Towards Artificial ATRON Animals:

Scalable Anatomy for Self-Reconfigurable Robots

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Robotics: Science & Systems
Workshop on Self-Reconfigurable Modular Robots
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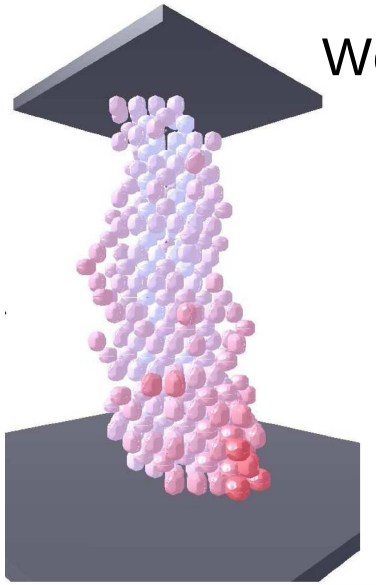

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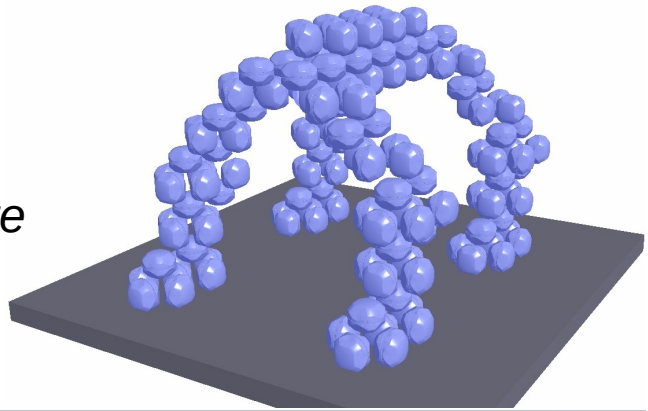
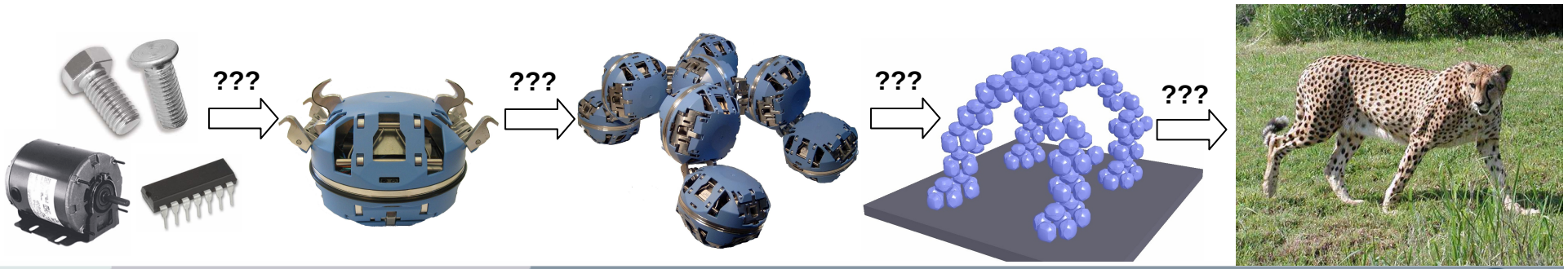


Overview

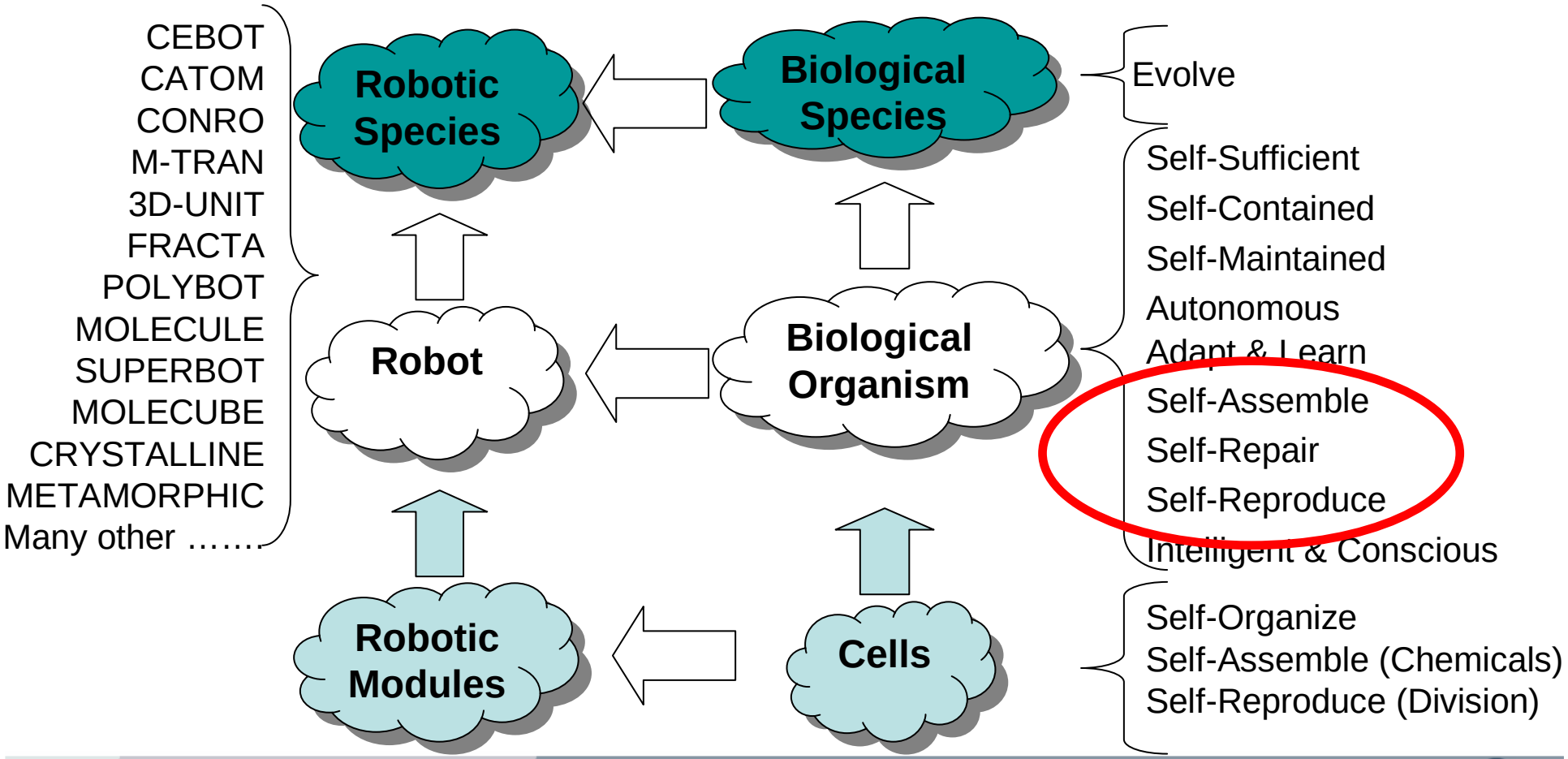
- Why study Self-Reconfigurable robots?
- The ATRON system.
- Scaling the robot.
- Challenge of Scalable Functionality
- Scalable Anatomy for ATRON robots
- Discussion, Future work & Summary



