Detection of Gas Turbines Malfunctions from Emission Concentration Plots

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Detection of Gas Turbines Malfunctions from Emission Concentration Plots

- The problem of engine fault diagnosis from emission concentrations

- Overall diagnostic procedure
  - o Image analysis
  - o Pattern recognition tool
  - o Health condition estimation

- Method application
  - o Single specie
  - o Multiple species – fusion

- Summary - Conclusions

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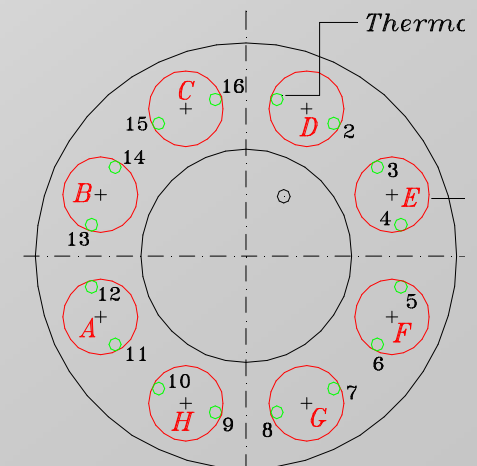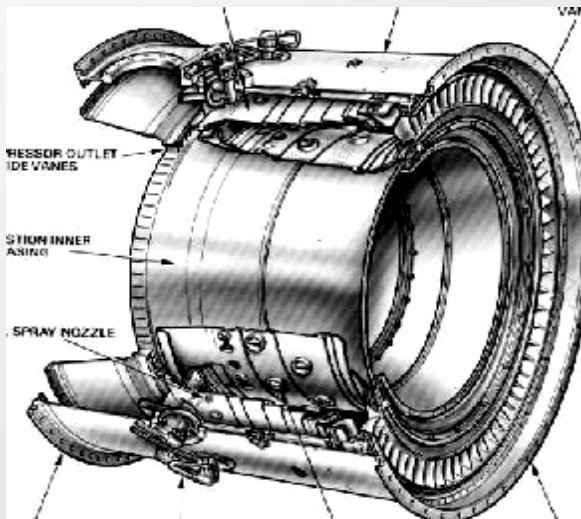Proceedings of ASME TURBO EXPO '07, May 14-17, 2007, Montreal, Canada

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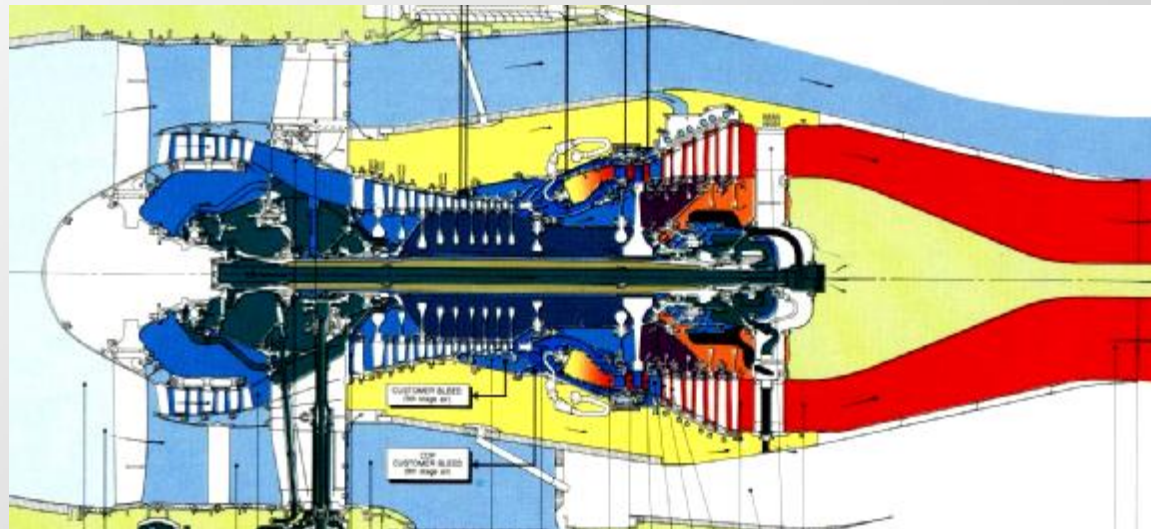Detection of Gas Turbines Malfunctions from Emission Concentration Plots
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Emissions stem from combustion

Local combustion inefficiency will result in asymmetric patterns of quantities at exhaust

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OPR for the detection of

faults disrupting peripheral distributions

Healthy Combustor   **Faulty Combustor**

**For example,
a faulty combustor can
may affect emission
concentrations on a
specific region of the plot**

The goal is to detect the region of the plot that changes due to the presence of a combustor fault.

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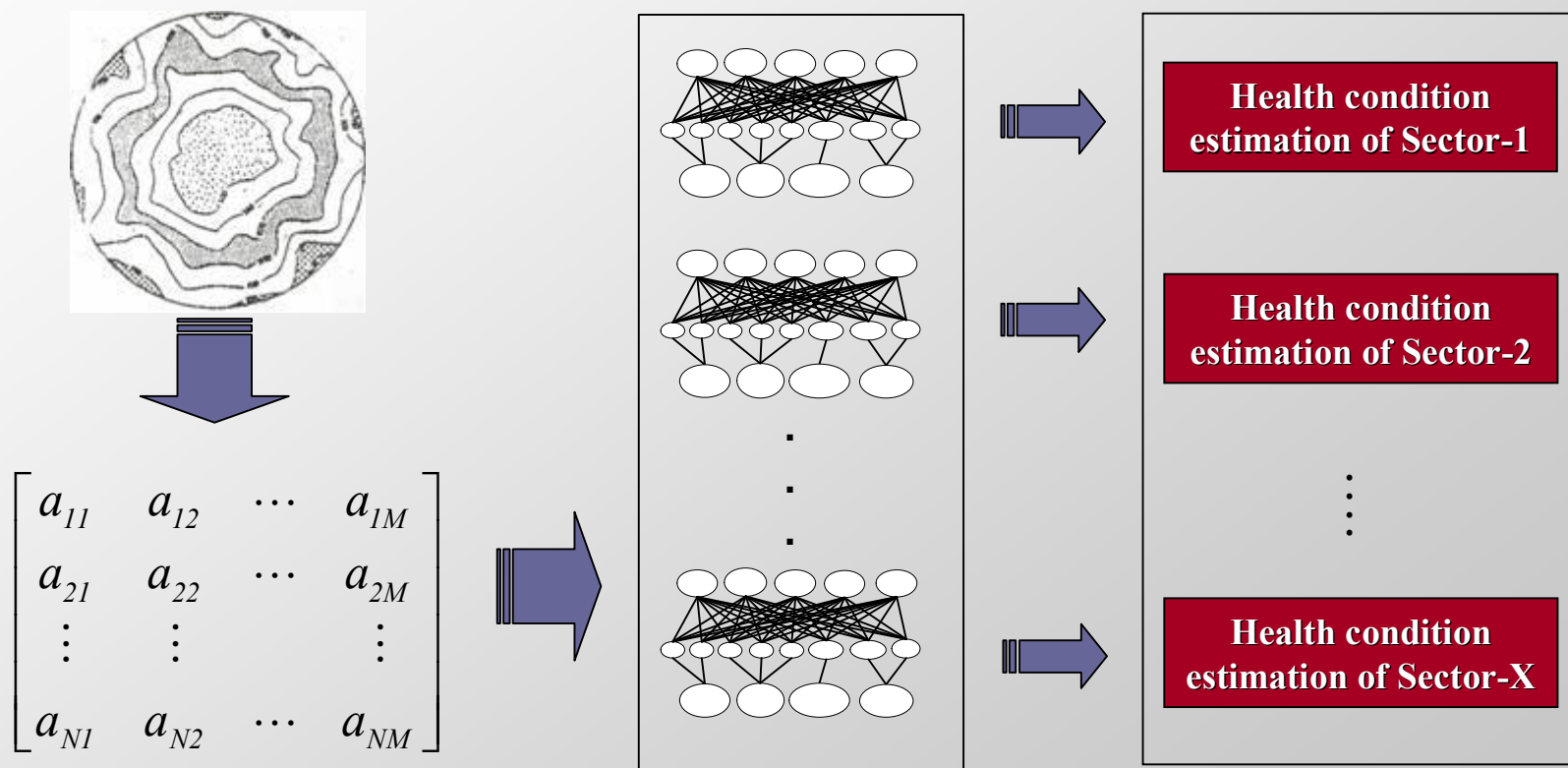Proceedings of ASME TURBO EXPO '07, May 14-17, 2007, Montreal, Canada

