



# SHIFTTREE:

## AN INTERPRETABLE MODEL-BASED APPROACH FOR TIME SERIES CLASSIFICATION

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

Budapest University of Technology and Economics,  
Hungary

ECML/PKDD, 6TH SEPTEMBER 2011, ATHENS

# OUTLINE

- General concept
- Task & adaptation
- Labeling & learning
- Evaluation
- Forest methods
- Conclusion

# GENERAL CONCEPT

- Not limited to time series
  - Time series
  - Semi-structured data
  - Graphs
- Two questions:
  - „Where to look at?”
  - „What to observe?”
- Operator families
  - EyeShifter Operator(s) (ESO) 
  - ConditionBuilder Operators (CBO) 
- Dynamic attributes
- Model: sequence of simple operators / rules

# TIME SERIES CLASSIFICATION

## ○ Time series

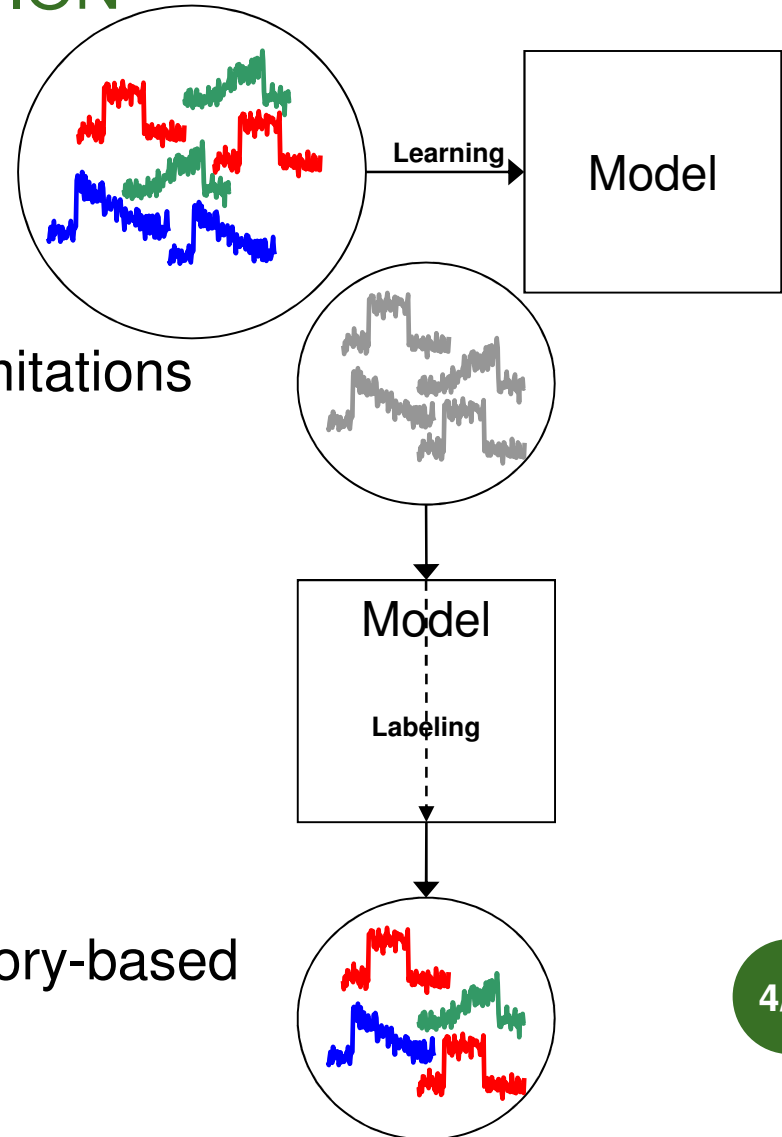
- With one observed variable
- Evenly sampled
- The algorithm has no such limitations

## ○ Standard classification task

- Focusing on accuracy

## ○ Goals

- Satisfying accuracy
- Model-based instead of memory-based
- Interpretable models



# EXPLAINING THE GOALS

- Why model-based?
  - Labeling is much faster ✓
  - Can learn more general properties of the classes ✓
  - Needs more training samples ✕
- What is interpretability good for?
  - Getting user trust ✓
  - Helping in understanding the data ✓

# CONCEPT APPLIED TO TIME SERIES

## ○ Dynamic attributes of time series

- EyeShifter Operator (ESO): „Where to look at?”

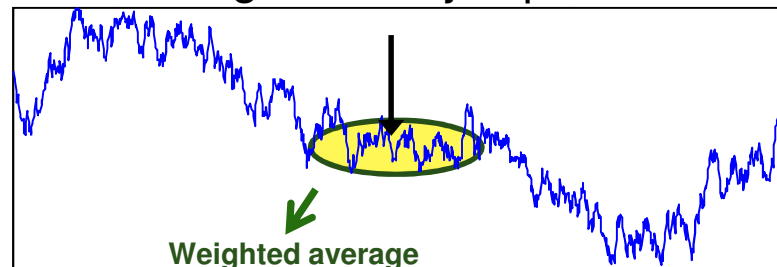


- Moves a cursor along the time axis
- To a specified point of the series
- E.g.: „To the next local minimum”, „100 steps ahead”, etc.
- Note: result of operator sequence depends on the order

- ConditionBuilder Operator (CBO): „What to observe?”



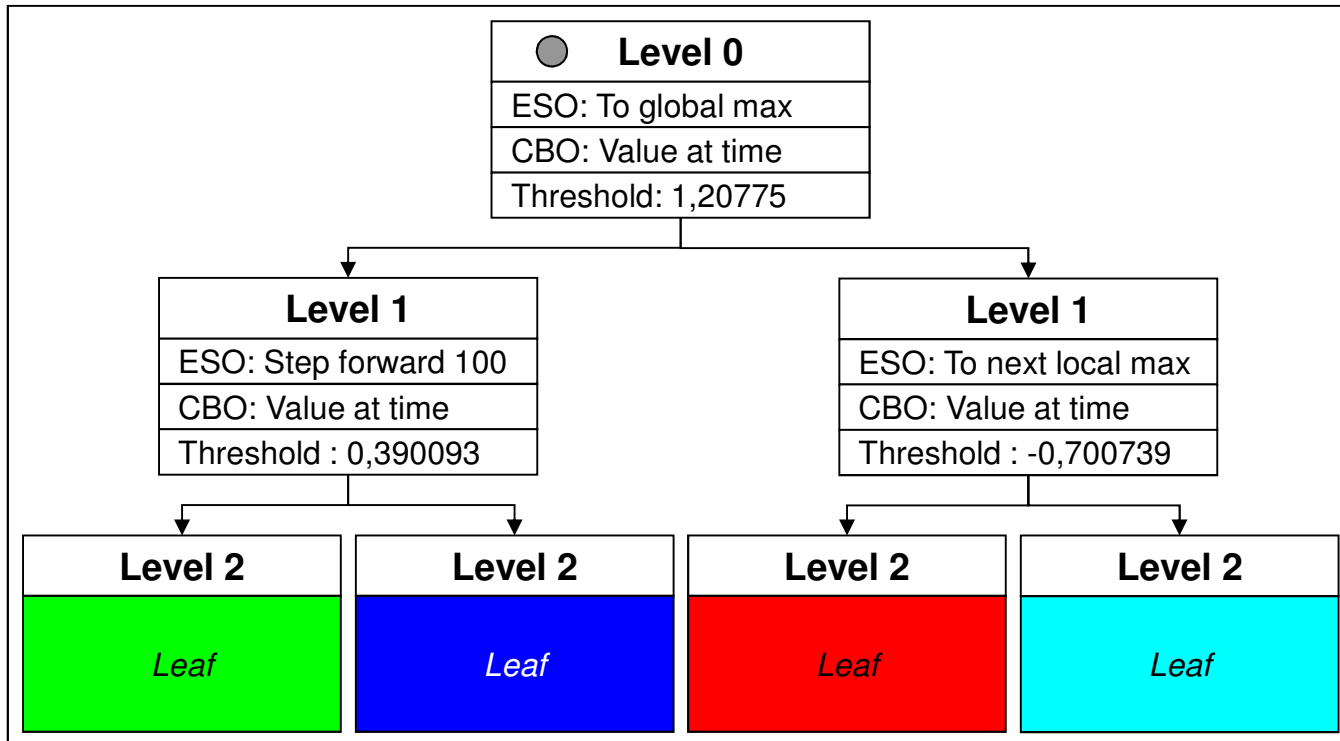
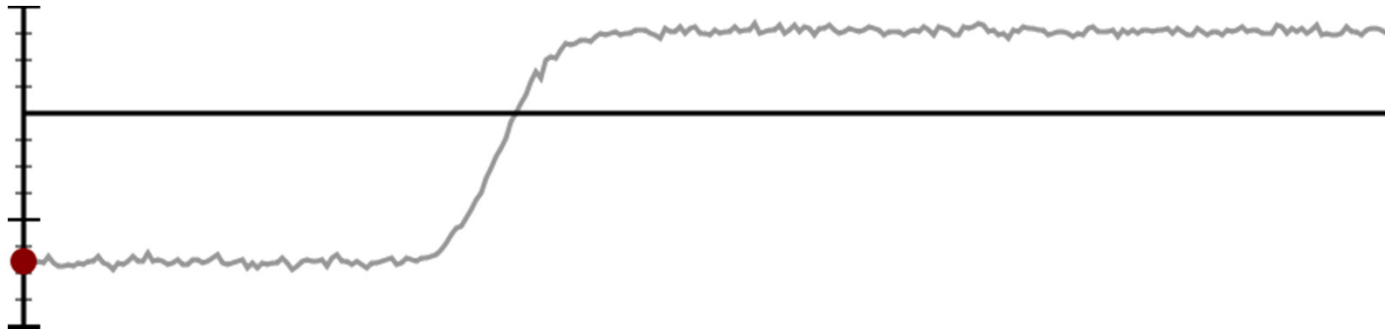
- Computes the dynamic attribute
- E.g.: „Value at the given time”, „Length of the jump”, etc.



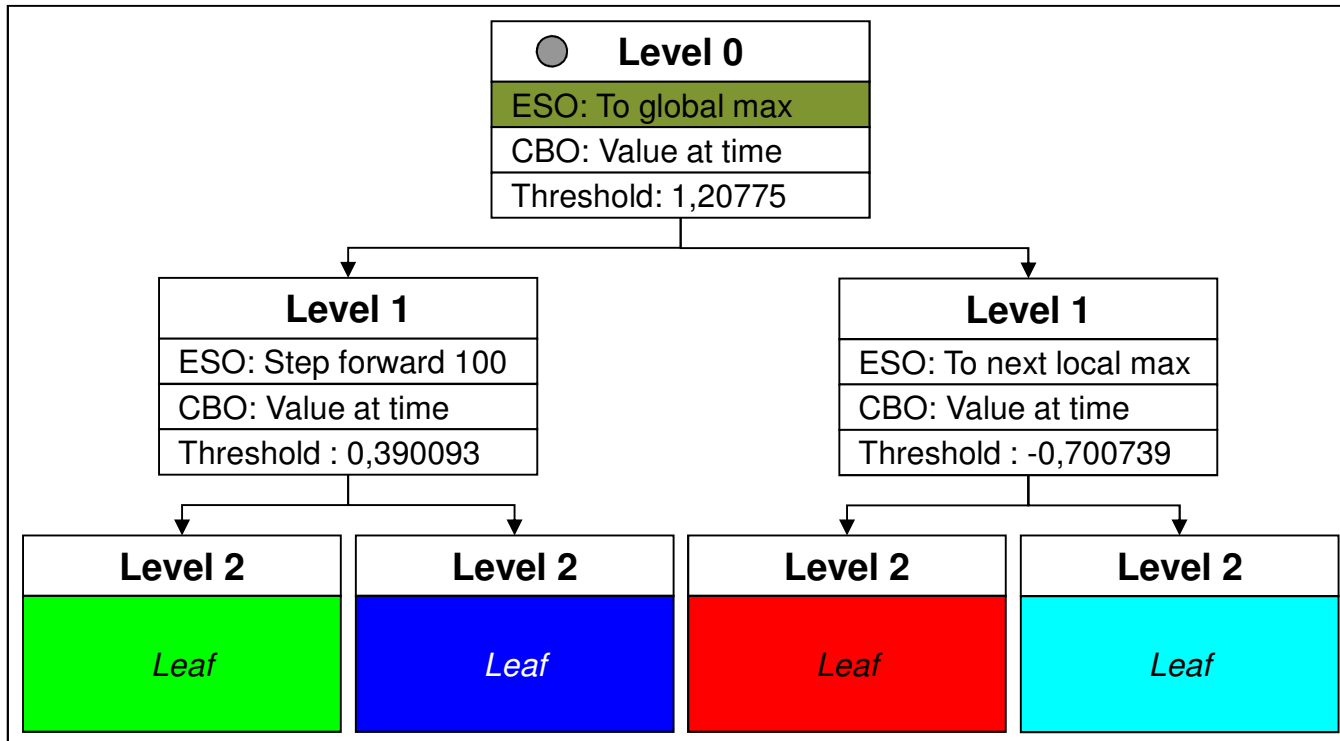
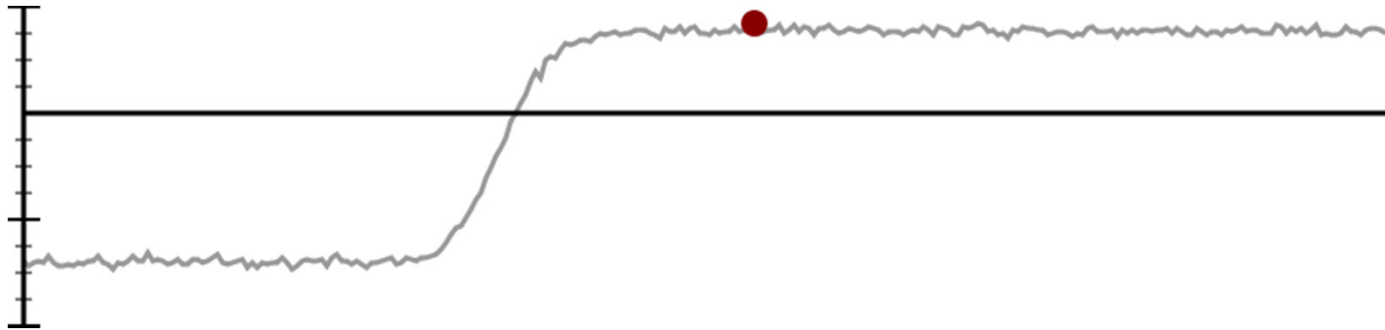
## ○ Decision tree as model

