Dresden Database
Systems Group

Lastgesteuerte Modellwartung für Prognoseanfragen

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Defence of Diploma thesis
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Motivation: Time series forecasting

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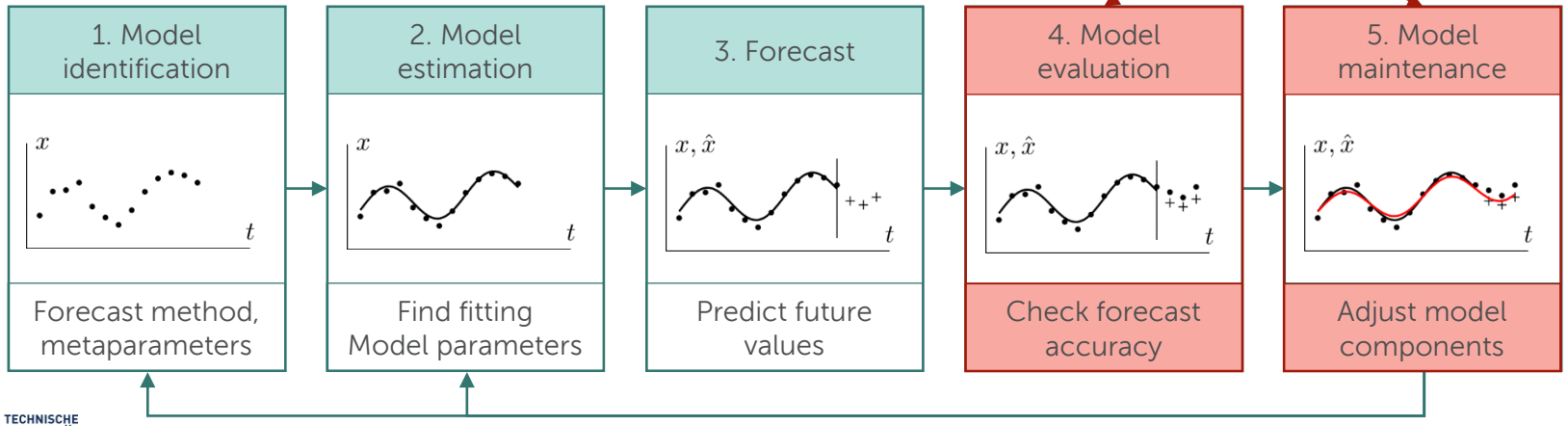
Time series forecasting

- Analysis of time series and description of the likely outcome in the immediate future
- Prerequisite for decision-making processes :
  - Production planning
  - Business intelligence
  - Energy load balancing

Components of Forecasting process

x ... Measuring value
$\hat{x}$ ... Forecast value
t ... Timestamp

The thesis is subject to these components



Motivation: Forecasting in Databases

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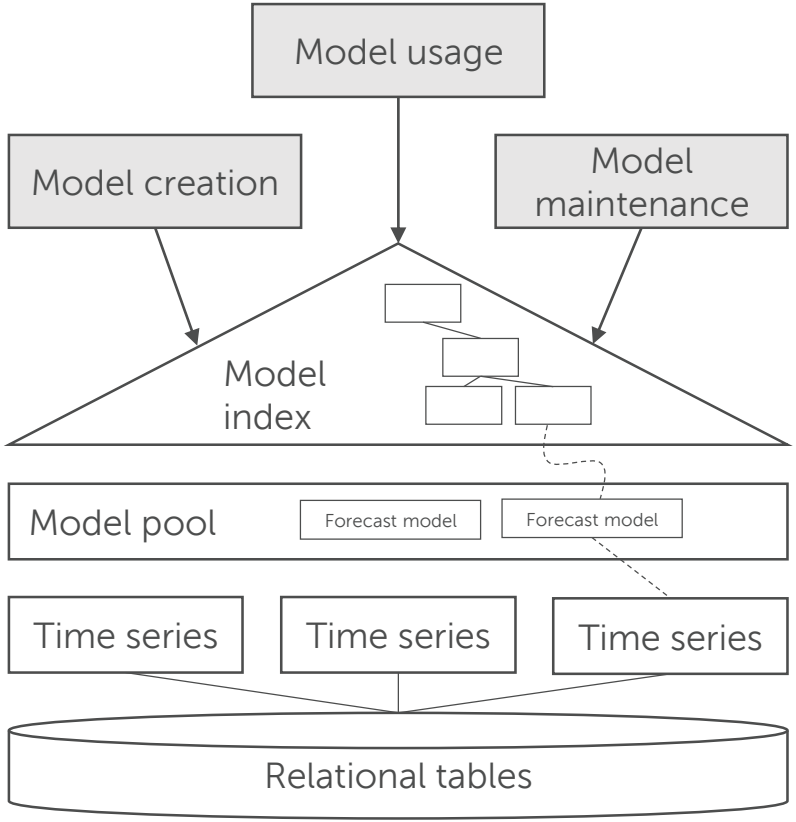
Flash-Forward Query Framework

- Integration of Time series forecasting in Database Management System (DBMS)
- Advantages
  - Time series are processed within a DBMS
  - Shared use of forecast models
  - Embed forecast in complex query

Life cycle of forecast models

- Model creation
  - Storage of forecast model in model pool
  - Indexing model for query and tuple matching
- Model usage: query matches model and returns forecast
- Model maintenance
  - Update forecast model if new tuples arrive
  - Adjust forecast model if forecast is inaccurate
  - Forecast accuracy is measured by
    - Elapsed timestamps since last model estimation
    - Forecast error since last model estimation



[Ulrike Fischer, 2014]