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OPR for Fault Diagnosis and Condition Monitoring

Procedure based on Probabilistic Neural Networks (PNN) for the detection of specific faults on an engine through the analysis of emission concentration plots
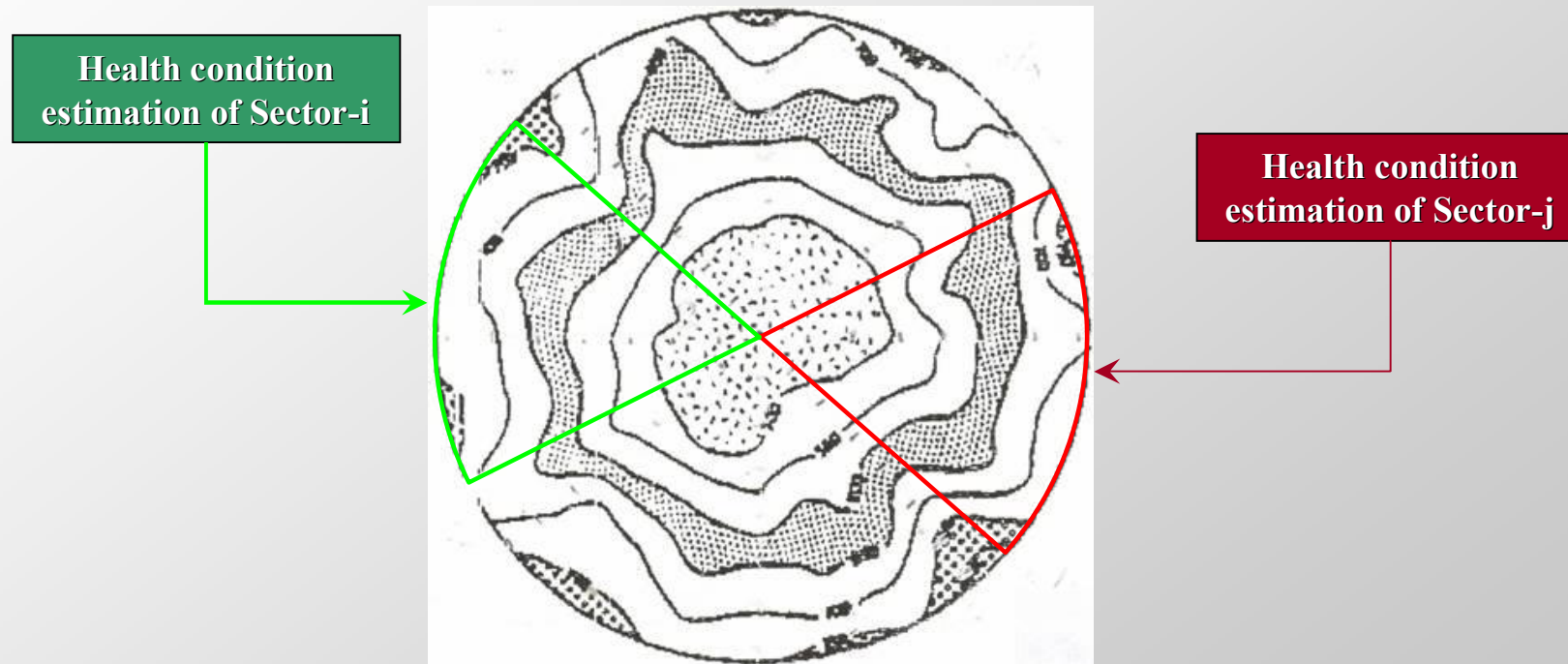
$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1M} \\ a_{21} & a_{22} & \cdots & a_{2M} \\ \vdots & \vdots & & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NM} \end{bmatrix}$$

