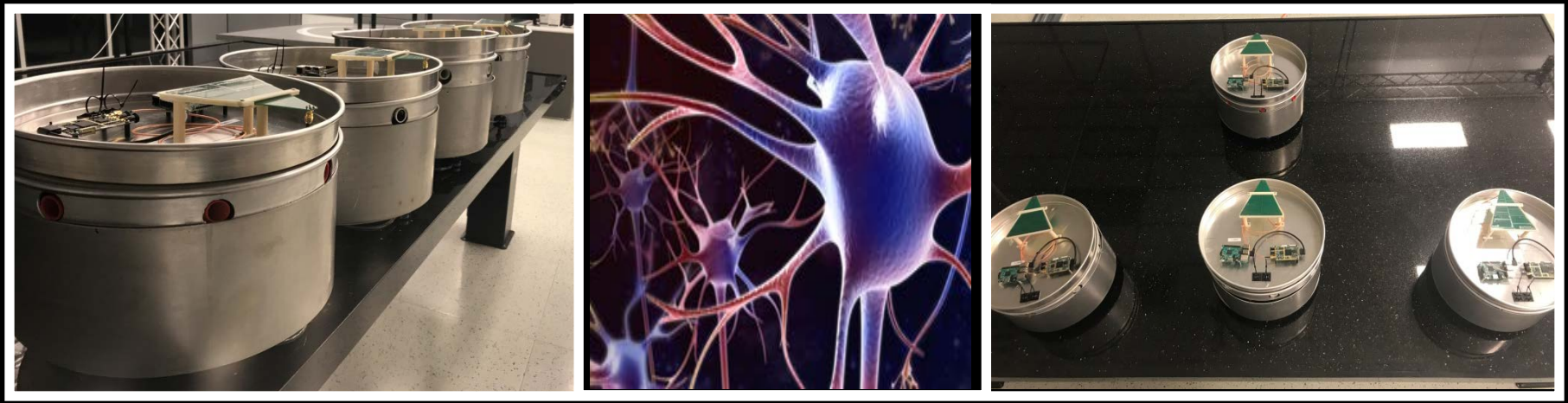


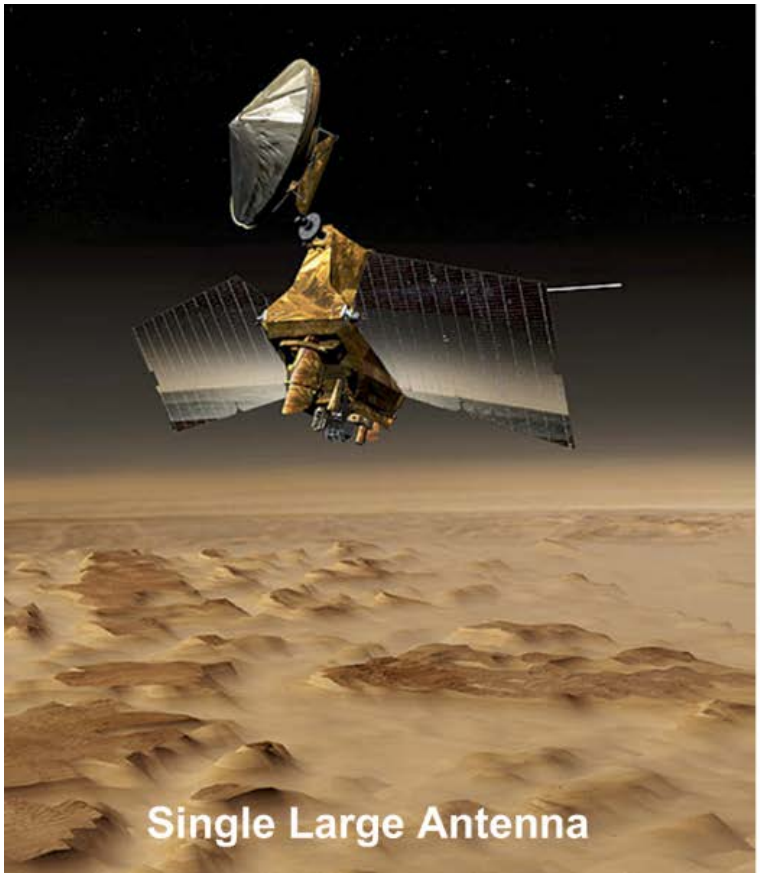
An Experimental Platform for Multi-spacecraft Phase-Array Communications

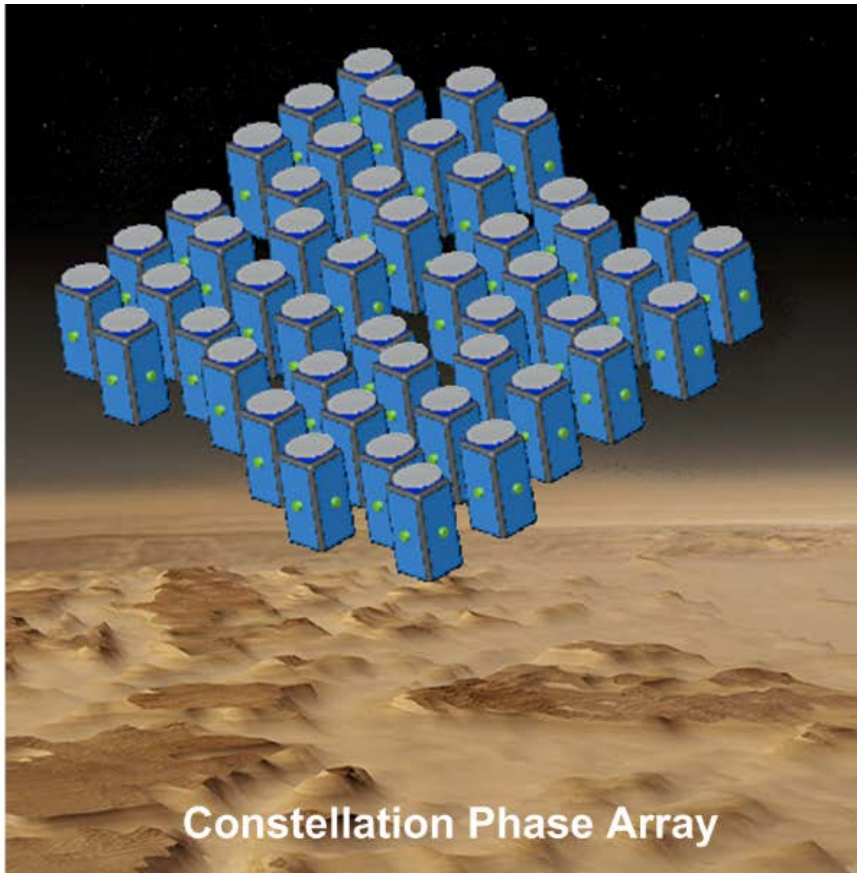
A. Ravindran, R. Nallapu, A. Warren, J. Thangavelautham

Space and Terrestrial Robotic Exploration (SpaceTREx) Laboratory
Arizona State University

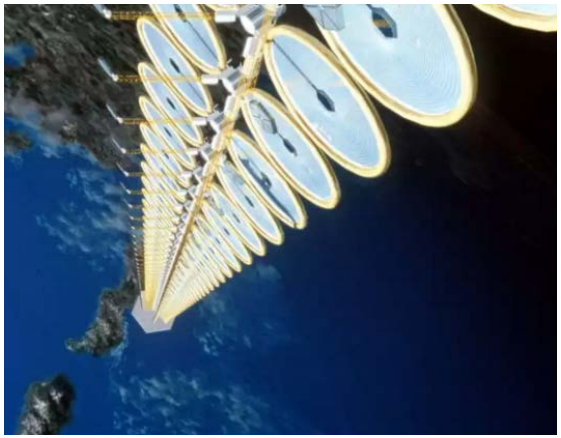
A. Babuscia*, J. Vasco*,
***Jet Propulsion Laboratory, California Institute of Technology**

Motivation: Communication Arrays in Space

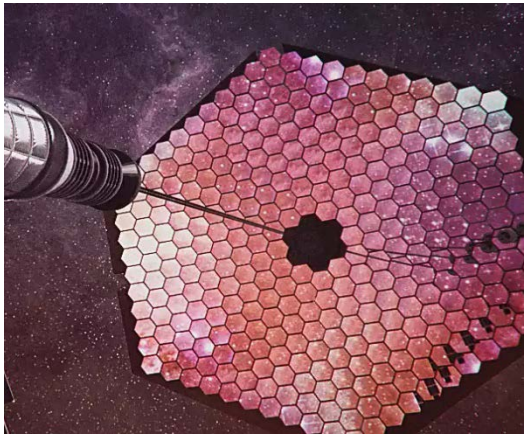




Motivation



Space Power



Astronomy

Communications

Challenges

- Cognitive communications
- Autonomy vs. teleoperation
- Scalability
- Accurate deep space positioning

Biological Inspiration

Biological Inspiration

- **Natural selection**

  "*The theory of evolution by cumulative natural selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity*" [Dawkins, 1986]

Biological Inspiration

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- **Biological Nervous system**

Biological Inspiration

- **Natural selection**

  "The theory of evolution by cumulative natural selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity" [Dawkins, 1986]

- **Biological Nervous system**
  - **Product of evolution**

Biological Inspiration

- **Natural selection**

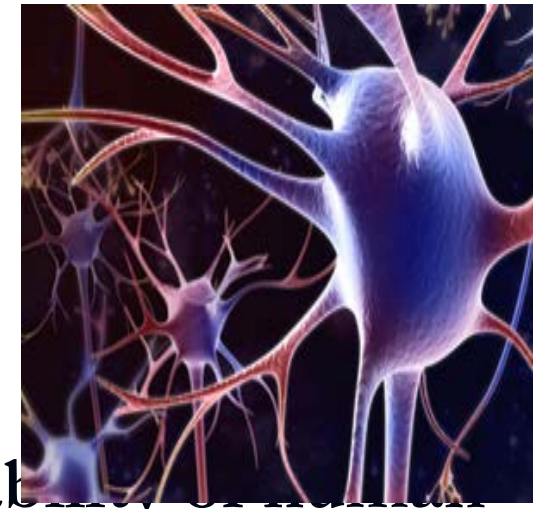
  "The theory of evolution by cumulative natural selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity" [Dawkins, 1986]

- **Biological Nervous system**
  - **Product of evolution**
  - **Adaptive**
  - **Decentralized**
  - **Self-organizing**

Biological Inspiration

- **Natural selection**

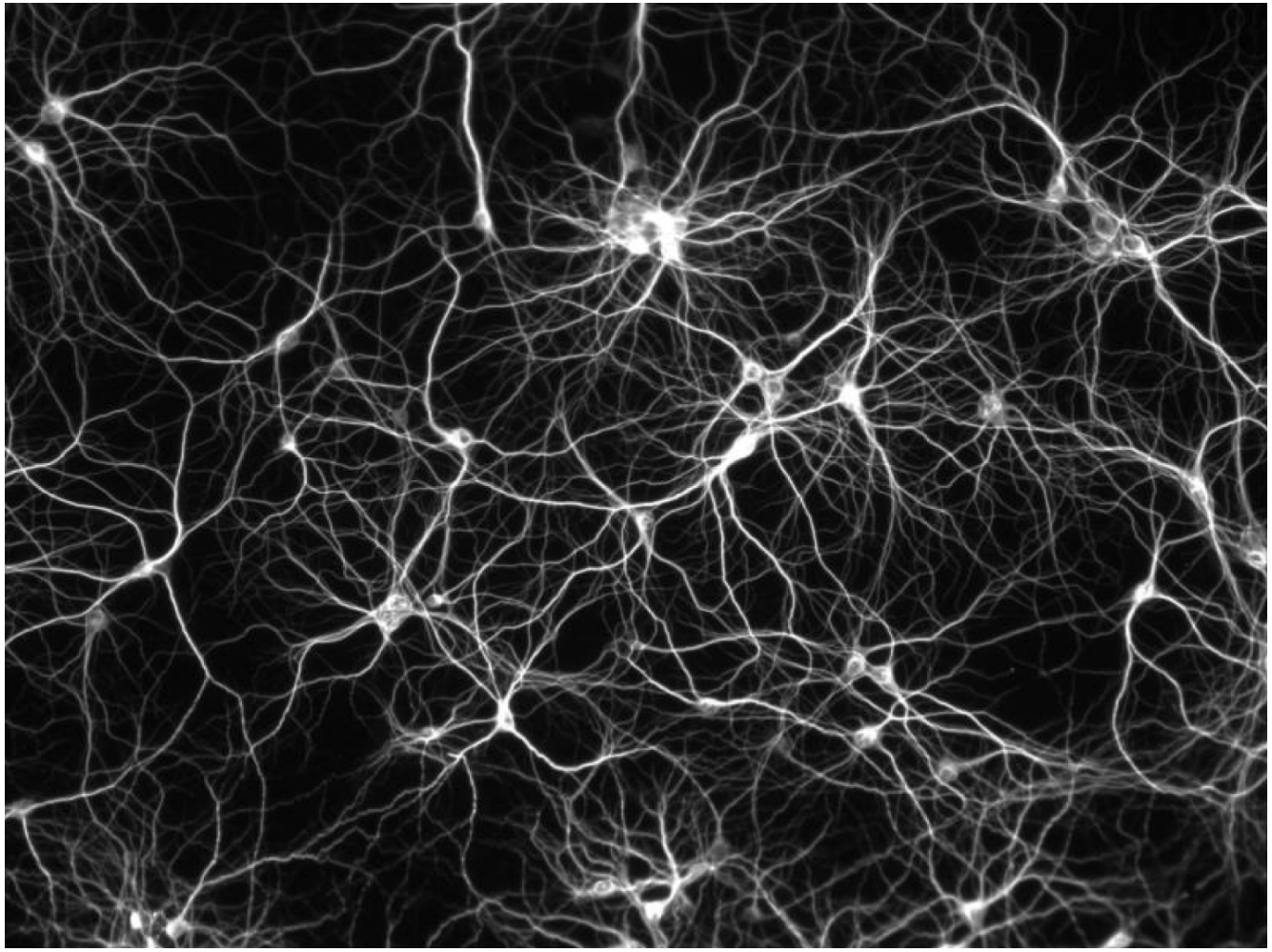
  "The theory of evolution by cumulative natural selection is the only theory we know of that is in principle capable of explaining the existence of organized complexity" [Dawkins, 1986]