Motivation: Hierarchical forecasting

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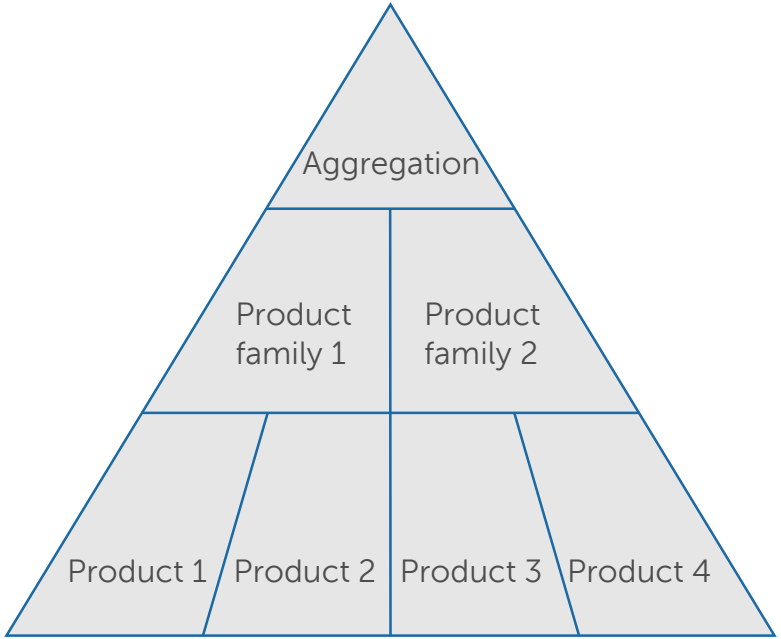
Hierarchical forecasting

- Time series may be classified by one or more hierarchies
- Figure shows functional dependency of product time series and product families
- Measuring values are aggregated to superior level
- *Forecast values can be derived, too*

Advantages

- Reduce number of forecast models when data consists of hierarchical time series
- Research shows that derivation can increase forecast accuracy



Agenda

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Problem	Concept presented in this work
▪ Creation of many forecast models for a given data set	▪ Reuse of forecast models by derivation models
▪ User has different accuracy expectations on forecast models ▪ System has general accuracy assumptions only	▪ Accuracy classes for forecast queries ▪ Priorization of maintenance tasks for queried forecast models
▪ High system load causes maintenance tasks to slow down ▪ The delay of forecast queries increases	▪ Limit maintenance component to a maximum of load ▪ Provide maintenance of queried models during high system load

Derivation schemes

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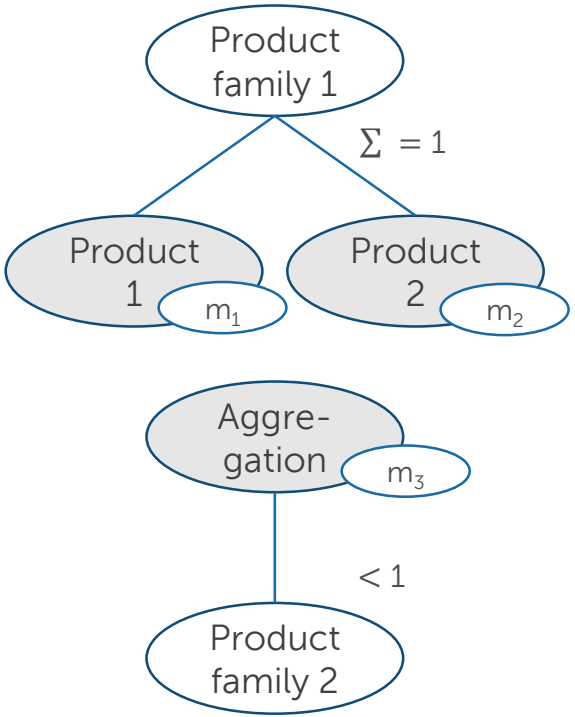
Aggregation model ("Bottom-Up")

- An aggregation model aggregates the forecast of inferior forecast models
- Example: An aggregation model for Product family 1 aggregates forecast of Products 1 and 2

Disaggregation model ("Top-Down")

- A disaggregation model uses a proration of the forecast of the superior forecast model
- Example: The forecast of Product family 2 is a proration of the aggregation, i. e. the forecast of the whole dataset
- Proration is represented by a derivation weight



Automatic retrieval of forecast models

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Extension of model index

- Model index represents conditions of forecast query
- Support functional dependency in index structure
  - Functional dependency is induced by foreign key or manually (red arrows):

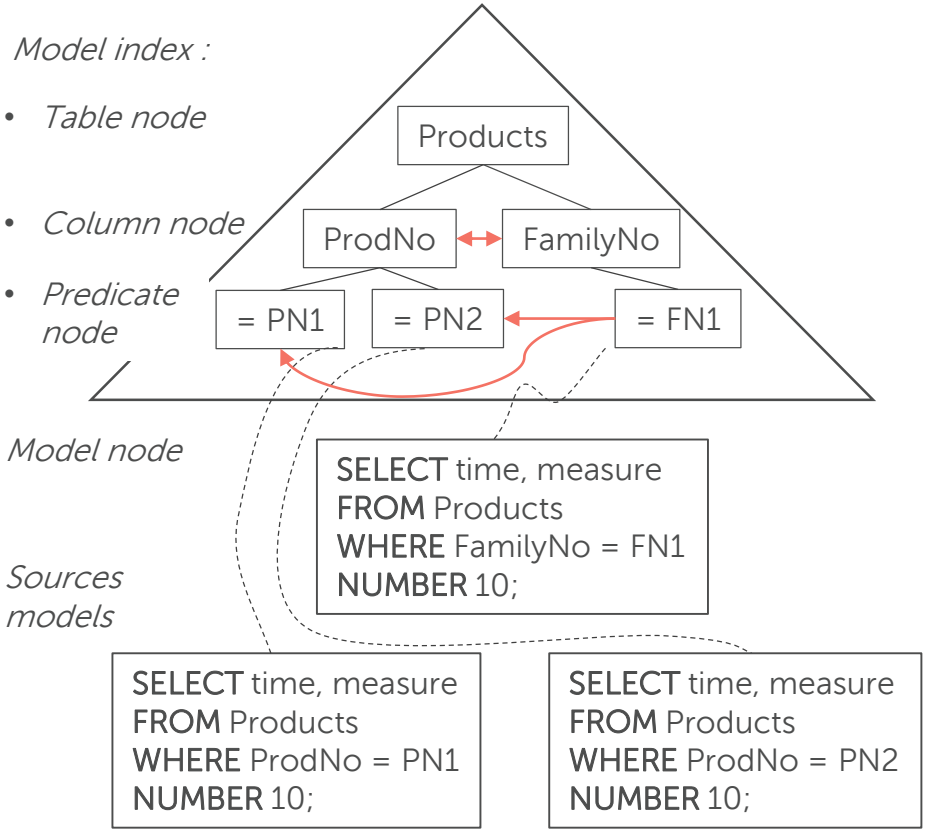
```
CREATE HIERARCHY 'Family' (
        ProdNo CHILD OF FamilyNo
) ON (SELECT * FROM Products);
```

