SDSC6004 PROCESS ENGINEERING AND SYSTEMS MODELING

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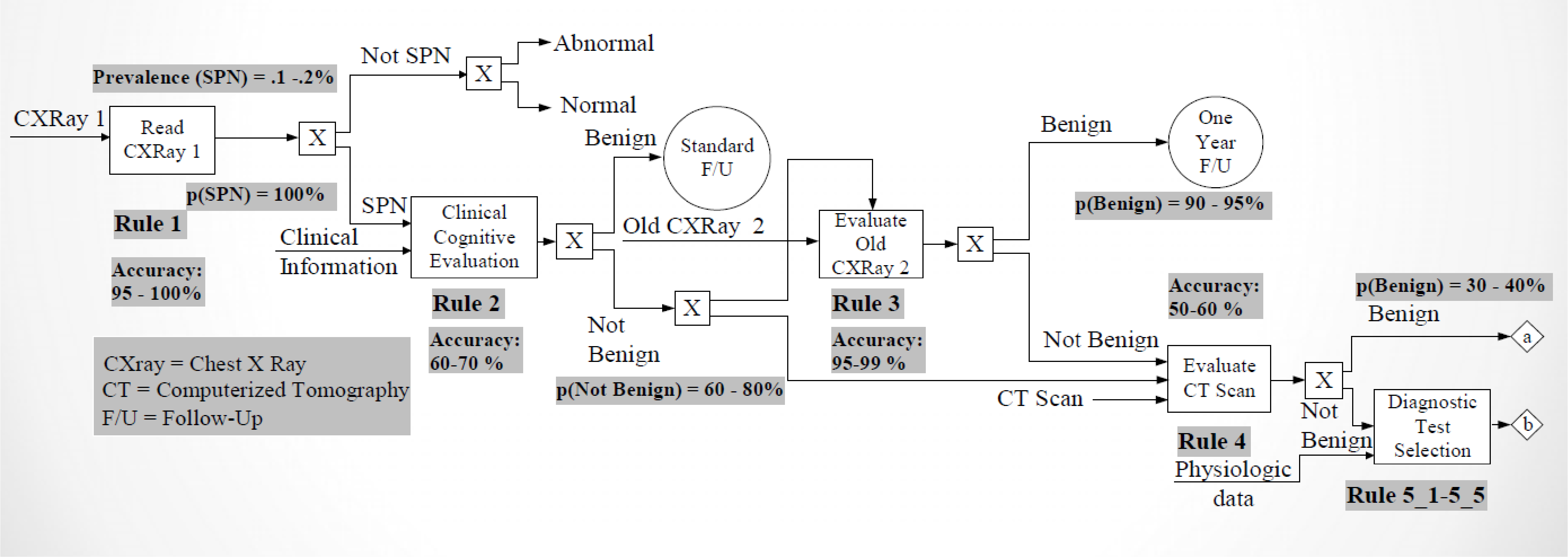
Parts of materials are from lecture notes of Prof. Andrew Kusiak

PROCESS ENGINEERING

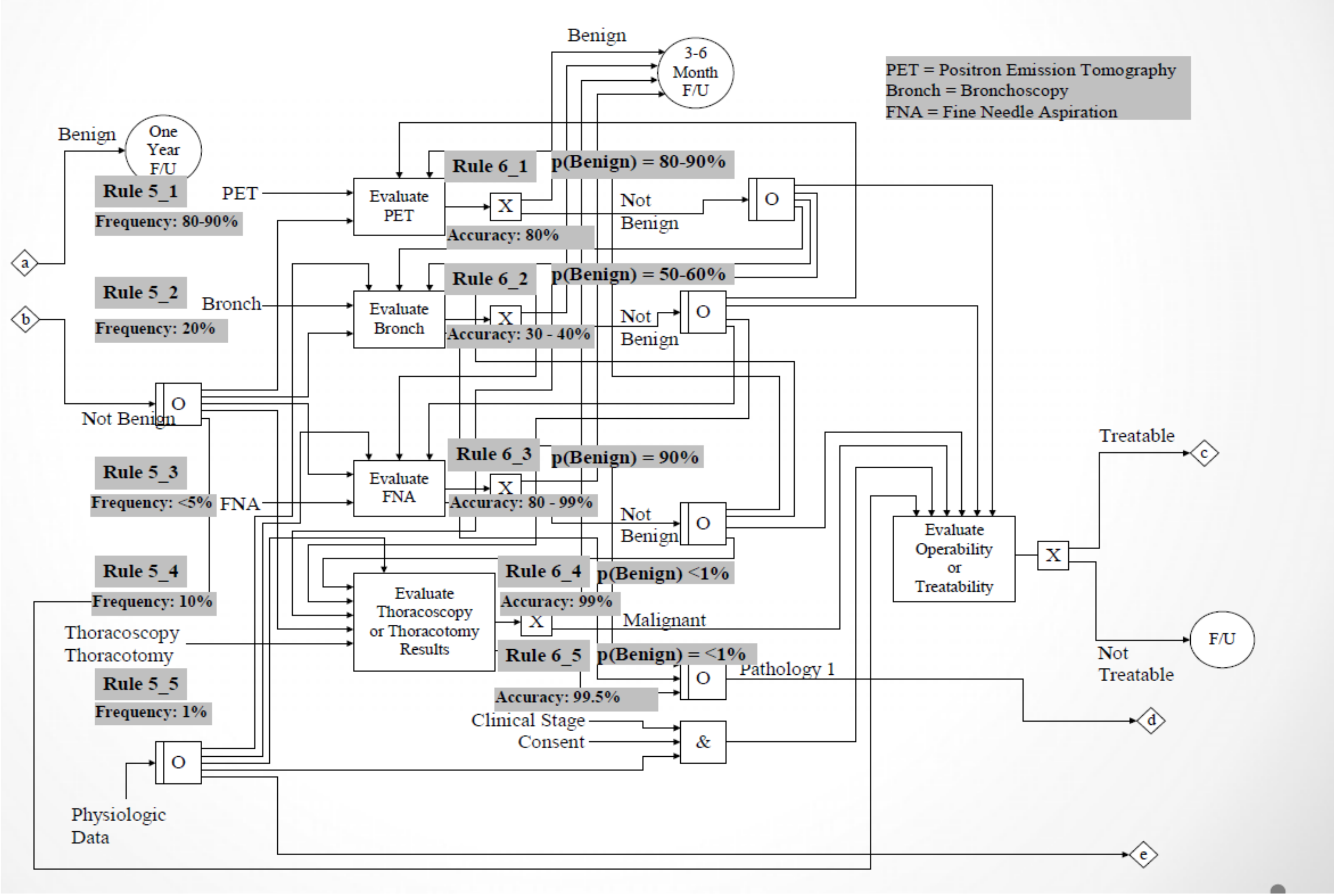
What is a process? Definition?

