Morphogenetic Self-Reconfiguration of Modular Robots

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Outline

- Motivation / Introduction
- Background
- Applications
- Evaluation
- Conclusion

Modular Robotic Systems

- Robots with **variable morphology**
  - Reorganizing the connectivity of modules
  - Perform new tasks, adapt to new environments, recover from damage
- Consists of **independent units**: connect/disconnect

Potentially more **robust** and more **adaptive** under dynamic environments

Modular Robotic Systems – Classification

Chain-based:

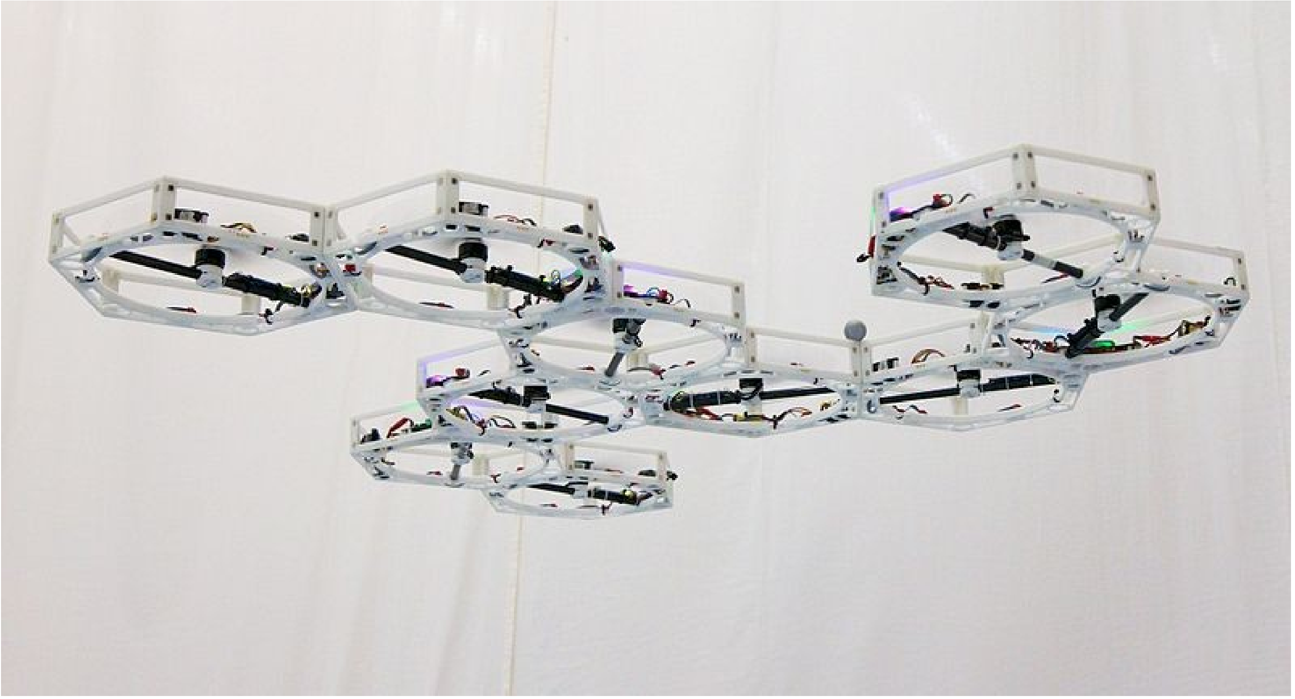
- **Pro**: scalable, easy motion planning
- **Con**: can't build complex 3D patterns

http://www.iearobotics.com/wiki/images/4/48/Modular-snake-usar-1.jpg

Modular Robotic Systems – Classification (cont.)

Lattice-based:

- **Pro**: easy build of complex 3D patterns
- **Con**: complicated control and motion planning

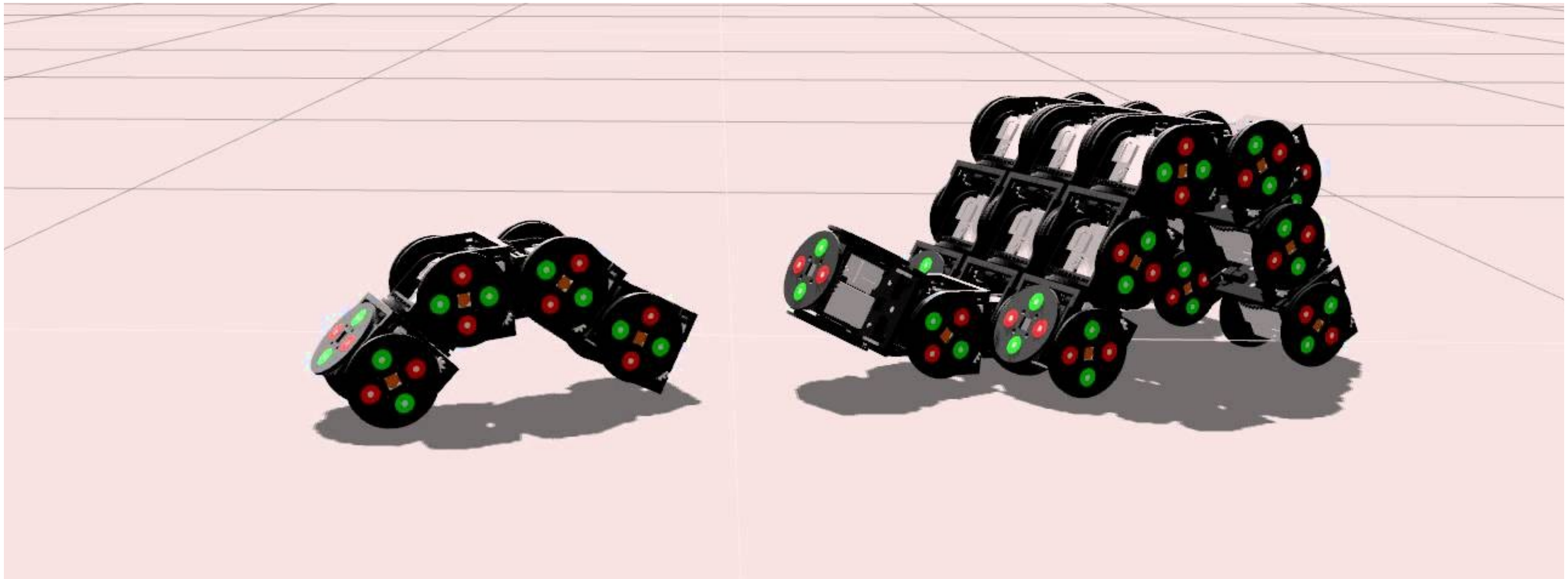


https://upload.wikimedia.org/wikipedia/commons/thumb/5/5c/The_Distributed_Flight_Array.jpg/800px-The_Distributed_Flight_Array.jpg

Modular Robotic Systems – Classification (cont.)