Why Study Self-Reconfigurable Robots?

Purpose from Scientific Perspective?

- **Understand, explain** and **recreate** the characteristics of **life!!**



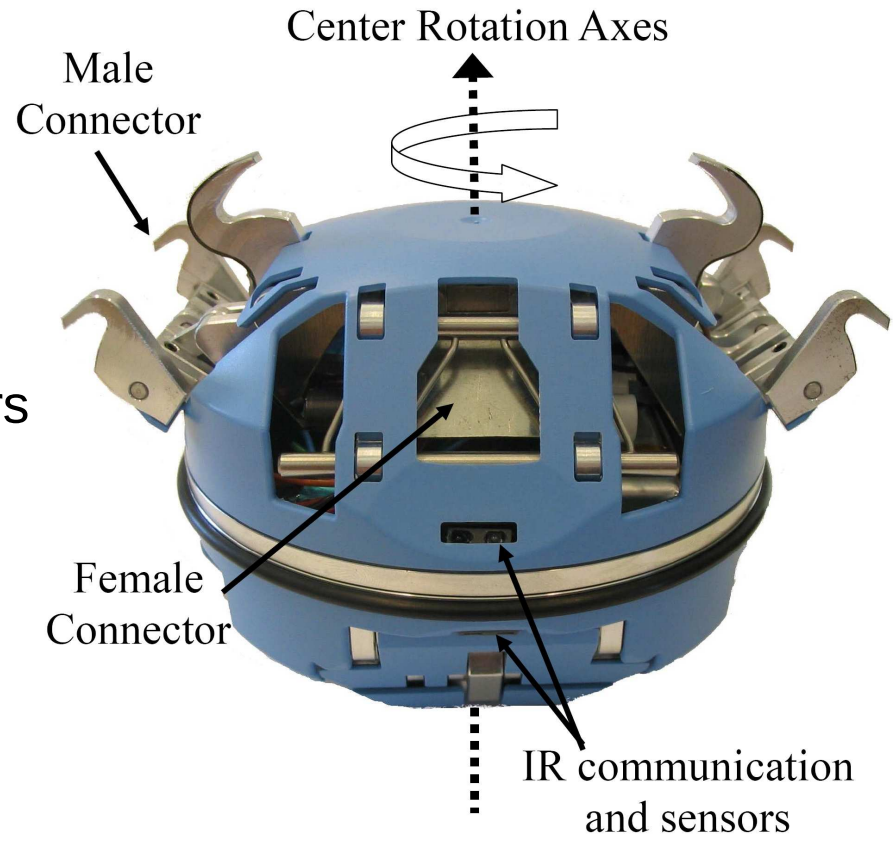
Purpose from Engineering Perspective?

- We want to build Better Robots!
- Why should it Modular?
  - Multi-Purpose => **Versatility** (by clever design)
  - Mass-Produce => **Low Cost**
  - Extendable => **Scalable**
- Why should it be Self-Reconfigurable?
  - Self-Repair => **Reliable** & **Robust** (from redundancy)
  - Self-Assembly => **Automated Production**
  - Adaptation => **Increased Performance** (both functional and morphological adaptation)

ATRON

Our Platform: The ATRON System

- Module Characteristics:
  - Single degree of freedom
  - 4 male, 4 female connectors
  - Batteries (had power sharing)
  - Computation, communication,
  - Sensing: Distance, Tilt, Encoders
  - 800 grams pr. module
- Manufactured: 100 modules



