

# Bio-Inspired Design 2010-2011

**Wb2436-05 (Entirely in English)**

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

**Bio-Mechanical Design  
Mechanical Engineering**

# Lecture 13: March 21 (Mon)

## 8:45-10:30, Room TNW F

- **Bioconstruction – Biomaintenance & Repair**
- **Maintenance and Repair**
  - Machine
  - Biological System
    - Different Strategies
    - Self-Repair Depending on the Degree of Damage
    - Although We are Already Pretty Much Cyborgs?
- **Can We Learn from Biological Systems?**

# What is Maintenance?

- **Faults Happen**
  - Wear
  - Fracture
  - Chemical Reactions
  - Foreign Objects
- **Monitor and Identify Faults**
  - Symptoms
  - Diagnose
- **Repair**
  - Exchange Broken Components
  - Physical Operations
    - Adjustment, Welding, Polishing, Cleaning, Removing Foreign Objects, etc.

# Strategies of Maintenance

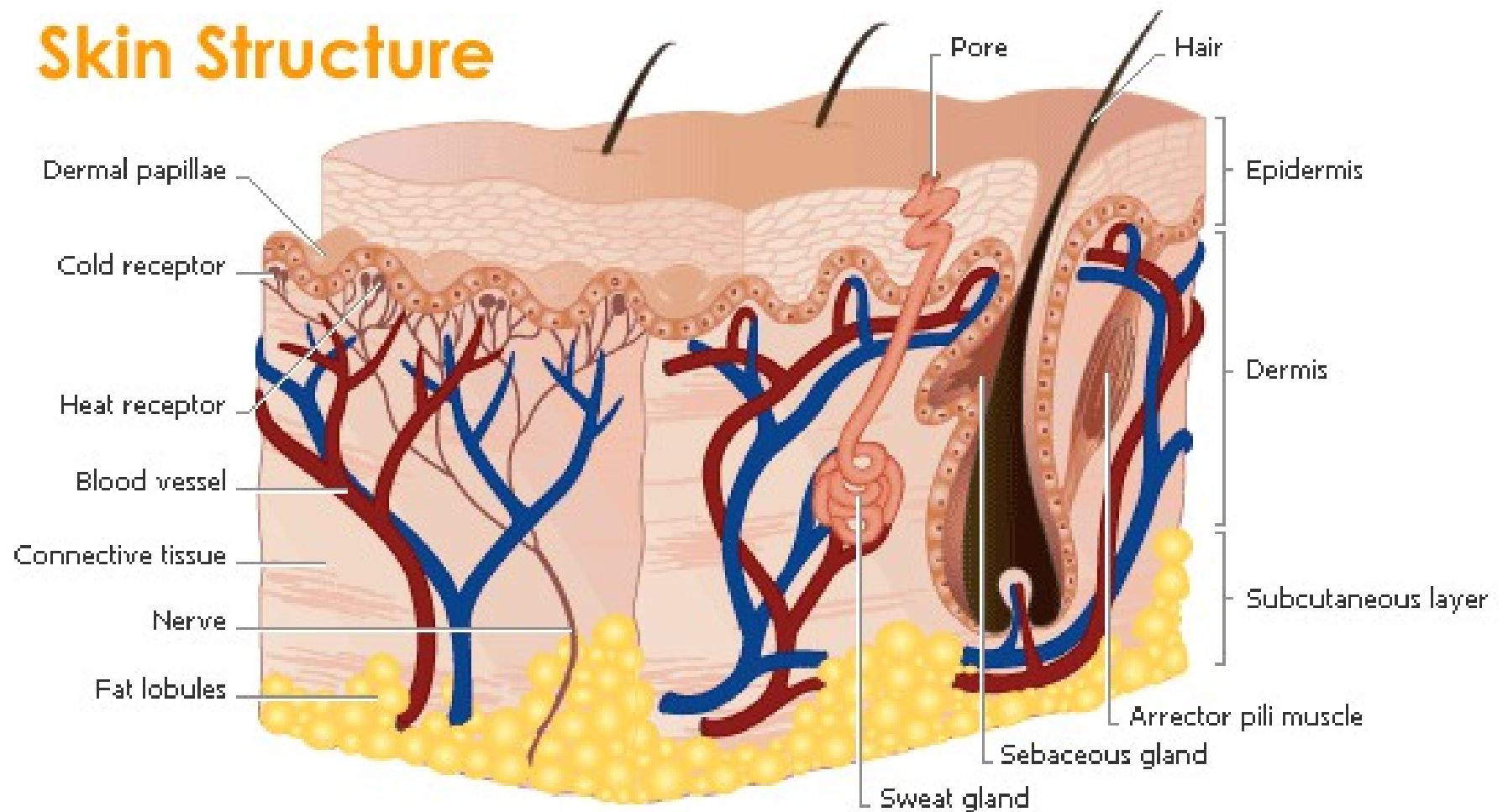
- **First, Try to Achieve Higher Reliability by Design**
  - So Than Nothing Happens
    - High Reliability Design
    - Quality Assurance
- **However, There is No Machine that Doesn't Break or Deteriorate**
  - If They Never Break nor Deteriorates, We Cannot Even Throw Them Away!
- **We Must Accept Faults, Deterioration, Breaks**
  - Prevent Them as Much/Early as Possible (Prepare Yourself)
    - Monitor, Inspect, Exchange Components, Repair
    - Monitor, Inspect, ...
  - Throw Them Away Before They Break
    - Maintenance-Free
  - Even if It Happens, They Do Not Result in Catastrophe
    - Robustness, Fault-Tolerant Design, Non-Stop
    - Fail-Safe Design

# Strategies of Maintenance and Repair in Biological Systems

- **Regeneration**
  - Skin, Hair, Nail, Bone, Liver
- **Role Change/Take Over**
  - Duodenum
- **Redundant System**
  - Component Redundancy
    - Kidney, Lung, Hands, Legs, Eyes
  - Extremely Redundant (No Repair)
    - Brain Cells?
      - 1,000,000,000,000 Cells, 100,000 Deaths/Day
      - Schizophrenia, Amnesia
- **No Redundancy**
  - Heart

# Skin

## Skin Structure



<http://www.organicskincarepro.com>

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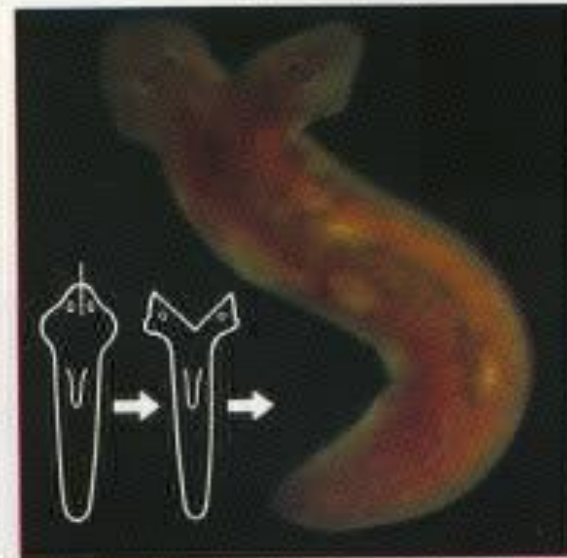
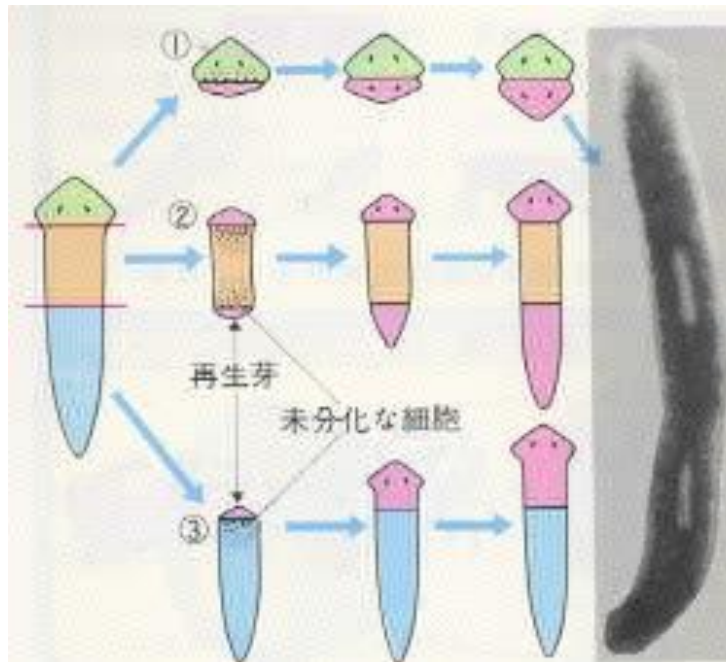
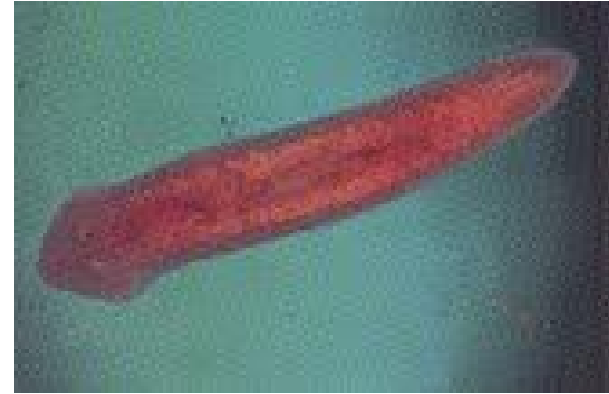
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# Skin Recovery from Damage