- **Biological Nervous system**
  - **Product of evolution**
  - **Adaptive**
  - **Decentralized**
  - **Self-organizing**

- **Natural systems exceeds capability of human designed controllers**
  - **Learning, reasoning, creativity, vision, motor control**

Biological Inspiration



Social Insects

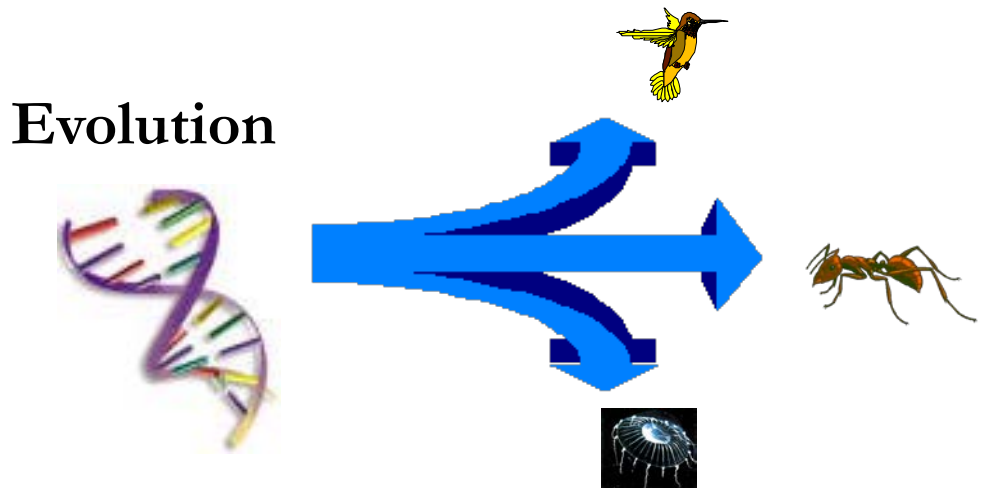




Perform localized sensing, action/reaction to produces global consensus

Artificial Evolution

"Design" Goal: Survival

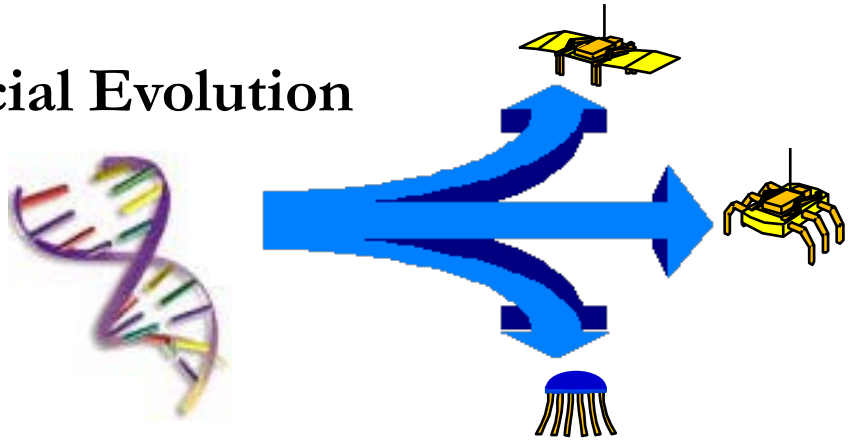


JPL

Artificial Evolution

Space Systems Design Goal: Meet Requirements

Artificial Evolution



JPL

Multi-robot Controls Approach

- Distributed, decentralized
- Local sensing
- Actuation: Motor primitives, basis behaviors

Requires:

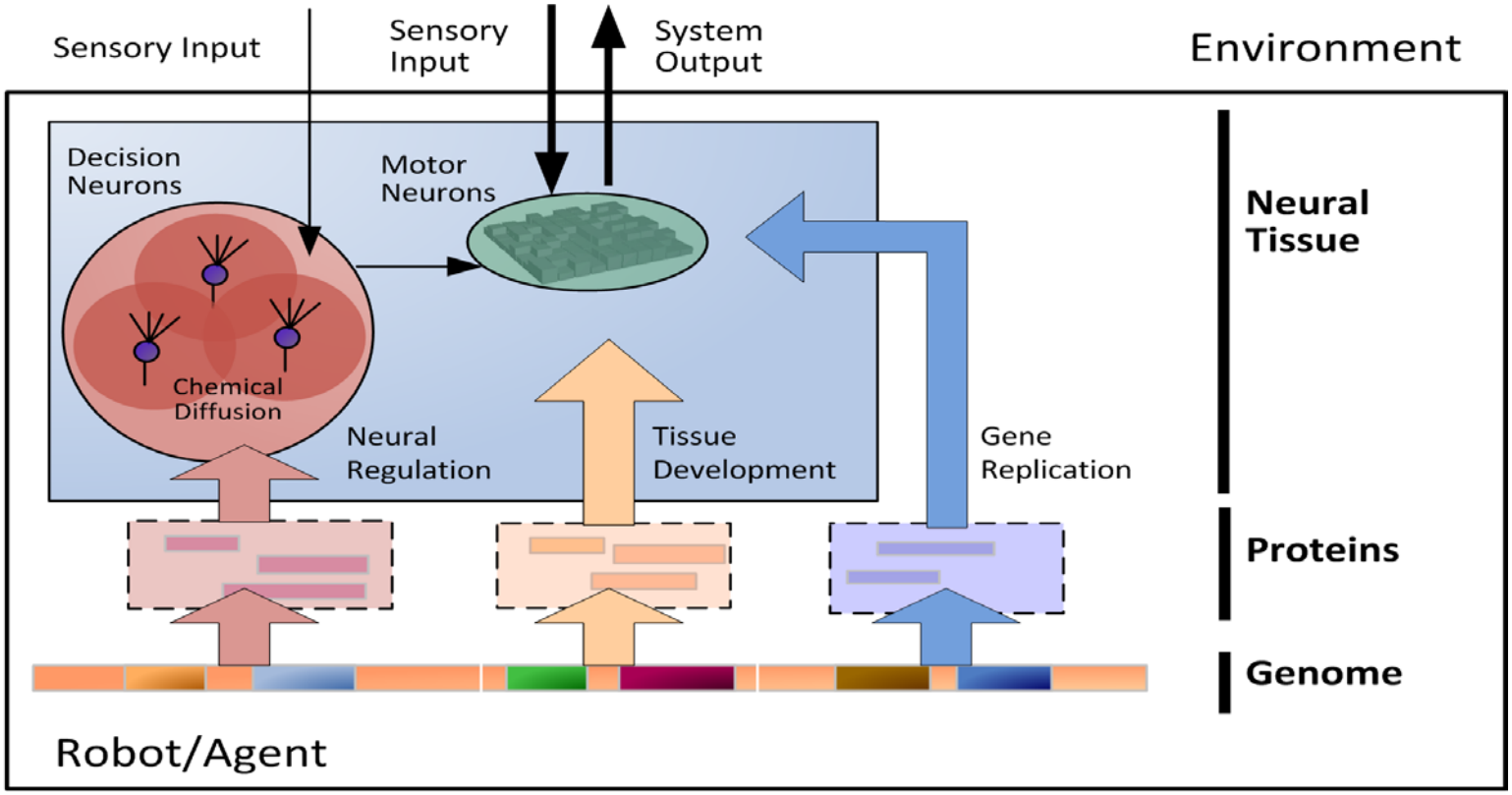
1) A numerical goal function or “potential” map

2) Training environment

Multi-robot Control Approach

- In theory we can simultaneously obtain controller and required number of robots to complete task.
- Training approach typically forgiving
  - Wrong number of robots
  - Preconceived solutions etc.

Artificially evolved controllers



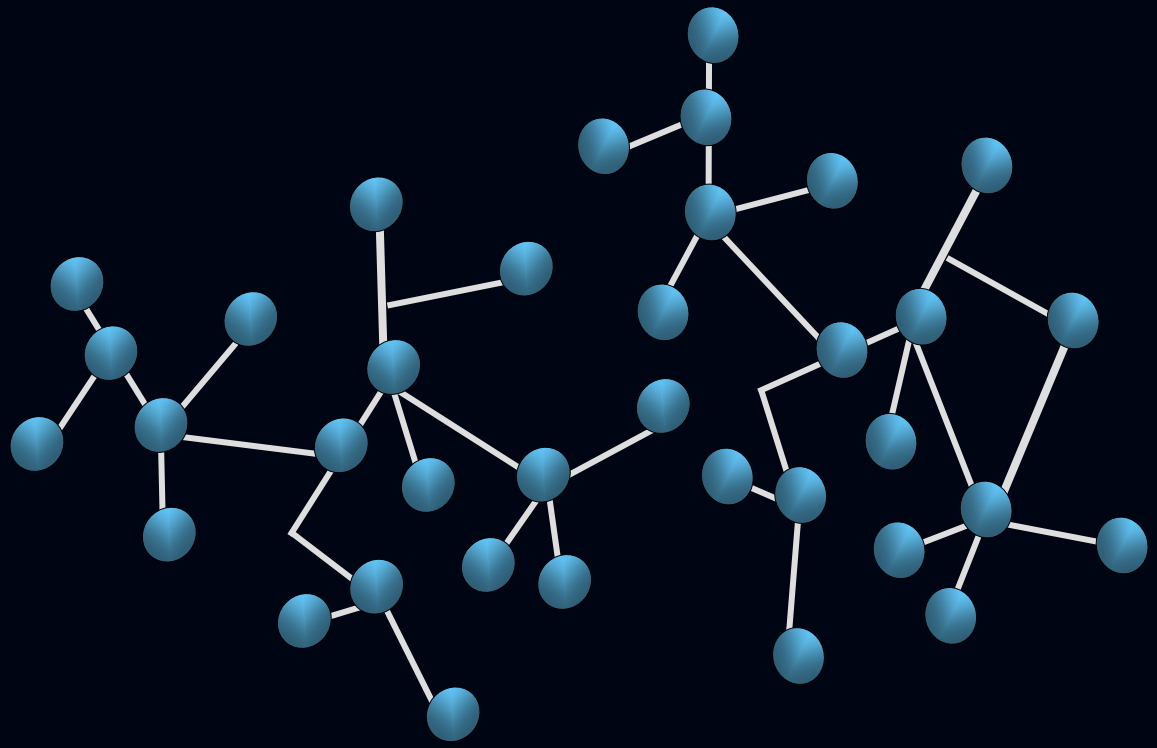
Artificial Neural Tissues [Thangavelautham & D'Eleuterio, 2005..]