Using solitary pulmonary nodule (SPN) diagnosis process as an example

EXAMPLE PART I



EXAMPLE PART II



PROCESS ENGINEERING

It is a collection of events, actions, factors, …

More examples in real applications:

Manufacturing process

Design process

Business process

PROCESS TYPES

Process type can be categorized via different ways, e.g.:

Way 1

Structured, e.g., manufacturing, v.s. unstructured, e.g., healthcare

Way 2

Deterministic v.s. stochastic

PROCESS MODELING METHODOLOGY

Computer Integrated Manufacturing-Open Systems Architecture (CIM-OSA)

EXPRESS

GRAI Method

Integrated Enterprise Modeling (IEM)

Problem Statement Language/Problem Statement Analyzer (PSL/PSA)

Structured System Analysis and Design Method (SSADM)

Object-Oriented modeling methodology for Manufacturing Information Systems (OOMIS)

MOSYS (Modeling System)

Petri Nets

IDEF Methodology

QUESTION

What is more important?

The modeling tool itself or the user familiarity with the tool?

IDEF METHODOLOGY

IDEF = Integrated DEFinition

IDEF METHODOLOGIES

IDEF0: modeling a wide variety of systems which use hardware, software, and people to perform activities

IDEF1x: to semantically model the relationships between various pieces of data

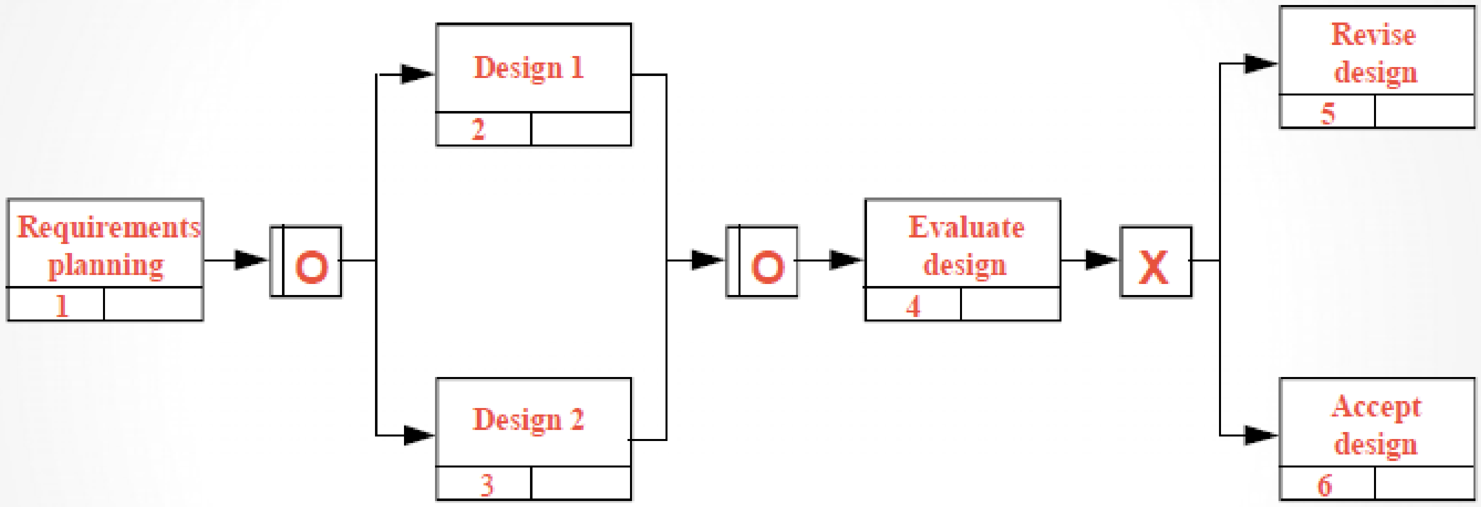
IDEF2: to capture the dynamic behavior of a system