Hybrid approaches:

- Integrates advantages of chain and lattice based classes
- M-TRAN II + III, SUPERBOT, SMORES



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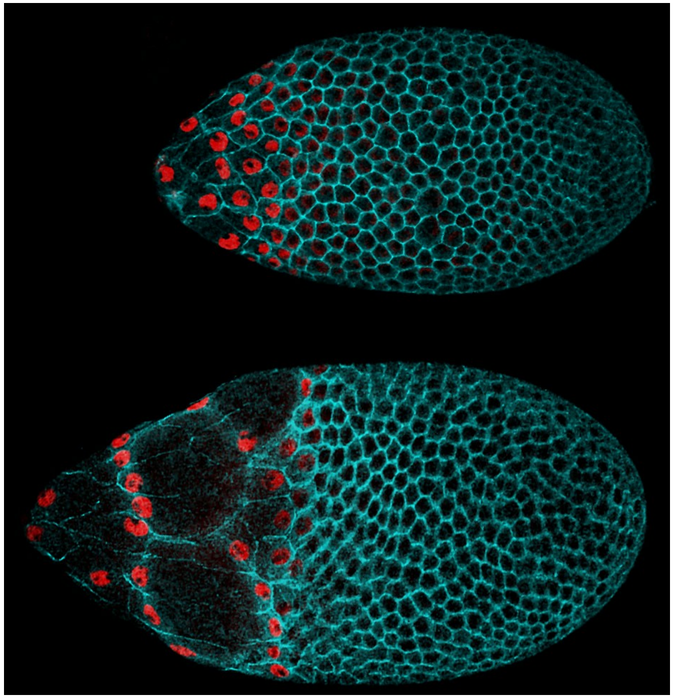
Morphogenesis

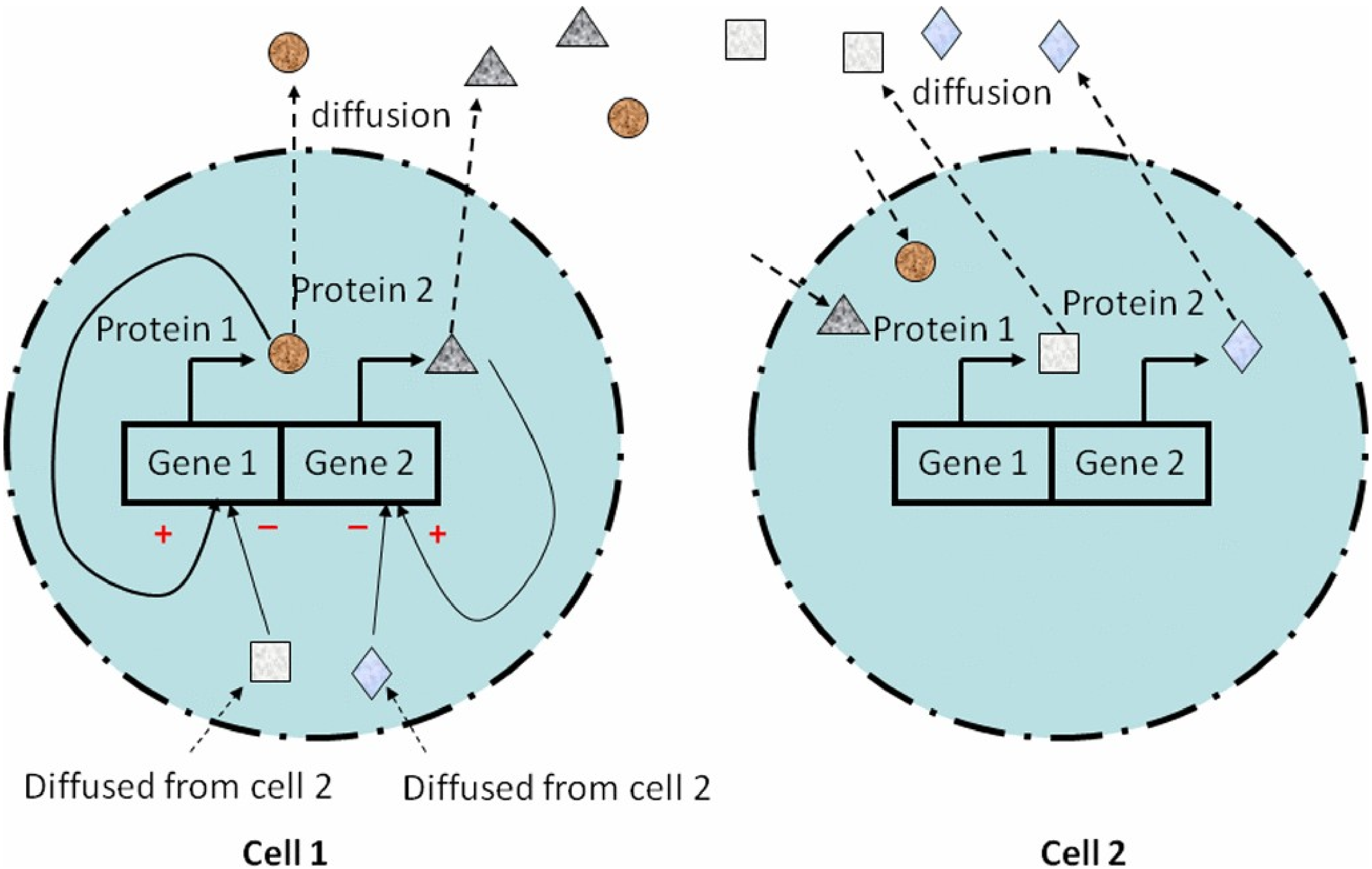
Morphogenesis = "biological pattern formation"



