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Neural network time series classification of changes in nuclear power plant processes

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Statistical models deployment in industry, technology and research

Quantification

Model building

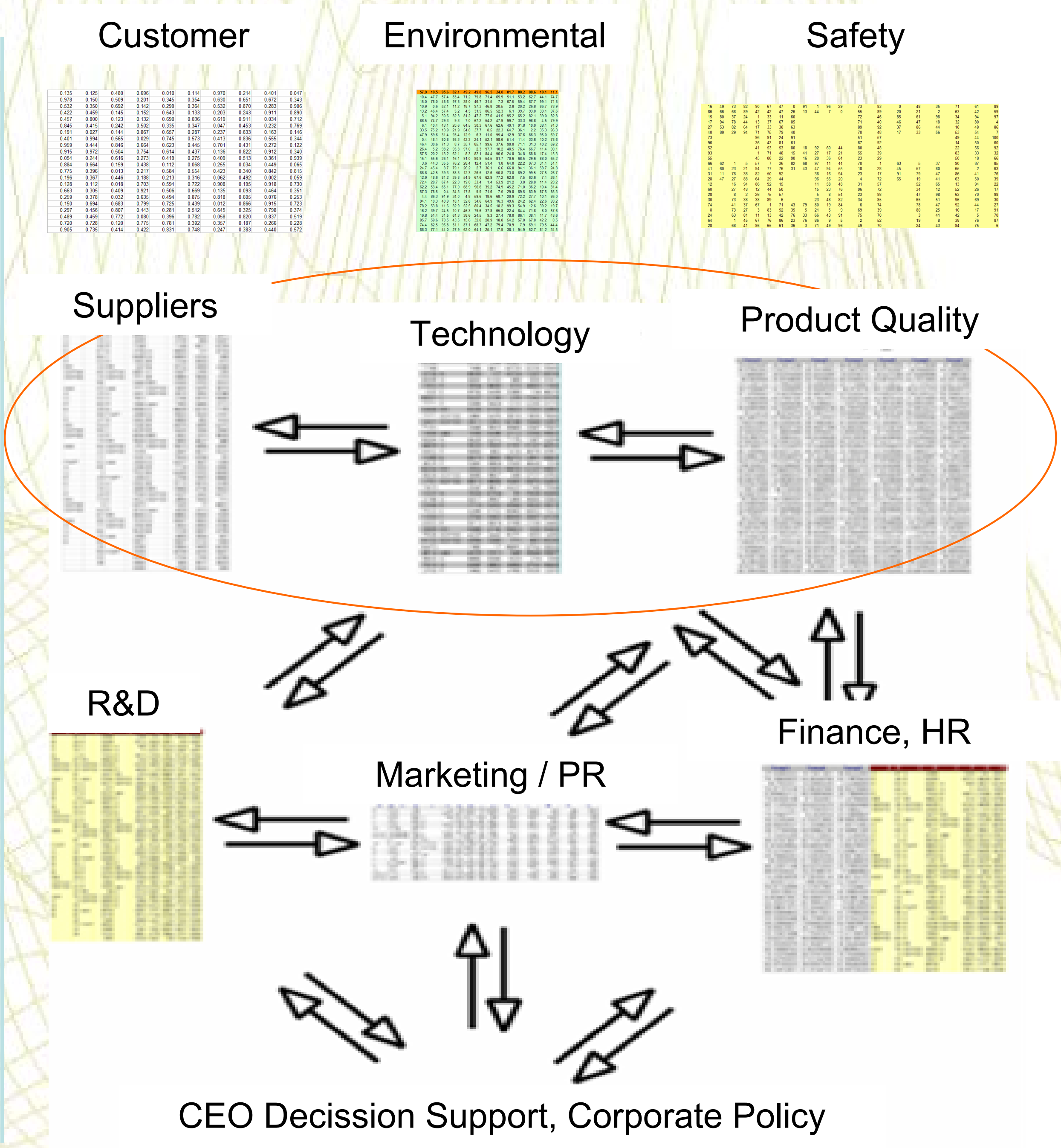
Evaluation

Interpretation

Decission Support

Profit

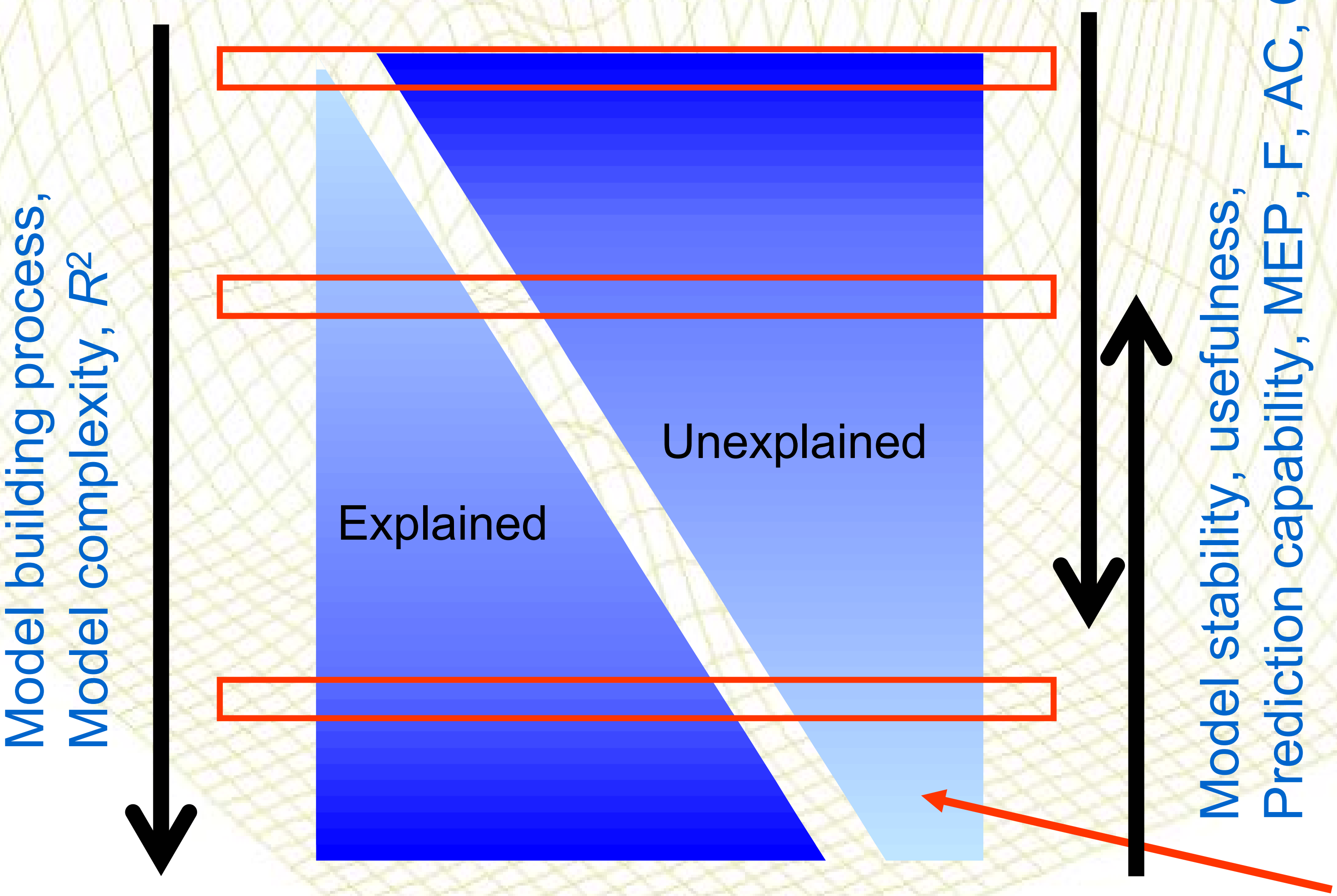
Data and Information Flow in a Company



Model building process

$$Q \propto \frac{1}{\sigma^2}$$

X = MODEL + NOISE



- Gradual variability explanation/ reduction
- Criterion: practically applicabe (empirical) prediction model

Unexplained (-able), inherent variability

Prediction model application examples

Steel works – Predict/classify mechanical&physical properties based on chemistry&technology parameters

Brewery – Find relationship between (bio-)chemistry and sensoric evaluation/classification of beer