ANT – How It Works

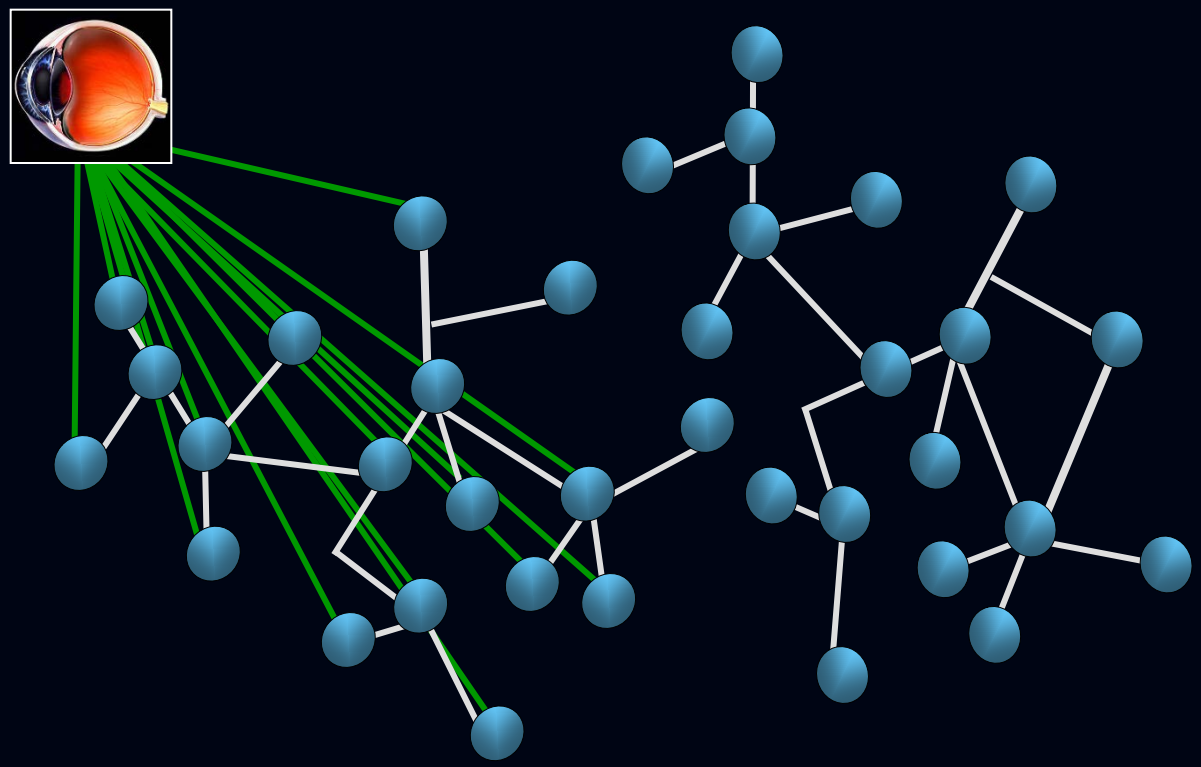
ANT – How It Works

ANT – How It Works

ANT – How It Works

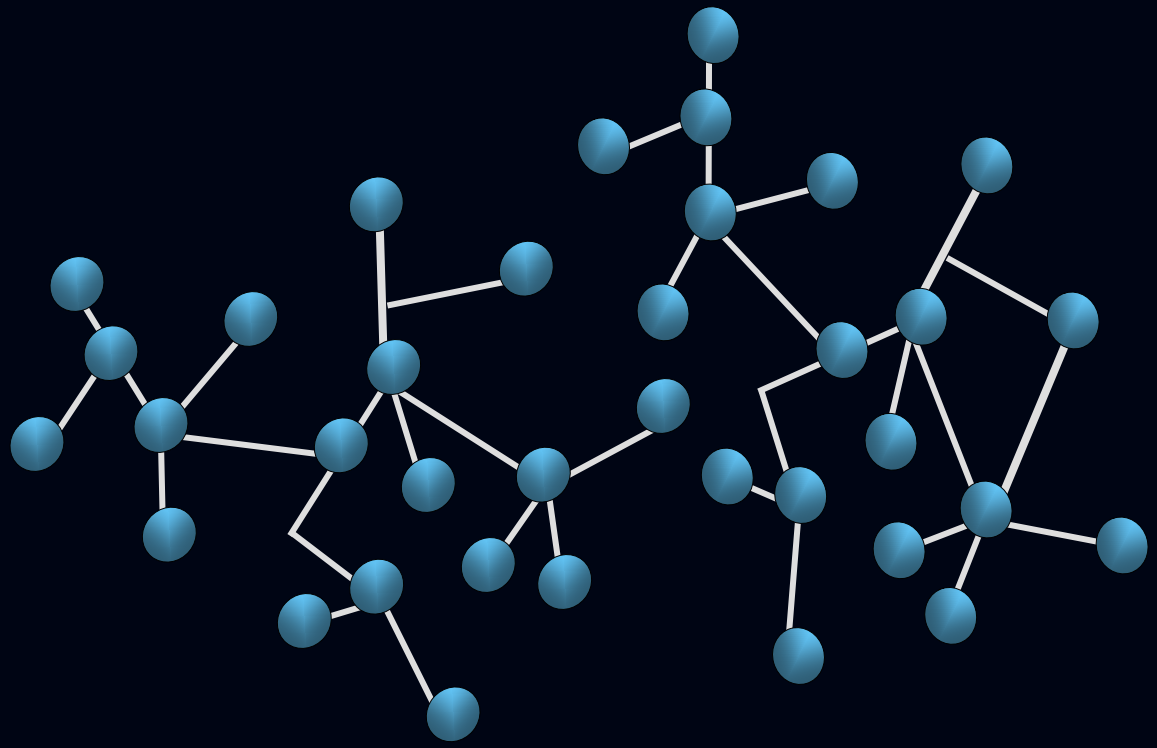


ANT – How It Works



Sensory Input

ANT – How It Works



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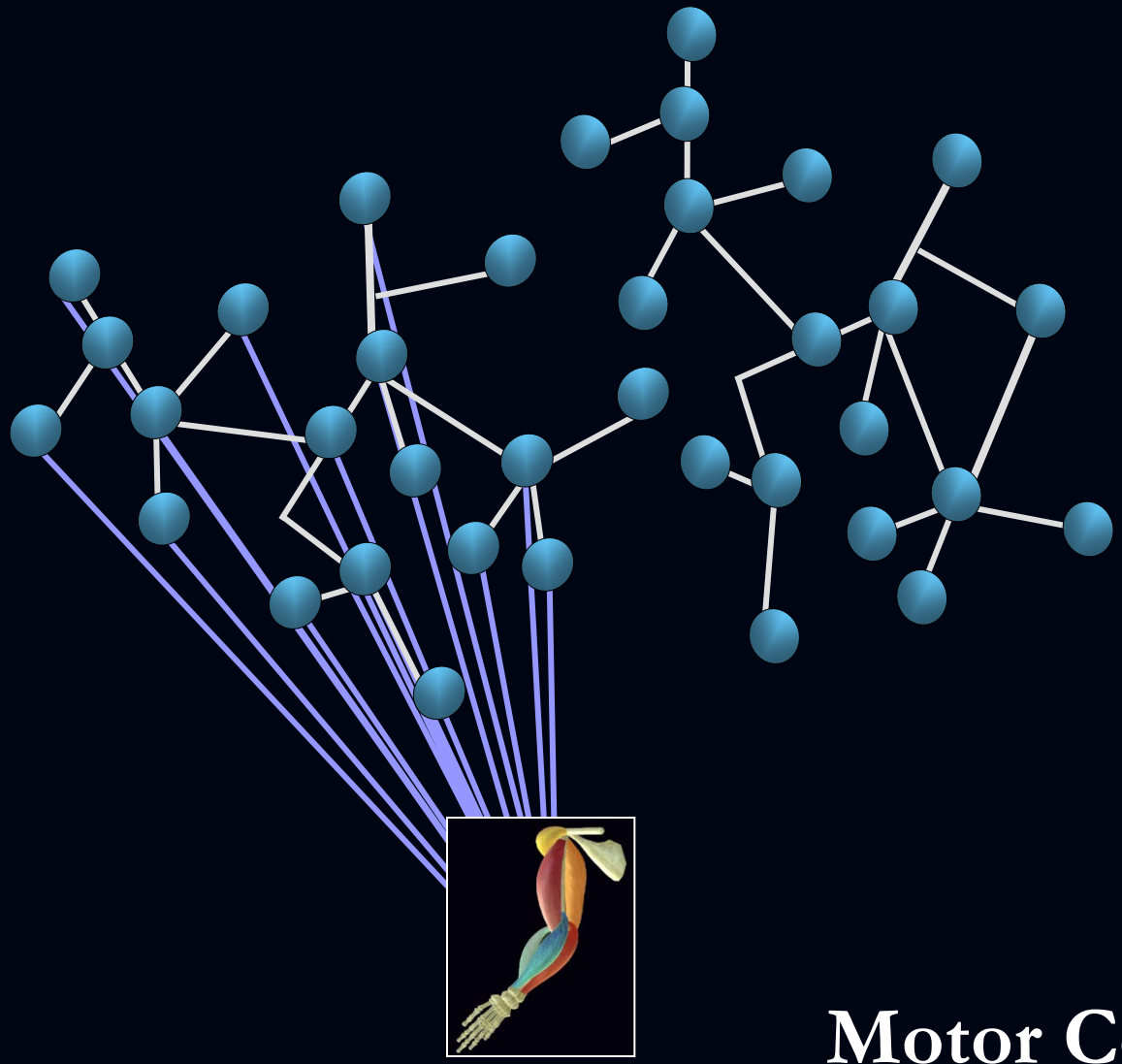


Motor Control

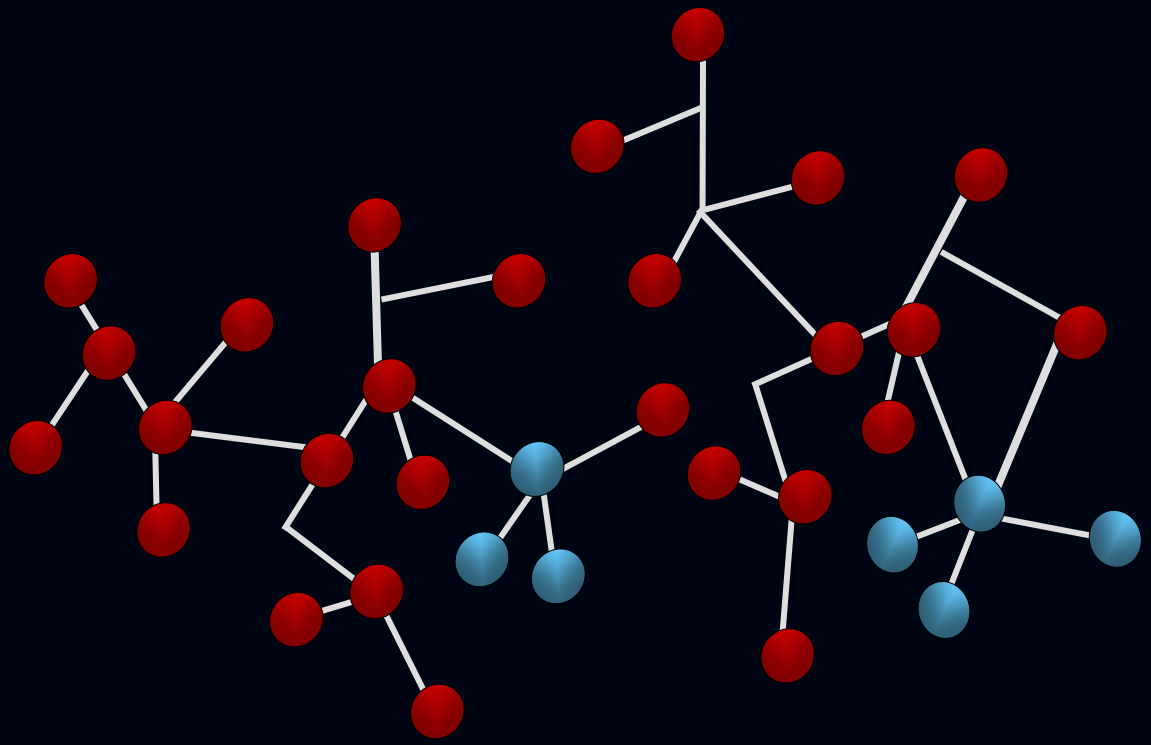
ANT – How It Works

ANT – How It Works

Spatial Crosstalk

[Jordan & Jacob, 1991]

ANT – How It Works



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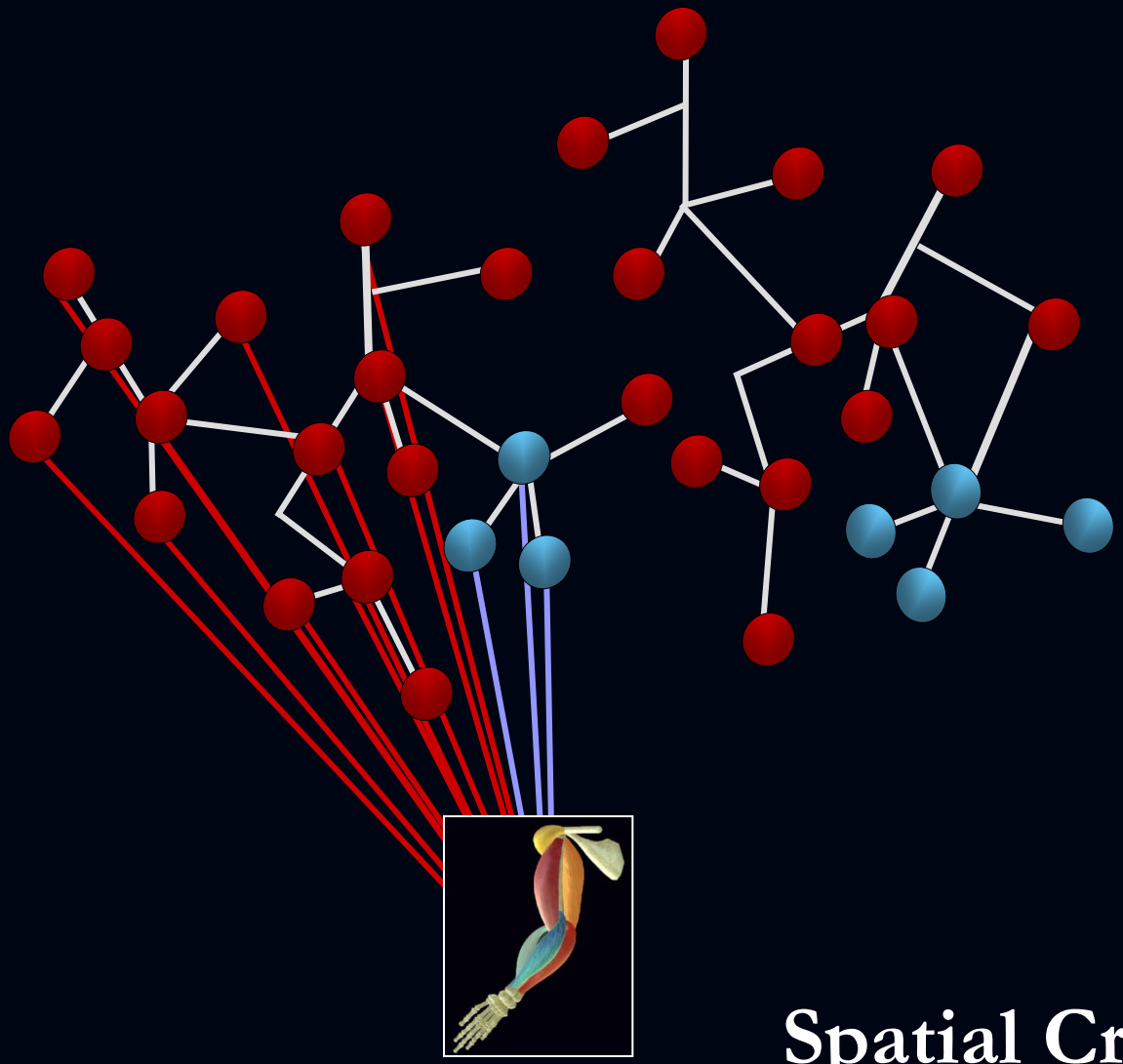

