

Bio-Inspired Design 2011

Wb2436-05 (Entirely in English)

Prof. Dr. Tetsuo Tomiyama (3mE/BMechE/IMS)

**Bio-Mechanical Design
Mechanical Engineering**

Lecture 12: March 16, 2011 (Wed)

8:45-10:30, Room A

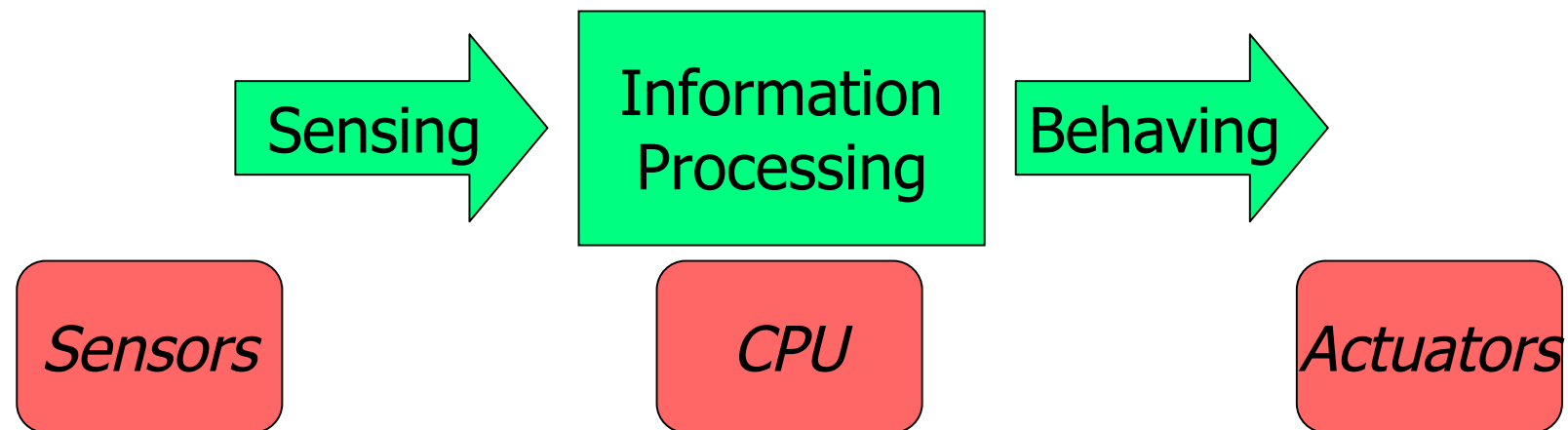
- **Similarities and Differences Between Mechanical and Biological Systems**
 - Behavior and Intelligence
 - Life Cycle Stages
 - “Design Principles”
- **Bioconstruction**
 - Reproduction, Generation

Mechanical and Biological Systems

- **Similarities and Differences?**

Mechanical and Biological Systems

- **Information Processing View**
 - Total Performance
 - Capabilities of
 - Sensors
 - CPU
 - Actuators



Similarity: Programmed

- **Mechanical Systems**
 - Move as Designed
 - Program = Design, Control Software
 - Even “Learning” is Programmed
- **Biological Systems**
 - Behave as Dictated by Gene Information (DNA)
 - Instinct
 - Learning Enhances Programmed Behaviors

Two Types of Science

- **Law Based Science**
 - Laws are Given (by Nature)
 - Physics, Chemistry
 - Laws are Semi-Artificial
 - Mathematics, Economics
- **Program Based Science**
 - Programmed by Nature
 - Biology
 - Programs are Free to Design
 - Computer Science
 - Engineering Design

Behaviors of Artificial and Biological Systems

Behavior	Mechanical Systems	Biological Systems
Feelings	None	Many, Different
Power	Tough	Easily Become "Fatigue"
Repetitive Work	Can Repeat Forever Not Getting Bored	Cannot Repeat Forever Getting Bored
Fluctuations Variations	None/Few	Many, Irregular
Malfunctioning	Wear, Foreign Objects, Oxidation	Disease

Life Cycles of Artificial and Biological Systems

Life Cycle	Artificial Systems	Biological Systems
Design	Drawings based on Intention	DNA (Crossbreeding, Mutation)
Production	Material, Component, Assembly	Reproduction (Cell Cleavage, Development)
Operation	Need to be Programmed, Supported, Controlled	Autonomy based on Intelligence
Maintenance	Repair	(Self-)Healing
End-of-Life	Recycling, Incineration, Reuse	Death (Reduction to Non-Organic Materials)

