Is it Adaptive?
Self-Managing?
Self-Organizing?

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Motivation

- The terms adaptive, self-managing, and self-organizing systems are used in many articles with similar meanings but without a precise definition!

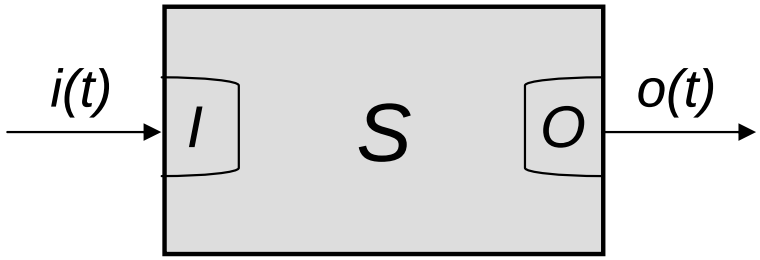
- Questions raised
  - Are these terms synonyms?
  - If not, what are the differences among them and what could be a precise definition for them?

Overview

- System Model
- Adaptive Systems
- Self-Managing Systems
- Self-Organizing Systems
- Illustration Using an Exemplary System
- Conclusions and Outlook

System Model: Input and Output [Willems91]

- *Input function* $i: T \rightarrow I$
- *Output function* $o: T \rightarrow O$
- *Input Interface I*
  - defines the values an input function may take
- *Output Interface O*
  - defines the values an output function may take
- *T* may be $\mathbb{R}^{+,0}$ for continuous time systems and $\mathbb{N}^0$ for discrete time systems



System Model: Behavior

- Binary relation B defining which output functions may be observed for which input functions
- If $(i, o) \in B$, the system may output o when fed with i
- Example: $B = \{(i, o) \mid o(t) = i^2(t)\}$, where $I = O = \mathbb{R}$
- Non-deterministic systems:
  for one i there is *at least one* o such that $(i, o) \in B$
- Deterministic systems:
  for each i there is *exactly one* o such that $(i, o) \in B$

Adaptive Systems [Zadeh63]

- *"A system is adaptive iff it performs acceptably well for a defined set of input functions"*

- A performance function *p*
  - takes an input function *i* and an output function *o*
  - returns a time-dependent, vector-valued function
- An acceptability criterion *W* is a set of a time-dependent, vector-valued functions

- A System is *adaptive* wrt. a set of input functions *F* iff

$$\forall(i \in F): (i, o) \in B \Rightarrow p(i, o) \in W$$

Self-Managing Systems

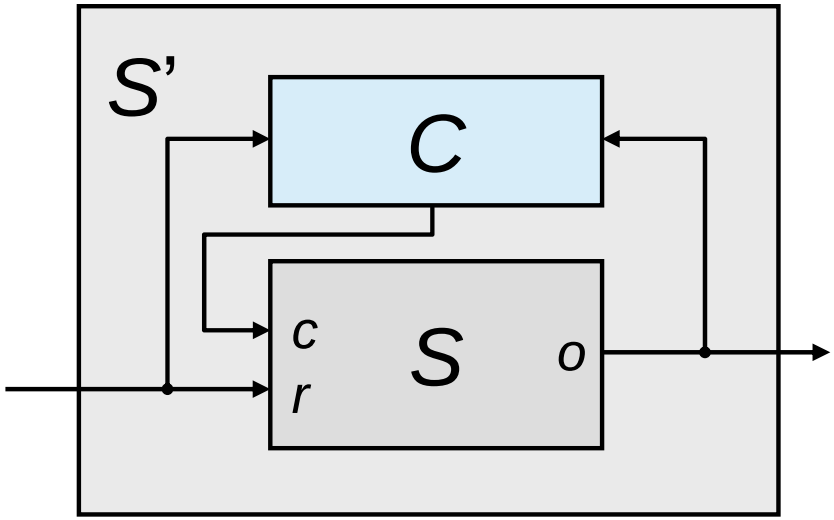
- *"Self-managing systems are adaptive without being controlled from the outside"*
- But adaptive systems may be controlled from the outside
  - E.g., an air conditioning may manually be switched on and off to keep the room temperature below a given threshold
- Division of input into control input *c* and regular input *r*
- Whether or not input is control input or regular input depends on the performance function [Lendaris64]

- A system is *self-managing* iff it
  1. is adaptive
  2. receives no control input

Self-Manageable Systems

> A system is *self-manageable* iff its control input can be computed solely from its regular input and its output