Health condition estimation of Sector-1

Health condition estimation of Sector-2

Health condition estimation of Sector-X

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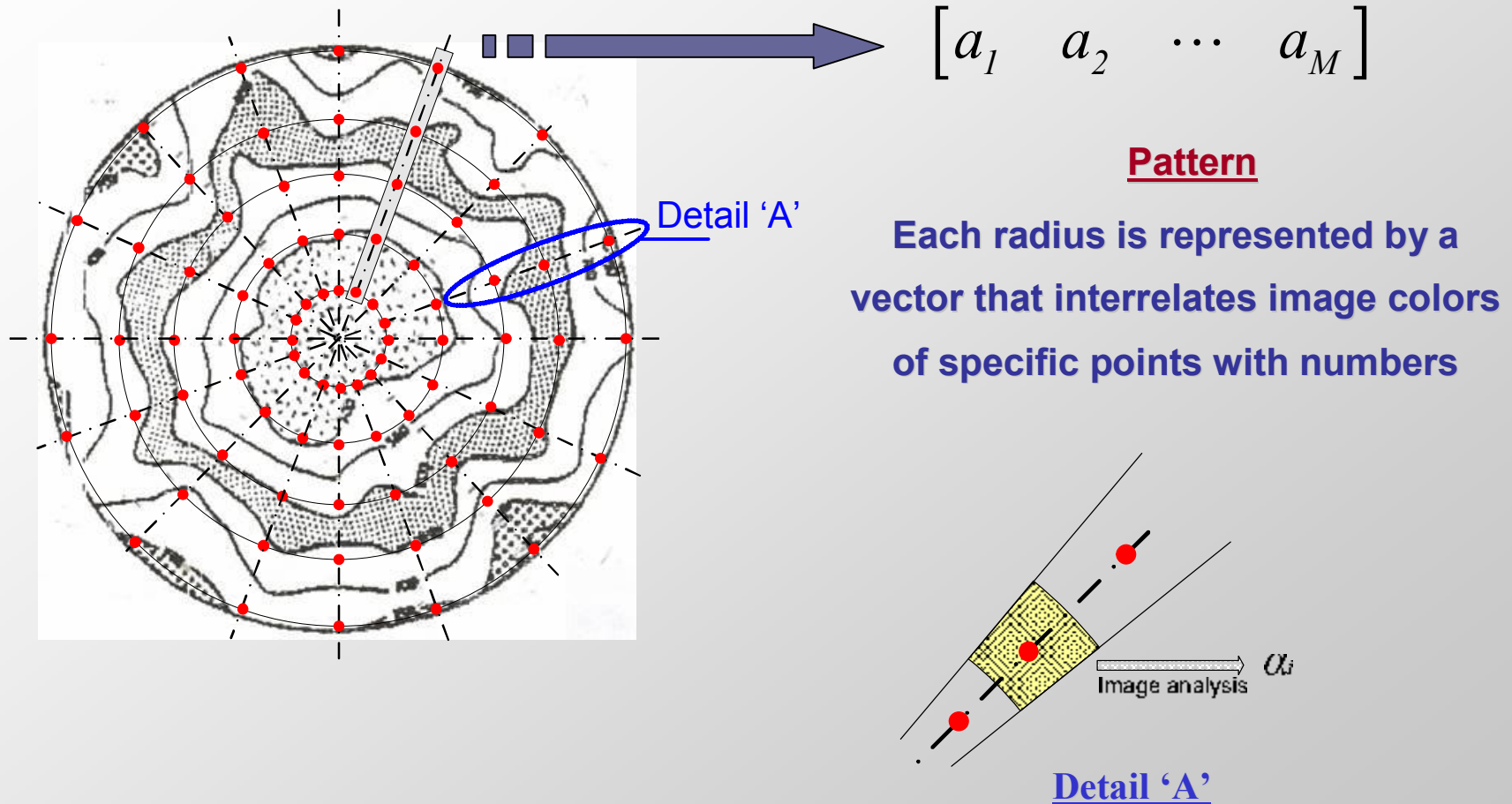Proceedings of ASME TURBO EXPO '07, May 14-17, 2007, Montreal, Canada

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OPR for Fault Diagnosis and Condition Monitoring

The anomaly detection takes place in each sector individually

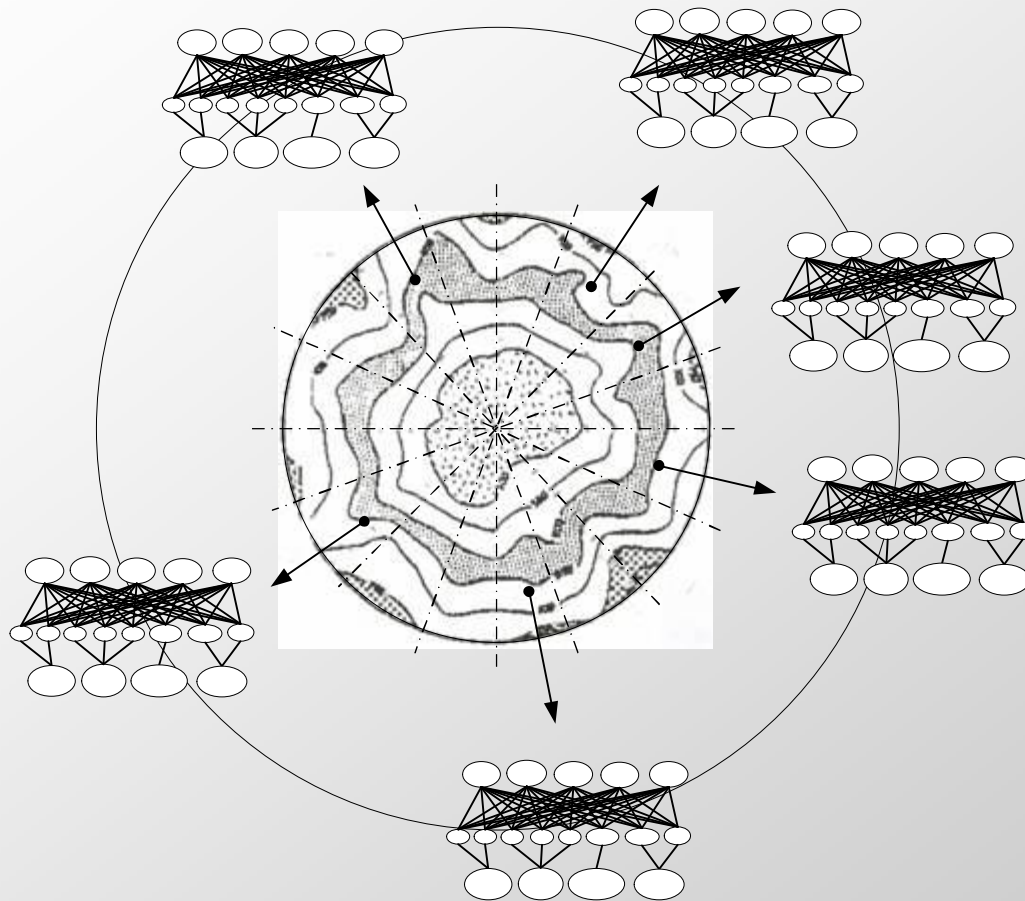Health condition estimation of Sector-i

Health condition estimation of Sector-j

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Analysis of the emission concentration plots

$$\begin{bmatrix} a_1 & a_2 & \cdots & a_M \end{bmatrix}$$

Pattern

Each radius is represented by a vector that interrelates image colors of specific points with numbers

Detail 'A'

$$a_i$$
Image analysis

Detail 'A'

