A Vision for Biomorphic Explorers: Adaptation, Self-repair, and Evolution in Reconfigurable Heterogeneous Multi-Functional Modules with Artificial Genome

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This paper proposes an aggressive design of biomorphic system that can possibly be accomplished within existing framework of technology. The essential characteristics of biological systems that are relevant to the theme of the workshop are: (a) omni-/multi-potency of cells that are differentiated into various cells, (b) possession of genetic information in each cell, and (c) contextually-dependent commitment of cell types. A straight forward approach is to use large number of homogeneous cellular elements that has universal operation primitives. While such an approach is mathematically elegant, it poses numbers of engineering problems and inefficiency. A practical approach is to use multi-functional subunits that can be reconfigured into other type of modules.

Technical requirements for such a system are: reconfigurable physical components, standard bus and electrical connector technology, built-in morphogenesis capability, differentiation modeling of living systems. I will describe and propose an integrated scheme based on my experience on Oprn-R, development-based GA, and others.

I may refer to more futuristic options on fully biological and reconfigurable systems based on the most recent findings.

A Vision for Biomorphic Explorers

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NASA/JPL Workshop on
Biomorphic Explorers for Future Missions
Pasadena, 1998

How Can We Achieve Cost-Effective and Persistent Presence in Space?

- On-the-fly Assembly
  - Current: Assemble-and-Launch
  - Future: Assemble and Reconfigure during the Mission
- Adaptation and Evolution
- Reconfigurable Multi-Potent Modules

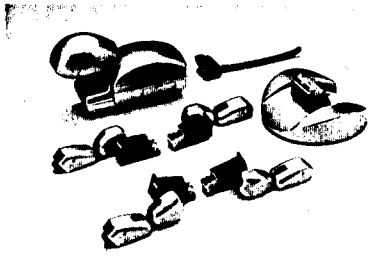
Physically Reconfigurable Agent

- Configurable Physical Compoments
- Three-Layer Architecture
  - Hardware Abstraction Layer
  - System Service Layer
  - Application Layer
- Generic System Functional Reference Model

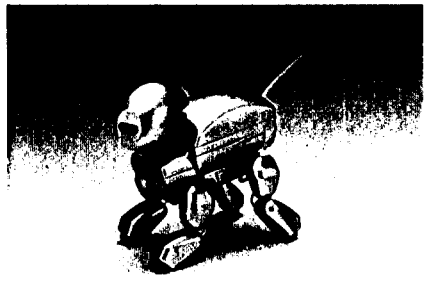
OpenR Standard

- Industrial Standard for Reconfigurable Mobile Robots mainly designed for robot entertainment
- Meets Various Scalability Requirements
  - Size (Number of Modules)
  - Style (Legged, Wheel, Flying, Multi-CPU,...)
  - Complexity / User skills
- Hot Plug-in and Play and Software Interoperability

Sony Reconfigurable Legged Robot based on OPENR Standard



Legged Configuration



Wheel-Based Configuration with Arms

RoboCup-98 Paris

Sony Legged Robot League was organized for research of legged robot teamwork.
Participated by:
Carnegie Mellon Univ.
Osaka U.
Paris-VI.

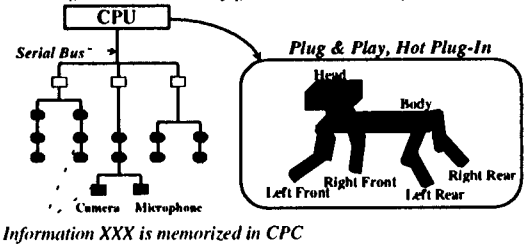
More teams will participate in RoboCup-99 Stockholm.

Configurable Physical Components

- Standard Interface
  - Physical
  - Electrical
  - Software
- Embedded Chip stored basic properties of the CPC module