- Works well with the dynamic attribute concept
- Operator sequence from root to leaf

# LABELING

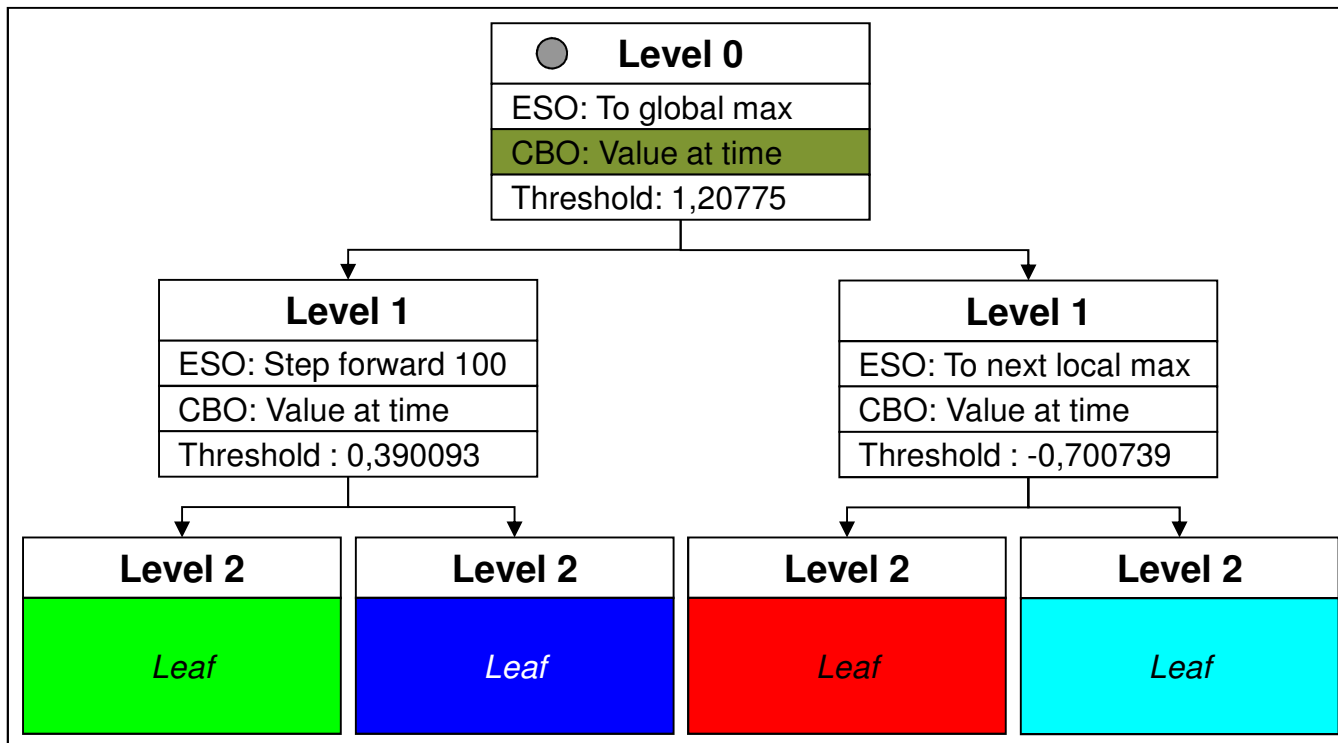
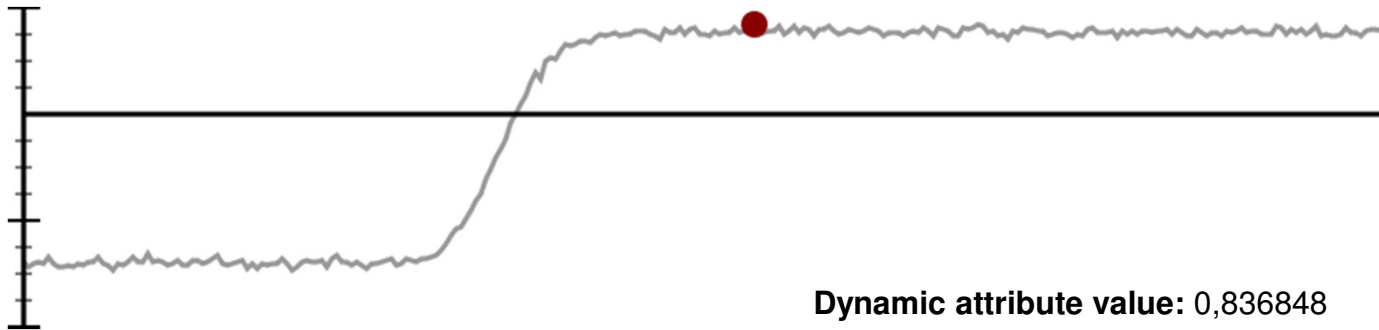


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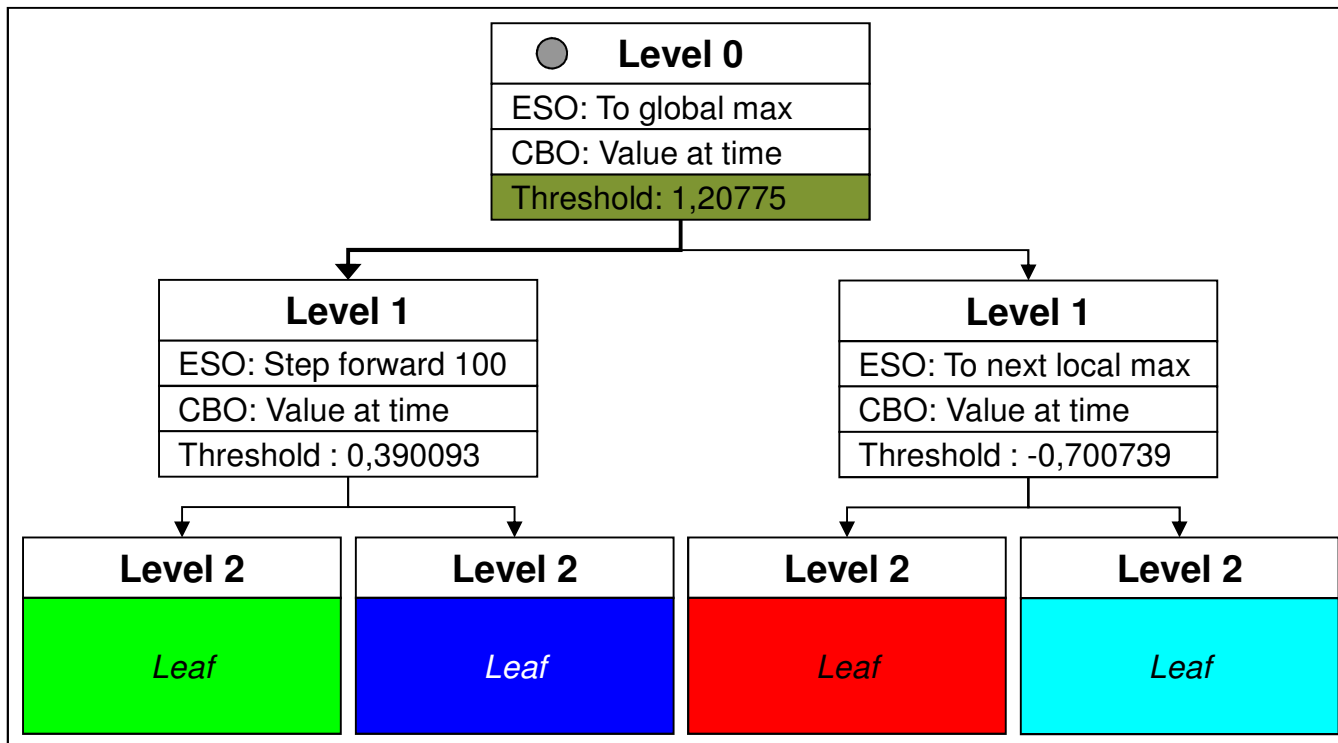
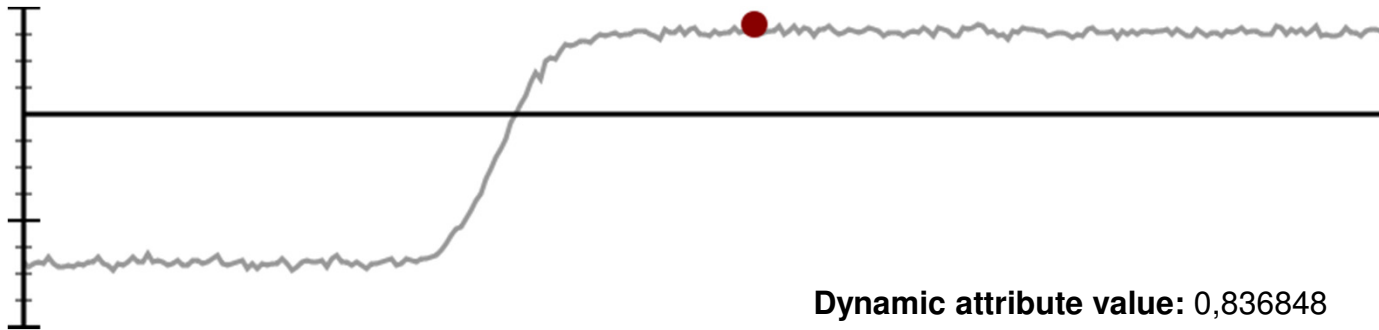