Pharmaceutical/Cosmetics – Find quantitative structure – activity relationship (QSAR)

Financial – Classify loans, credit scoring, risk analysis

Climatology/Environment – Antarctica-based solar activity and ozone prediction, Industrial air pollution analysis

Regression, PCA, PLS, CART, ANN, ANNTS, SVM

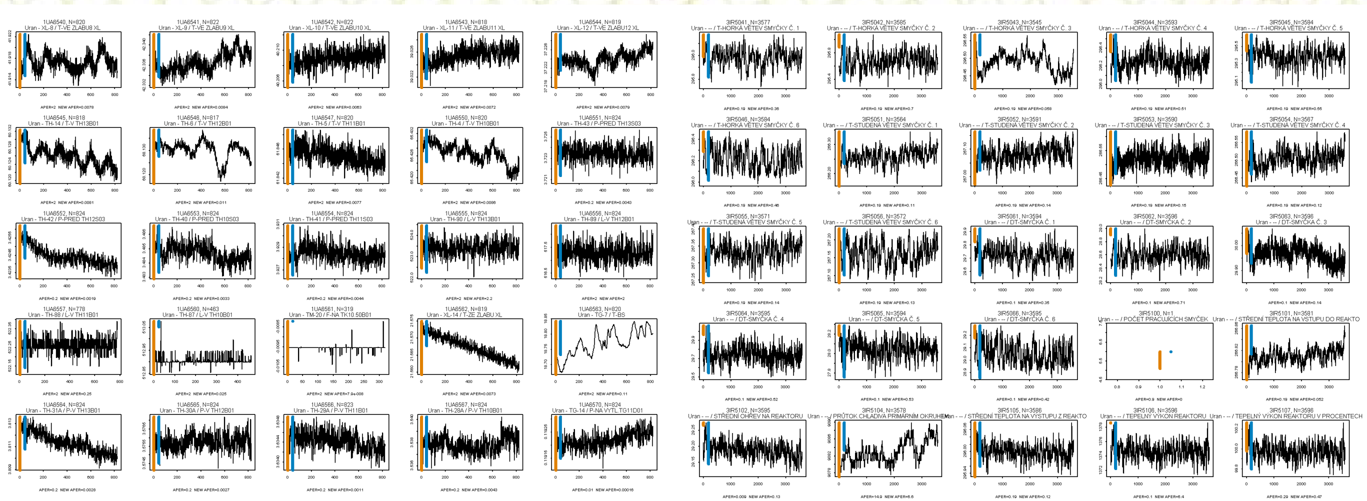
Nuclear power plant time series

The Plant

The Reactor

The Sensors

Temperatures, energy flow rates, meta-stable process modes



Driven by complicated nonlinear local physical processes

Some modes more important than others

Classify known metastable states *Y* of the process using process time series

The idea -

Sample space (*n*) → Variable space (*m*) → Model parameter space (*p*)

$n > m \geq p$

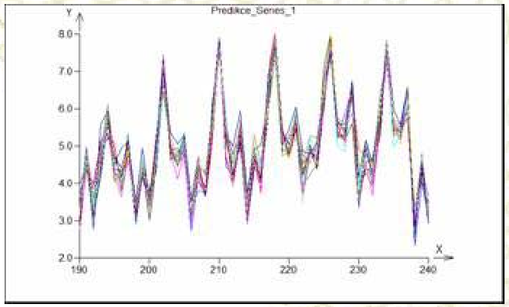
Use parameters as predictors in suitable classification model

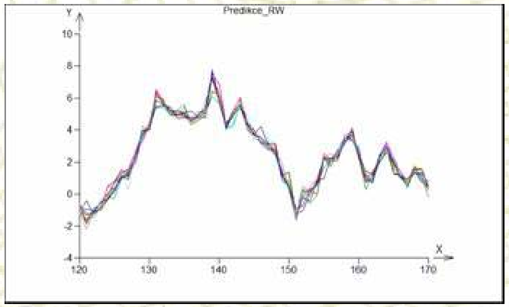
$$Y = \Theta\left(p, \alpha\right)$$

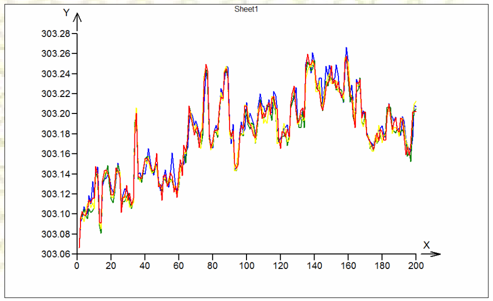
Time series model – (Differential) ANN Autoregresion