Building from Components

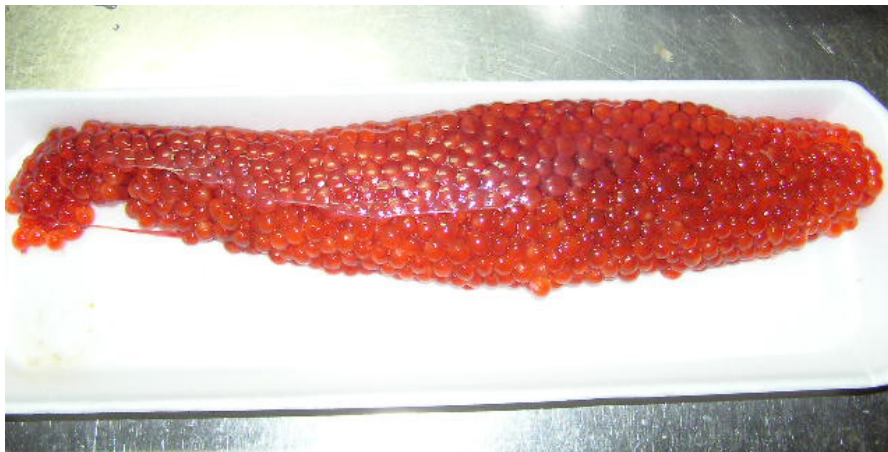


The Most Significant Design Difference

- **Artificial**
 - Purposeful Design
 - No Waste, No Nonsense
- **Biological**
 - Wasteful
 - Too Many Redundancy

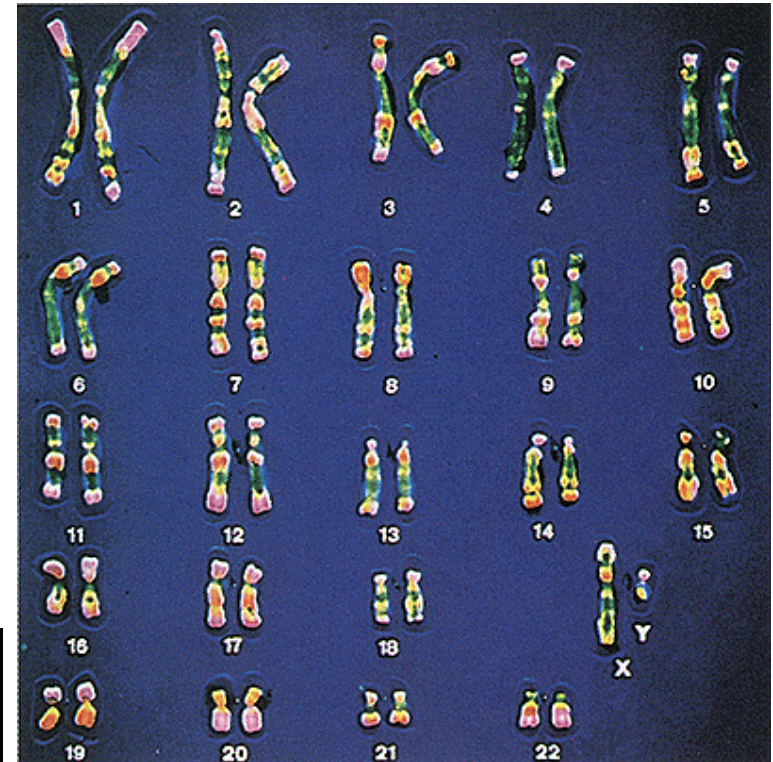
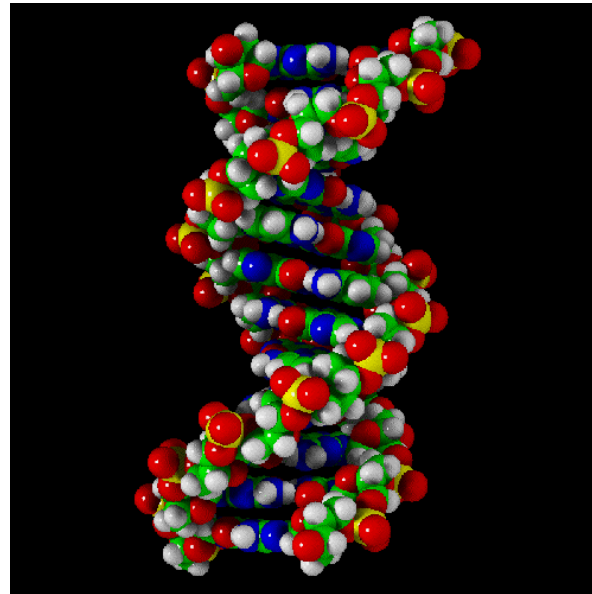
Fish Eggs

- **Salmon**
 - 2,500–3,500 Eggs/Female
 - Only 2 Survive
- **Herring**
 - 100,000 Eggs/Female
 - Only 2 Survive



