Neuro-Mechanical Networks

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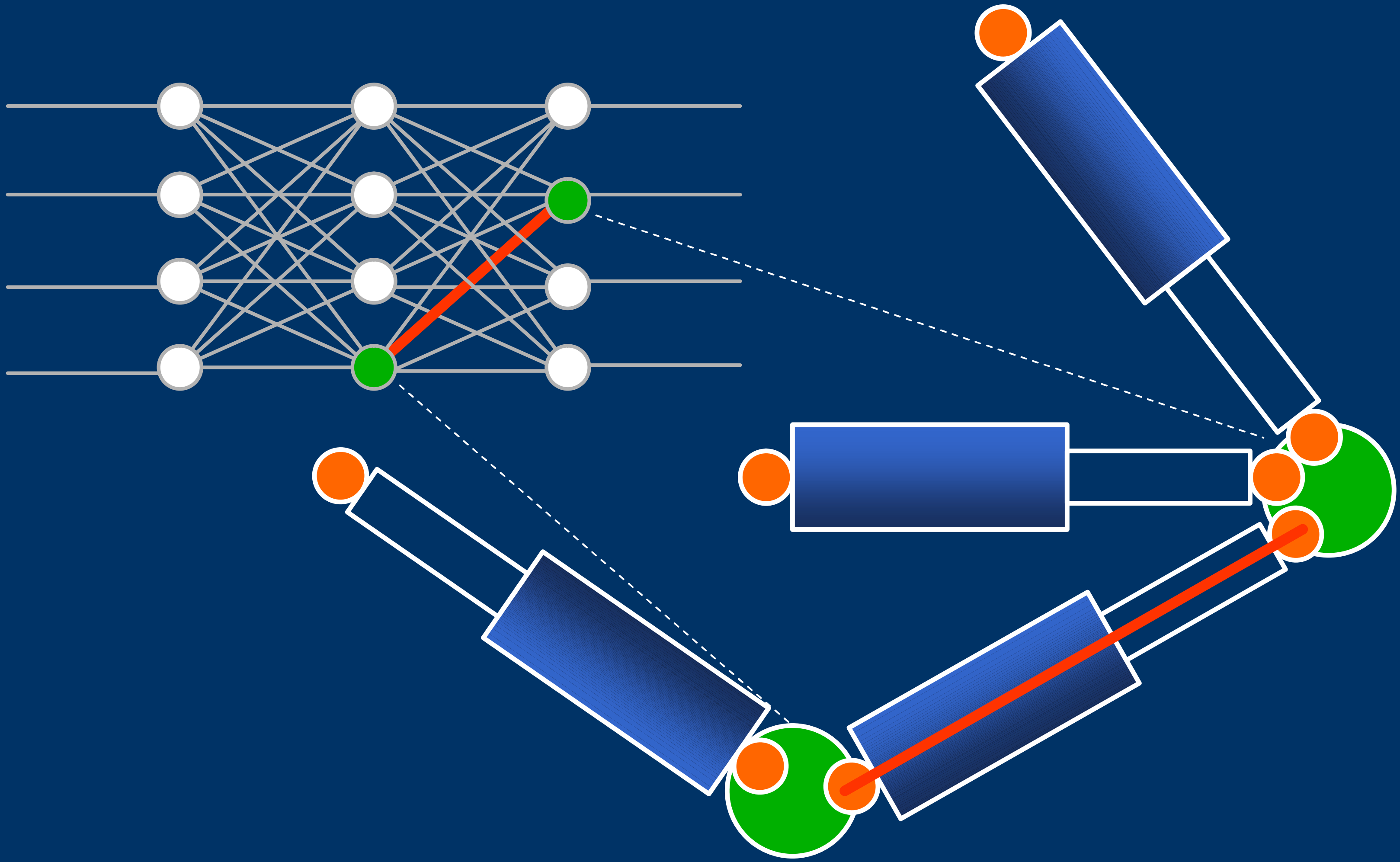
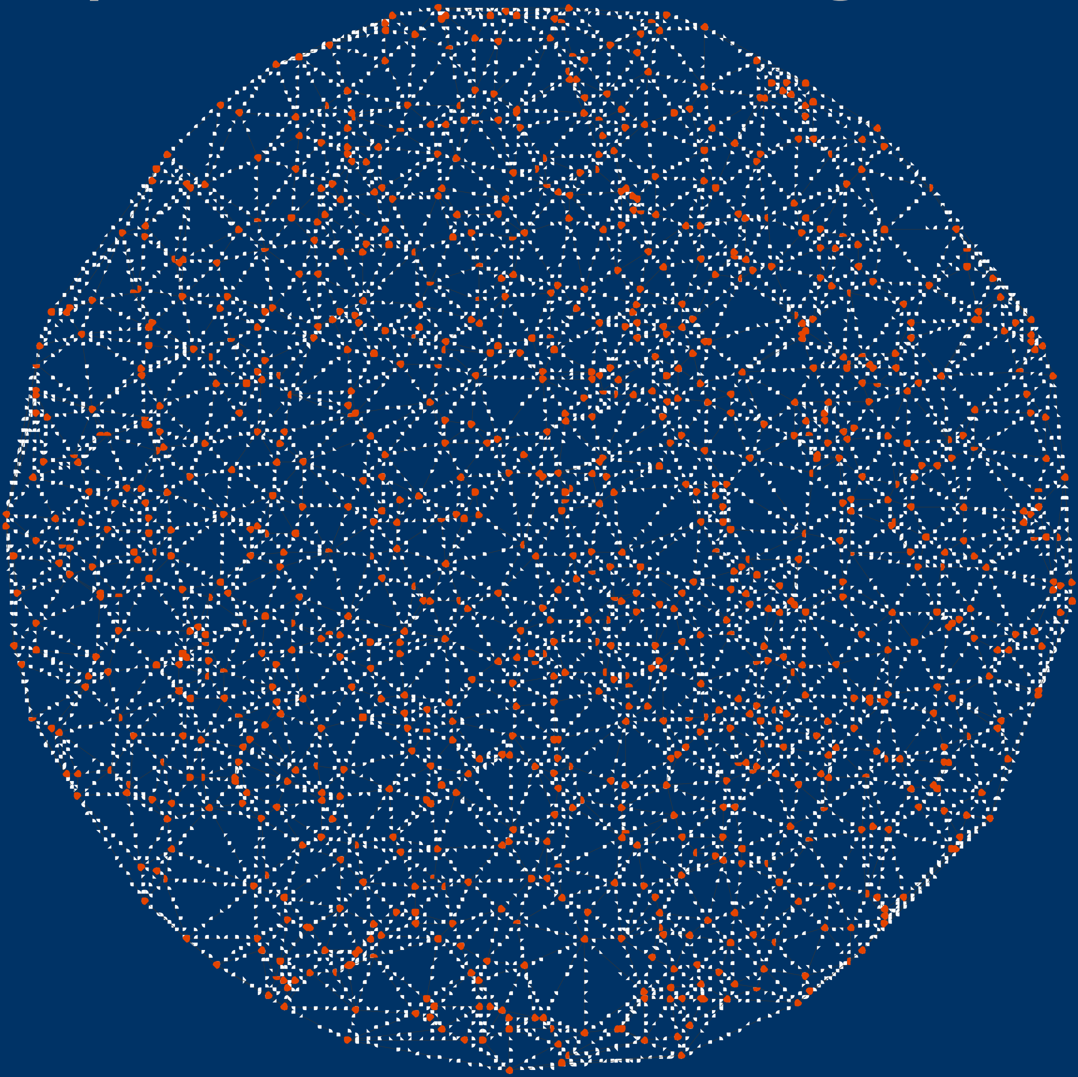
Mix Neural Networks with multi-Actuator Systems



The simple element in large numbers



Micro Electro Mechanical Systems MEMS

“MEMS-based actuators and motors will have the ability to provide sufficient force and torque to replace conventional mechanisms”