https://mcb.berkeley.edu/labs/bilder/images/Morphogenesis/Picture5.jpg

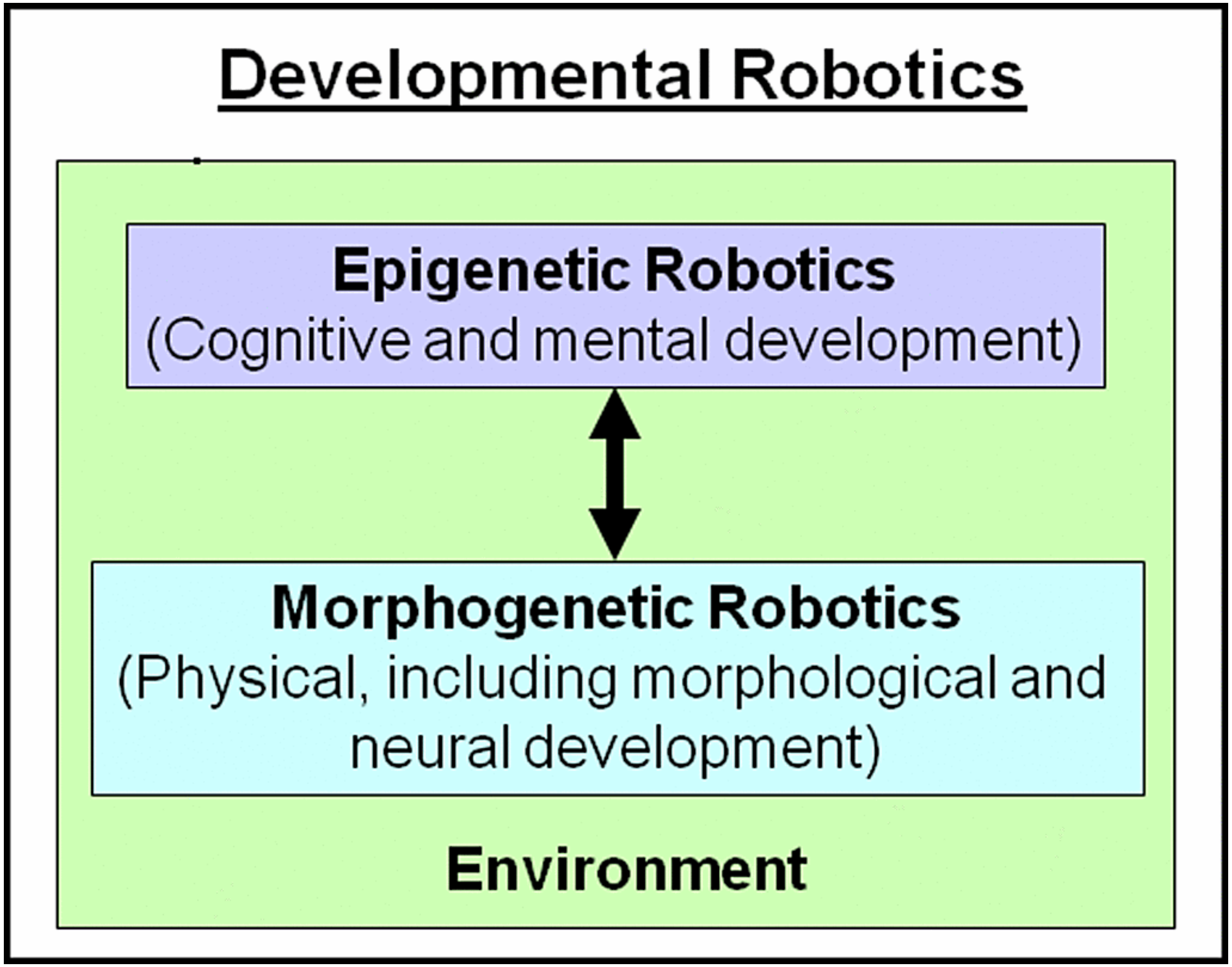
http://www.livescience.com/images/i/000/037/153/original/zebra.jpg

Gene Regulatory Networks (GRNs)



[1]

What is Morphogenetic Robotics?



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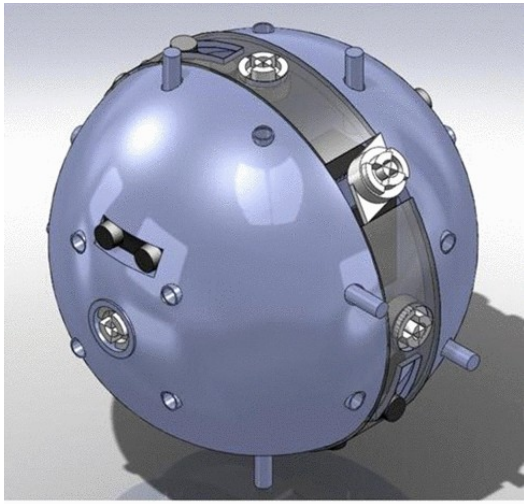
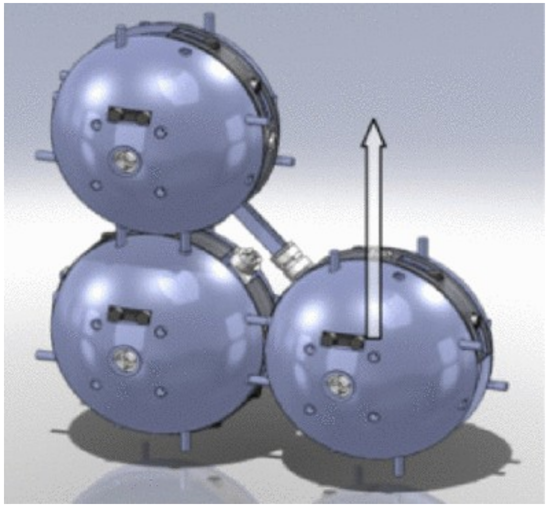
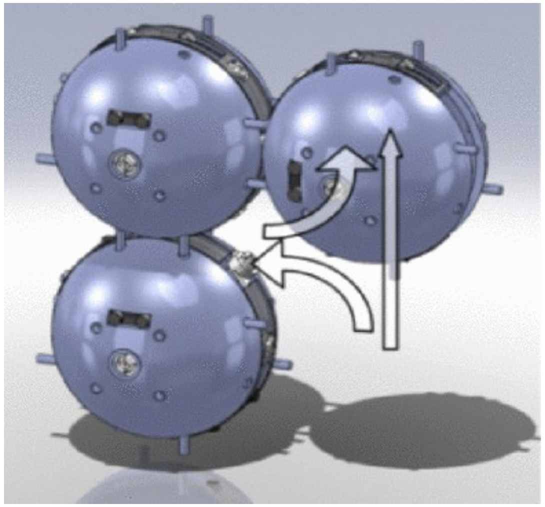
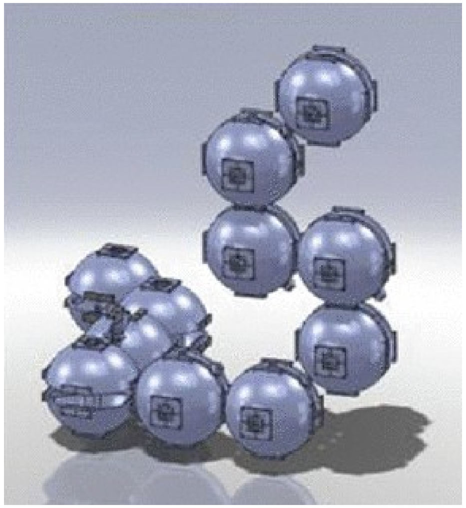
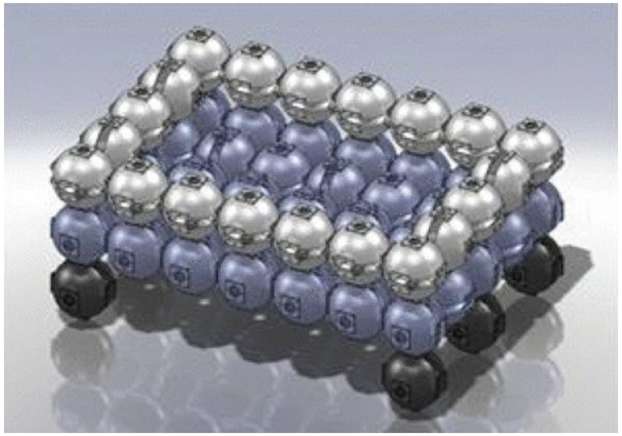
Cross-Ball