Versatility of the ATRON System

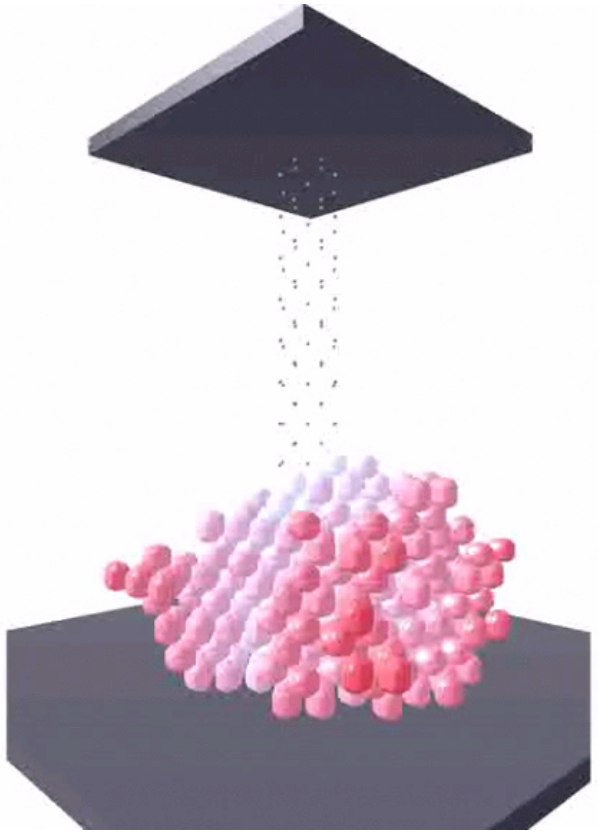
- Manipulation & Locomotion

(Real Time)

Versatility of the ATRON System

- Self-Reconfiguration

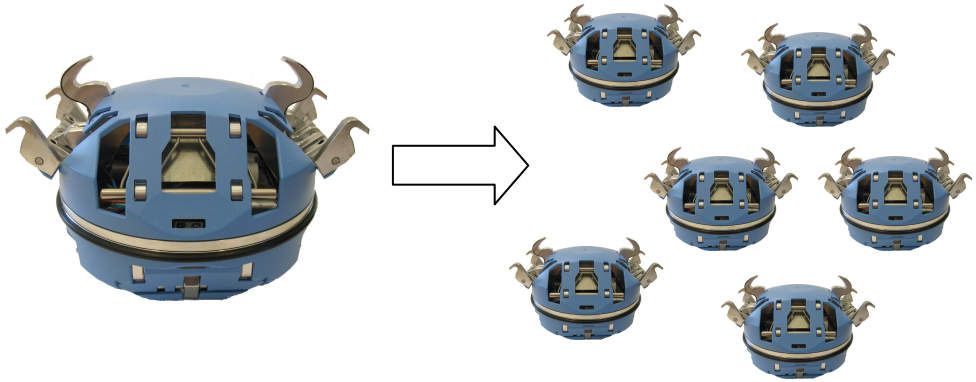
(8x Speed)



Scaling

Scaling the Robot

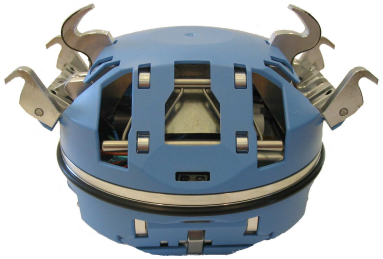
- Scaling down module size (cm to µm)
- Scaling up number of modules (tens to millions)



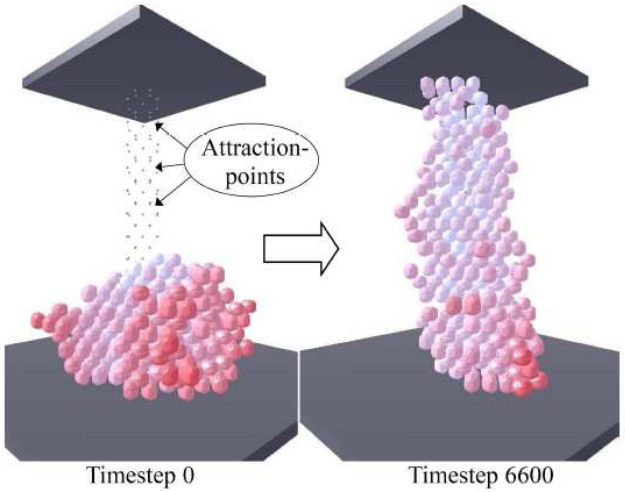
- Why?
  - Closer to the cell metaphor.
  - Improve engineering metrics (e.g. resolution of shape)

Scalability Challenges of Self-Reconfigurable Robots

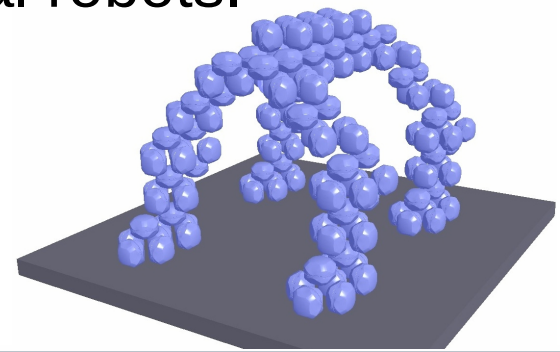
- What are the Challenges?
  - **Hardware**
    - What to build?



  - **Self-Reconfiguration**
    - Morph between configurations.



  - **Functionality** **(THIS TALK!)**
    - Fast responding and functional robots.