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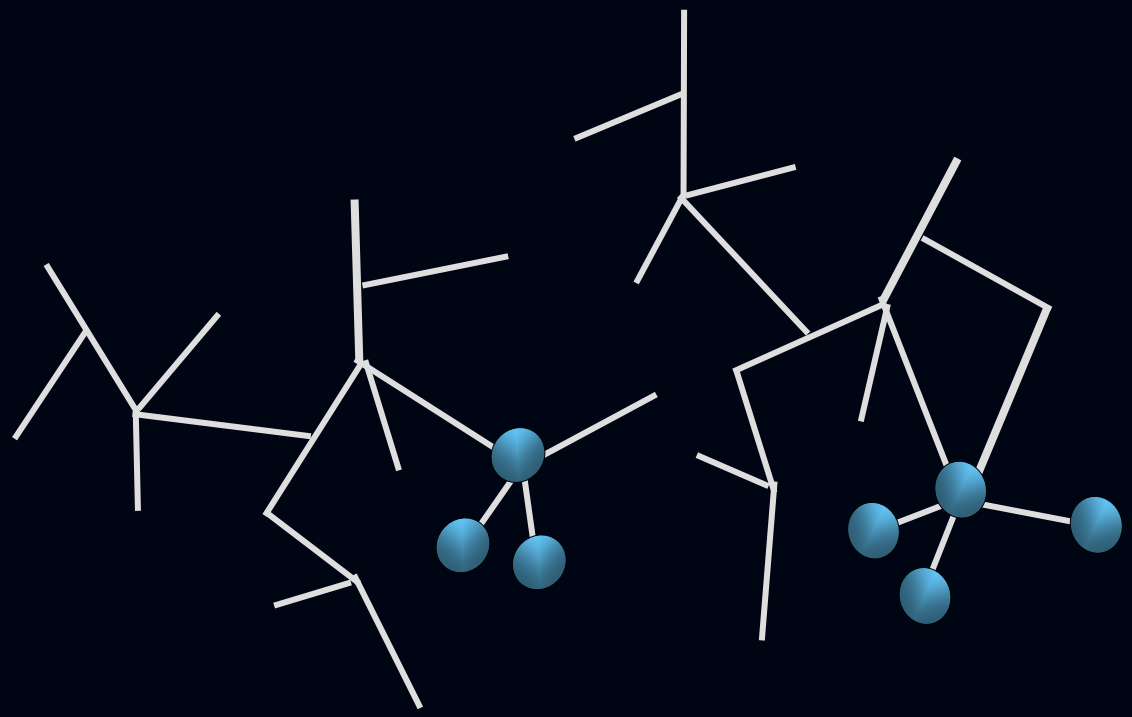
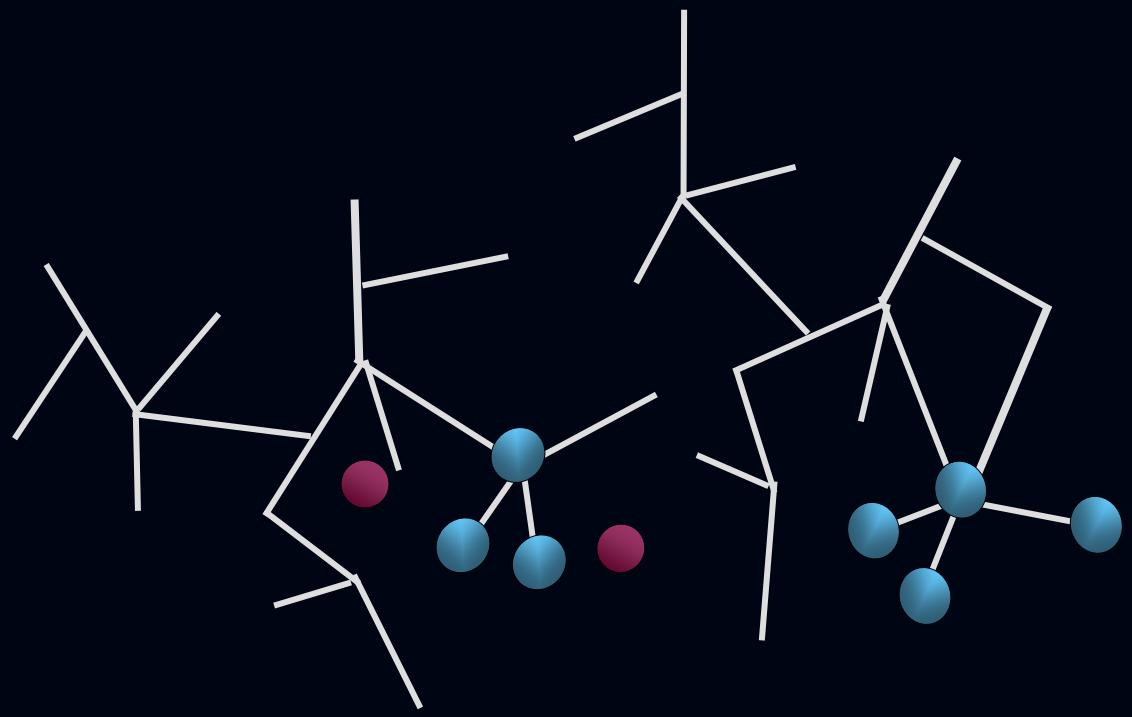
ANT – How It Works



ANT – How It Works



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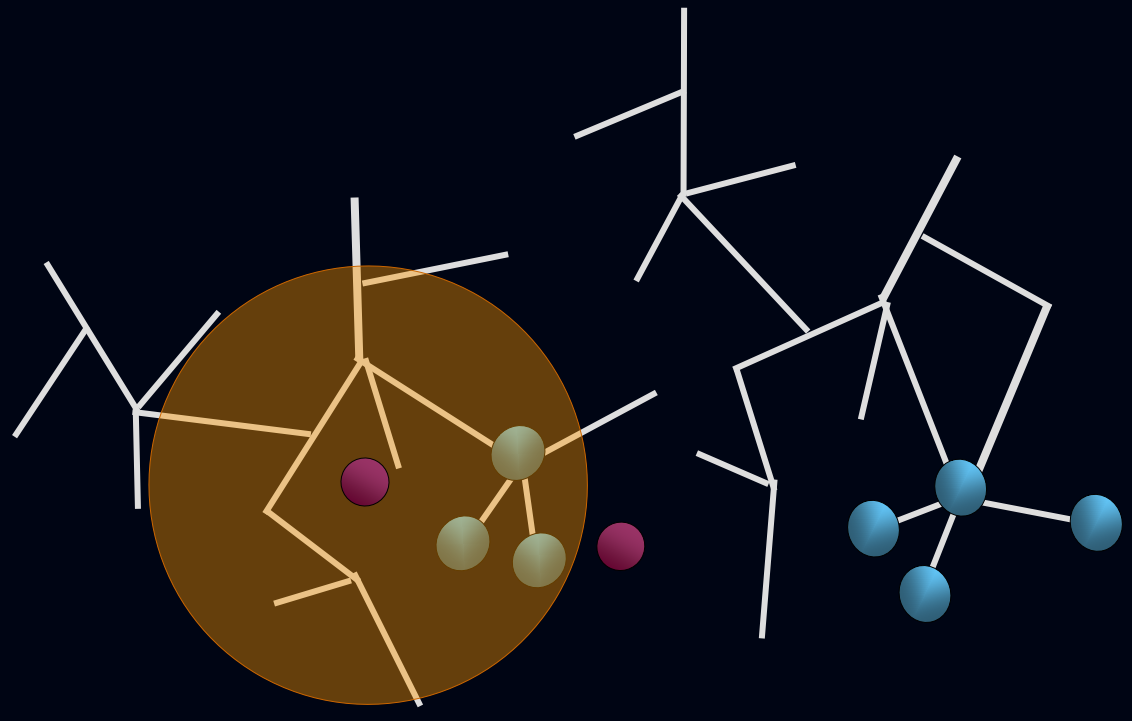
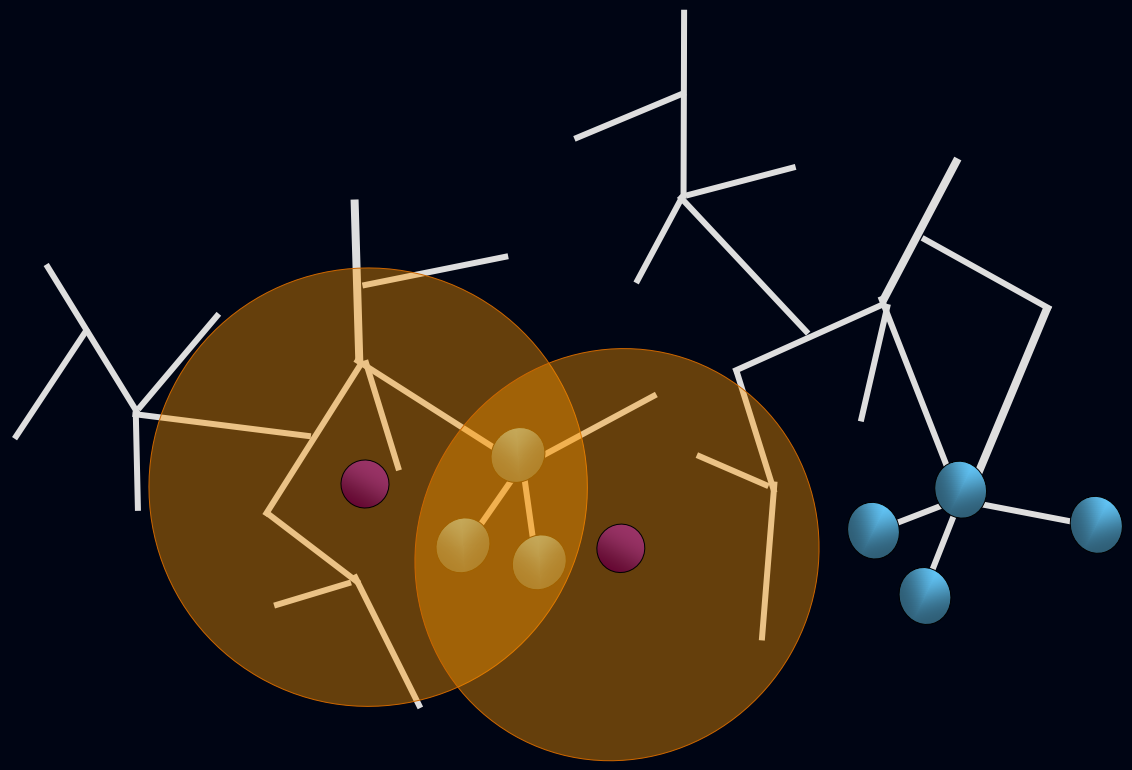
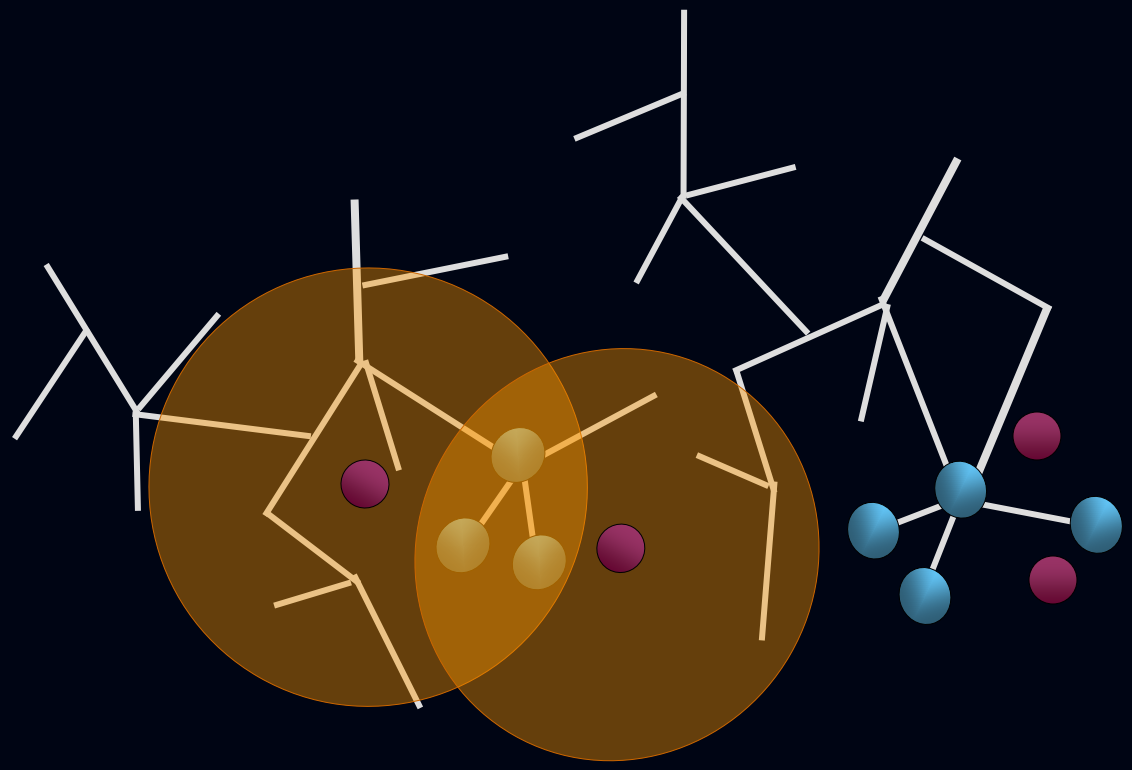