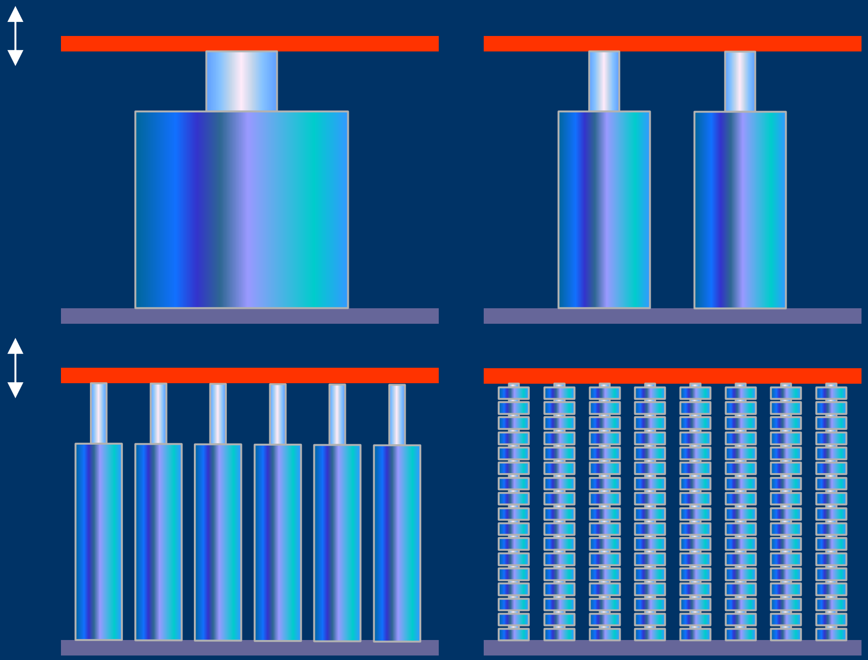
NASA Technology Plan 2001, Strategic Areas
Advanced Miniaturization

ElectroActive Polymers
EAP

“Biomimetic robots actuated by EAP can be made highly maneuverable, noiseless and agile, with various shapes and they can enable to make science fiction ideas a faster reality than would be feasible with any other conventional actuation mechanisms.”

ELECTROACTIVE POLYMERS AS ARTIFICIAL MUSCLES - CAPABILITIES, POTENTIALS AND CHALLENGES
Yoseph Bar-Cohen, JPL/CalTech, Pasadena, CA, USA, 2000

System Complexity



Performance (force)

$$P = \sum_{i=1}^{n} c_{pi} s_i$$

Cost

$$C = \sum_{i=1}^{n} c_{ci} s_i^{g}$$

System Cost

If all s are the same

$$P = \sum_{i=1}^{n} c_p s = nc_p s$$

This yields the component size as:

$$s = \frac{P}{nc_p}$$

In the same way the cost can be calculated

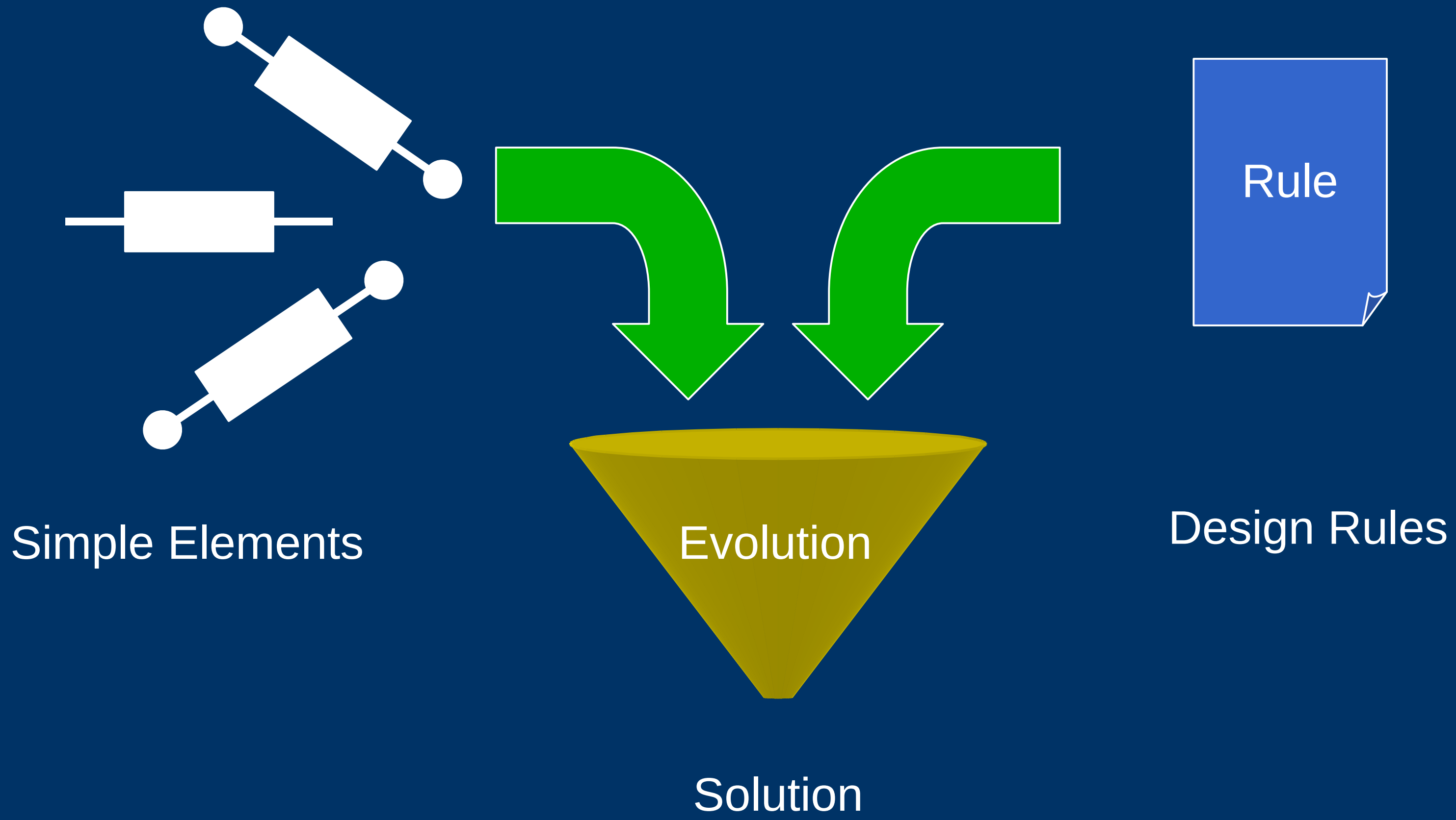
$$C = \sum_{i=1}^{n} c_c s^g = nc_c s^g = nc_c \left(\frac{P}{nc_p} \right)^g = n^{1-g} c_c \left(\frac{P}{c_p} \right)^g$$

Peter Krus, Matts Karlsson
Neuro-Mechanical Networks
SELF-ORGANISING MULTIFUNCTIONAL SYSTEMS
PTMC2002, Bath, UK

Motives for NMN

- If the cost of a system more or less can be related to the mass of its components, then the best thing is to build a system with as many elements as possible configured into a network.
- Compare to electronics and MEMS.
- Layered Manufacturing