> A self-manageable system *S* can be extended to a self-managing system *S'* using the *observer/controller pattern*



Self-Organizing Systems

- *“Self-organizing systems change their structure to adapt themselves; they are scalable and robust against failures”*
- But self-managing systems may have a static structure and may have a central point of failure (e.g., a controller)

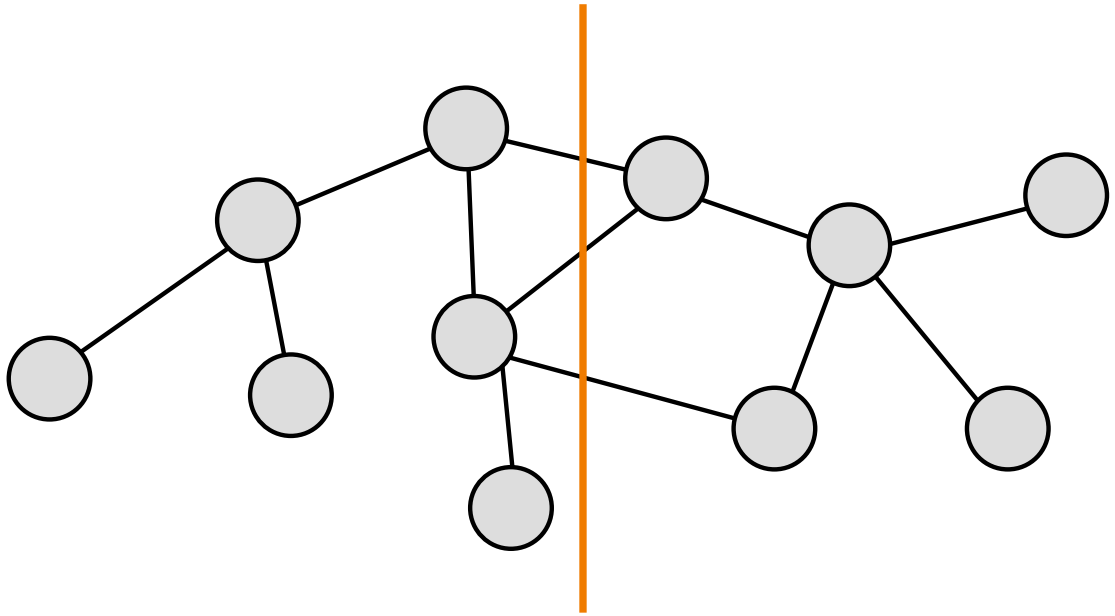
- A system is *self-organizing* iff it is
  1. self-managing
  2. employs decentralized control
  3. structure-adaptive

- But what exactly means
  - decentralized control?
  - structure and structure-adaptivity?

Decentralized Control

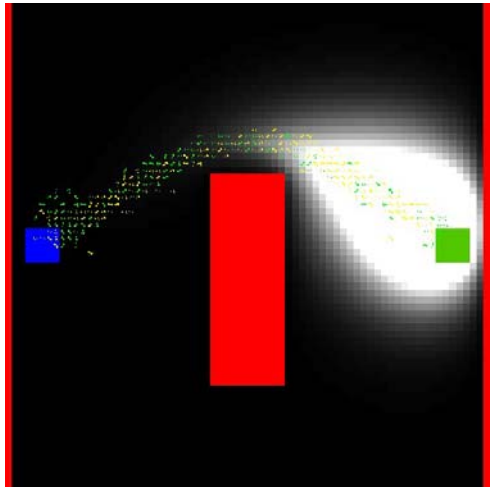
> A system employs *decentralized control* if it is not possible to decompose it into two subsystems such that neither subsystem is able to perform the original function

> Example: Routing Information Protocol (RIP)



Structure

- *Structure* is the property of a system by which it constrains the degrees of freedom of its components
- Can often be modeled as a relation (or by a family of relations)
- Example: Trail building of ants
  - Established structure
    - Position
    - Heading