- **Cut at Epidermis**
  - May Not Even Bleed
  - Regeneration at Dermis to Form Epidermis
- **Cut at Dermis**
  - Bleeding
  - Blood Platelets Stop Bleeding, a Scab is Formed
  - Cleaning Up by Macrophages and White Blood Cells
  - Regeneration at Dermis to Bridge the Gap and then Epidermis (Maybe Stitches Necessary)

# Planaria

- **Platyhelminth, Flatworm**
  - Regeneration Capability



ブラナリアの頭部の少し後方まで縦断すると、双頭のブラナリアができる。



# Lizards



# Bone Fracture

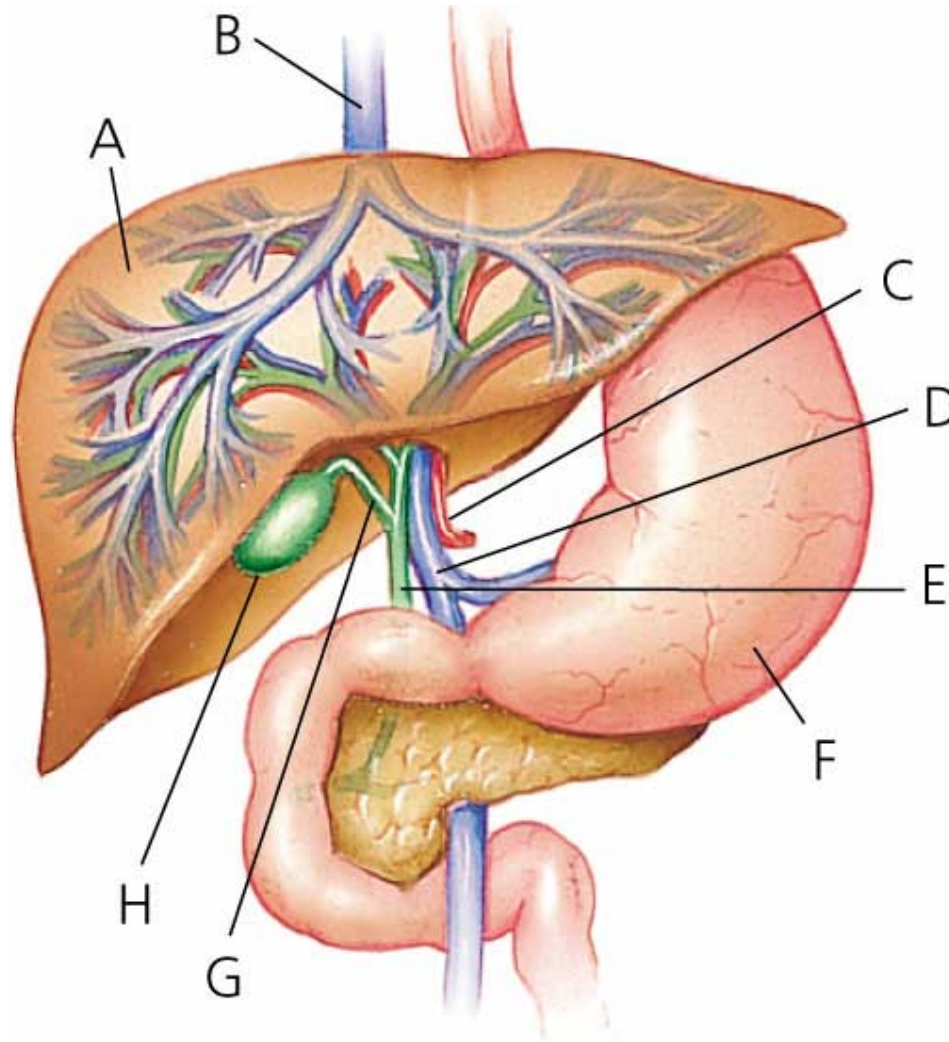


Radiograph of fracture at reduction



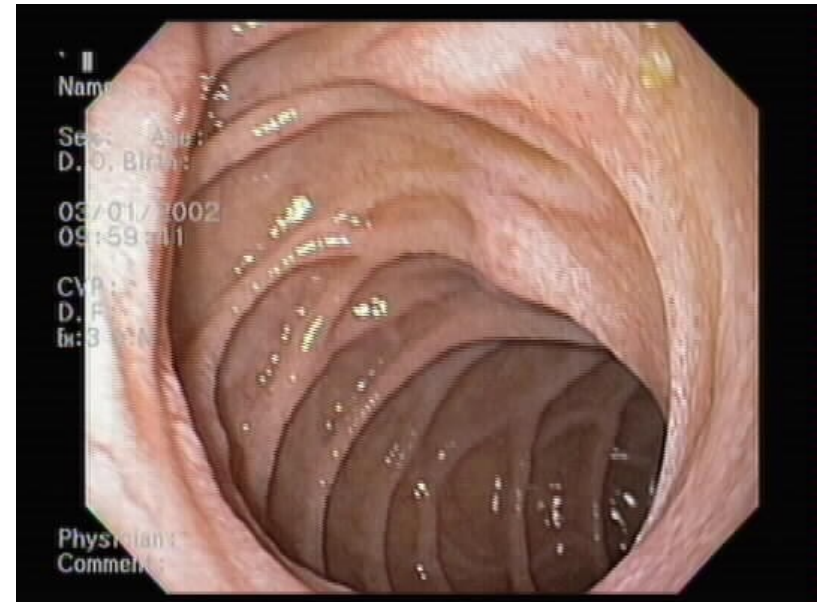
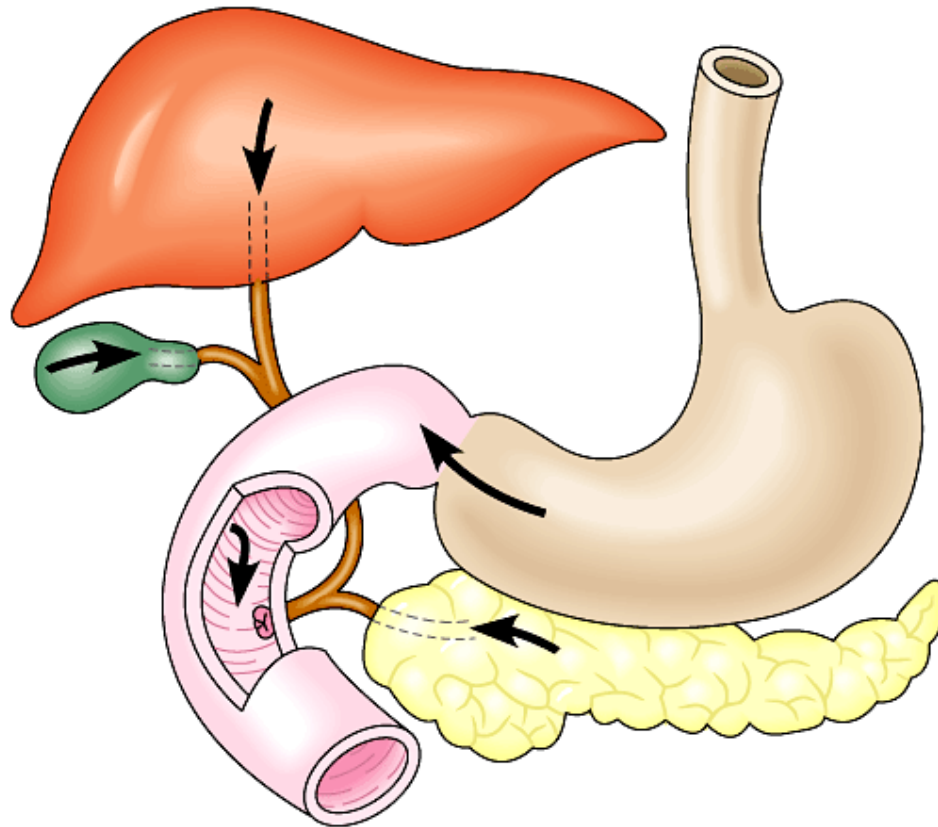
Radiograph of fracture at 12 weeks