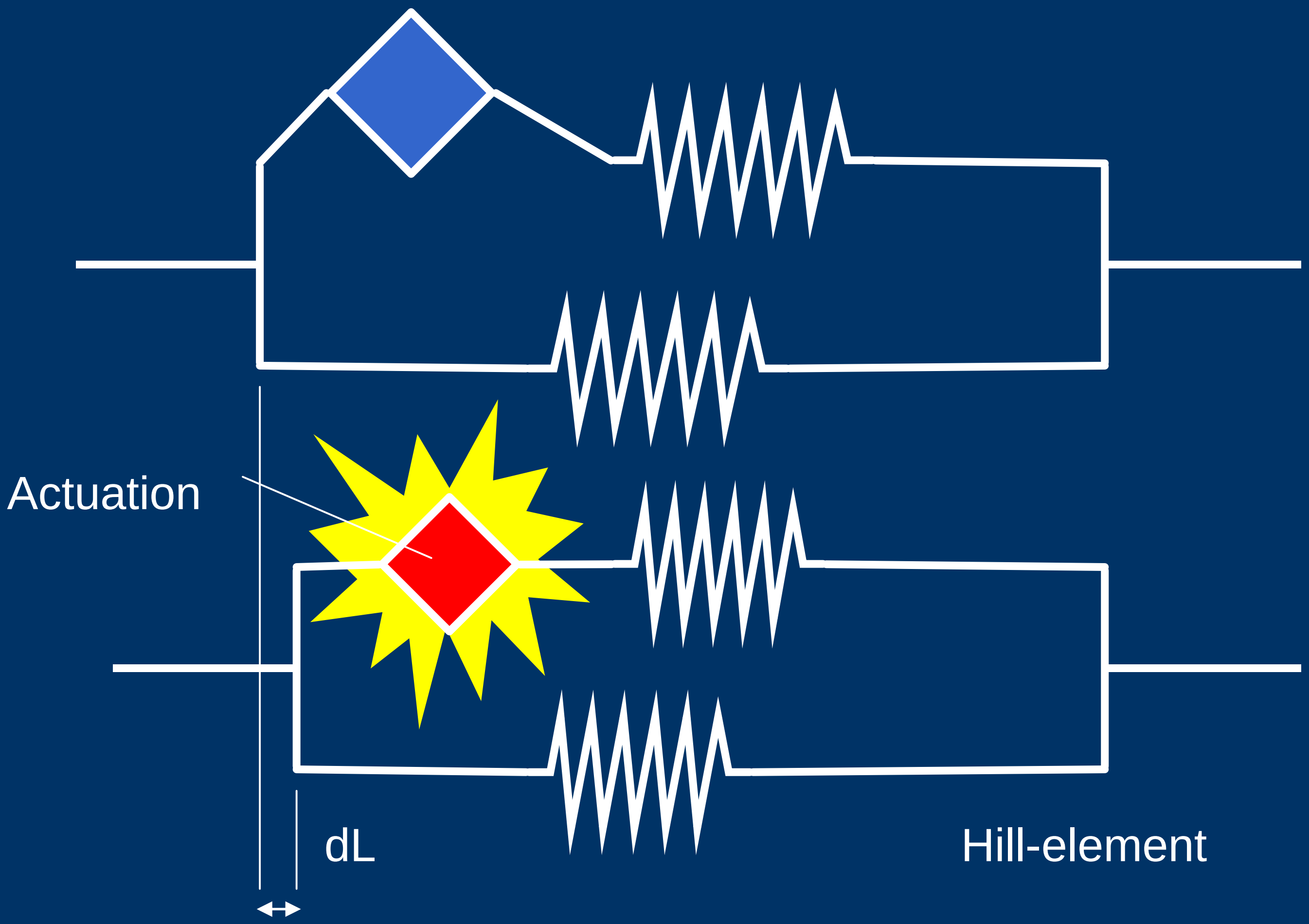
Design of NMN



Why studying NMN?

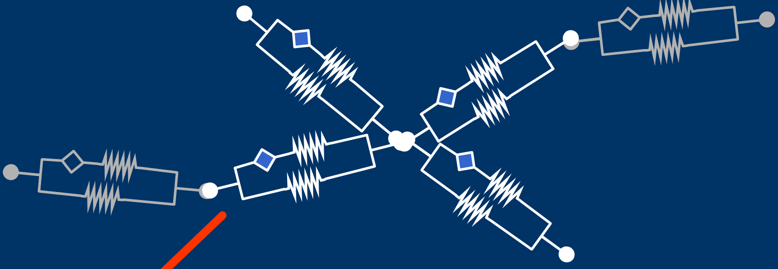
- A tool for studying and explanation of biological systems
- A tool for future massively redundant mechatronic systems
- As a generic structure using optimisation for mechatronic system design
- As a concept evaluation tool for identifying traditional design solutions, artificial reverse engineering

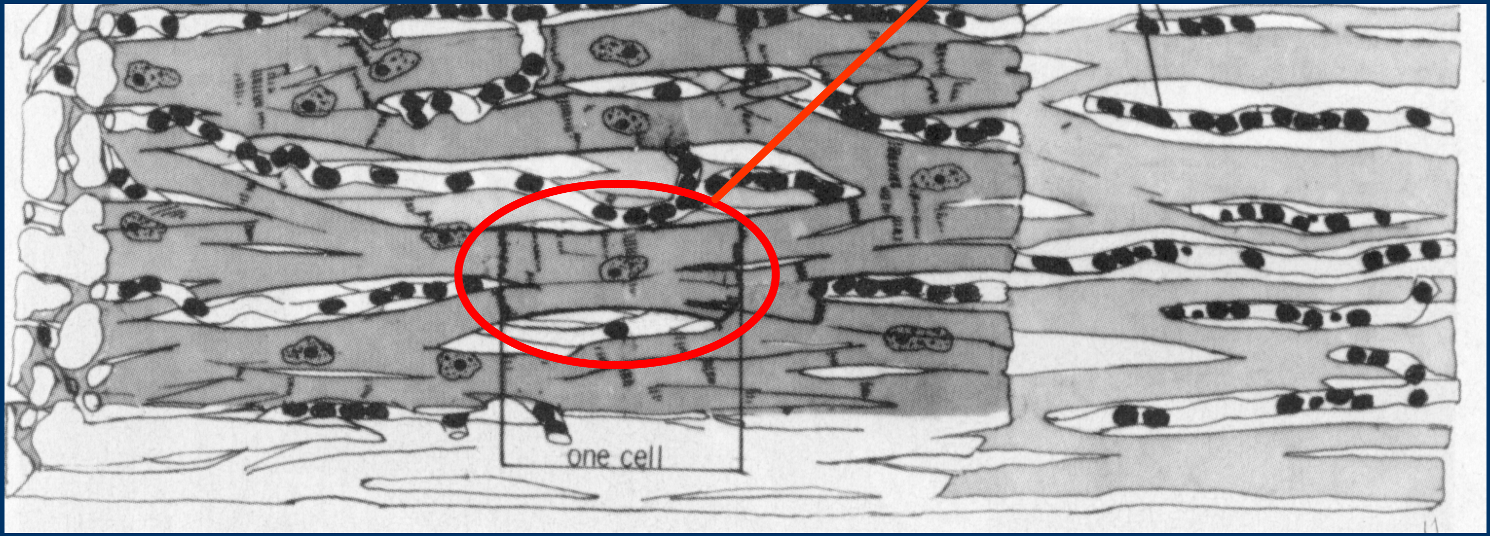
Example of element



Bio-mimicking

- The active structure of human tissue

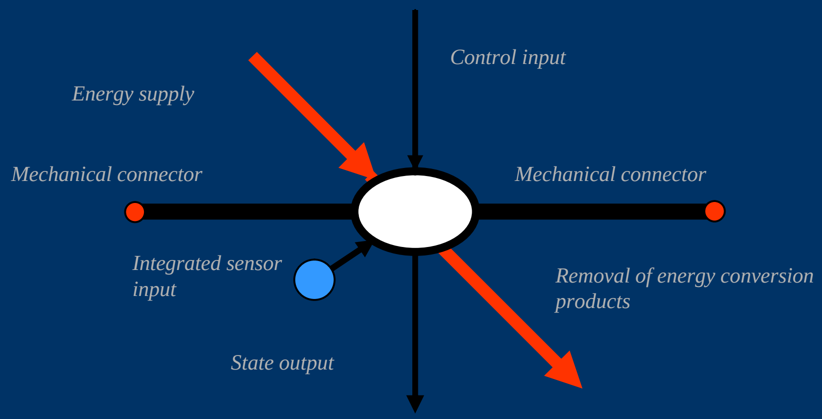




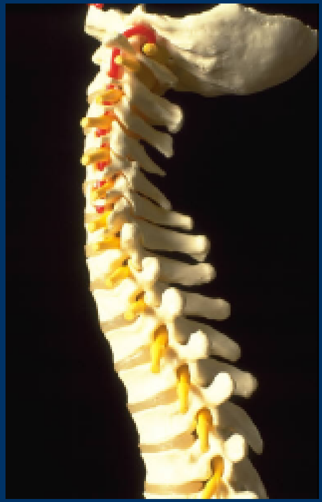
Fox, CC and Hutchins, GM (1972) The architecture of the human ventricular myocardium. Johns Hopkins Med J 130: 289-299