Application to Aggregation (cf. figure)

- Find inferior dimension level and predicates
- The set of found models form the source models of an aggregation model
- Recursive: inferior model can be aggregation model

Application to Disaggregation

- Find superior dimension level and predicate
- The found model is the source model of a disaggregation model



New Maintenance tasks

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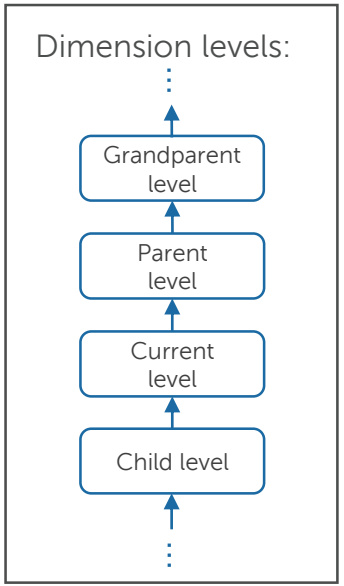
Maintenance of derivation weights

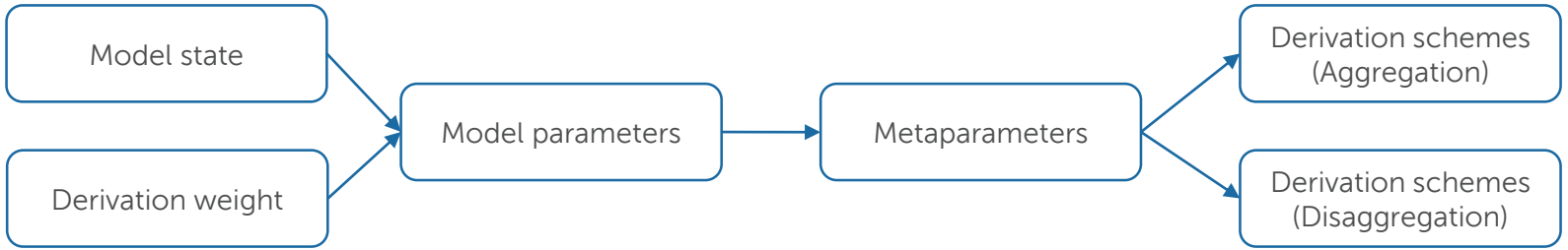
- Update of derivation weight after each new timestamp
- Task is done during tuples insert because it is fast

Maintenance of derivation schemes

- Create and evaluate derivation model of both derivation schemes in all dimensions
  - For evaluation, consider only the parent level (next higher level) and child level (next lower level)
- The derivation model with the highest accuracy is chosen for forecasting the time series
- Complex task that needs the temporary creation of source models of all derivations candidates and is time-consuming



Summary of maintenance tasks



Evaluation

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Motivation

- Evaluate that derivation models can increase or maintain forecast accuracy
- Evaluate that number of forecast models can be reduced

Data set "Tourism"

- Domestic overnight trips of Australians
- Quarterly observations from 1999 to 2014
- Time series in two dimensions
  - Purpose (holiday, business, visiting friends, other)
  - Location, representing the State (New South Wales, Queensland, ...) and Region (Sydney, Blue Mountains, ...)
- 228 base time series + 112 time series for higher dimension levels = 340 time series

Procedure

- Build forecast models for 340 time series, training period 1999 to 2002
- Insert time series from 2003 to 2014
- Trigger Maintenance tasks

Limits	Value	Notice
Error limit	SMAPE = 24 %	-
Time limit (minimum)	4	One year
Time limit (maximum)	-	-