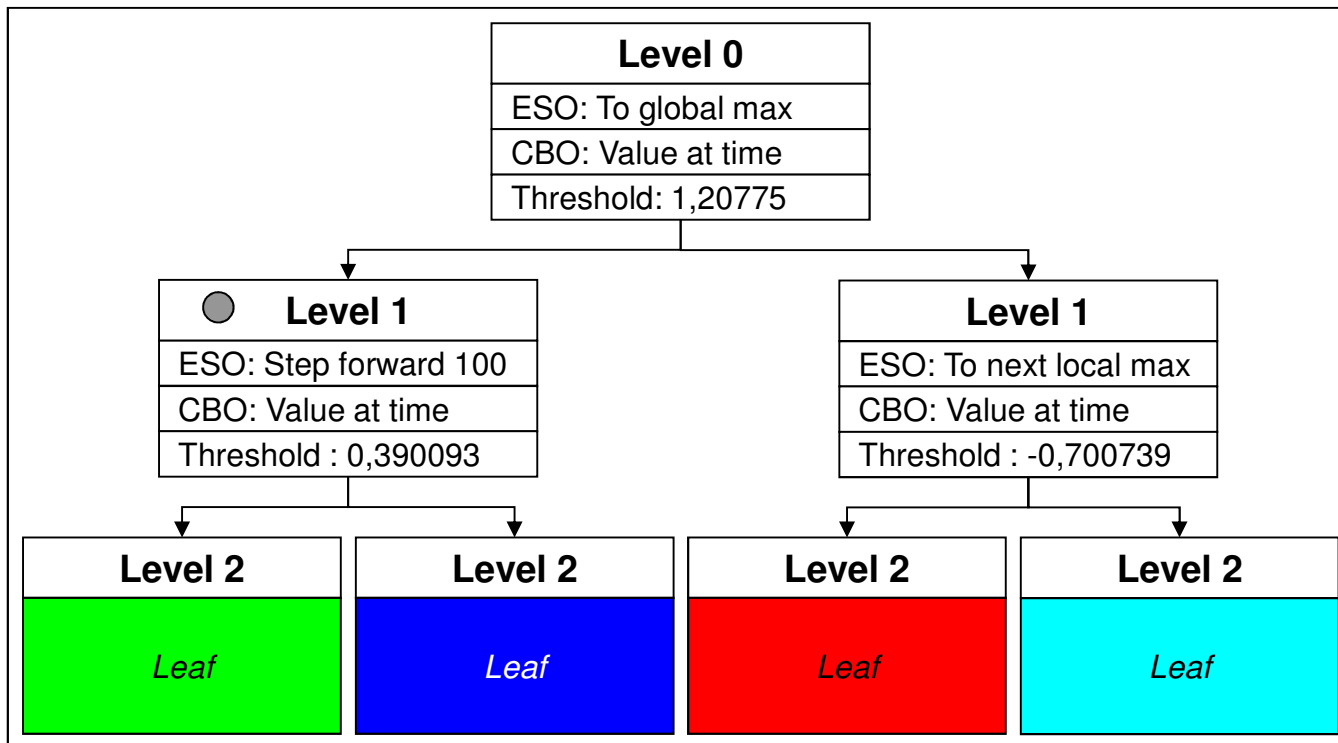
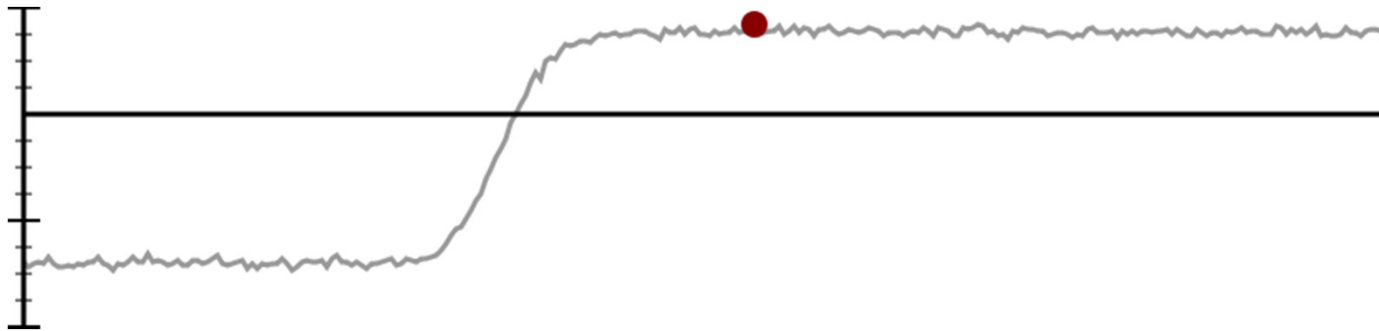
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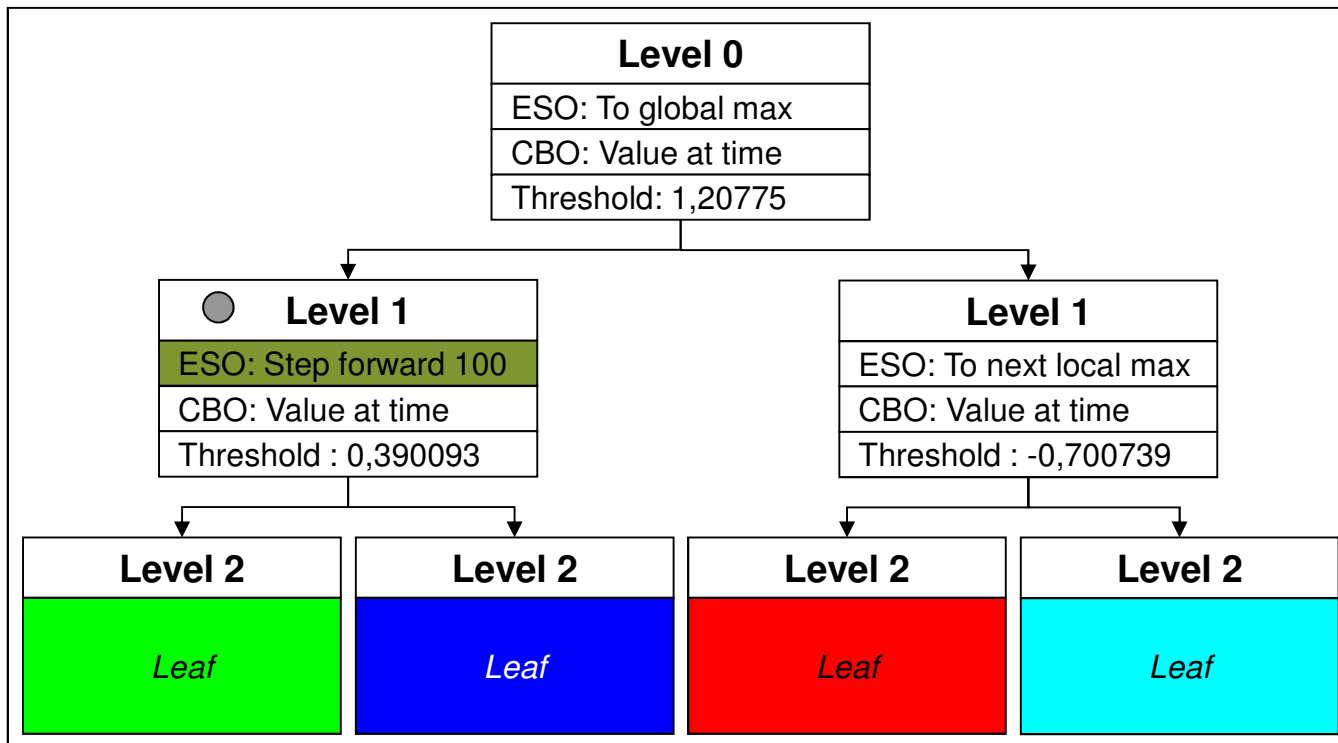
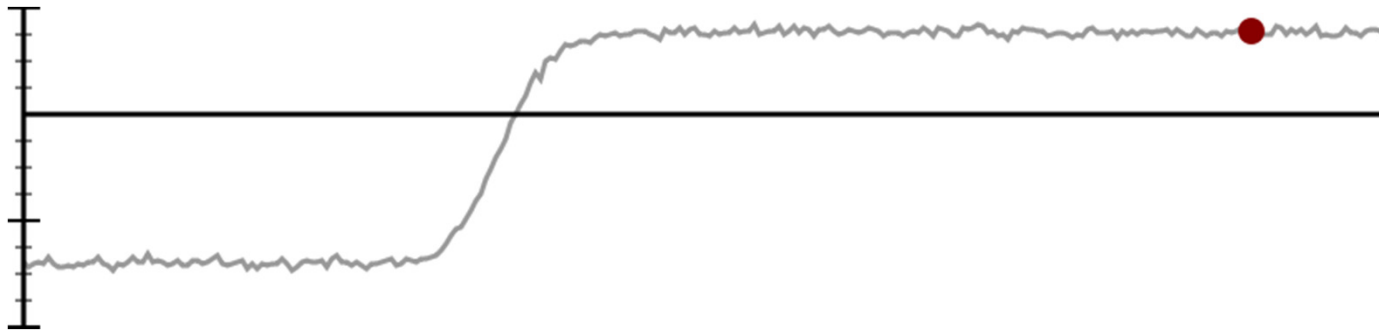
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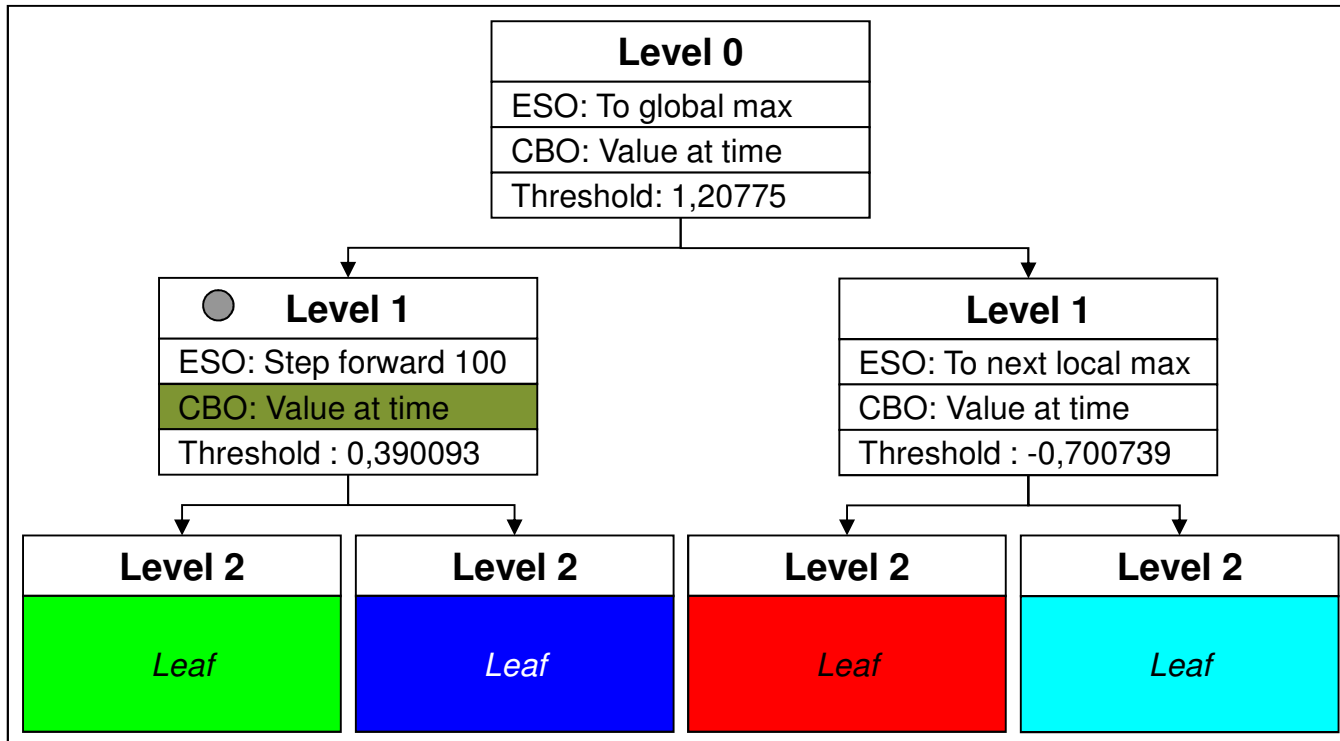
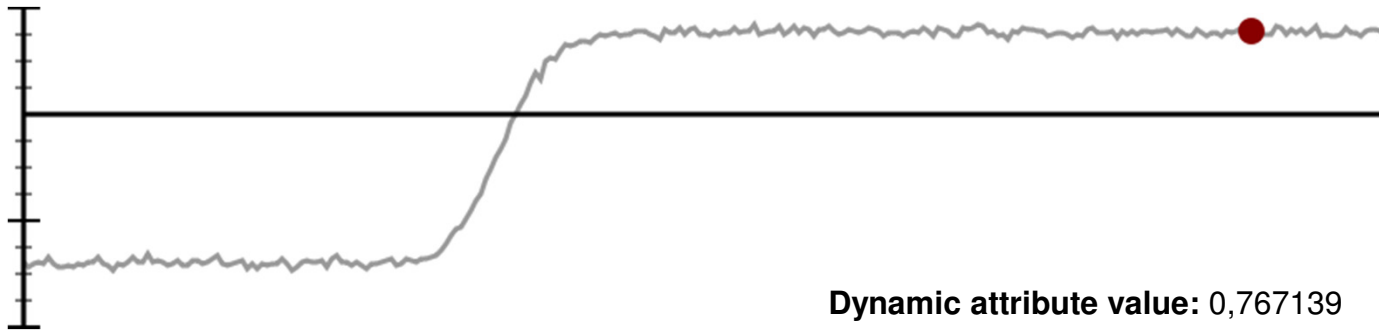
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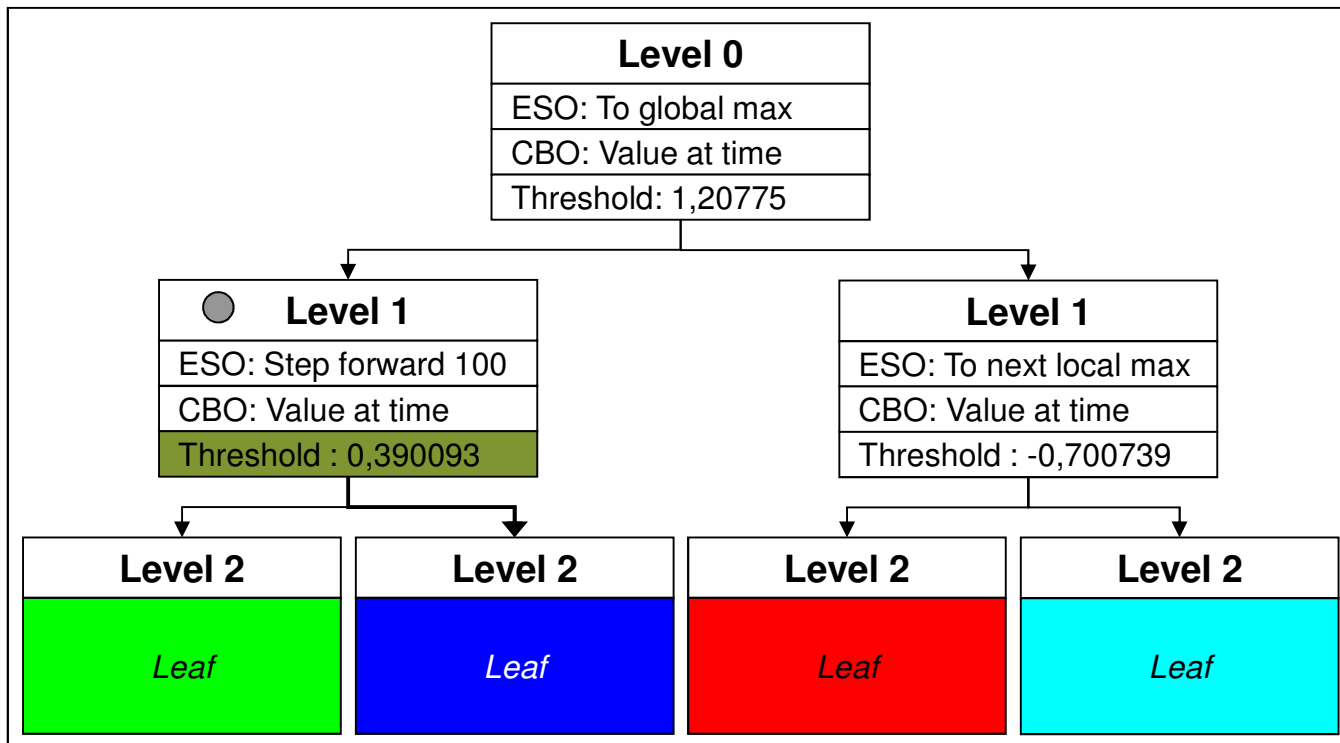
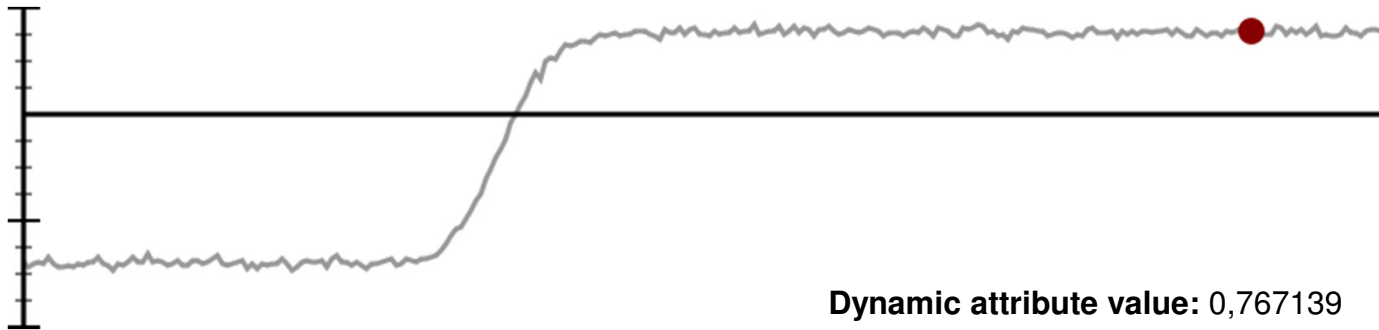
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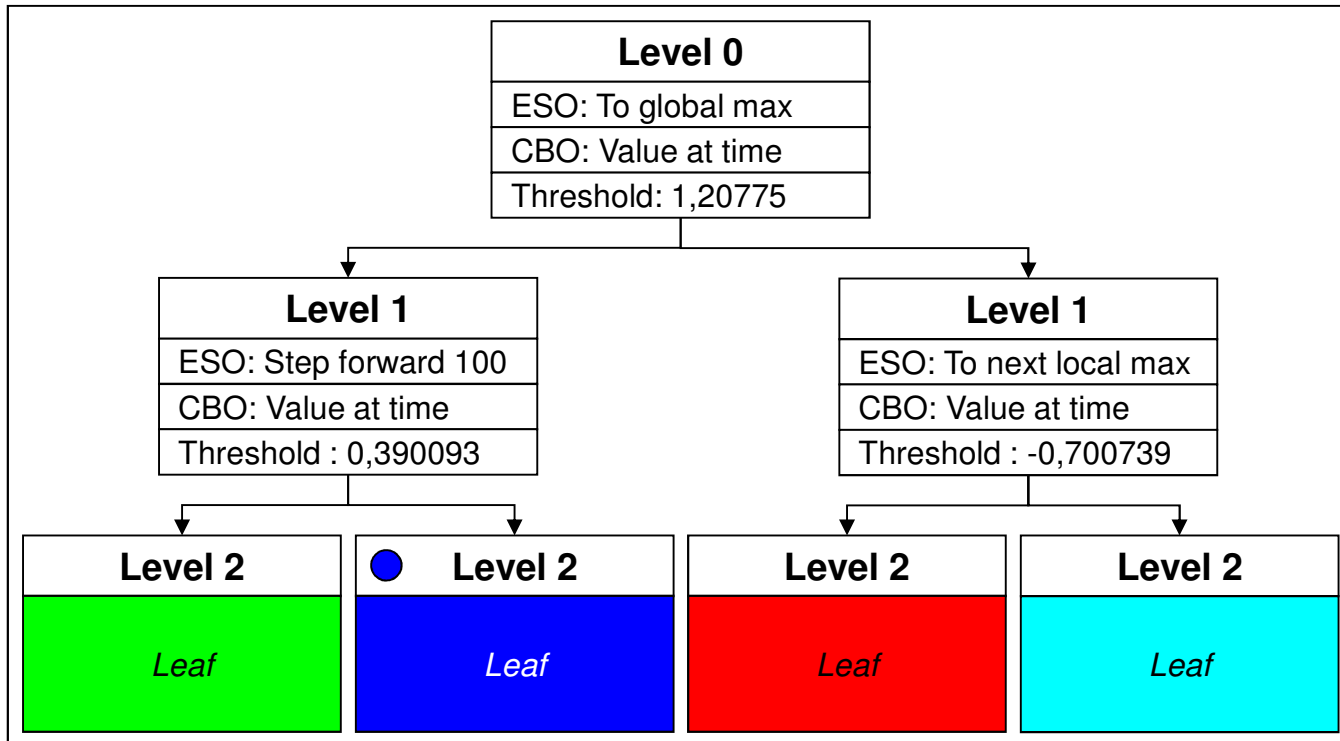
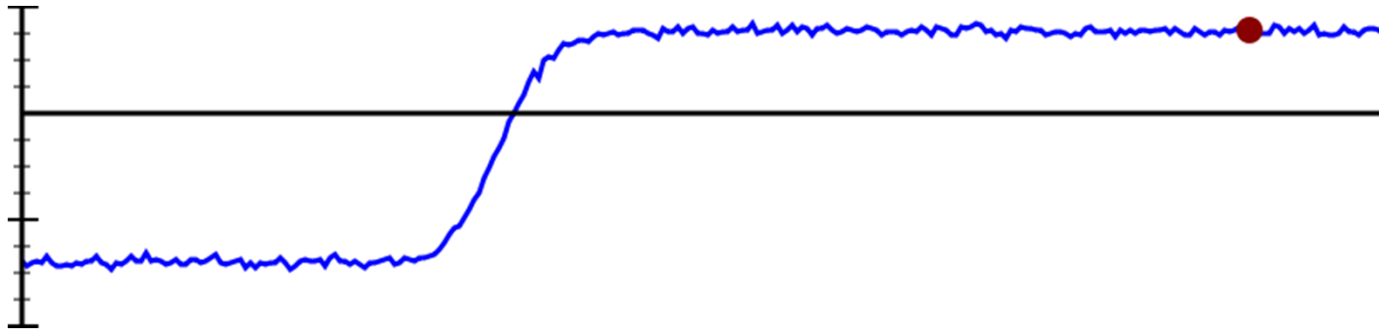
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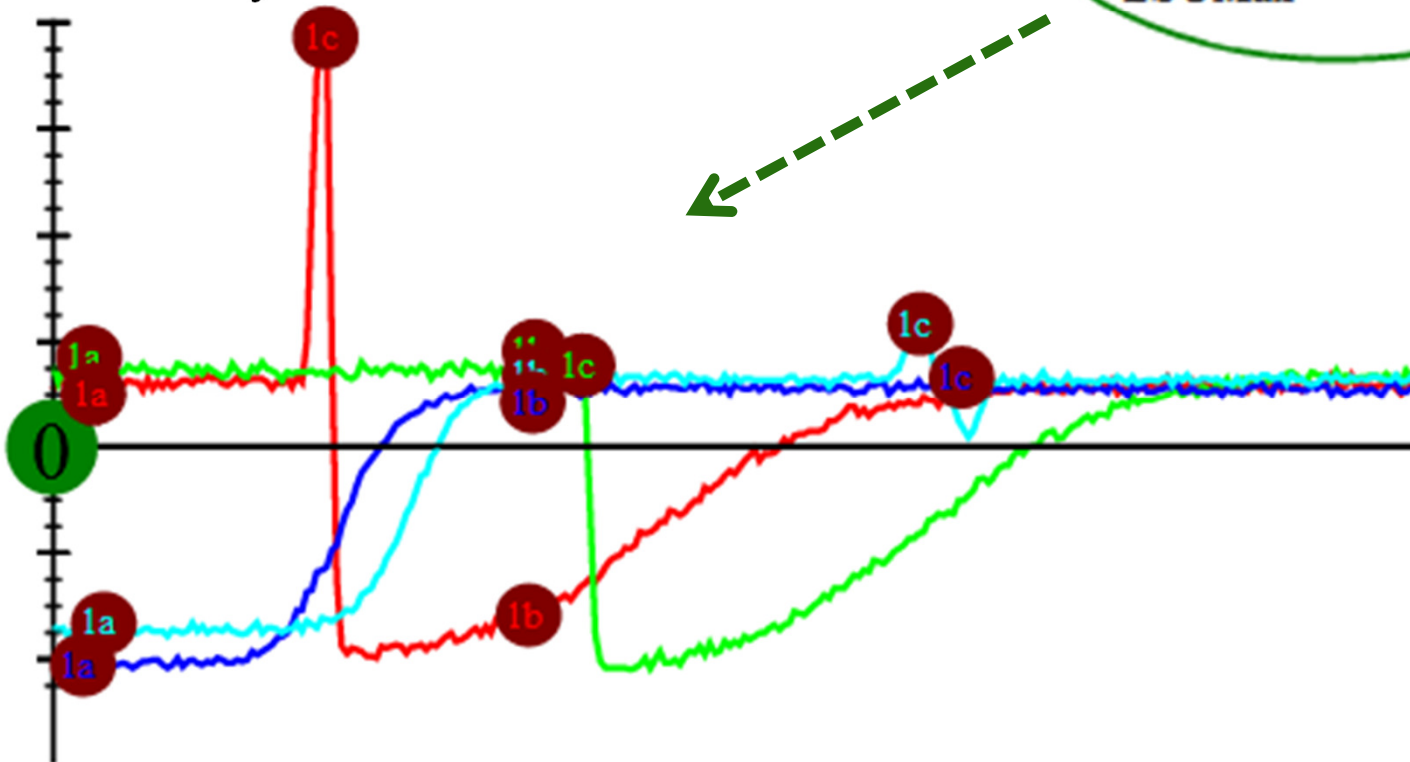
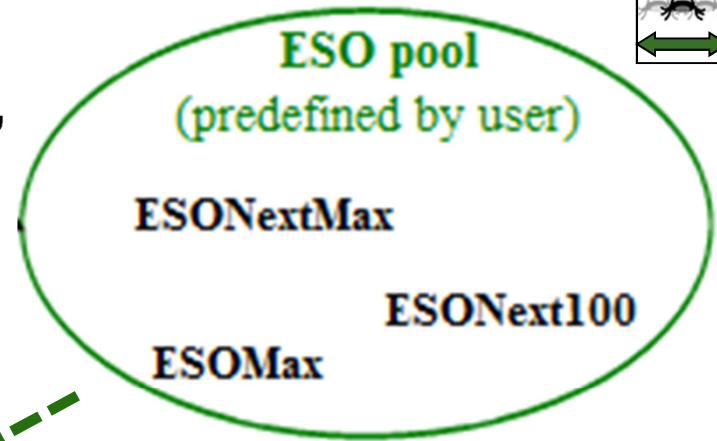