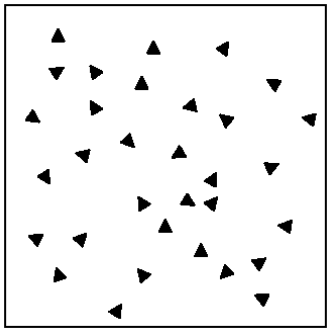


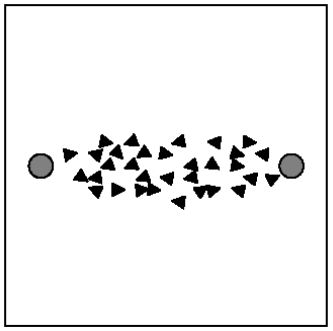
Detecting Structure

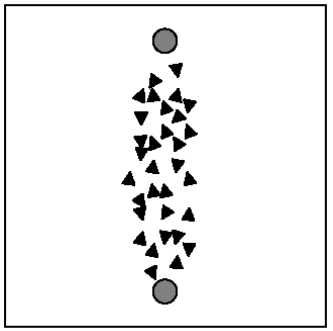
- Structuring can be detected by applying the information entropy introduced by Shannon

$$H(P) = -K \sum_{s \in S} P(s) \cdot \log P(s)$$

- Entropy is at its maximum if a given system is free to be in any of its potential states
- It decreases if the system is subsequently constrained to a subset of its potential states
- A system might change its structure without changing its degree of structuredness
- Change of entropy is sufficient but *not* necessary to show that a system changes its structure





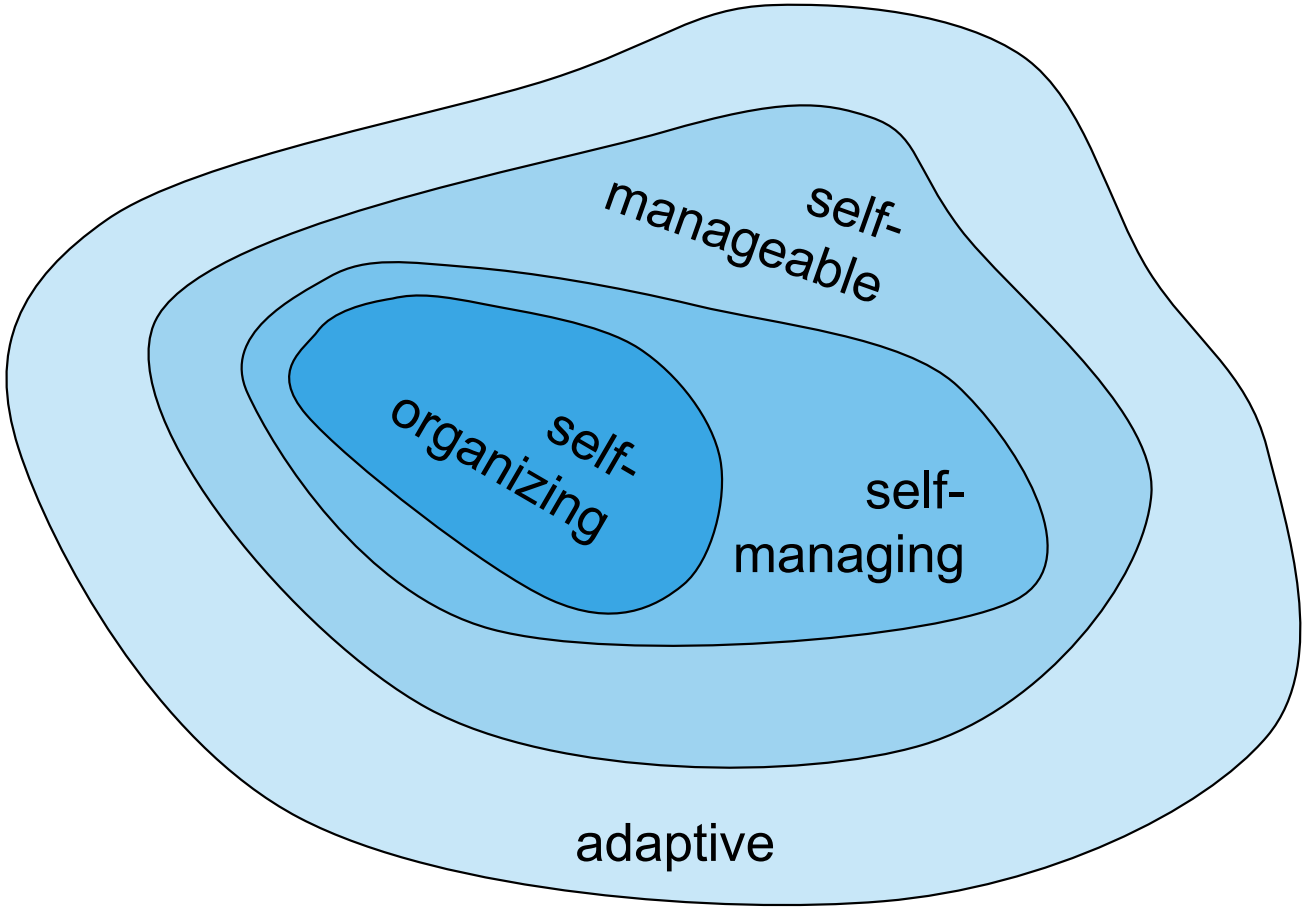


Structure-Adaptive Systems

- An adaptive system is *structure-adaptive* iff it achieves its adaptivity by changing its structure

