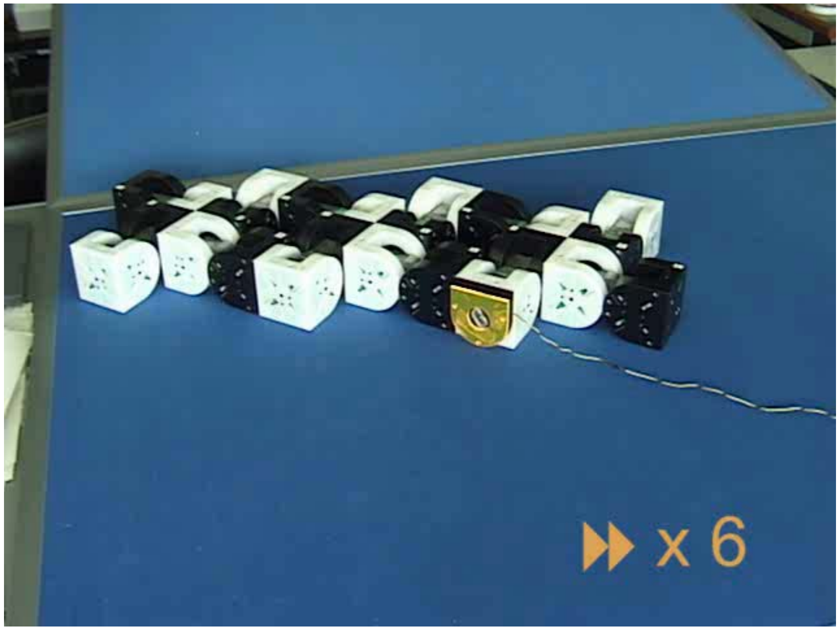

code size ≈ 2 KB

Connection retrial

Neighbor to neighbor communication
Connection retrial

Problems (1)

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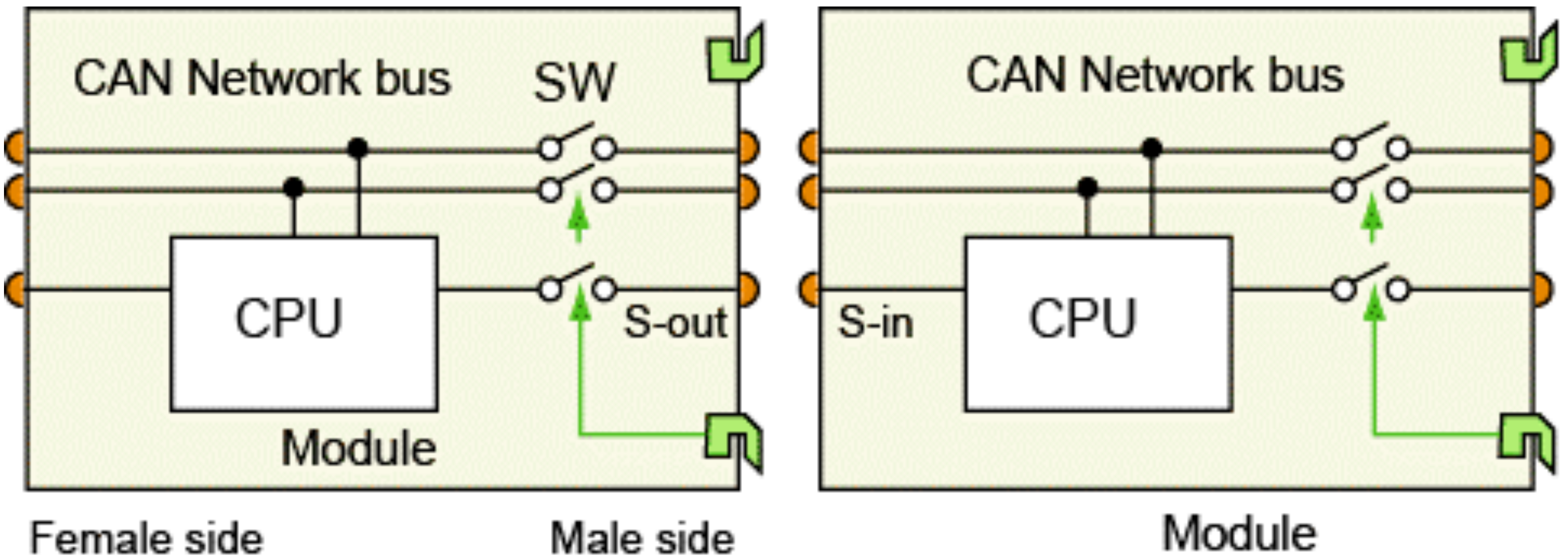
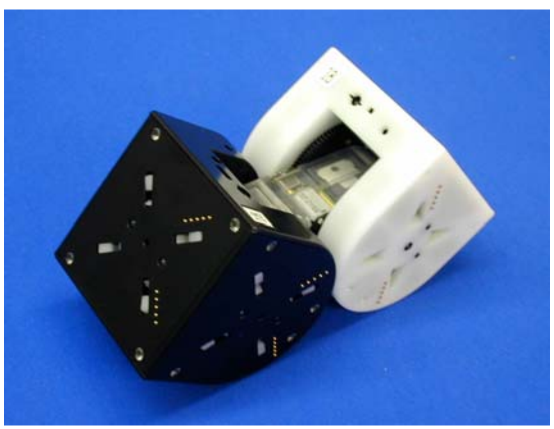