# LABELING



# LEARNING (1/3)

- Operator pool definition: ESOs,
- Root node
- Cursor starts at the beginning
  - May be overridden



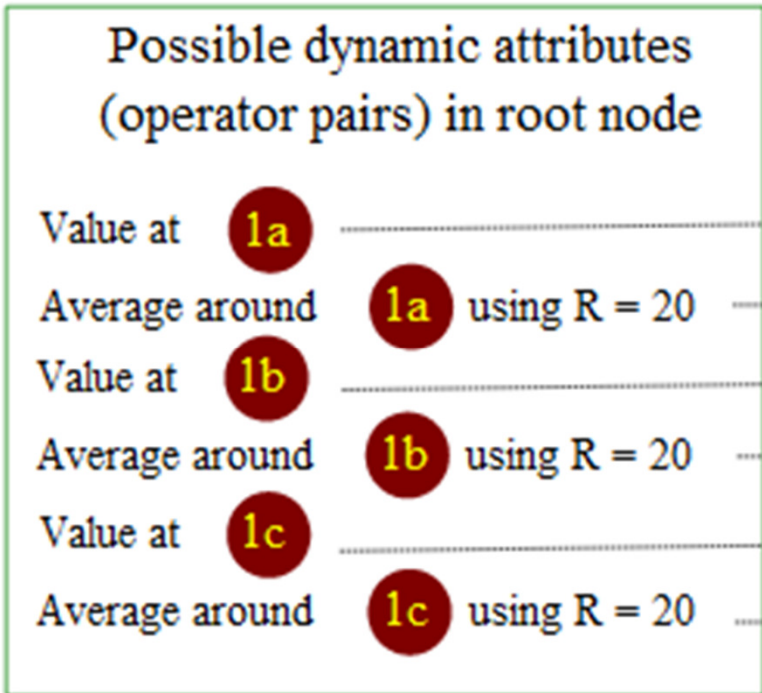
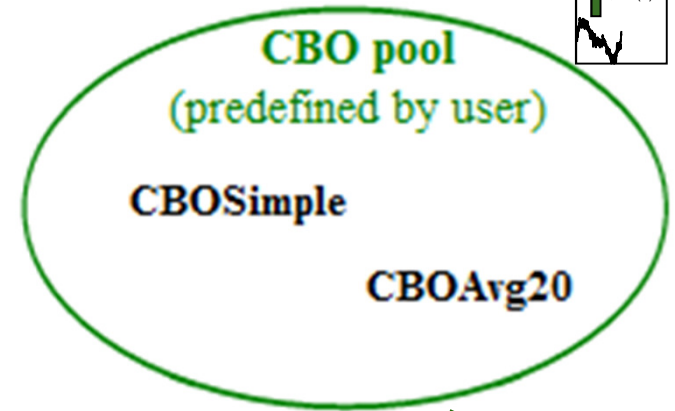




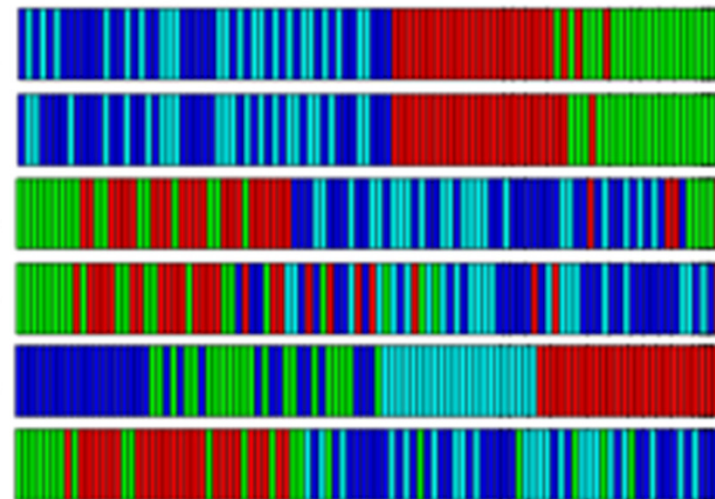
# LEARNING (2/3)