Gene Information

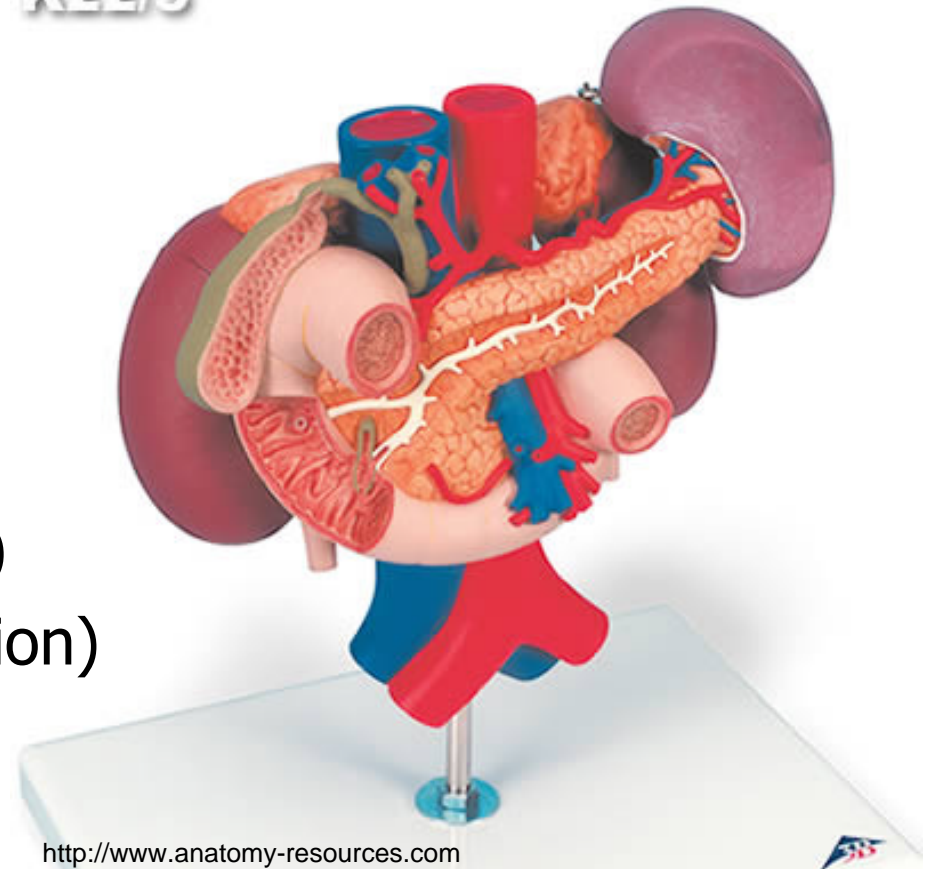
- **30,000,000,000 Base Pairs in Human DNA**
 - 20,000–30,000 ? Genes Coded on DNA
 - Only 5–20% Usage?



Flexibility in Performing Functions

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- **Artificial**
 - Mono Functional
- **Biological**
 - Multi Functional
- **Pancreas**
 - Hormones (Insulin, etc.)
 - Pancreatic Juice (Digestion)



The Current Machine Design Methodology

- **To Construct a Machine from Dumb Machine Elements**
 - Perform a Single or a Few Functionalities
 - Fastening, Guiding Motion, Transmitting Power
 - Machine Elements are Fixed with Each Other
 - Interfaces Usually Transmit Only Energy, Motion, Force

The Mechatronics Design Principle

- **Mechatronics**
 - Mechanical Engineering
 - Electronics/Electrical Engineering
 - Control Engineering
 - Software Engineering
- **Controlling Functionalities and Intelligence**
 - Interfaces Explicitly Transmit Information
 - Components Still Remain Single-Functionality Components

The Current Machine

- **If One of the Components Is Missing or Broken**
 - The Entire Machine Cannot Perform Its Functionalities
 - Hard Fail
 - Our Body Behaves Differently
 - Soft Fail
- **The Machine Has to Be “Assembled”**
 - After Assembly the Machine Needs (Minor) Adjustment
 - Once Assembled, It Cannot (be) Reconfigure(d) Itself to Adjust to Changes of the Surrounding Environment

Bio-Systems are Based on a Totally Different “Design Principles”

- **Organs and Even Cells**
 - Autonomously Perform Fairly Complicated Functionalities
 - Based on Simple Mechanisms
 - “Intelligence” Depending on Not Only a Central Control System (i.e., Brain) but Also Locally Collected Information and Local Environment
- **Robust Against Minor Faults of Sub-Systems**
 - Soft Fail
 - Do Not Loose All Functionalities All of a Sudden
 - Minor Faults Are Even Self-Healed
- **No Assembly Concept but “Generation” or “Growth” from Pre-defined Gene Information**

Machine Production and Generation

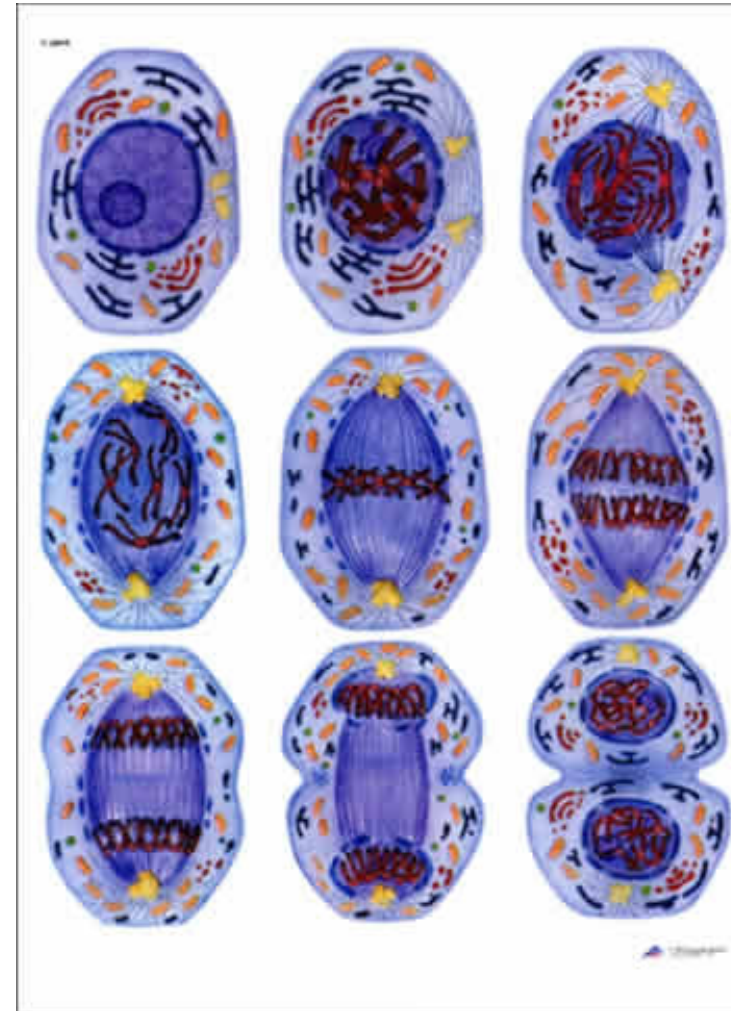
- **Machines**
 - Design of Components and the System
 - Materials
 - Machining
 - Assembly
- **Biological Systems**
 - Fertilization
 - Generation
 - Egg Division (Cleavage)
 - Self-Organization and Self-Assembly