2 SW for CAN bus lines
1 SW for a line of connection detection

Switches to avoid unexpected short circuit are unreliable

Problem (2)

- Misalignment between surfaces for connection

- Bus traffic jam

Connection failure

Problems (3)

- **Critical message**

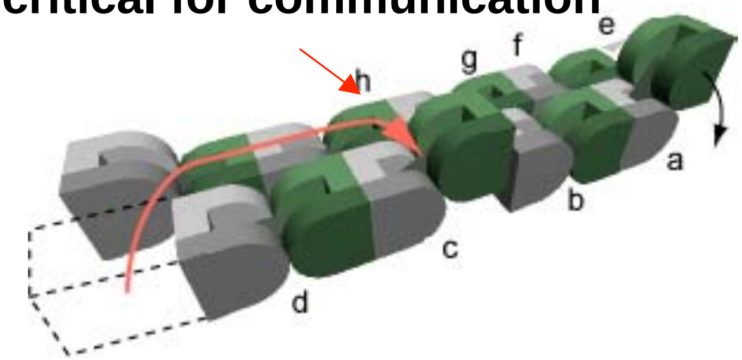
  → message & protocol design is important
- **Every step is critical**

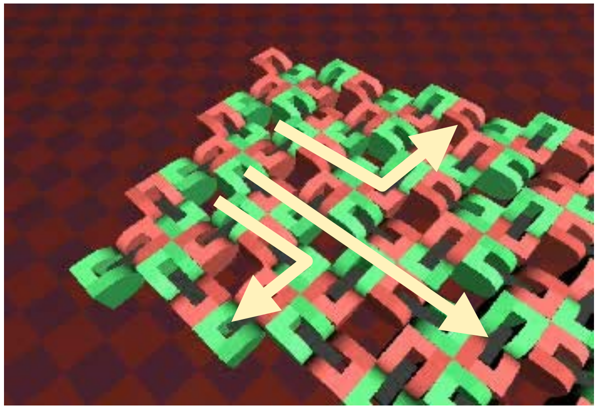
  (deterministic procedure)
- **Most connections are critical for communication**

→ redundancy

→ nondeterministic

critical for communication





Redundant connection
Process can be nondeterministic

Future works

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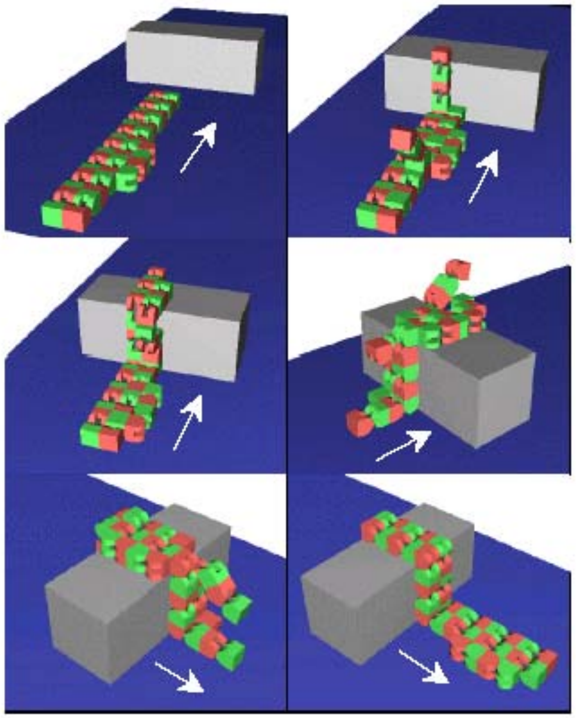
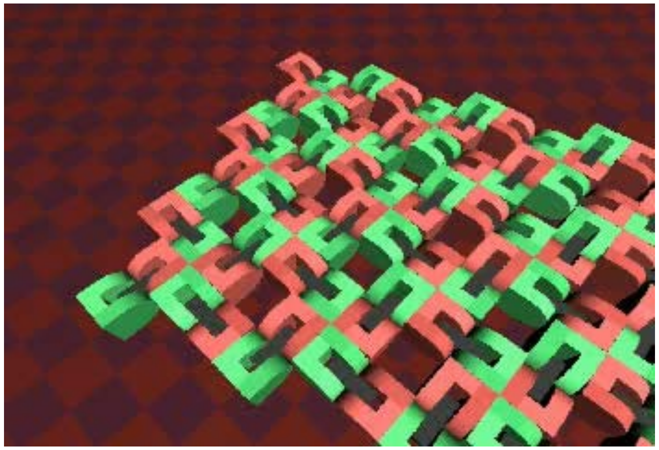