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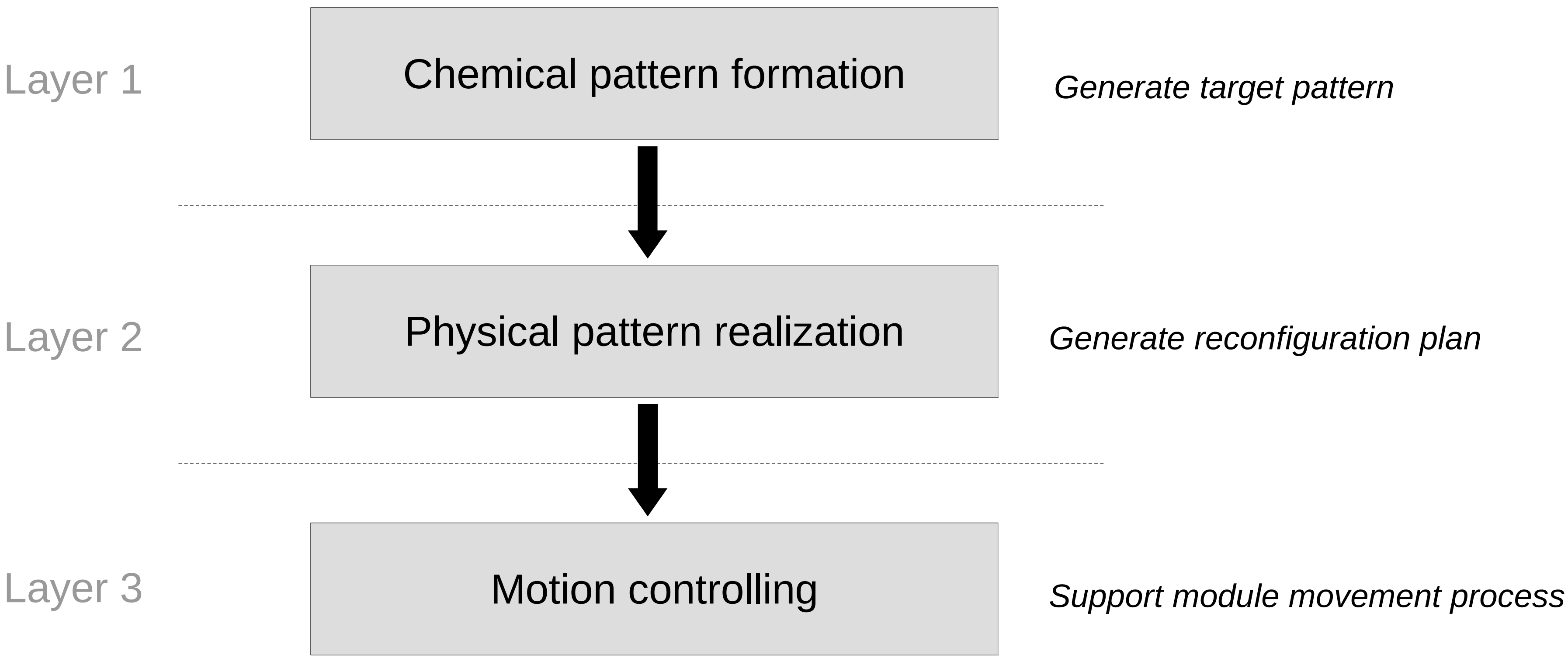
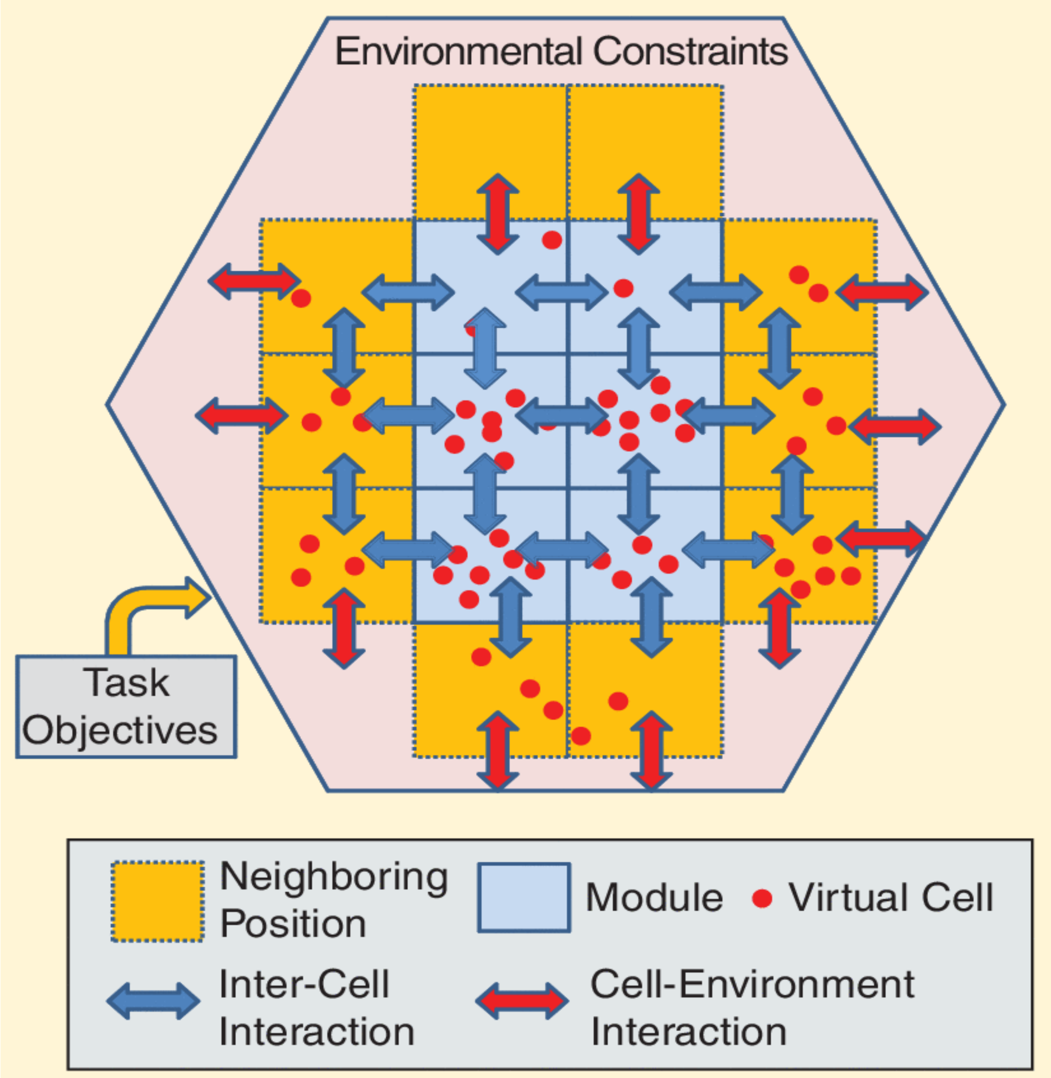
Cross-Ball: Hierachical Morphogenetic Model