The Integrated Actuator

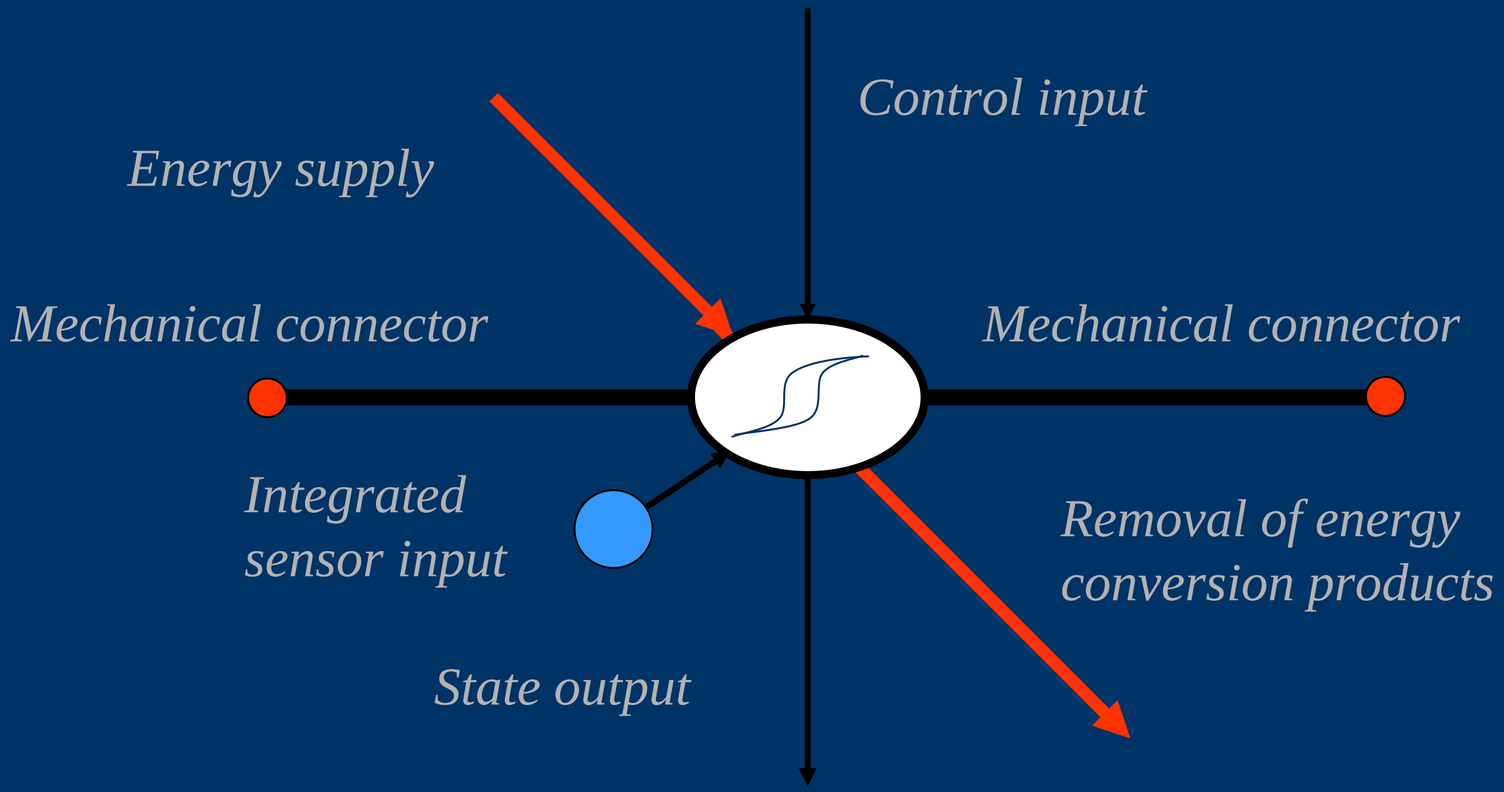
- The general building block for NMN systems



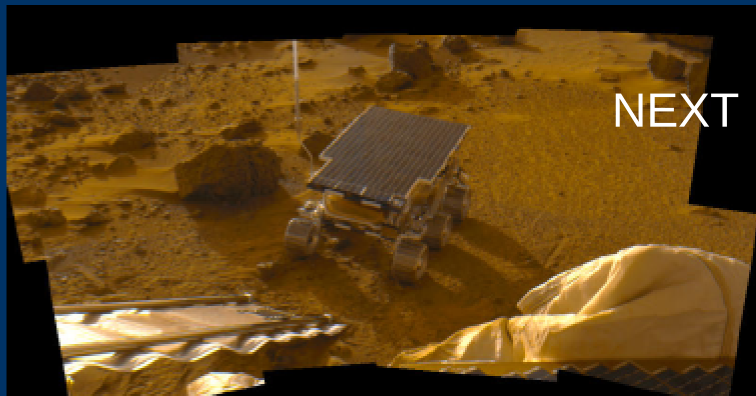
- Can evolve into different structure components, energy transport elements, links and joints or actuators

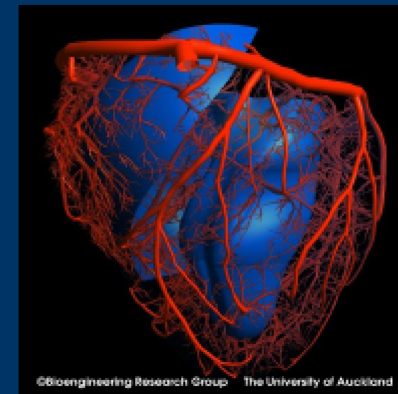


The anatomy of the General Actuator



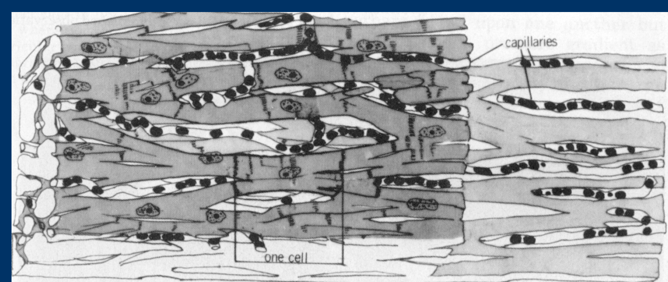
Several Magnitudes of Networks Sizes





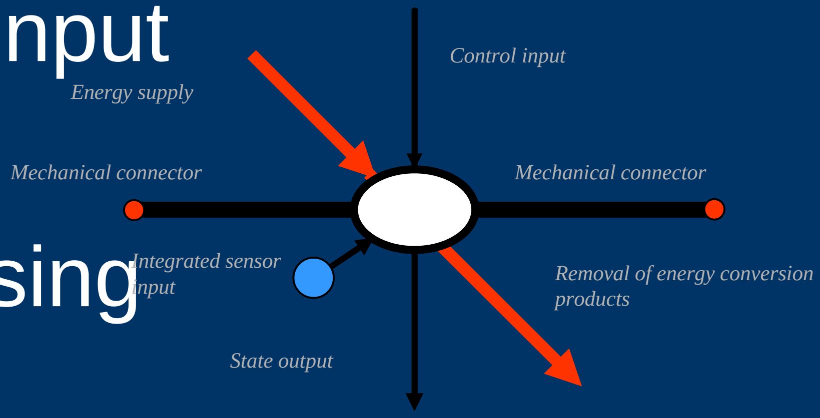
10 10^3 10^5 10^9

Sprawlita Project
Sean Bailey and Jonathan Clark 01/25/2000
Stanford



Features of the Generic Actuator

1. Actuation, through mechanical connections
2. Energy supply and removal of energy conversion residues
3. Control and sensory input
4. Sensory output
5. Simple signal processing

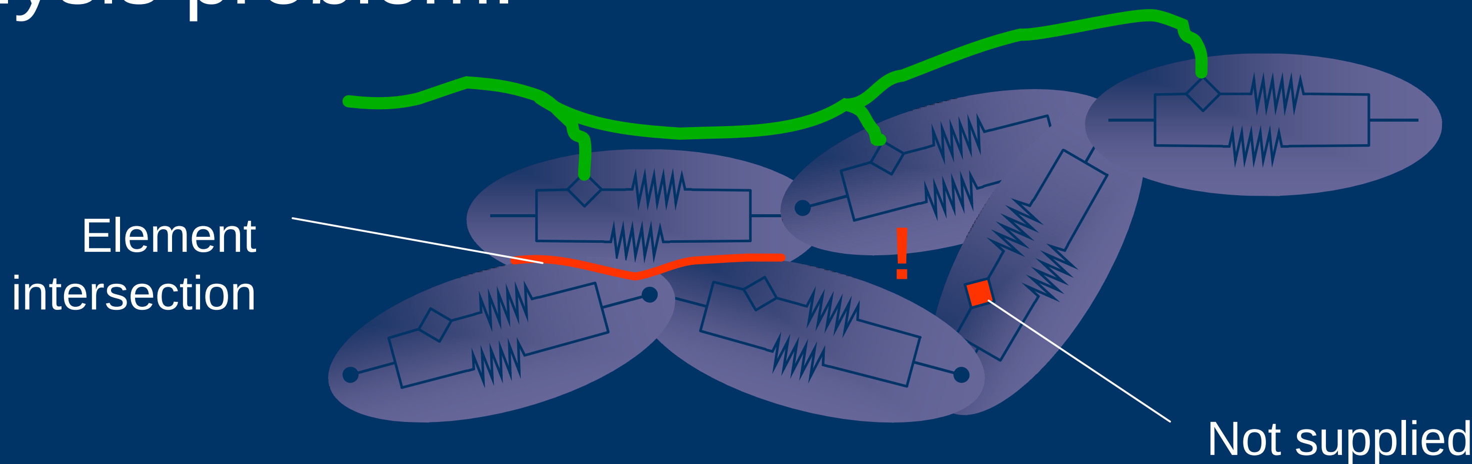


1 Actuation, through mechanical connections

- A multi domain simulation model that include both scalar models along the actuation axis of the actuator and a geometric model that relates the network to the surrounding environment.
- Proportional actuation or binary actuation
- Position control or force actuation