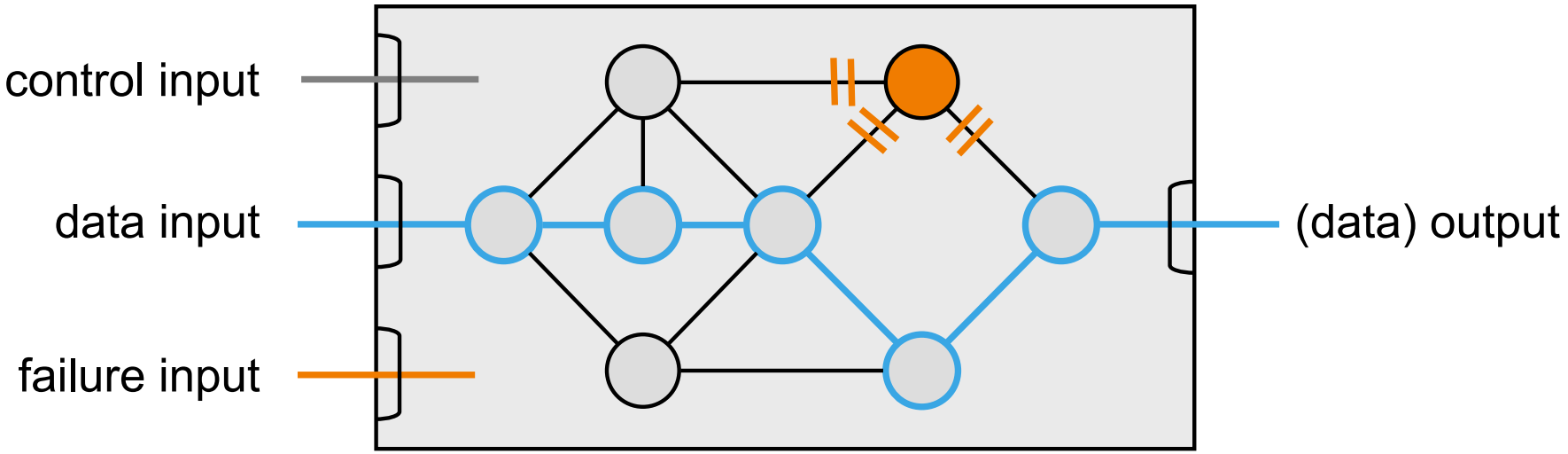
- Can be proved by showing that the system was not adaptive if it would not change its structure
  - E.g., RIP was not adaptive if it would not change the routes in reaction to failing nodes

Resulting Hierarchy



Example System

- System performs acceptably well iff the “connection” among data input and data output is not interrupted infinitely long for
  - all sequences of node failures and recoveries *not* leading to a partition of the network
  - appropriate control input determining which nodes connect
  - arbitrary data input



Example System: Variants S_1 and S_2

- S_1: Control delay much larger than the minimum time between failures and recoveries (MinTBFR)

⇒ S_1 is (structure-)adaptive but not self-manageable

  - An appropriate control input function exists but its computation would require an anticipatory behavior

- S_2: Control delay much smaller than MinTBFR

⇒ S_2 is self-manageable but not self-managing

  - Computing appropriate control input is possible
  - Still control input

Example System: Variants S_3 and S_4

- S_3 has no control input from the outside
  - Single component collects failure events, calculates a valid path, and sends appropriate control inputs to the nodes
- ⇒ S_3 is self-managing but not self-organizing
  - No control input but centralized control

- S_4 distributes the task of building a valid path to all nodes
- ⇒ S_4 is self-organizing because
  - decentralized control

Conclusions and Outlook

- Initial definition of adaptive, self-manageable, self-managing, and self-organizing systems proposing a hierarchy among these kinds of systems
- Aim: Facilitating further discussions

- Better definition needed for
  - Control input
  - Decentralized control
  - Structure

- Similar clarifications needed for the other self-x properties

Bibliography

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Thank you for your attention!

Questions, critique, or comments?

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