- Available dynamic attributes (CBO pool)
  - At/around reachable positions
- Selecting a...
  - Attribute
  - Threshold value

} Minimize weighted child node entropy

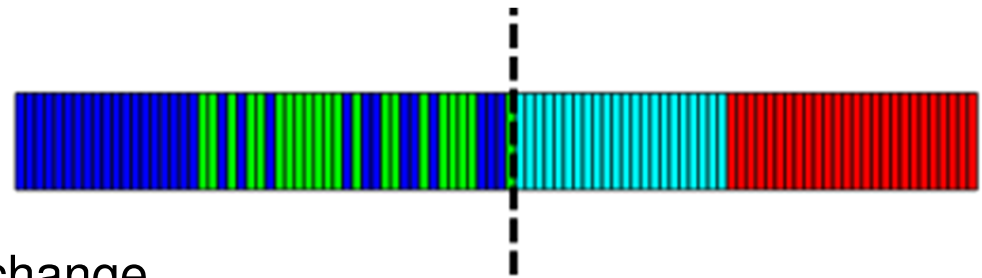


Ordering of the samples in the node by dynamic attributes

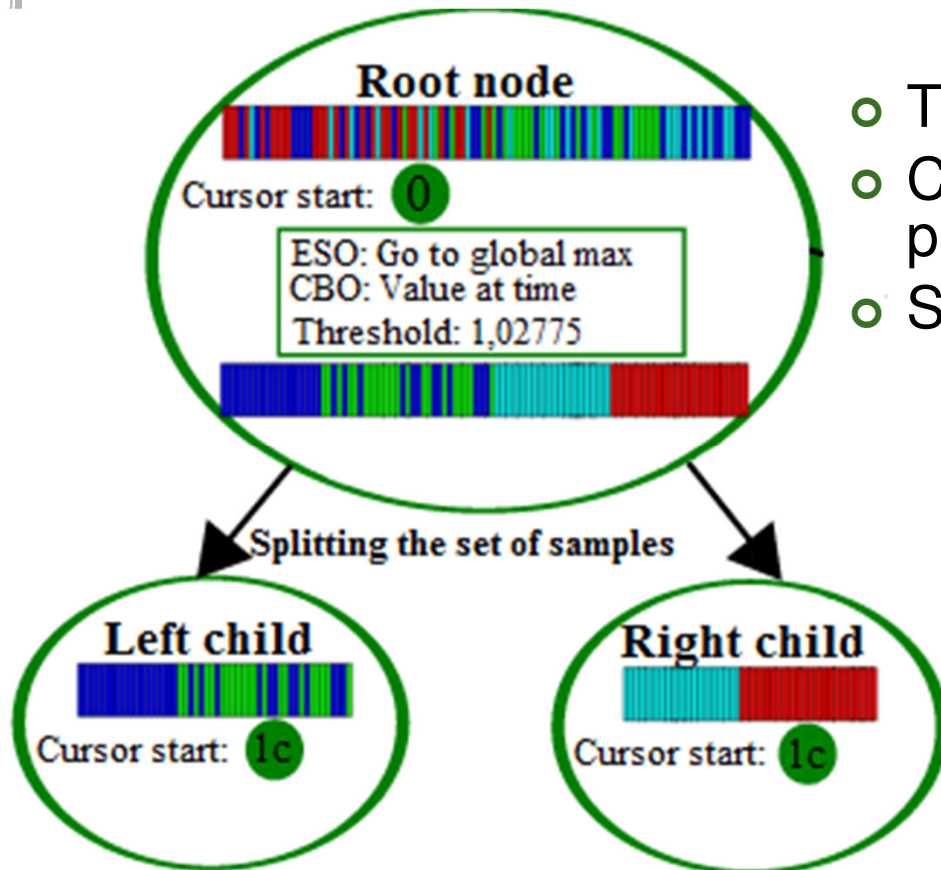


# LEARNING (3/3)

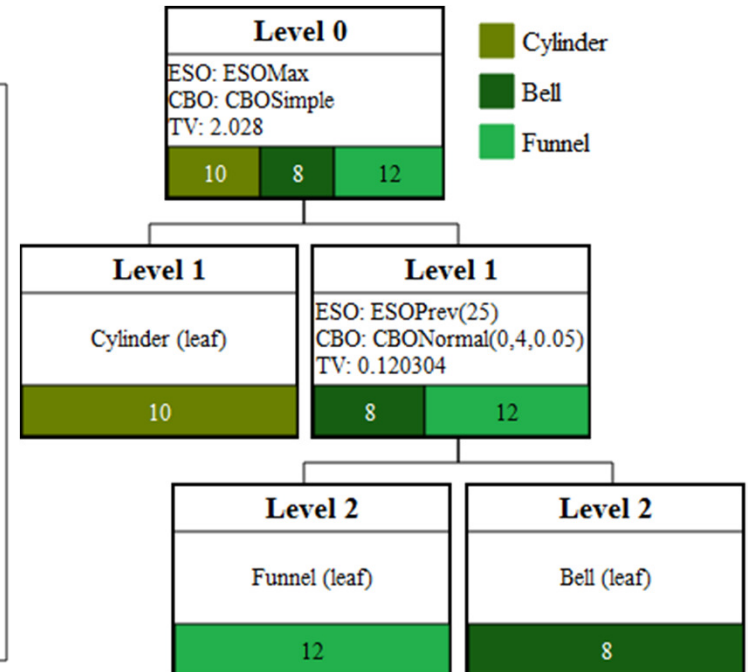
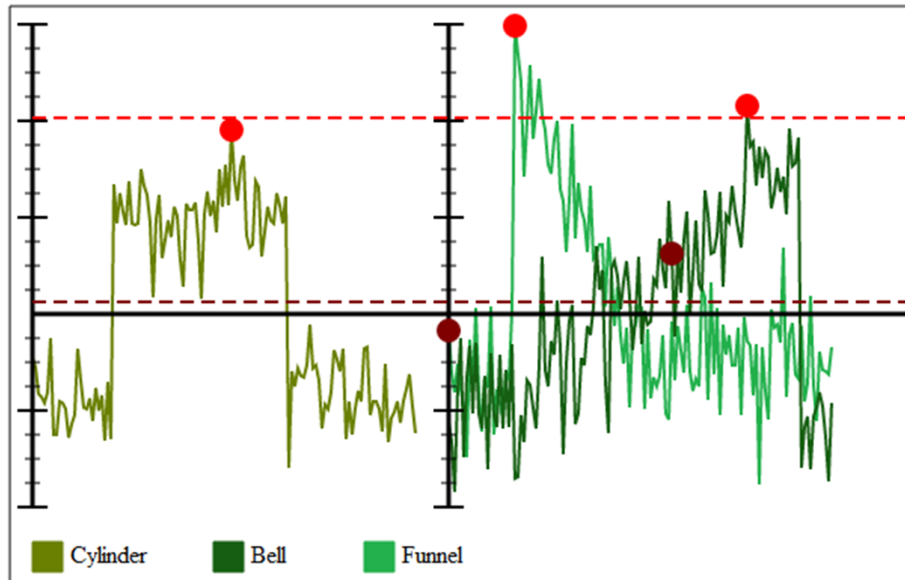
- Best split selected
- Cursor is moved by ESO
  - Reachable positions will change



- Train set split
- Child nodes continue the learning process
- Stop: homogenous nodes



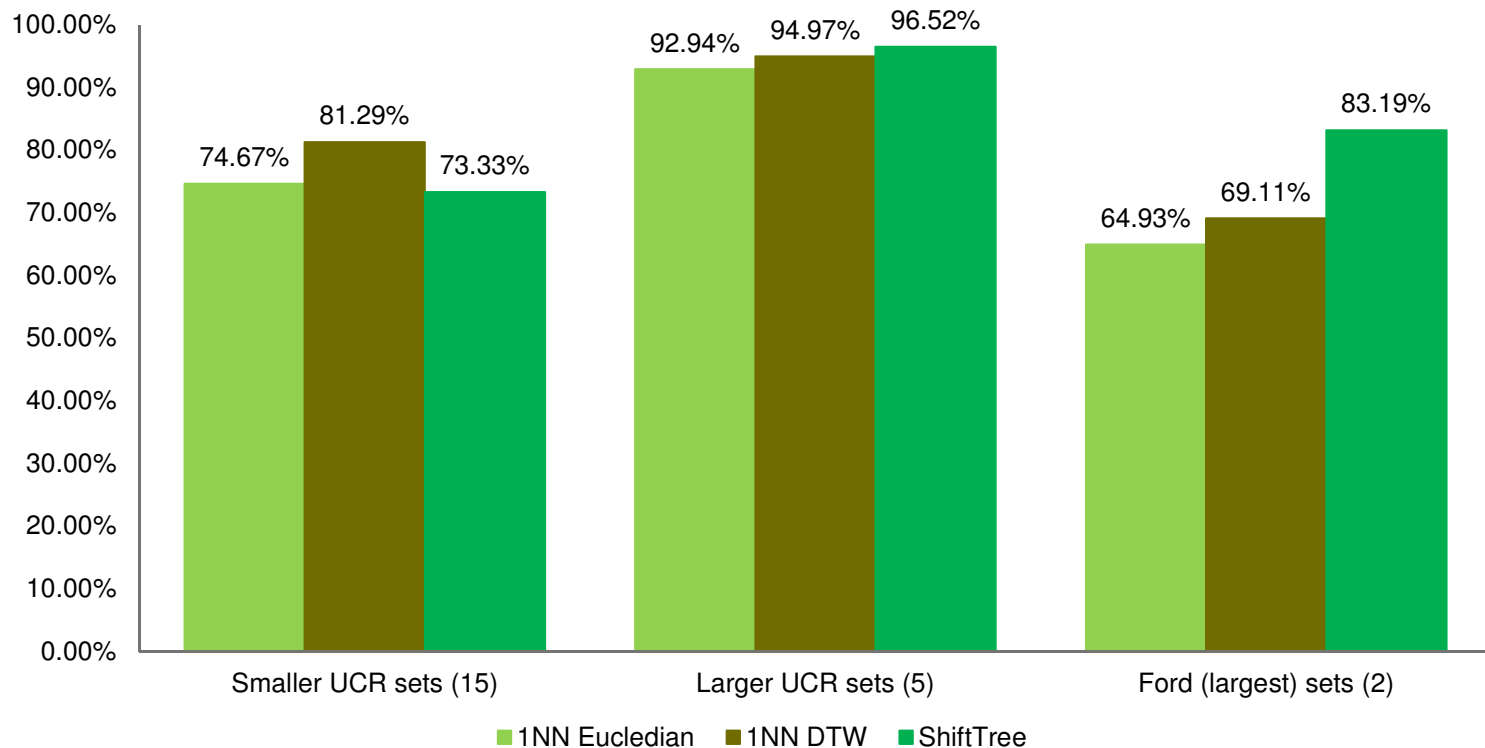
# INTERPRETABILITY



- Depends on the operators
- Helps understanding the data
- E.g.: CBF dataset
  - Z-normalized, 3 class: Cylinder, Bell, Funnel
  - Distinguish cylinder from bell and funnel by global maxima
    - The data is z-normalized (standardized)
  - Distinguish bell from funnel by stepping back 25 steps + noise filtering through weighted average
    - On which side is the peak

# PERFORMANCE OF THE ALGORITHM

- Databases
  - UCR: mostly smaller data sets (20)
  - Ford: larger data sets (2)
- No optimizations in the experiments
- Performance
  - Better on larger data sets (model-based)



# ADVANTAGES AND DRAWBACKS

## ○ Advantages

- Advantages of being model based (fast labeling, etc)
- Interpretable (depends on operators)
- Can be used independently of application domain
- Expert's knowledge can be built in through operators

## ○ Disadvantages

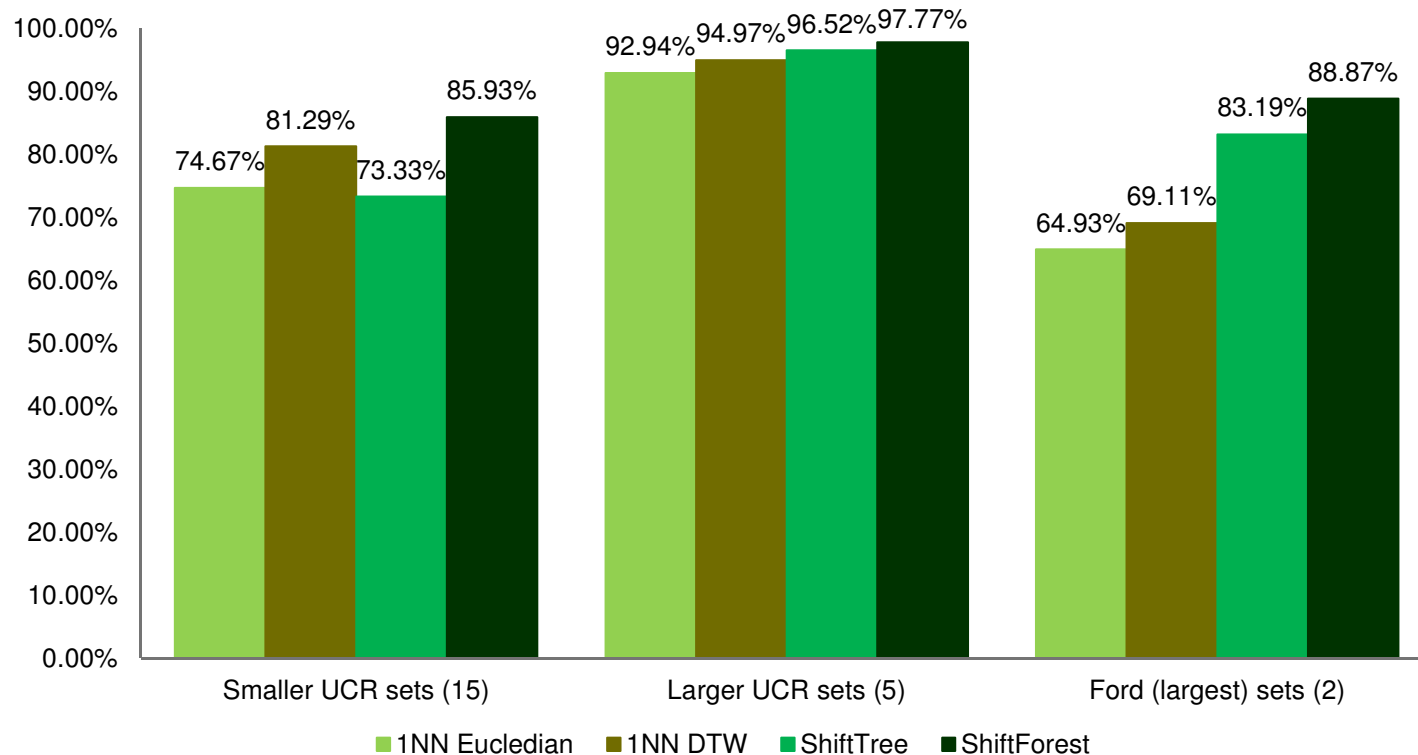
- Optimization of the operators is not trivial
- Learning may take a long time when too many operators used
- Disadvantages of the model based methods (larger training set required, etc)