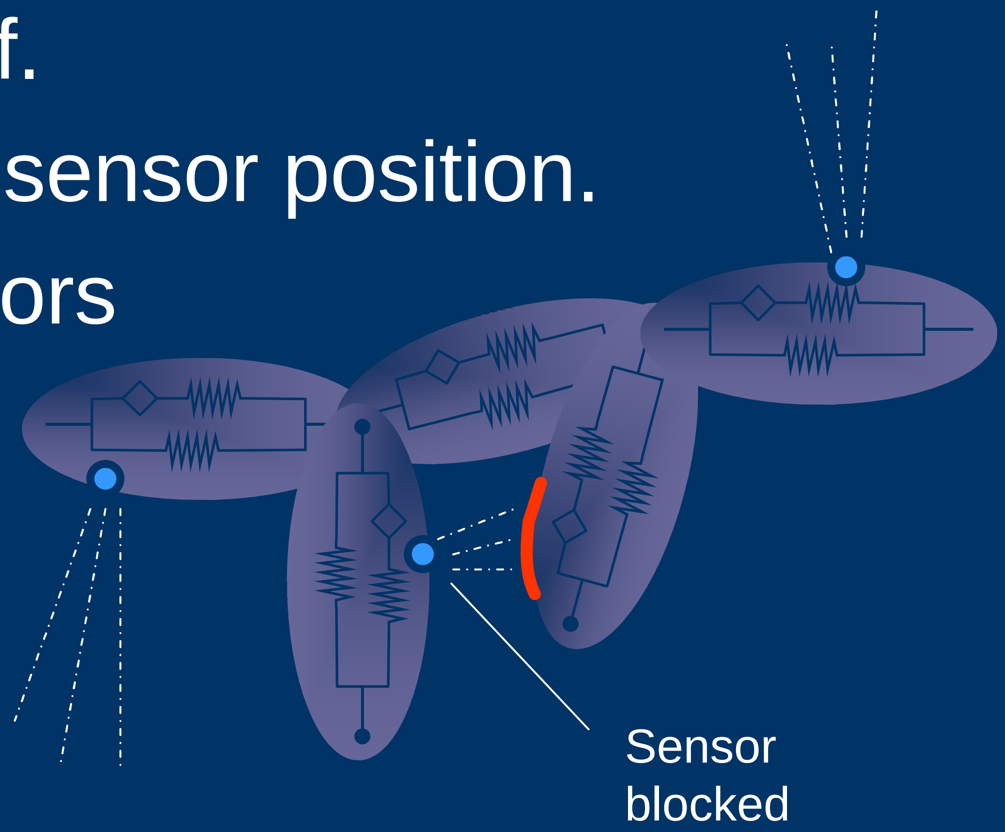
2 Energy supply and removal of energy conversion residues

- Topology layout of the supply and exhaust piping needed. Analysis of line losses.
- Both a scalar and geometric model analysis problem.



3 Control and sensory input

- Sensor disturbances from the effects of the network itself.
- Safe and robust sensor position.
- Redundant sensors

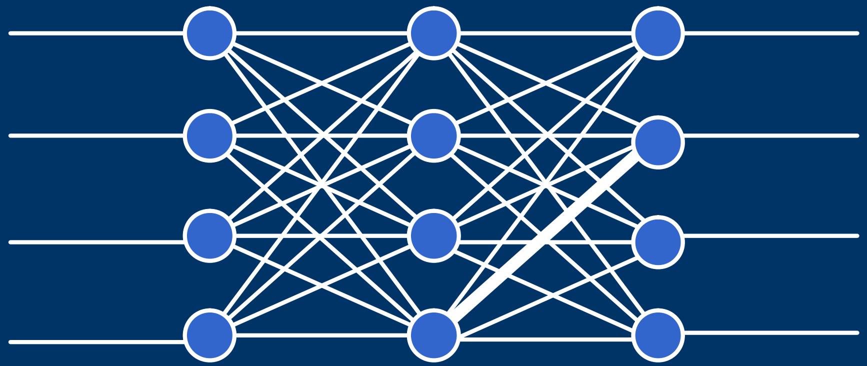


4 Sensory output

- Communication issues in multi sensor networks.
- Sensor failure detection.
- Global storage of the sensor information

5 Simple signal processing

- Neural network response
- Non-linear functions
- Overload detection and protection



Engineering challenges in the application of the Generic Actuator

- Scalar simulation models
  - Actuation (proportional, binary)
  - Dynamic forces and accelerations
  - Neural network response
- Geometric simulation models
  - Intersection test
  - Contact friction forces
  - Nearest neighbors

Our Approach

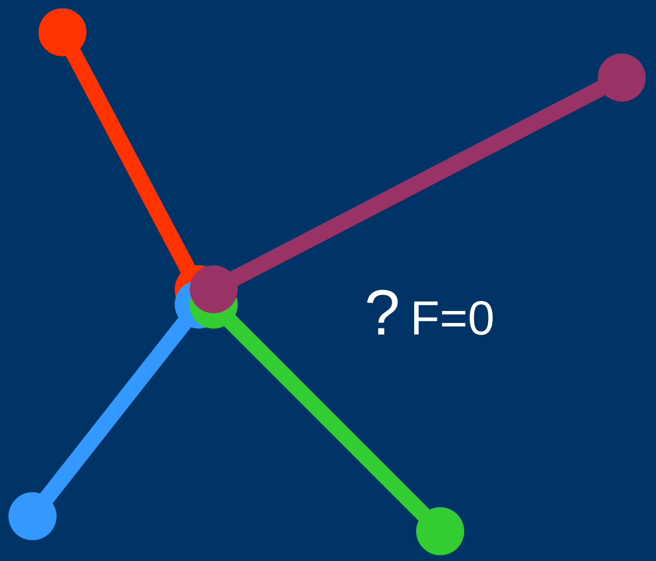
- A Simulation
- Some more Simulations
- Even more Simulations
- Simulations all week long
- Simulations and optimization
- Simulations in parallel
- Simulations and Linux Clusters

Evolutionary Design

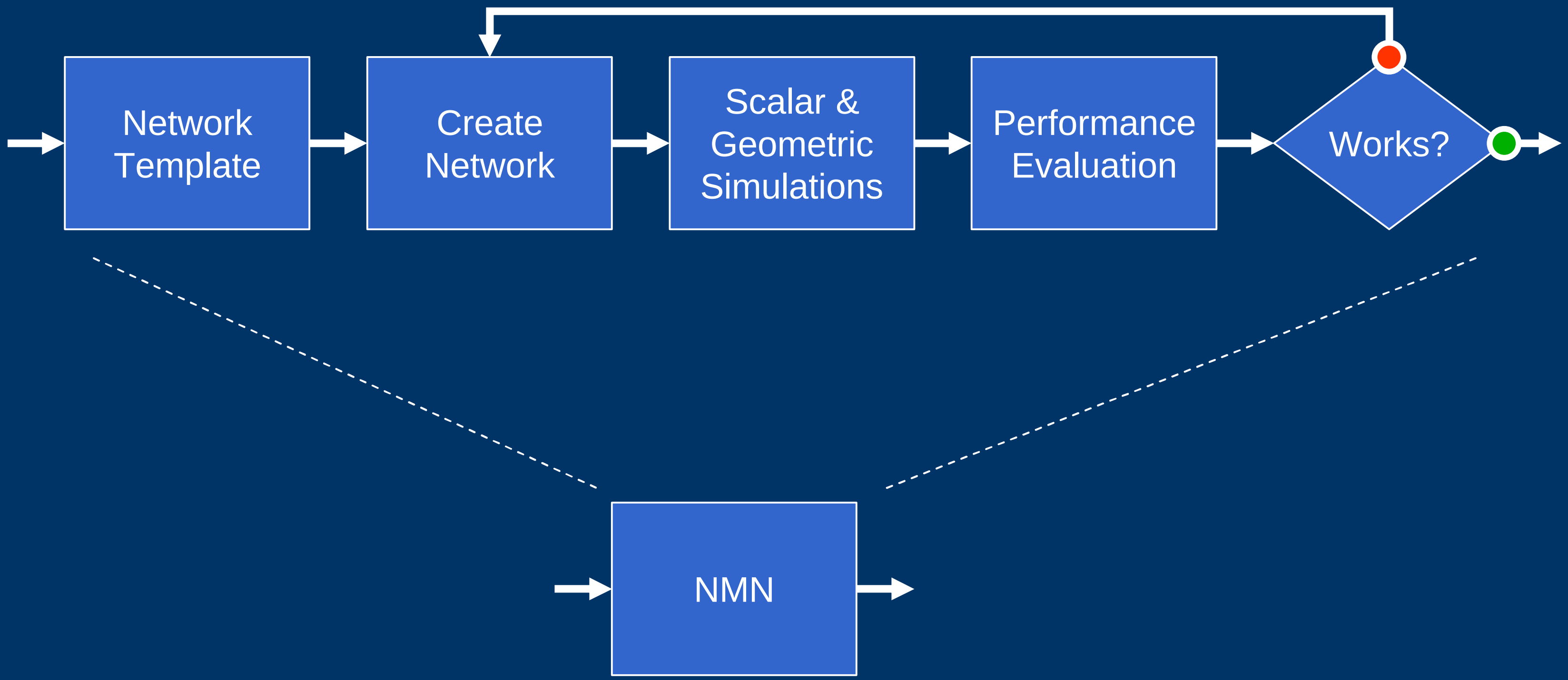
- Selection of network layouts
  - “The survival of the fittest”
- Tools needed to analysis complete networks of actuators
- The large number of actuators will remove the engineer from the selection or design of each individual actuator and its controller.

