## Engineering System Design (1.041J/ESD.01J)
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# COMPLEX SYSTEMS

## DISPLAYS

**SPEAKER: Joseph M. Sussman**
**MIT**

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# SYSTEMS AS PURPOSEFUL

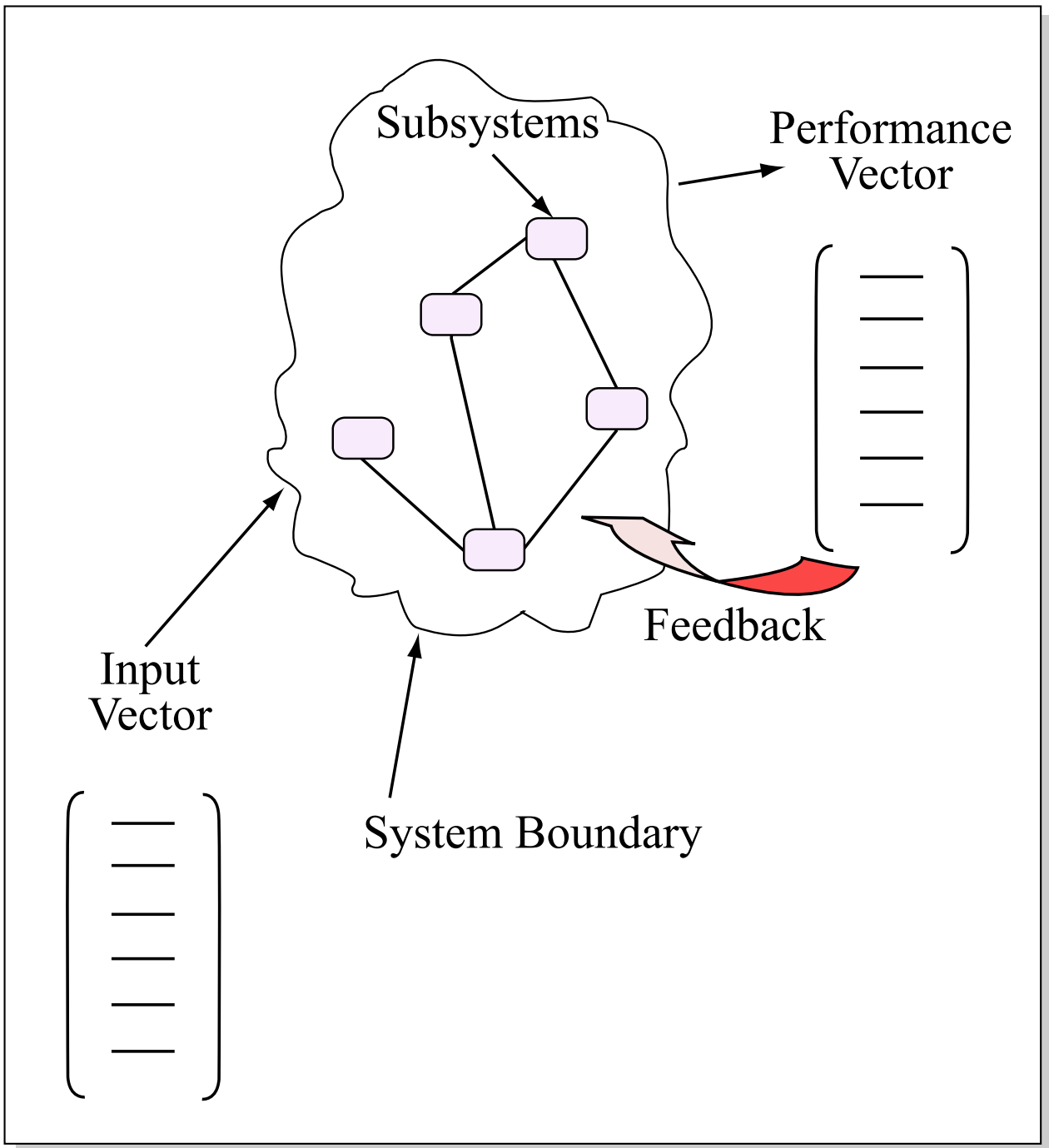




Figure by MIT OpenCourseWare.

# CHARACTERISTICS OF COMPLEX SYSTEMS

1. Change with time
2. Feedback, both positive and negative, with time delays
3. Non-linear in behavior and interactions, including threshold effects
4. Small changes in inputs or interactions may lead to big effects (the butterfly effect)
5. Causes and effects differ in space--spatial disconnect
6. Causes and effects differ in time--temporal disconnect
7. Causes and effects differ in nature--substantive disconnect

So 5, 6 and 7 imply it is hard to link causes and effects

8. Adaptive -- Systems and agents within systems can learn
9. Systems may evolve toward complexity to achieve better performance, e.g., the gas turbine originally had one moving part
10. Stochasticity

# IMPLICATIONS

1. System behavior often counter-intuitive. We cannot *readily* predict *emergent behavior* -- even if we understand the subsystems.
2. Simplification often does not work -- if you focus on single sectors, the results may be counterproductive.
3. The system may be policy-resistant! -- Perverse interactions.

# FOUR IDEAS FROM COMPLEXITY THEORY

Four ideas from complexity theory that will help us think in new ways about how to improve the metropolitan development system:

1. Simplification results in fundamentally wrong answers, and focus on individual sectors separately will be counterproductive.
2. Effects cannot be directly linked to causes because an intervention reverberates through the system in ways that can only be partially traced.
3. Even small changes introduced to the system may produce discontinuous, unpredicted effects.
4. Adaptive changes within a system can grow from learning generated by the individual interactions in the networks of system participants.

from: Metropolitan Development as a Complex System: A New Approach to Sustainability, Judith E. Innes and David E. Booher, Working Paper #699, University of California at Berkeley, December 1997.

# KINDS OF COMPLEXITY

1. Complexity in behavior
2. Complexity in internal structure -- like software
3. Complexity in evaluation
   - Many constituencies
   - High impact, low probability risks
   - Concentrated benefits vs. diffuse costs
   - or vice versa

# SYSTEM MODELING ISSUES

- Stochastic vs. Deterministic (both Internal/External)
- Linear vs. Non-Linear (both Internal/External)
- Coupled vs. Uncoupled (Strong/Weak)
- Feedback (Positive/Negative)
- Adaptive vs. Non-Adaptive
- Dynamic vs. Non-Dynamic Changes over Time -- Different Time Scales
- Emergent Behavior
- Human Agency
- Organizational Structure
  - Centralized ⟷ Decentralized (Distributed)
  - Hierarchical ⟷ Flat
- Network Structure (if any)
- Cost Structure
  - Fixed vs. Variable Costs Balance
  - Infrastructure-Intensive

and others