Layer 1: Chemical pattern formation



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Layer 1: Chemical pattern formation (cont.)

Change of v-cell density in grid *i*:

$$\frac{dn_i}{dt} = r \cdot n_i (N - n_i) - d \cdot K_i \cdot M_i - a \cdot \frac{\rho_i}{n_i + \rho_i} + \sum_k n_k^{rec}$$

$K_i = [k_i^{up}, k_i^{down}, k_i^{left}, k_i^{right}, k_i^{forward}, k_i^{backward}]^T$

$M_i = [m_i^{up}, m_i^{down}, m_i^{left}, m_i^{right}, m_i^{forward}, m_i^{backward}]^T$

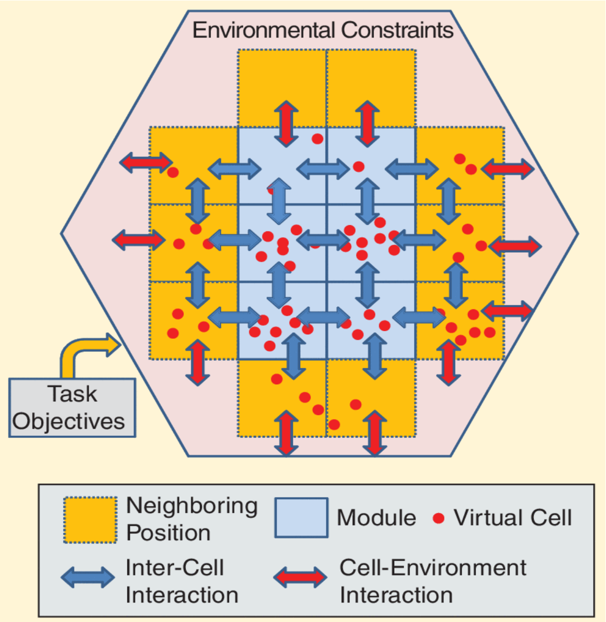
N : maximum number of v-cells in the grid

K_i: dispersal control vector

M_i: density gradient vector

ρ_i : ECM-value (environmental constraint)

r,d,a: predefined constants



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Layer 1: Chemical pattern formation (cont.)

Change of ECM value in grid i:

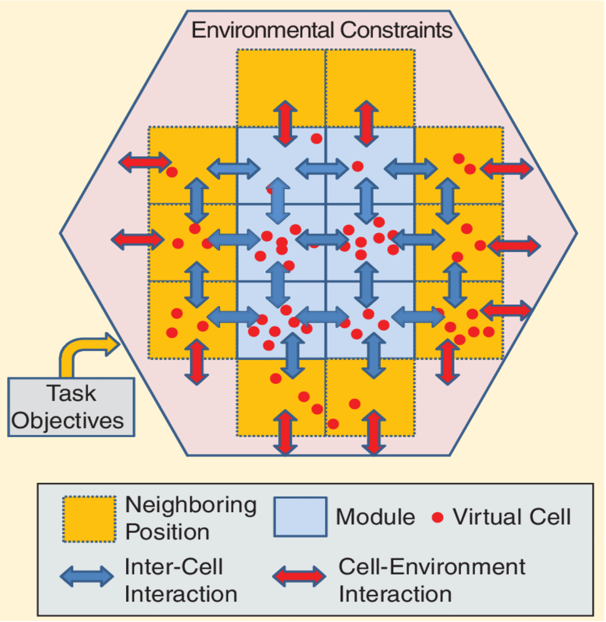
$$\frac{d\rho_i}{dt} = -b \cdot \frac{n_i}{n_i + \rho_i} + e \cdot \sum_j f_{ji}(n_j)$$

$f_{ji}(n_j)$: function rules depend on desired pattern (e.g. vehicle pattern)

b,e : predefined constants

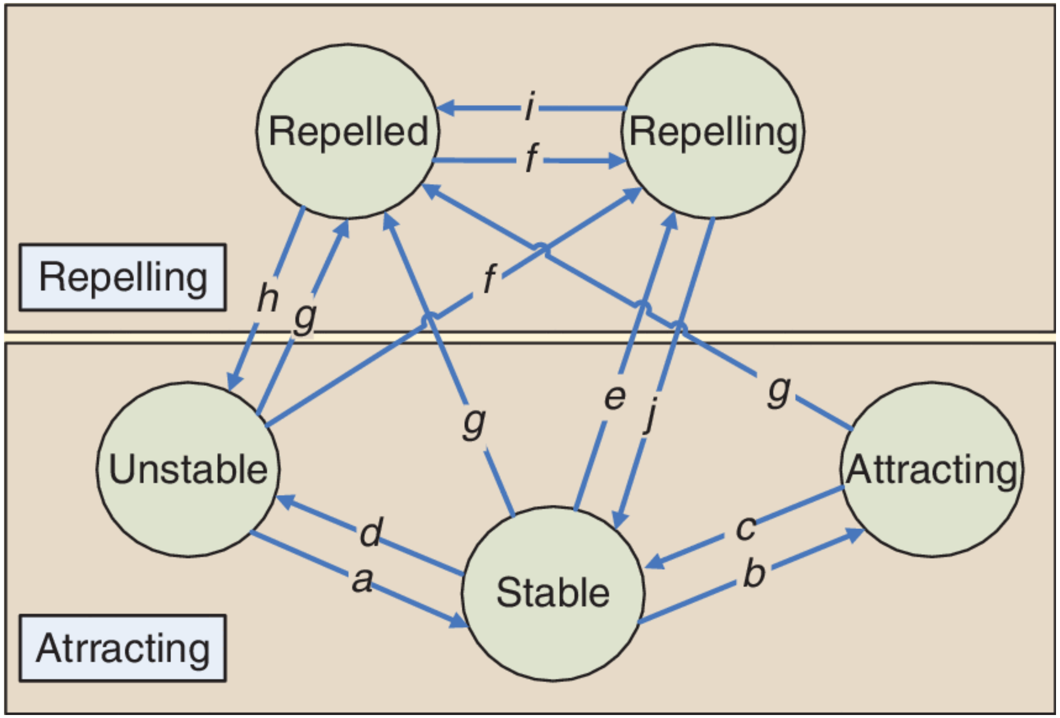
Morphogen level of grid i = $\Delta(n_i, \rho_i)$

