Tree based diagnosis enhanced with meta knowledge

Diagnosis indicator discovery as a by product

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Context

Goal: Diagnosis and correction of a system without model

Diagnosis of a system without physical model can be achieved with **Data-Based** methods

Correction of a faulty system requires **isolation/explanation** of the fault

→ **Data provides meaninfull information but important knowledge can be leveraged from Model-Based Diagnosis**

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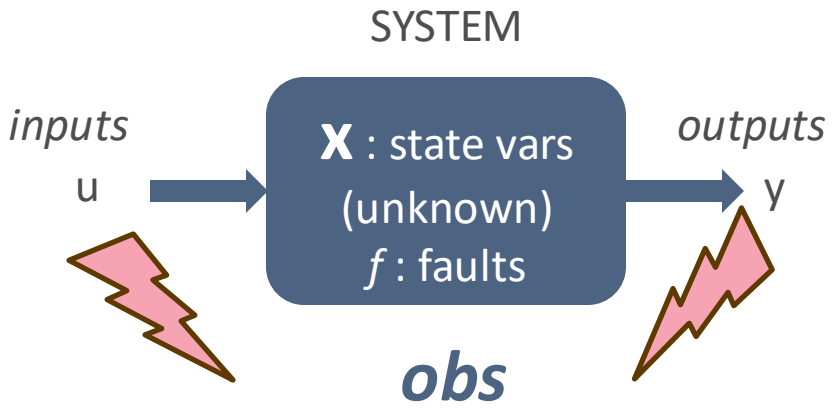
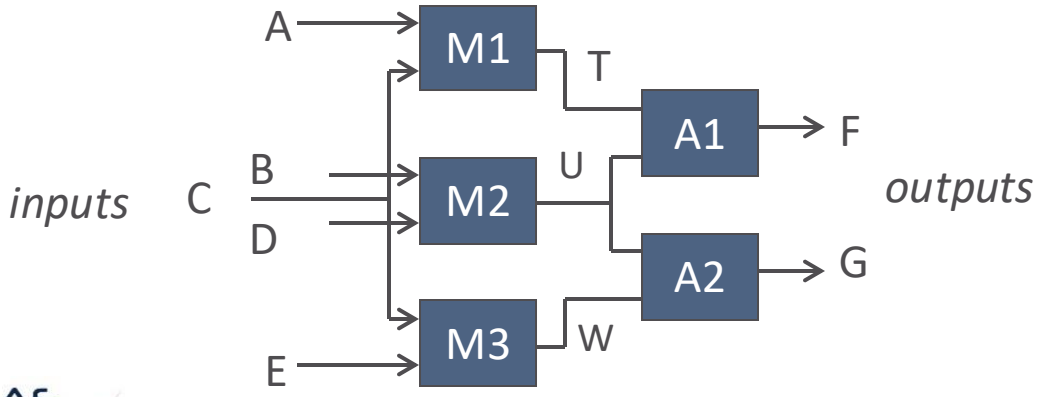
Model based diagnosis knowledge



Diagnosis indicators (ARR):

~~**X** : state vars (unknown)~~

Model ⇨ Relations $\mathbf{R}(obs) = r(t)$ such that $\lim_{t\to\infty} r(t) = 0$ for all ***obs*** consistent with normal behavior.

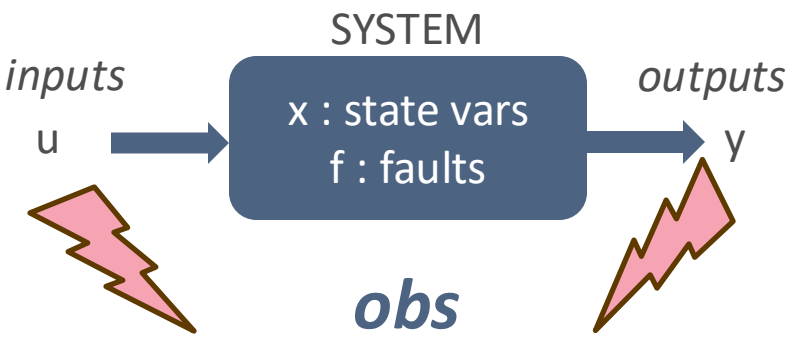


Simple static polybox

~~T, U, W~~ ⇨

	ok	Faulty M1	Faulty M2	Faulty M3	Faulty A1	Faulty A1
R1 : A*C + B*D – F = 0	0	X	X	0	X	0
R2 : E*C + B.D – G = 0	0	0	X	X	0	X
R3 : A*C – E*C – F + G = 0	0	X	0	X	X	X

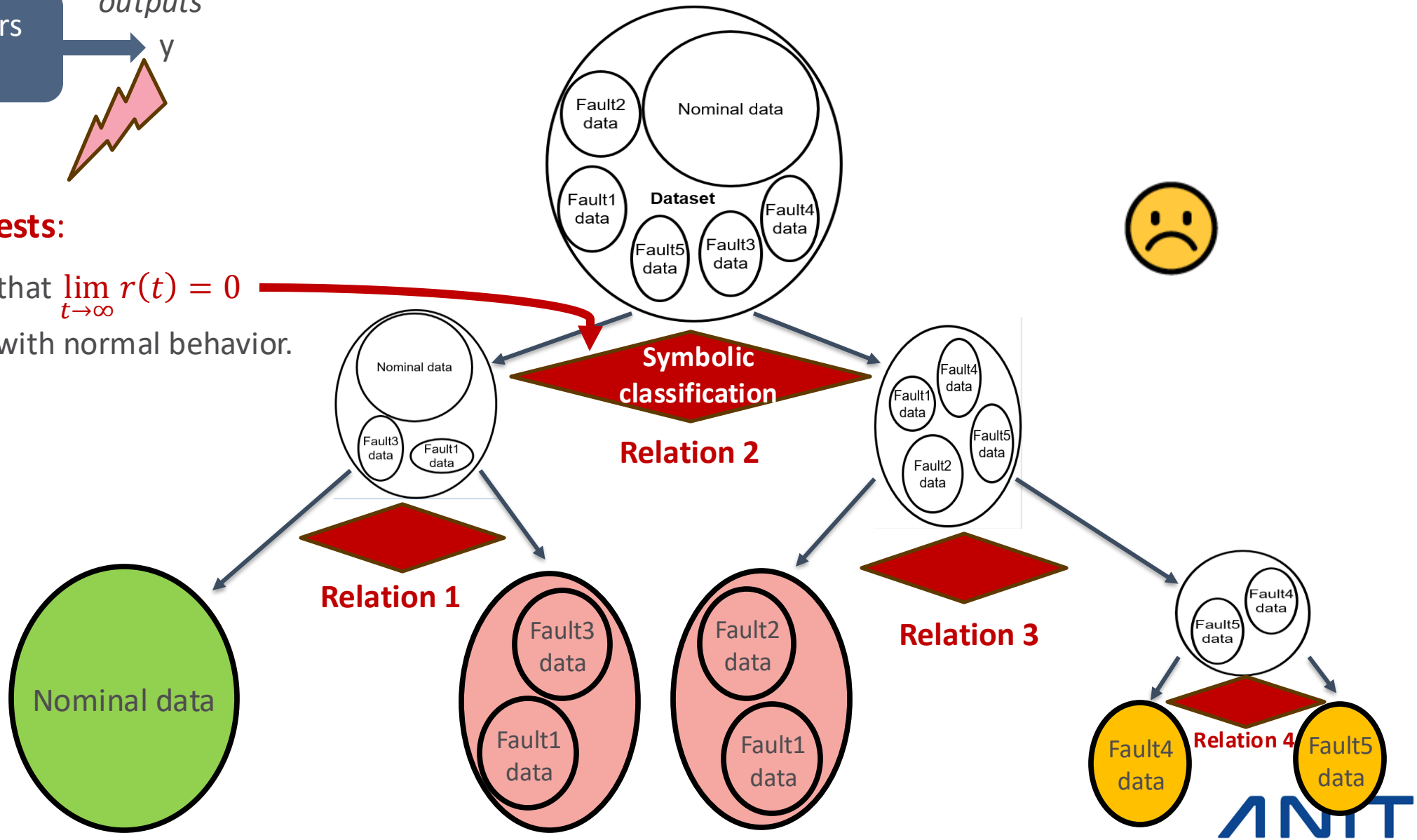
Data based diagnosis: multivariate decision trees



Diagnosis tests:

$\mathbf{R}(obs) = r(t)$ such that $\lim_{t\to\infty} r(t) = 0$

for all ***obs*** consistent with normal behavior.

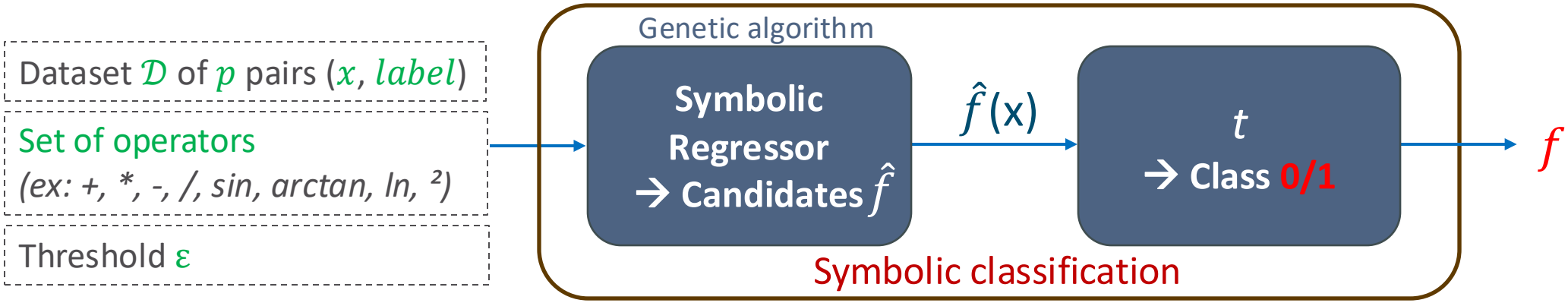


Symbolic classification

Algorithm to estimate a function f such as:

chosen by the user
unknown

$$x = (x_1, x_2, \dots, x_n) \in \mathbb{R}^n \xrightarrow{f} a \in \mathbb{R} \xrightarrow{t} label \in \{0, 1\}$$



Evaluation of the candidate c with the log-loss fitness function

$$Fitness(\hat{f}) = -\frac{1}{p} \sum_{(x,label)\in\mathcal{D}} [label * \ln\left(t(c(x))\right) + (1 - label) * \ln\left(1 - t(c(x))\right)]$$

Stopping condition

IF $Fitness(\hat{f}) < \varepsilon$ **THEN** algorithm stops and f is « found » **ELSE** $Mutate(\hat{f})$ **AND** $Repeat$

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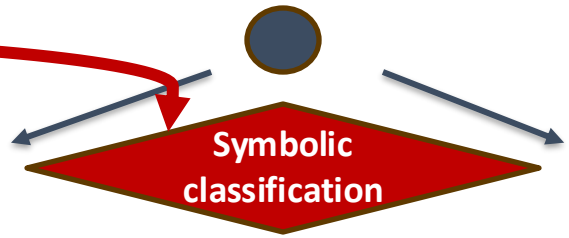
DT4X: Diagnosis Tree for eXplainability