# Liver



Carlyn Iverson

# Duodenum



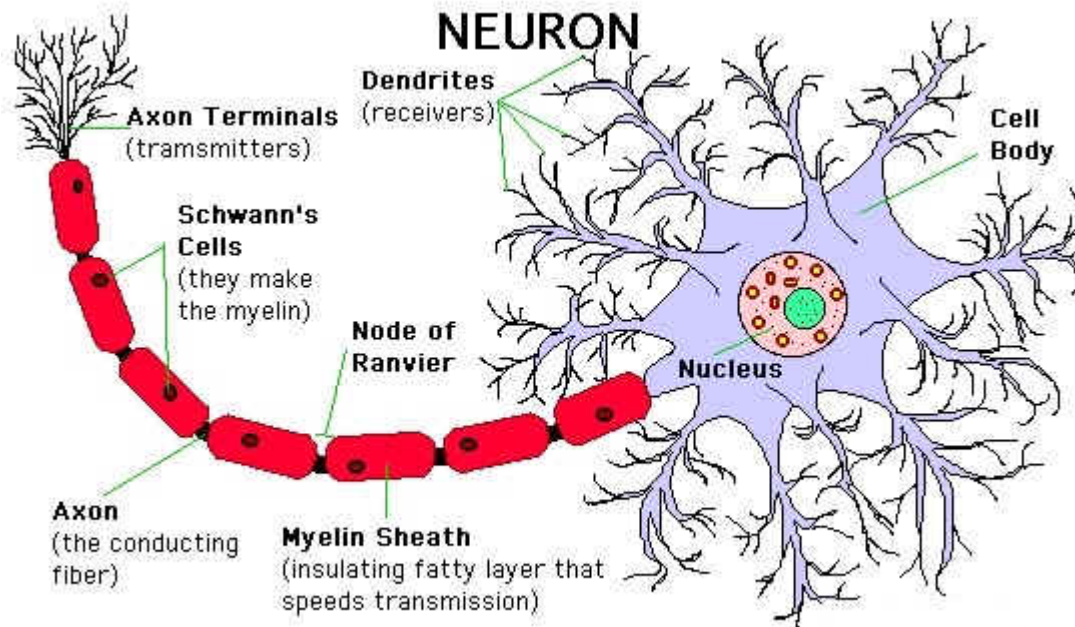
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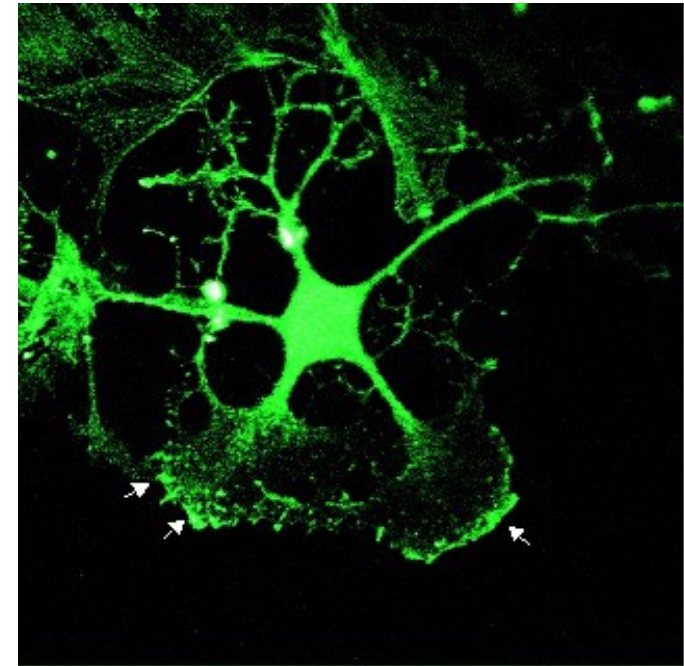
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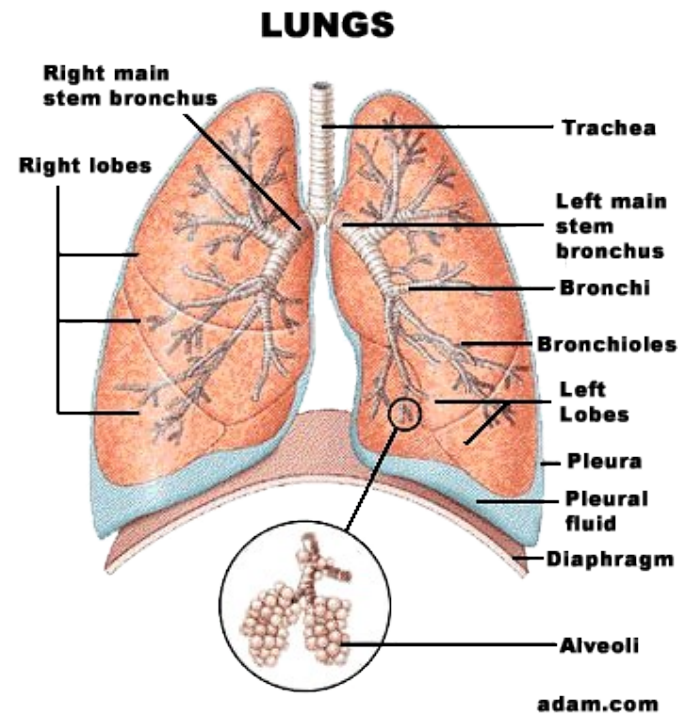
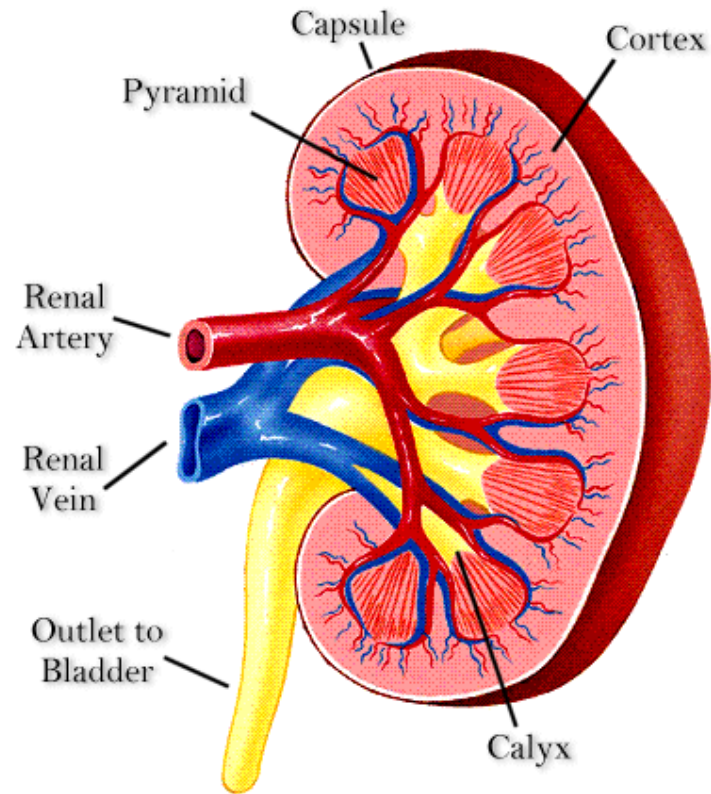
# Brain Cells



EnchantedLearning.com



# Kidney, Lung



# Highly Reliable Machines

- **Traditional High Reliability Design**
  - High Reliabilities of Individual Components
    - Expensive and Difficult to Achieve Above a Certain Level
  - Avoid
    - Wear, Impurity, Chemical Reactions
    - Fracture
- **Strategies**
  - Good Selection of Materials
  - Good Protection
  - Good Stress Considerations
  - Good Production
  - Test, Test, Test
- **There is a Limit!**
  - Cost
  - Physical Availability of the Material

# Are Biological Systems Designed for High Reliability?

- **Don't Seem So**
  - Natural End of Life
  - Built-In Self Healing Mechanisms
  - Extremely High Redundancy
- **Biological Systems are Not Reliable?**
  - Allows Malfunctioning Subsystems
    - "Fault Tolerant"



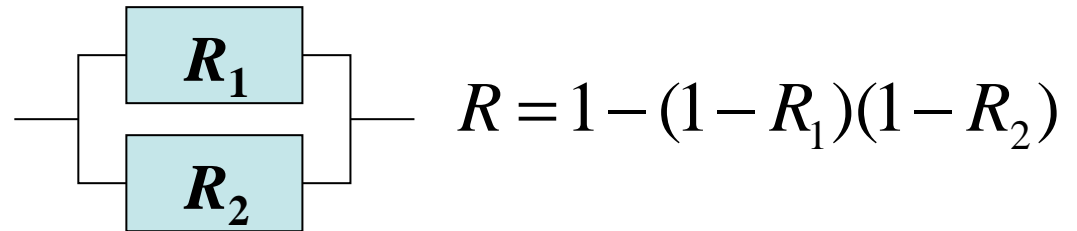
# Redundant Design

- **Redundant Design**
  - Part Redundancy
  - Function Redundancy
  - Network Type Redundancy
- **Redundancy is the Key for**
  - Fault Tolerance
  - Robustness
  - High Productivity (Through Put)

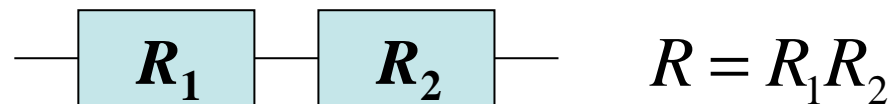
# Part Redundancy

- **Wiener**

- Twin Engine Jets/Four Engine Jets
- Parallel System



- Serial System



# Drawbacks of Part Redundancy

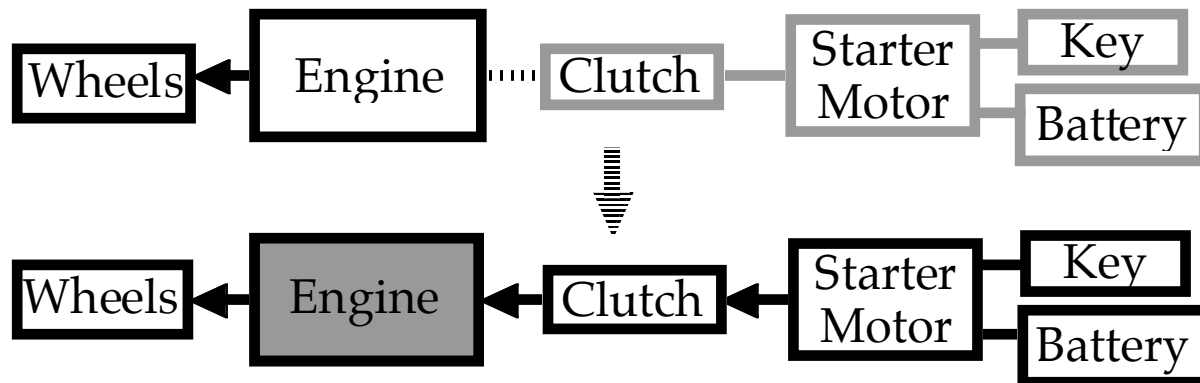
- **Expensive**
- **Heavy**
- **Component Reliability Need to be Reasonably High**
- **Faults of Integrator, Distributor**
- **Distributed Opinions Cannot be Guaranteed Correct**