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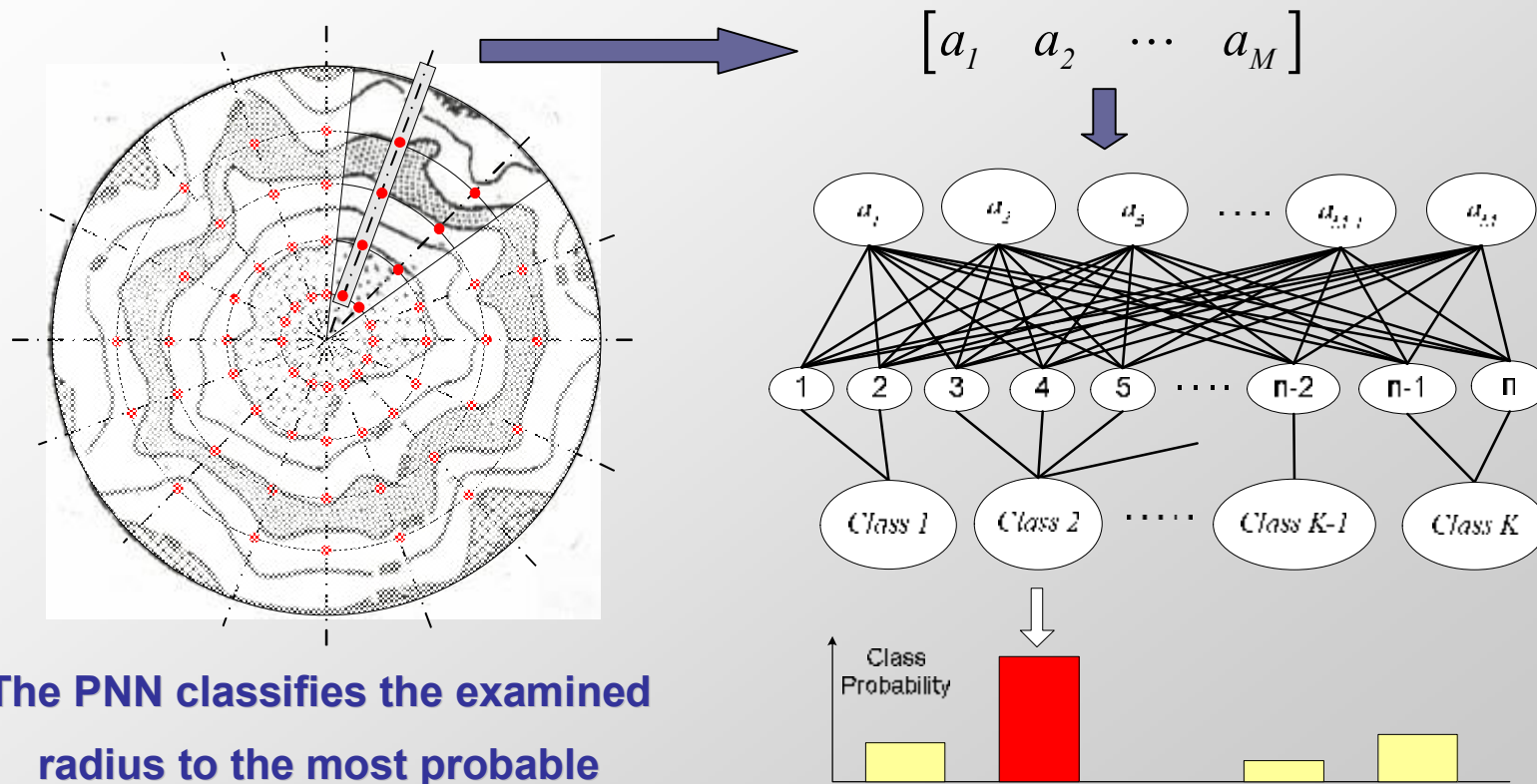Proceedings of ASME TURBO EXPO '07, May 14-17, 2007, Montreal, Canada

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The pattern recognition tool

The plot is divided into sectors of interest, each one tied to one PNN

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Health Condition Estimation

$$[a_1 \quad a_2 \quad \cdots \quad a_M]$$

The PNN classifies the examined radius to the most probable among possible health conditions

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Structure of PNN

Hidden Layer

Input Layer

Output Layer

$$\overline{x} = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_{n-1} \\ a_n \end{bmatrix} \Rightarrow \qquad \Rightarrow \begin{bmatrix} P(S_1 \mid \overline{x}) \\ P(S_2 \mid \overline{x}) \\ \vdots \\ P(S_k \mid \overline{x}) \end{bmatrix}$$

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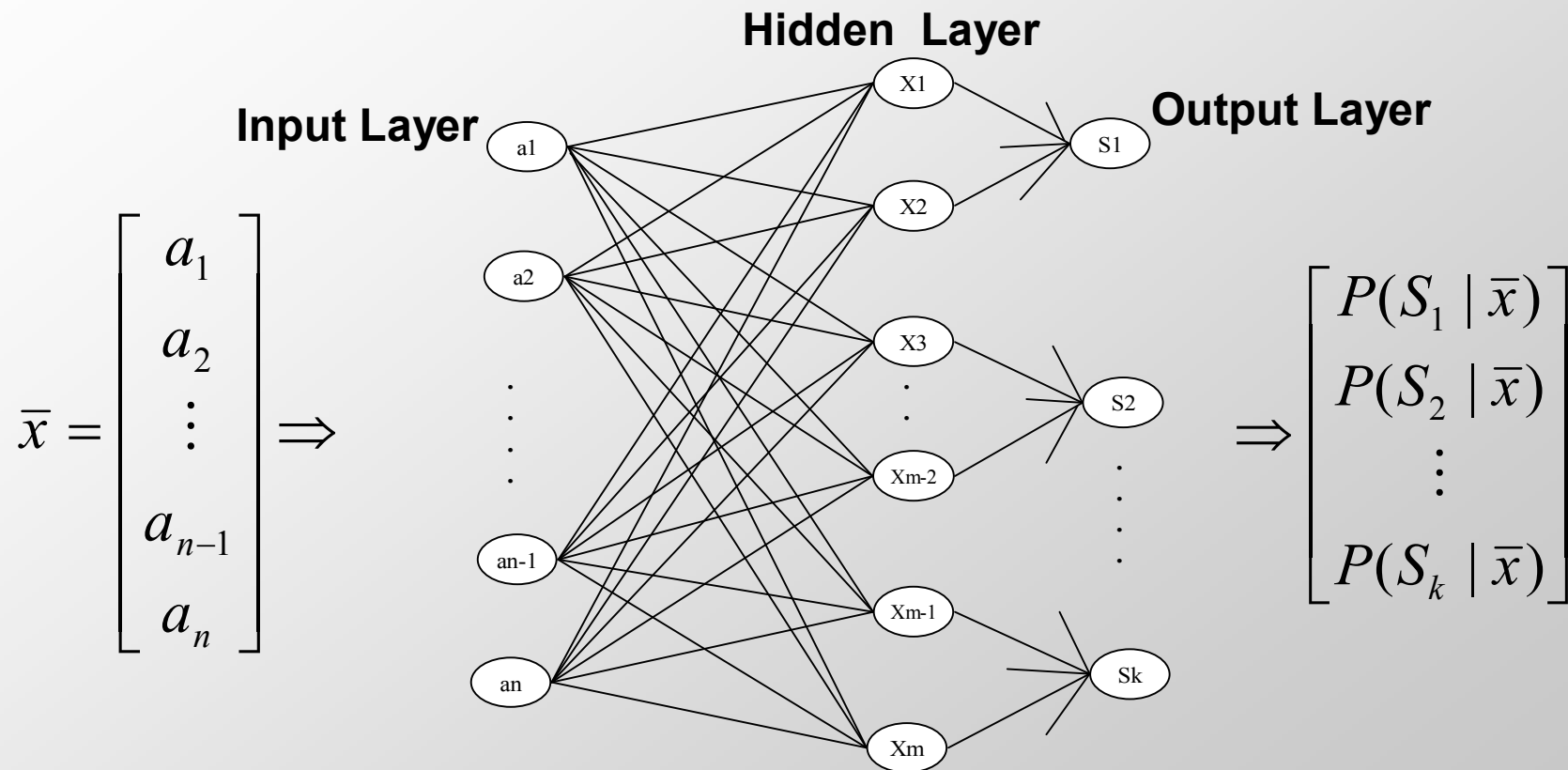
Health Condition Estimation