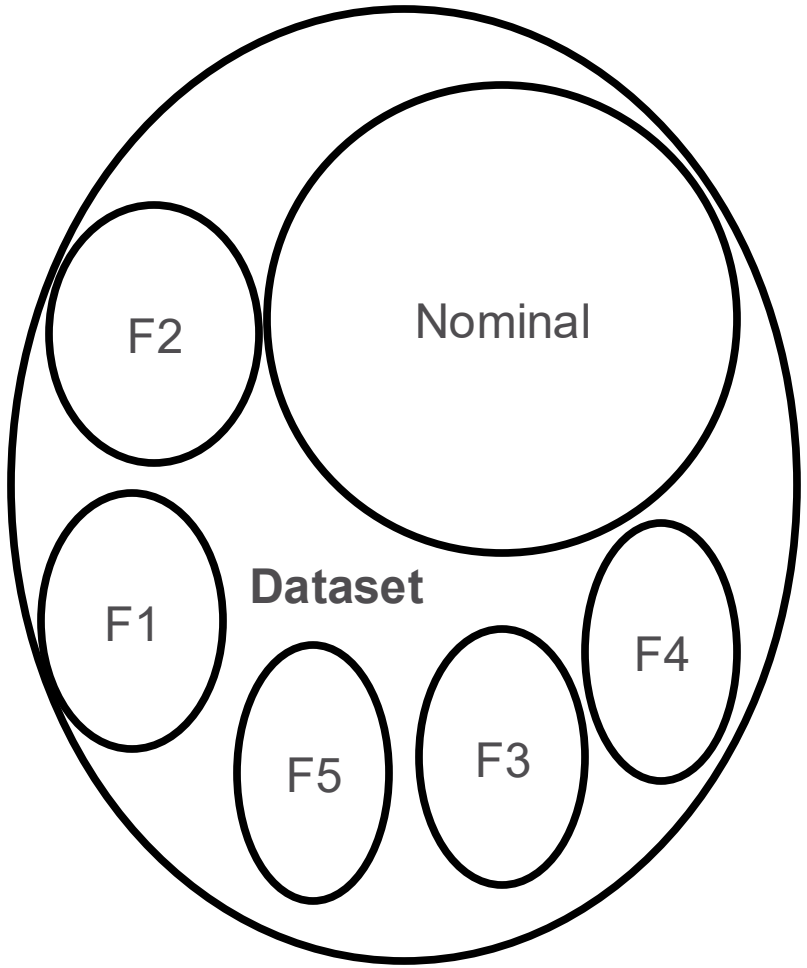
Diagnosis

Meta-knowledge



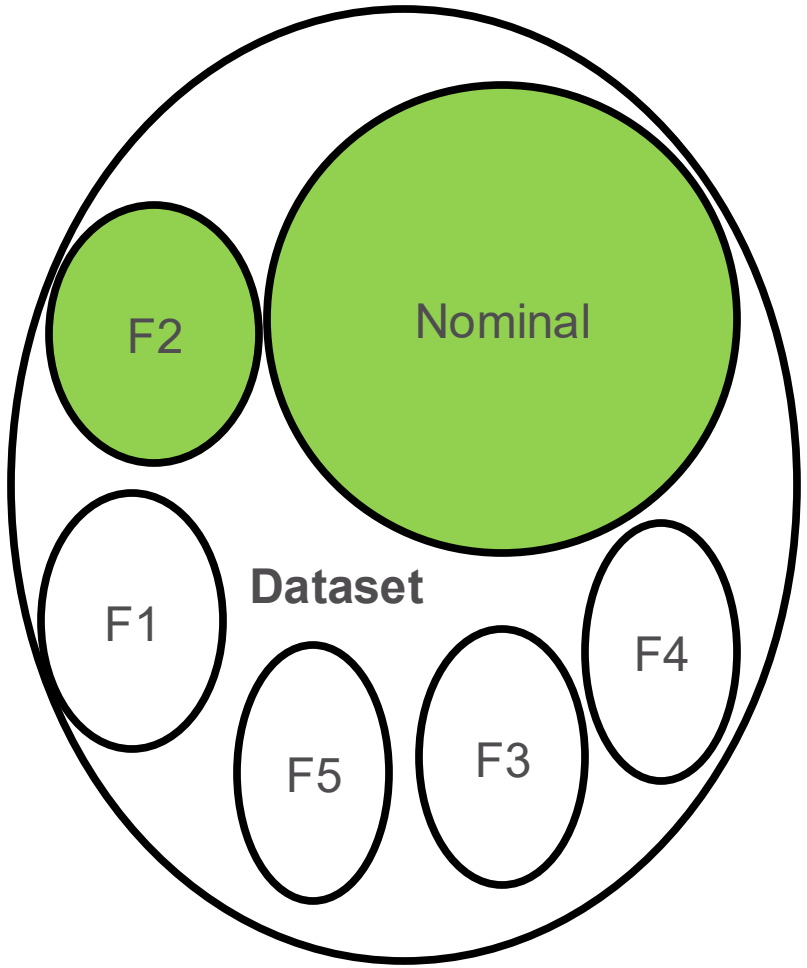
Train a symbolic classifier to find f

DT4X - Principle

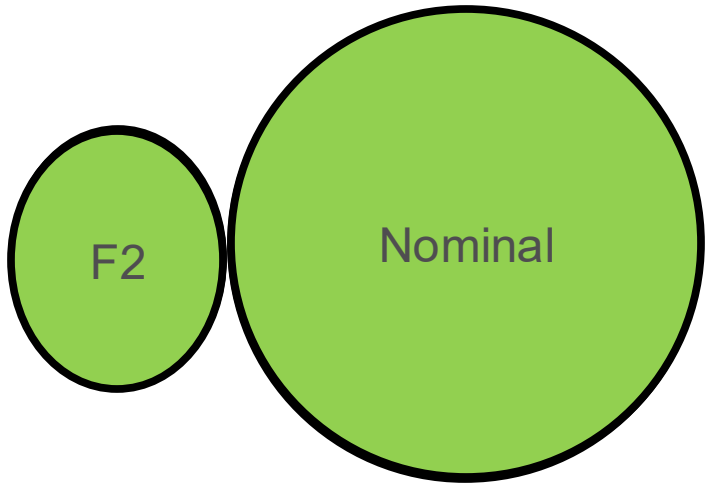


DT4X - Principle

Select 2 classes
(preferably one being the nominal class)



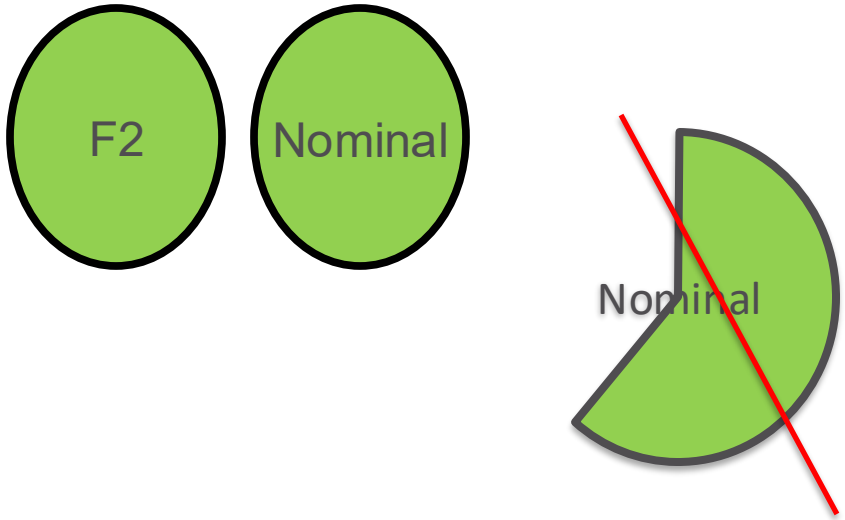
DT4X - Principle



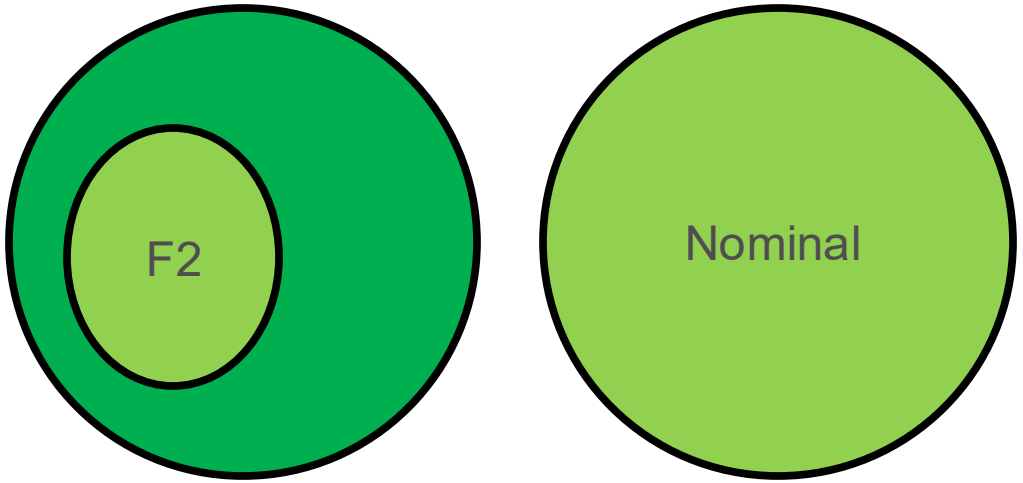
DT4X - Principle

Balancing classes

Reducing the majority class



Increasing the minority class



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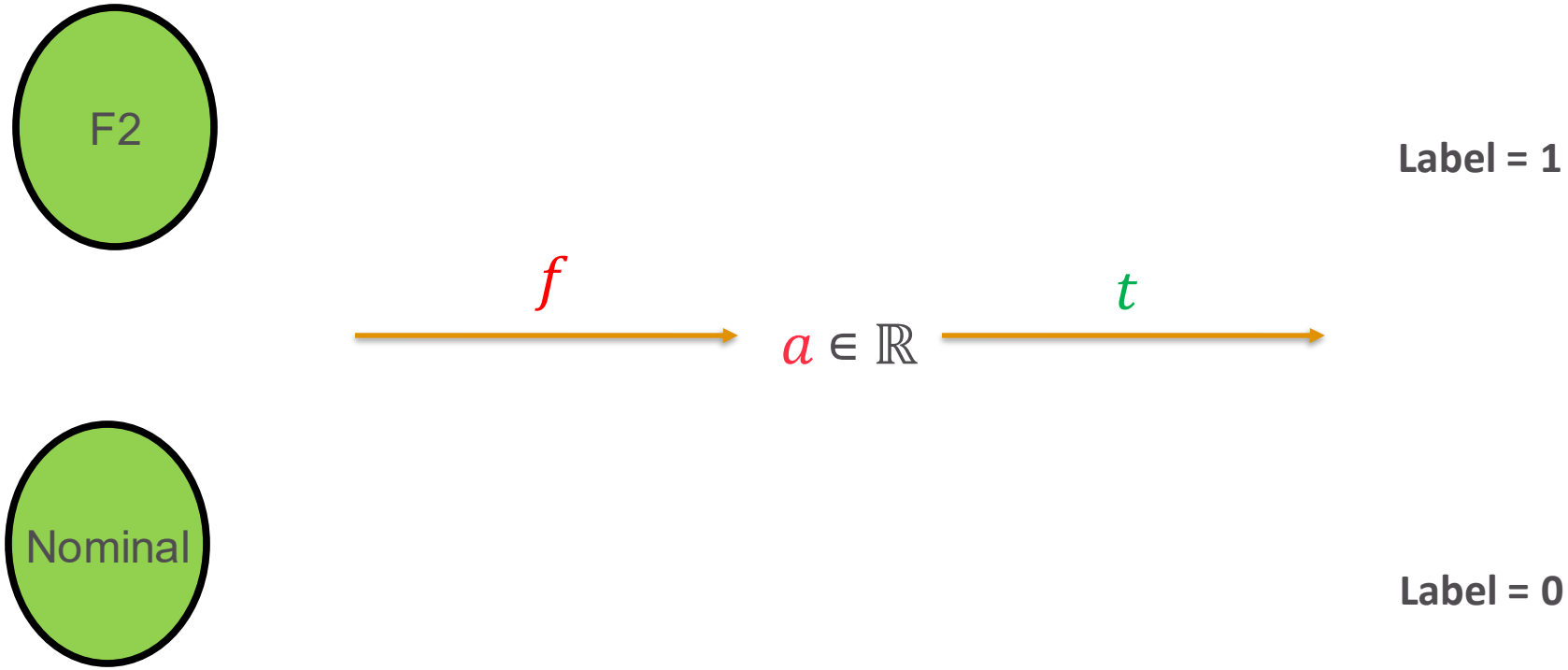
DT4X - Principle