Evaluation

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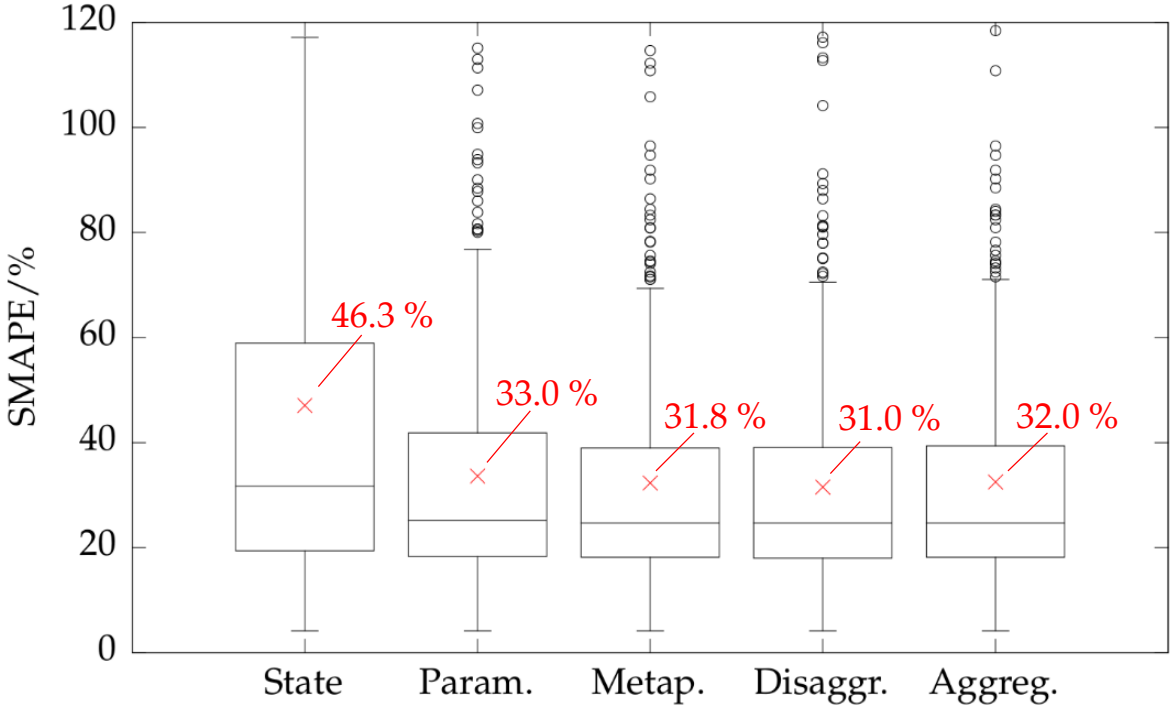
All time series from tourism

- Compare usage of maintenance tasks and forecast error on 48 measuring values



Comments

- Box plot show 5 Maintenance tasks switched on one by one
- Either Disaggregation or Aggregation is used
- Forecast error is relative between 0 % and 200 %

Conclusion

- Usage of disaggregation keeps or increases forecast accuracy
- Comparing to other maintenance tasks (modelparameter, metaparameter) the effect is rather small

Evaluation

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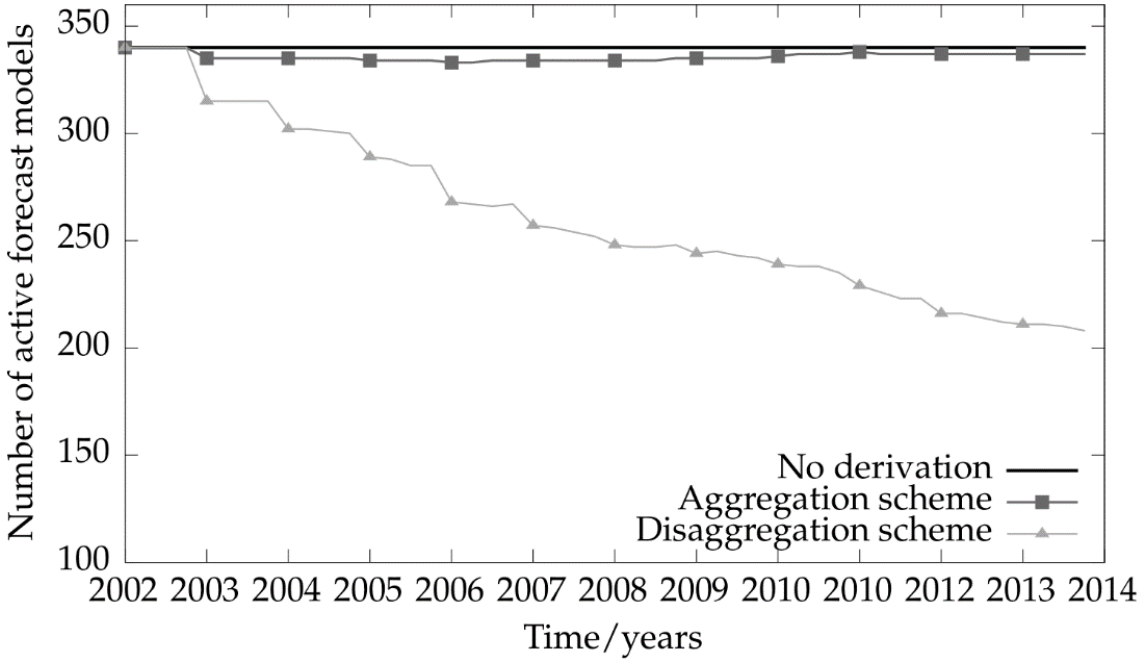
All time series from tourism

- Measure how many forecast models are in use at each timestamp
- Show the usage of derivation schemes that reuse models



Conclusion

- Aggregation is not successful for Tourism, direct models are switched on again
- Disaggregation allows reuse of many models
- There are more timeseries which can use a disaggregation model than an aggregation model

Agenda

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Problem	Concept presented in this work
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▪ User has different accuracy expectations on forecast models ▪ System has general accuracy assumptions only	▪ Accuracy classes for forecast queries ▪ Priorization of maintenance tasks for queried forecast models
▪ High system load causes maintenance tasks to slow down ▪ The delay of forecast queries increases	▪ Limit maintenance component to a maximum of load ▪ Provide maintenance of queried models during high system load

User-defined accuracy classes

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Criteria in selecting forecasting technique [cf. Yokuma and Armstrong, 1995]