ANT – How It Works



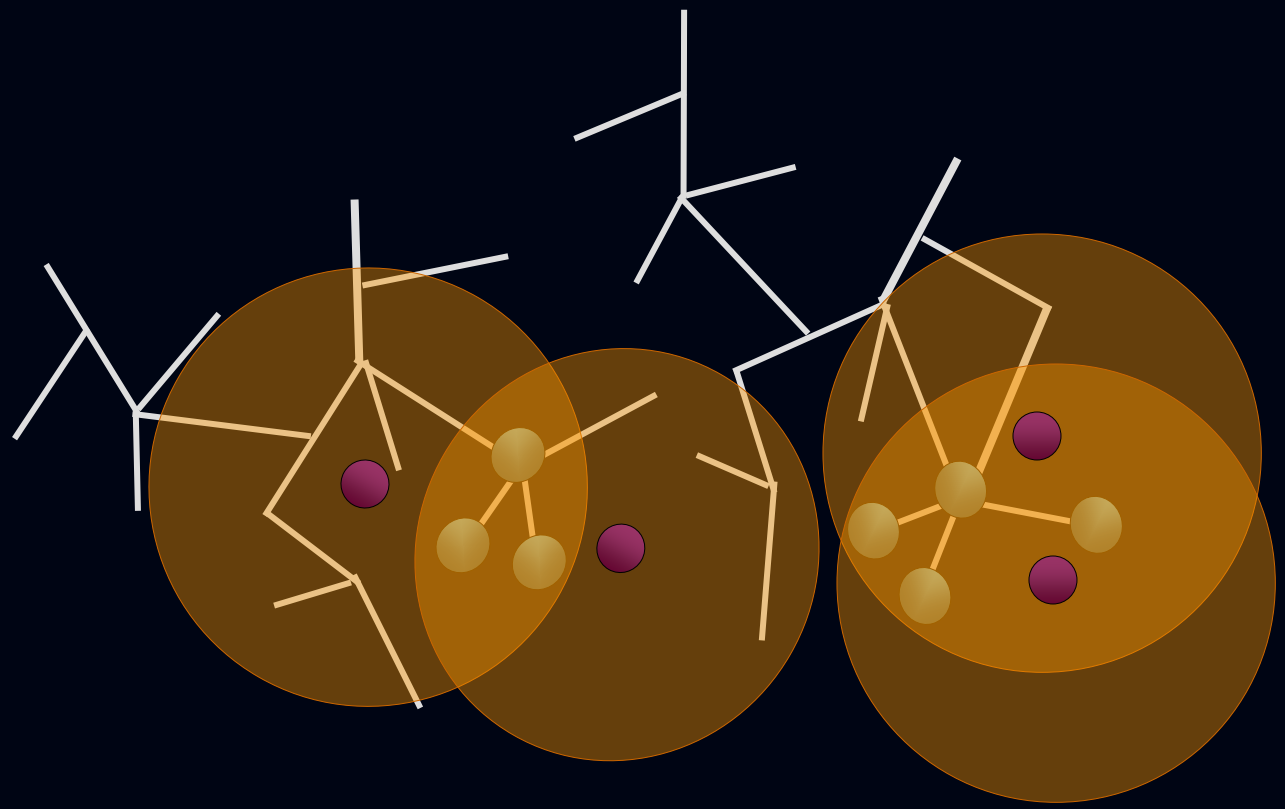
Increased Resolution

ANT – How It Works



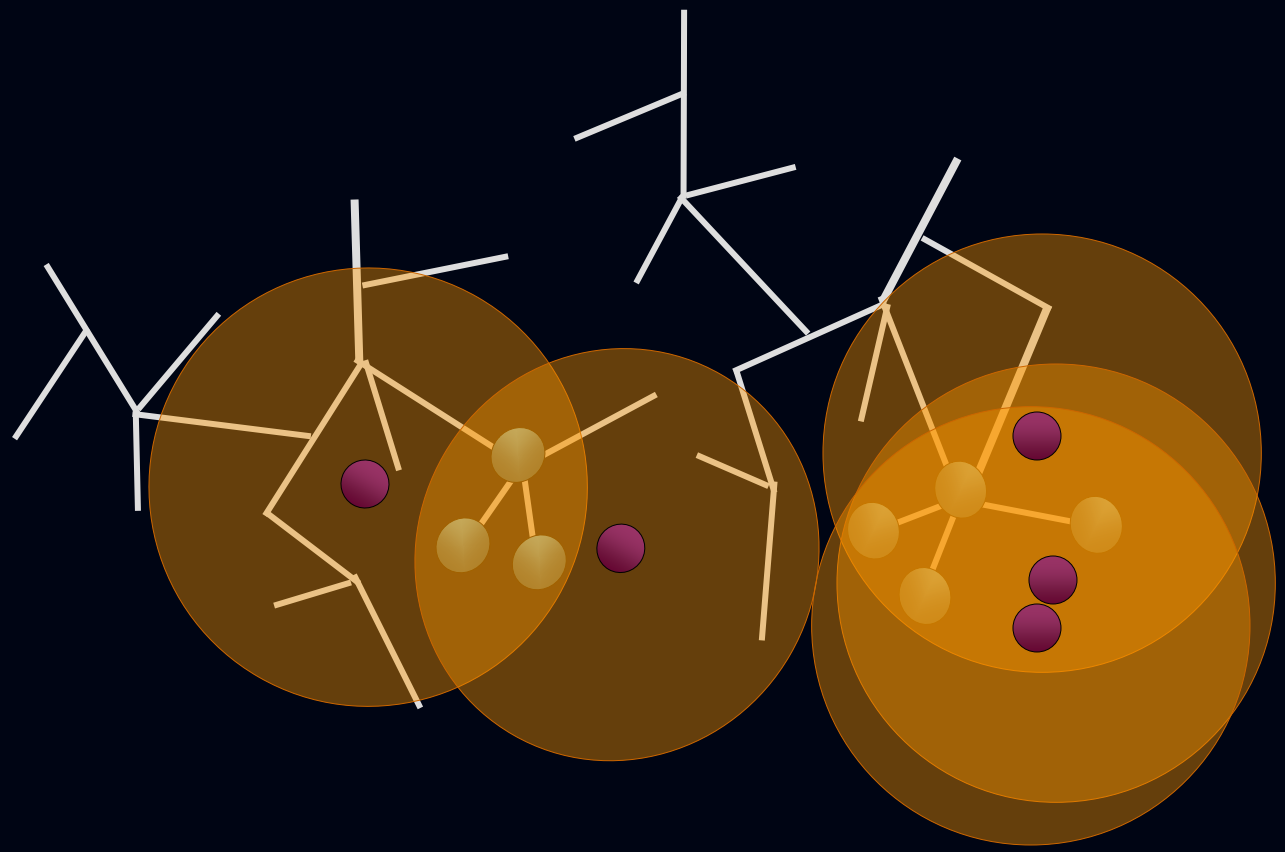
Increased Resolution

ANT – How It Works

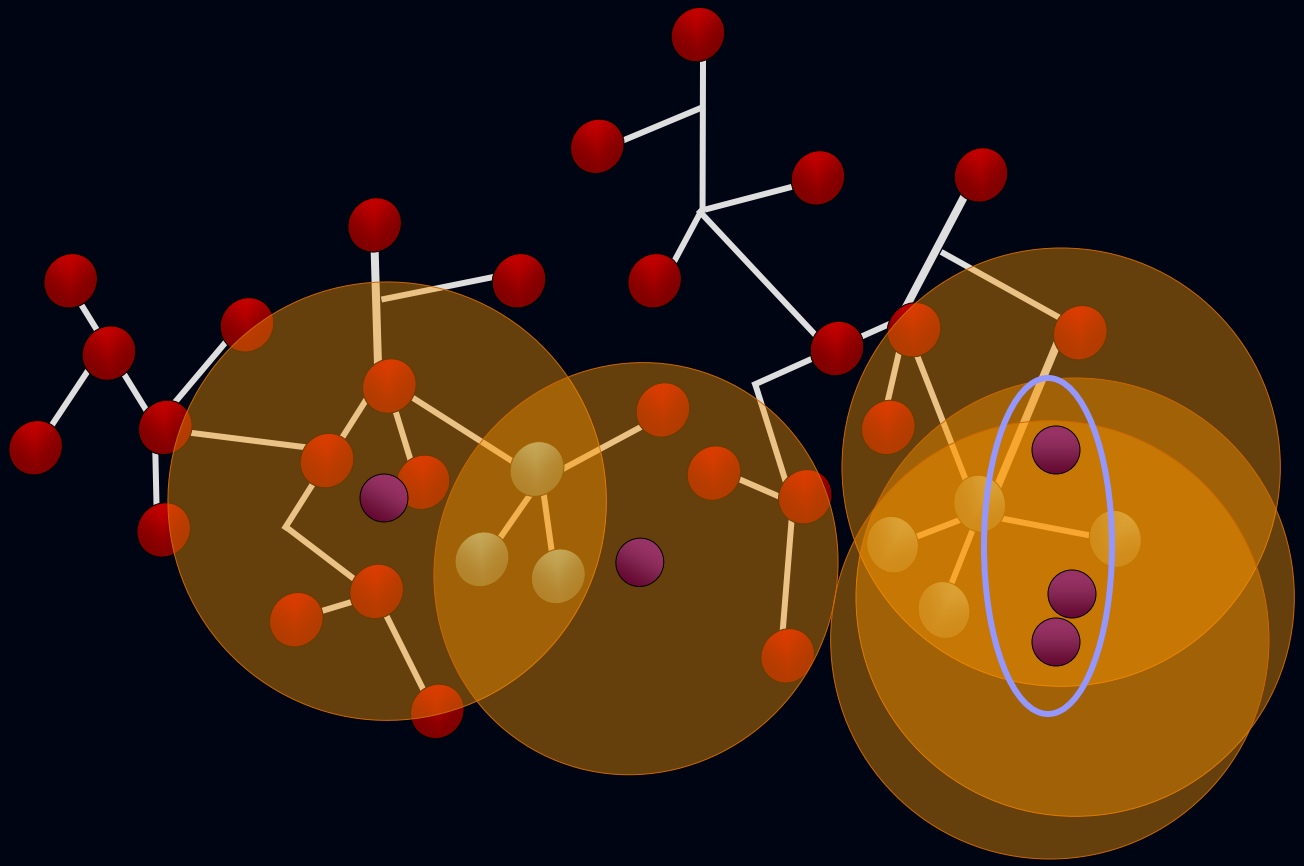


Increased Resolution

ANT – How It Works

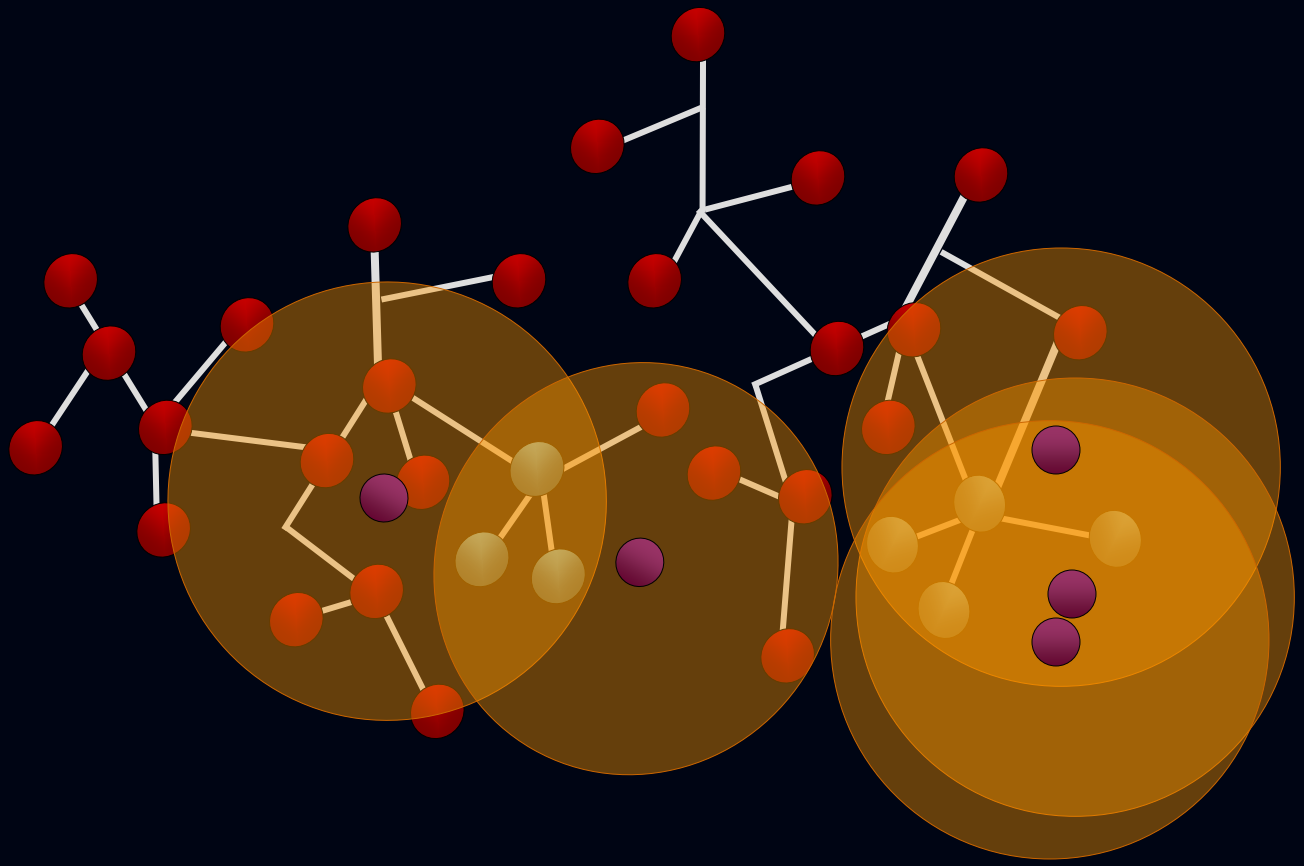


ANT – How It Works



Redundancy

ANT – How It Works



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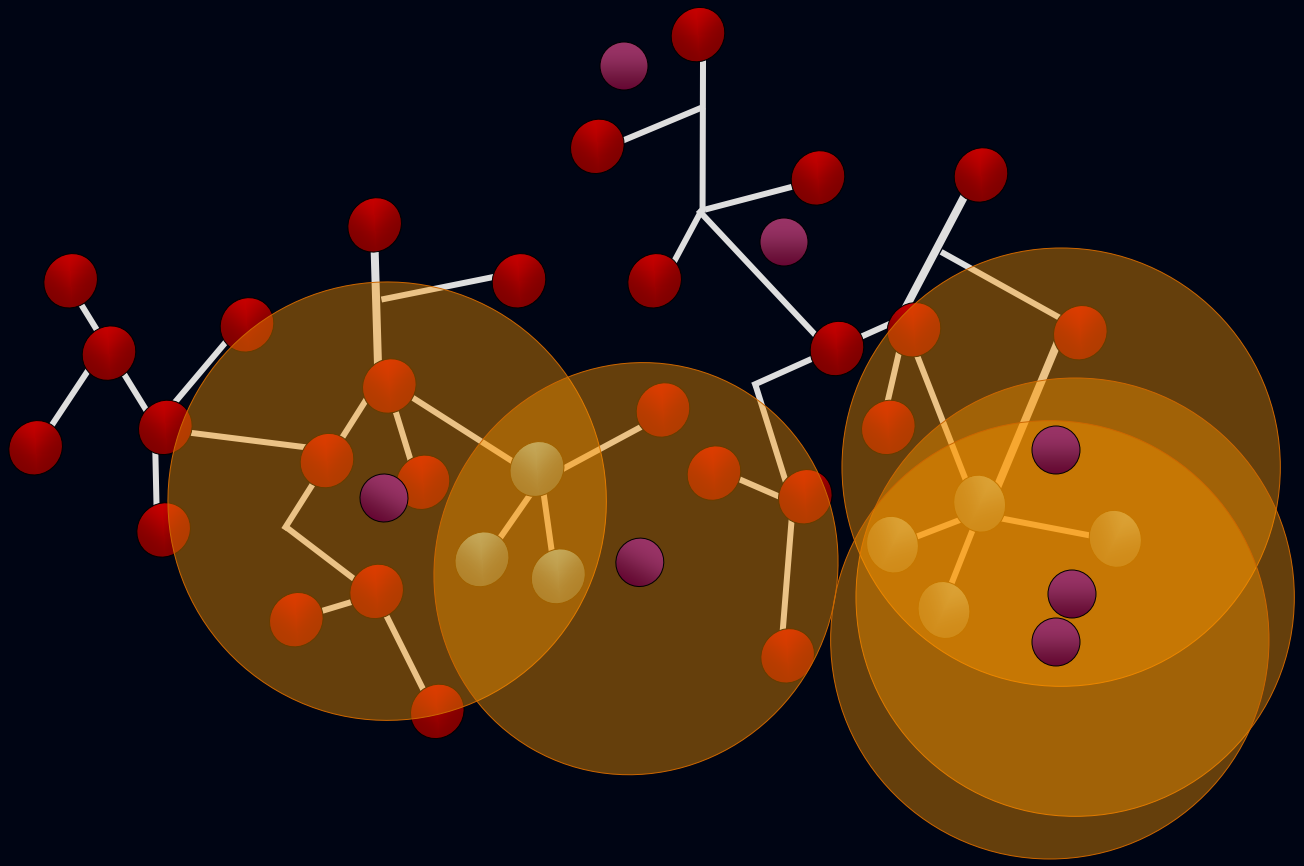

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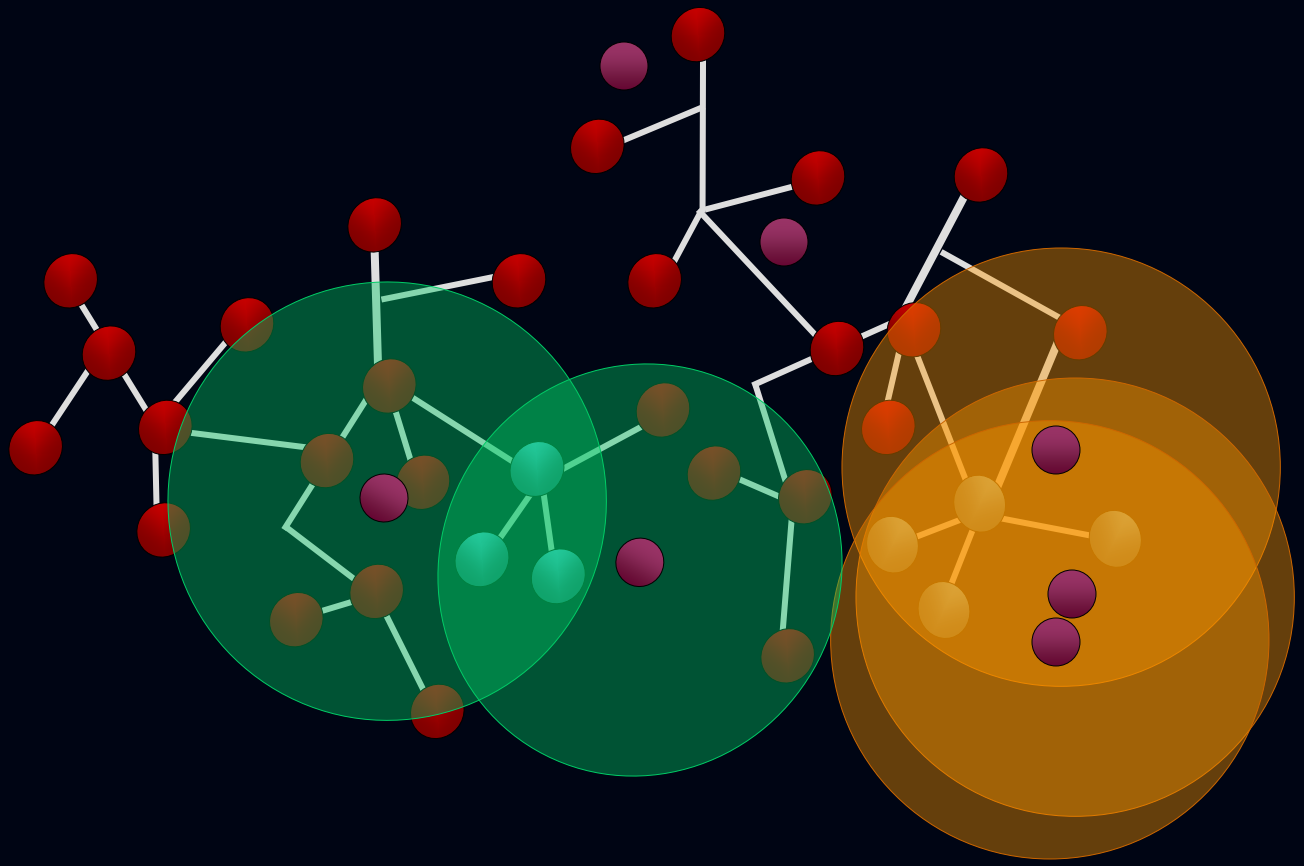
