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# Feature Selection for High-Dimensional Industrial Data

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## Motivation

### *Problem statement*

Quality control in semiconductor manufacturing plants (FABs) is becoming increasingly complex. Production problems causing low wafer yield are often hard to find.

### *Goals*

Identify problems during wafer production
Give engineer problem insight
Robust yield prediction

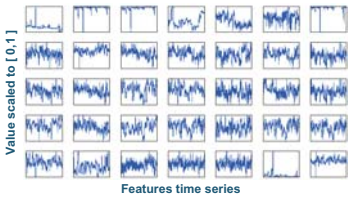
### *Methods*

Fuzzy ARTMAP neural network (FAM) [1]
Feature selection [2] (feature extraction destroys semantic information)

### *Challenges*

High data dimensionality, unbalanced classes
Process drift (non-stationarity of data due to changing machine state)
Analysed data is merely a subset of whole process

## Data




A subset of 35 electrical measurements from wafer is shown. Two classes signify "high yield" and "low yield". Ratio of training to test data is 3:1 (in chronological order). Independent test set is vital for feature selection [4].

| | Method | Features | Samples | "Low Yield" |
|---|---|---|---|---|
| Data Set 1 | Feature sel. | 61 | 3000 | 57% |
| | Test | 61 | 1000 | 31% |
| Data Set 2 | Feature sel. | 85 | 1000 | 48% |
| | Test | 85 | 313 | 57% |

## Funding

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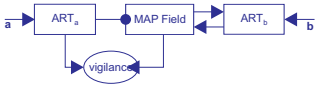
## Methods

### *Yield prediction*

FAM is a suitable classifier for wafer data

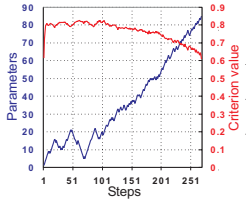



Extract Fuzzy-Rules:
"IF parameter A in [0.0476,0.524]
AND ...
THEN "Low Yield"

Few Rules — Many Rules
Easy Interpretation — High Accuracy

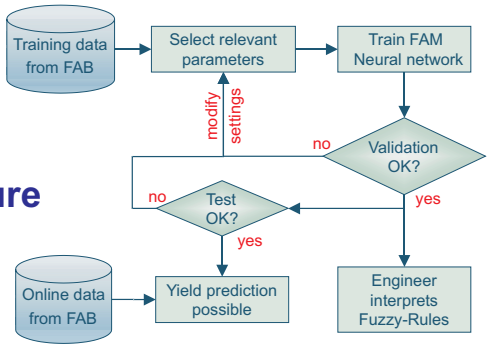
### *Feature Selection*

Sequential Forward Selection (SFS)
Sequential Forward Floating Selection (SFFS) [3]

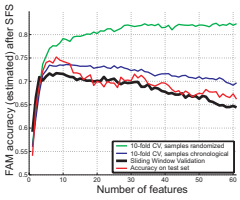



Criterion functions used:
Fuzzy ARTMAP (FAM)
k-NN (k=5, Euclidean distance)
Mahalanobis distance (M-dist)

## System Architecture




## Error Estimation

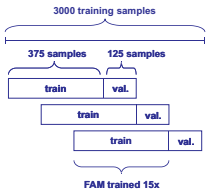



### *Problem*

Cross-validation is overoptimistic due to low within-lot variation

### *Solution*

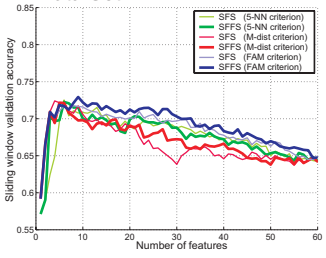
- Do not randomise data during CV
  Keep chronological order of data
- Sliding window validation (SWV)
  SWV imitates online case - data from a few lots is used to train the FAM, chronologically succeeding data is used for the test



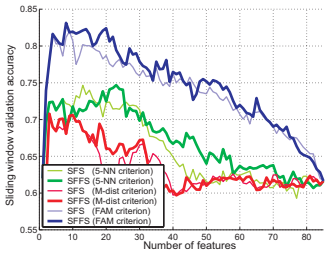

## Results

### *Sliding Window Validation*

Data Set 1

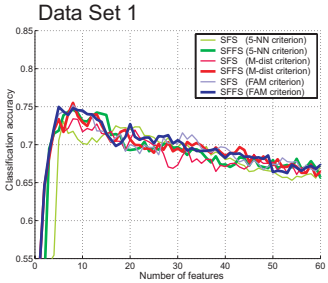



Data Set 2

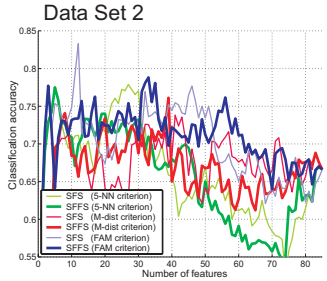



### *Yield Prediction (test)*

Data Set 1




Data Set 2




A feature subset of size 5-15 gives best yield prediction for Data Set 1.
The trend is not as clear for Data Set 2.
As expected, the FAM criterion function delivers the best results.

## Discussion

- SFFS is not superior to SFS when predicting wafer yield
- A small feature subset can model a production problem well
- Yield prediction improves after feature selection

A real production problem was solved by combining
- Feature selection
- Fuzzy Rules extracted from FAM
- Engineer's problem solving competence

### *Further Challenges*

- Visualisation of Fuzzy Rules
- More datasets needed to prove generality of results and allow online yield prediction

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[1] G.A. Carpenter and S. Grossberg. Fuzzy ARTMAP: A neural network architecture for incremental supervised learning of analog multidimensional maps. IEEE Transactions on Neural Networks, 1992.
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