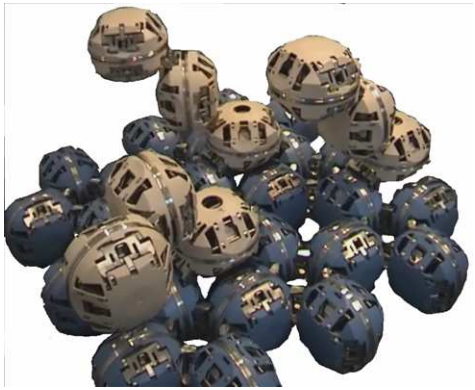


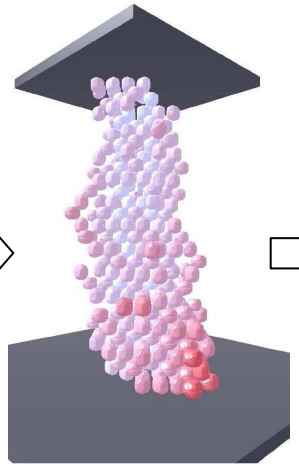
  - Many other challenges….

Challenge of Scalable Functionality

The Challenge of Scalable Functionality

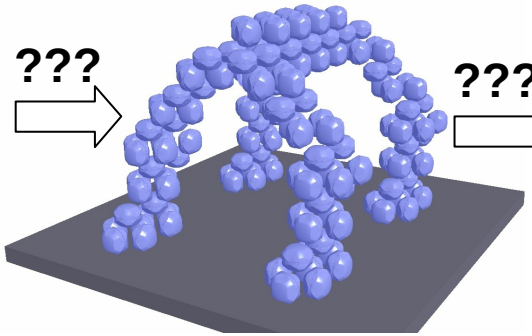
Number of Cells/Modules





Speed of Response
Complexity of Functionality

???



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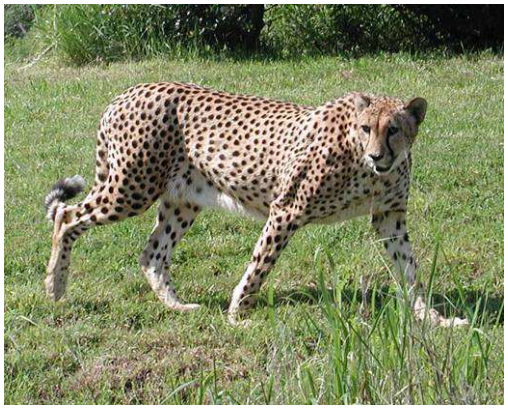


What is the problem anyway?

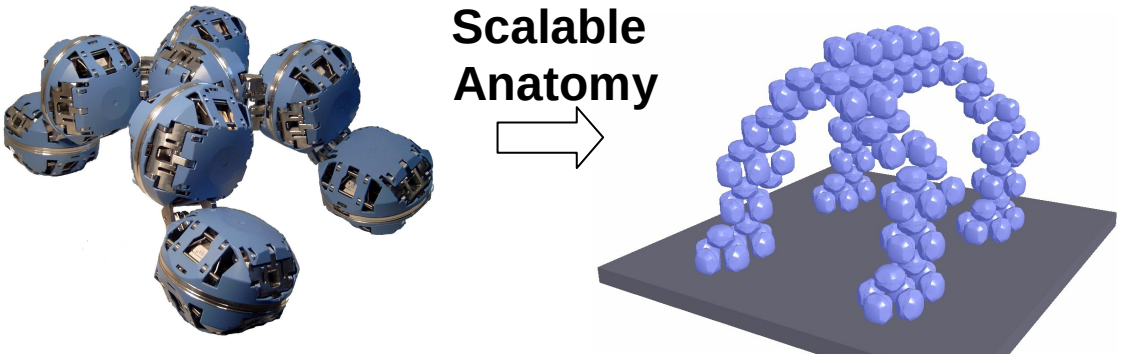
- Self-Reconfiguration too slow: (for fast response)
  - Slower with more modules (more moving)
  - Faster with smaller modules (faster modules)

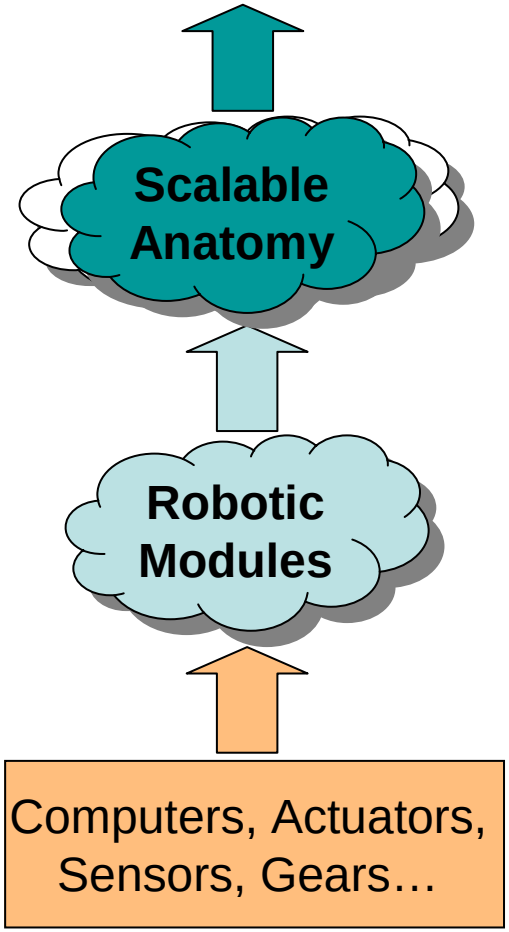
  } Basically constant with volume.
- Modules are locked rigidly:
  - Modules are stuck in a global lattice.
  - Actuation Forces does not add up.