[3]



Layer 2: Physical pattern realization

- Target pattern known
- **State transitions** controlled by a GRN model:
  - Attracting gene-protein pair (g_A, p_A)
  - Repelling gene-protein pair (g_P, p_P)



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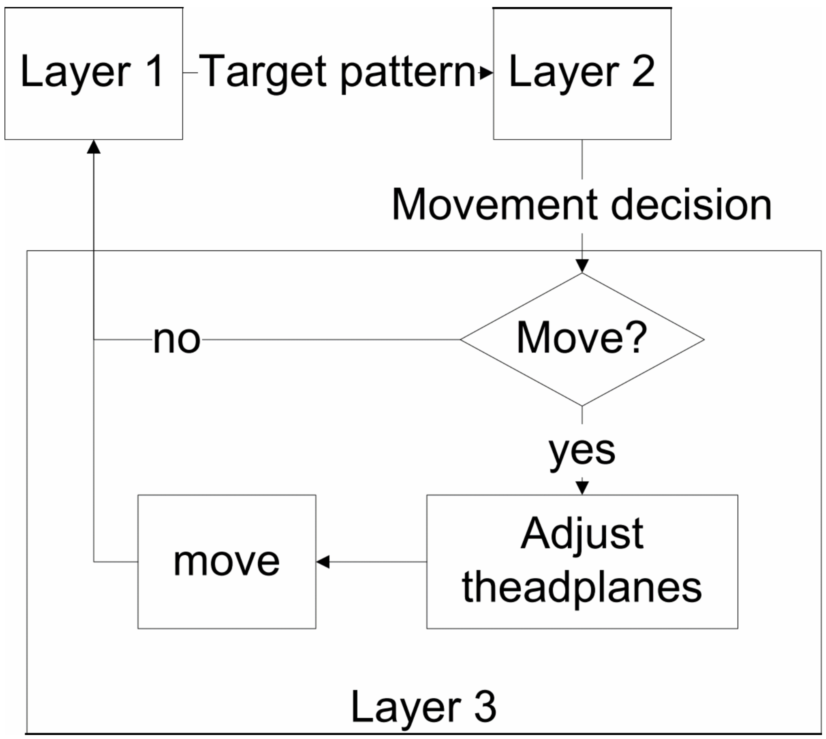
- Modules with a **higher morphogen level** are more likely to **attract** other modules
- Modules with a **lower morphogen level** are more likely to **be repelled**

Layer 3: Motion controlling

- Evaluate self-reconfiguration plan generated from layer 2 controller
- Hardware-specific controller
- Introducing **skeleton modules** and allow modules to work in groups



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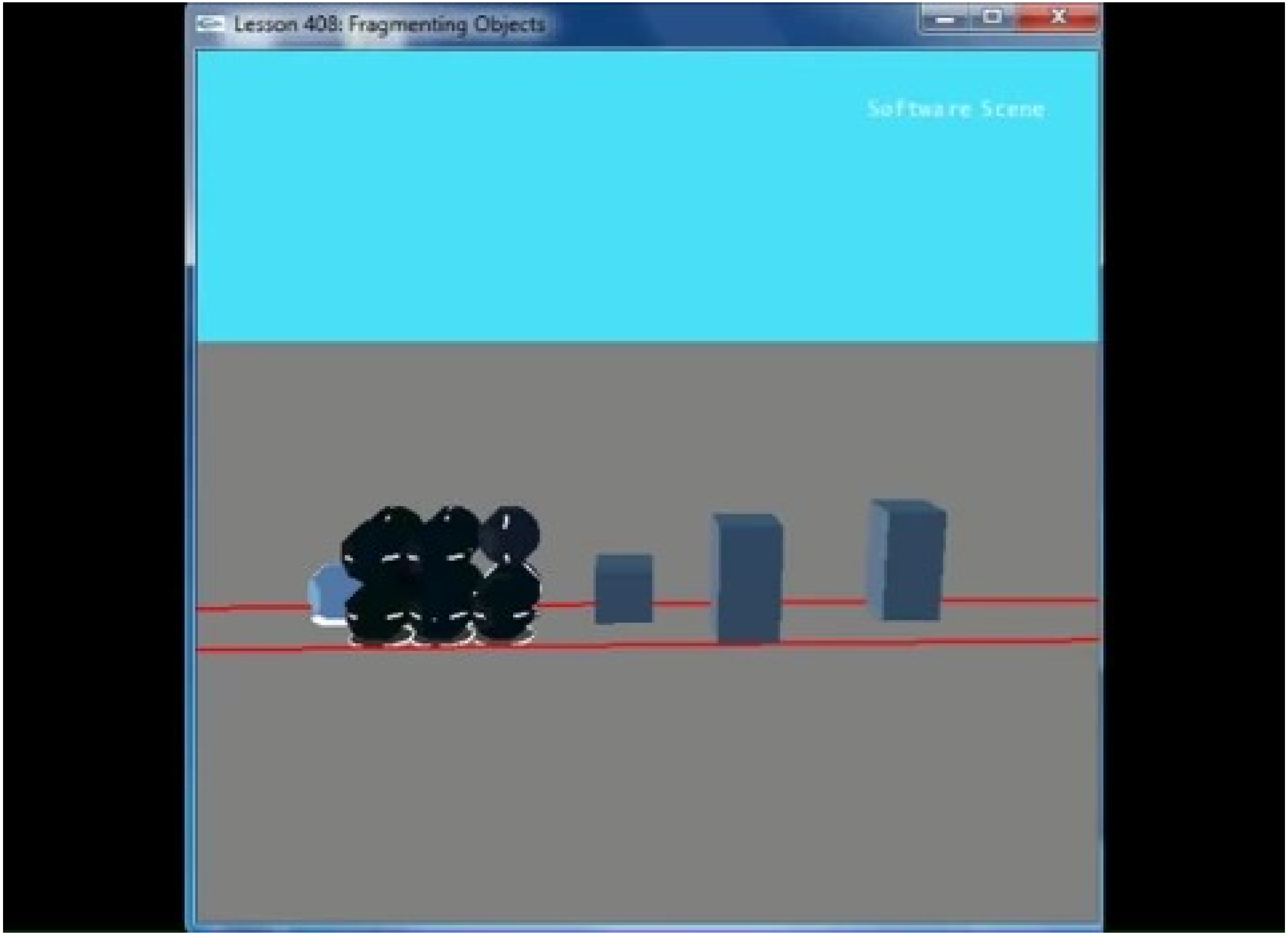
Reducing complexity of searching process on the module movement plan