# SHIFTFOREST: COMBINING MULTIPLE MODELS

- Combining models enhances accuracy
- Boosting
  - Some issues on smaller datasets
- The „XV” method
  - Splitting training set (random splits)
  - Building model on the first part, evaluating on the second
  - Model weight: the measured accuracy

# SHIFTFOREST RESULTS

- Accuracy increases
- Interpretability is often lost
  - May the intersection of the trees can be interpreted

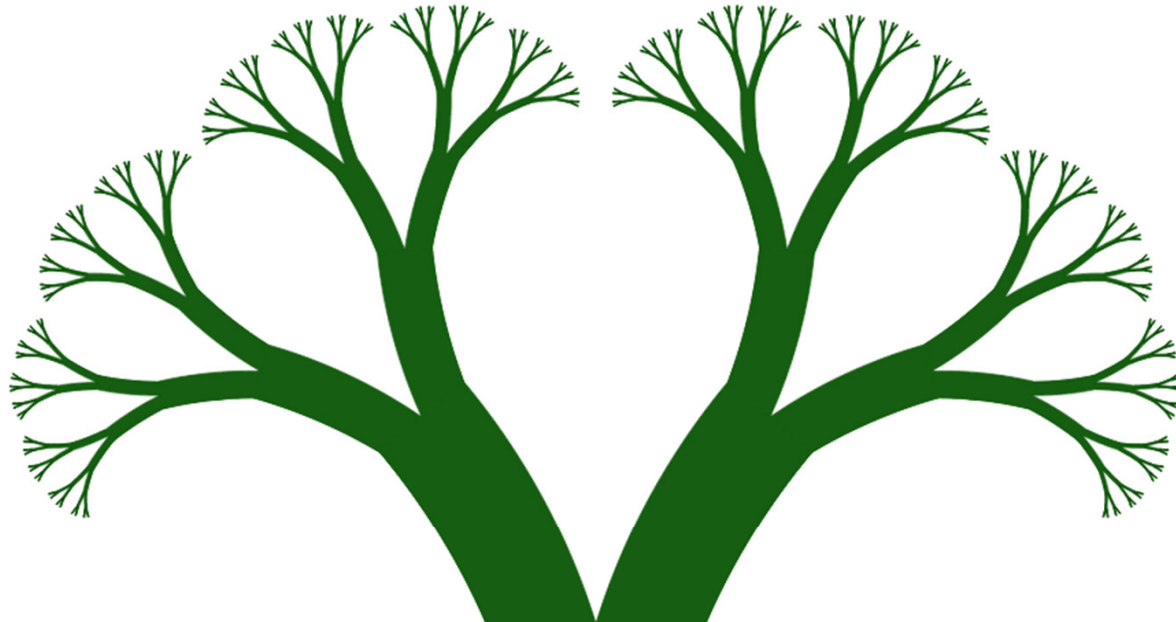


# CONCLUSION

- Novel model-based algorithm
- Uses cursors and operators
  - Cursor movement
  - Attribute computation
- Sequence of simple operators as the model
  - Decision tree
- Base of a whole algorithm family



THANK YOU FOR YOUR ATTENTION!



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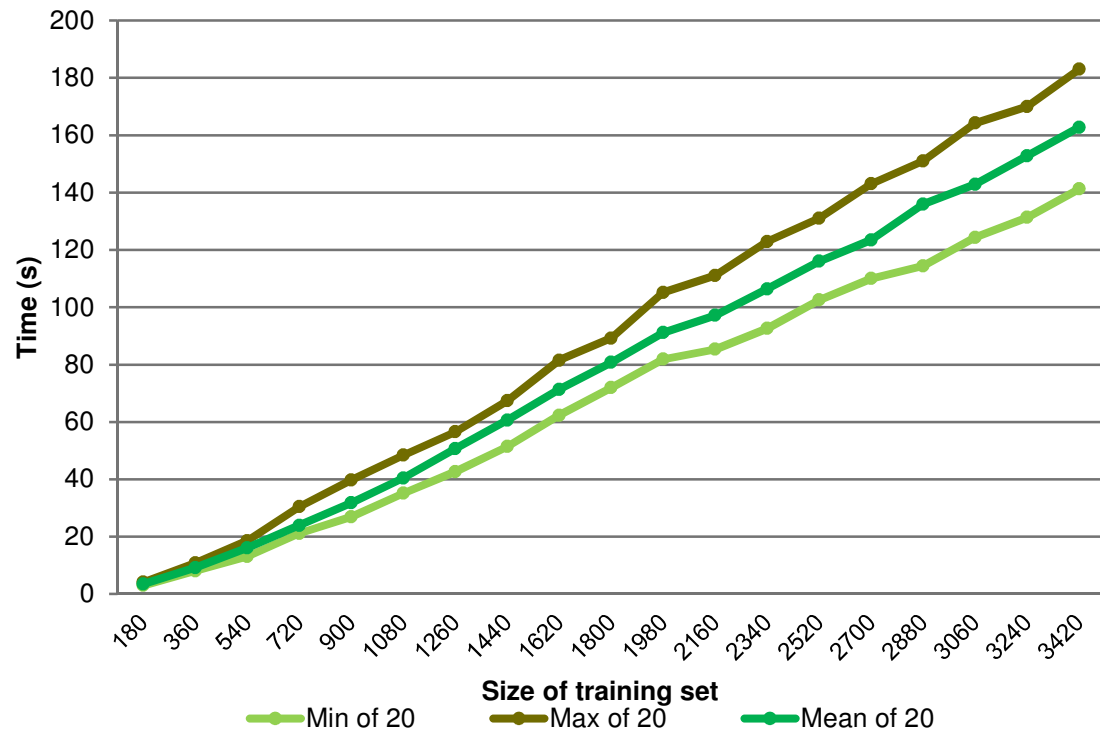
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17/17

For more ShiftTree related research visit my side: <http://www.hidasi.eu>

# TIME OF MODEL BUILDING, SCALABILITY

- $O(N \cdot \log(N))$  per node (ordering)
- Time of model building
  - Depends on tree structure
  - Acceptable
- Scales linearly
  - Experiments



# LEARNING THE MODEL

## Defined operators

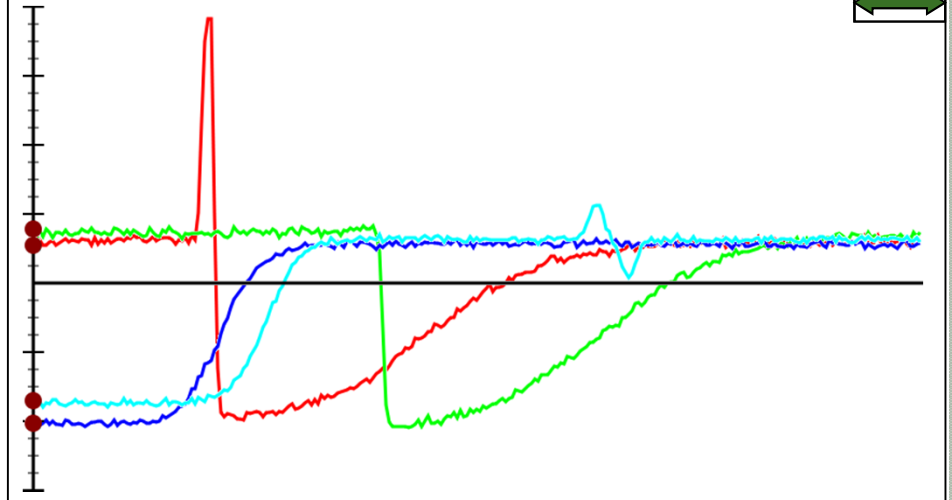
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	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

## ShiftTree



Best split in node (so far)	
ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far)	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

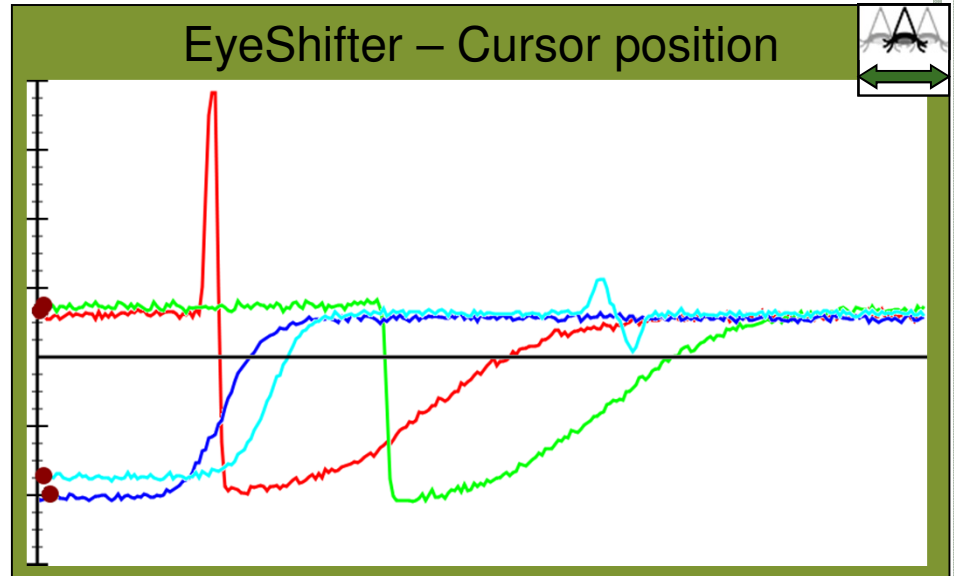
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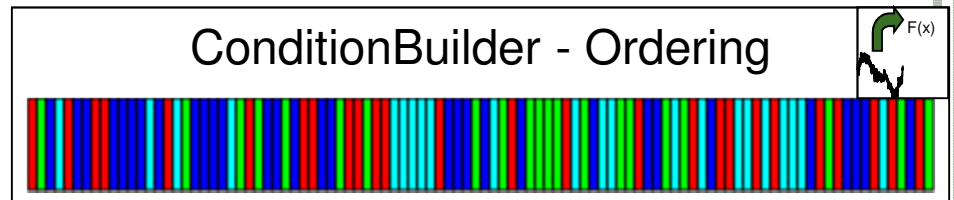


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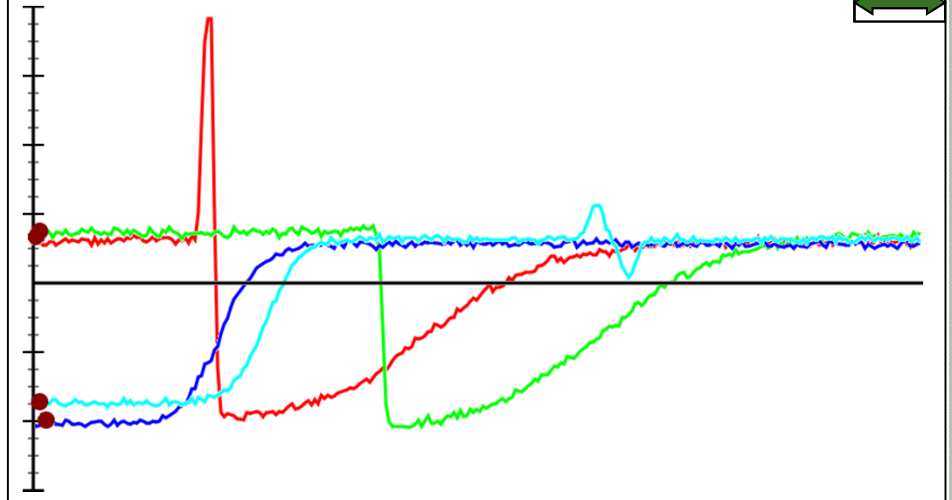
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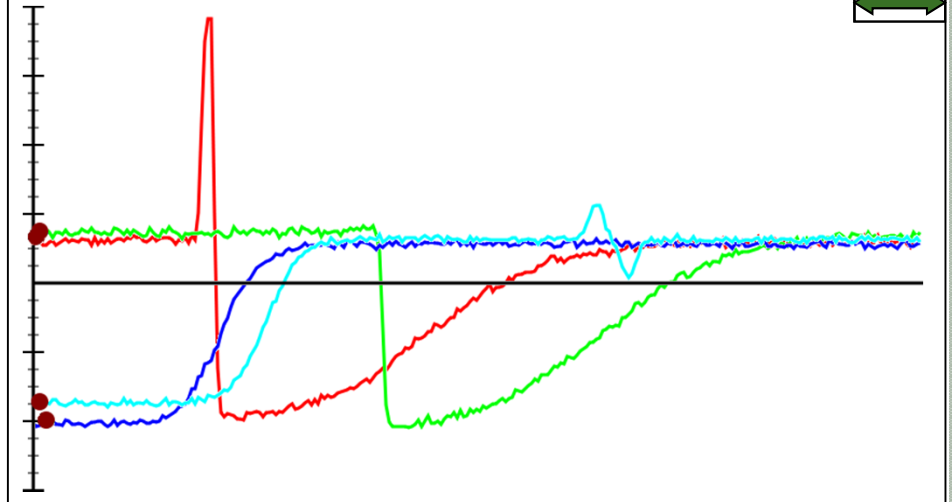
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Best split in node (so far)	
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## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



