Computer Controlled Systems II.
Case study: Diagnosis with colored Petri nets

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Overview

Problem statement

Technological systems

- continuous time, continuous variables
- discretization: time sampling, quantization
- $\rightarrow$ discrete event system

Fault diagnosis of discrete event systems

- fault detection: Has any fault occurred?
- fault isolation: Which fault has occurred? What is the location of the fault?
- fault identification: characterising the fault (size, criticality, importance)

Problems

- available information
- fault modeling

Motivation

- Compact representation of complex systems
- Reduced size of the model
- More modeling potential
    - colors
    - arc functions
    - stochastically firing transitions

Basic concepts

Qualitative range spaces

- $Q_s = \{e^-, 0, L, N, H, e^+\}$

Events: $event_\tau = (\tau, input\ values, output\ values)$
Traces: $trace = event_1, event_2, \ldots, event_\tau$

- nominal: normal operation
- faulty: faulty operation
- characteristic: real trace from the process

Deviations from the nominal trace:

- *never happened (NH)*
- *later (LAT) or earlier (EAR)*
- *greater (GRE) or smaller (SML)* var_out_i

Colored Petri Net model

Places

- input and output variables
- operational mode
- deviations

Colors

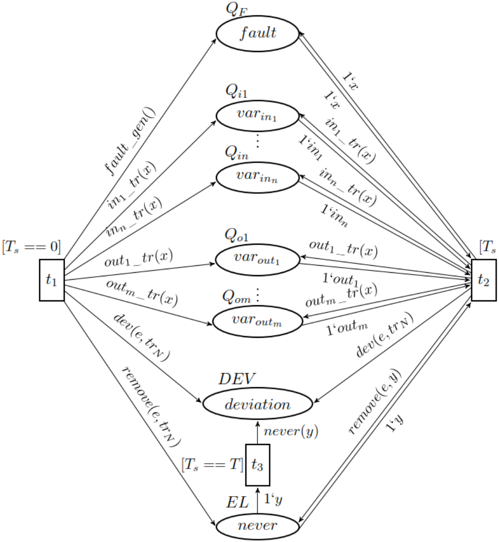
- qualitative values of variables
- type of fault
- type of deviation

Transitions

- timing
- fault generation

Arc functions

- change of colors
- generating deviations



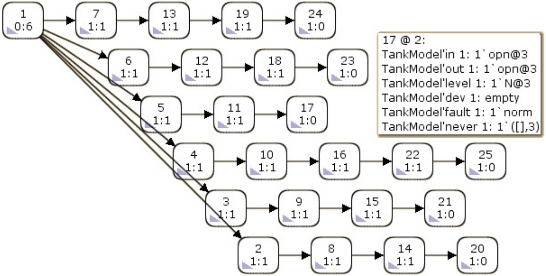
Diagnosis based on the occurrence graph

Nodes

- reachable states
- deviation lists
- fault type

Diagnosis

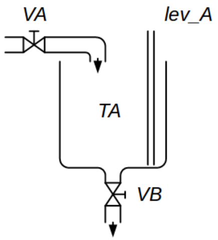
- given characteristic trace
- compute the deviations between the characteristic and the nominal trace
- search nodes with the same deviation list
- identify the fault mode from the token color



Diagnosis of a single unit

Tank with two valves and a level sensor

- Inputs
  - valve VA
- Outputs
  - valve VB
  - level sensor L
- Normal operation
  1. open VA
  2. fill the tank
  3. open VB
  - valves are time controlled!
- Faults
  - leak
  - sensor with +bias
  - sensor with -bias