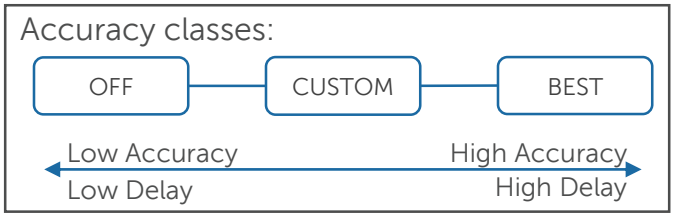
- Accuracy, cost savings from improves decisions, ease of interpretation, ease of use, maintenance cost,...
- Most important: Accuracy and Timeliness (Delay) in providing forecasts

User-defined accuracy classes

- Provide user ability to weigh most important criteria in given forecast query
- BEST: Provide best forecast accuracy that is possible but take into account a delay for maintenance tasks
- OFF: Expect fastest forecast query and ignore any maintenance task, risk of higher forecast error
- CUSTOM: User provides error limits and expected maintenance tasks

Measuring Criteria

- Forecast accuracy: As before, accuracy is measured as forecast error since the last model estimation
- Timeliness in providing forecast: Query time of forecast query



Implementation

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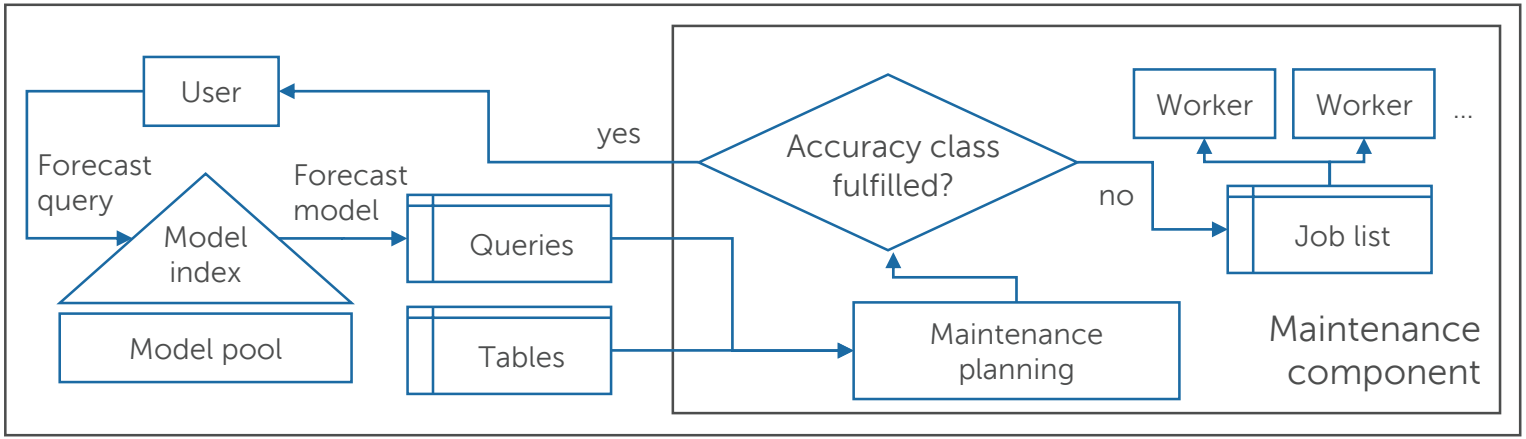
Extension of Maintenance component



Priorization of forecast queries

- During query periods, the maintenance component evaluates only queried tables
- Priorization of maintenance tasks of queried forecast models
  - Evaluation is done before evaluation of non-queried forecast models
  - Creation of a Job list with Priority that is served before Job list without priority

Evaluation

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Motivation

- Compare influence of accuracy classes on forecast error and query delay
- Evaluate that CUSTOM allows gradual changes

Procedure

- Build forecast models for 340 time series of Tourism, training period 1999 to 2002
- Insert time series from 2003 to 2012, maintenance tasks supported, derivation scheme is disaggregation
- Forecast query for each model
  - Forecast accuracy on forecast 2013 to 2014, expressed as relative error measure
  - Query time is delay in maintenance component
- Increase accuracy class

```
SELECT time, measure FROM Tourism
WHERE state = 'New South Wales'
GROUP BY time ORDER BY time NUMBER 8
MAINTENANCE CUSTOM (
        MAX_ERROR 24, MAX_TIME 16
) OPERATIONS (
        MODELPARAMETER, METAPARAMETER
);
```

Accuracy class	Highest maintenance task	Error limit / SMAPE
OFF	Model state	-
C1	Model parameter	24 %
C2	Metaparameter	24 %
C3	Derivation	24 %
C4	Model parameter	12 %
C5	Metaparameter	12 %
C6	Derivation	12 %
BEST	Derivation	-