IDEF3: created specifically to model the sequence of activities

IDEF5: to model domain ontologies

IDEF6: to define the motives that drive the decision making process

IDEF3 PROCESS MODEL

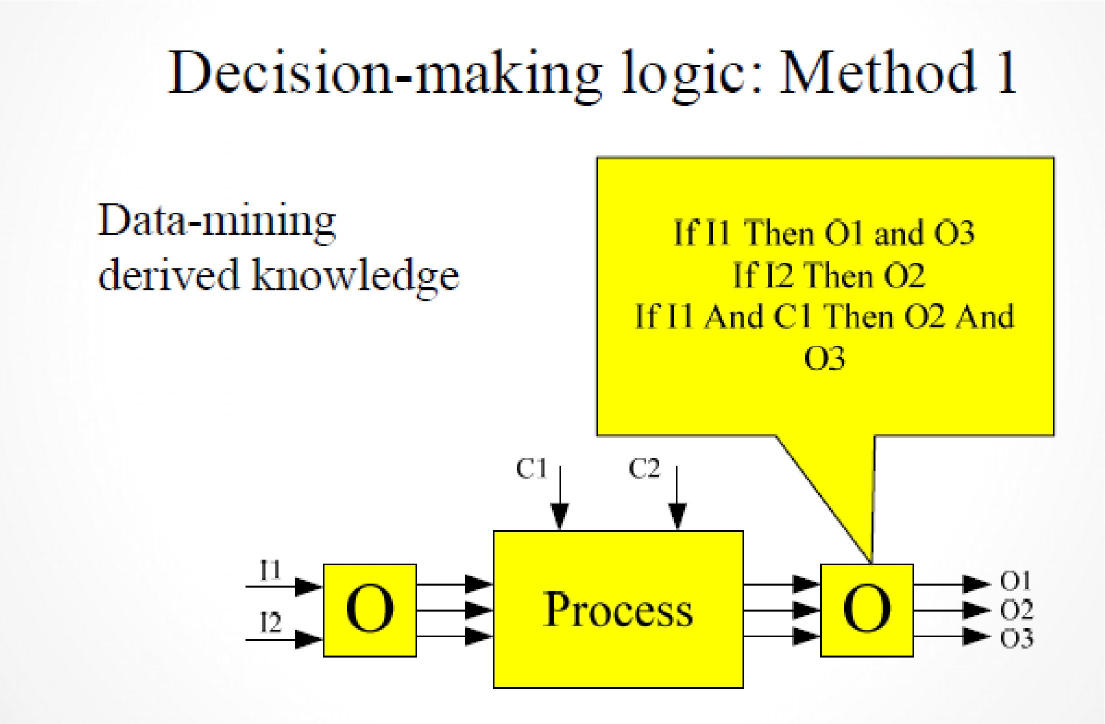


Activities: Units of behavior (UOBs)

Links: Relationships between activities which are of three types: precedence links, relational links, and object flow links

Logic Junctions: AND (&), OR (O), and Exclusive OR (X)

ANNOTATED PROCESS MODEL



PROCESS AND SYSTEMS

Interpretation can be made from multiple aspects:

If the system is very specific mechanical or electrical components utilized in some processes, we can say process includes some of systems

If the system means a high-level scope, it will be regarded as a collection of processes which transforms a set of inputs under certain conditions to a set of outputs

SYSTEMS MODELING

Terms utilized in mechanical engineering, physics, electrical engineering, control, etc. majorly refer to system dynamics

Model types: ODE, PDE, State Machines, Hybrid, etc.

Modeling approaches:

Physics-based models (white box)

Input-output models (black box)

SYSTEM MODELING

System dynamics models:

Model is a mathematical representations of a system

- Models allow simulating and analyzing the system
- Models are never exact

Modeling depends on your goal

- A single system may have many models
- Always understand what is the purpose of the model
- Large “libraries” of standard model templates exist
- A conceptually new model is a big deal

