A Methodology for Predictive Failure Detection in Semiconductor Fabrication

Peter Scheibelhofer (TU Graz)
Dietmar Gleispach, Günter Hayderer (austriamicrosystems AG)

09-09-2011

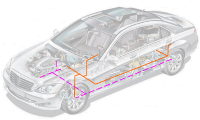
Agenda

- Overview austriamicrosystems
- Statistics in semiconductor fabrication
- Classification and Regression Trees (CART)
  & Random Forests methodology
- Case studies

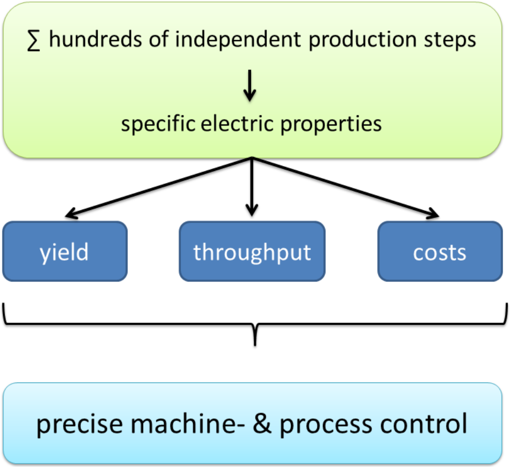
austriamicrosystems AG

- Design and fabrication of analog integrated circuits
- Power Management, sensors, mobile infotainment
- worldwide customers
- 100k+ fabricated wafers per year





Why use statistics in semiconductor fabrication?



Concepts

State of the art:

- Statistical Process Control (*SPC*)
- Fault Detection and Classification (*FDC*)

Advanced:

- Predictive Maintenance (*PdM*)
- Virtual Metrology (*VM*)

Requirements for statistical methods

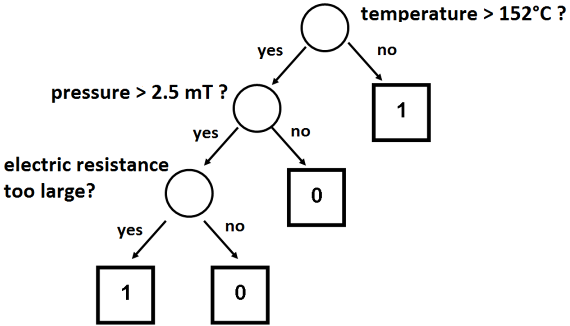
- Handle multivariate classification and regression problems
- Identification of important machine parameters
- Analysis of complex data situations,
  often unknown interaction structure
- Reliable prediction

Requirements for statistical methods

- Handle multivariate classification and regression problems
- Identification of important machine parameters
- Analysis of complex data situations,
  often unknown interaction structure
- Reliable prediction

$\rightarrow$ **Classification and Regression Trees**

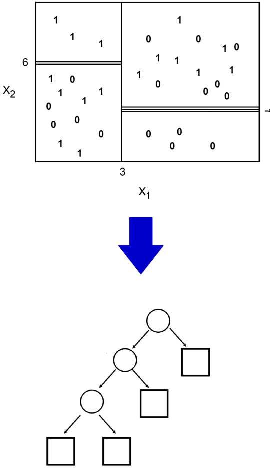
Classification And Regression Trees (CART)



⇒ *binary recursive partitioning* of given data

CART - Approach

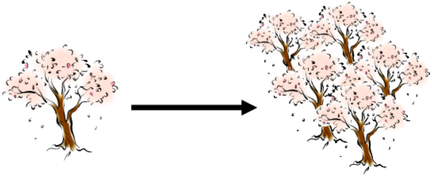
- *Split* response at predictor thresholds
  $\rightarrow$ resulting partitions as *pure* as possible
- Impurity: $I(A) = \Phi(P(Y = 1|A))$
- Minimize *Class-Impurity* (binary) / *squared error* (continuous)
- **binary:**
  $$\max \left[I(A) - \left(P(A_L) * I(A_L) + P(A_R) * I(A_R) \right) \right]$$
- **continuous:**
  $$\max_{\tilde{x}} \left[\mathrm{SE} - (\mathrm{SE}_{1,\tilde{x}} + \mathrm{SE}_{2,\tilde{x}}) \right]$$