# Part Redundancy of Biological Systems

- **Are They Really Redundant Systems?**
  - Kidney, Lung
  - Legs, Arms, Fingers
  - Eyes, Ears

# Function Redundancy

- **Starting Motor of a Car with Manual Transmission**



# Network Type Redundancy

- NS Network



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# Not How to Live but How to Die

- **The Best Machine Performance**
  - Functions Very Well without Any Maintenance
  - Starts to Show Gradual Deterioration (i.e., Warning), but Still Functions Perfectly
  - When it Stops Functioning, All the Components Should Have Reached their Physical End of Life
- **Technically**
  - Monitoring, Warning, Diagnosing
  - (Self-)Maintenance
  - Equal MTBF

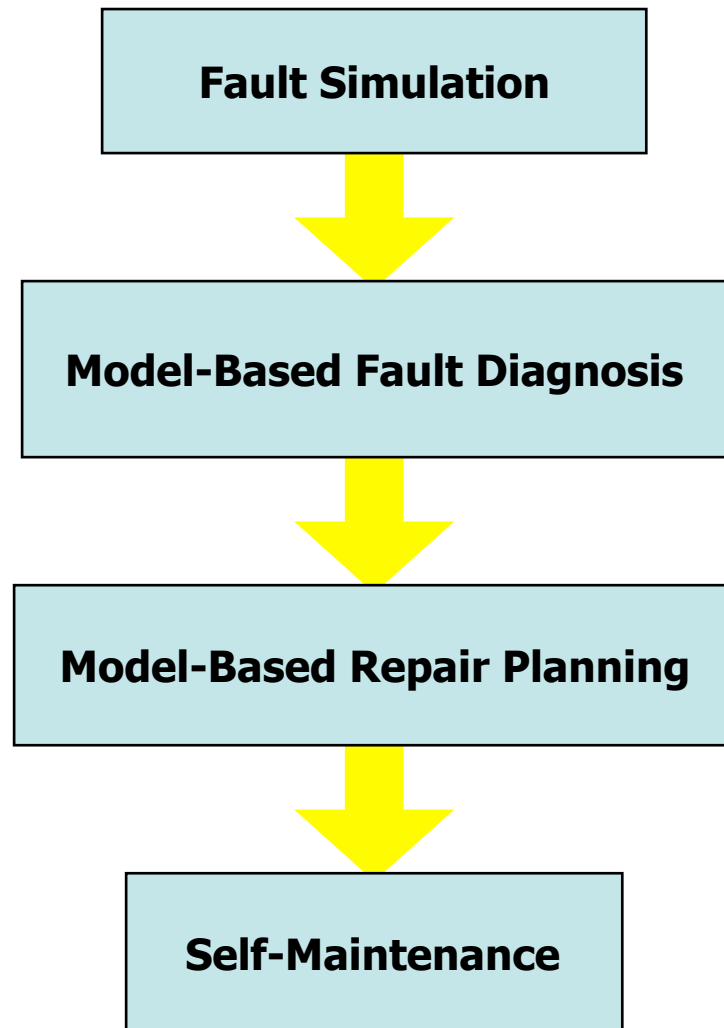
# A Mooty (1986)

- **Self-Maintenance Robot**
  - Accident Maintenance Robot
  - Maintenance Robot for Nuclear Reactors
  - Wheels to Climb Up Stairs
  - 9 DoF Manipulator





# Toward Self-Maintenance Machines



- **Model-Based Qualitative Reasoning**

- Confluence Type + Parameter Model
- Event Driven Type + Structural Model

- **Model-Based Qualitative Reasoning**

- Generate & Test (by Simulation)

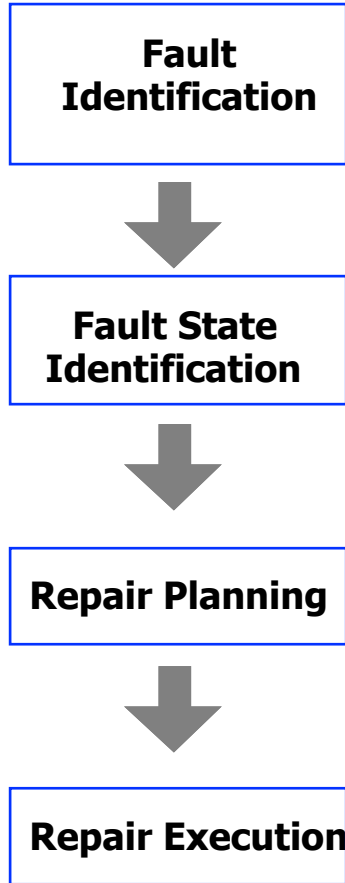
- **Model-Based Qualitative Reasoning**

- Repair Knowledge
- Checking “Side Effects” through Fault Simulation

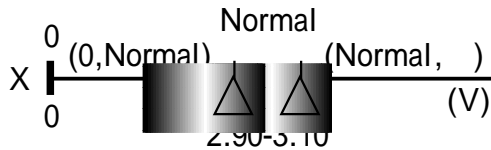
- **Model-Based Qualitative Reasoning**

- Knowledge Compilation
- Fuzzy Reasoning to Deal with Sensors
- Sensor Calibration

# Model-Based Self-Maintenance



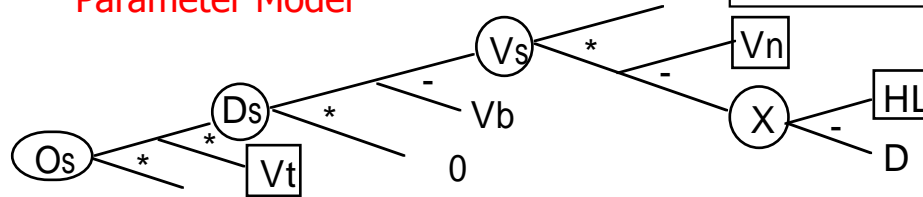
Knowledge to Convert Quantitative Value to Qualitative Value



Phenomenon Knowledge

Function Knowledge	
<b>Name:</b>	to get regular output image
<b>Parameter:</b>	Os
<b>Constraint:</b>	lowlimit <= Os <= highlimit

Parameter Model



A	Parameter	(A)	Function Parameter
[A]	Control Parameter	(A)	Sense Parameter

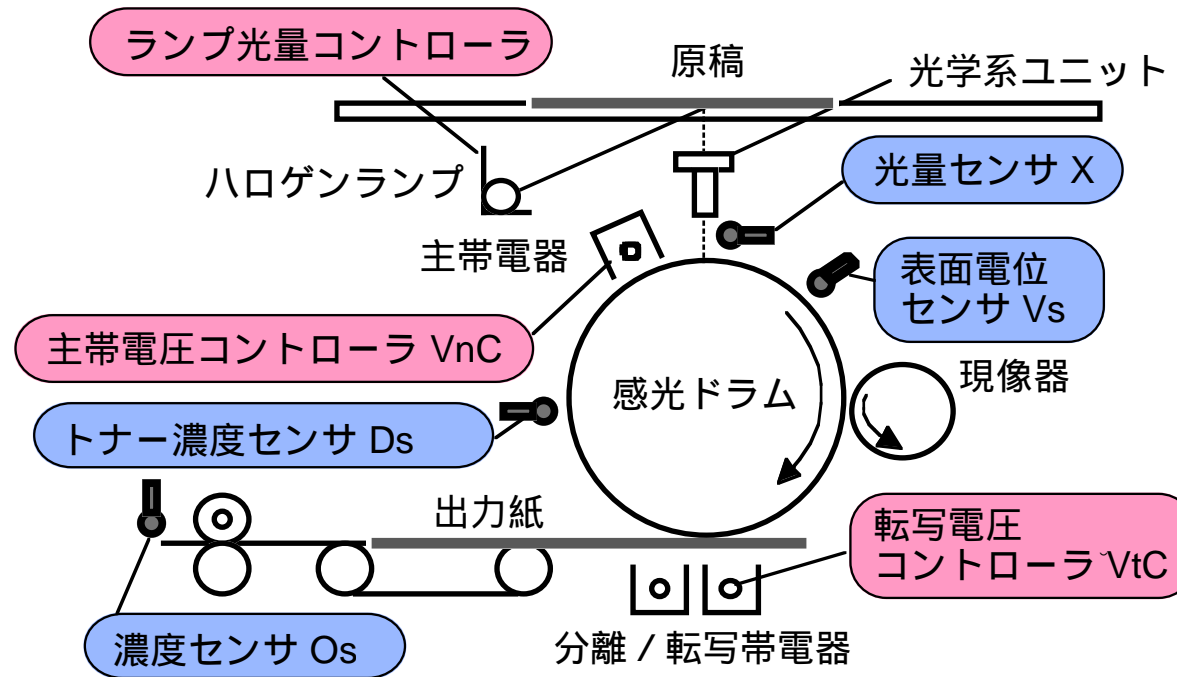
Functional Knowledge

Phenomen Knowledge	
<b>Name:</b>	deterioration of halogen lamp
<b>Condition:</b>	value(deterioration) > Limit
<b>Effect:</b>	decrease(HI)