Qualitative ranges, traces

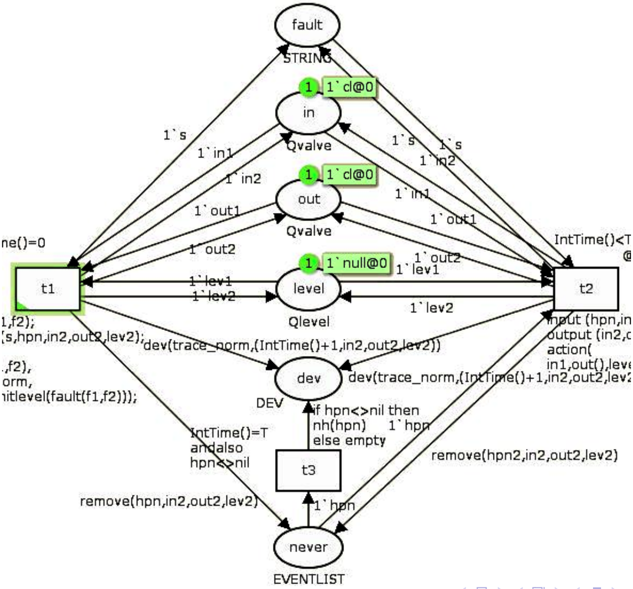
Qualitative range spaces:

- $Q_V = \{op, cl\}$
- $Q_L = \{e^-, 0, L, N, H, e^+\}$

Traces:

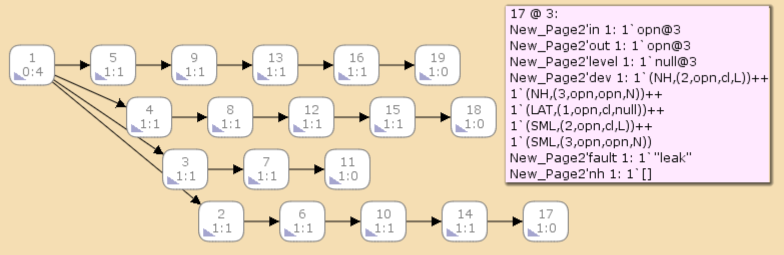
nominal:	[(1,op,cl,0),	(2,op,cl,L),	(3,op,op,N)]
+bias:	[(1,op,cl,L),	(2,op,cl,N),	(3,op,op,H)]
-bias:	[(1,op,cl,e-),	(2,op,cl,0),	(3,op,op,L)]
leak:	[(1,op,cl,0),	(2,op,cl,0),	(3,op,op,0)]

CPN model of the tank



Diagnosis

- nominal trace: (1,op,cl,0),(2,op,cl,L),(3,op,op,N)
- characteristic trace: (1,op,cl,0),(2,op,cl,0),(3,op,op,0)
- deviations: LAT(1,op,cl,0), SML(2,op,cl,L), SML(3,op,op,N), NH(2,op,cl,L), NH(3,op,op,N)



Composite systems

Composite systems

- composed of more than one units
- connection between the units are known

Faults

- may occur in each unit
- may affect other units

Diagnosis

- localization AND
- identification of faults

Diagnosis with structural decomposition

Disadvantages of occurrence graph based methods:

- increasing size of the model
- increasing size of the graph
- computational effort

Structural decomposition of complex systems

- decomposition by technological units
- diagnosis by components

System model

- The system is decomposed and the units are modelled separately
- Each CPN describes the operation of the corresponding unit
- Faults in previous units
  - the color set of faults is extended with the location of the fault
  - the faults in previous units: initial tokens on place *fault*
- The traces describing the possible fault combinations need to be known

Decomposition of the traces

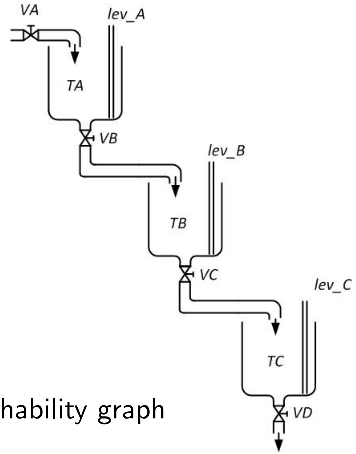
- The full trace contains all variables in the system
- For the diagnosis of one component not all variables are needed
- Decomposition of the traces
  - Separate the input/output variables of each unit
  - Find the time interval when the unit operates
  - Shift the time to 1 at each subtrace of a unit
- The subtraces have their own relative time
- The subtraces contain only the variables of the given unit
- Subtraces of nominal and faulty operations

Diagnosis

Perform the diagnosis in the technological order of the units

For each unit:

1. initial token on place *fault*: diagnosed faults in the previous units
2. generate reachability graph with the given initial faults
3. create the deviations between the nominal and characteristic subtraces of the unit
4. find the deviations in the reachability graph
5. result: faults in the actual unit with the given faults in the previous units
6. repeat until there is no previous fault



Serial connection of 3 tanks

In each tank

- input valve
- output valve
- level sensor

Two additional faults

- valve half opened
- valve closed
- 1 normal and 5 faulty branches in the reachability graph

Technological process

- fill the tanks in a row

Diagnosis with structural decomposition - example

Nominal trace

time	Input variables				Output variables		
	VA	VB	VC	VD	lev_A	lev_B	lev_C
1	op	cl	cl	cl	0	0	0
2	op	cl	cl	cl	L	0	0
3	op	op	cl	cl	N	0	0
4	op	op	cl	cl	N	L	0
5	op	op	op	cl	N	N	0
6	op	op	op	cl	N	N	L
7	op	op	op	op	N	N	N

Diagnosis with structural decomposition - example

Full characteristic trace

time	Input variables				Output variables		
	VA	VB	VC	VD	lev_A	lev_B	lev_C
1	op	cl	cl	cl	L	0	0
2	op	cl	cl	cl	N	0	0
3	op	op	cl	cl	H	0	0
4	op	op	cl	cl	H	0	0
5	op	op	op	cl	H	0	0
6	op	op	op	cl	H	0	0
7	op	op	op	op	H	0	0

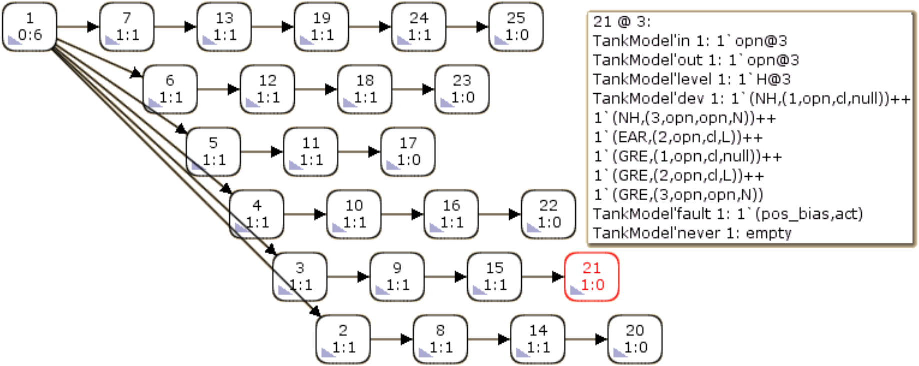
Diagnosis with structural decomposition - example

First tank

time	Input variables				Output variables		
	VA	VB	VC	VD	lev_A	lev_B	lev_C
1	op	cl	cl	cl	L	0	0
2	op	cl	cl	cl	N	0	0
3	op	op	cl	cl	H	0	0
4	op	op	cl	cl	H	0	0
5	op	op	op	cl	H	0	0
6	op	op	op	cl	H	0	0
7	op	op	op	op	H	0	0

Deviation list

$NH, (1, op, cl, 0)$
$NH, (3, op, op, N)$
$EAR, (2, op, cl, L)$
$GRE, (1, op, cl, 0)$
$GRE, (2, op, cl, L)$
$GRE, (3, op, op, N)$


1
0:6
7
1:1
13
1:1
19
1:1
24
1:1
25
1:0
6
1:1
12
1:1
18
1:1
23
1:0
5
1:1
11
1:1
17
1:0
4
1:1
10
1:1
16
1:1
22
1:0
3
1:1
9
1:1
15
1:1
21
1:0
2
1:1
8
1:1
14
1:1
20
1:0
21 @ 3:
TankModel'in 1: 1`opn@3
TankModel'out 1: 1`opn@3
TankModel'level 1: 1`H@3
TankModel'dev 1: 1`(NH,(1,opn,cl,null))++
1`(NH,(3,opn,opn,N))++
1`(EAR,(2,opn,cl,L))++
1`(GRE,(1,opn,cl,null))++
1`(GRE,(2,opn,cl,L))++
1`(GRE,(3,opn,opn,N))
TankModel'fault 1: 1`(pos_bias,act)
TankModel'never 1: empty