CART - Advantages

- Intuitive and interpretable overview of data
- Suitable for complex data situations with interactions
- Important parameters recognizable
- Robust with respect to outliers
- Prediction of new observations possible
- Modeling in `R` with packages `rpart` and `party`

Random Forests



- Averages over many (> 500) different CART-models
- Lower variance
- No overfitting
- In `R` with `randomForest` package

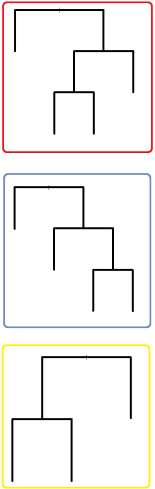
Random Forests

Randomization

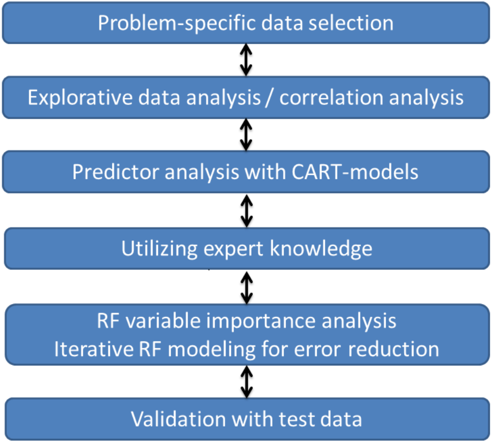
- draw data with replacement from original data (bootstrap samples)
- *random feature selection* for every split
- Test error estimation with remaining data (*out-of-bag error*)

Variable Importance:

- Aggregating change in out-of-bag error
- Change in error after random value shuffling

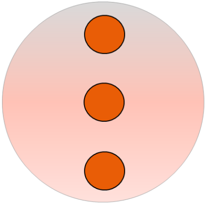


Methodology for building models

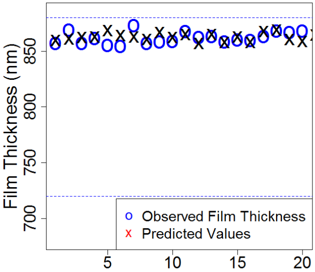


Case Study 1: Virtual Film Thickness Measurement

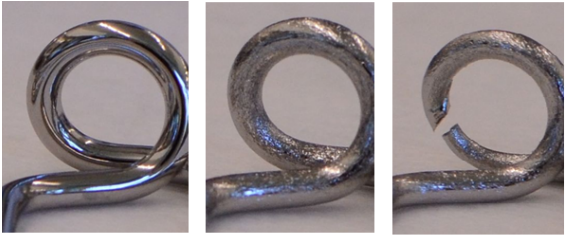
- Thickness of metal film measured using test wafers (target 800nm)
- Material and time consuming
- **Goal:** Replace measurement with estimation based on process data



- RF model allows accurate prediction
- $R^2 \sim 75\%$, RMSE $\sim$ 7nm
- high potential for cost reduction



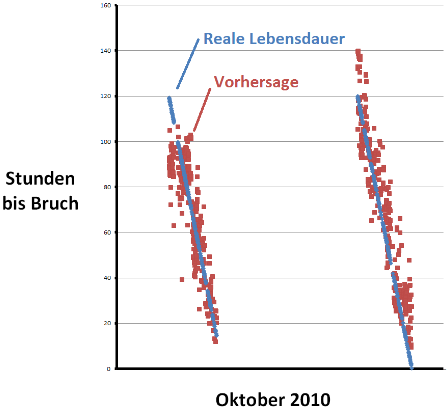
Case Study 2: Prediction of Implanter Maintenance



- Implanting: impinge ions under wafer surface
- Part of ion source: *filament*
- Part breaks approximately every 5-14 days
- **Goal:** Prediction of filament breakdown moment

Case Study 2: Prediction of Implanter Maintenance

- Model for continuous time-to-event response (in h)
- Prediction accuracy of $+/-$ 12 hours (test error)
- Model allows condition based maintenance



Summary

- CART-based models suitable for high-dimensional data analysis, classification and regression problems
- Used statistical method allows
  $\longrightarrow$ Real time monitoring of production tools
  $\longrightarrow$ save qualification material and maintenace costs
  $\longrightarrow$ Increase throughput
- Tree-based methods combined with multidimensional methods (Hotelling T^2, PCA, cluster analysis,...) suitable for practical modelling