Dynamic Simulation

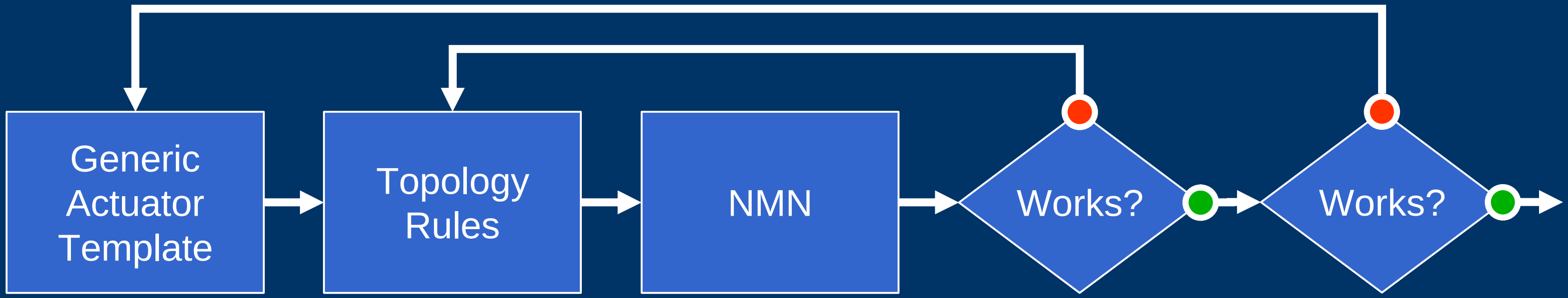
- Compare to trusses
- Transmission line method for dynamic simulations
- Algebraic solutions for simulations



The NMN Design Process



The NMN Design Process



The creation of an NMN

- Bottom-Up
  – Insert more “cells” where it is most useful. Use the “cells” already in the network as templates for the insertion.
  – Compare this with the healing process of our bodies.
- Top-Down
  – Start with a “full featured” network and remove the cells that does not work or provide anything to the overall performance.
  – “If you don’t work you don’t eat”

The Layout of the Network

- The topology may be fixed or varying.
- It may change during the operation.
- It might be damaged or even broken.

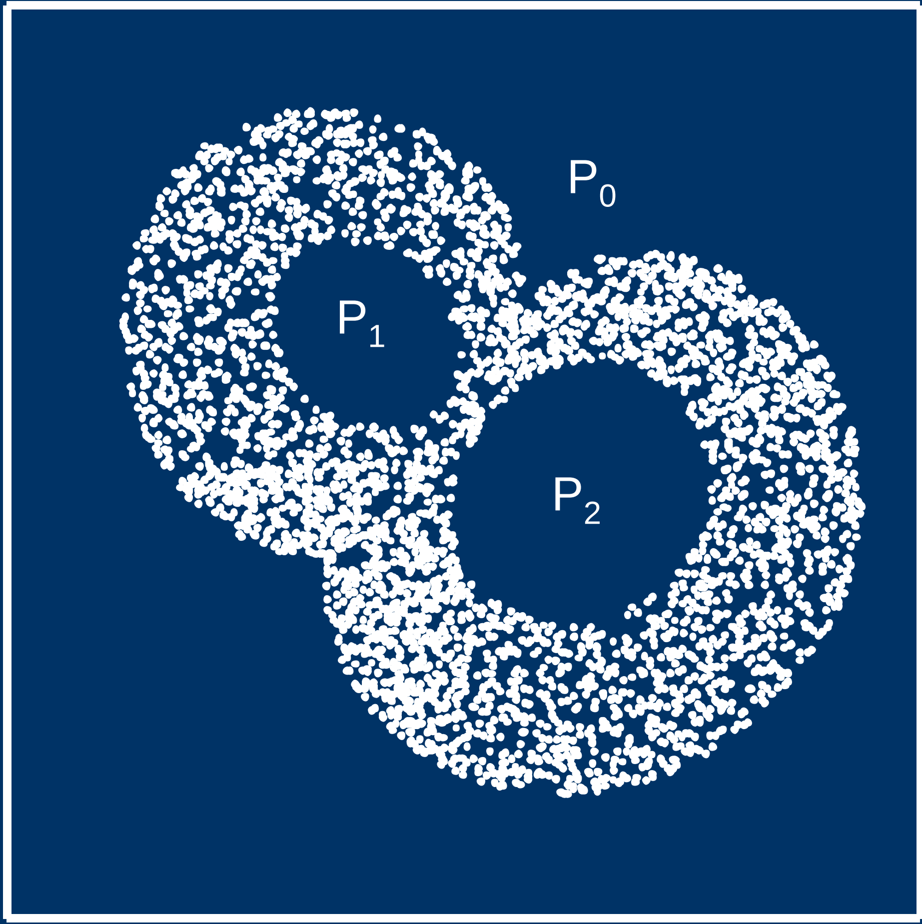
- Topology Complexity
  - Static (no actuation)
  - Dynamic (externally controlled)
  - Dynamic (self actuated)
  - Varying outer shape (airfoils)
  - Varying topology (reconfiguring robots)
  - Cell lifecycle (biological, cellular automata)

Initial Questions in the project

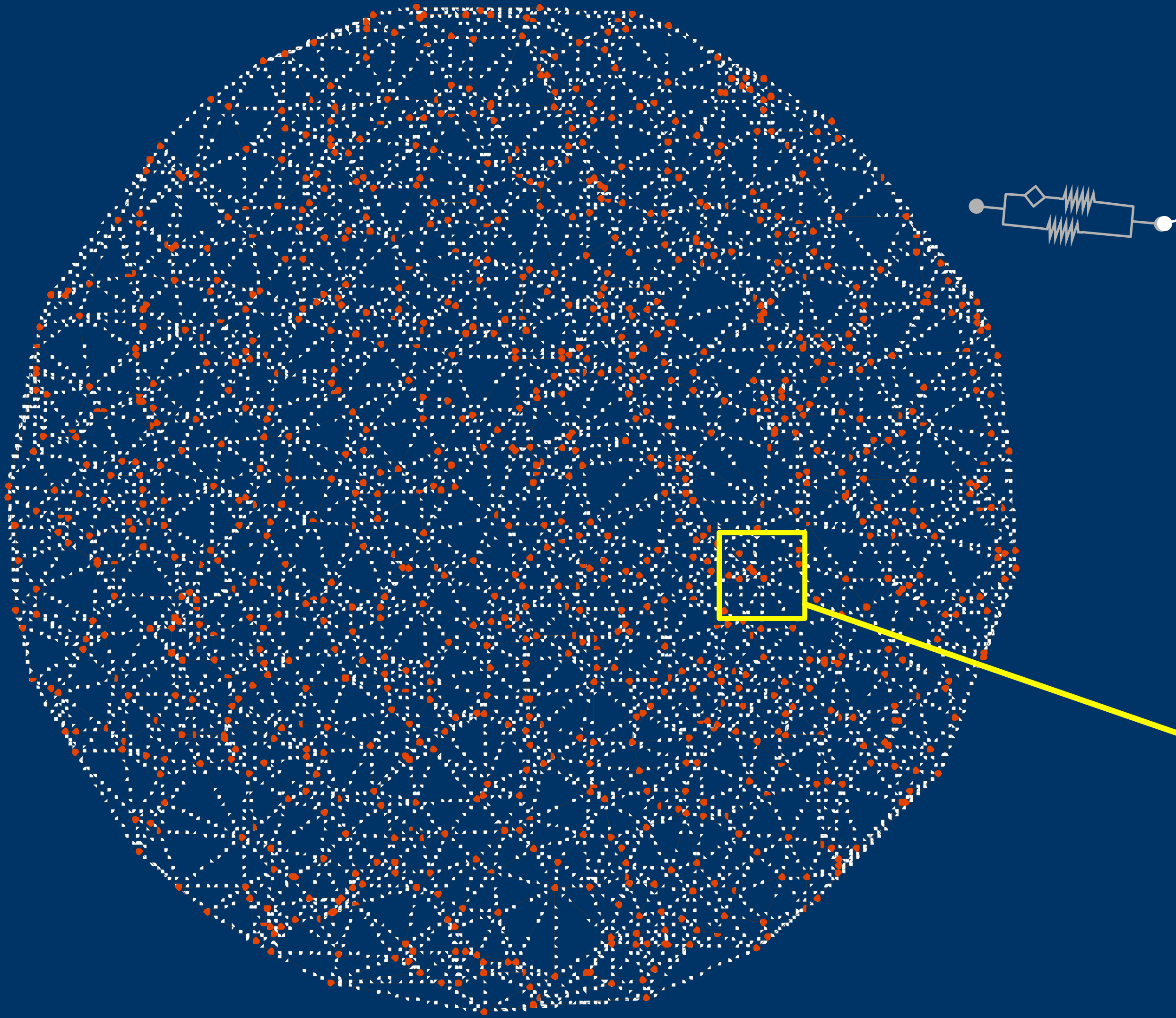
- What computer power is needed?
  - Who may work with this kind of systems?
  - Can it be combined with traditional engineering tools?
- What optimization method is best suited?
  - Is non-gradient methods really needed?
- What internal information structures is needed to handle large number of dynamic components?
  - How to handle the combined structure of geometric models and scalar simulation models?