DT4X - Principle

Use **symbolic classification** to find f



DT4X - Principle

F2

Nominal

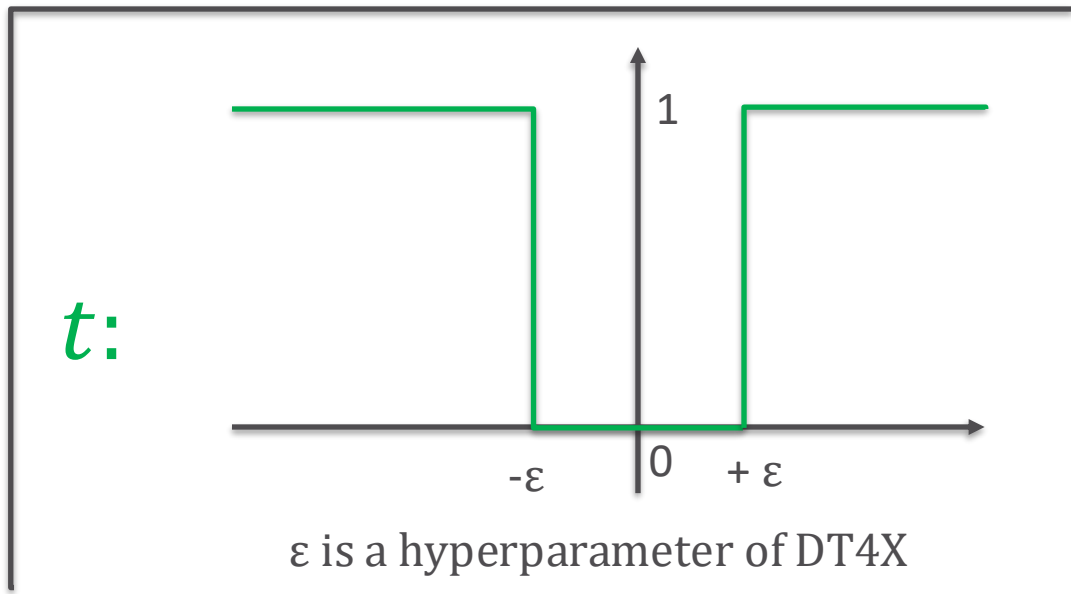
f → $a \in \mathbb{R}$ → t

Label = 1

Label = 0

$f(x) = a$ $\neq 0$ / $\simeq 0$

meta-knowledge of model-based diagnosis



ε is a hyperparameter of DT4X

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DT4X - Principle

f is found

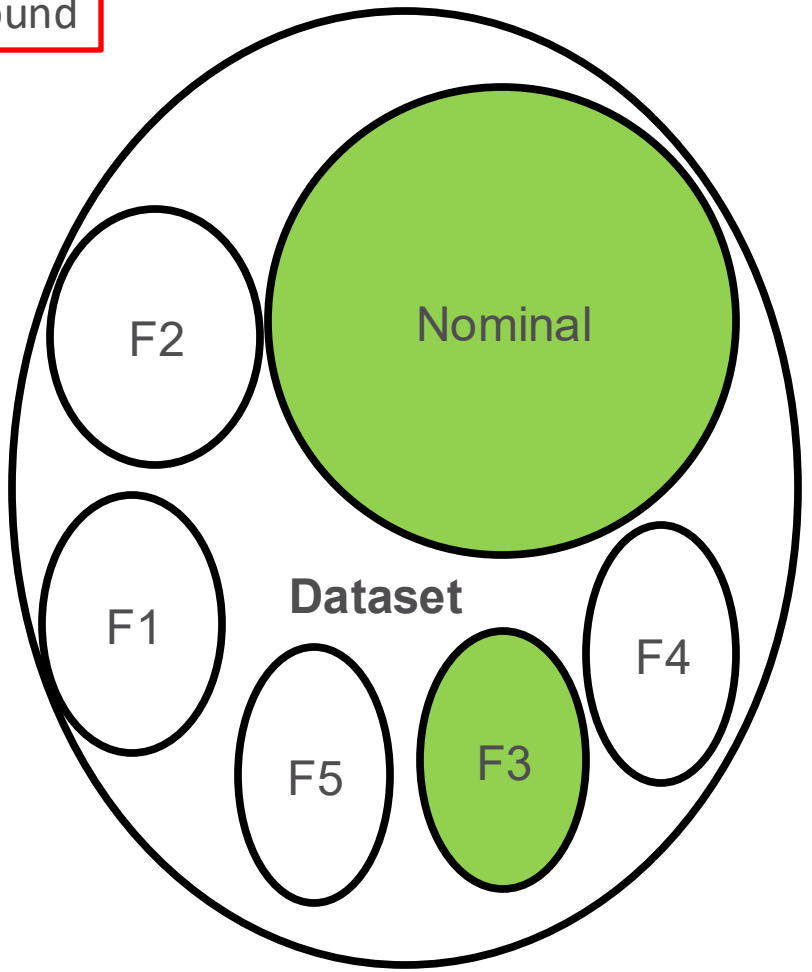
f is not found

DT4X - Principle

f is found

f is not found

Choose another pair

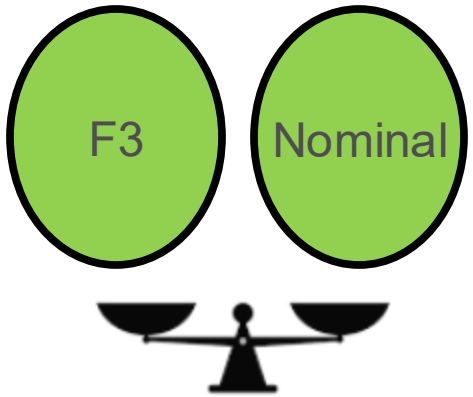


DT4X - Principle

f is found

f is not found

Repeat steps

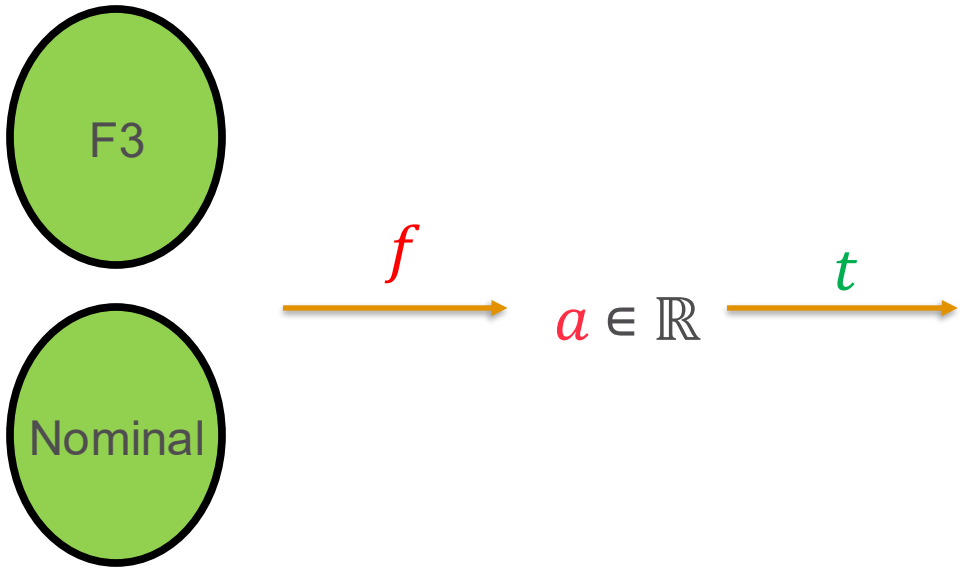


DT4X - Principle

f is found

f is not found

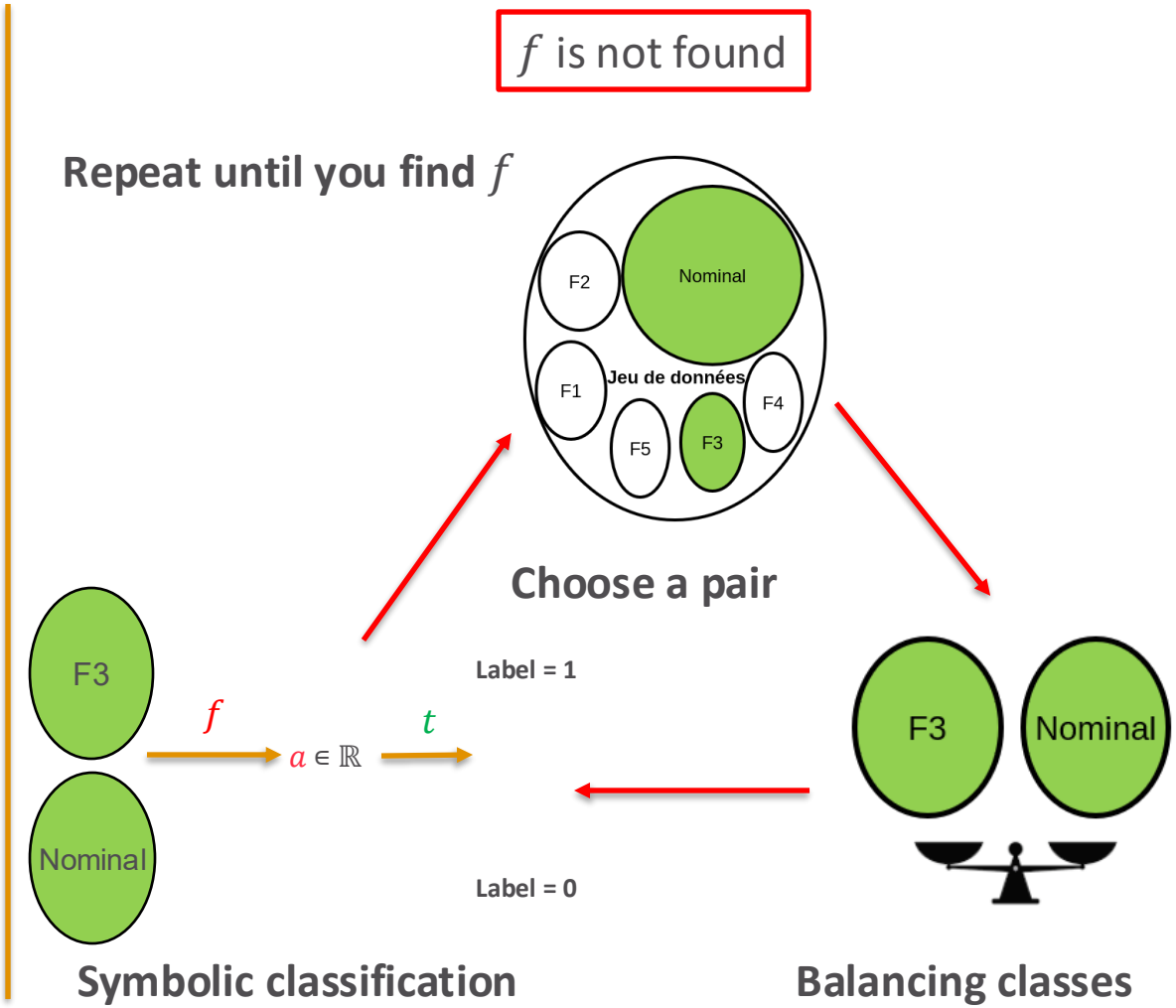
Repeat steps



DT4X - Principle

f is found

f is not found



DT4X - Principle

f is found

f is not found

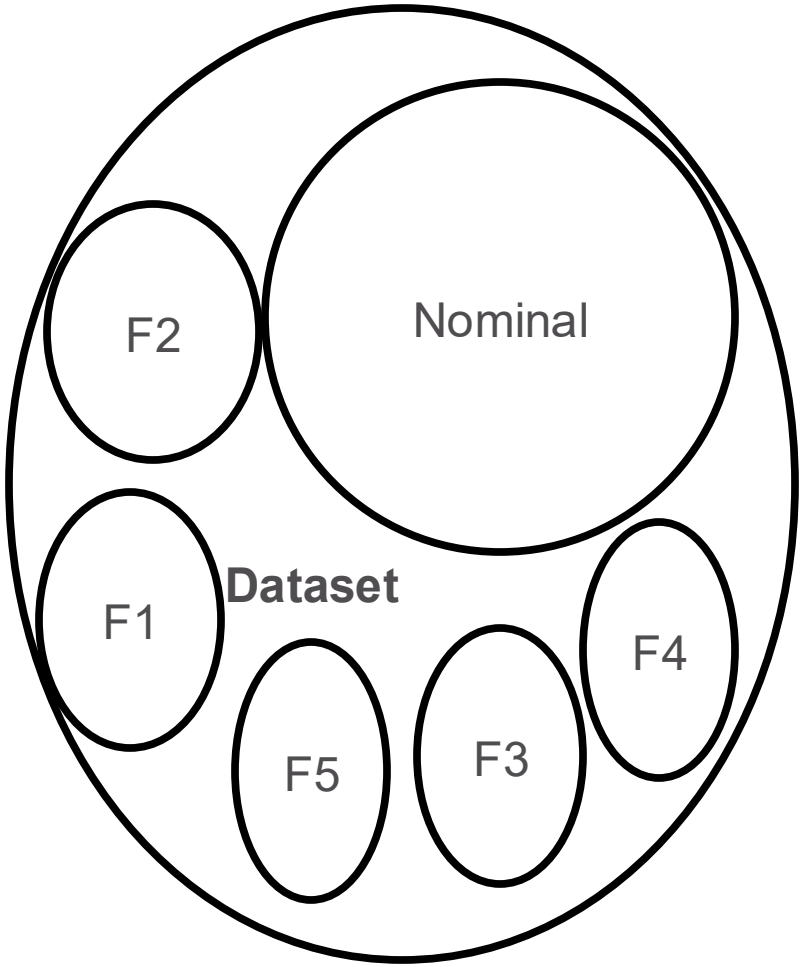
IF
all pairs have been tried on
AND
f is not found