Evaluation

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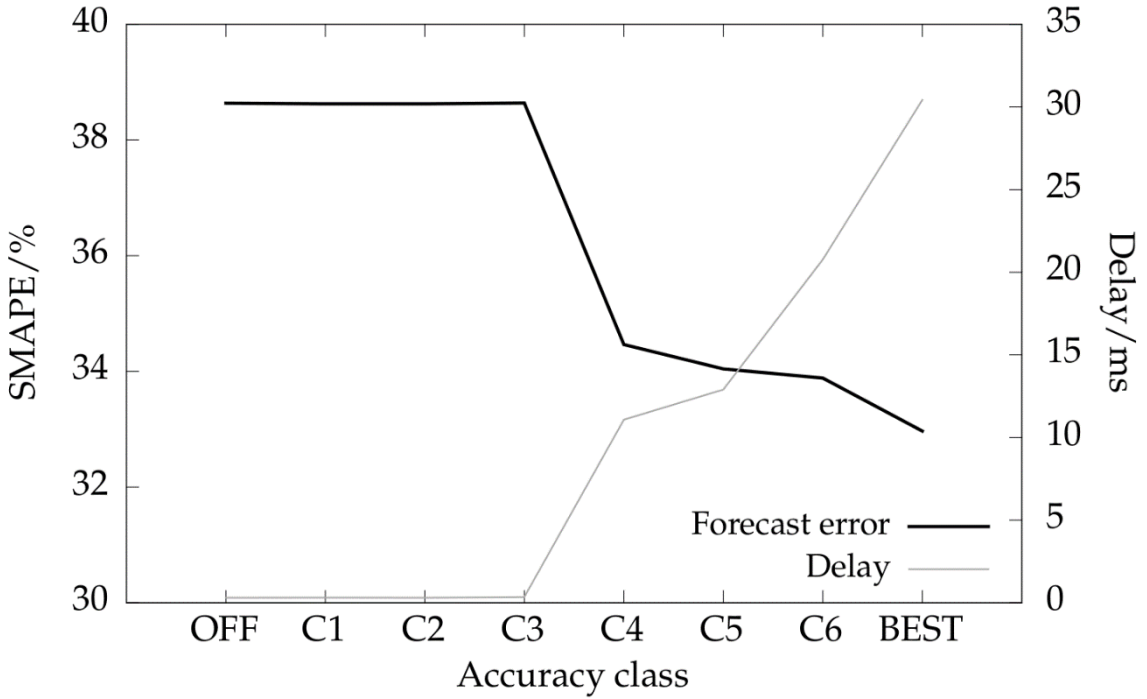
Results of User-defined accuracy classes



Conclusion

- Forecast accuracy and Query time are opposed criteria, the user must weigh their importance
- Accuracy classes are more accurate than the system given error and time limits

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Load-controlled maintenance component

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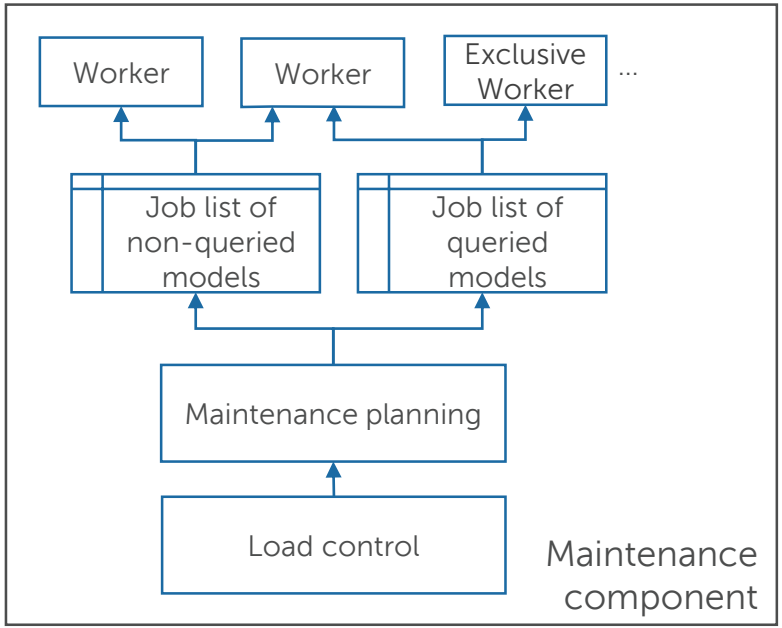
Representation of system load

- Process load represents the active clocks of each processor
- Average load represents the number of active or waiting processes in a period of time (1 minute)
- *In Unix system, Average load is a commonly used representation*

Load control in Maintenance component

- High system load is due to maintenance tasks
- During high load, limit parallel maintenance tasks by reducing number of workers for non-queried forecast models
- Exclusive workers accept jobs for queried models only and assure a fast service



Evaluation

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Effects on system load

- Evaluate that controller reduces system load
- Evaluate that it sets workers exclusive

Data set "Wind"

- Energy supply data of 1326 US wind plants from 2004 to 2006 and a high resolution (10 minutes)
- Dimension Location (US states) allows derivation models
- 1326 base time series + 35 time series for higher dimension levels = 1361 time series

Procedure

- Build forecast models for all time series, training period from 2004 to 2005
- Insert time series for January and February 2006, maintenance tasks are triggered
- Avoid hard drive access by buffering time series in main memory

Limits	Value	Notice
Error limit	SMAPE = 14 %	-
Time limit (minimum)	1008	One week
Time limit (maximum)	4320	One month

Evaluation

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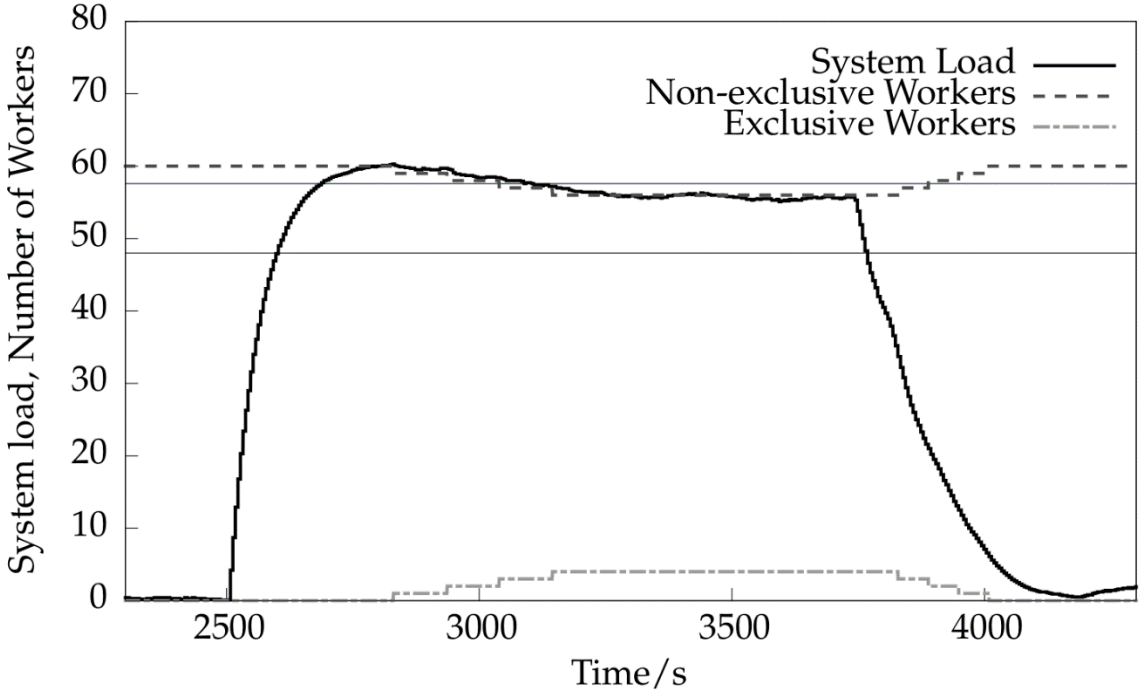
Effects on system load