  } Functionality reduces to self-reconfiguration.
- So scaling functionality is hard.
  - Functionality do not transfer from a 10 to a 1000 module robot

How can we approach the problem?

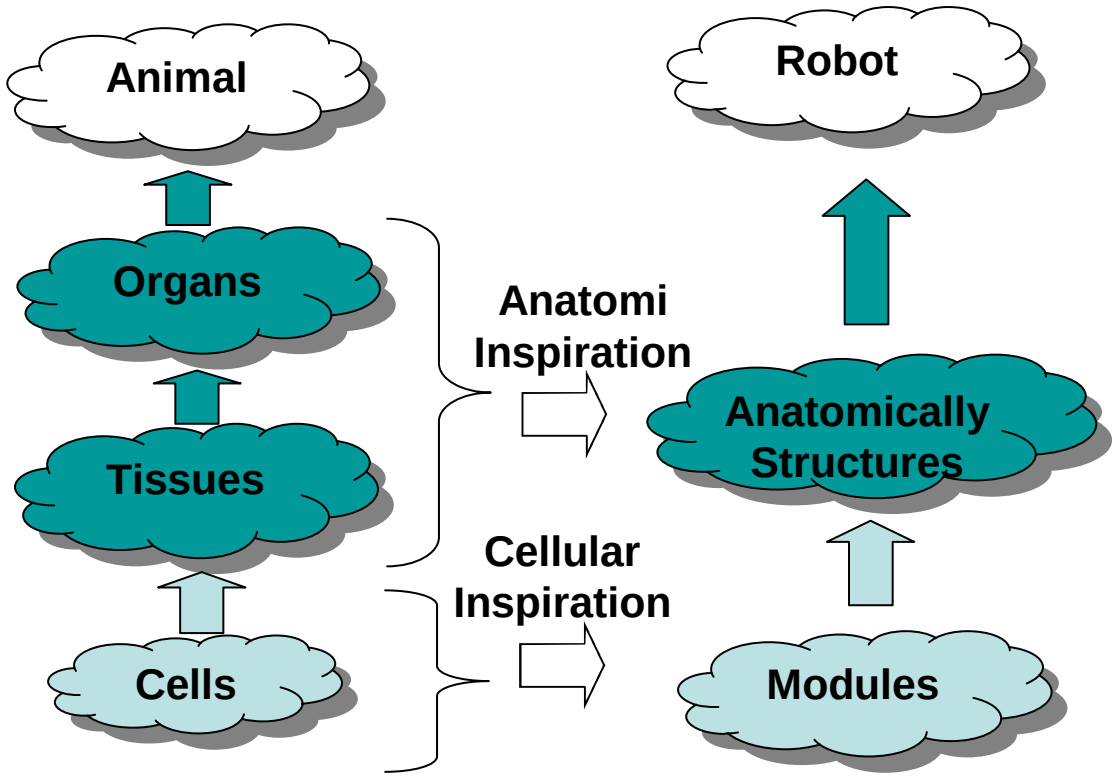
- How to build Myriad-Module Robots?
  - Functional & Fast-Responding
- Approach: Defining a Robot Anatomy
  - Biological Inspired by Animal Anatomies
  - Scalable Anatomically Structures
    - Bone, joints, muscles, nerves, etc..





Where does this comes from?

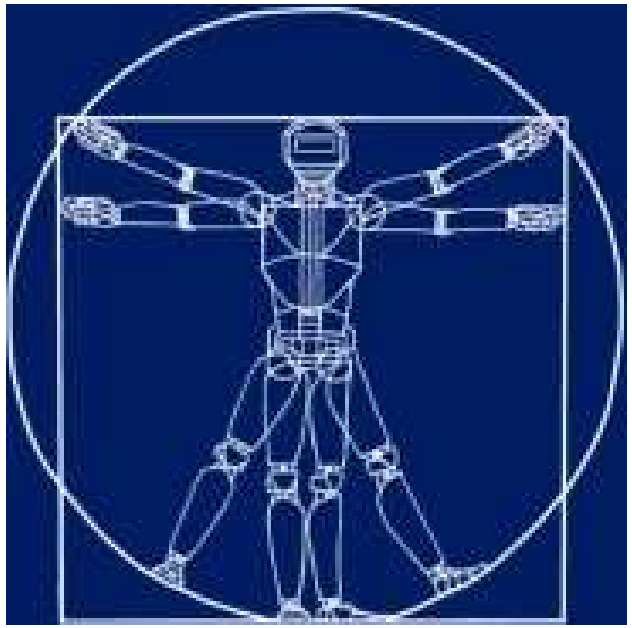
- Hieratical Organization of cells
- Differentiation dependent on role in organism