$\mathbf{x}_t = Z_{NNAR}\left(\mathbf{x}_{t-k}\right)$ $\quad$ $\mathbf{x}_t = Z_{NNAR}\left(\mathbf{x}_{t-k}, \Delta\mathbf{x}_{t-k}\right)$ $\quad$ $m \geq p$ is usualy not met

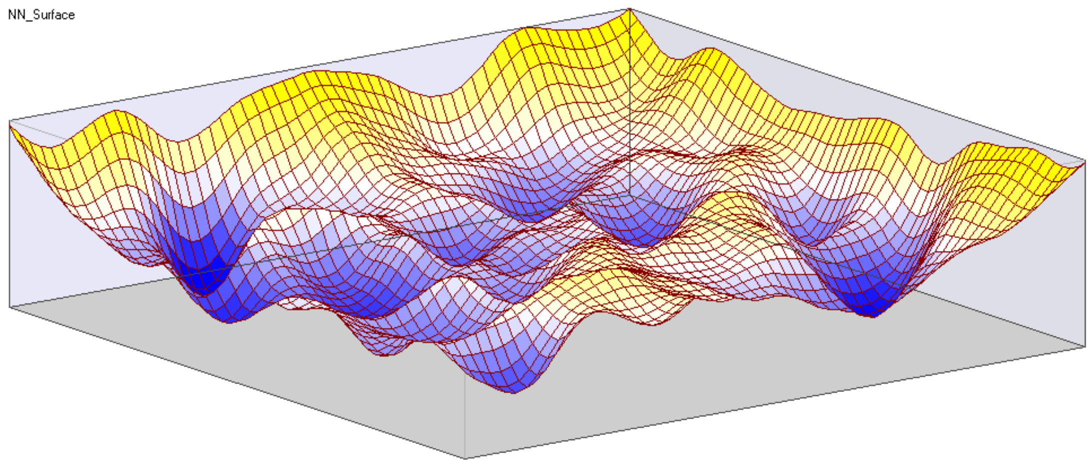
Time series examples -





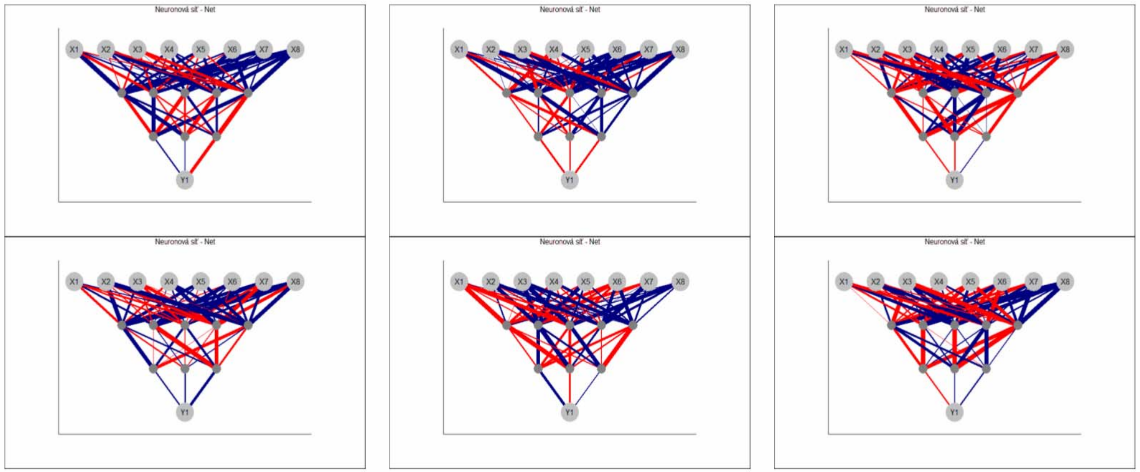


ANN solution stability problem



$$R(\theta) = \sum_j \left(y_j - f\left(\theta, \mathbf{x}_j\right)\right)^2$$

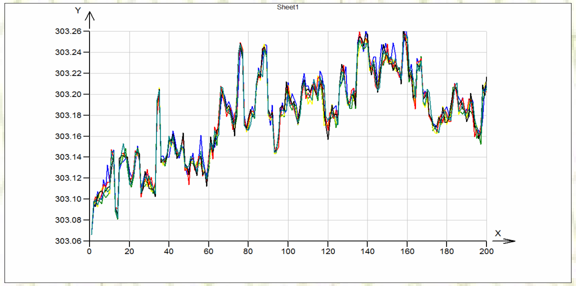
Adaptive Gauss-Newton optimization strategy