Estimated probabilities for

each health condition and sector

Sector	Health Conditions			
	1st	2nd	...	M
1	83.64	10.16		1.10
2	95.67	0.54		2.22
3	93.13	1.24		4.65
.	.	.		.
.	.	.		.
.	.	.		.
j	8.00	91.10		0.90
.	.	.		.
.	.	.		.
.	.	.		.
N	99.99	0.00		0.01
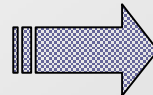
Estimated health condition

per sector

Sector	Health Condition
1	1st
2	1st
3	1st
.	.
.	.
.	.
j	2nd
.	.
.	.
.	.
N	1st
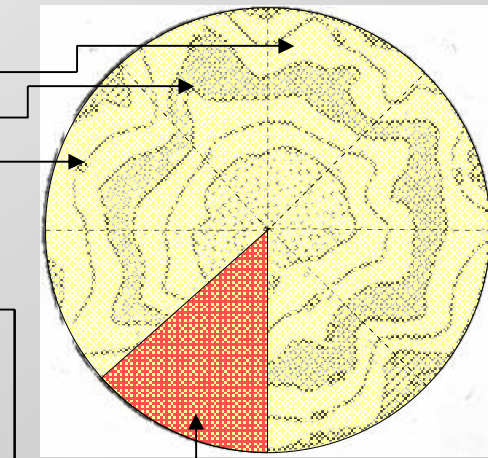
From the group of PNNs, the method allows a peripheral health

condition estimation of the plot

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Application of the method

Concentration contour plots at several thrust levels

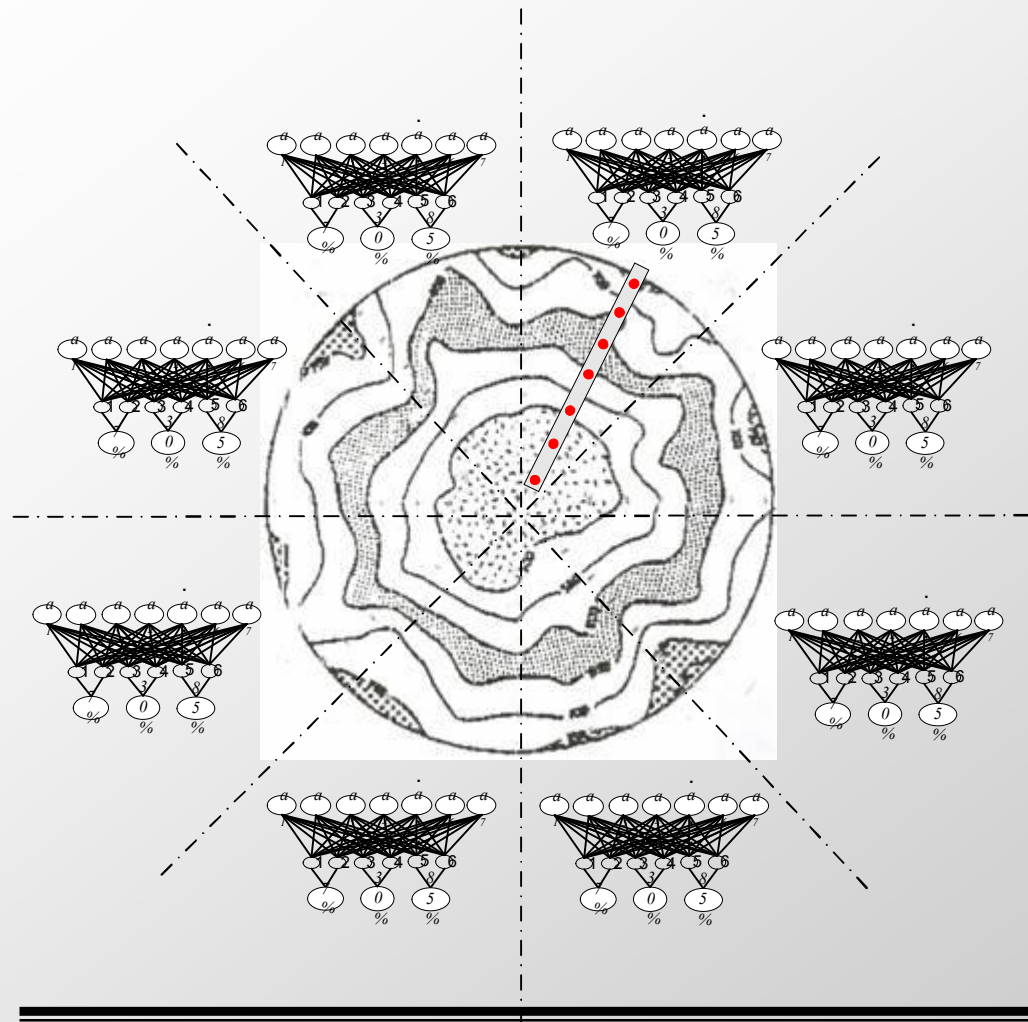**of CO emission for the RB211 engines[1]**

| 7% | 30% | 85% |

The goal is to estimate the engine thrust level,

circumferentially.

[1]Plots taken from: 'Emissions variability and traversing on

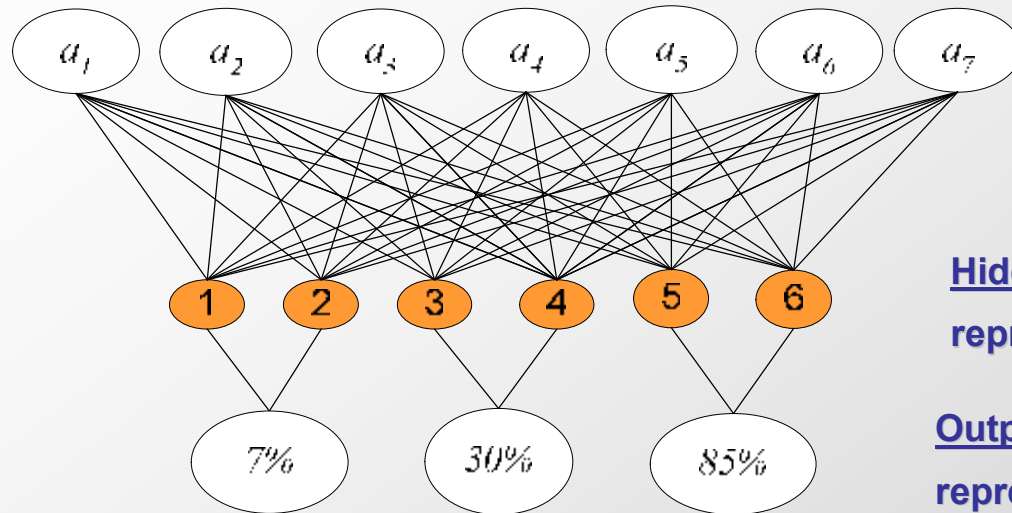**production RB211 engines', ASME paper, 83-GT-1411**