ATRON Anatomy

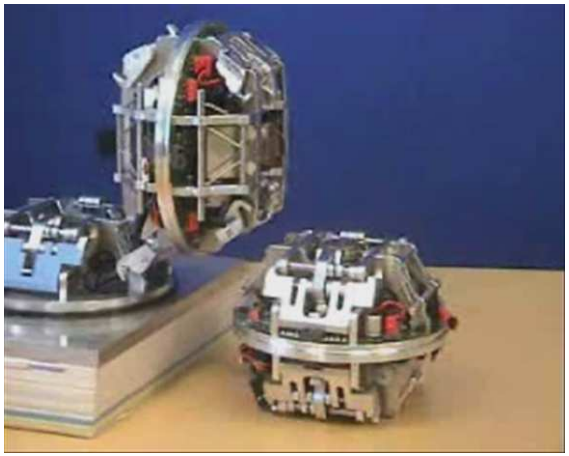
Moving from idea to system…

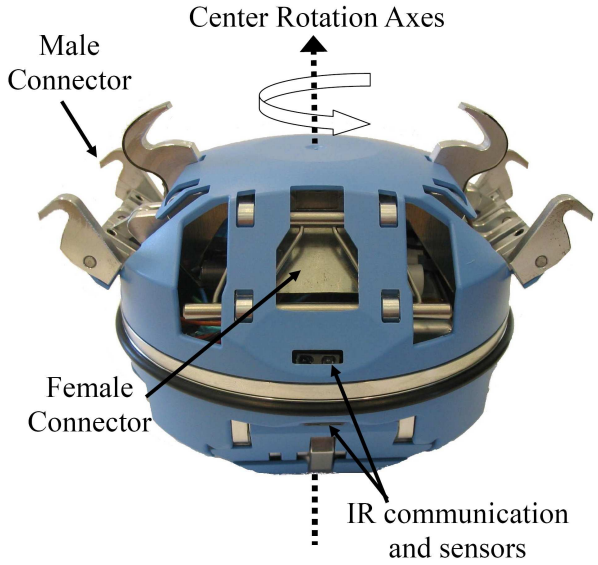
- ATRON Anatomy
  - ATRON-Nerve
  - ATRON-Arteries
  - ATRON-Bone
  - ATRON-Joint
  - ATRON-Muscle
  - ATRON-Skin

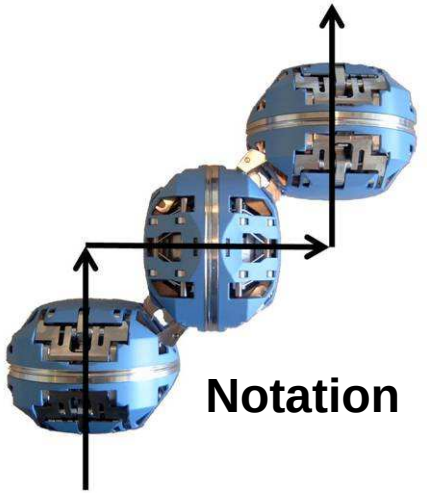


ATRON Anatomy: Neurons and Arteries

- ATRON-Neuron
  - Computation ~ Microprocessors
  - Coordination ~ IR-Communication
  - Sensing ~ Sensors
- ATRON-Artery
  - Transportation of energy ~ Power sharing







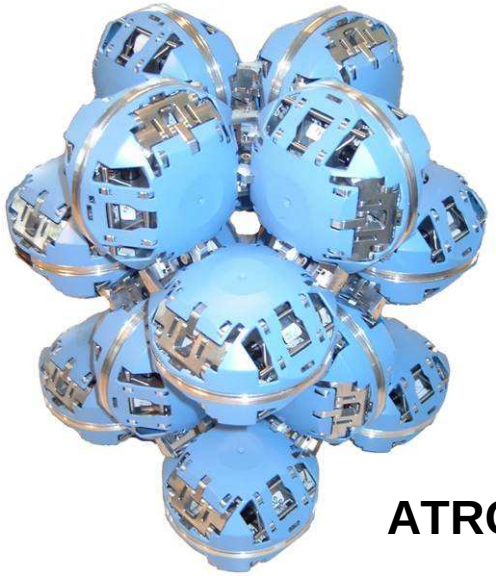
ATRON Anatomy: Bone

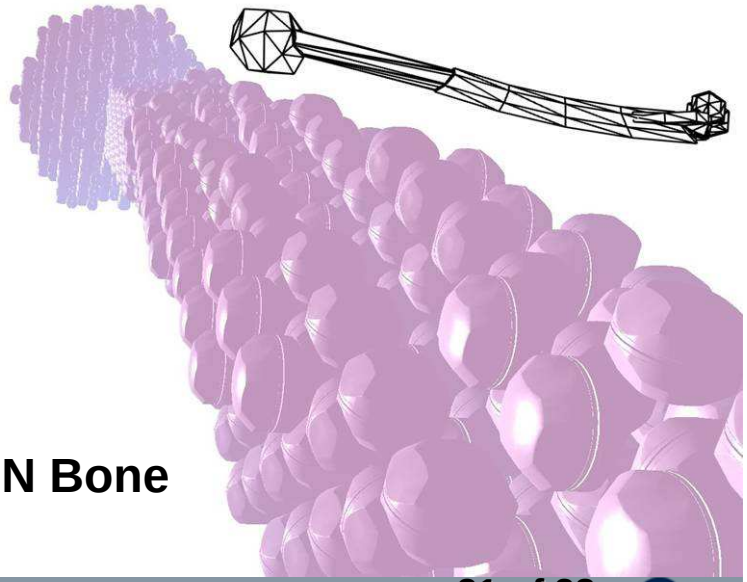
- ATRON-Bone
  - Support Weight of Robot.
  - Strong Connector.
  - Lattice Interconnection.
  - Scales in 3D.

	ATRON-Bone	Bio-Bone
Density	720kg/m^3	1900 kg/m^3
Yield Strength	0.067MPa*	50MPa

*Østergaard et al., Design of the ATRON lattice-based self-reconfigurable robot. Autonomous Robots, to appear, 2006.