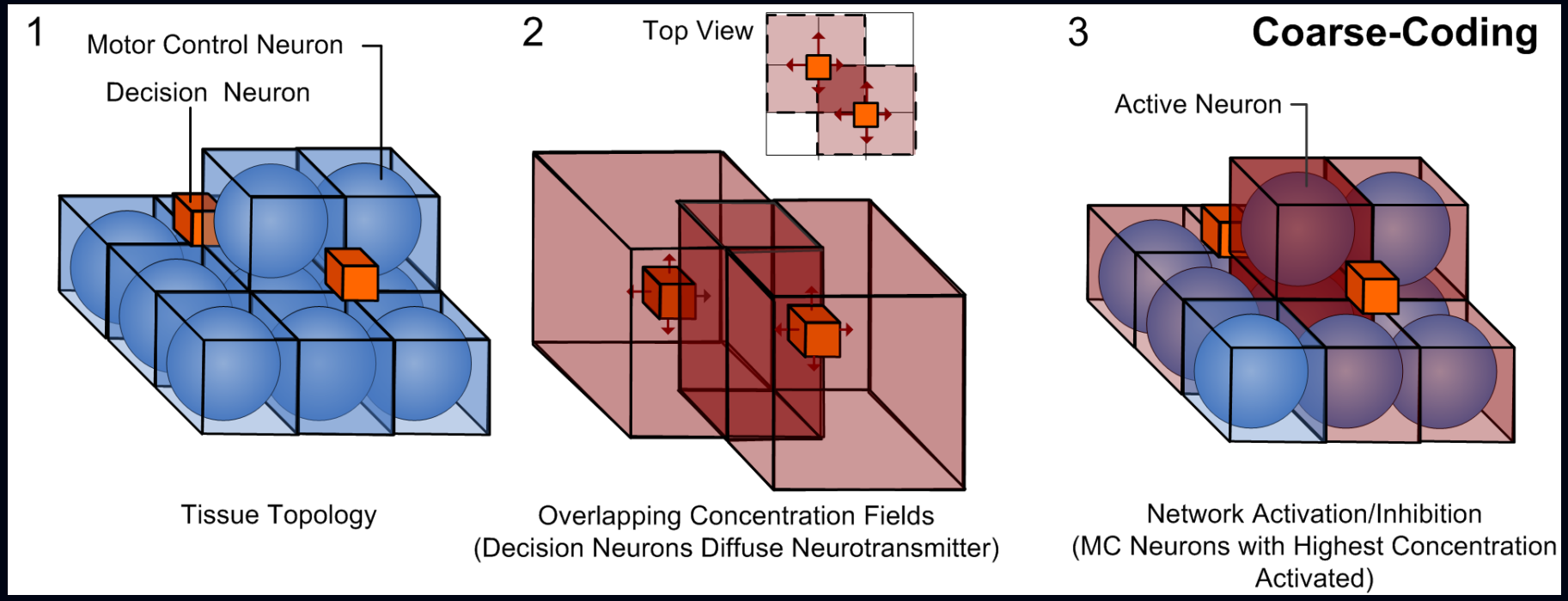


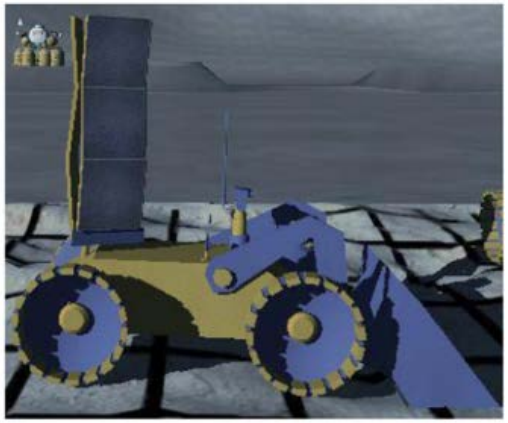
Competition

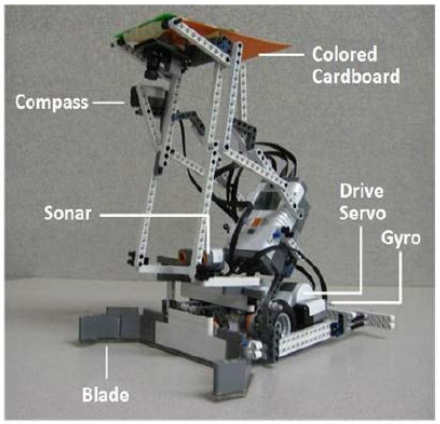
ANT – How It Works

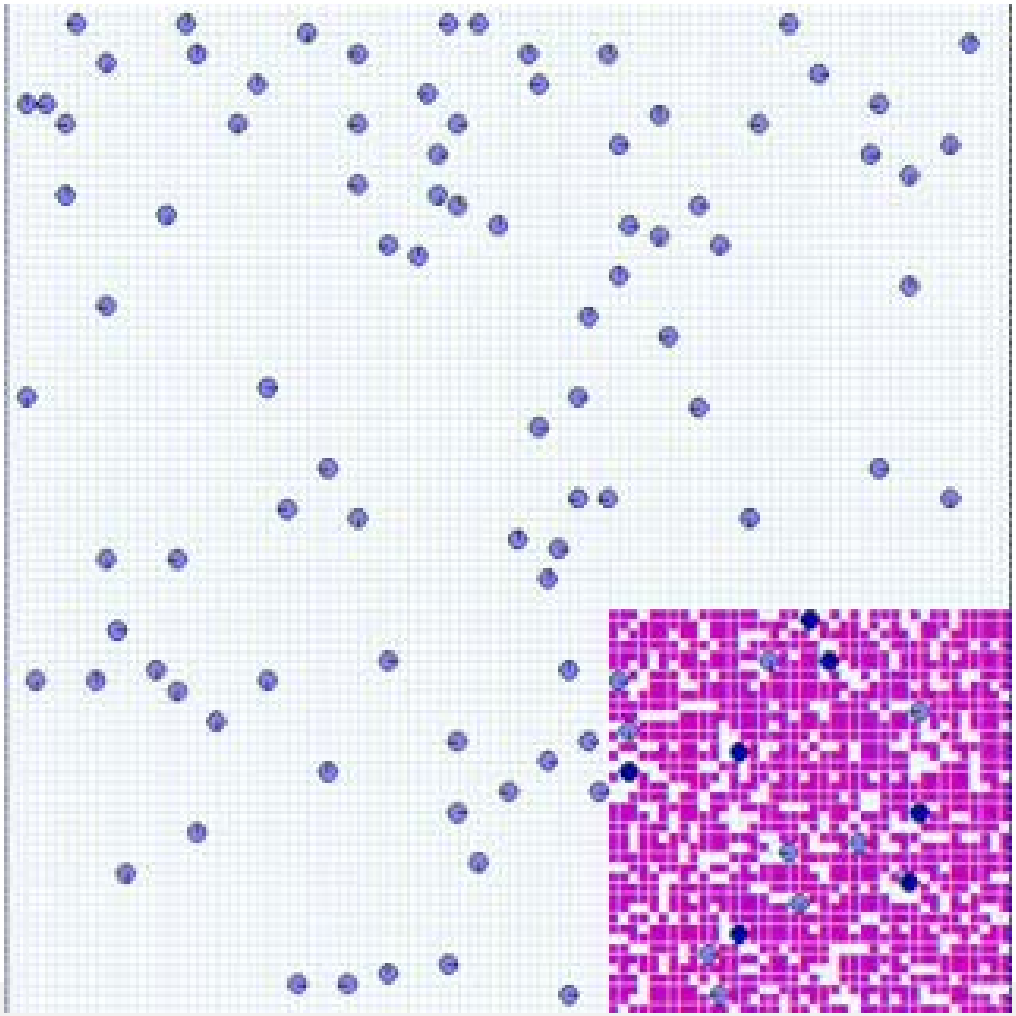


One Controller - Multiple Robot Platforms

1 - Wireless Radio
2 - LED Light Beacon
3 - Camera
4 - Laser Range Finder
5 - PC-104 Computer
6 - Electronics
7 - Pan Tilt Unit
8 - 3-Axis Accelerometer
9 - Sonars
10 - Blade 1-DoF Actuator
11 - Blade Force Sensor
12 - Bulldozer Blade