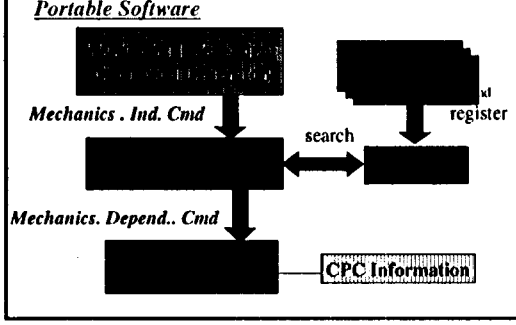
OPEN-R: Configurable Physical Component

CPU recognizes the robot configuration automatically

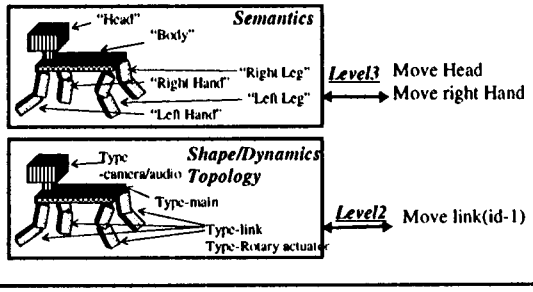


Information XXX is memorized in CPC

Mechanics Independent Layer for Software Portability



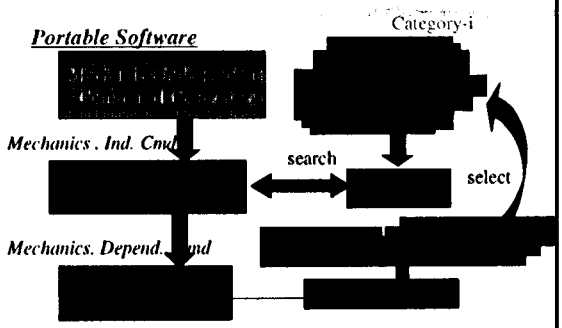
Information in a CPC



Hot Plug-in and Play

- Reconfigure Robot
- Master CPU probes physical configuration
- Create a Virtual Robot (A model of self)
- Adapt middle-ware software for a new body
- Execute applications

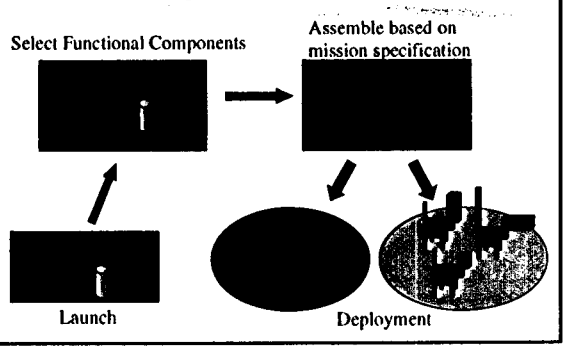
Categorization Method



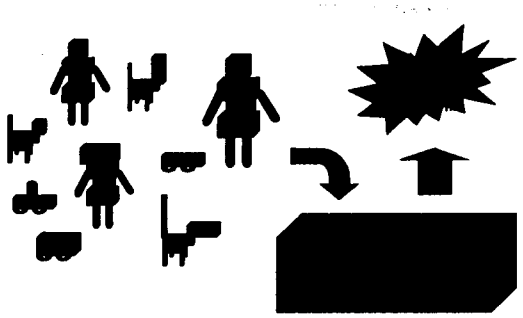
On-The-Fly Assembly

- Launch semi-assembled systems and modules from Earth.
- Start final assembly near the orbit using intact modules.
- Reconfigure or replace modules during exploration on surface of the planet.

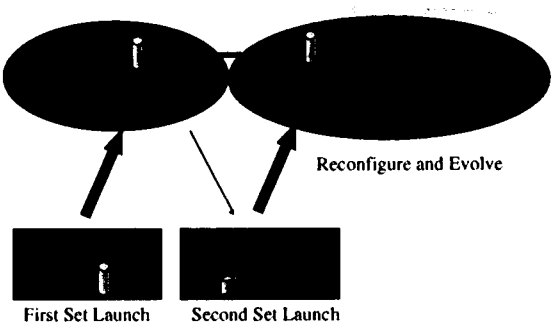
On-The-Fly Assembly



Evolution and Adaptation



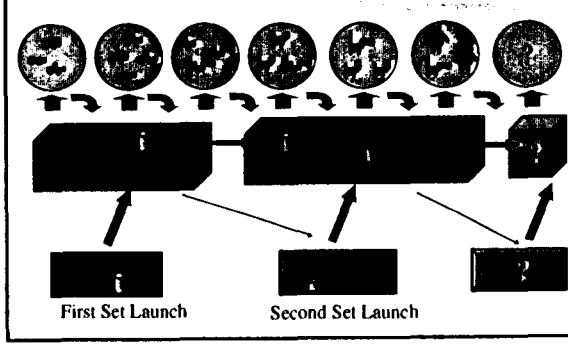
Generation and Style Scalability



Generation and Style Scalability

- 2010: First Set Launch
- 2012: Configure and Exploration Mission on Europa, and send back Terran Information.
- 2014: Design new modules
- 2015: Second Set Launch with new technology
- 2017: Reconfigure Exloprer with old and new modules.

Combining On-The-Fly Reconfiguration and Generation Scalability



Conclusion

- A new and emergent technologies enables totally new type of explorer systems.
- Industrial Standard is now being proposed, which reduces cost for such systems.
- It can be reconfigurable, adaptive, and cost-effective.
- More ideas can be generated systematically along this technology.