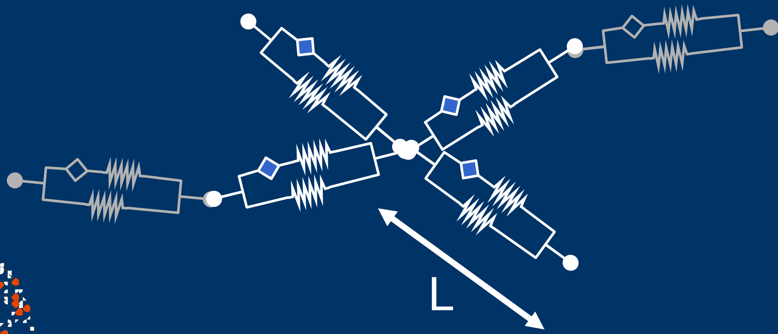
The Network Generation Process studied so far

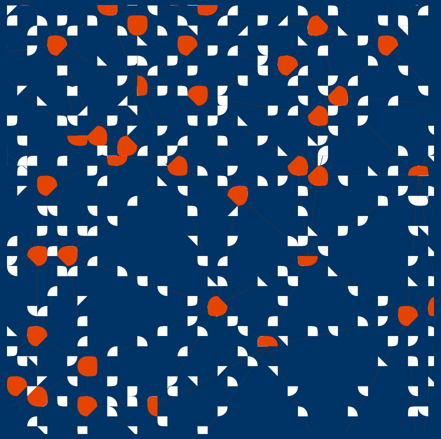
- Fixed number of elements.
- Changing the positions of the nodes so that a discreet number of length units fit between the nodes.