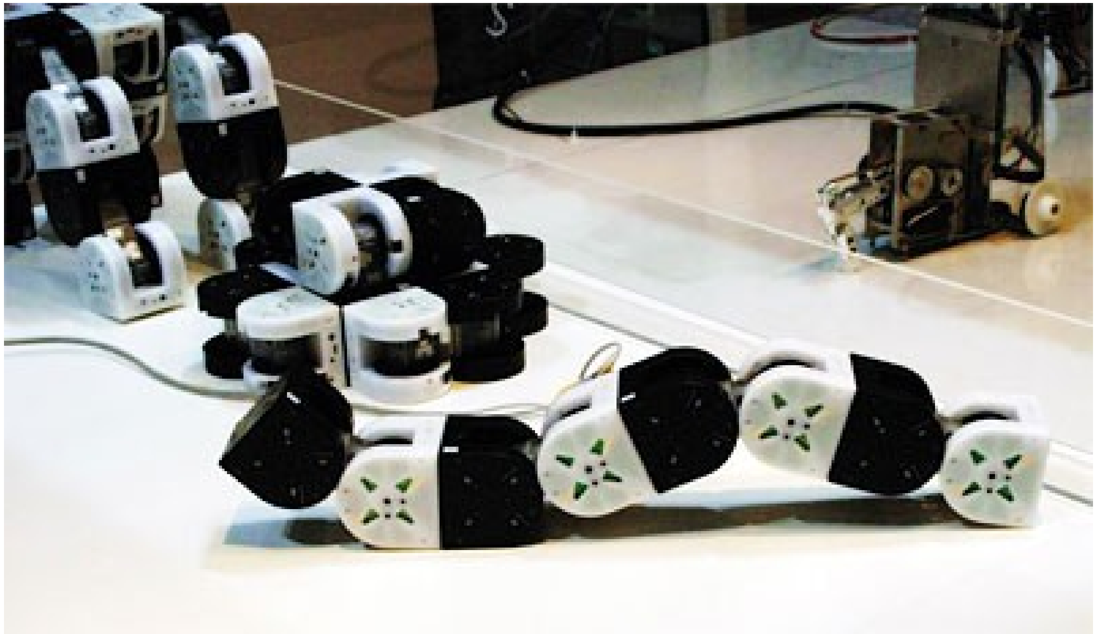


https://www.youtube.com/watch?v=z9yemQJtyQg

M-TRAN III

Modular Transformer III:

- Developed by AIST and Tokyo-Tech (since 1998)
- Hybrid design



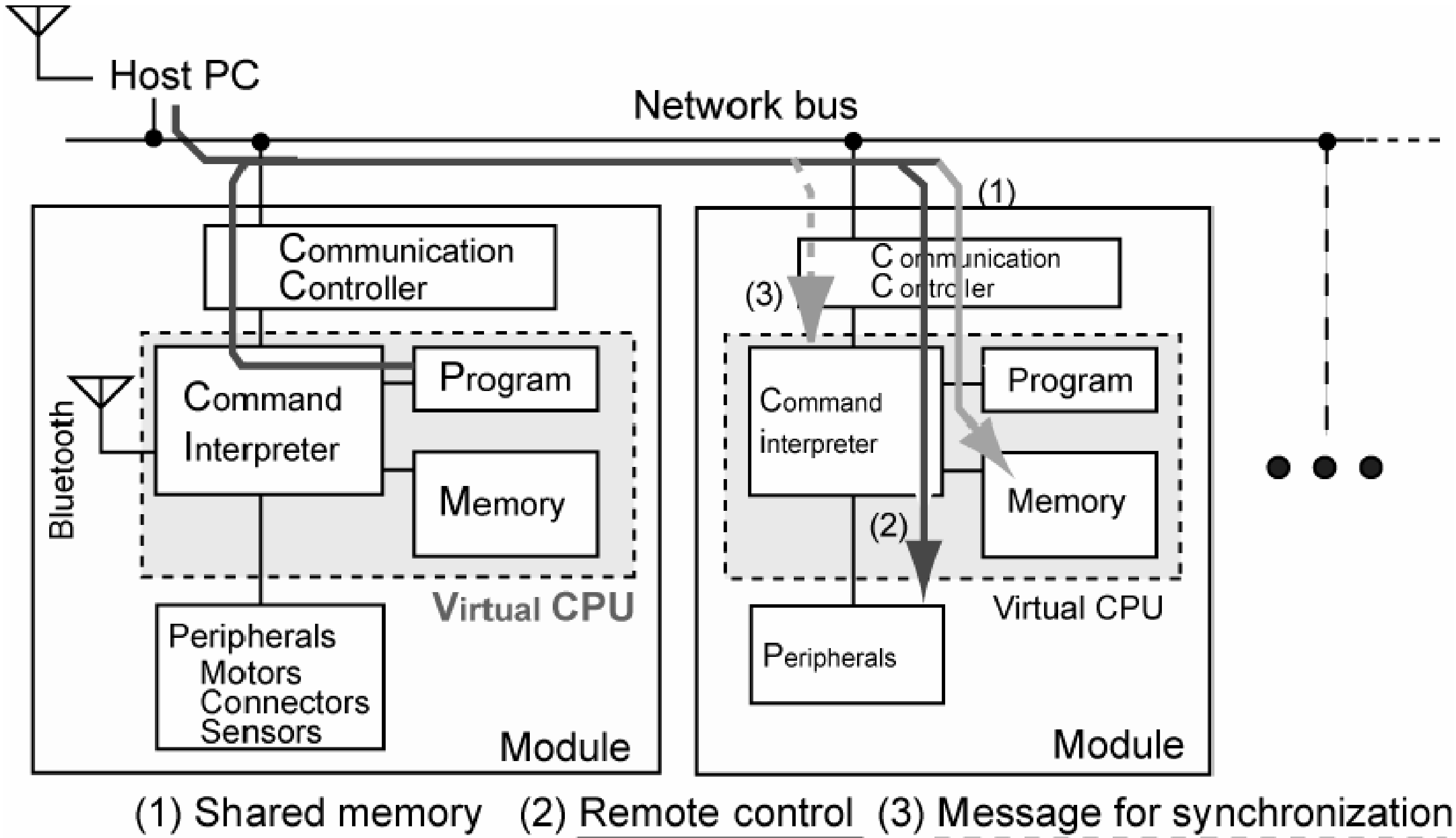
http://www.tech-blog.pl/wordpress/wp-content/uploads/2008/05/modular-robot_m-tran.jpg

https://unit.aist.go.jp/is/frrg/dsysd/mtran3/mtran123.jpg

M-TRAN III (cont.)