1. Larger structure (> 20 modules)



2. Autonomous self-reconfiguration by sensor information

3. Automatic separation of faulty module

Future works (detail)

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- Neighbor-to-neighbor communication by IR devices

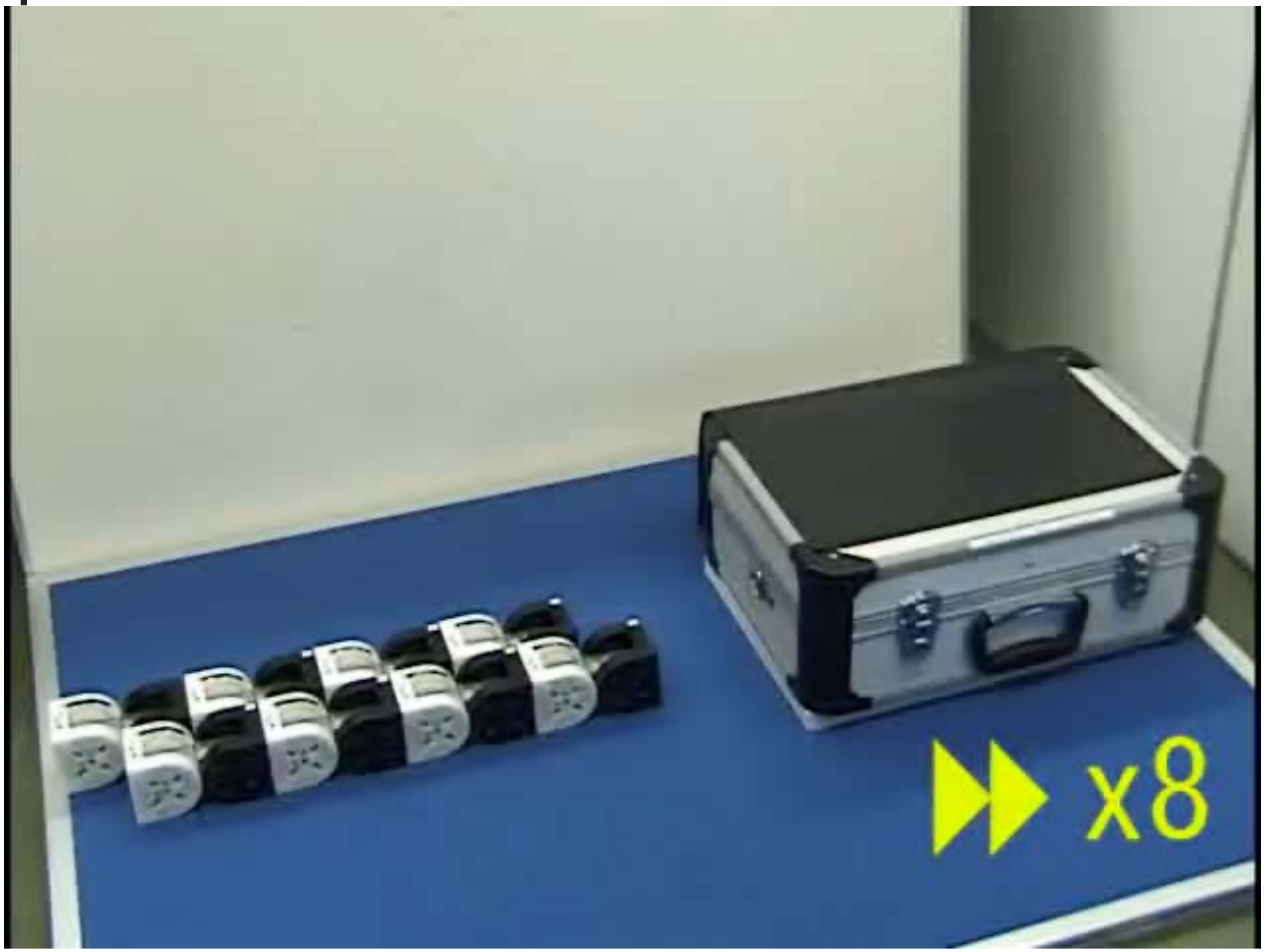
  Reliable, scalable, slow (100 bps)

- Controller language

  Assembler language → High level

- Sensing and decision making

Experiment (single master)



Single Master Playback

Verification of hardware performance

⇨ **Autonomous path following**

Summary

- Development of a new Hardware (M-TRAN III) and software
- Distributed controller for centralized & decentralized self-reconfiguration control
- Simple parallel self-reconfiguration was verified by experiments