Reproduction of Biological Systems

- **Asexual Reproduction**
 - Cell Division
- **Sexual Reproduction**

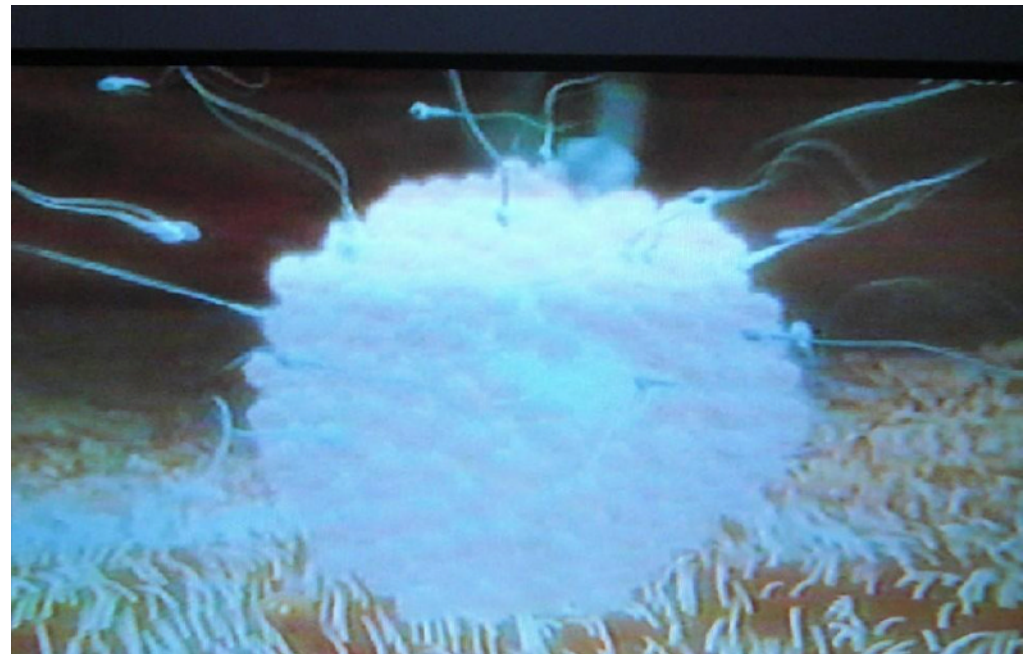
Reproduction of Biological Systems

- **Monogenesis**
 - Unisexual (Asexual) Reproduction
 - Reproduction without Exchanging Genes
 - Cell Division
 - Mutation Only



Reproduction of Biological Systems

- **Gamogenesis**
 - Sexual Reproduction
 - Two Reproductive Cells Exchange Genes
 - Egg + Sperm
 - Cell Division + Cell Fusion
 - Mutation + Cross Fertilization (Breeding)



Daphnia (Plankton)

- **Unisexual Reproduction**
 - Eggs by Cloning Self
- **Sexual Reproduction**
 - When Environment Becomes Difficult