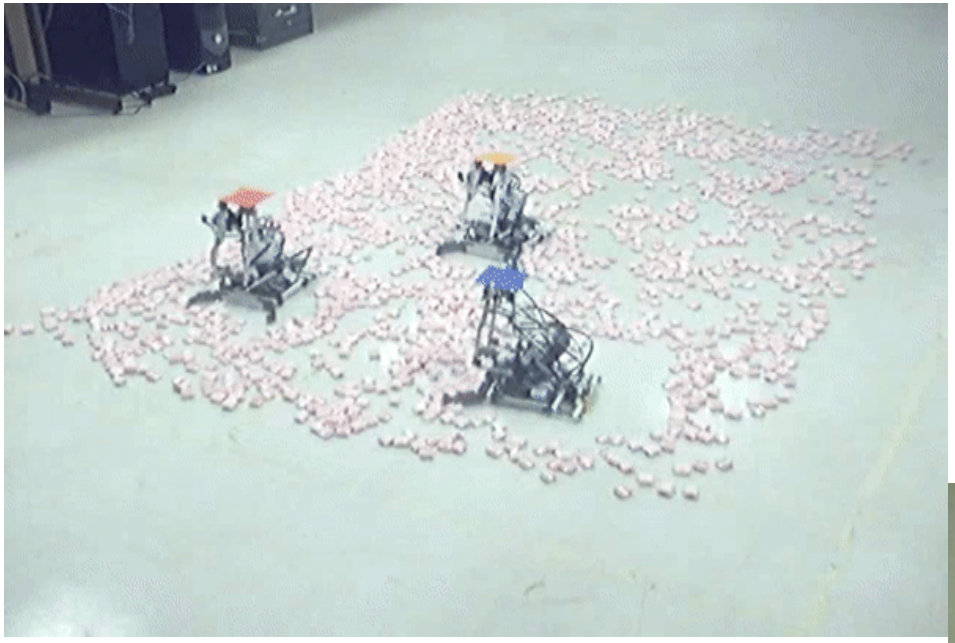
Scalable to hundreds or thousands of individuals

(Thangavelautham, Smith, D'Eleuterio, 2007-)

Robust system performance with imperfect individuals

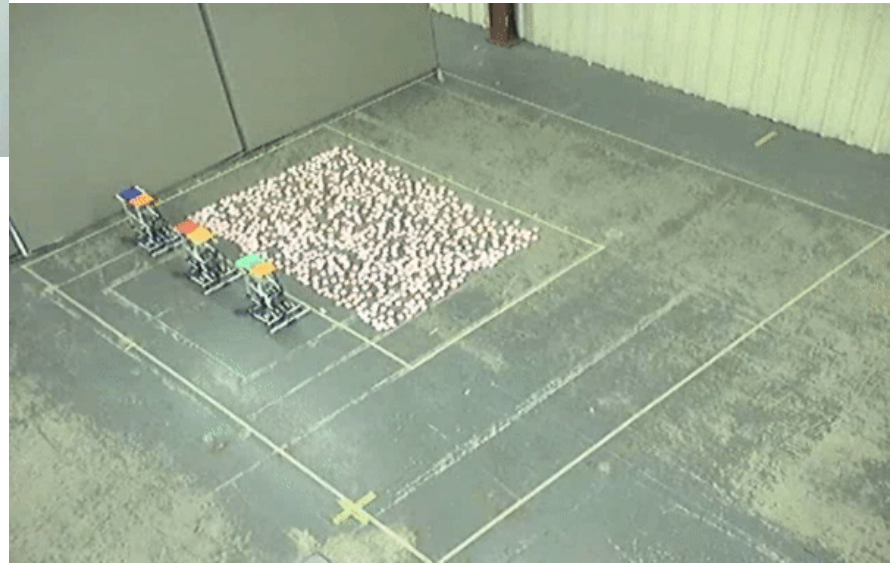
Multirobot Cooperation Methods

(Thangavelautham, Smith, D'Eleuterio, 2009-)



Completely Decentralized

Aggregate Decentralized

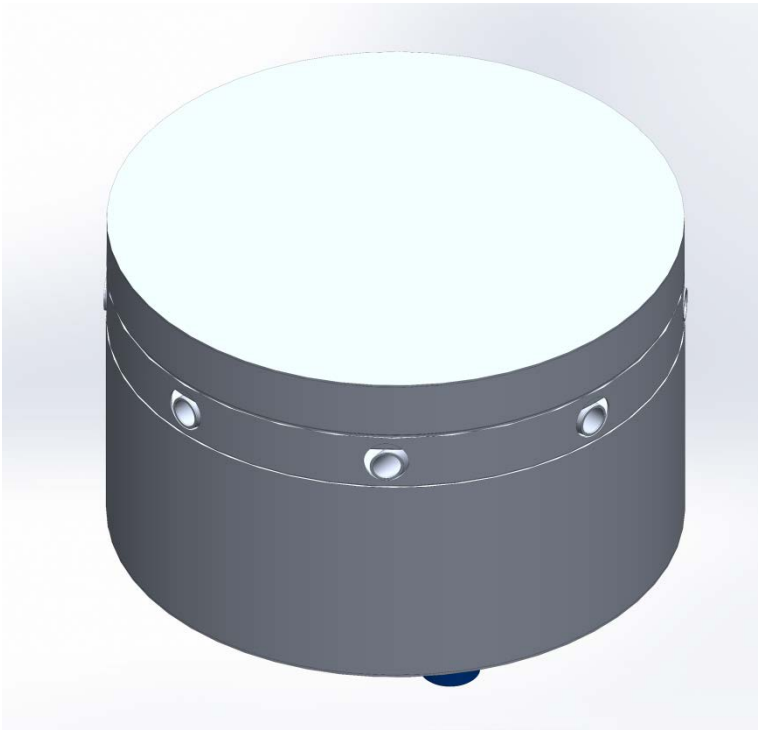


Athena Platform

- Developing 5 modular robots for performing cognitive multirobot communications experiments.
  - Utilizes COTS components, with plans for use of open-access CubeSat electronics
  - Plans to make it open-source
  - Open to multi-institutional collaboration

- Robots mounted on air-bearings to simulate frictionless env. of space.

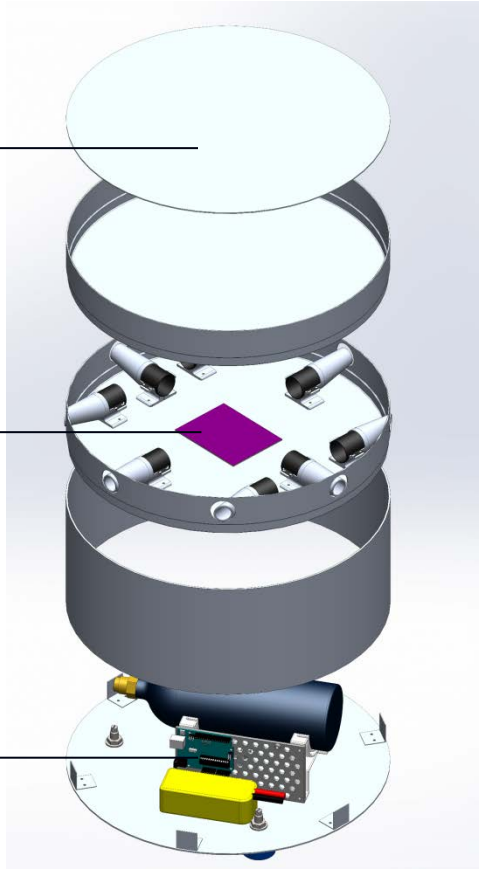
Athena Robot



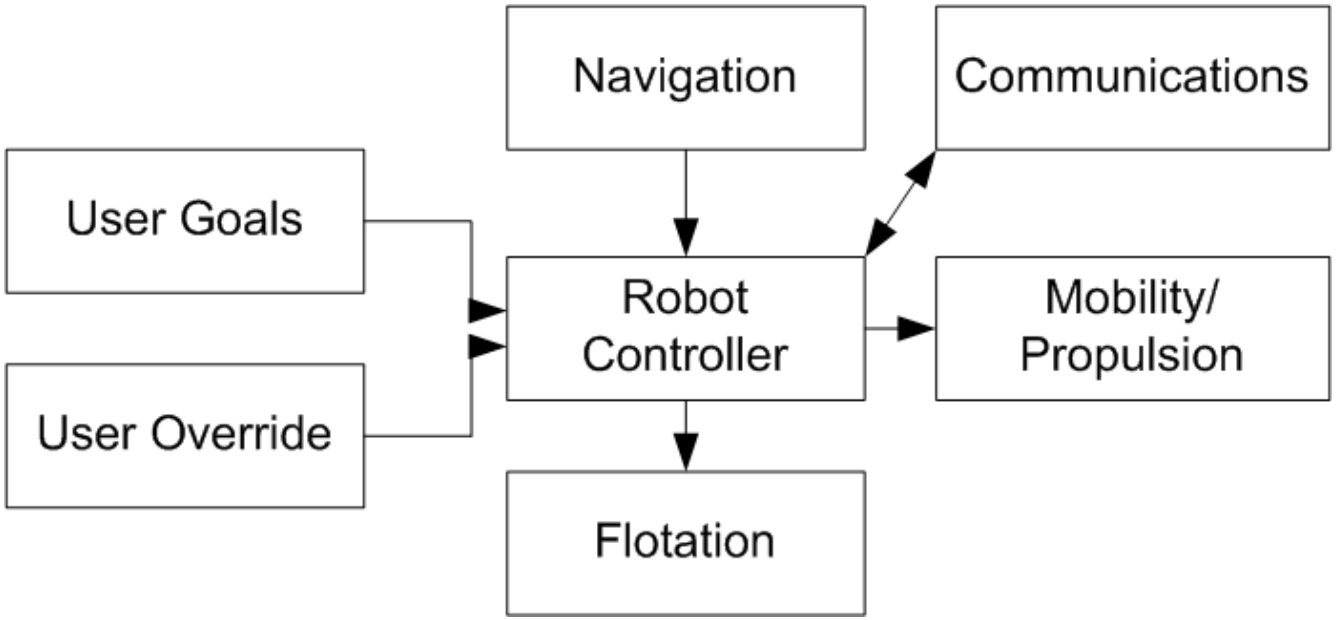
CDH &
Comms.