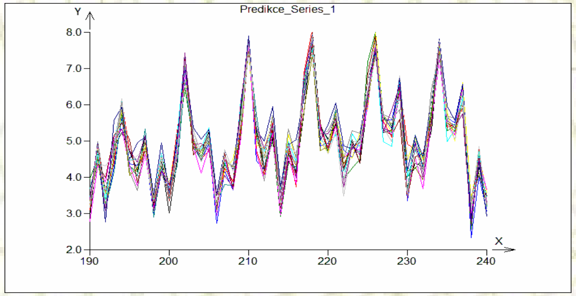


Non-convex error surface
Multiple local minima

Many different „good“ solutions to the same problem

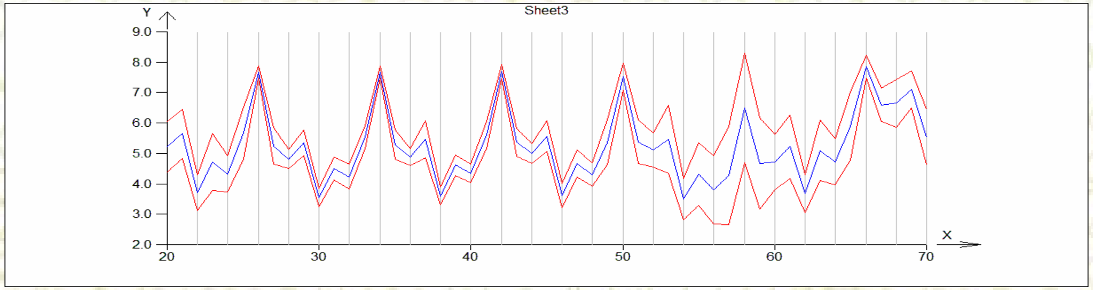
Error Distribution Estimation



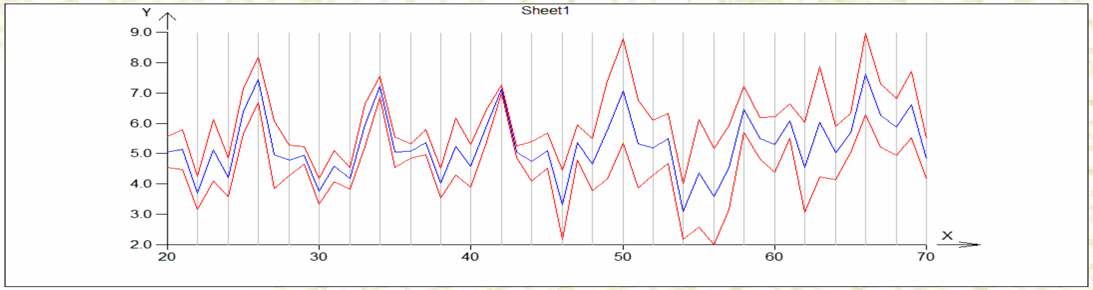


Take advantage of the ANN models drawback use unstability as „bootstrap“

Re-construct confidence intervals of prediction

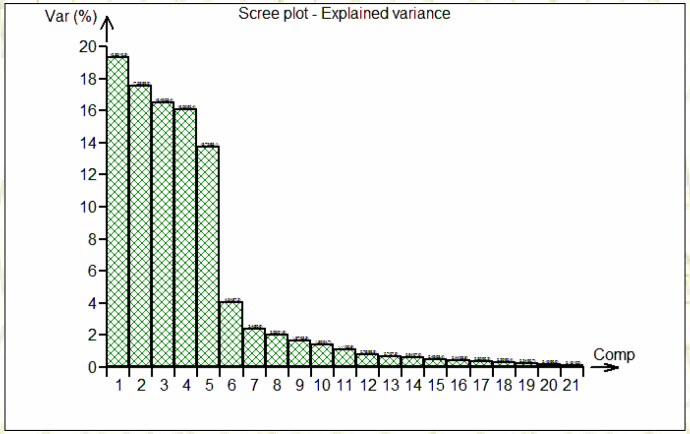


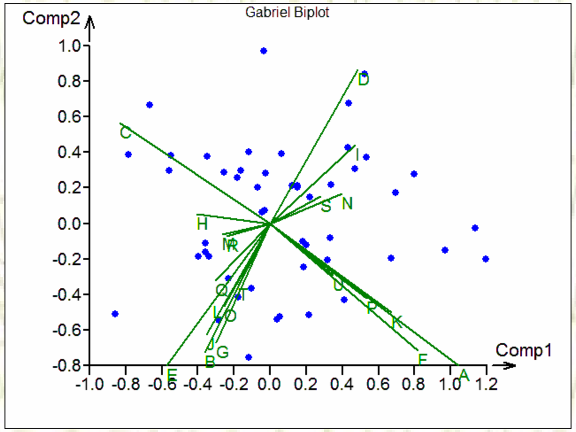
Robustification by choosing non-Eucleidian distance for optimizing the fit