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Application of the method

Networks: 8 PNNs covering

8 sectors of emission

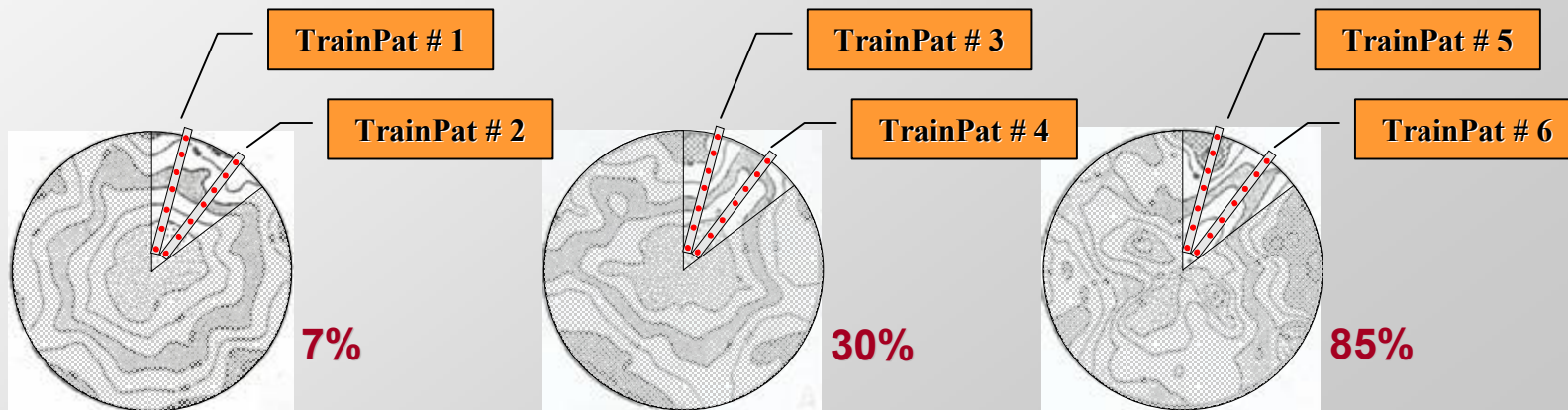concentration plot

Pattern: Analysis of

7 radial points

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Training the PNNs

Input Layer: 7 nodes

representing the pattern vector

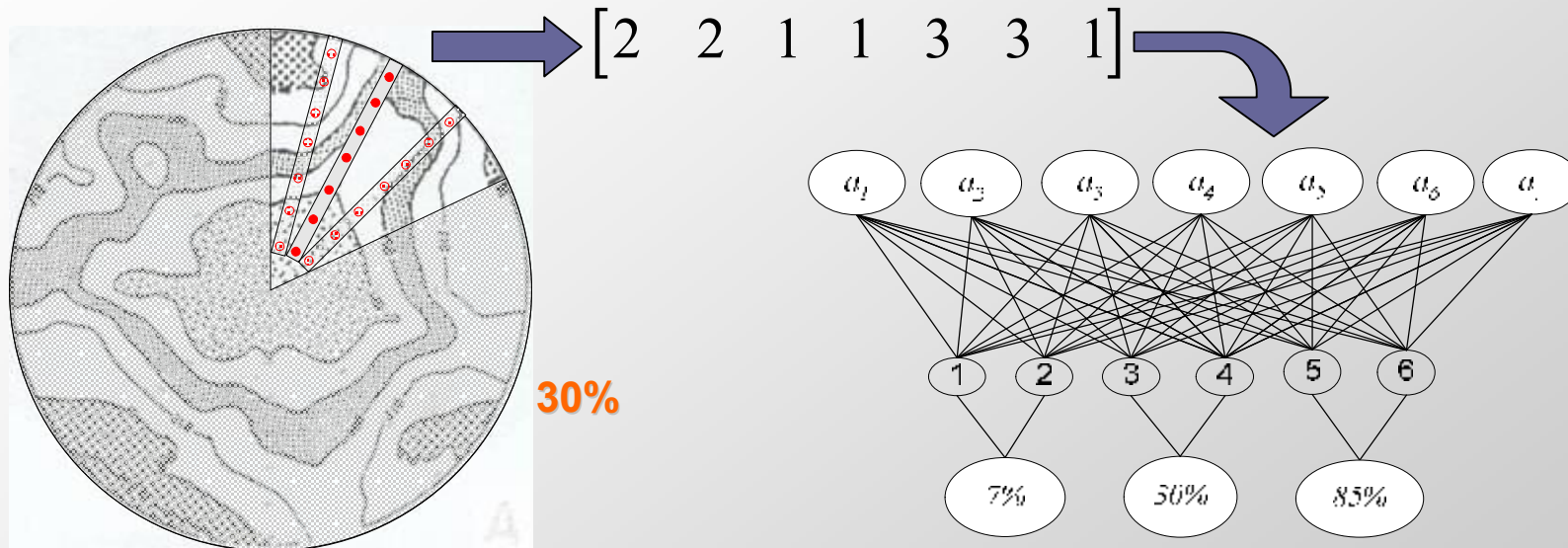**Hidden Layer**: 6 nodes

representing the training patterns

Output Layer: 3 nodes
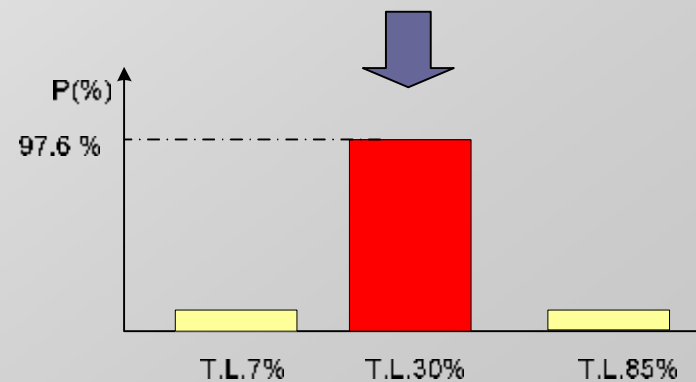
representing the considered thrust levels

TrainPat # 1   TrainPat # 3   TrainPat # 5

TrainPat # 2   TrainPat # 4   TrainPat # 6

7%   30%   85%

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Assessment of method effectiveness

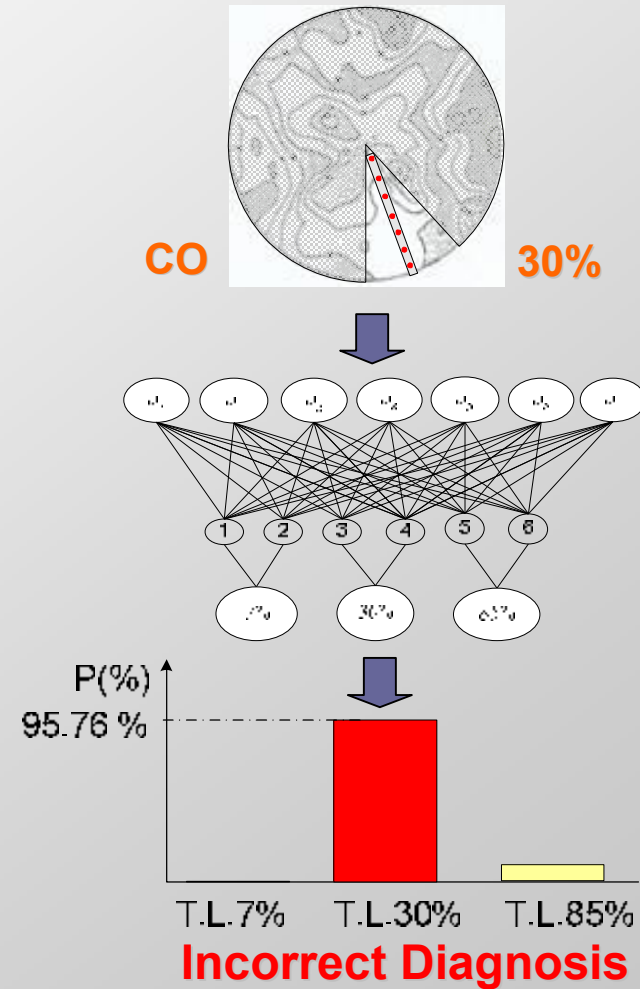$$\begin{bmatrix} 2 & 2 & 1 & 1 & 3 & 3 & 1 \end{bmatrix}$$