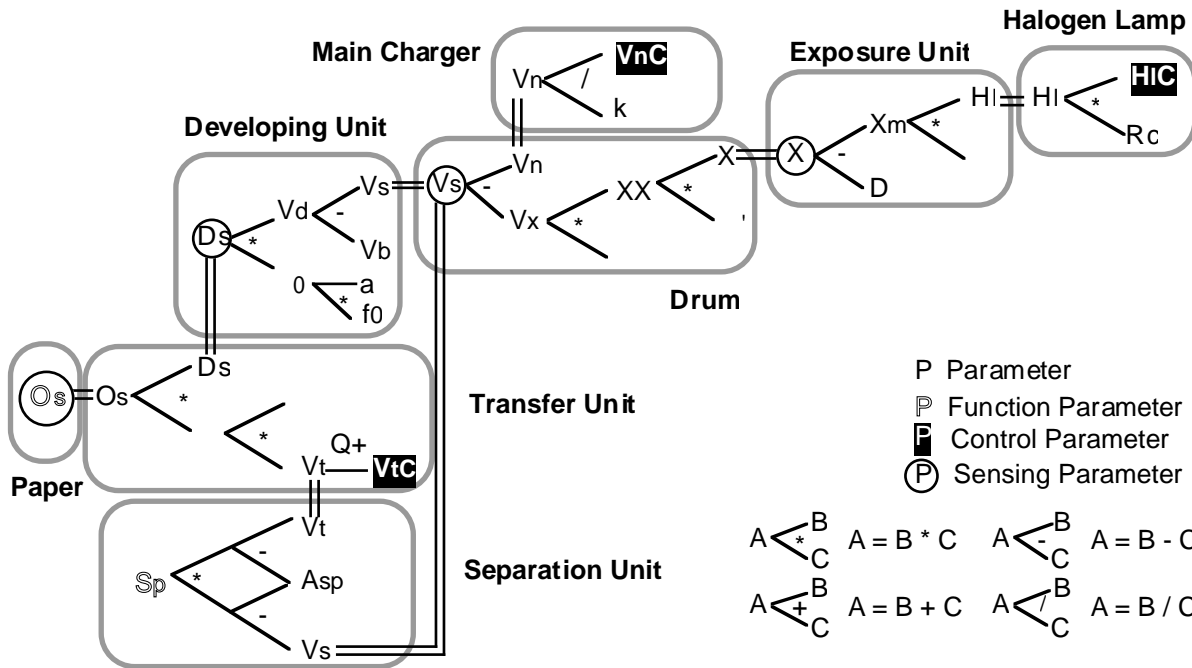
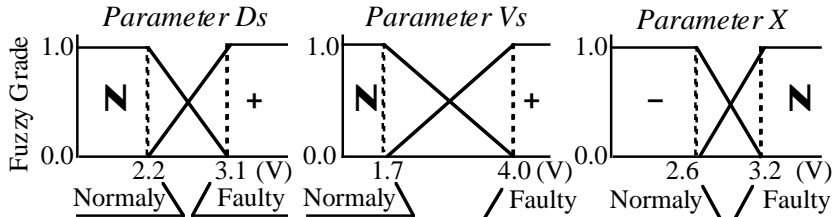
Repair Knowledge

Repair Knowledge	
<b>Name:</b>	lamp up
<b>Parameter:</b>	HI
<b>Direction:</b>	up

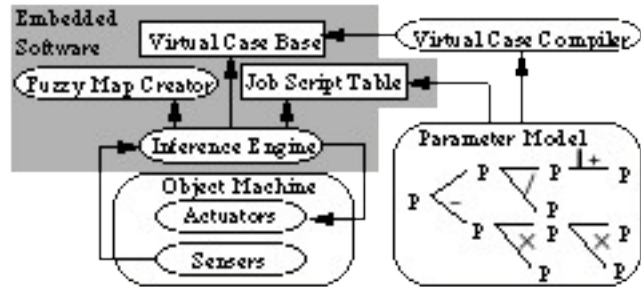
# Photo Copier



# Parameter Model



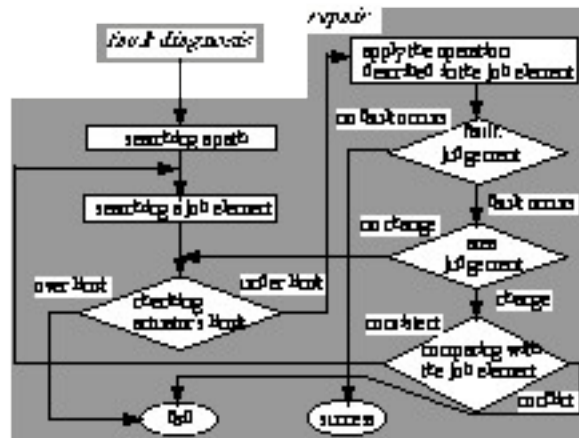
# Repair



実験システムの構成

US Heater 3rd Func. Value : 2.74017 Normal : 0.257 Abnormal : 0.257	US Heater 2nd Func. Value : 0.72017 Normal : 0.257 Abnormal : 0.257	US Heater 1st Func. Value : 3.34017 Normal : 0.257 Abnormal : 0.257	<b>Repair Informations</b> 故障症状 : 画像カブリ 修復を開始します 修復に成功しました
<b>Actuator Informations</b> ハロゲンランプコントロール : 44 メインチャージコントロール : 147 現像バイアスコントロール : 59		<b>Script Informations</b> 現在の所属領域はHA-8#です スクリプトはハロゲンランプ上昇です このスクリプトにより領域は HA-8# HA-8# HA-19# に遷移する可能性があります --目標領域: HA-19#--	
<b>Domain Informations</b> 目標領域への遷移に成功しました			
<b>System Transcript</b> External Domain(Ub UP)→External Domain(HL UP)→HA-3#(HL LP)→HA-3#(HL LP)→HA-3#(HL LP)→HA-3#(HL LP)→Neutral(Ub UP)→HA-1#(HL LP)→Neutral(Ub LP)→Neutral(Ub LP)→Neutral(Ub LP)→Neutral(Ub LP)→Neutral(HL LP)→			

修復ソフトウェアの実行画面



実験システムの修復アルゴリズム



実験機による故障修復結果

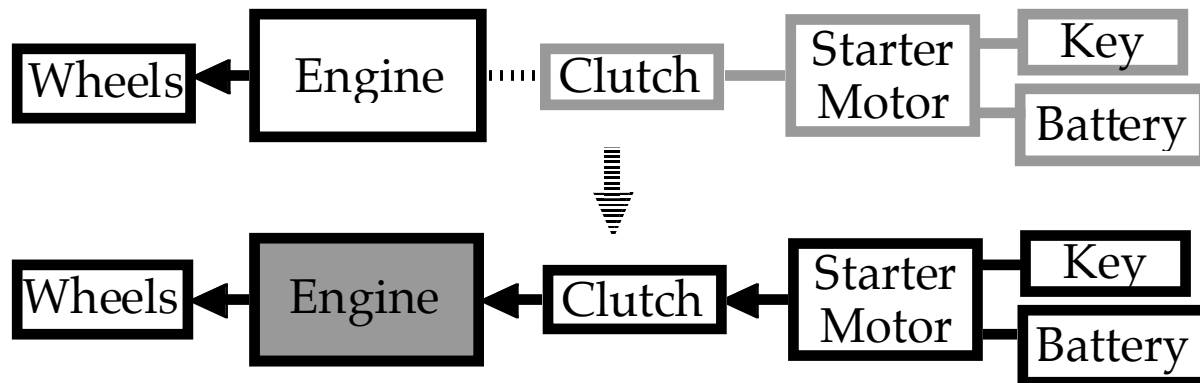
# Control-Type Self-Maintenance Photocopier: A Commercial Version



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# Example of Function Redundancy: A Car with Manual Transmission