Femur Bone

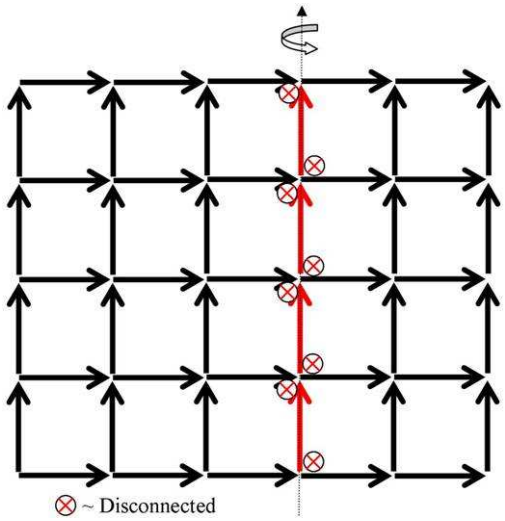




ATRON Bone

ATRON Anatomy: Hinge Joint

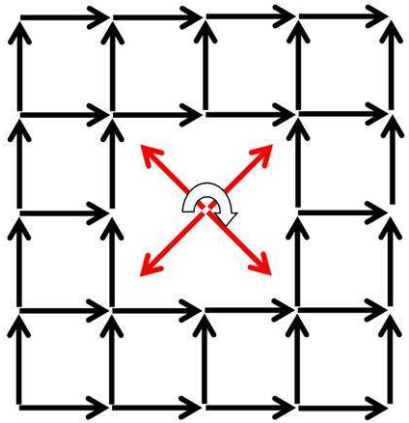
- ATRON-Joints
  - Connection and relative rotation of bones.
- Hinge Joint
  - Scales along rotational axes.
  - Reversible to global lattice.

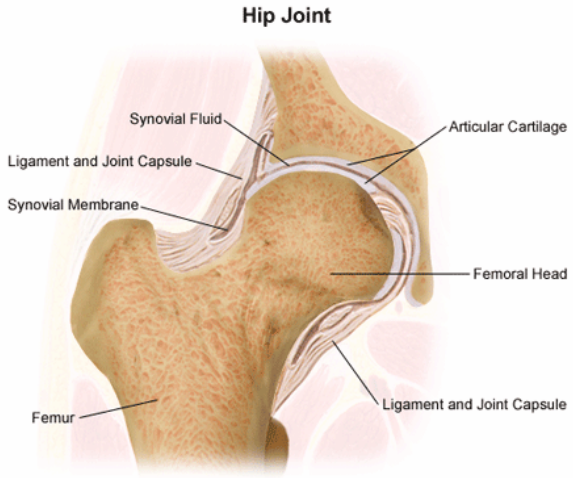


Hinge Joint

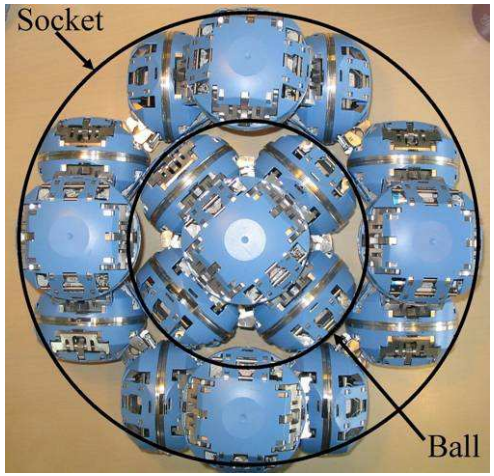
ATRON Anatomy: Ball-Socket Joints

- ATRON-Joints
  - Connection and relative rotation of bones.
- Ball-Socket Joint
  - Scalable in 3D.
  - Reversible to global lattice using muscles as anchors.