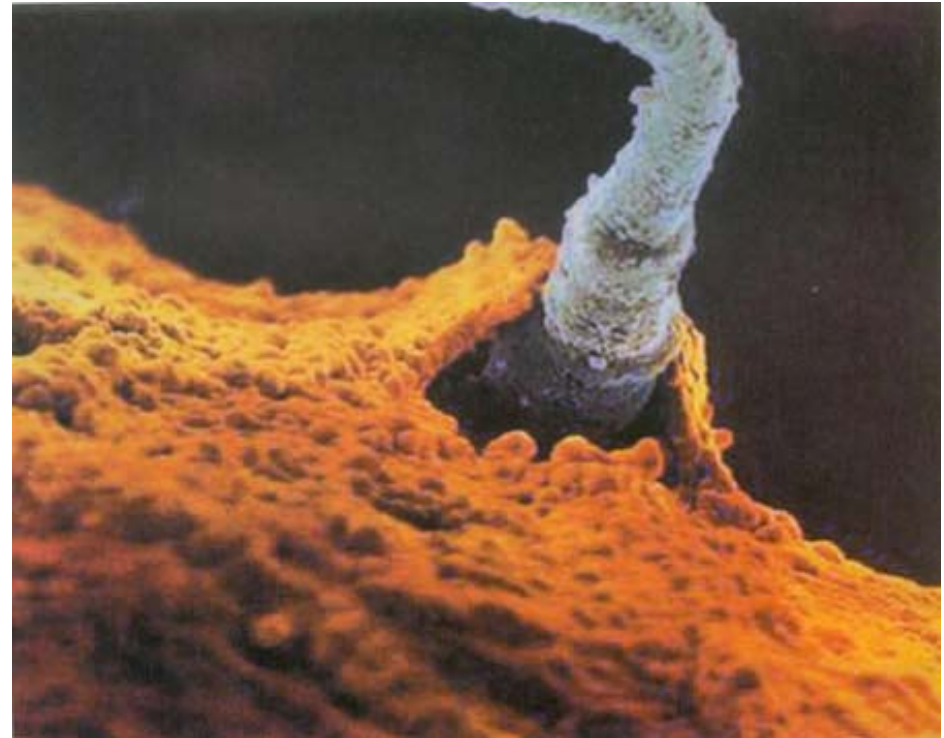
Credit: Paul Hebert

Hermaphrodite

- **Snails**

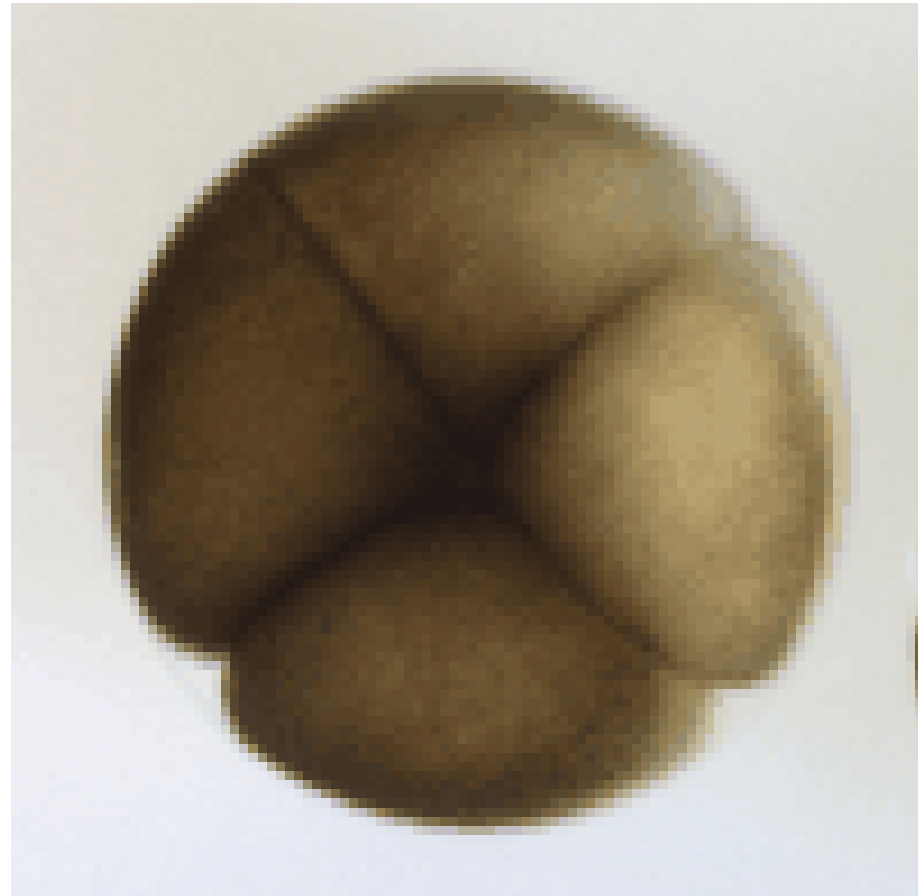


Fertilization

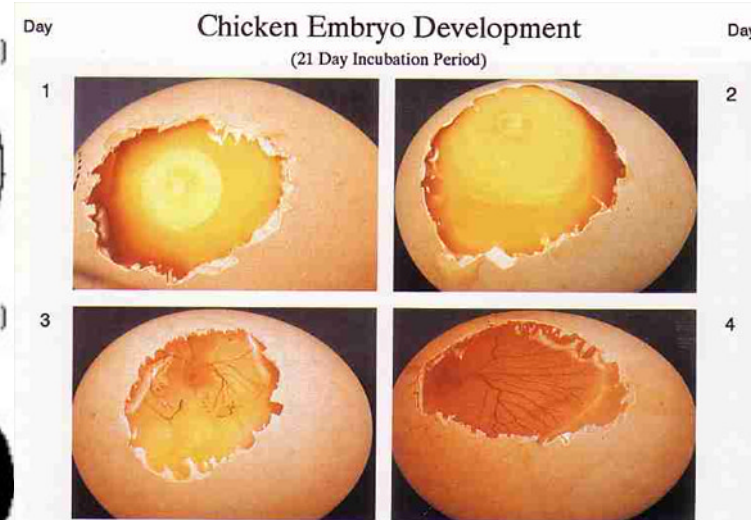
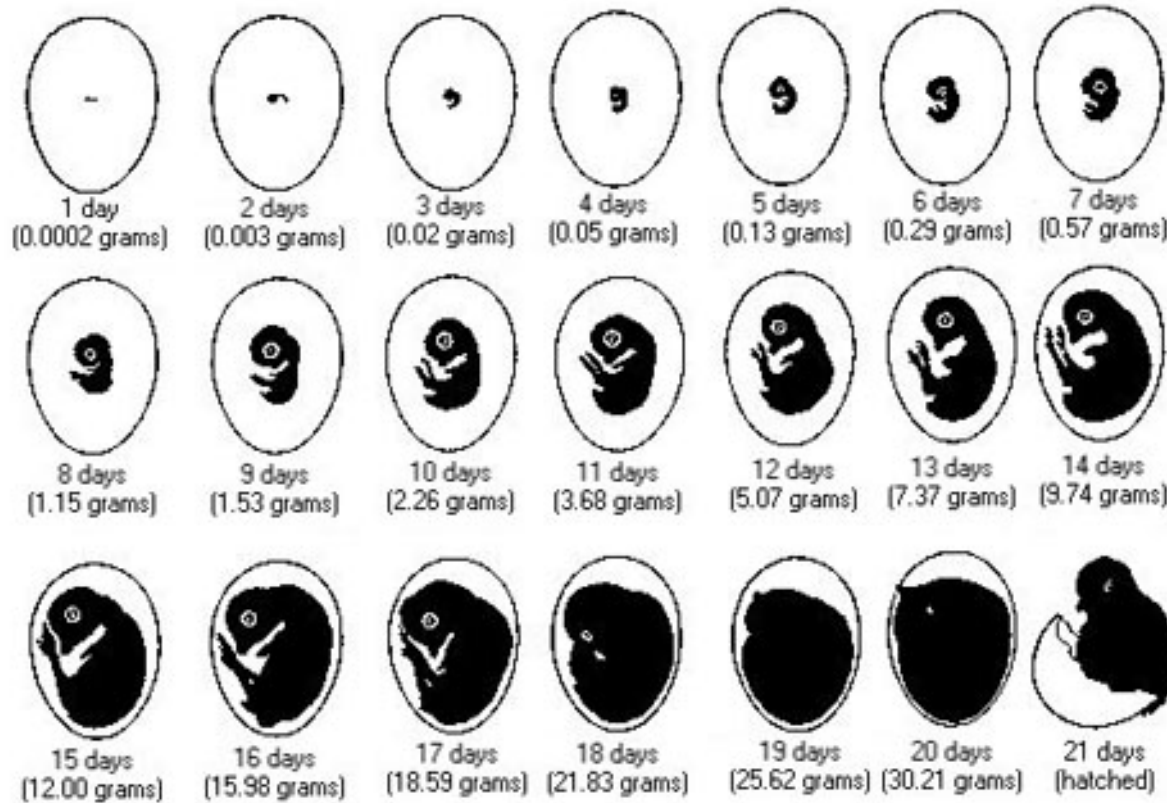


Cleavage (Cell Division)

- **Gravity**
- **Potential Fields**
 - Induction
 - Activin A (1989 Asajima)
- **External Stimuli**



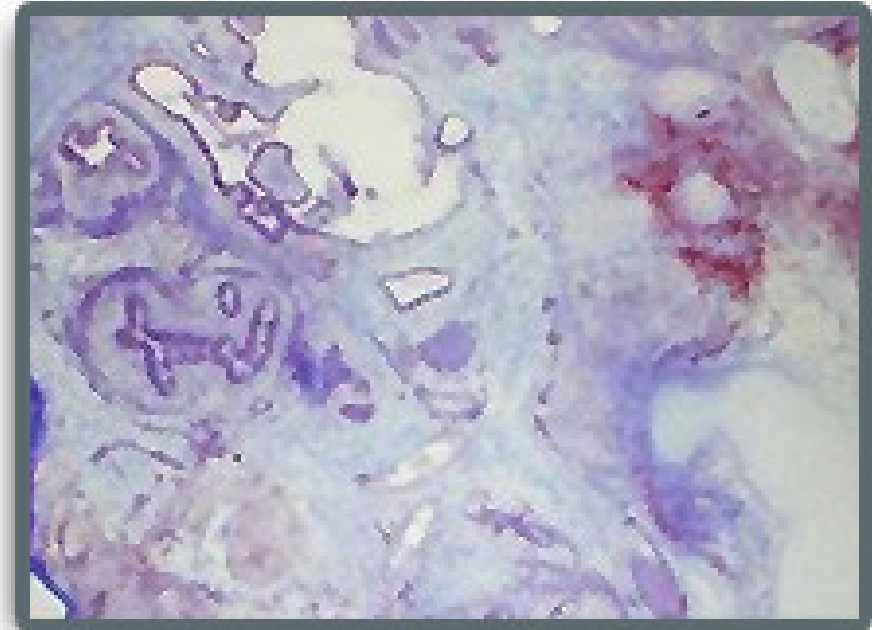
Generation



DAILY CHANGES IN THE WEIGHT AND FORM OF THE DEVELOPING CHICK EMBRYO (WHITE LEGHORN)

Generation

- **During Division, Any Cell can Become Any Organ in the Future**
 - Embryonic Stem Cells
 - Up to 6×10^{13} Cells
- **Cells are Specialized, while Division**
 - Before Specialization, Cells Have Potential to Perform Different Functions



Can We Learn from Reproduction of Biological Systems?