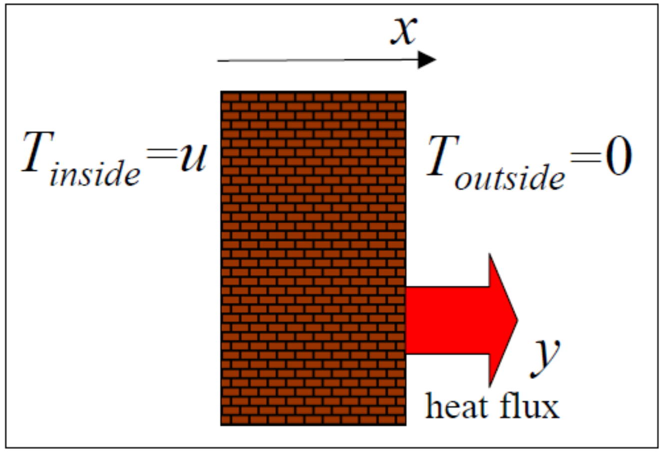
PDE MODELS

- Include functions of spatial variables
  - electromagnetic fields
  - mass and heat transfer
  - fluid dynamics
  - structural deformations
- Example: sideways heat equation

$$\frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2}$$

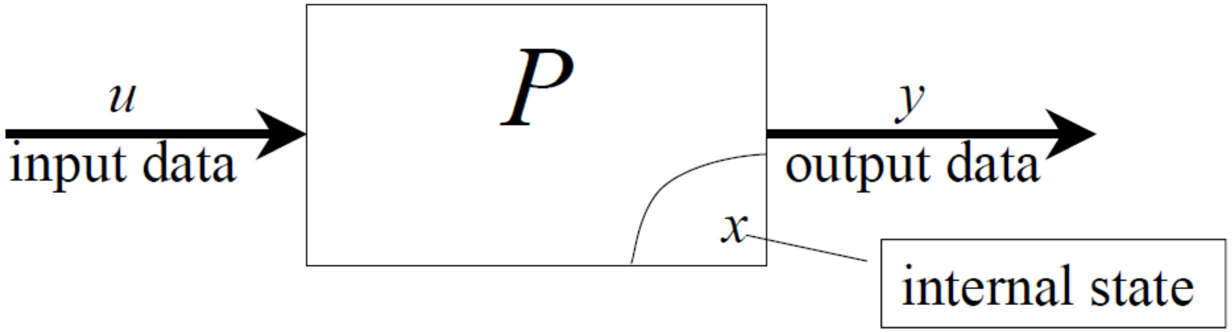
$$T(0) = u; \qquad T(1) = 0$$

$$y = \left. \frac{\partial T}{\partial x} \right|_{x=1}$$



BLACK-BOX MODELS

- Black-box models - describe *P* as an operator



  - AA, ME, Physics - state space, ODE and PDE
  - EE - black-box,
  - ChE - use anything
  - CS - state machines, probablistic models, neural networks

BLACK-BOX MODEL FROM DATA

In control, due to the system complexity, exact form of models or deterministic form of model parameters cannot be easily obtained.

Thus, according to system observations and responses, a new direction of determining the black-box was emerged, model identification from data

However, in control, a lot of times, the structure of model to be identified is typically assumed while the estimation focuses on model parameters or a number of assumptions is applied into the problem

PROCESS MODELS

A process model created through a modeling effort, referred to as “as-is” model, needs to be transformed into “to-be model” that meets the goals of the re-engineering effort

Two types of analysis

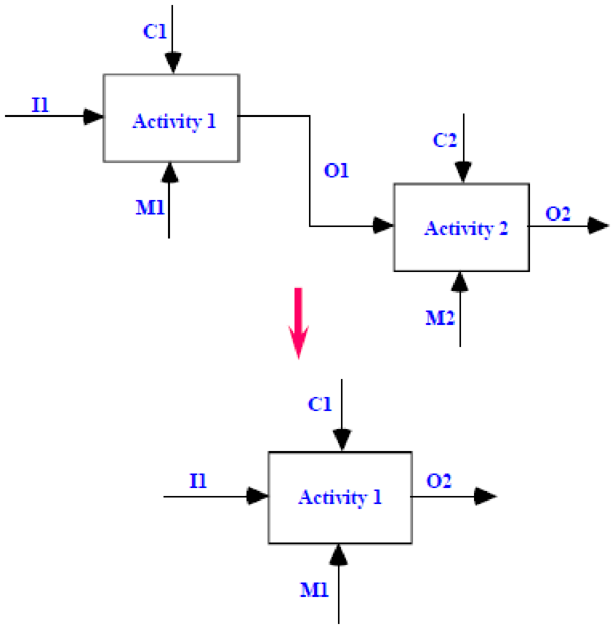
- Observational analysis
- Computational analysis