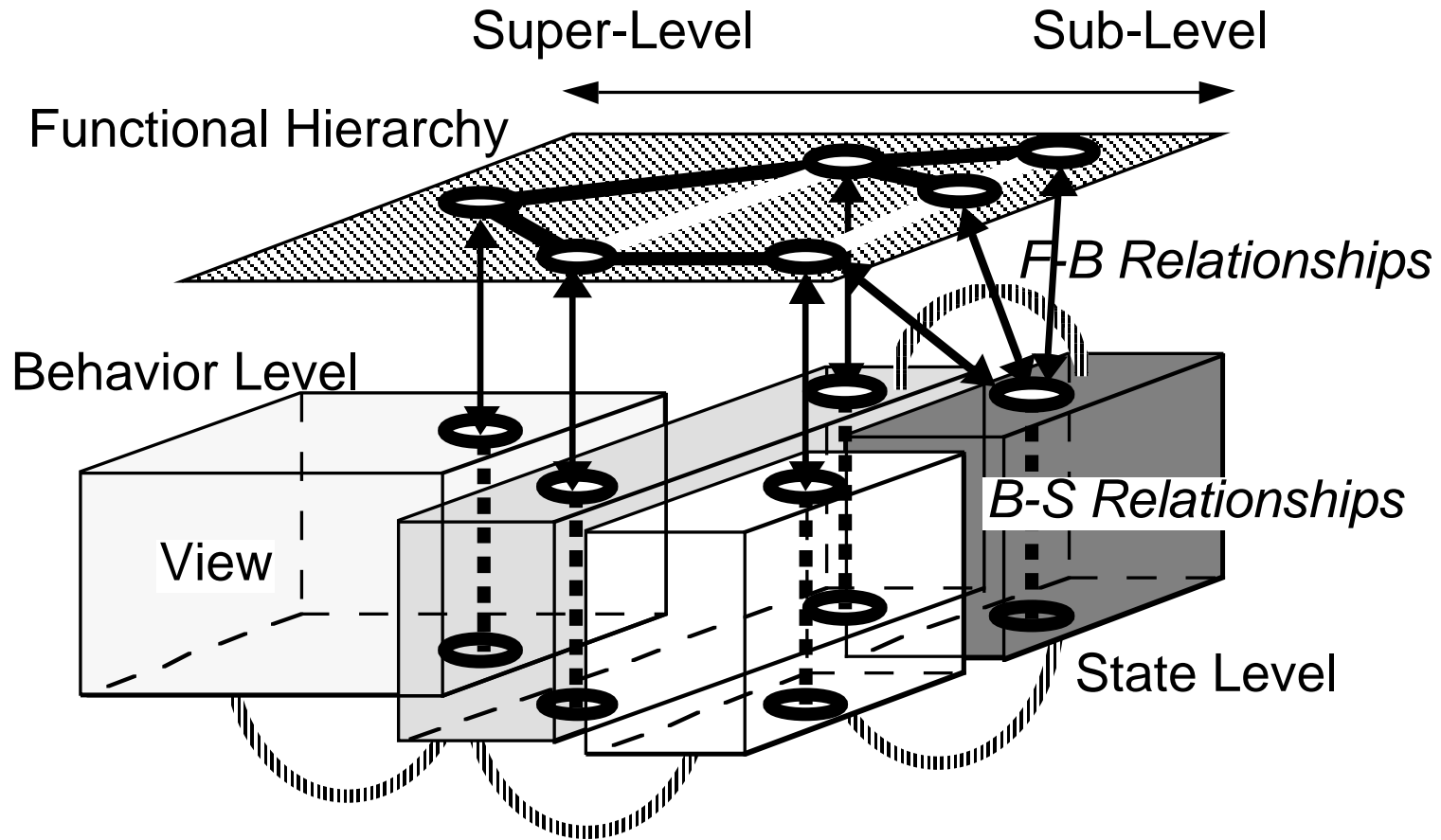


# Function-Redundancy

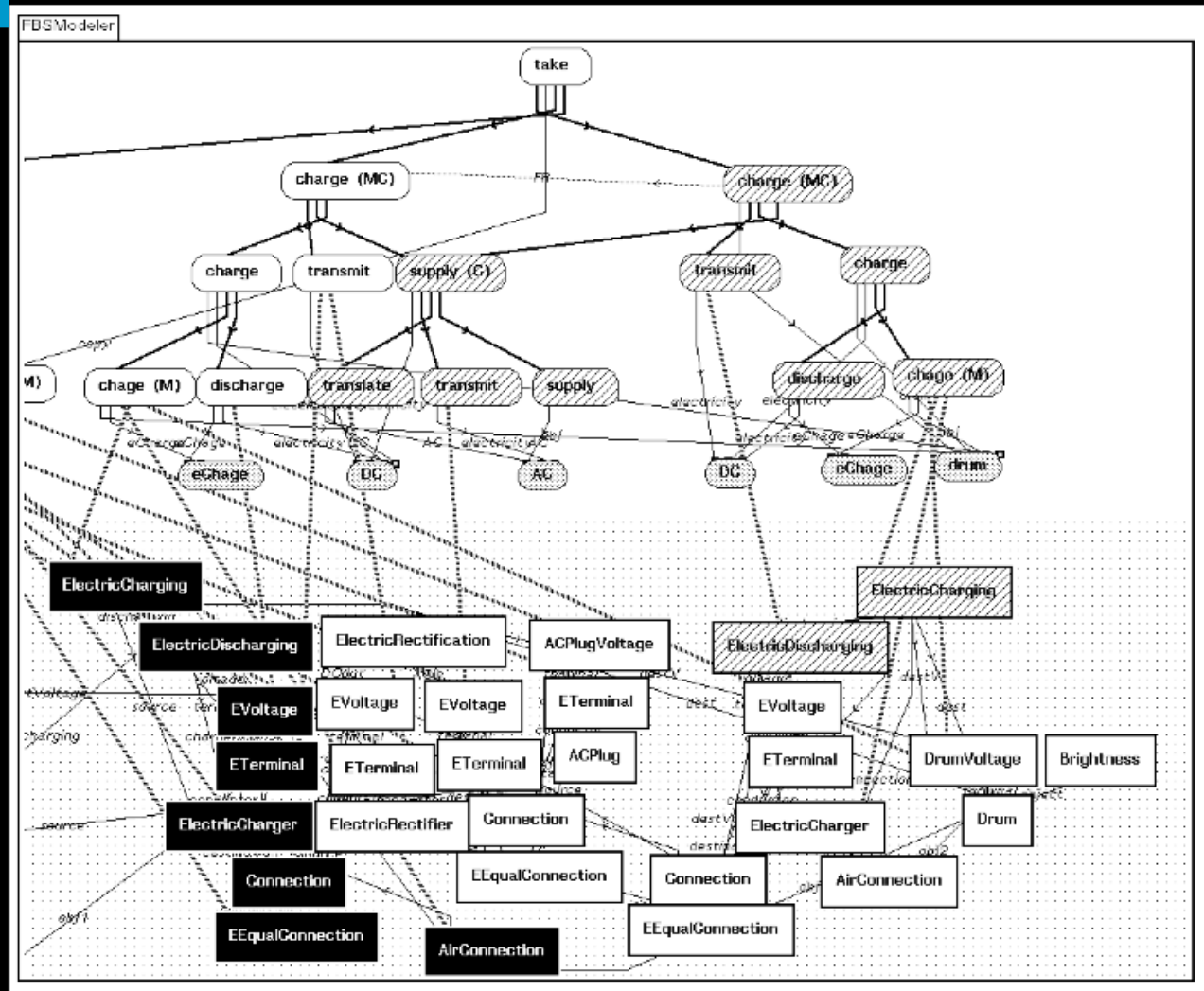
- **Use Other Components that Exhibit Similar (or Identical) Functions to Compensate the Lost Function**
  - Starting Motor of an Automobile
  - Function-Redundant Type Self-Maintenance Machine
  - Maintaining Functions by Reconfiguring its Behavior
    - Reconfiguration of Control Software for Mechatronics Products
- **FBS (Function-Behavior-State) Modeler is Used to Discover Such Components**
  - State
    - Relationships among Structure, Components, and Attributes
  - Behavior
    - Temporal Transitions of States
  - Function
    - Subject Judgment of the User from Observations of the Behavior
      - To Do Something