THEN
Stop the algorithm

DT4X - Principle

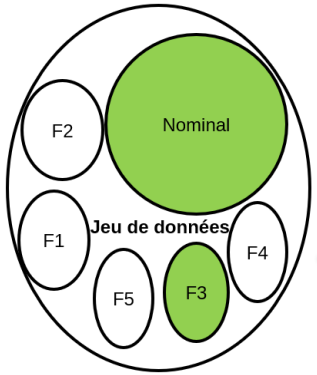
f is found

The entire dataset **is evaluated by** $t \circ f$

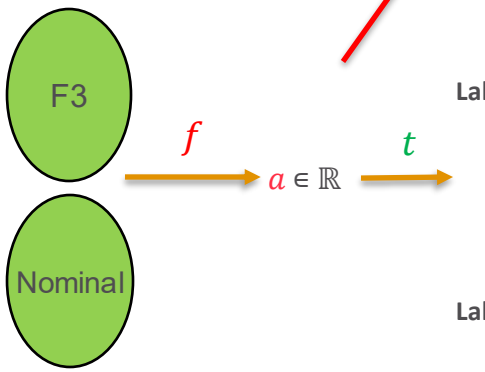


f is not found

Repeat until you find f

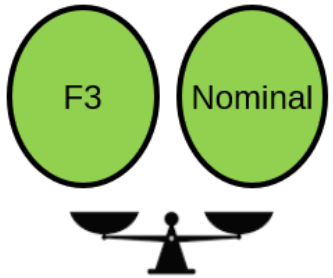


Choose a pair



Label = 1

Label = 0



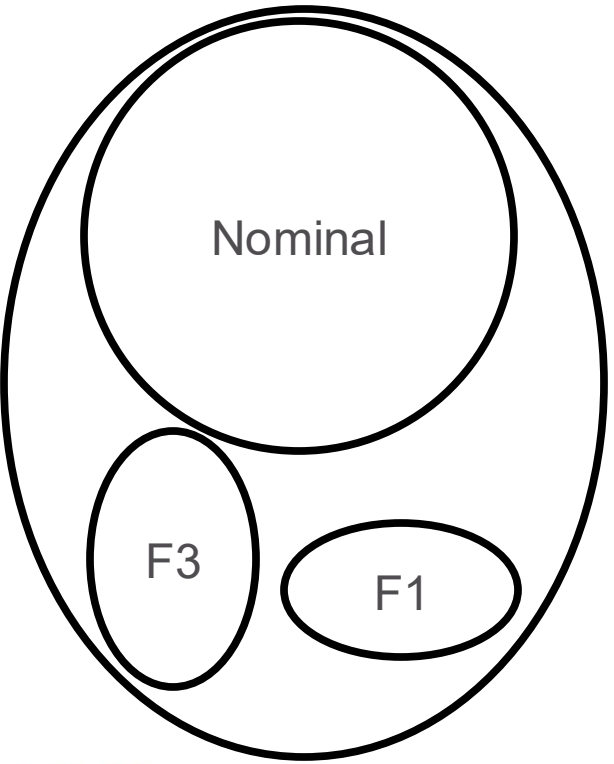
Symbolic classification

Balancing classes

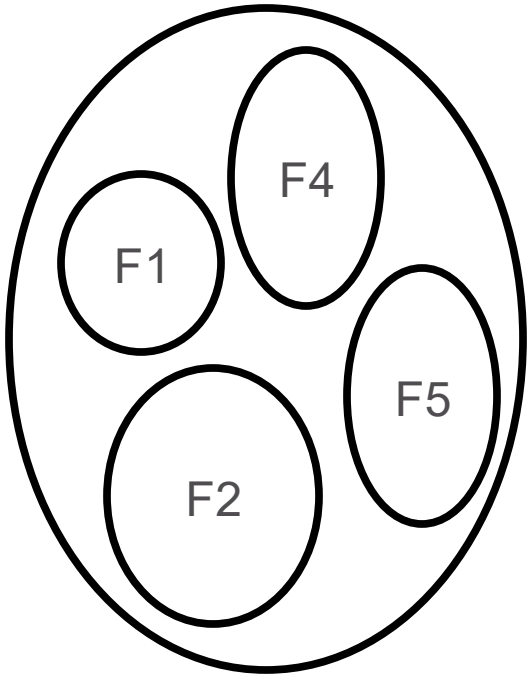
DT4X - Principle

f is found

$t \circ f = 0$

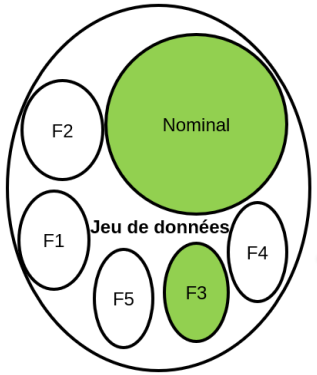


$t \circ f = 1$

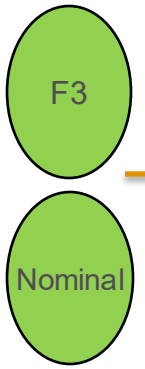


f is not found

Repeat until you find f



Choose a pair



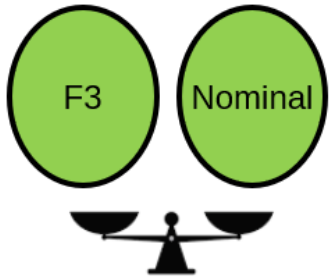
f

$a \in \mathbb{R}$

t

Label = 1

Label = 0



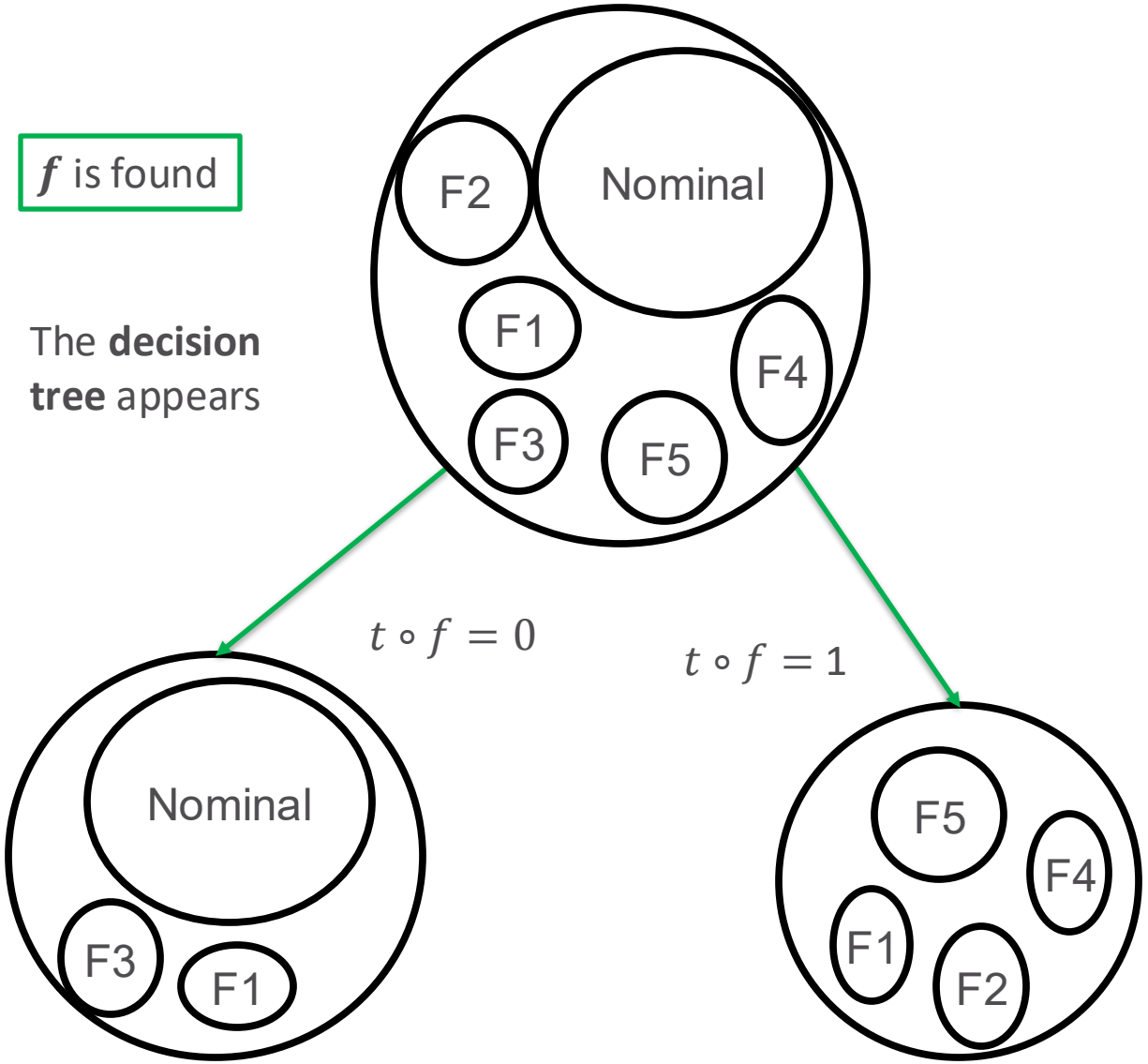
Symbolic classification

Balancing classes

DT4X - Principle

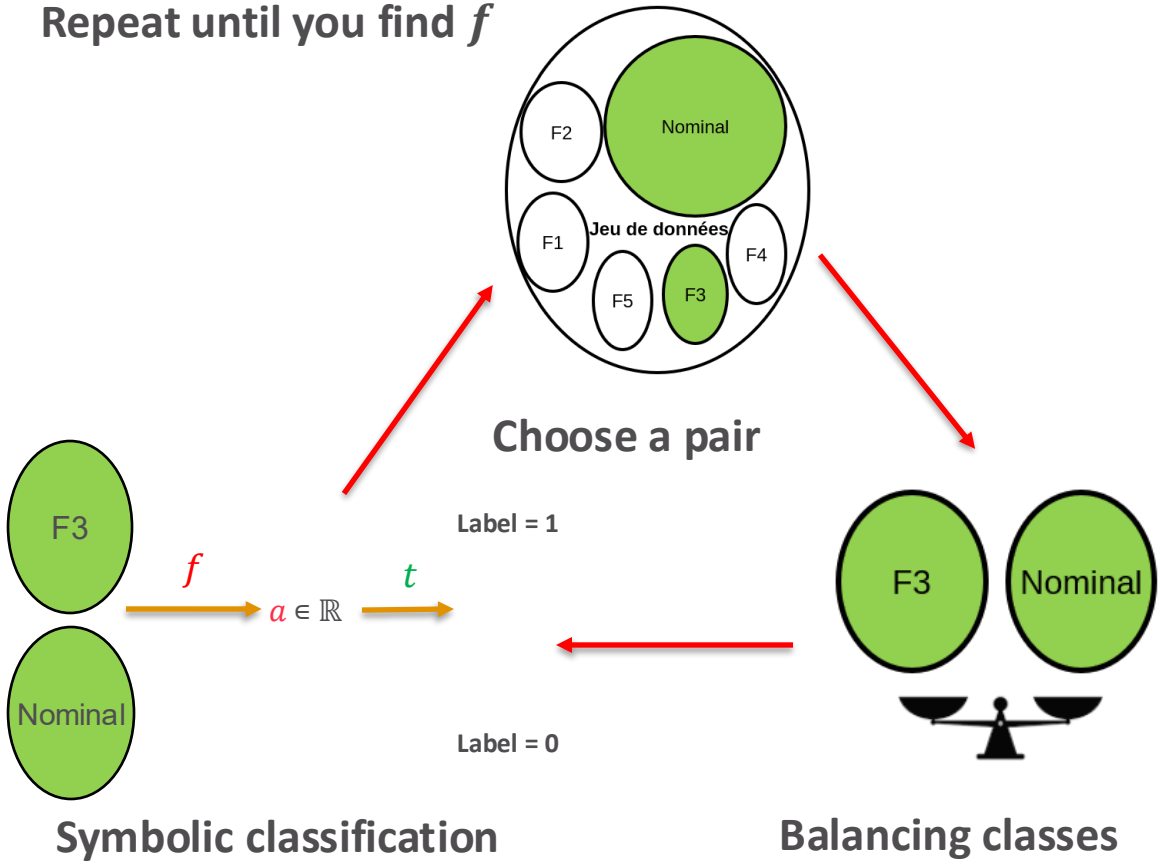
f is found

The **decision tree** appears



f is not found

Repeat until you find f



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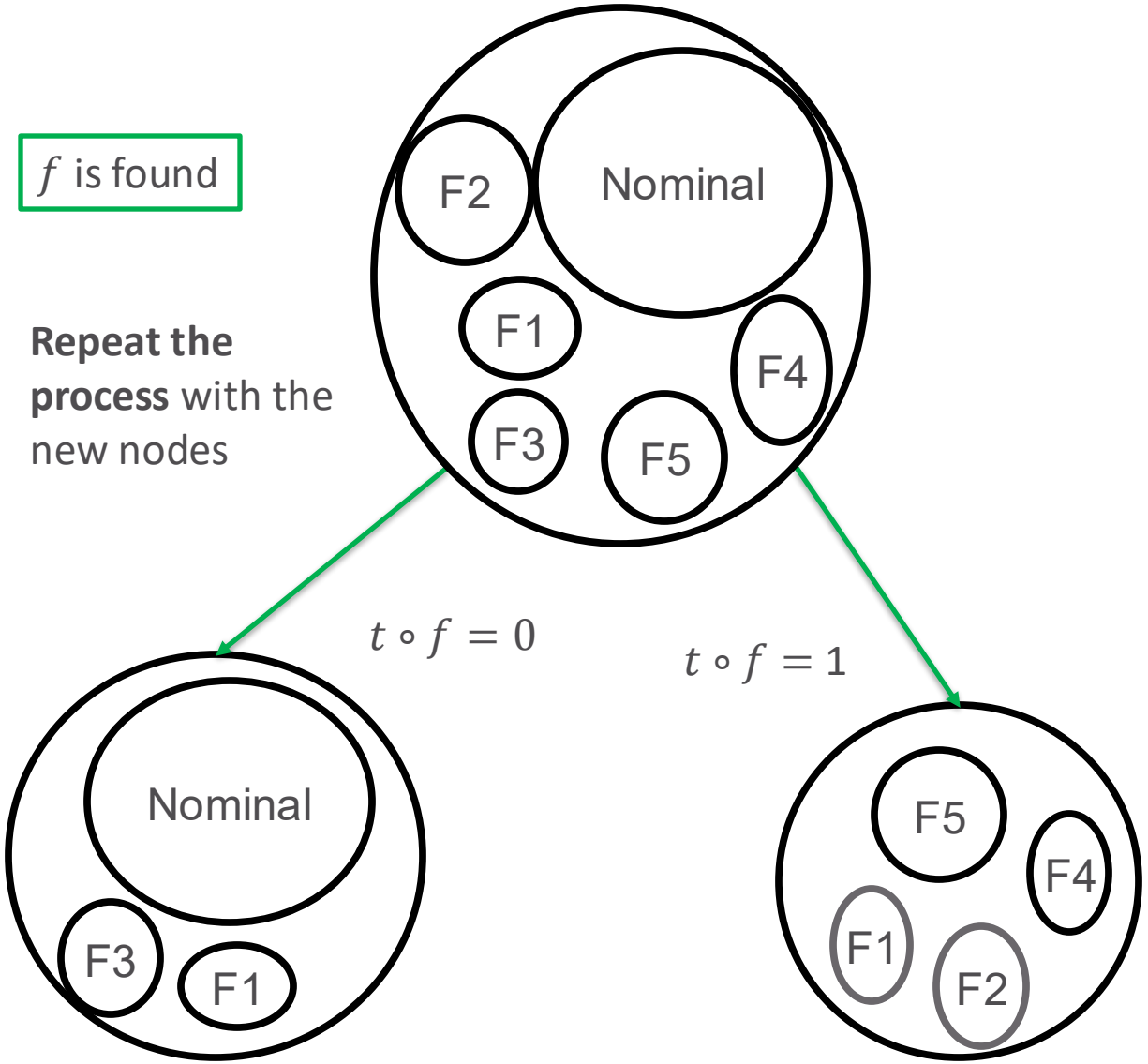
DT4X - Principle