30%

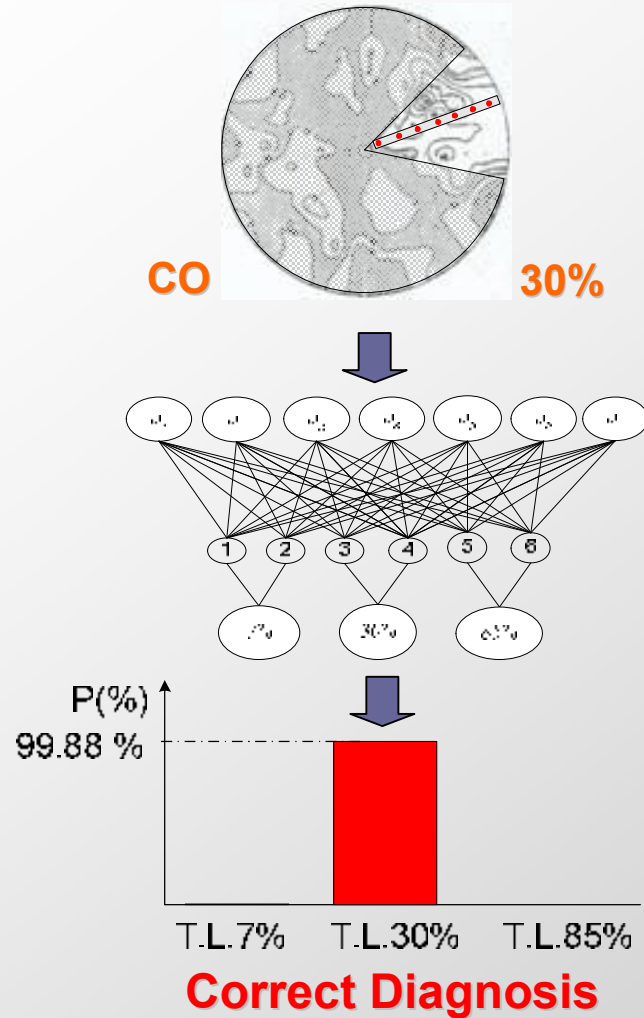**93% of not-trained examined patterns**

were classified correctly

100% of trained patterns were

classified correctly

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Assessment of method effectiveness

CO   **30%**

Correct Diagnosis

CO   **30%**

Incorrect Diagnosis

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Fusion of diagnostic conclusions based

on individual species

CO **NOx** **UHC**

7%

30%

85%
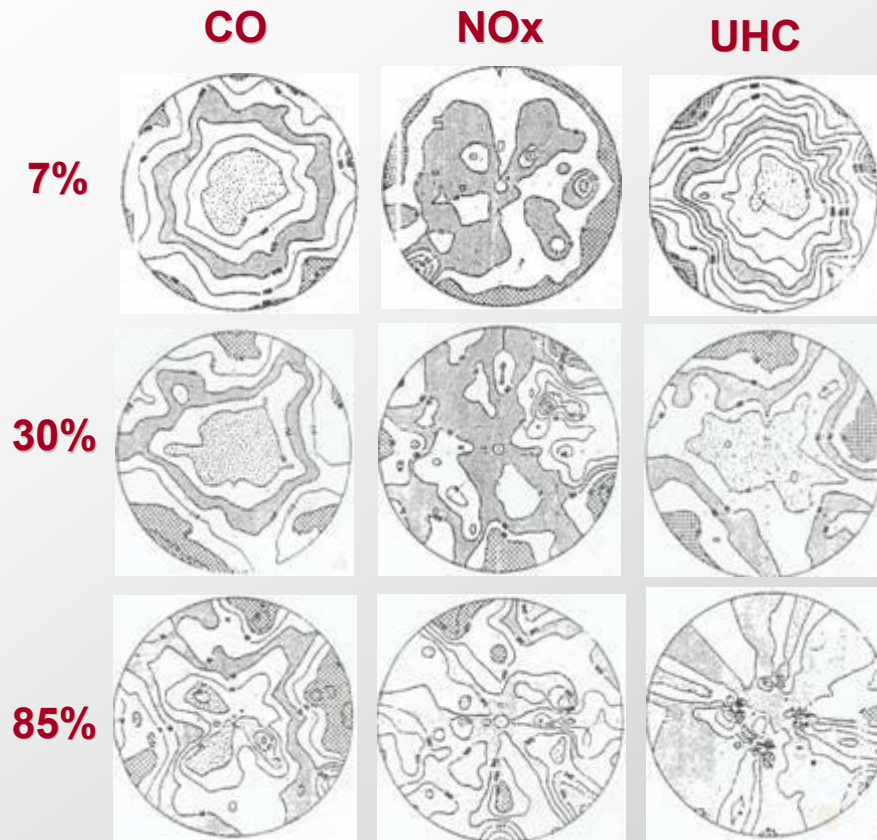
Application of the method in other emission concentration plots, may improve diagnosis