Best threshold by current dynamic attribute:	-0,332858
Score of the best split by current dyn. attribute :	0,985078
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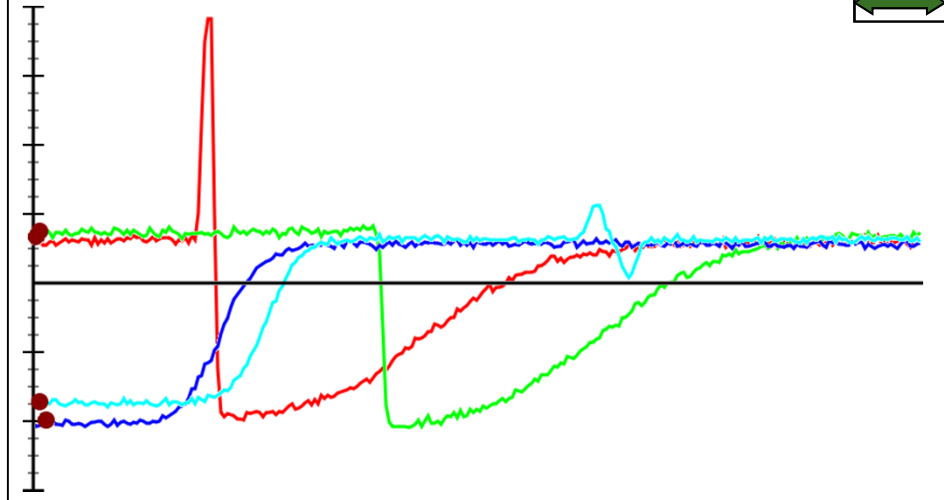
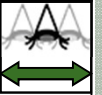
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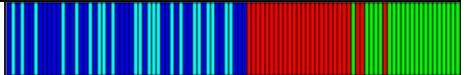


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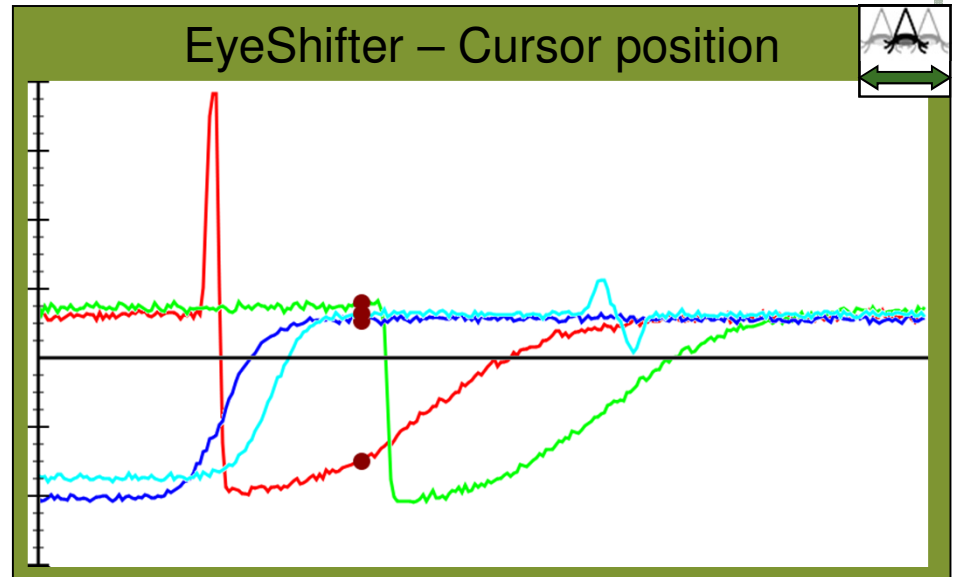
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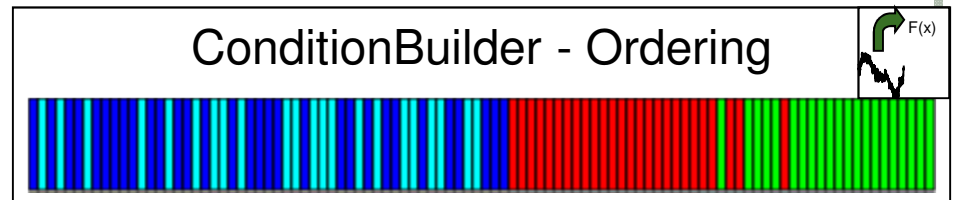


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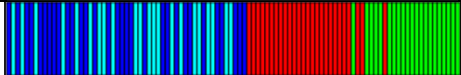
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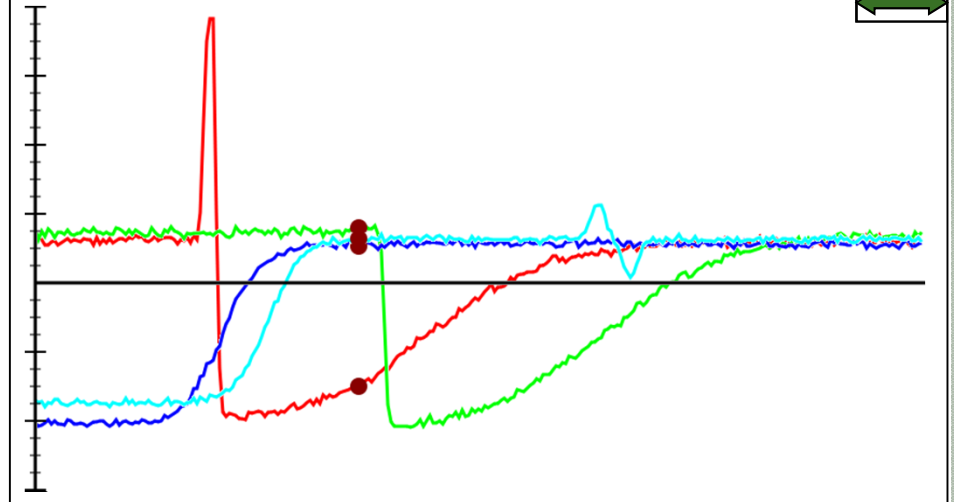
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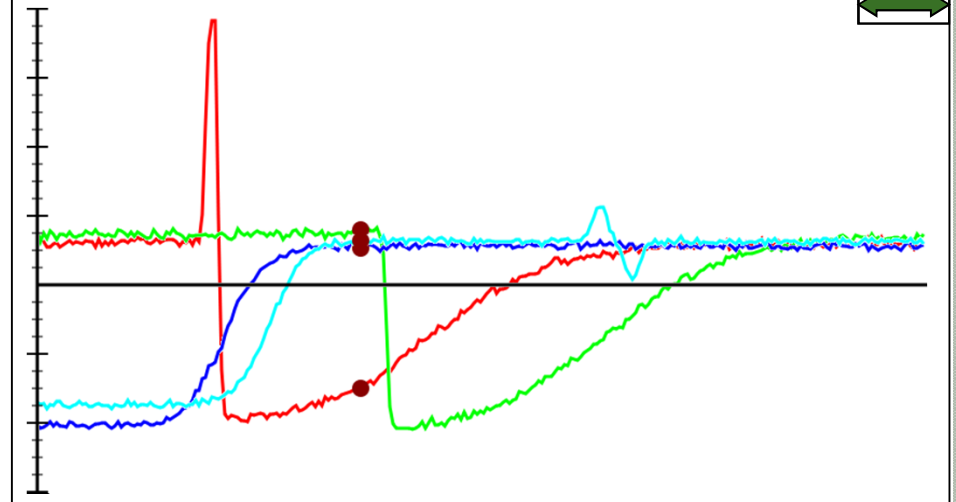
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## ConditionBuilder - Ordering



## Dynamic attribute selection



Best threshold by current dynamic attribute:	-1,16155
Score of the best split by current dyn. attribute :	1,32624
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# LEARNING THE MODEL

## Defined operators

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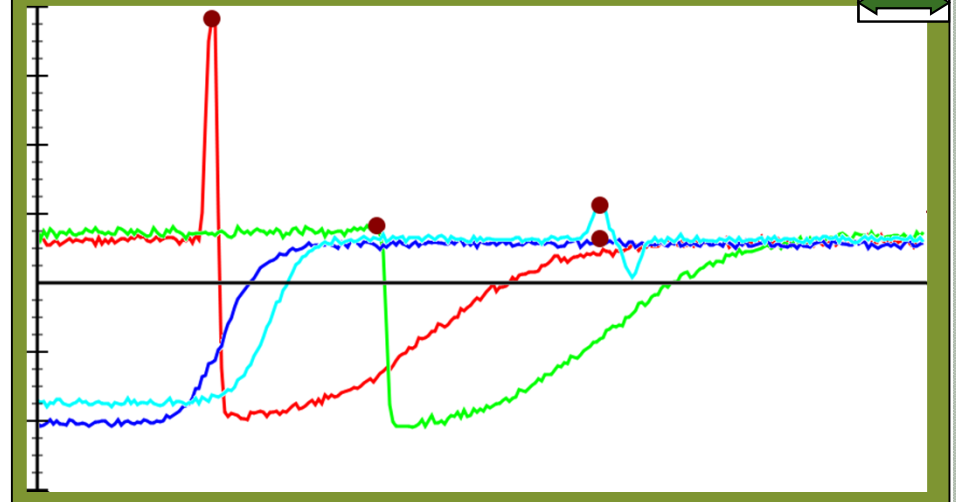
## ShiftTree



### Best split in node (so far)

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## EyeShifter – Cursor position

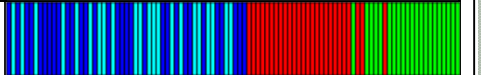


## ConditionBuilder - Ordering



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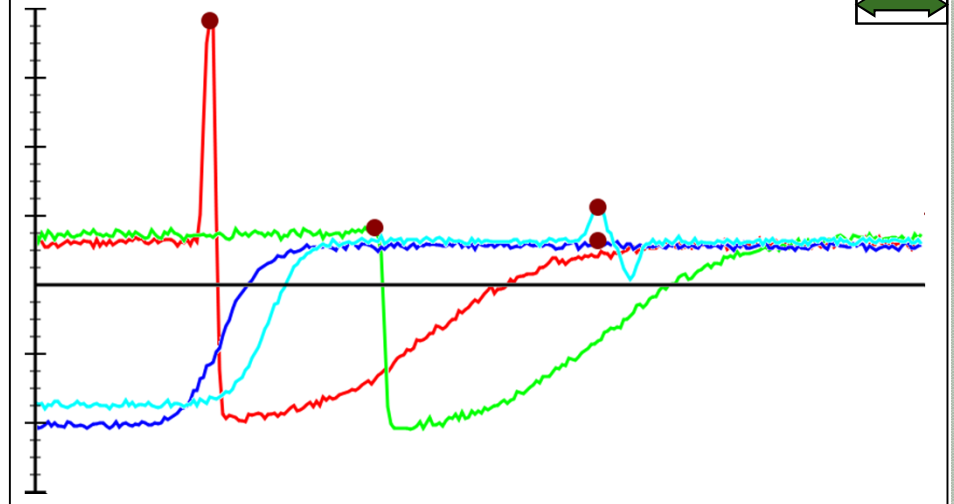
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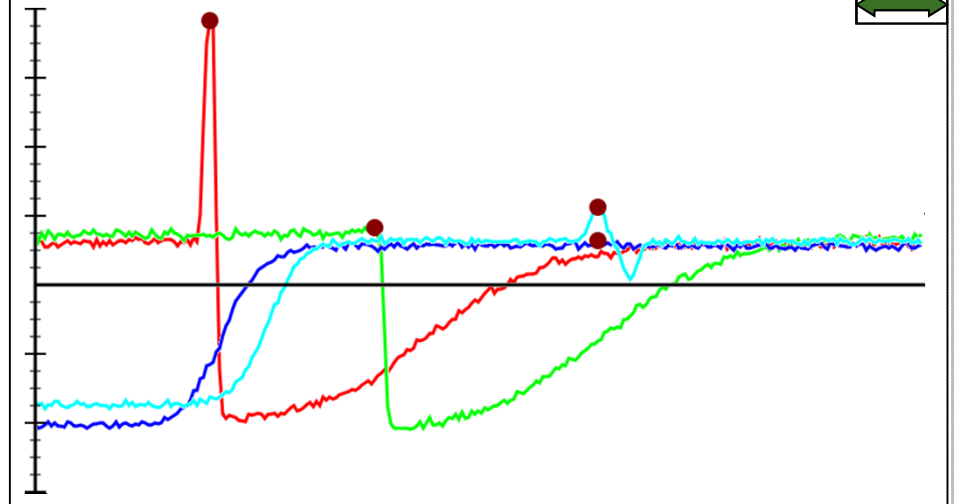
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## EyeShifter – Cursor position



## ConditionBuilder - Ordering



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Best threshold by current dynamic attribute:	1,02775
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## Defined operators