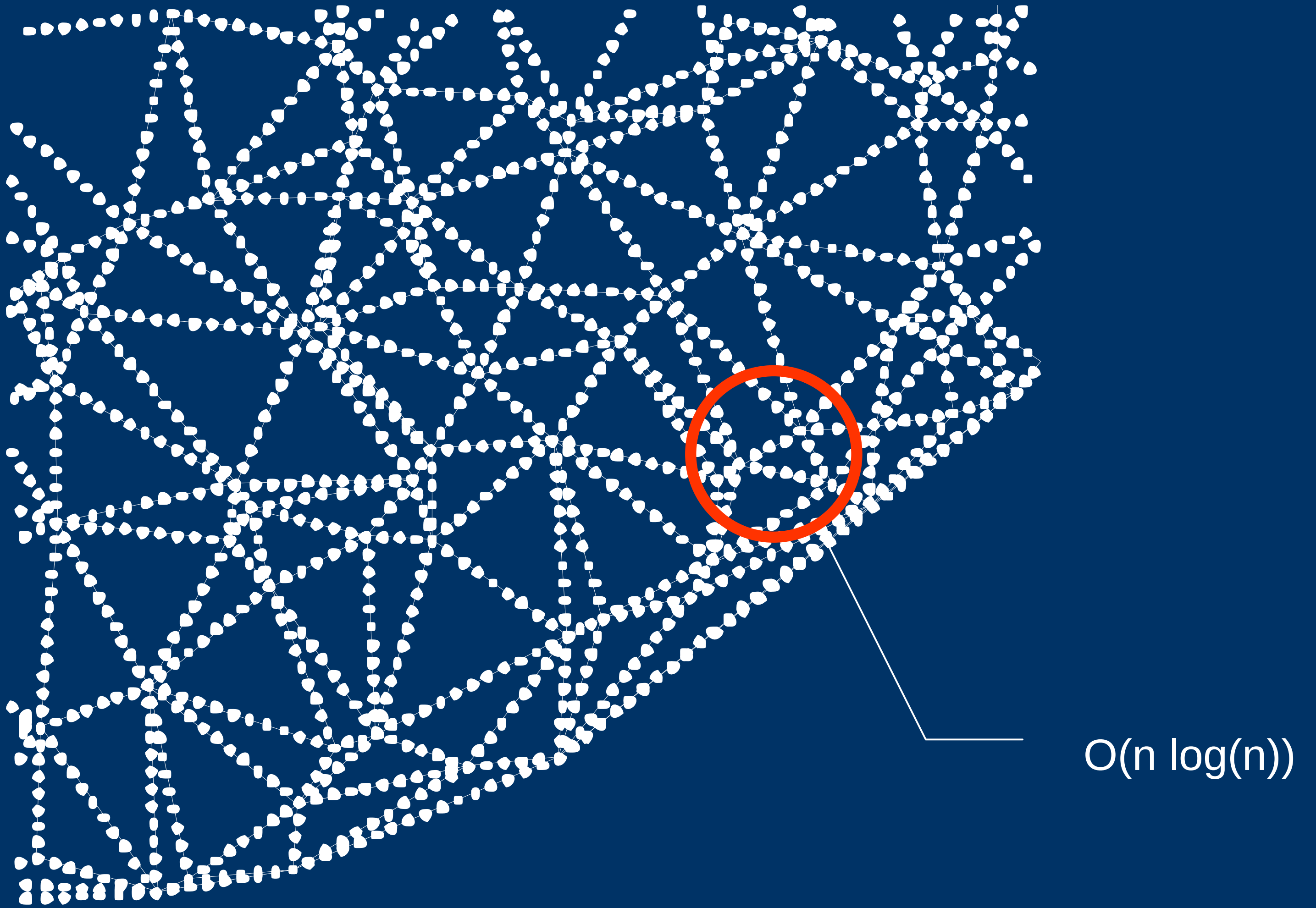
Initial Grid



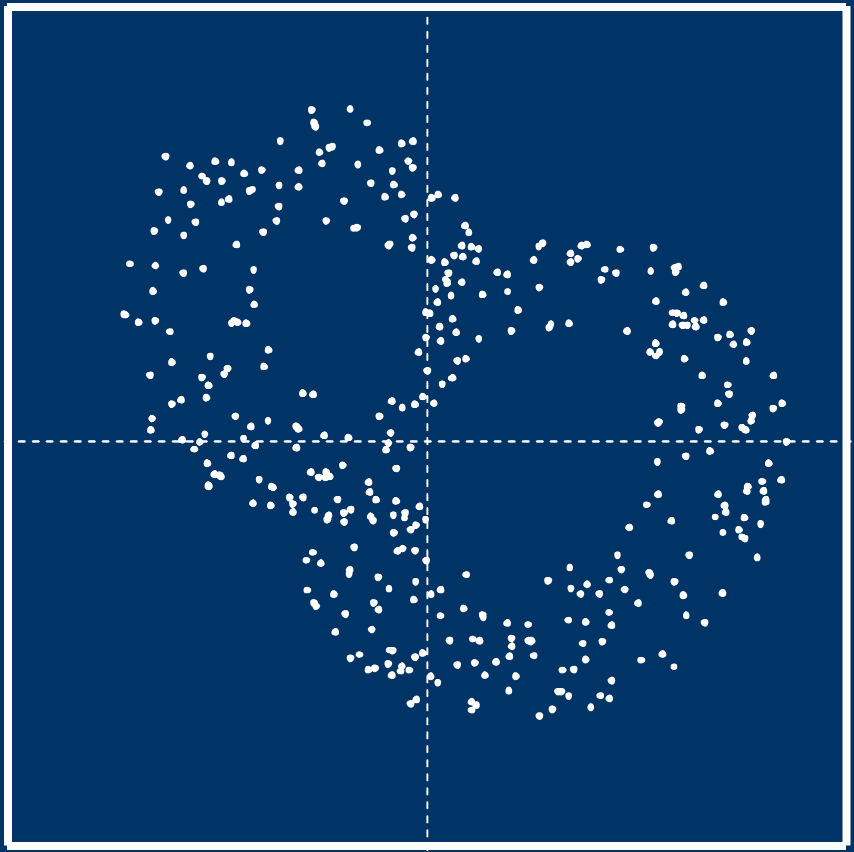


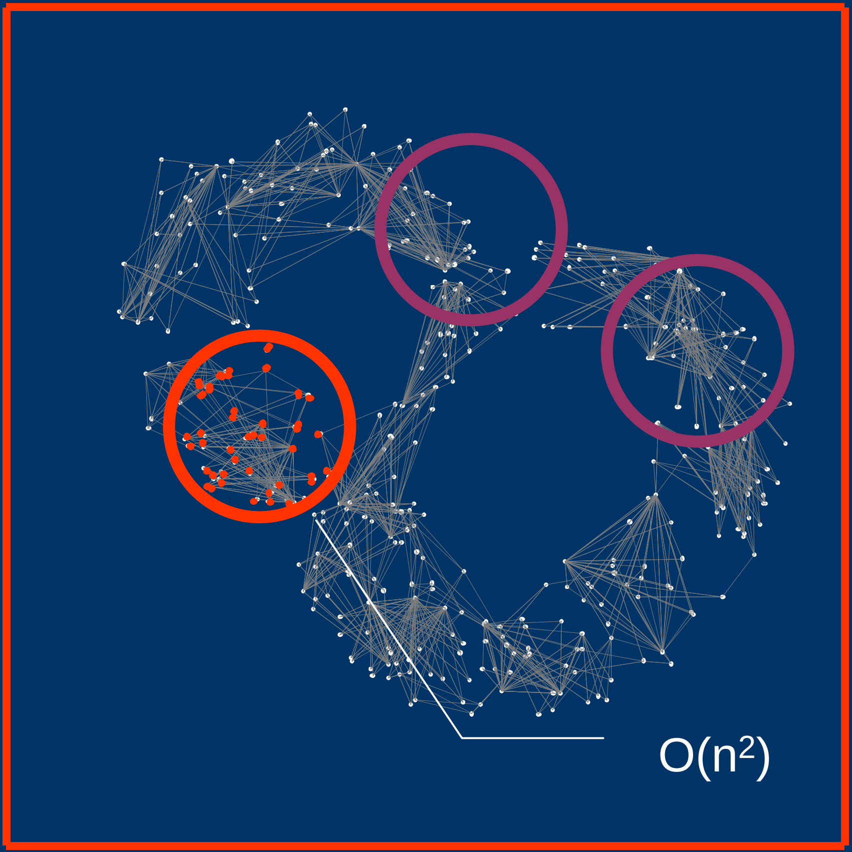


Fixed Size Fixed Topology

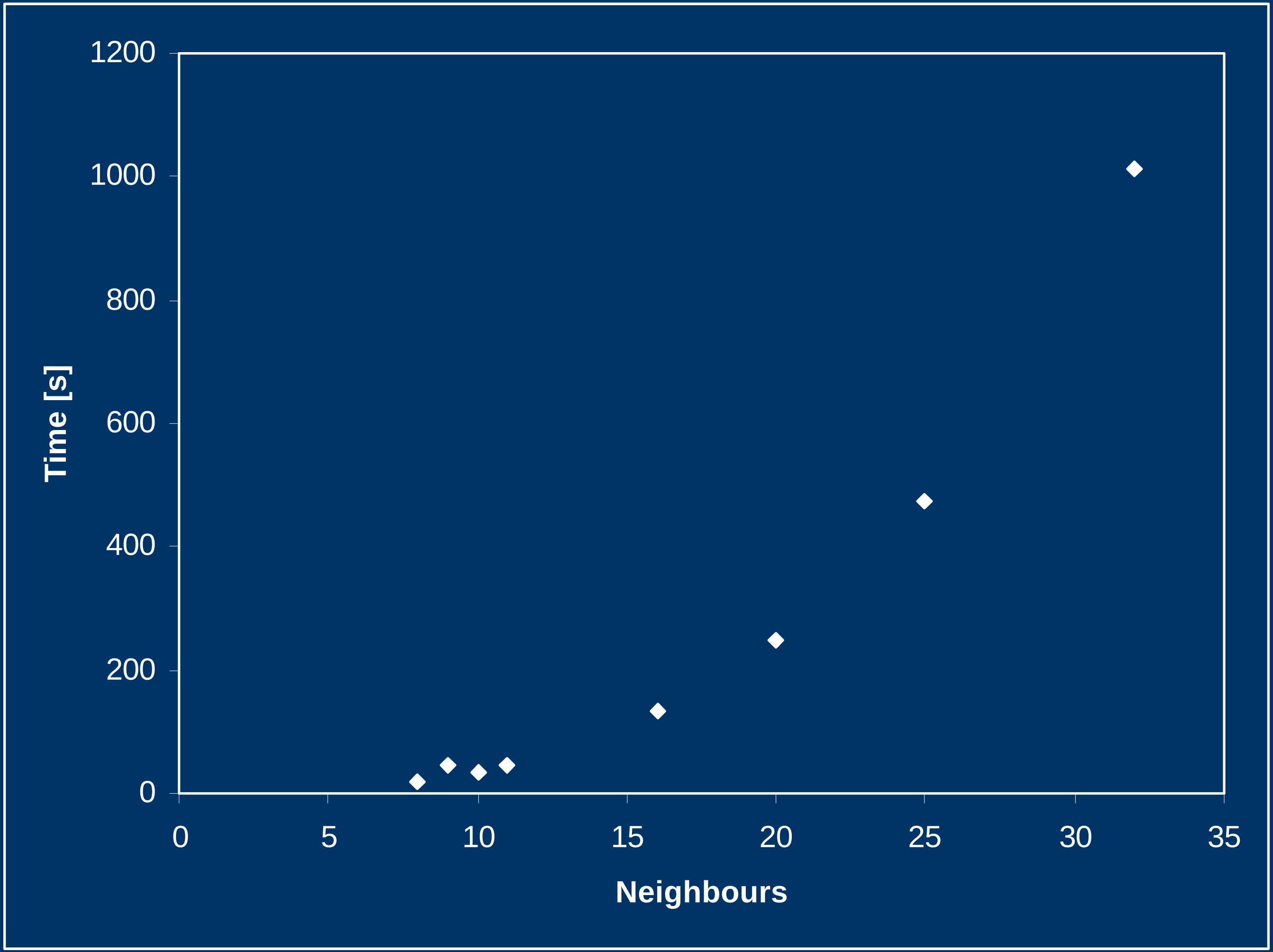


Sections in Network
Variable Topology





Preliminary Results

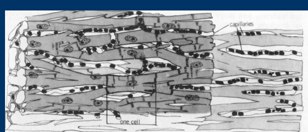
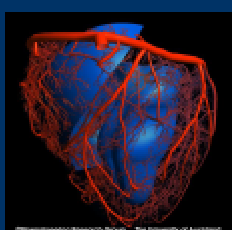


Computer Challenges

- Conquer the $O(n^2)$ penalty in variable structures
- Move into a parallel execution environment

Computer Power Needed
Worst Case Scenario

Well Relaxed

	10	CPU 10^{4} seconds	hour
	10^{3}	CPU 10^{5-6} seconds	some days
	10^{5}	CPU 10^{8} seconds	some years
	10^{9}	CPU 10^{10} seconds	some human generations

Simple Relaxed

CPU = Intel PIII-800MHz PC

Statements

- The NMN may be used to get better understanding for the biological systems.
- The NMN may be used as an design tool for mechatronic designs.
- The NMN may widen the application of techniques like Cellular Automata and Graph Theory into traditional fields of mechanical engineering.

Conclusions

- Evolutionary design of neuro-mechanical networks will require super computing power
- Even though the basic element is simple to analysis, the characteristics of the hole network will be difficult to predict
- There will be a need to combine geometric and scalar information models

gadesignlib.sourceforge.net