result: +bias

Diagnosis with structural decomposition - example

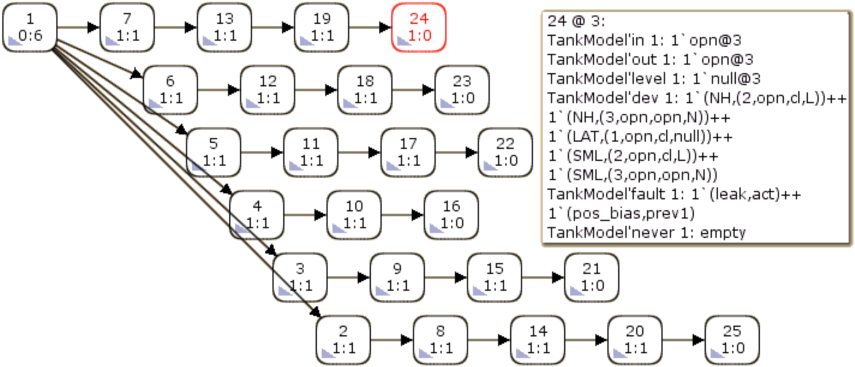
Second tank

time	Input variables				Output variables		
	VA	VB	VC	VD	lev_A	lev_B	lev_C
1	op	cl	cl	cl	L	0	0
2	op	cl	cl	cl	N	0	0
3	op	op	cl	cl	H	0	0
4	op	op	cl	cl	H	0	0
5	op	op	op	cl	H	0	0
6	op	op	op	cl	H	0	0
7	op	op	op	op	H	0	0

Deviation list

$NH, (2, op, cl, L)$
$NH, (3, op, op, N)$
$LAT, (1, op, cl, 0)$
$SML, (2, op, cl, L)$
$SML, (3, op, op, N)$

Diagnosis with structural decomposition - example



result: leak

Diagnosis with structural decomposition - example

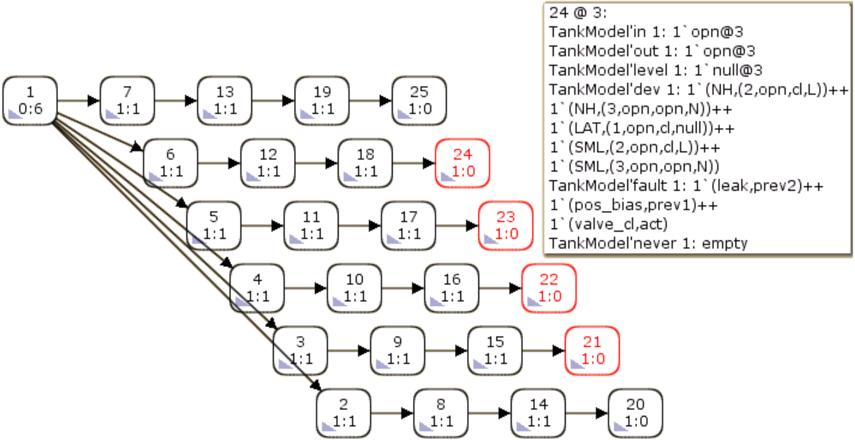
Third tank

time	Input variables				Output variables		
	VA	VB	VC	VD	lev_A	lev_B	lev_C
1	op	cl	cl	cl	L	0	0
2	op	cl	cl	cl	N	0	0
3	op	op	cl	cl	H	0	0
4	op	op	cl	cl	H	0	0
5	op	op	op	cl	H	0	0
6	op	op	op	cl	H	0	0
7	op	op	op	op	H	0	0

Deviation list

$NH, (2, op, cl, L)$
$NH, (3, op, op, N)$
$LAT, (1, op, cl, 0)$
$SML, (2, op, cl, L)$
$SML, (3, op, op, N)$

Diagnosis with structural decomposition - example



result: normal, leak, valve half opened, valve closed

Result

- Fault in the 1st tank: +bias sensor error
- Fault in the 2nd tank: leak
- Fault in the 3rd tank: normal, leak, valve half opened, valve closed $\rightarrow$ **only the set of possible faults are diagnosed**