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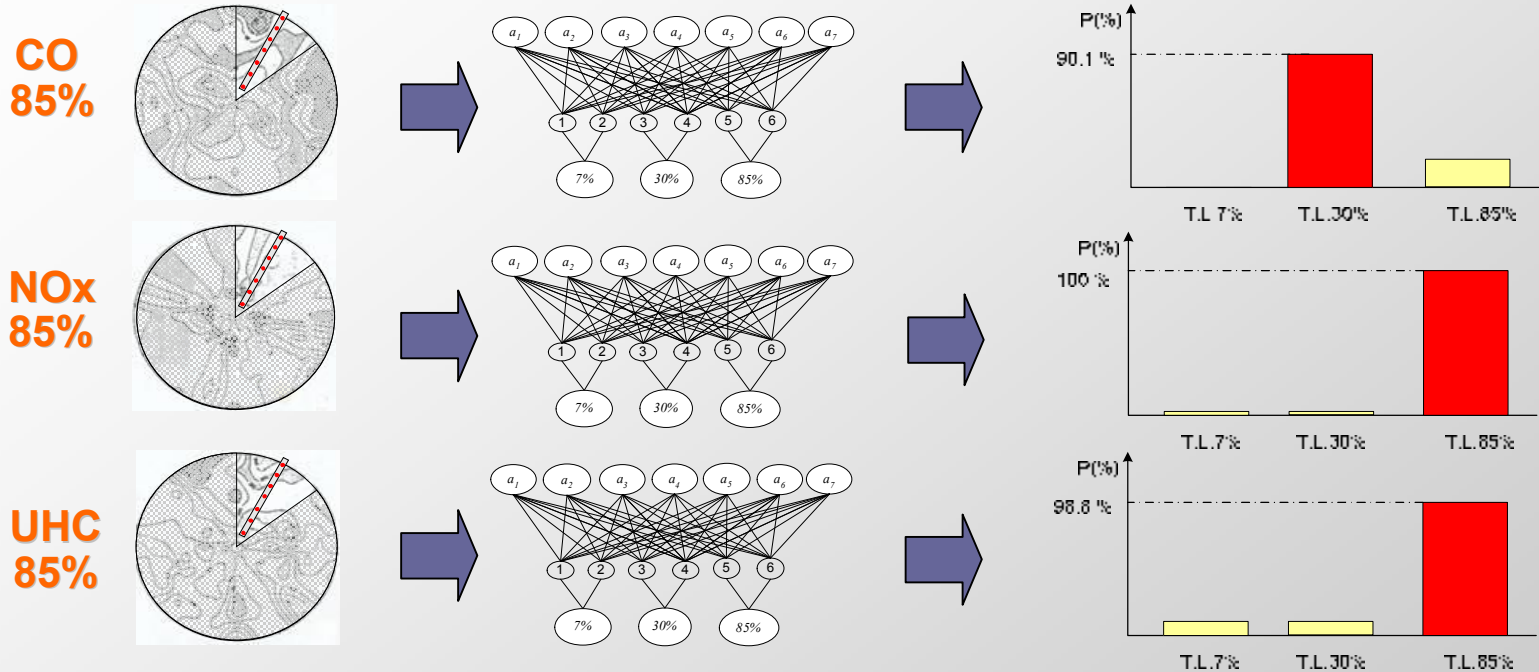
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Fusion of diagnostic conclusion

CO

85%

NOx

85%

UHC

85%
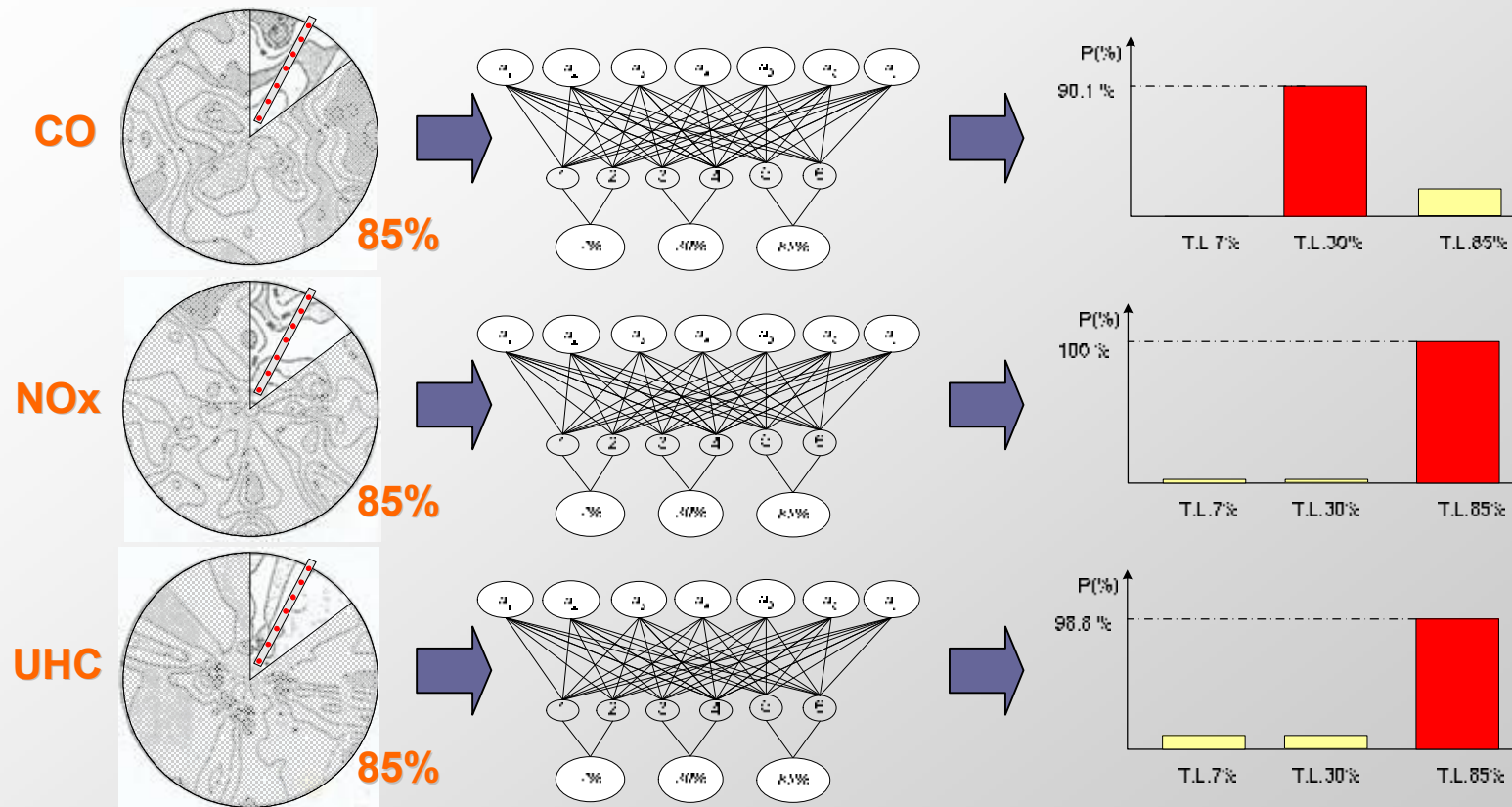
A first possible approach: Averaging of estimated probabilities

leads to a correct classification in all cases

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Fusion of diagnostic conclusion

Fusion of diagnostics results

by application of the method

on different species led to a

correct diagnosis
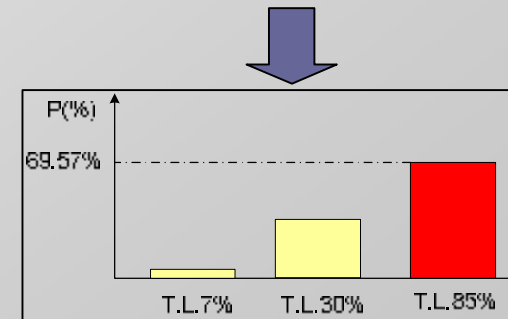
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Summary - Conclusions

• A method allowing fault diagnosis from emission concentration plots has been presented

• The method is based on pattern recognition through the use of a specific type of Artificial Neural Networks, the Probabilistic Neural Networks.

• A first application has shown that the presented method can be an efficient tool for the diagnosis of engine faults, once data is available.

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