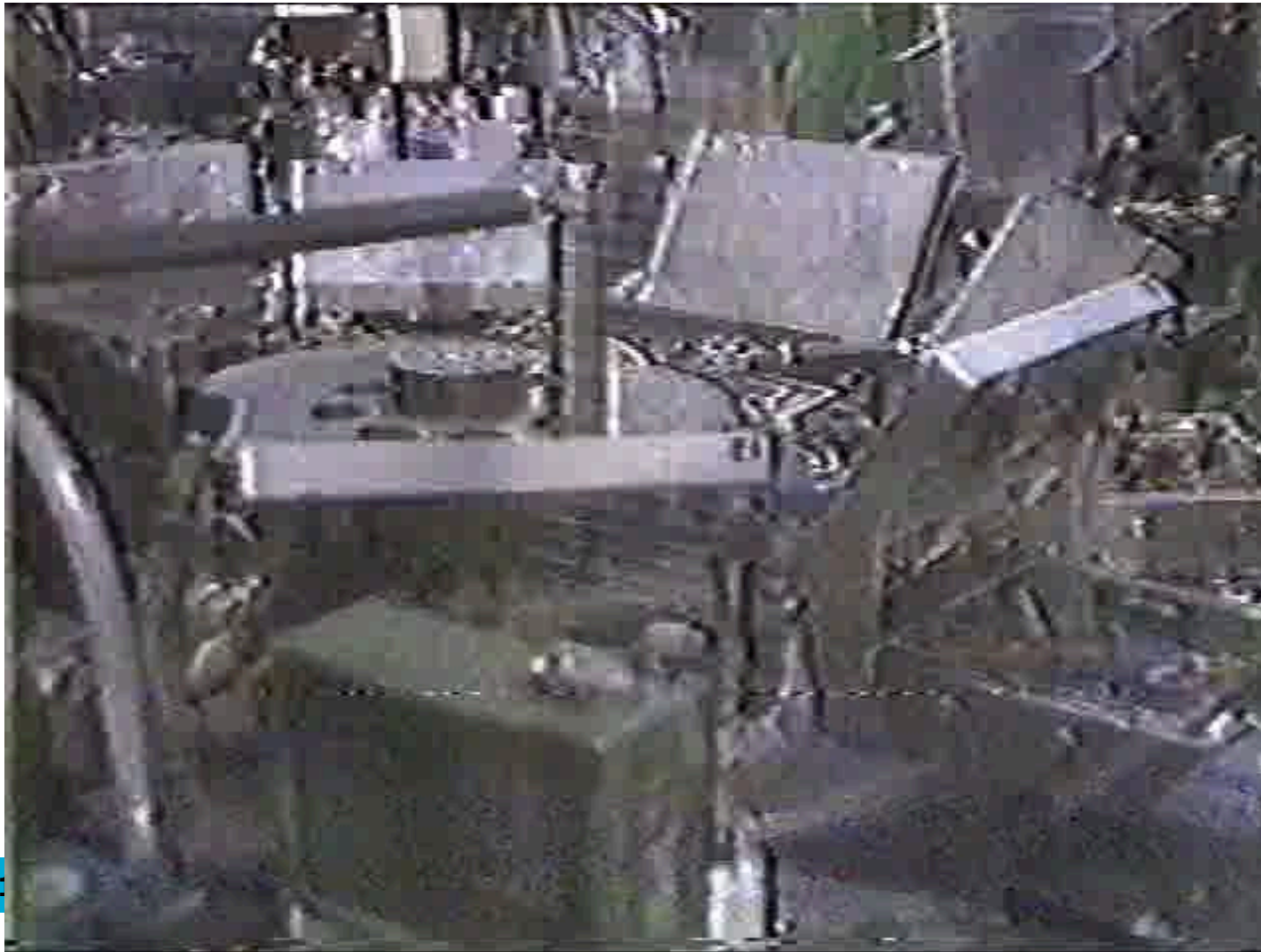
# FBS Modeling



# Function-Redundancy Design on the FBS Modeler



# Function-Redundant Self-Maintenance

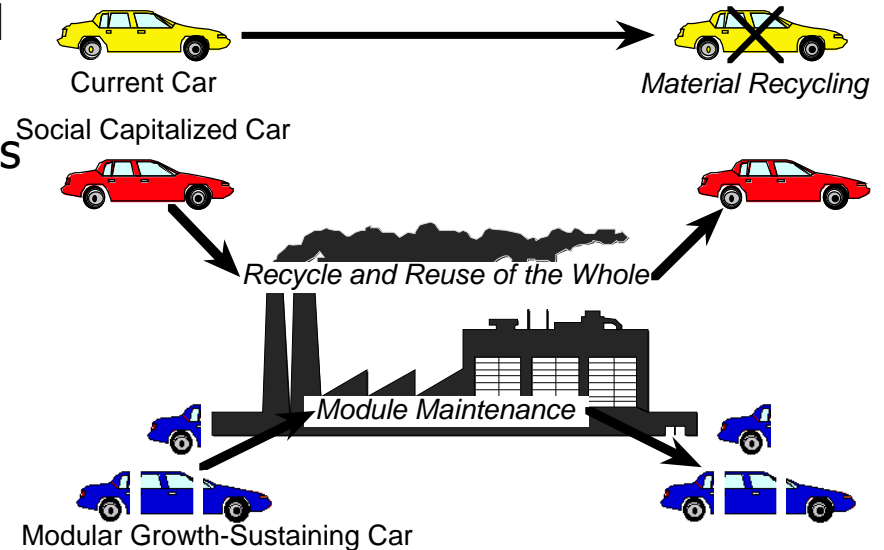
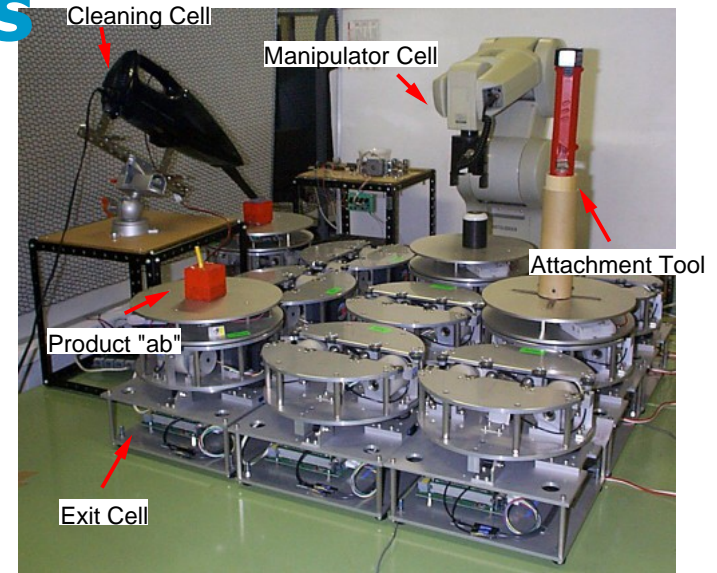


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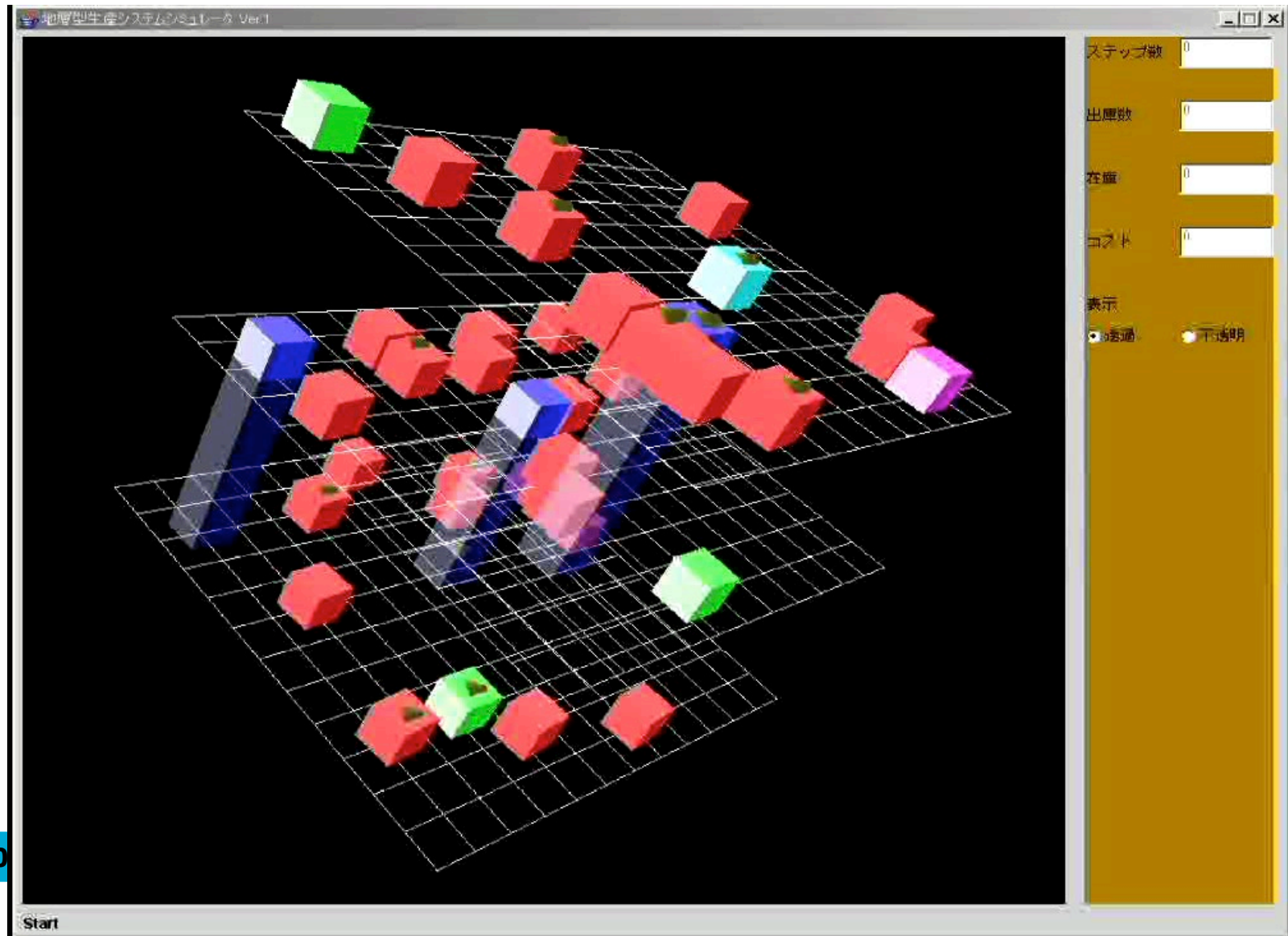
# Reconfigurable Artifacts

- **Reversible Reconfiguration**
  - As Opposed to Irreversible Reconfiguration
- **Modular Machines**
  - Physical Reconfiguration to Maintain its Value
  - Growth-Sustaining and Highly Reusable
  - Adjusting to Environmental Changes and Purposes
  - Catching Up with Technological Advances
  - Never Out-of-Fashion
  - Upgradeable/Downgradeable