Limits	Value
Upper limit	57.6
Lower limit	48
Delay of action	60 s

Conclusion

- During high load, the controller reduces system load under given limit
- Exclusive workers don't cause load that's why the system load is stable

Evaluation

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Effects on query delay

- Create {1,10,20} users sending continuously queries to the system
- Measure query delay of forecast models that are maintained, other models pass quickly

Conclusion

- Exclusive workers allow a faster service to forecast queries during high system load

Agenda

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Problem	Concept presented in this work	
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▪ High system load causes maintenance tasks to slow down ▪ The delay of forecast queries increases.	▪ Limit maintenance component to a maximum of load ▪ Provide maintenance of queried models during high system load	✓

Outlook

Maintenance of derivation schemes

- During evaluation of derivation models, source models have to be built temporarily
- *Avoid this time-consuming action by buffering old forecast values or by backcasting*

System load definition

- Former evaluation relies on buffering time series in main memory
- Hard drive access avoid scalability, high system load would be never reached
- *Formulation of system load considering hard drive access*

Forecast model for query rate

- In practice, the query rate is not fixed
- Analyze query rate and create a forecast model that predicts its immediate future
- *Provide exclusive workers in advance if high query rate is expected*

The End

Evaluation on real data

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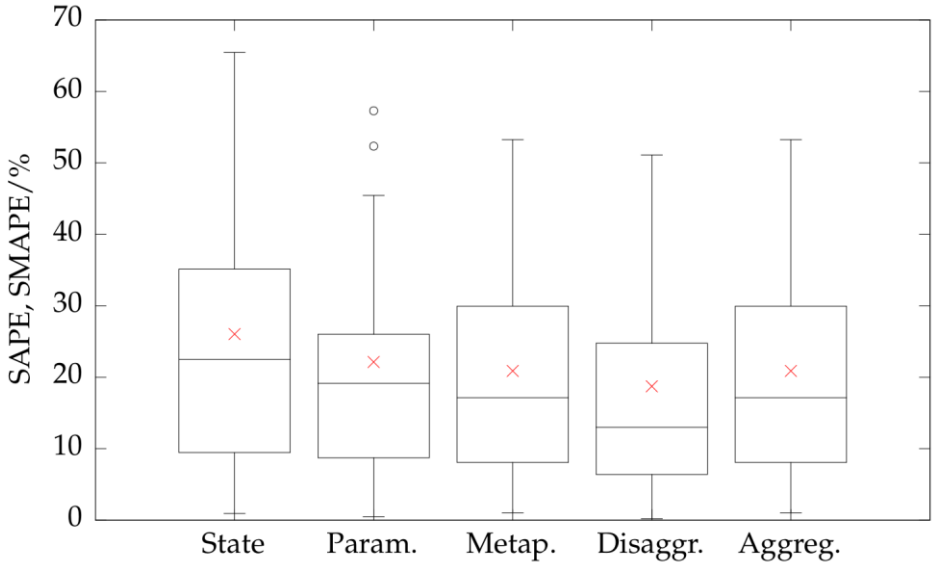
Single time series from tourism

- Compare usage of maintenance tasks and forecast error on J = 48 measuring values
- Forecast error is given as symmetric average percentage error $\text{SAPE} = 200 \cdot \frac{|x_T - \hat{x}_{T-1,1}|}{|x_T| + |\hat{x}_{T-1,1}|}$
- Mean of measuring values is given as $\text{SMAPE} = 200 \cdot \frac{1}{J} \sum_{j=1}^{J} \frac{|x_{T+j} - \hat{x}_{T+j-1,1}|}{|x_{T+j}| + |\hat{x}_{T+j-1,1}|}$



Analysis

- Decreasing mean (red cross), median, quartiles if maintenance tasks are allowed
- Usage of disaggregation model after one year
- No usage of aggregation model
- Outlier Q3 of Metap. due to wrong metaparameter estimation in 2004, correction after 1 yr

Conclusion

- Usage of disaggregation can increase forecast accuracy
- Derivation scheme enables to ignore own forecast model