Similar Idea?

- **LEGO Blocks?**

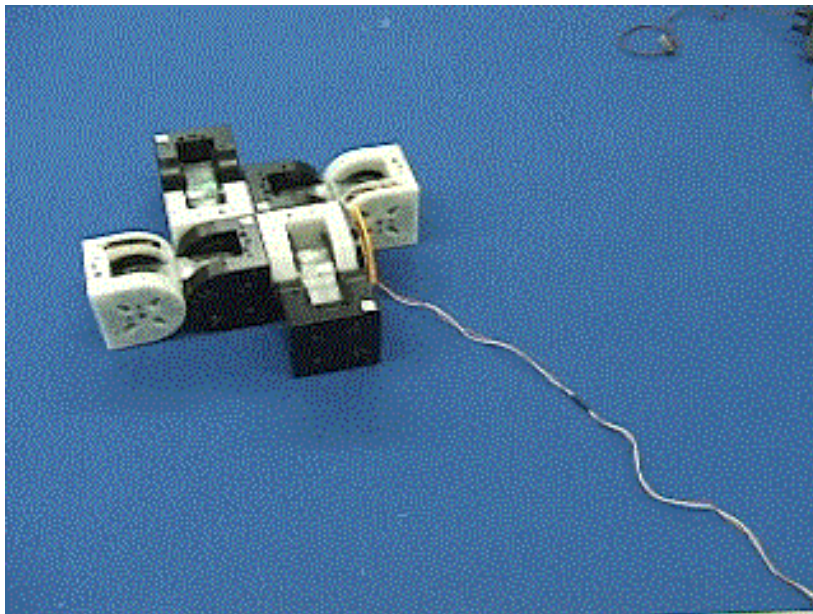


Image: LEGO

Crazy Ideas?

- **Production of Machines**
 - Beginning with “Cells”
 - Self-Organization of Cells
 - Self-Assembly
 - Production by Generation
- **Maintenance of Machines**
 - Generation
 - Reproduction

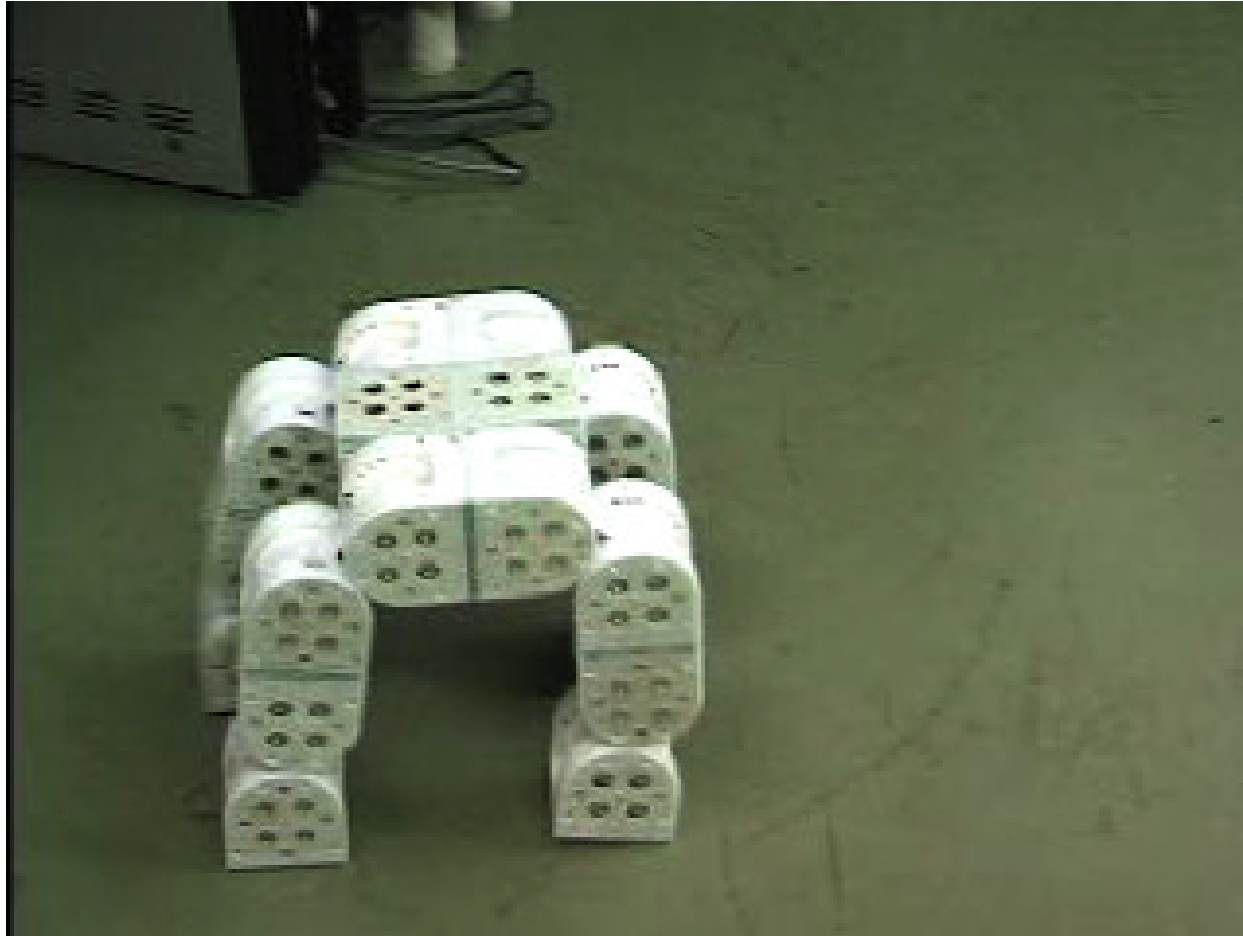
Self-Assembling Robot (AIST, JP)