Propulsion
& ACDS

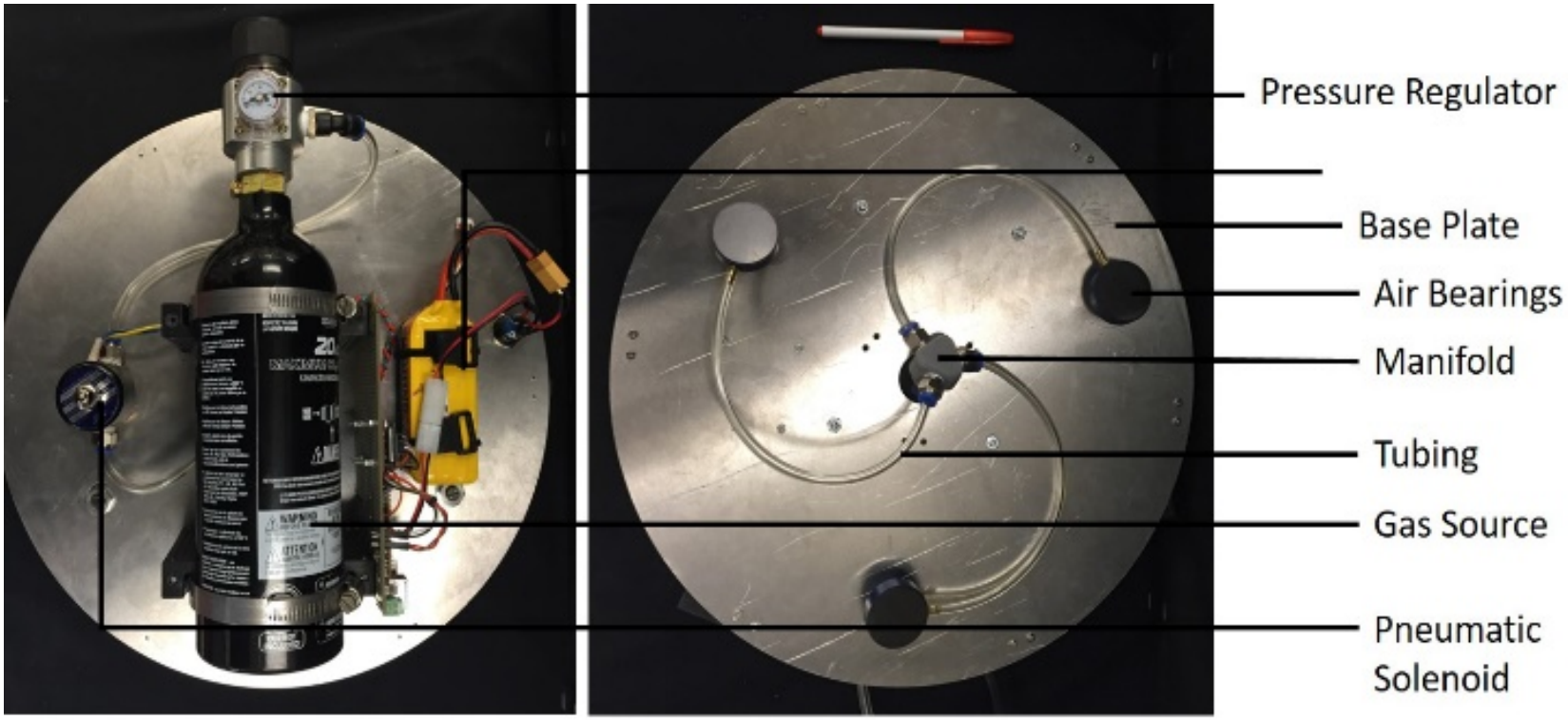
Flotation



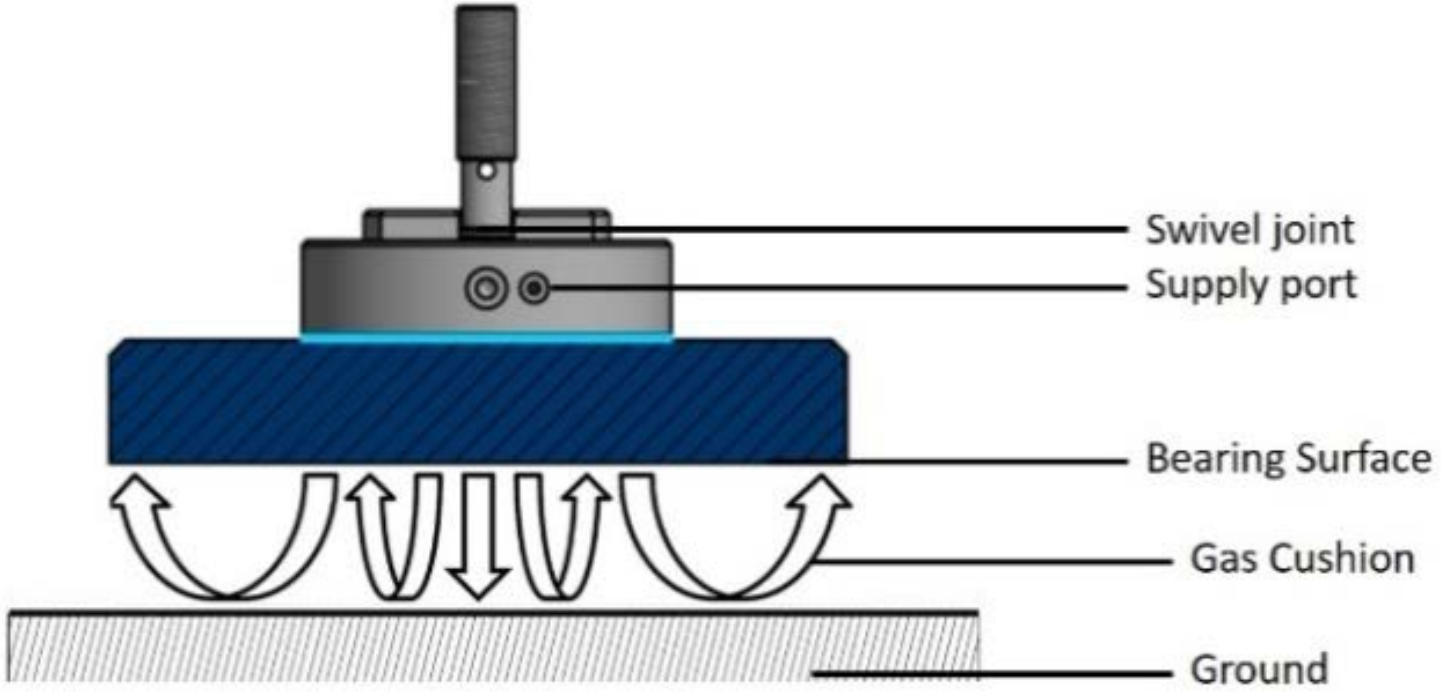
Athena Robot System



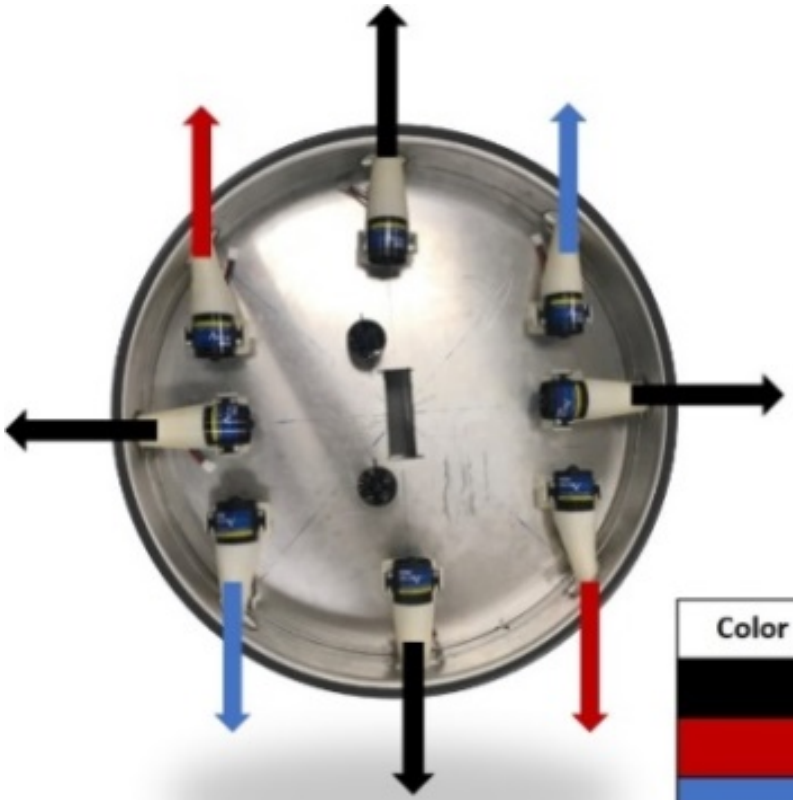
Flotation


Pressure Regulator
Base Plate
Air Bearings
Manifold
Tubing
Gas Source
Pneumatic Solenoid

Flotation

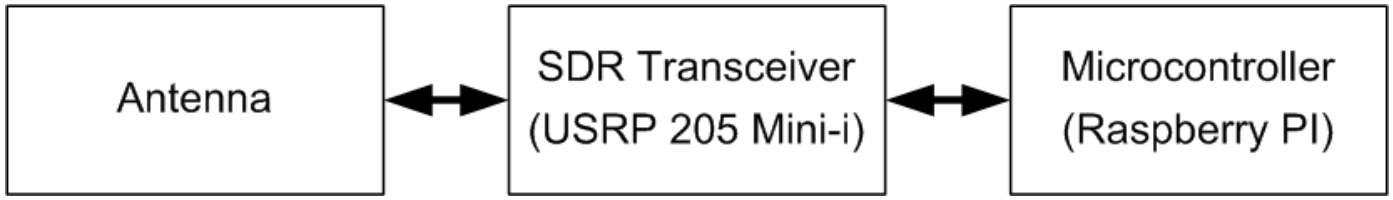

Swivel joint
Supply port
Bearing Surface
Gas Cushion
Ground

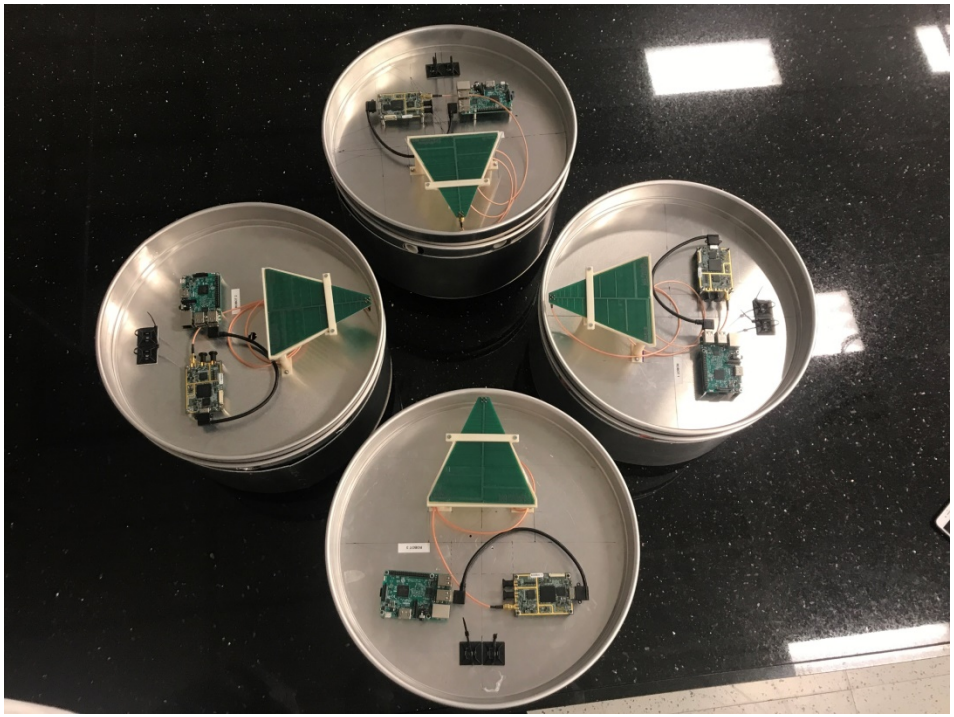
Propulsion



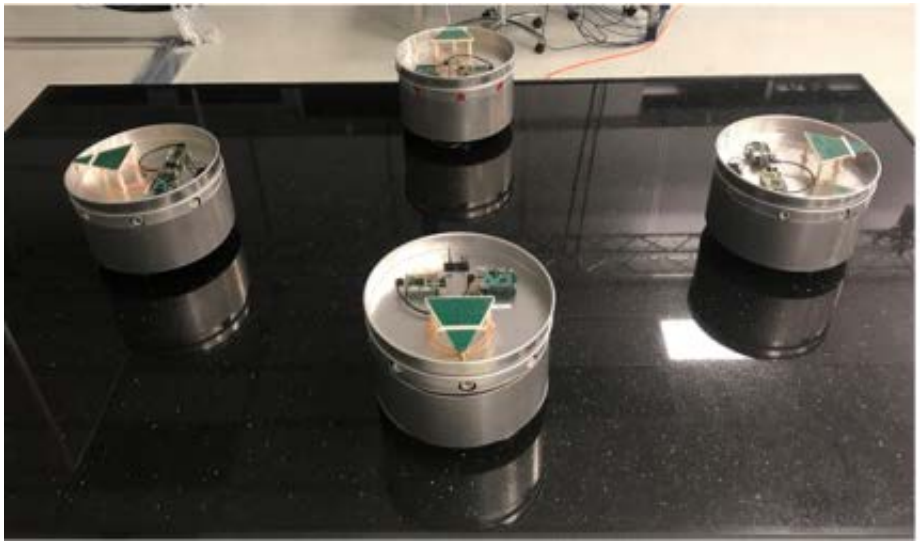
Color	Fans causing
	Translations
	Clockwise Rotation
	Counter-Clockwise Rotation

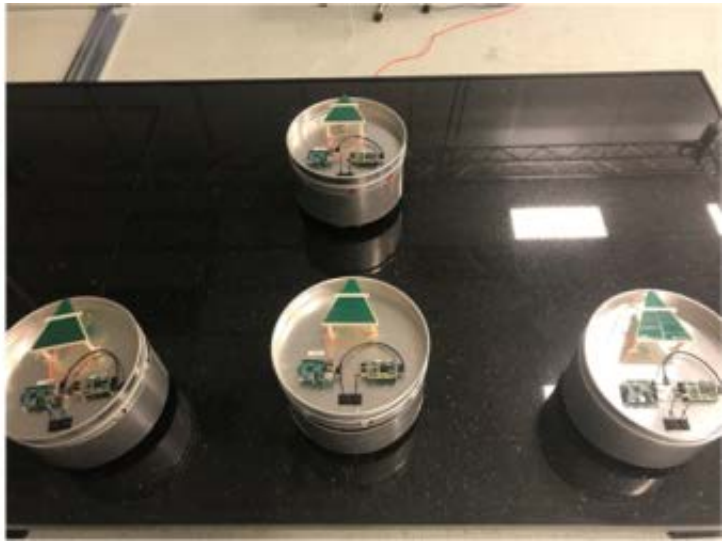
Communication Payload





Experiments





Discussion

- Ongoing work to develop a open-source platform for multi-spacecraft cognitive communication research.
- Platform facilitates research in sliding mode autonomy and teleoperation.
- Use of Software Defined Radios (SDR) enabling wide re-configurability of the radios.

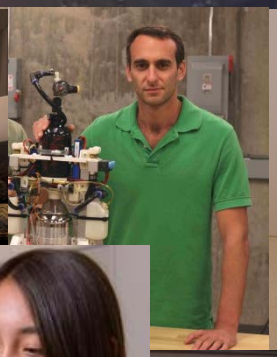
Future Work

- Self-formation experiments to demonstrate accurate positioning
- Re-configurability experiments
  - Demonstrate loss of one or more spacecraft
  - Demonstrate multiple formations
  - Assess reliability, robustness, fuel cost
- Potential for scalability

SpaceTREx Capabilities

SpaceTREx

Design, Build, Test, Fly…













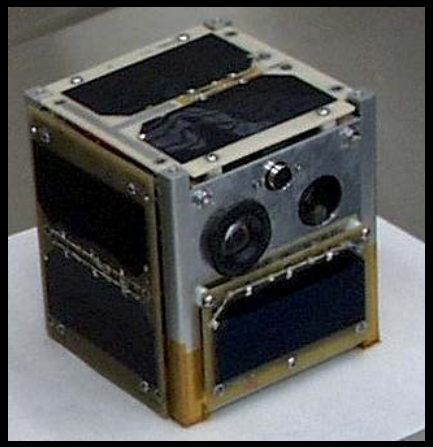

Space Missions

SpaceTREx

Canadarm

Canadarm II, Dexter

DARPA Orbital Express

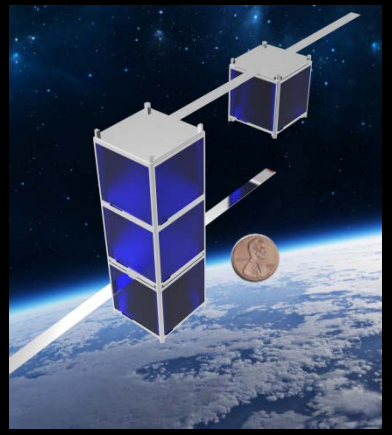


CanX1

CanX2

AOSAT I

SWIMSat



SunCube
FemtoSats

SpaceTREx Team

Thank you !

Questions ?