$$R(\theta) = \sum_j \left(y_j - f\left(\theta, \mathbf{x}_j\right)\right)^r ; 1 < r < 2$$

Reducing parameter space dimension





PCA reveals inherent dimensionality of ANN weights $D(p) < p$

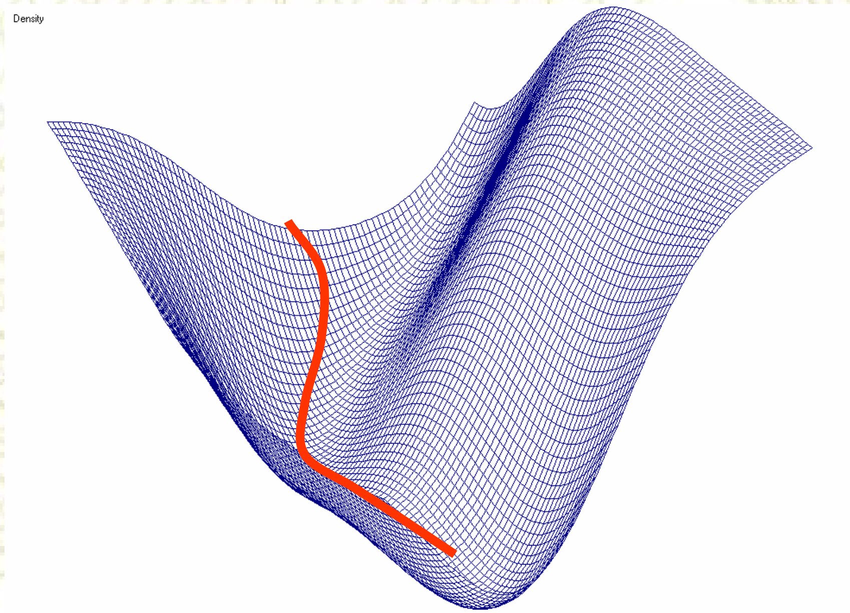
Significant principal components of model parameters appear to be a good predictor

$$\begin{pmatrix} \frac{\partial w_1}{\partial w_1} & \cdots & \frac{\partial w_1}{\partial w_p} \\ \vdots & \frac{\partial w_i}{\partial w_j} & \vdots \\ \frac{\partial w_p}{\partial w_1} & \cdots & \frac{\partial w_p}{\partial w_p} \end{pmatrix}$$