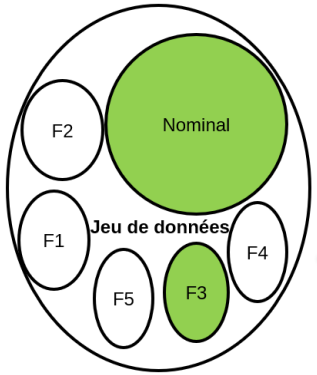
f is found

Repeat the process with the new nodes

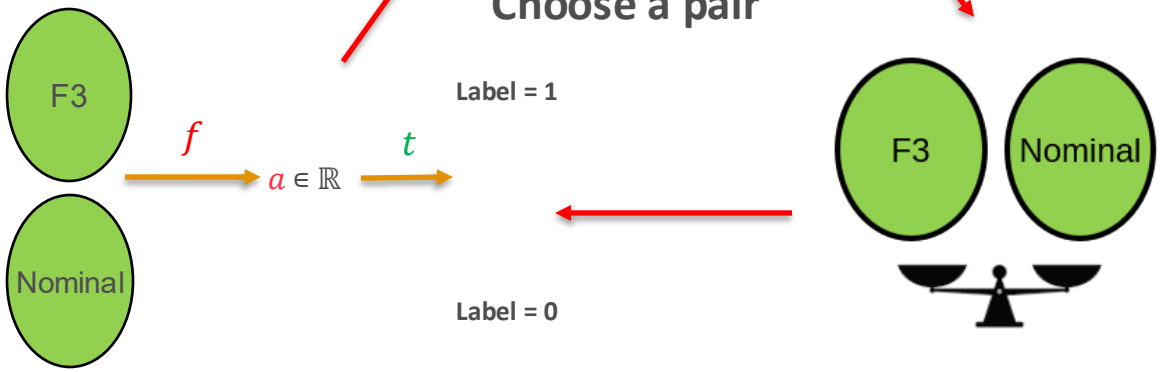


f is not found

Repeat until you find f



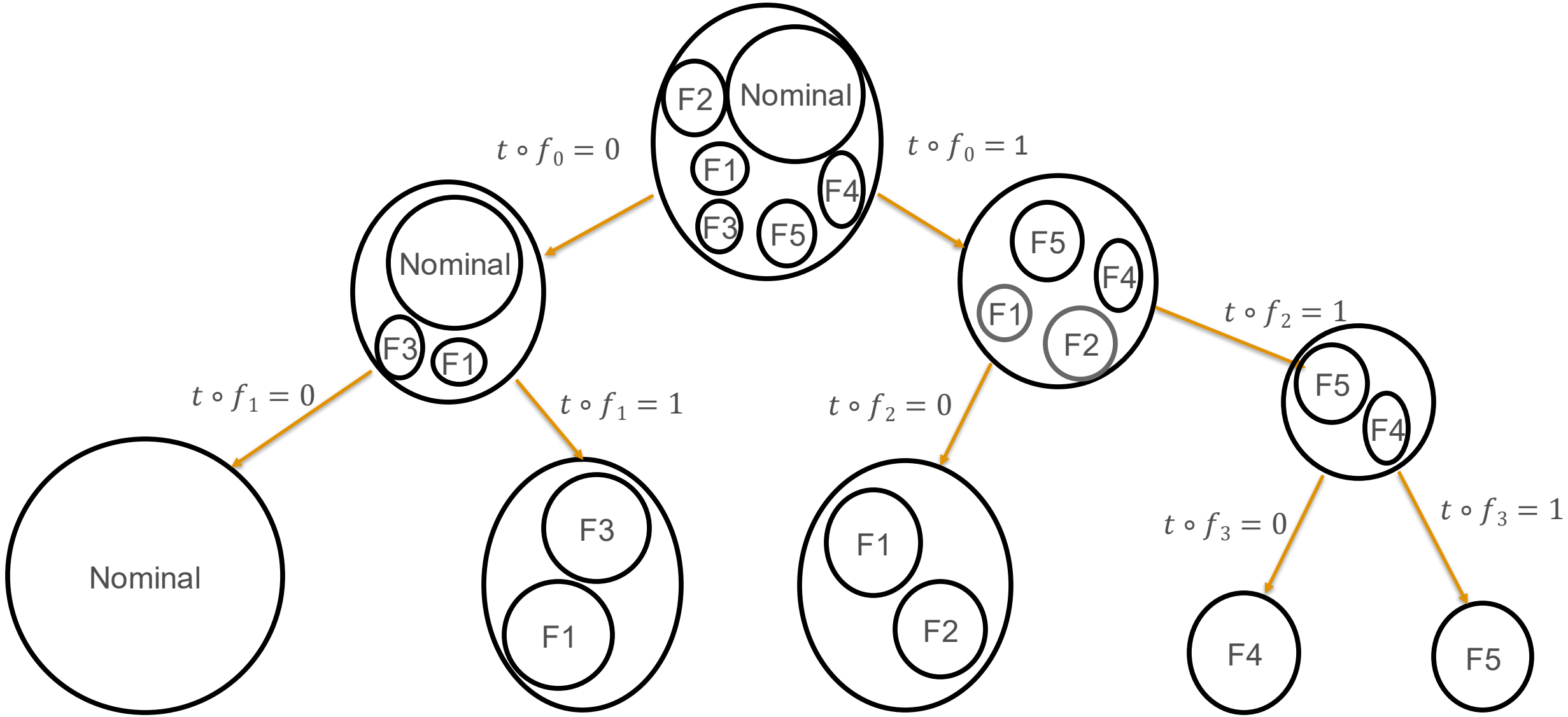
Choose a pair



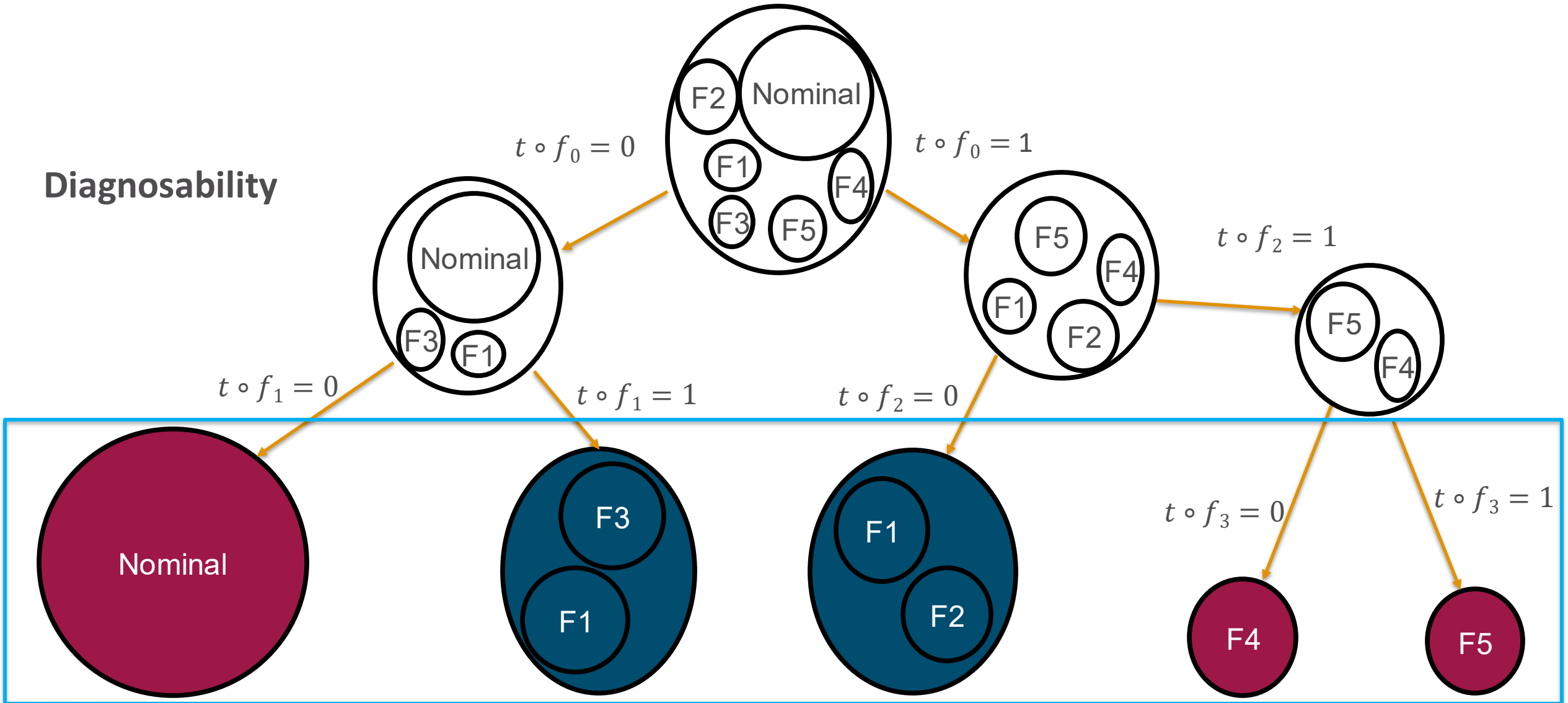
Symbolic classification

Balancing classes

DT4X - Principle



DT4X - Properties

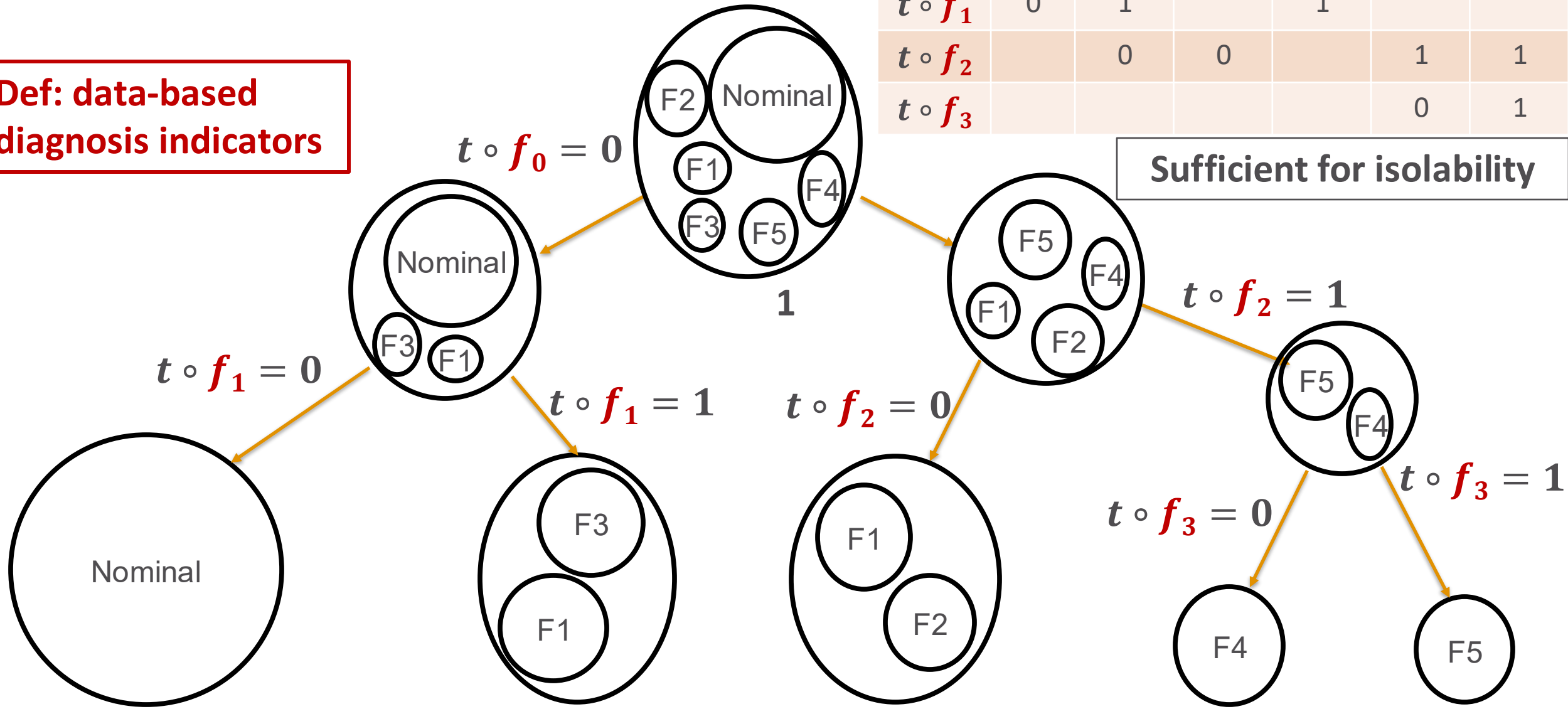


DT4X - Properties

Def: data-based diagnosis indicators

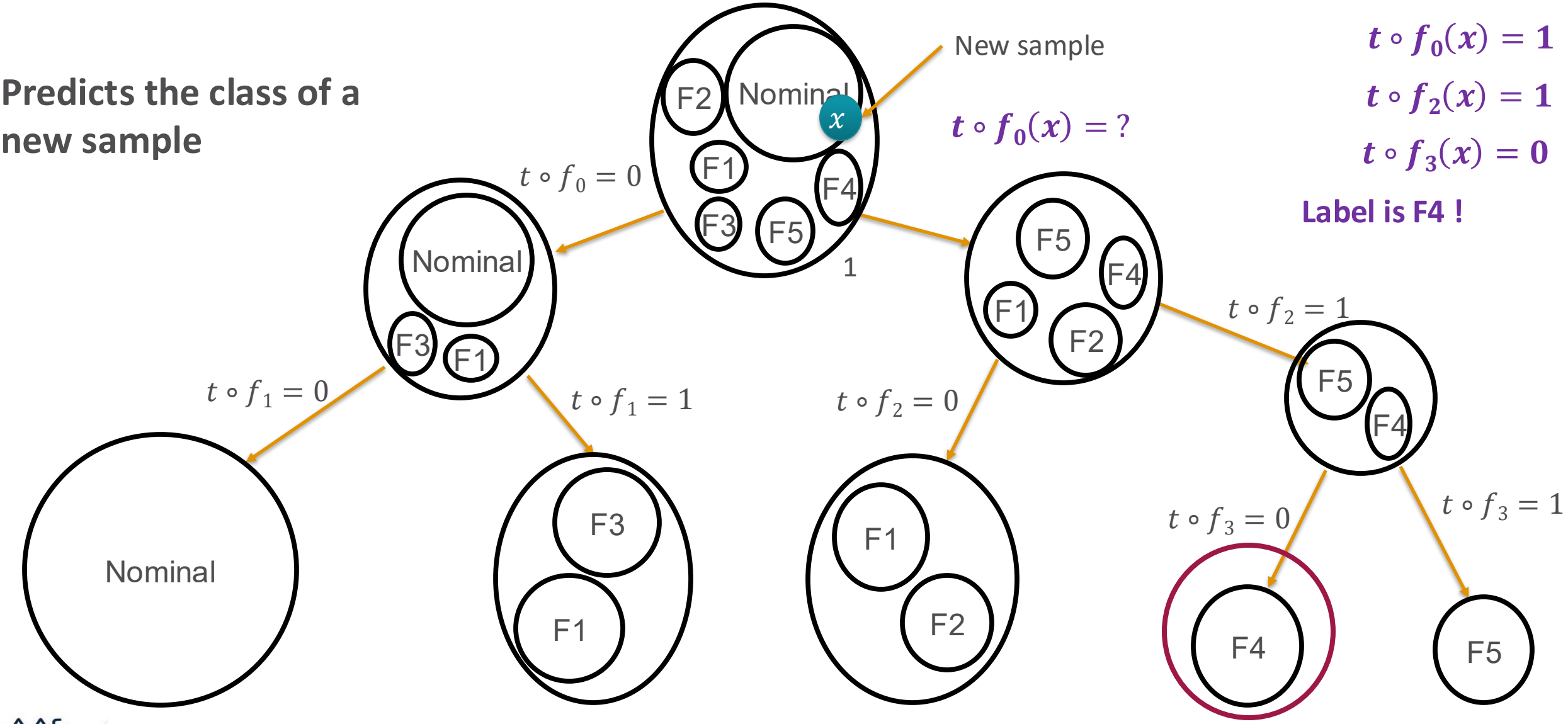
	N	F1	F2	F3	F4	F5
$t \circ f_0$	0		1	0	1	1
$t \circ f_1$	0	1		1		
$t \circ f_2$		0	0		1	1
$t \circ f_3$					0	1