PROCESS MODELS

Observational analysis

Elimination of Redundant Activities

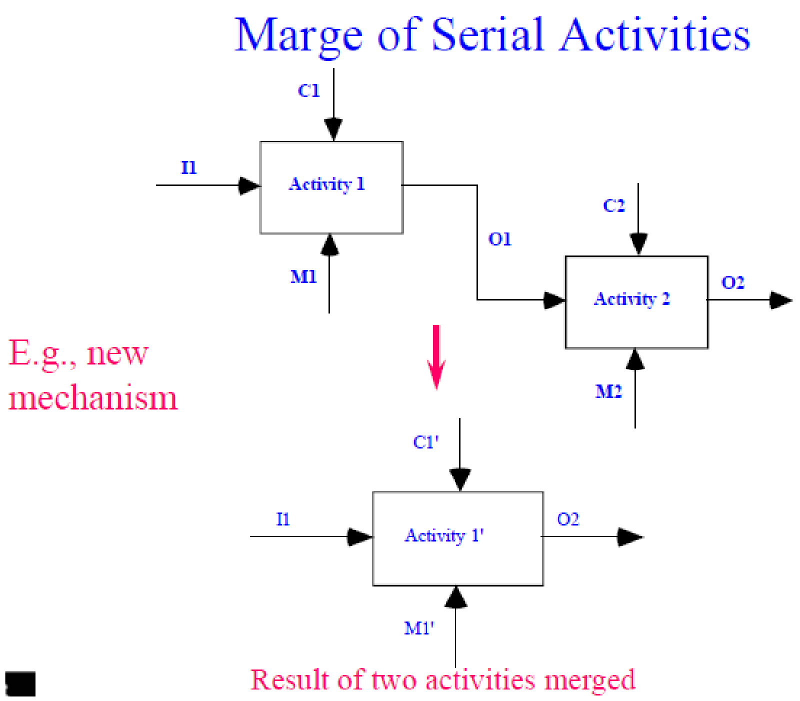
E.g., doing
and undoing



Result of eliminating a redundant activity

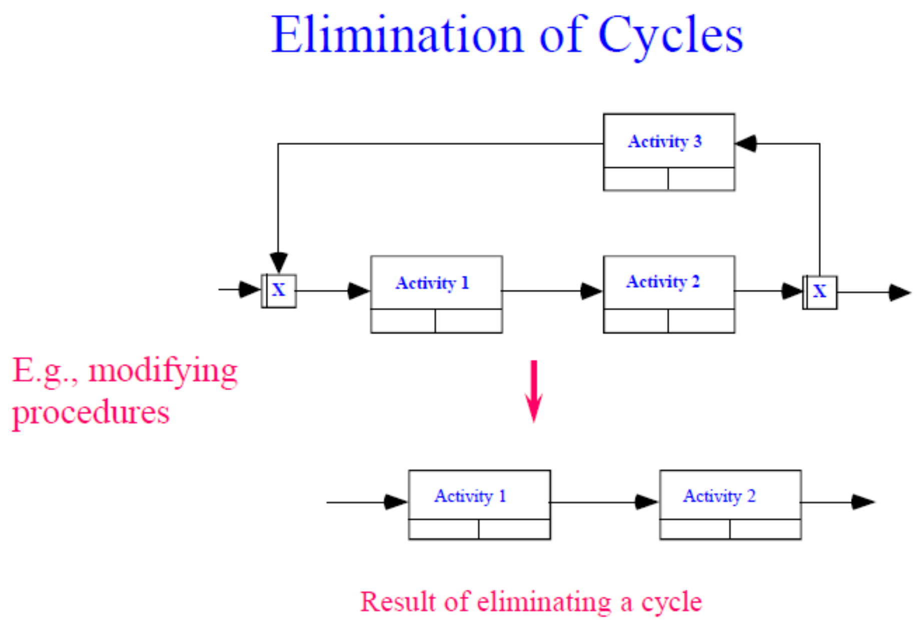
PROCESS MODELS

Observational analysis



PROCESS MODELS

Observational analysis



PROCESS MODELS

Observational analysis – Question

What is the end result of observational analysis of a process model?

PROCESS MODELS

Re-engineered “to-be” process model:

Contains normally less activities than “as-model”

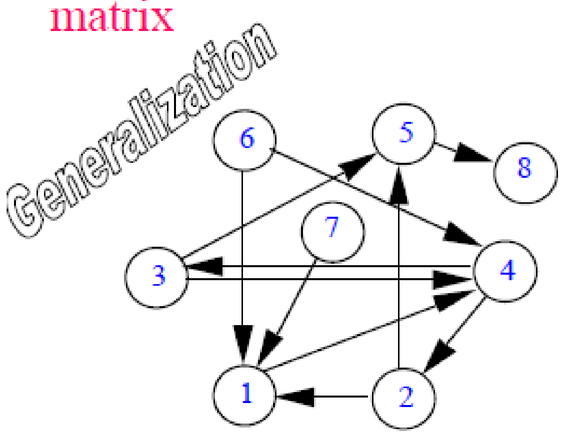
Has a better performance, e.g., shorter process cycle time

PROCESS MODELS

Computational analysis

Graph Representation of Dependencies in Process Models

Digraph of activities and the corresponding incidence matrix



Extracted from an IDEF3 model

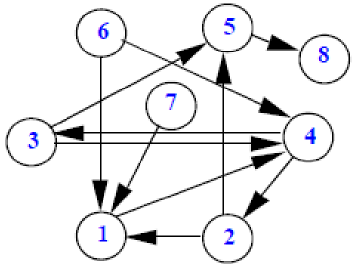
Output

Input	1	2	3	4	5	6	7	8
1	+	*				*	*	
2		+		*				
3			+	*				
4	*		*	+		*		
5		*	*		+			
6						+		
7							+	
8					*			+