Interval forecast

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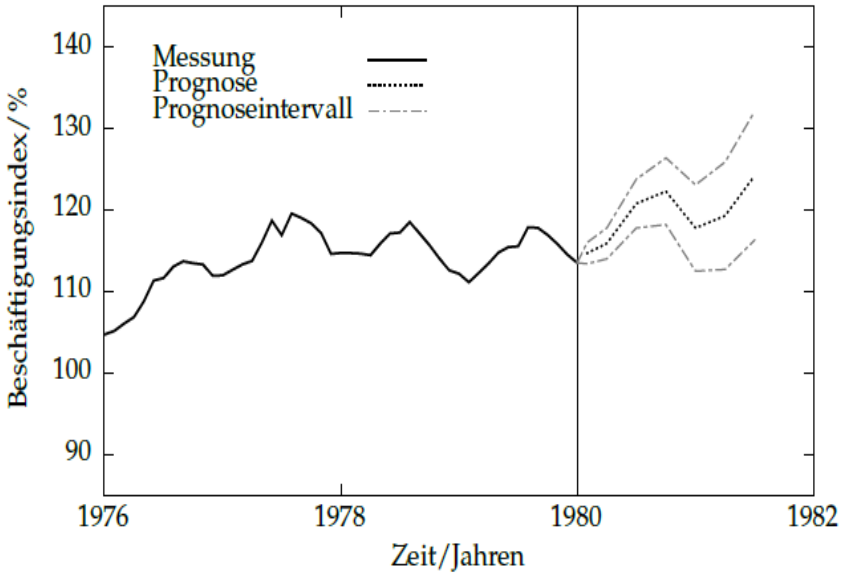
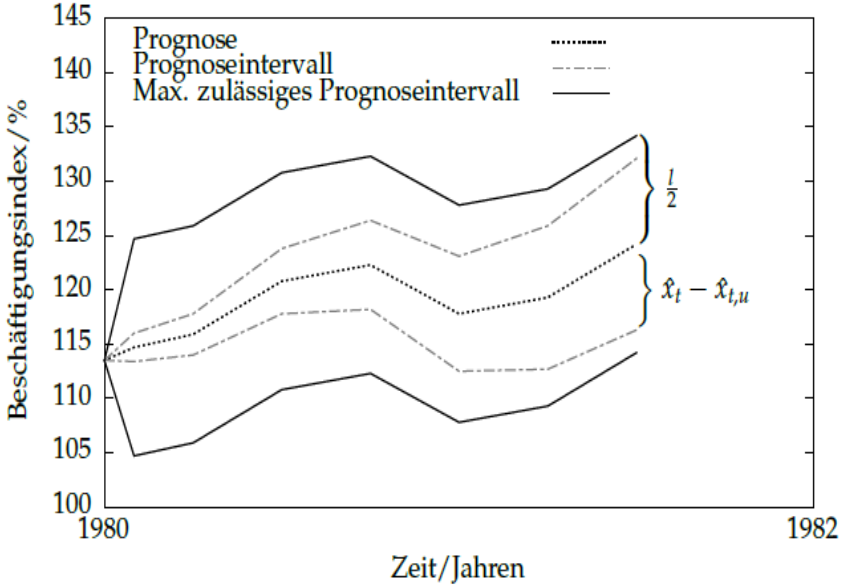
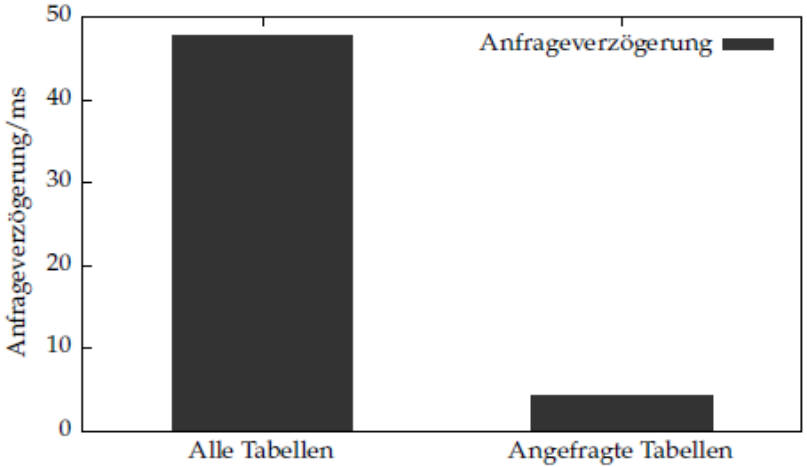
GIVE TWO PARAMETERS

- α ... Probability of forecast interval ("It's 1-α sure that the forecast value is within the interval")
- l...maximum size of forecast interval, if forecast interval is to large, it's rejected

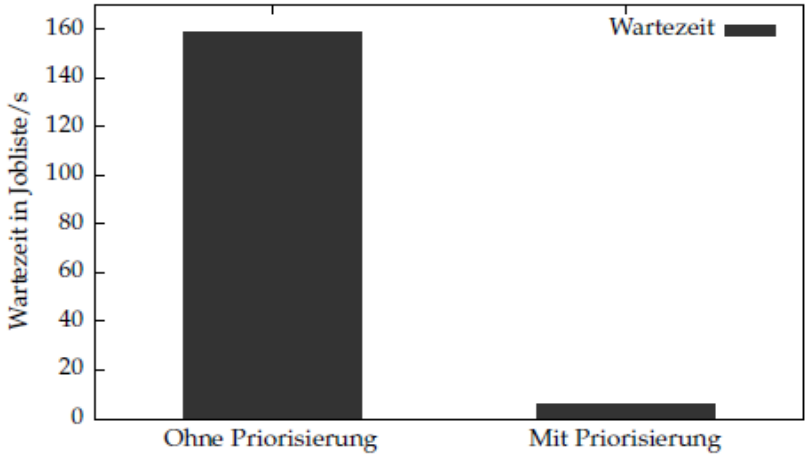




Priorization



(a) Zustandswartung angefragter Tabellen



(b) Priorisierung von Jobs

Abbildung 4.5: Minimierung der Anfrageverzögerung

Load-controlled maintenance component

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Realization as three-point controller

- If current system load z exceeds upper limit z_u, then set exclusive workers
- If current system load decreases z_l, then reset workers
- Short delay time, waiting for reaction of control