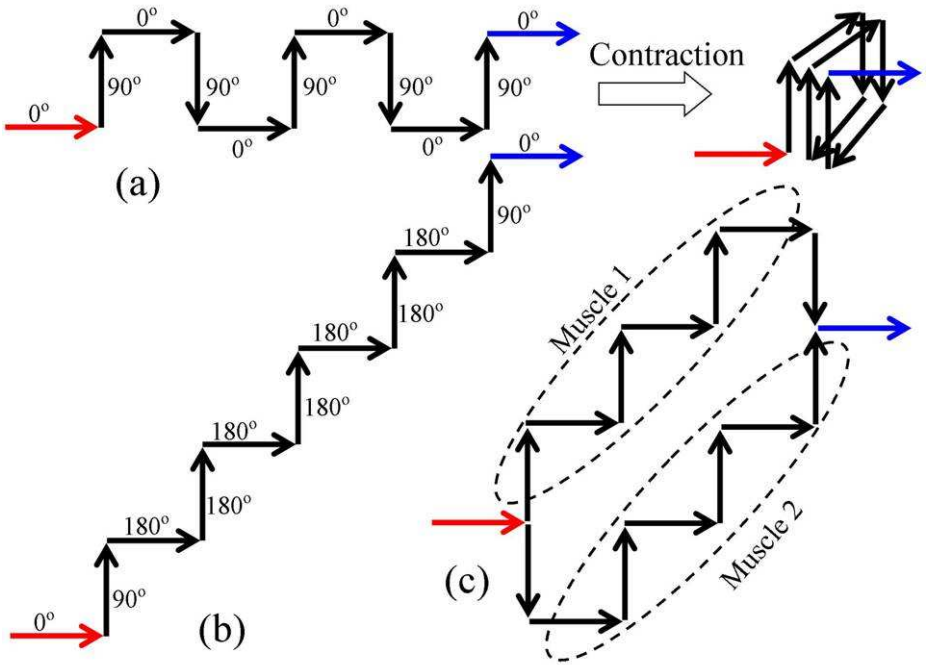
Hip Joint

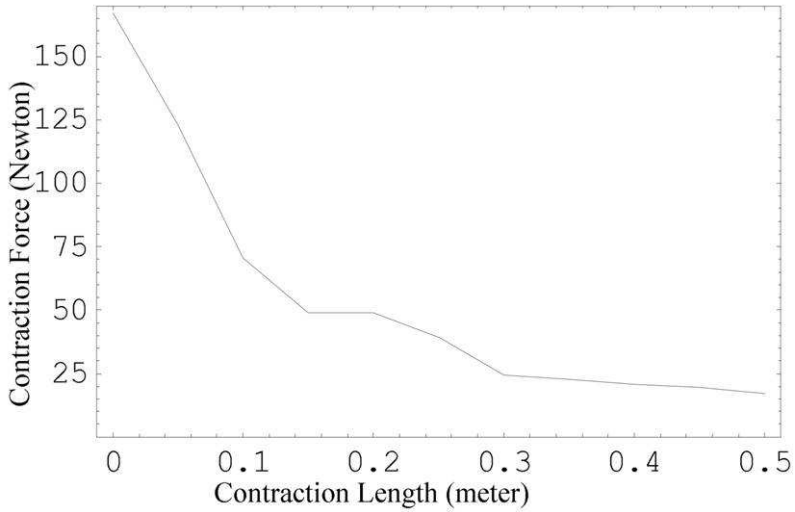


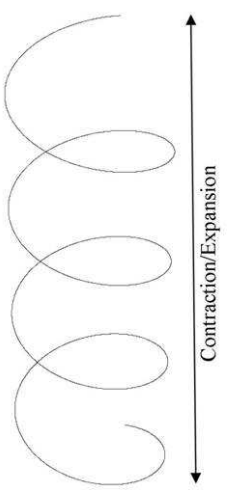
Ball-Socket Joint

ATRON Anatomy: Muscle

- ATRON-Muscles
  - Actuation of myriad-module robot
  - Parallelizable to achieve scalability

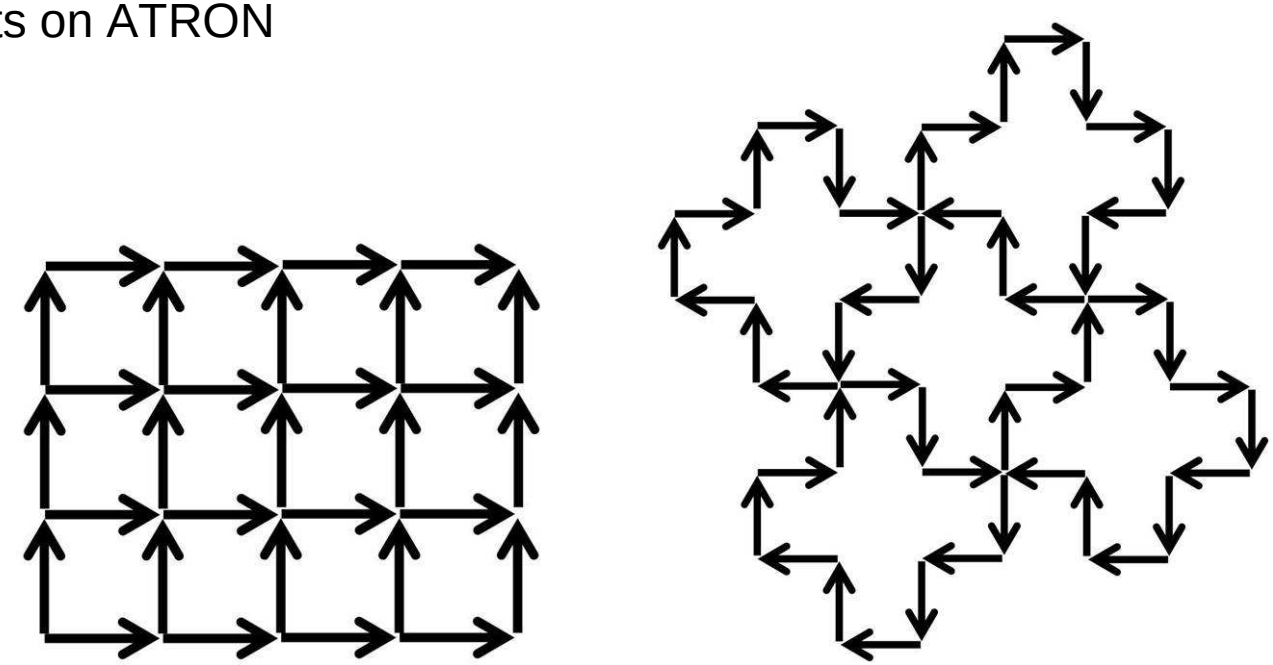






ATRON Anatomy: Skin

- ATRON-Skin
  - Purpose: e.g. protection from environment.
  - ATRON Surfaces that can deform and stretch
  - However:
    - Rigid constraints on ATRON
    - Full of Holes



Two sheets patterns for skin

Discussion, Future work & Summary

Lesson Learned…

- Will it ever work?
  - Probably not with the ATRON alone…
- Why not?
  - **Morphological differentiation** of modules seems necessary:
    - Functional differentiation are not enough.
    - 210 different cell types in adult human
- What then? (Future work)
  - Collect more experience from different systems:
    - Which anatomical structures?
    - How to combine anatomical structures?
  - Design novel SR system based on scalable anatomy.

Summary

- Challenge of Scalable Functionality:
  - Fast responsive functionality myriad-module robots…
- Our Approach:
  - Biological Inspired Scalable Anatomy.
  - Anatomical Parts: Bone, Joint, Muscle, Skin, Nerve.
- Scalable Anatomy for ATRON System.