Sufficient for isolability



DT4X - Properties

Predicts the class of a new sample



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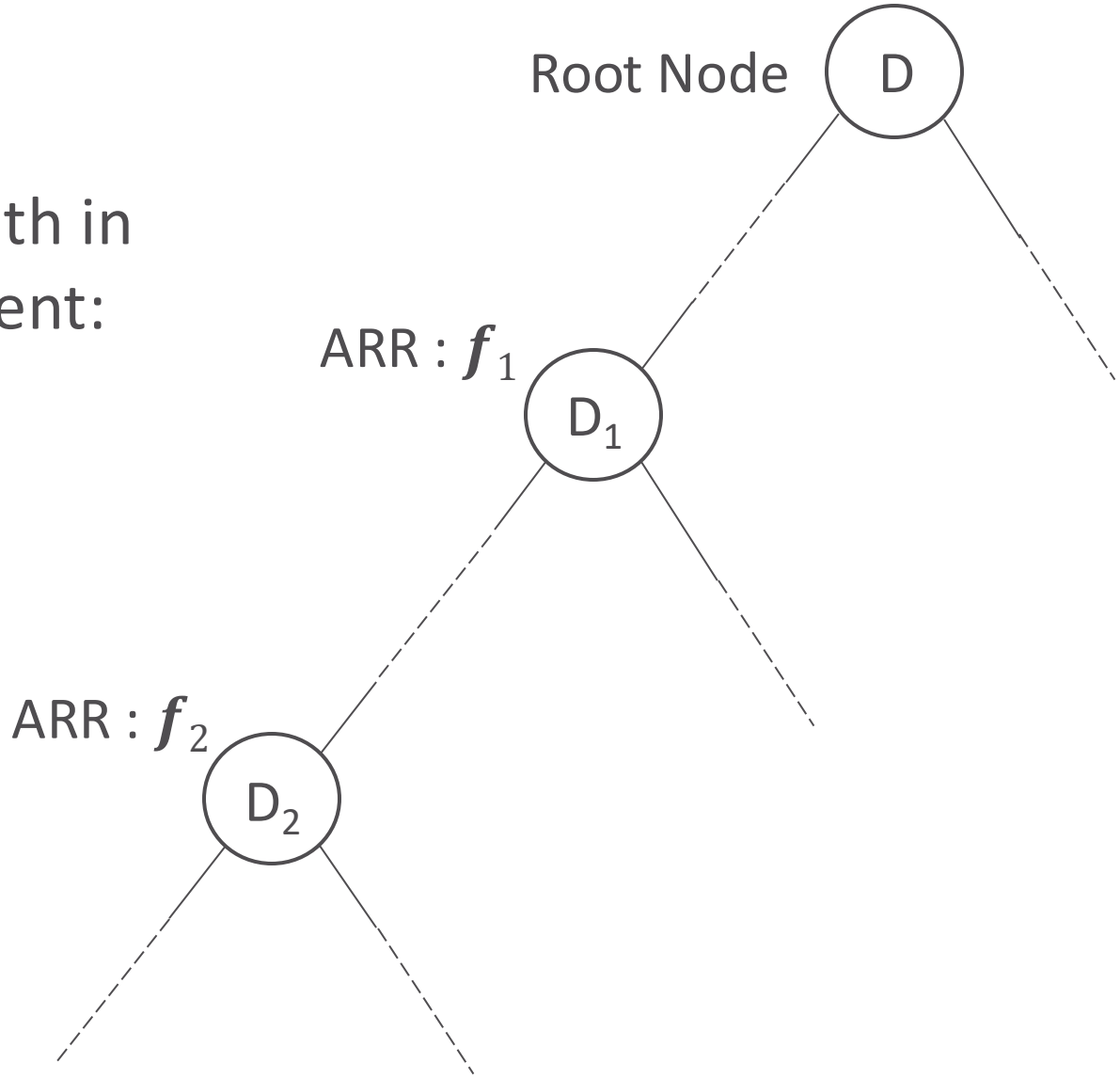
DT4X - Properties

Two data-based ARRs on the same path in the tree generated by DT4X are different:

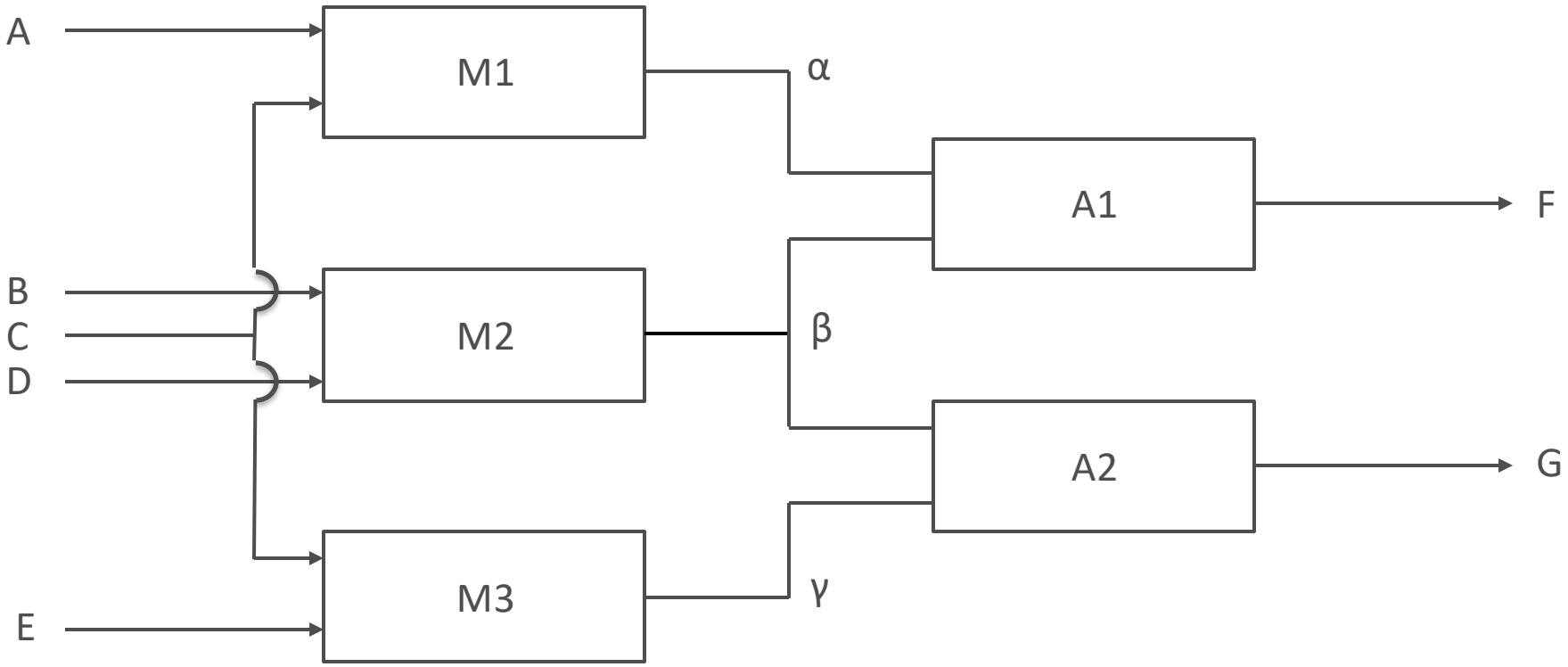
$$f_1 \neq f_2$$



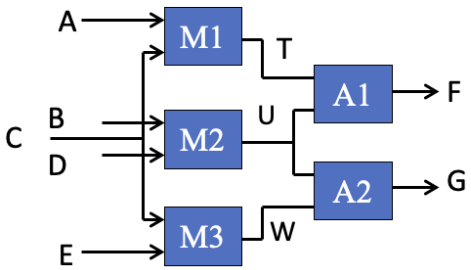
Responds to tree optimality issues, no superfluous nodes

Polybox

Type: static
Known ARRs: yes
Data: simulated

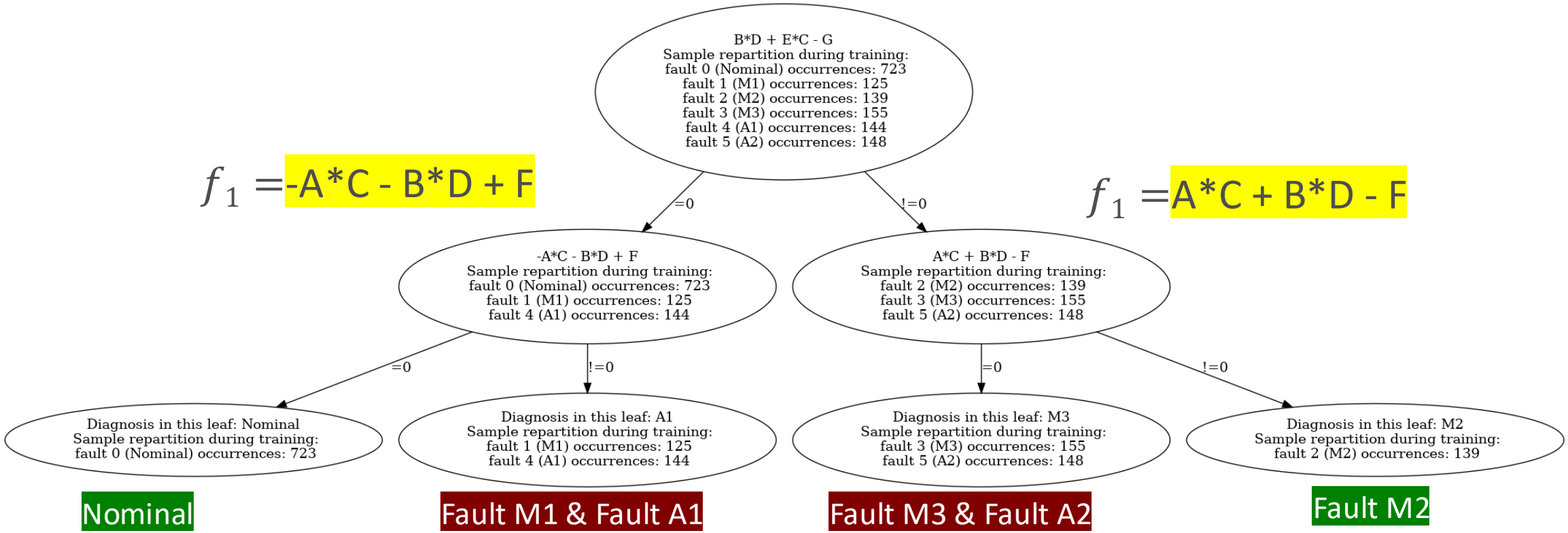


PolyBox Results – Single Faults



	ok	Faulty M1	Faulty M2	Faulty M3	Faulty A1	Faulty A1
R1 : A*C + B*D – F = 0	0	X	X	0	X	0
R2 : E*C + B.D – G = 0	0	0	X	X	0	X
R3 : A*C – E*C – F + G = 0	0	X	0	X	X	X

$$f_0 = B*D + E*C - G$$



$$f_1 = -A*C - B*D + F$$

$$f_1 = A*C + B*D - F$$

Nominal

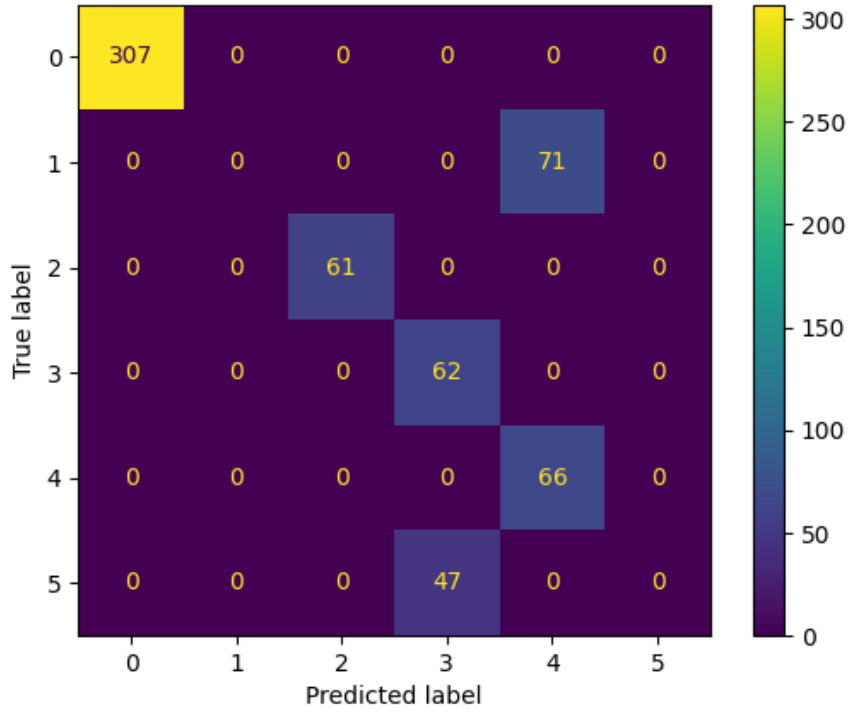
Fault M1 & Fault A1

Fault M3 & Fault A2

Fault M2

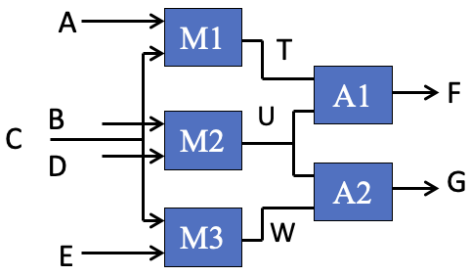
Polybox - Single faults

Algorithm	Scoring Time (s) 614 samples	Accuracy (%)	f1-score (%)
DT4X*	0.04	80.78	74.25
sklDT	0.00	46.91	46.02
sklRF	0.01	46.09	38.41
sklLR	0.00	50.00	33.33
sklNB	0.00	49.67	34.17
sklSVM	0.02	50.16	33.69
sklKNN	0.01	48.05	37.43