Module Control:

- Centralized or distributed
- Communication via bus
  → Controller Area Network (CAN)



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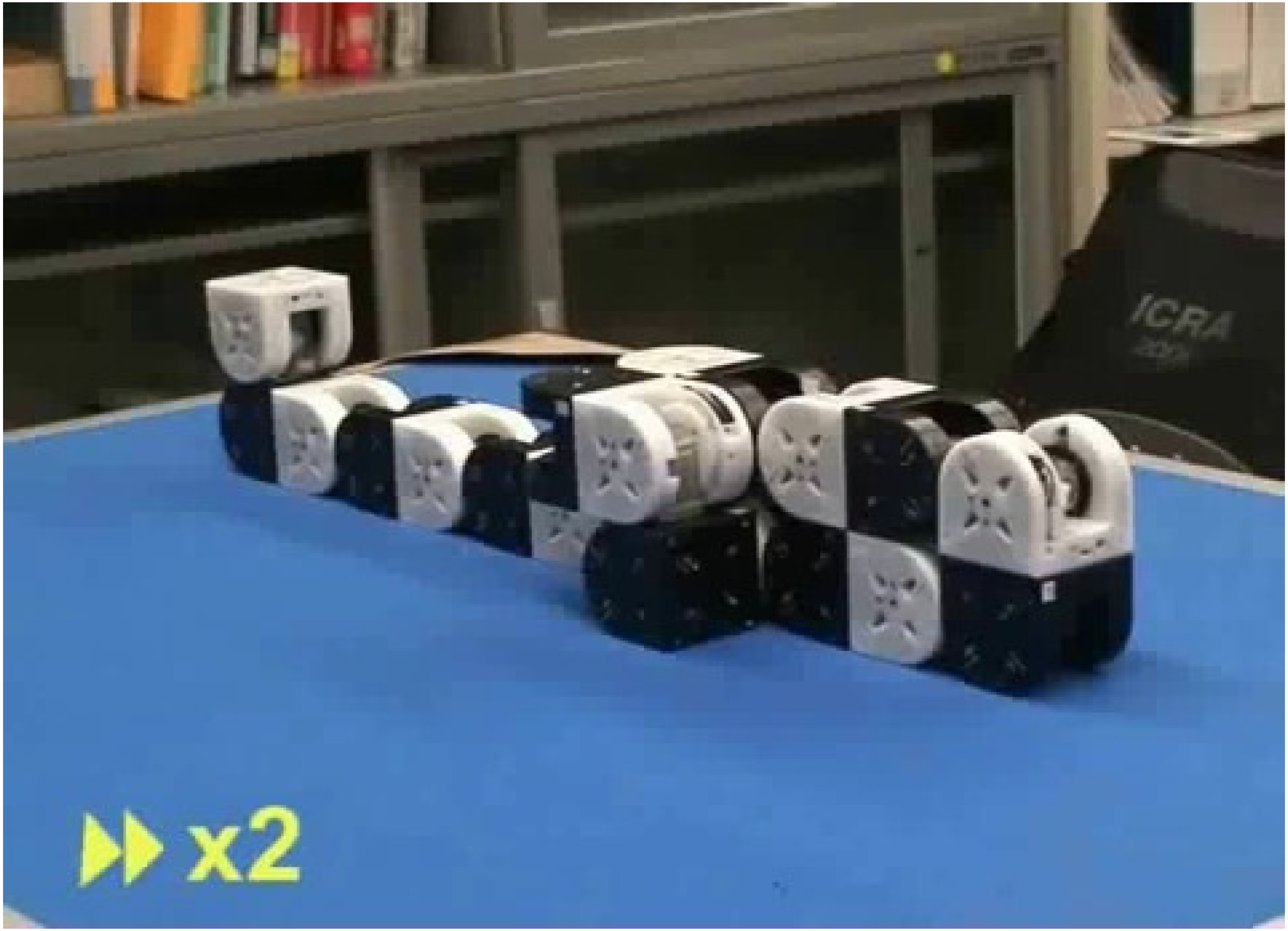

https://www.youtube.com/watch?v=4oSavAHf0dg

Comparison of Cross-Ball and M-TRAN III

	Cross-Ball	M-TRAN III
Design	• Hybrid design	• Hybrid design
Experiments	– Embodied simulation environment	+ Physical prototype
Controlling mechanism	• Bio-inspired approach using the theory of morphogenesis with GRNs + Completely independent modules	• Distributed controller and global communication using a network bus • Mostly independent modules
Autonomy	+ Fully autonomous self-reconfiguration (target pattern dependent on predefined function).	– No autonomous self-reconfiguration.
Scalability	• Successful simulation using 27 modules + Theoretically no limitations	• Successful experiments using 24 modules – Limited by global bus and ID numbering (max. 50 modules)

Conclusion

Advantages

- Modularity reduces cost of design, manufacturing, maintenance
- Easy adaptation to changes in the environment
- Robust to system failures, malfunctions
- Ability for self-repairing
- Hierarchical framework almost completely generic

Future work

- Build and evaluate physical design
- Simplify controllers to further reduce complexity and computational costs

Questions?

Thank you for your attention!

Literature

[1] Jin, Y., & Meng, Y. (2011). Morphogenetic robotics: An emerging new field in developmental robotics. Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 41(2), 145-160.

[2] Kurokawa, H., Tomita, K., Kamimura, A., Kokaji, S., Hasuo, T., & Murata, S. (2008). Distributed self-reconfiguration of M-TRAN III modular robotic system. The International Journal of Robotics Research, 27(3-4), 373-386.

[3] Meng, Y., Zhang, Y., & Jin, Y. (2011). Autonomous self-reconfiguration of modular robots by evolving a hierarchical mechanochemical model. Computational Intelligence Magazine, IEEE, 6(1), 43-54.

[4] Meng, Y., Zhang, Y., Sampath, A., Jin, Y., & Sendhoff, B. (2011, May). Cross-ball: a new morphogenetic self-reconfigurable modular robot. In Robotics and Automation (ICRA), 2011 IEEE International Conference on (pp. 267-272). IEEE.