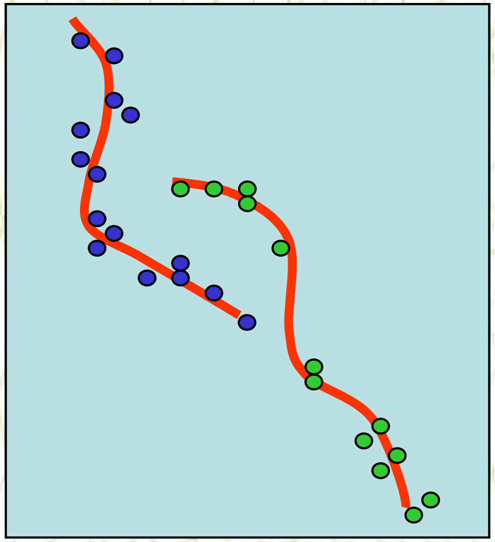
A nonlinear system defining a subspace in the parameter space with lower inherent dimensionality p' < p thus allowing stable prediction in p'.

subject to

$$\frac{\partial R(w)}{w_i} \le \delta; \delta \ge 0$$



Model classification



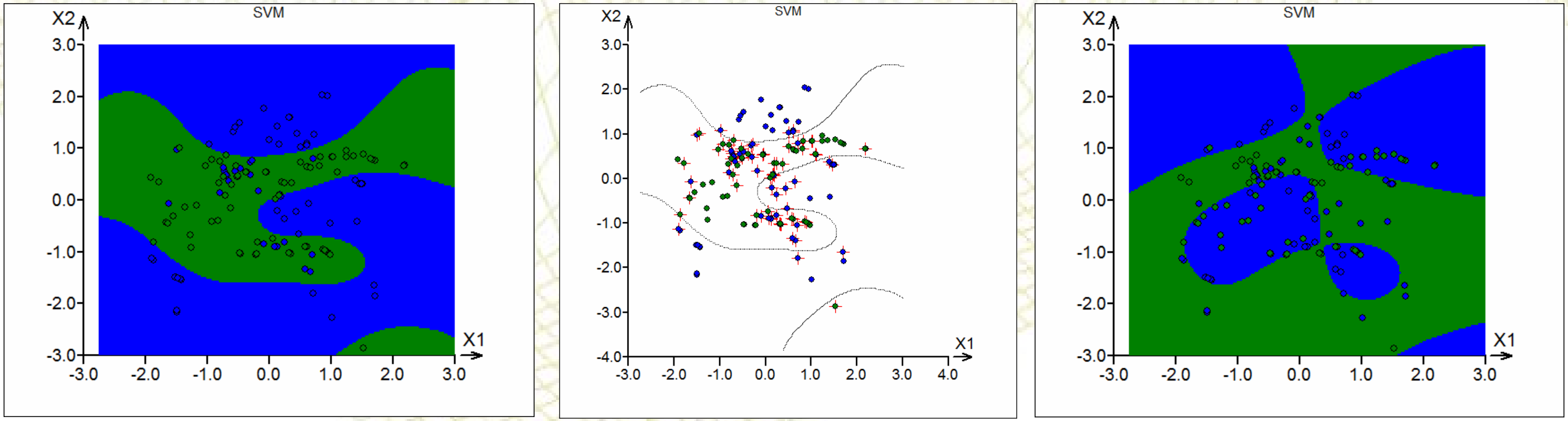
Linearly non-separable data on first p' components
Suitable for SVM separation

$$
\begin{aligned}
\min_{\mathbf{w},b,\boldsymbol{\xi},\rho} \quad & \frac{1}{2}\mathbf{w}^T\mathbf{w} - \nu\rho + \frac{1}{l}\sum_{i=1}^{l}\xi_i \\
\text{subject to} \quad & y_i(\mathbf{w}^T\phi(\mathbf{x}_i) + b) \geq \rho - \xi_i, \\
& \xi_i \geq 0, i = 1, \ldots, l, \rho \geq 0.
\end{aligned}
$$

svm_type	c_svc	
kernel_type	RBF	
Gamma	0.5	
cases	153	
variables	5	
nr_class	2	
total_sv	49	
label	1	2
nr_sv	26	23

Misclass Table	
Correct	151
Misclass	2
Misclass Rate	0.013

RBF Kernel SVM projection to pc_1, pc_2, m.r.=0.17



Conclusion

Applicability to static and dynamic multivariate problems

Significant dimension reduction

Applications in brewery, pharma, steel, medicine

(-) Computationally extensive

(-) No simple model

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