PROCESS MODELS

Computational analysis

Convention



Output from activity *i*

Input to activity *j*

	1	2	3	4	5	6	7	8
1	+	*				*	*	
2		+		*				
3			+	*				
4	*		*	+		*		
5		*	*		+			
6						+		
7							+	
8					*			+

—

OR

Preceding activity *i*

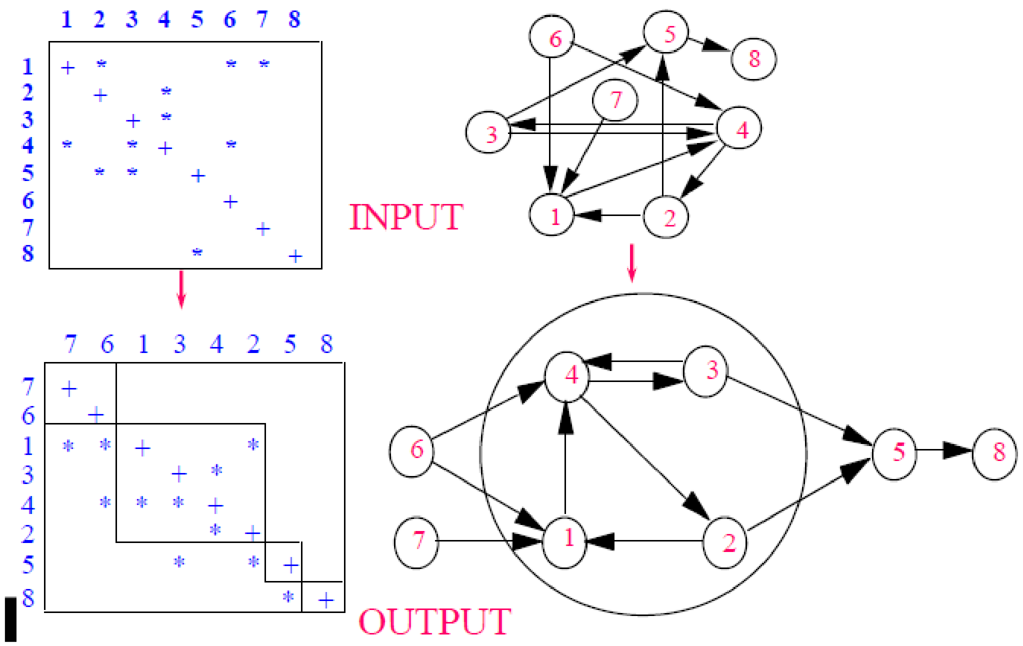
Succeeding activity *j*

	1	2	3	4	5	6	7	8
1	+	*				*	*	
2		+		*				
3			+	*				
4	*		*	+		*		
5		*	*		+			
6						+		
7							+	
8					*			+

PROCESS MODELS

Computational analysis

The ordered incidence matrix and the corresponding digraph



PROCESS MODELS

Soft computing algorithms

Case 1: Organizing Non-cyclic Graphs

The Topological Sorting Algorithm

Step 1. Set i = 1.
Step 2. Draw a horizontal line through unlabeled row k of the incidence matrix with only one non-empty element (corresponding to a vertex with no predecessors).
Step 3. Draw a vertical line through column k (same column number k as the row number in Step 2) of the incidence matrix.
Step 4. Label i the cross out row k and column k of the matrix.
Step 5. If each row and column of incidence matrix has been labeled, stop; otherwise set i = i + 1 and go to Step 2.