* DT4X also finds the analytical expression of model based RRAs

PolyBox Results – Double Faults



$f_0 = -B*D - E*C + G$

	ok	Faulty M1	Faulty M2	Faulty M3	Faulty A1	Faulty A1
R1 : A*C + B*D – F = 0	0	X	X	0	X	0
R2 : E*C + B.D – G = 0	0	0	X	X	0	X
R3 : A*C – E*C – F + G = 0	0	X	0	X	X	X

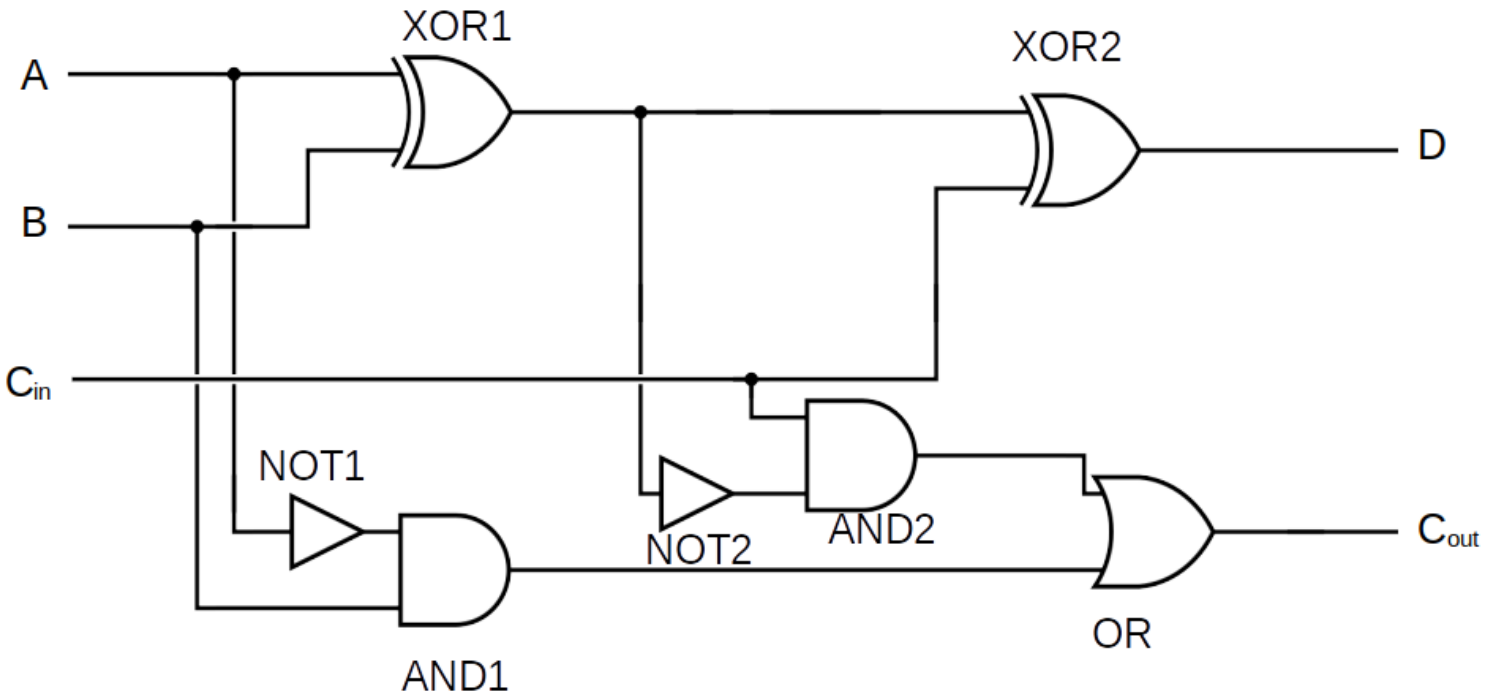
$f_1 = A*C + B*D - F$

$f_1 = -A*C - B*D + F$

$f_2 = A*C - E*C - F + G$

Binary subtractor

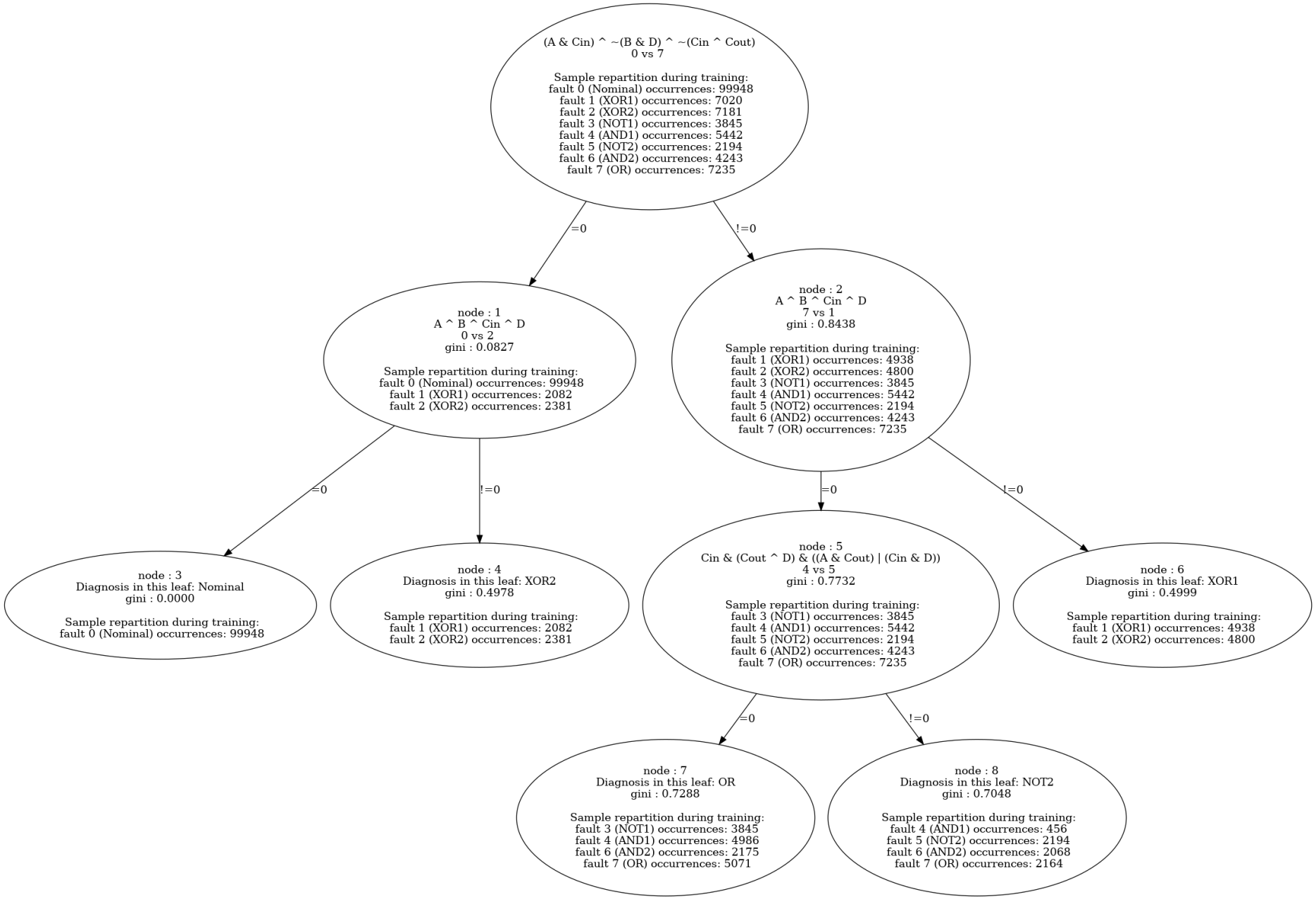
Type: static
Known ARRs: no
Data: simulated



Fault: output stuck at 0 or 1 → Faulty samples behave like nominals

Solution: data pre-processing (from 125,000 to 46384 faulty samples)

Binary subtractor



Binary subtractor

Inputs			Outputs		Diagnosis Indicators		
A	B	C_{in}	D	C_{out}	$(A\&C_{in})$ $\hat{}\neg(B\&D)$ $\hat{}\neg(C_{in}\&C_{out})$	$A\hat{}B$ $\hat{}C_{in}\hat{}D$	C_{in} & $(C_{out}\hat{}D)$ & $((A\&C_{out})\mid(C_{in}\&D))$
0	0	0	0	0	0	0	0
0	0	1	1	1	0	0	0
0	1	0	1	1	0	0	0
0	1	1	0	1	0	0	0
1	0	0	1	0	0	0	0
1	0	1	0	0	0	0	0
1	1	0	0	0	0	0	0
1	1	1	1	1	0	0	0

: XOR
& : AND
| : OR

Binary subtractor

Inputs			Outputs				Expression	
			f_{XOR1}		f_{XOR2}		f_{XOR1}	f_{XOR2}
A	B	C_{in}	D	C_{out}	D	C_{out}	$A \hat{} B \hat{} C_{in} \hat{} D$	
0	0	0	1	0	1	0	1	1
0	0	1	0	0	0	1	1	1
0	1	0	0	1	0	1	1	1
0	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	1	1
1	0	1	1	1	1	0	1	1
1	1	0	1	0	1	0	1	1
1	1	1	0	0	0	1	1	1

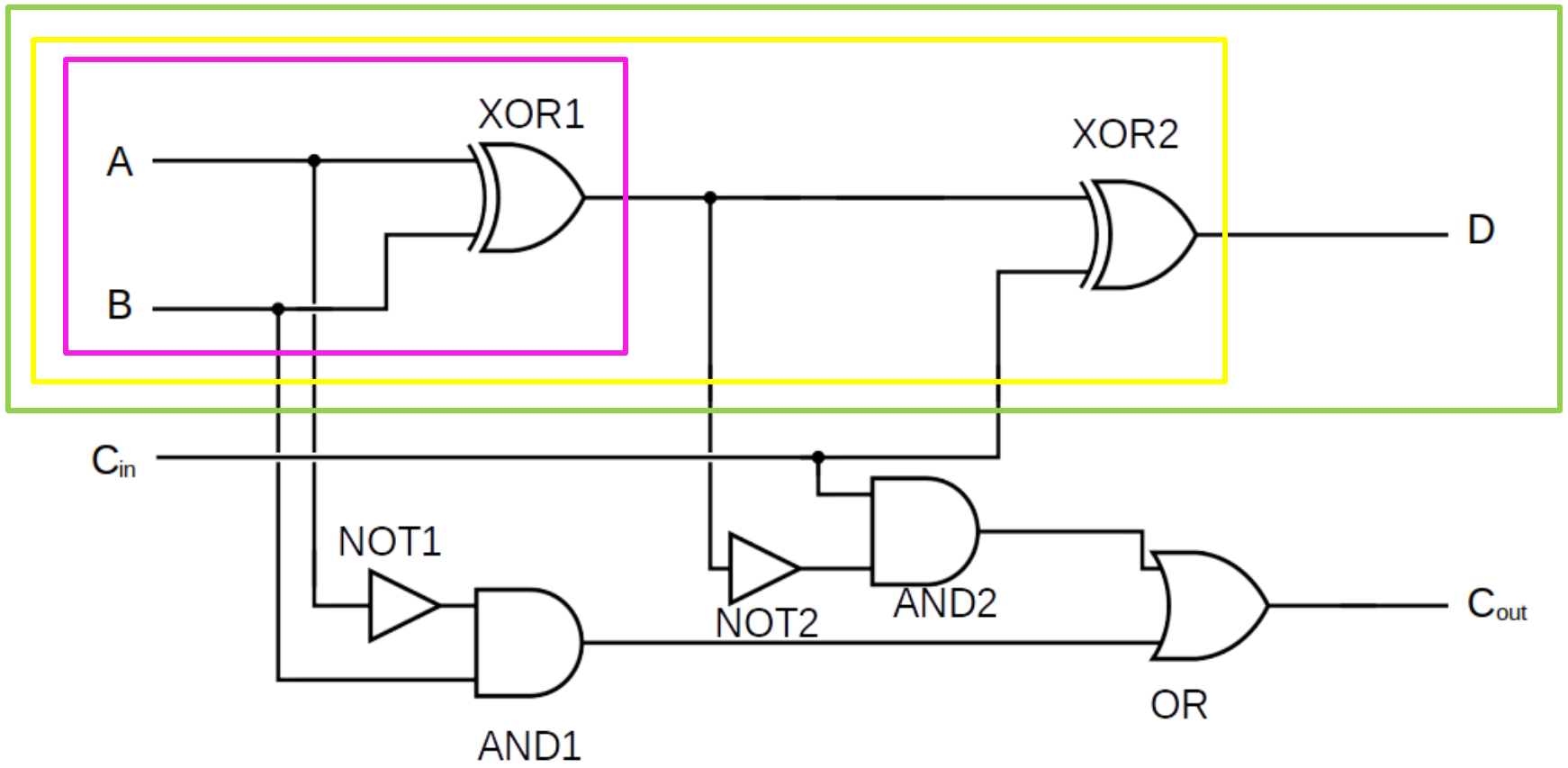
Def : Logical ARR := Data-based ARR whose operators are logic gates

: XOR
& : AND
| : OR

Binary subtractor

$A \hat{} B \hat{} Cin \hat{} D$

$A \hat{} B \hat{} Cin \hat{} D$ $A \hat{} B \hat{} Cin \hat{} D$ $A \hat{} B \hat{} Cin \hat{} D$