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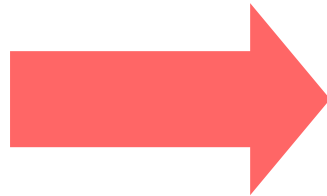
Self-Assembling Robot



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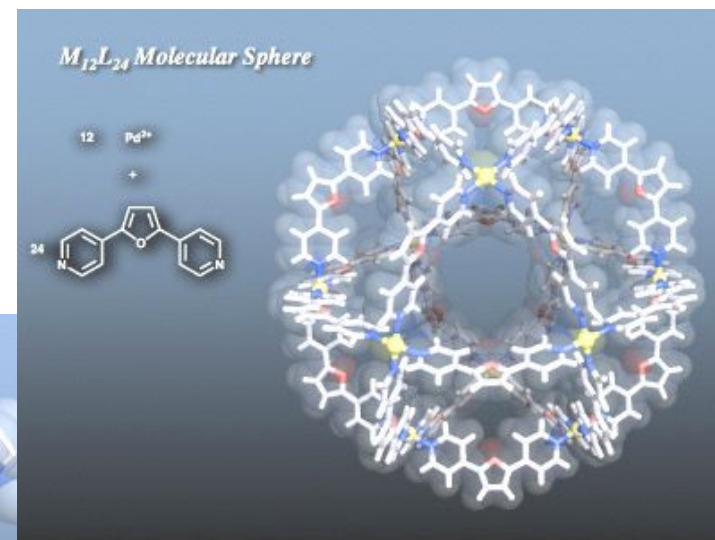
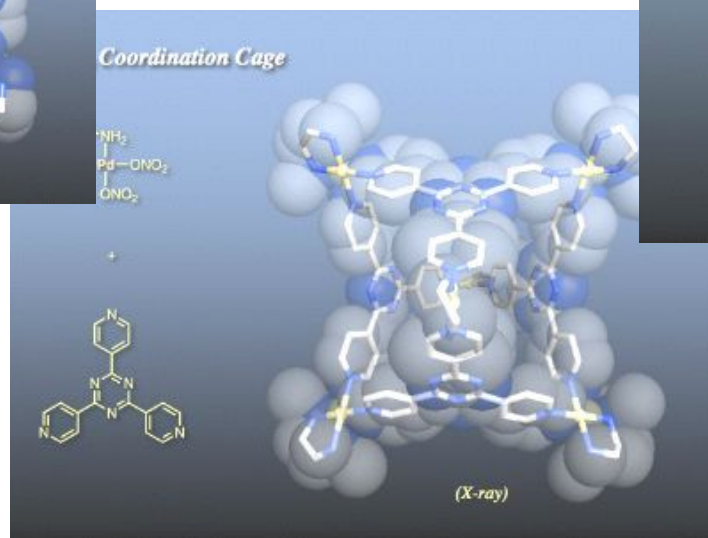
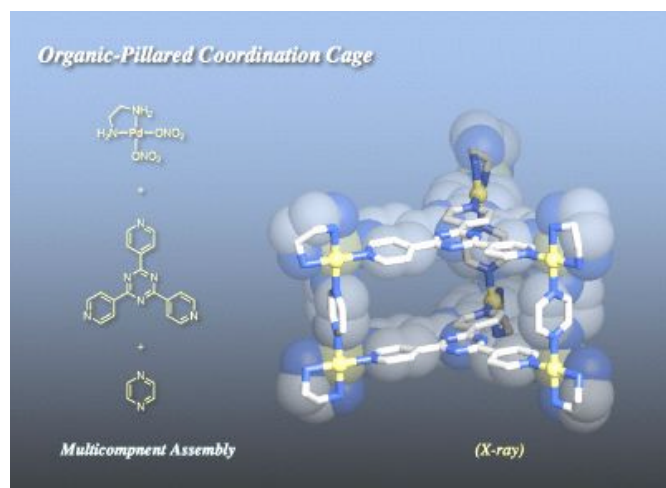
Self-Assembly by Shaking?



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However, Molecular Structures Can Be Already Self-Assembled!



<http://www.appchem.t.u-tokyo.ac.jp/appchem/labs/fujita/res5a-e.html>