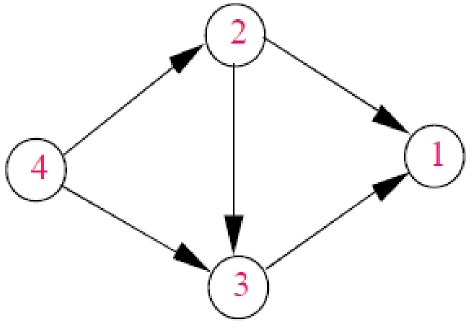
PROCESS MODELS

Computational analysis

Incidence matrix and the corresponding digraph with
four vertices

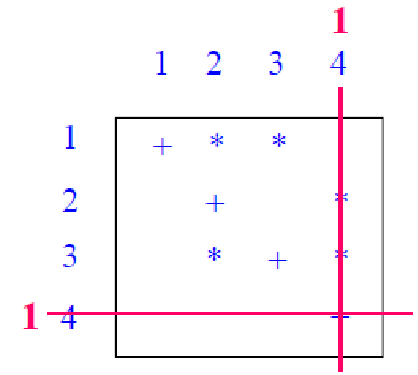
Output

Input	1	2	3	4
1	+	*	*	
2		+		*
3		*	+	*
4				+

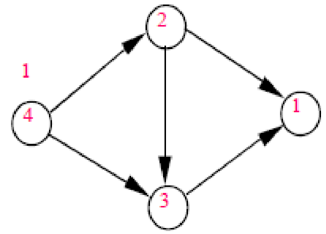


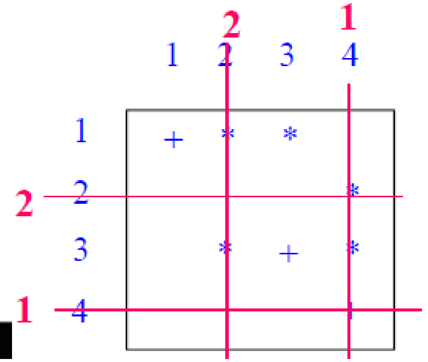
PROCESS MODELS

Computational analysis

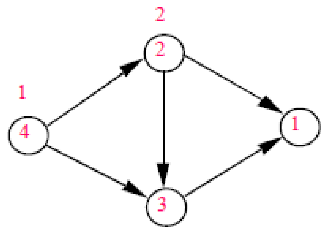


First iteration of the
topological sorting algorithm



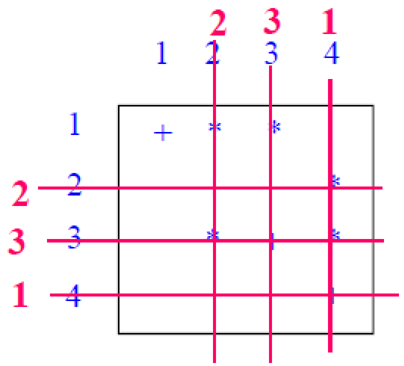


Second iteration of the
topological sorting algorithm

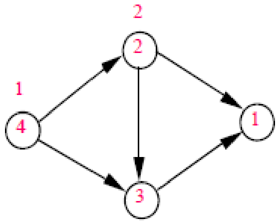


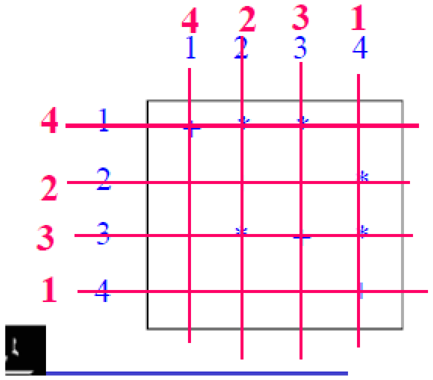
PROCESS MODELS

Computational analysis

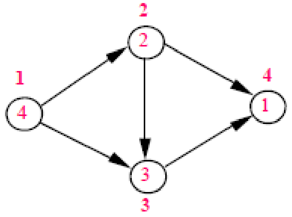


Third iteration of the topological sorting algorithm





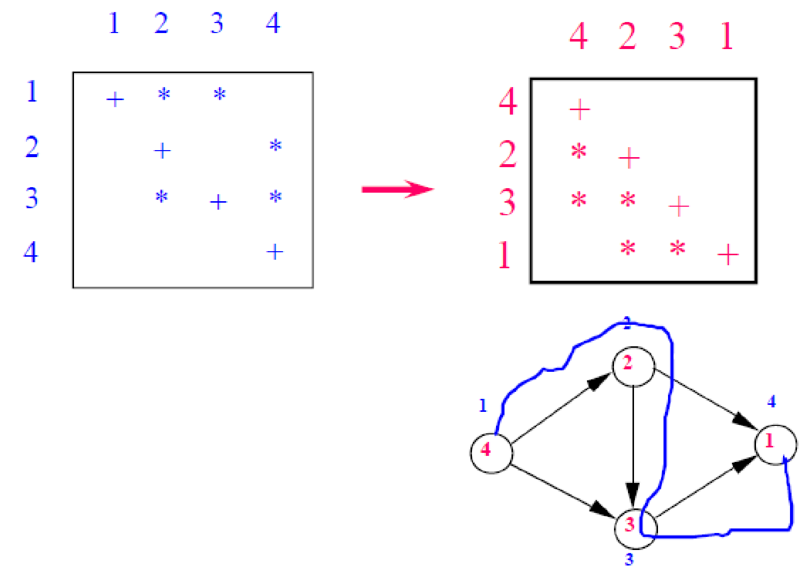
Fourth iteration of the topological sorting algorithm



PROCESS MODELS

Computational analysis

The reorganized matrix



DATA-DRIVEN MODELING

Based on previous examples, it is clear that due to the increase of system or process complexity, the chance of obtaining a exact parametric description of the system or process is pretty slim.

To obtain an approximated presentation of a complex system or process, a data-driven approach can be applied.

DATA-DRIVEN MODELING

Conceptual idea:

1. We believe that data is a replication of the physical world

2. Assume we don’t have any clue of the mathematical presentation of a system or process, but we have observations of inputs and outputs of them

3. The data-driven modeling process aims to identify the mathematical relationships based on applying machine learning algorithms into dataset of inputs and outputs of a system or process