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# Cellular Machines



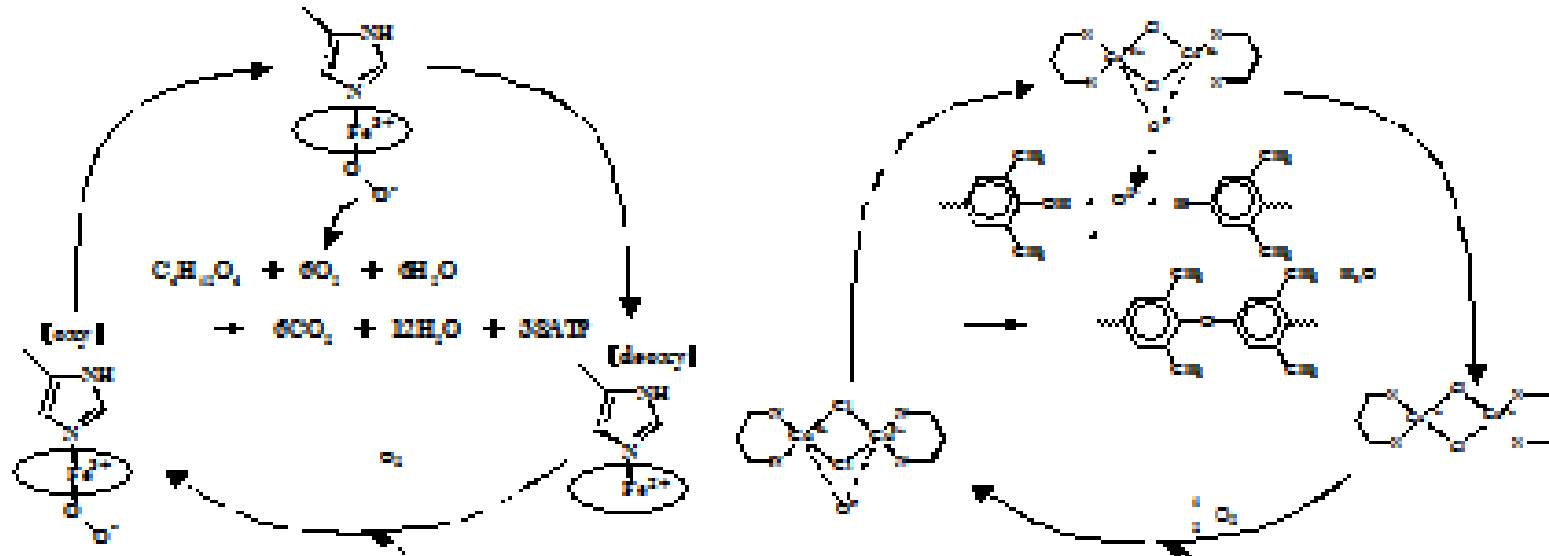
2010

# Self-Repair of PPE (Polyphenylene-Ether)

- **Damages of Polymers**
  - Damages to Macromolecular Chains
    - Mechanical Fracture (Instantaneous, Fatigue, Creep)
    - Oxidation
    - Chemical Reaction with Other Substances
    - “Poisons” that Damages the Material
    - Deterioration Due to Mixture with Other Materials
- **Repair of Damaged Polymers**
  - Metal Like Approach
    - “Cracking” Back to “Oil”
  - Self-Repair Approach
    - Even if Diffusion Speed is So Small, the Time Span is Long Enough
    - Doesn't Have to be a Quick Reaction

# Reconnecting Broken Bridges is a Metabolic Process

- **Repair Means = Cu**
- **Energy = O<sub>2</sub>**
- **Waste = H<sub>2</sub>O**
- **Initiator (First-Aid) = H<sub>2</sub>**



# Self-Maintenance of Artificial Materials

- **Not Only for Higher Reliability and Robustness, but Also for Recycling**
- **Requirements**
  - Identifying Faults
    - How Do Biological Systems Find Faults, Identify the Place, etc.?
  - Supplying Energy to Repair Continuously
  - Processing Waste (By-Products)
  - Repair Leading to the Same Material or Different Material
  - Recovery the Original Functionalities



# Self-Healing Materials

S. R. White, N. R. Sottos, P. H. Geubelle, J. S. Moore, M. R. Kessler, S. R. Sriram, E. N. Brown and S. Viswanathan: "Autonomic Healing of Polymer Composites", Nature 409, 794-797(15 February 2001)

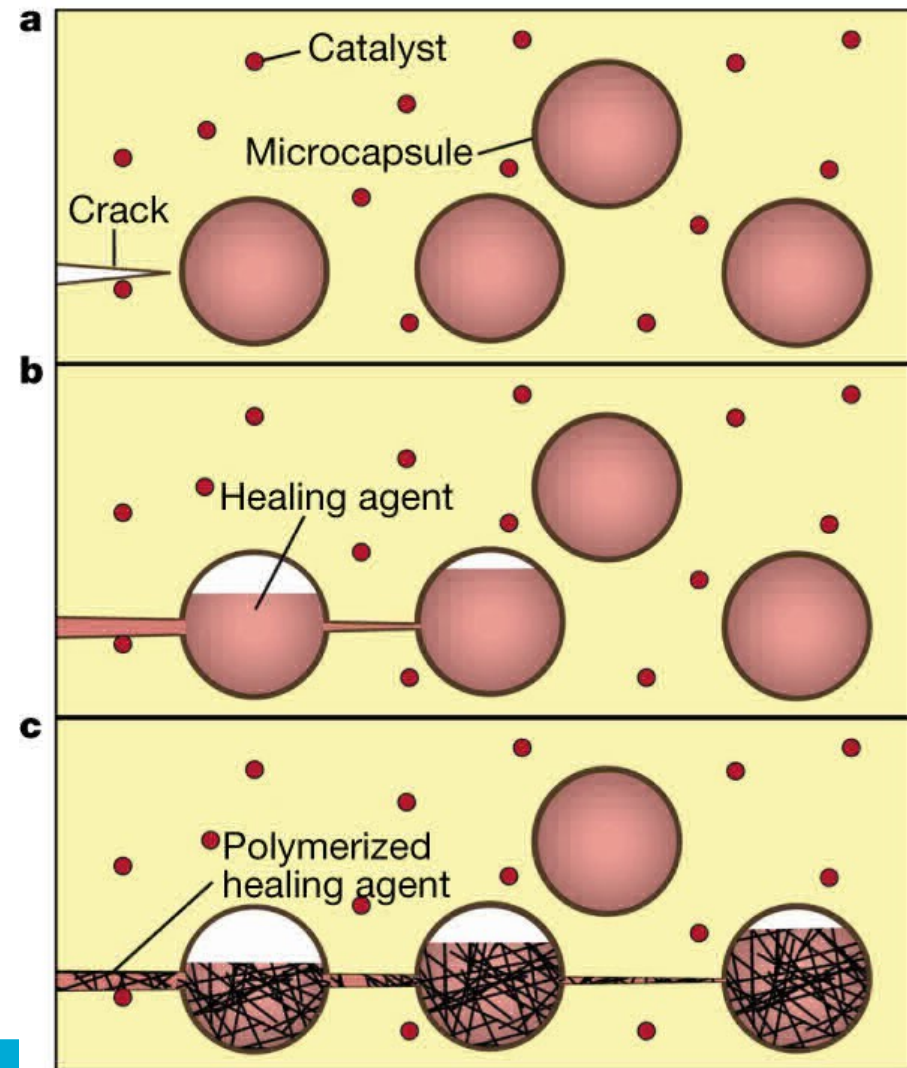


Photo: University of Illinois

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SenterNovem - IOP Selfhealingmaterials - Microsoft Internet Explorer

Address [http://www.senternovem.nl/IOP\\_Selfhealingmaterials/projects/index.asp](http://www.senternovem.nl/IOP_Selfhealingmaterials/projects/index.asp)

**SenterNovem**

IOP Self Healing Materials

SenterNovem > IOP Selfhealingmaterials > **Projects**

**Summary's of the IOP Self Healing Matrials projects**

Click on the projects for more information.

A B C D E F G H I J K L M N O P Q R **S** T U V W X Y Z

**ABC Titel**

**S** SHM0605 - Mechanical and thermal activated self healing surfaces made of composite ceramics for mechanical components (SELSURF)

SHM0606 - Damage healing in composite materials employing shape memory wires

SHM0614 - Healing Built-in Building Materials

SHM0616 Self-healing of carbonated cement-based materials by special chemical agents

SHM0617 Unravelling of porous asphalt

SHM0621 Autonomous restoration of polymer barrier coatings by activated phase change and stimulated hardening

SHM0625 - Development of Self Healing PMMA

SHM0626 Pre-emptive healing of stresses in coatings

SHM0631 - Self-healing materials based on radical-induced plasticity

SHM0633 Pre-emptive healing of corrosion attack by responsive release of novel corrosion inhibitors from organic coatings

SHM0634 - Self-Healing Thermal Barrier Coatings

SHM0636 Self healing of ultrafine cracks in steels by nanoscale precipitation

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# Conclusions

- **Maintenance Strategies of Biological Systems are Very Different**
  - Repair with External Means (Medicine?)
  - Self-Healing
- **Design Philosophies are Different**
  - Extreme Redundancies
  - Role-Take Over
  - Function Redundancy
- **Can We Learn Something from the Nature?**
  - We Just Started to Understand the Differences