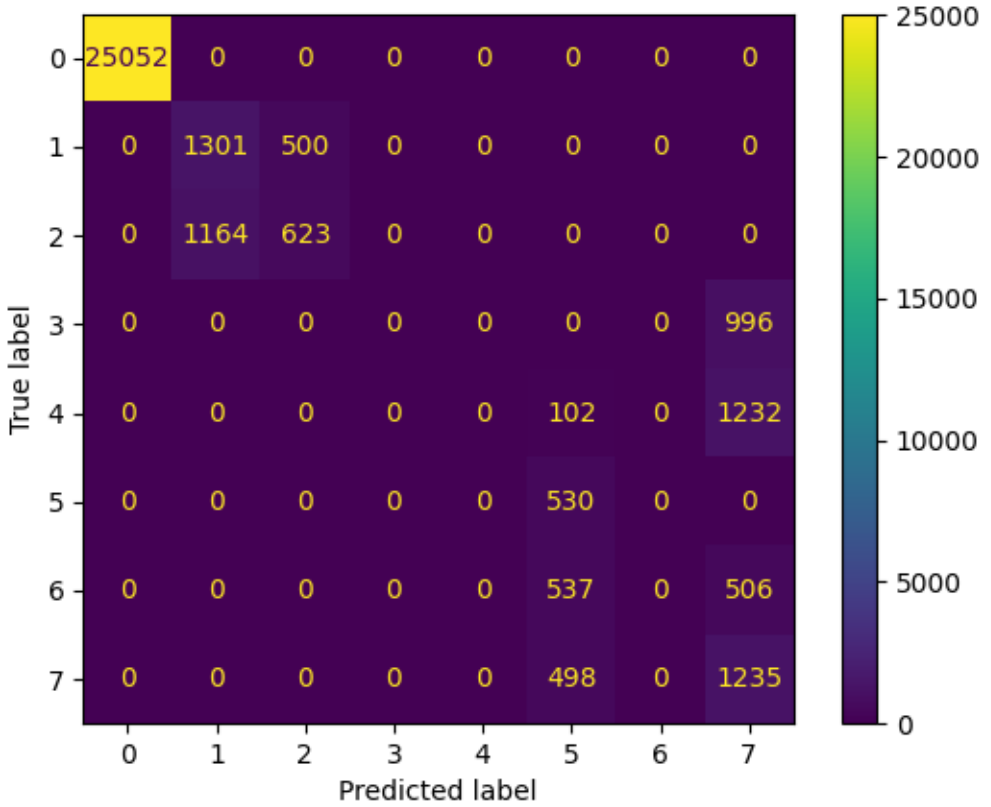


Input-output relationships like model-based ARRs

: XOR
& : AND
| : OR

Binary subtractor

Algorithm	Scoring Time (s) 34276 samples	Accuracy (%)	f1-score (%)
DT4X *	2.48	84.37	82.09
sklDT	0.00	85.07	84.48
sklRF	0.17	84.95	83.72
sklLR	0.00	73.09	61.73
sklNB	0.02	16.80	20.56
sklSVM	28.57	84.95	83.72
sklKNN	4.34	85.18	84.30



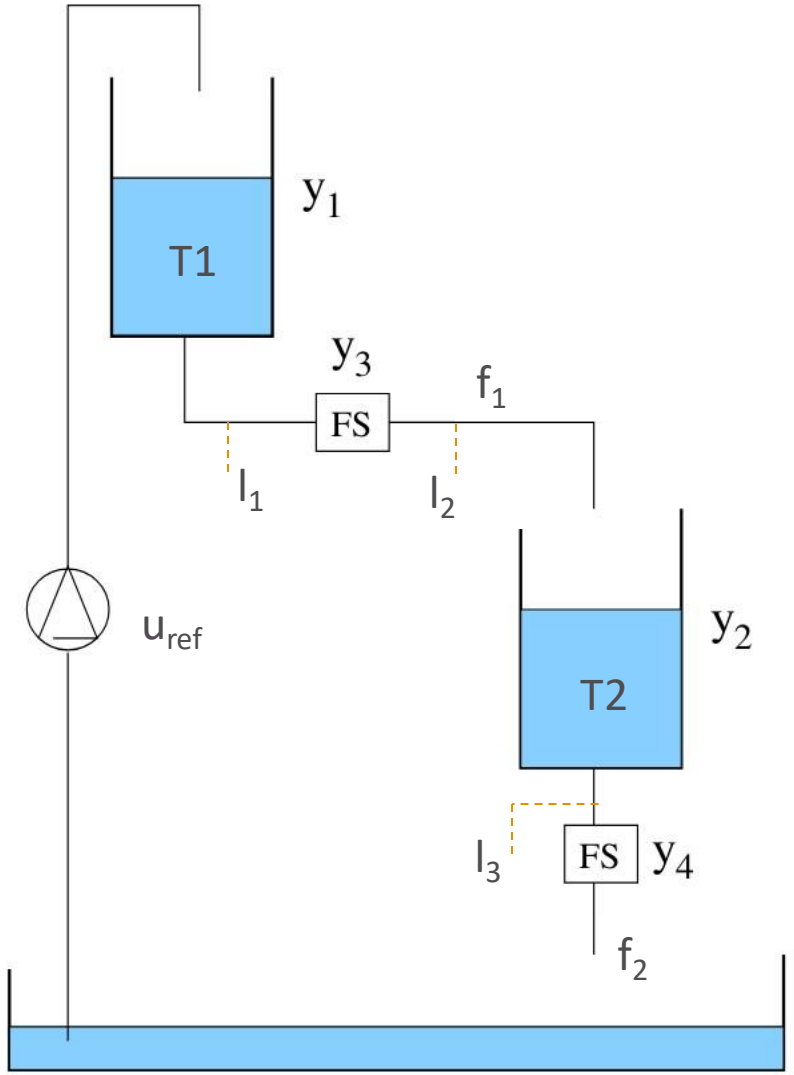
* DT4X also finds the analytical expression of model based RRAs

Dynamic systems

$$\text{Static: } x = (x_1, x_2, \ldots, x_n) \in \mathbb{R}^n$$

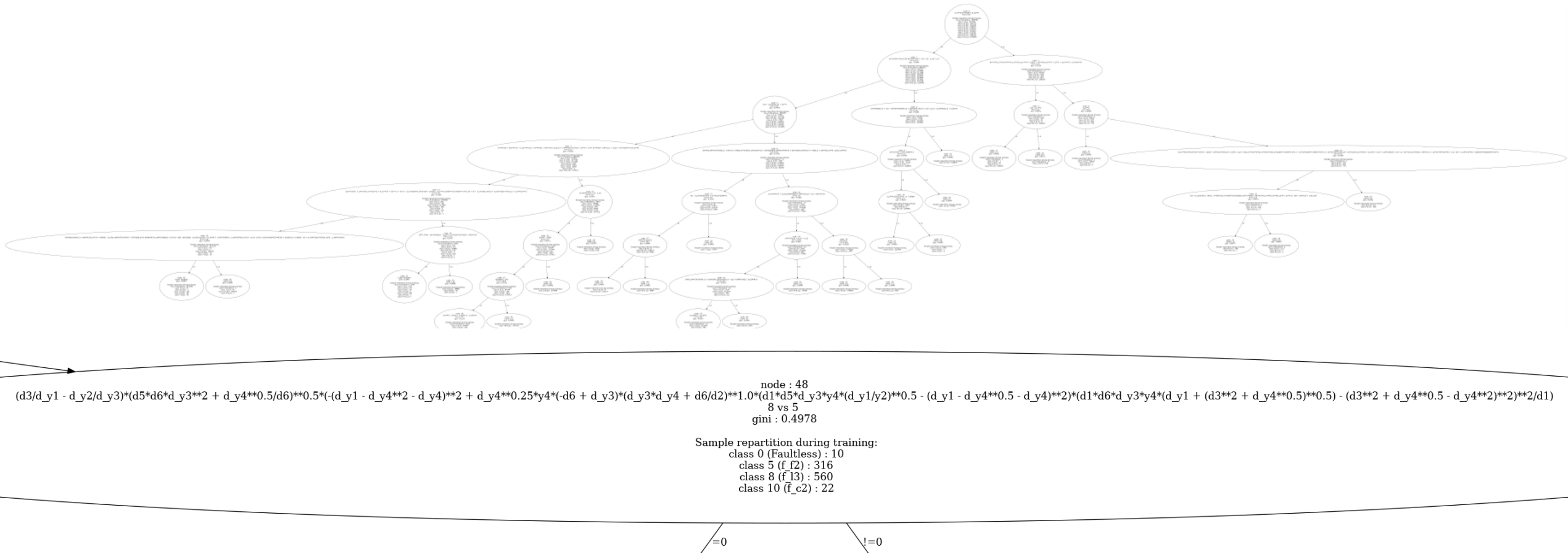
$$\text{Dynamics: } x = (x_1, \ldots, xn, \dot{x}_1, \ldots, \dot{x}_n, \ldots, {x_1}^{(d)}, \ldots, {x_n}^{(d)}) \in \mathbb{R}^{(d+1)n}$$

Water tanks



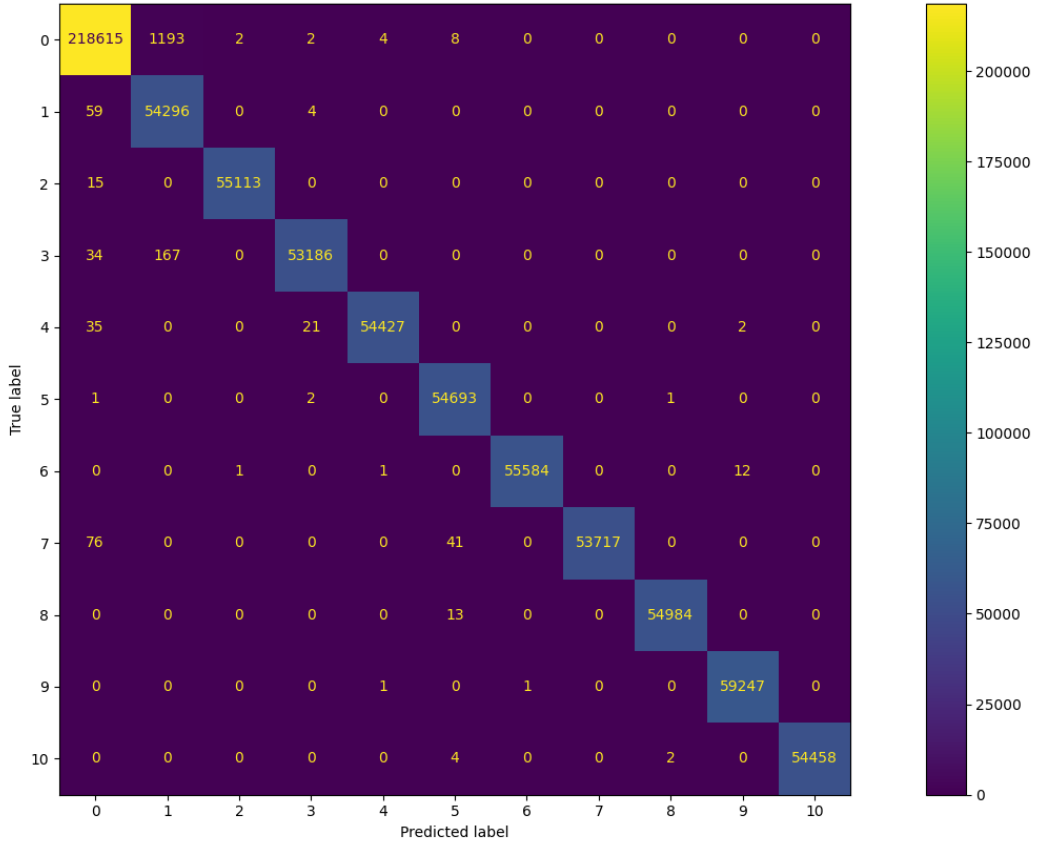
Type: dynamic
Known RRAs: yes
Data: simulated

Water tanks


node : 48
(d3/d_y1 - d_y2/d_y3)*(d5*d6*d_y3**2 + d_y4**0.5/d6)**0.5*(-(d_y1 - d_y4**2 - d_y4)**2 + d_y4**0.25*y4*(-d6 + d_y3)*(d_y3*d_y4 + d6/d2)**1.0*(d1*d5*d_y3*y4*(d_y1/y2)**0.5 - (d_y1 - d_y4**0.5 - d_y4)**2)*(d1*d6*d_y3*y4*(d_y1 + (d3**2 + d_y4**0.5)**0.5) - (d3**2 + d_y4**0.5 - d_y4**2)**2)**2/d1)
8 vs 5
gini : 0.4978
Sample repartition during training:
class 0 (Faultless) : 10
class 5 (f_f2) : 316
class 8 (f_l3) : 560
class 10 (f_c2) : 22
=0
!=0

Water tanks

Algorithm	Scoring Time (s) 770022 samples	Accuracy (%)	f1-score (%)
DT4X	373.74	99.78	99.78
sklDT	0.10	99.996	99.996
sklRF	7.30	99.997	99.997
sklLR	0.14	77.52	75.75
sklNB	0.49	77.51	78.37
sklSVM	-	-	-
sklKNN	15.10	99.998	99.998



Please note:

- DT4X does not find model-based ARR (syntactically)
- Isolation of classes structurally non-isolable
- Significantly slower predictions
- Performance close to the best algorithms

Conclusions

- **DT4X** is not only a data-based diagnosis system but it discovers the expressions of diagnosis indicators that provide explainability
- **Message**: do not forget the interpretable concepts and results of model-based methods !

Ideas for future work

- **Boost symbolic classification** with information extracted from the physical model of the system to reduce computation time and improve reliability (mostly for dynamic systems)
- Compare the genetic algorithm with **reinforcement learning**
- Analyse fault non-diagnosability in relation to **symbolic classification convergence** (not good f)

L. Goupil, L. Travé-Massuyès, E. Chanthery, T. Kohler, and S. Delautier. Tree based diagnosis enhanced with meta knowledge applied to dynamic systems. *Best Theory Paul M. Frank paper Award*, IFAC Safeprocess , June 2024, Ferrara, Italy. *IFAC-PapersOnLine*, 58(4):1–6, 2024.

Tree base diagnosis enhanced with meta knowledge

Diagnosis indicator discovery as a by product

Louis Goupil, Elodie Chanthery, ***Louise Travé-Massuyès,***
Sébastien Delautier (ATOS)

3ème Congrès de la SAGIP
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