DATA-DRIVEN MODELING

Real application examples

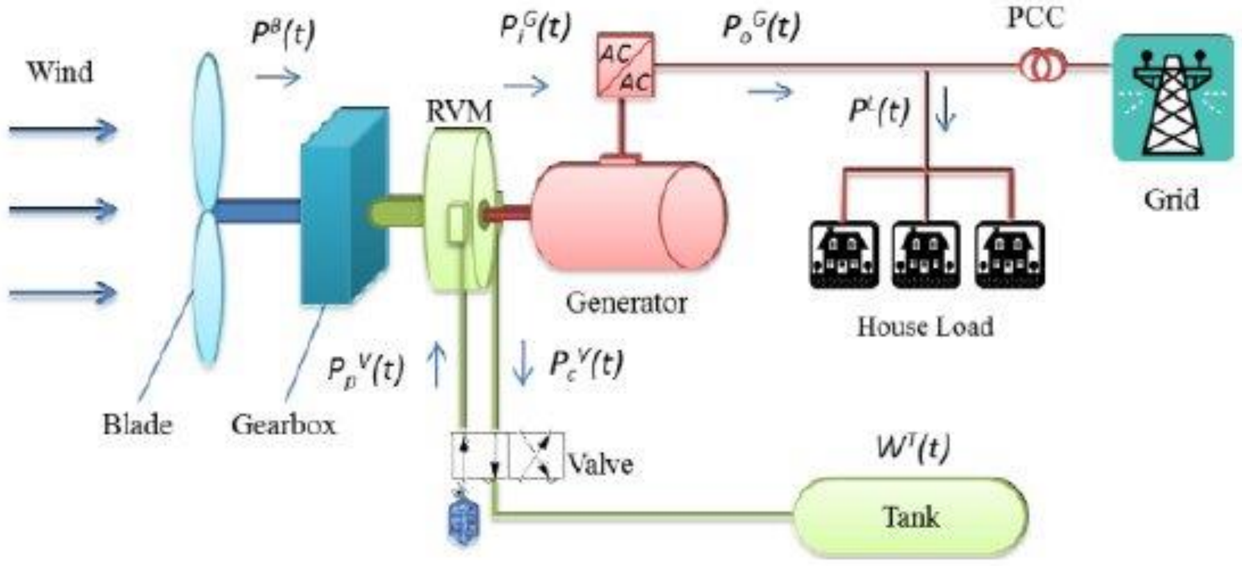
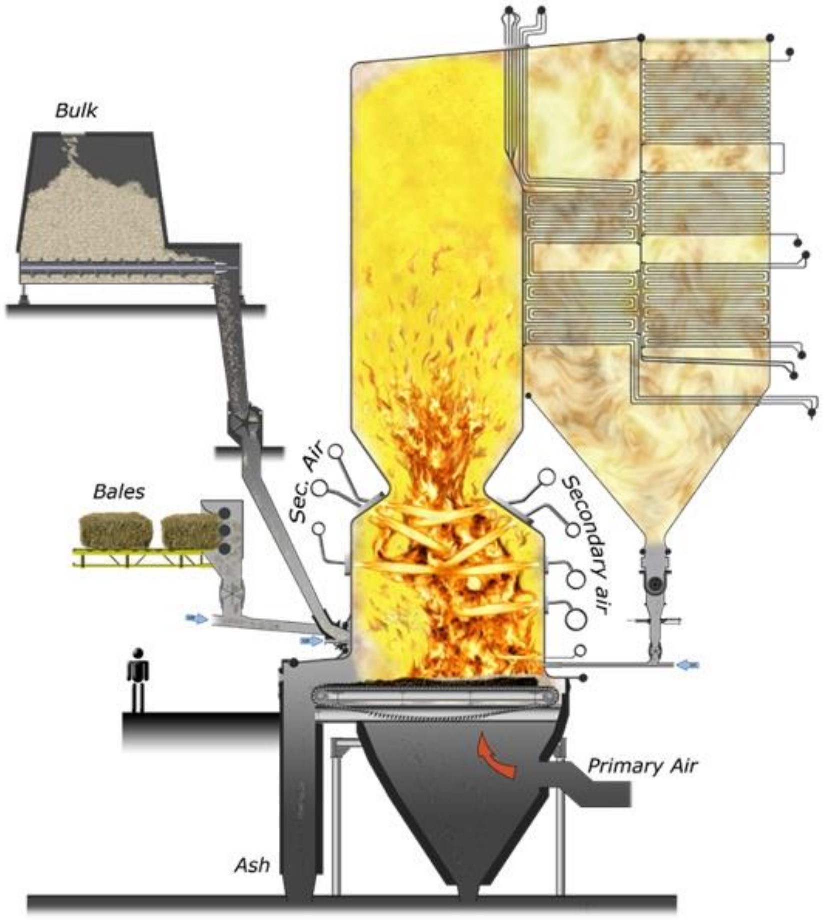


Figure 2. Proposed wind conversion system.

DATA-DRIVEN MODELING

Real application examples



DATA-DRIVEN MODELING

Real application examples

DATA-DRIVEN MODELING

The complexity typically comes from

1. A high dimension of system parameters
2. Strong nonlinearity in process
3. Domain knowledge in systems is limited

DATA-DRIVEN MODELING

Questions need to be answered before data-driven modeling

Domain knowledge level

Data availability

Attribute/Feature selection and data processing

Modeling problem formulation (supervised learning typically, discrete state or continuous)

Modeling algorithm selection

Modeling results validation