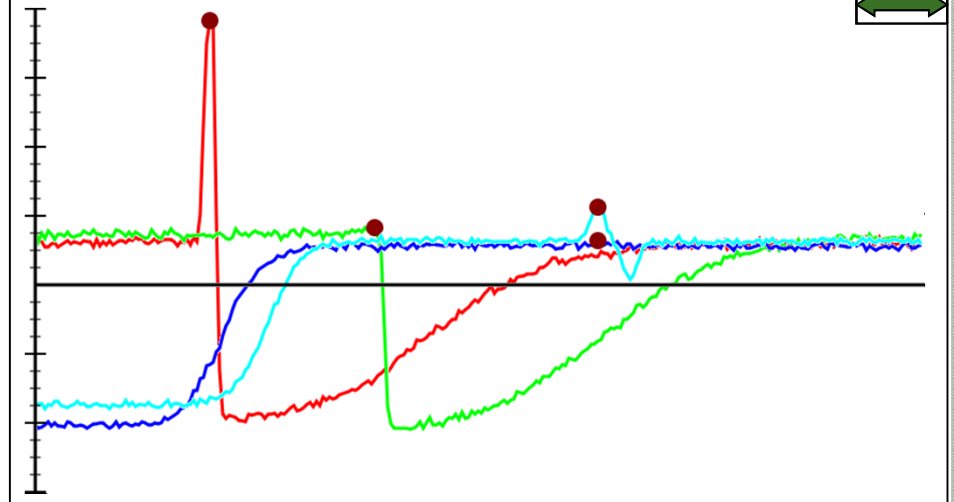
<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

## ShiftTree



Best split in node (so far)	
ESO:	ESOMax
CBO:	CBOSimple
Threshold:	1,02775

## EyeShifter – Cursor position

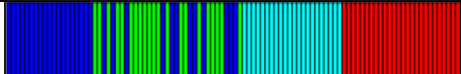


## ConditionBuilder - Ordering



## Dynamic attribute selection



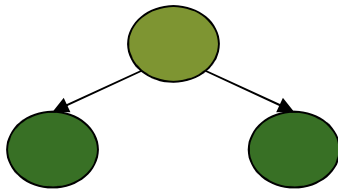
Best threshold by current dynamic attribute:	1,02775
Score of the best split by current dyn. attribute :	0,983634
Best score in the node (so far)	0,983634
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

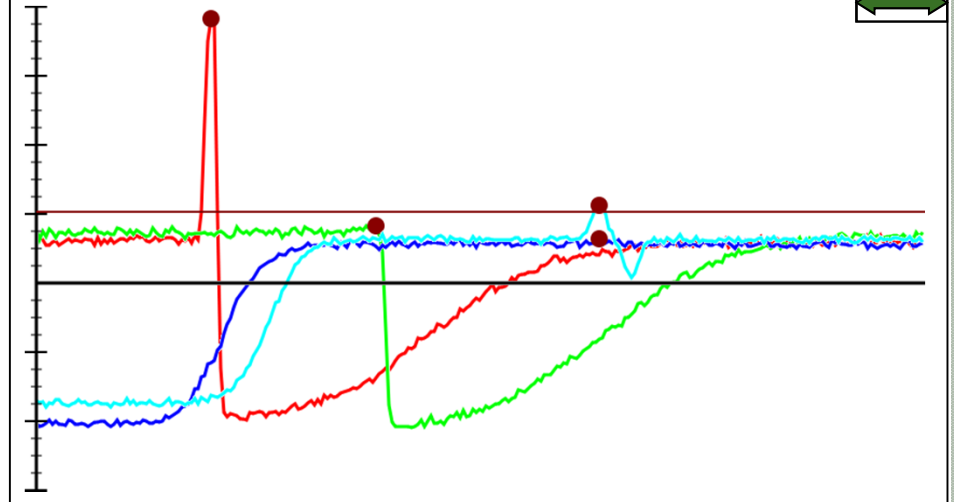
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



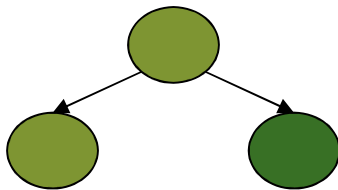
Best threshold by current dynamic attribute:	1,02775
Score of the best split by current dyn. attribute :	0,983634
Best score in the node (so far)	0,983634
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

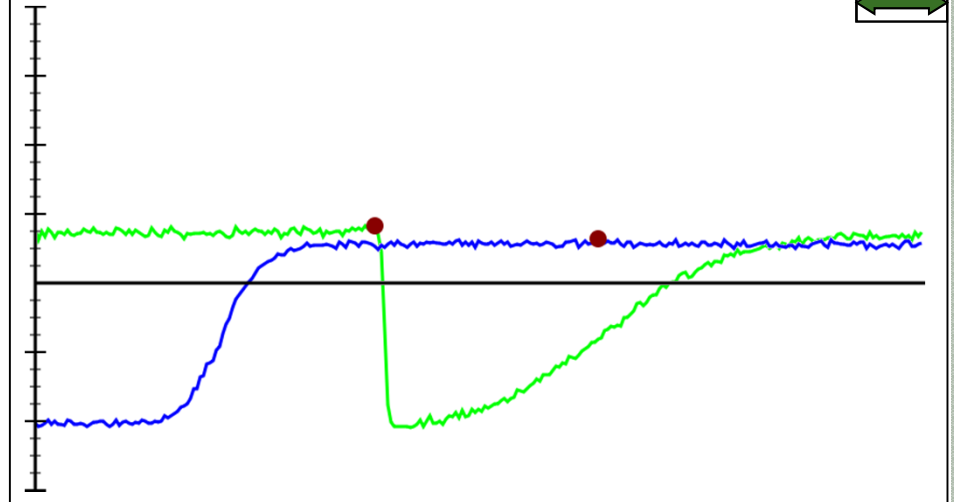
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far)	Inf
Best ordering:	

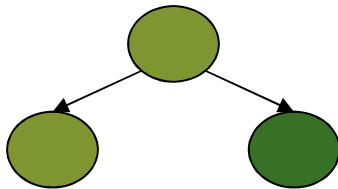


# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	<b>ESONextMax</b>	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

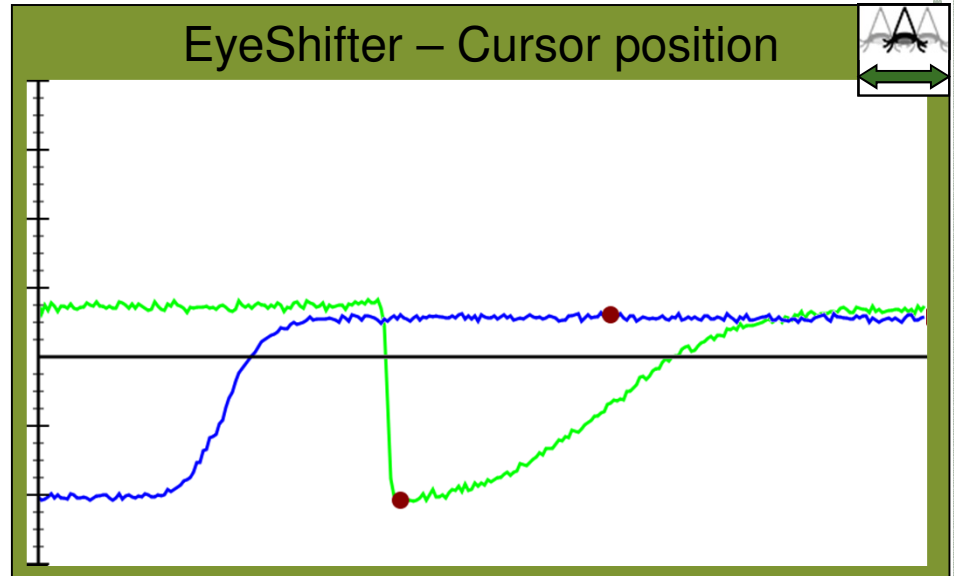
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

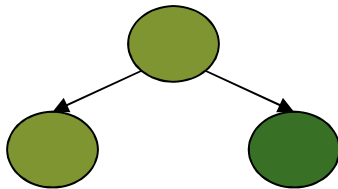
Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far):	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

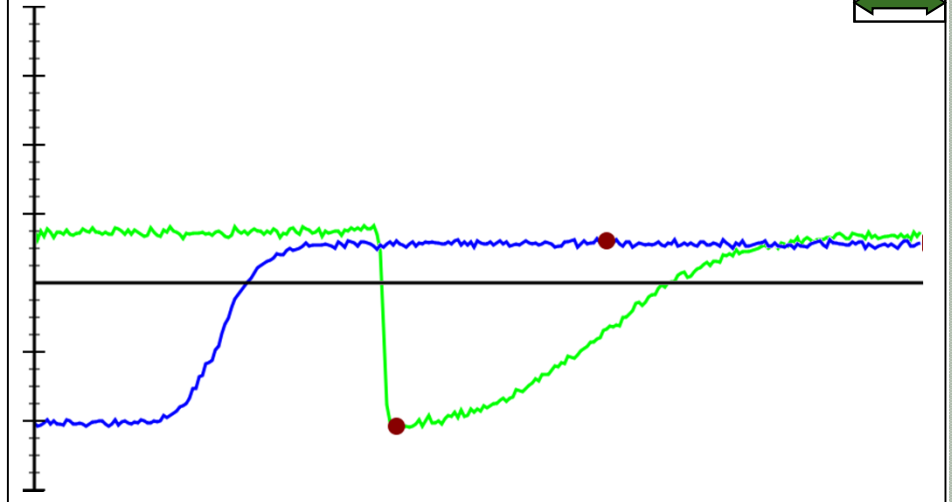
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



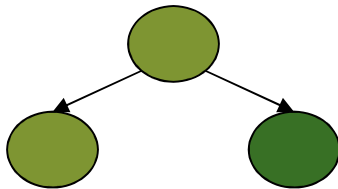
Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far)	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

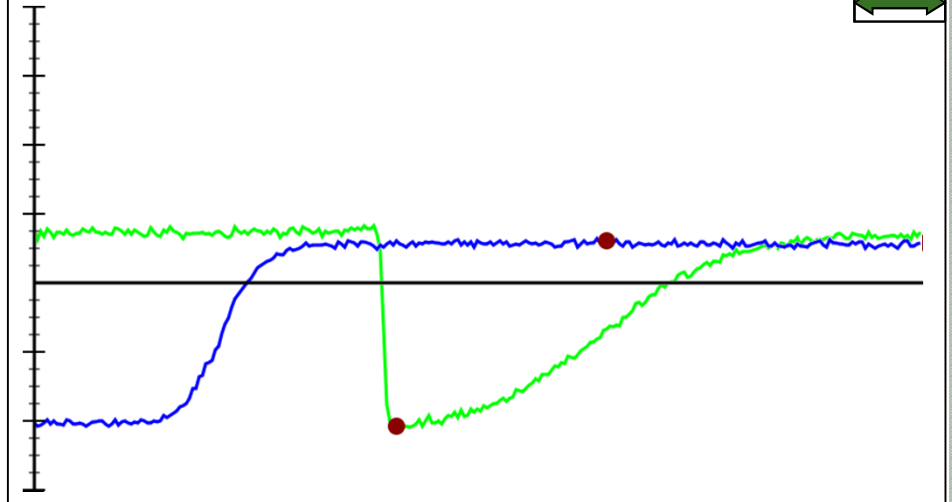
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



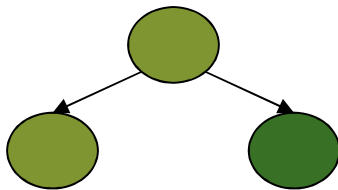
Best threshold by current dynamic attribute:	-0,739969
Score of the best split by current dyn. attribute :	0,805777
Best score in the node (so far)	0,805777
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

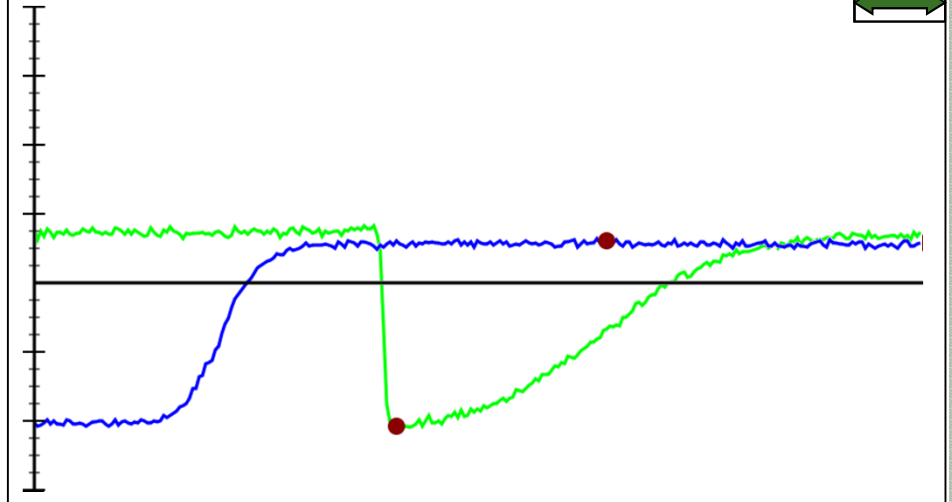
## ShiftTree



### Best split in node (so far)

ESO:	ESONextMax
CBO:	CBOSimple
Threshold:	-0,739969

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



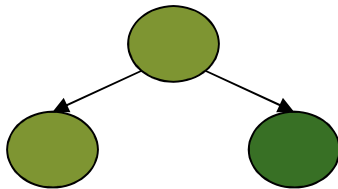
Best threshold by current dynamic attribute:	-0,739969
Score of the best split by current dyn. attribute :	0,805777
Best score in the node (so far)	0,805777
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	<b>ESONext100</b>	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

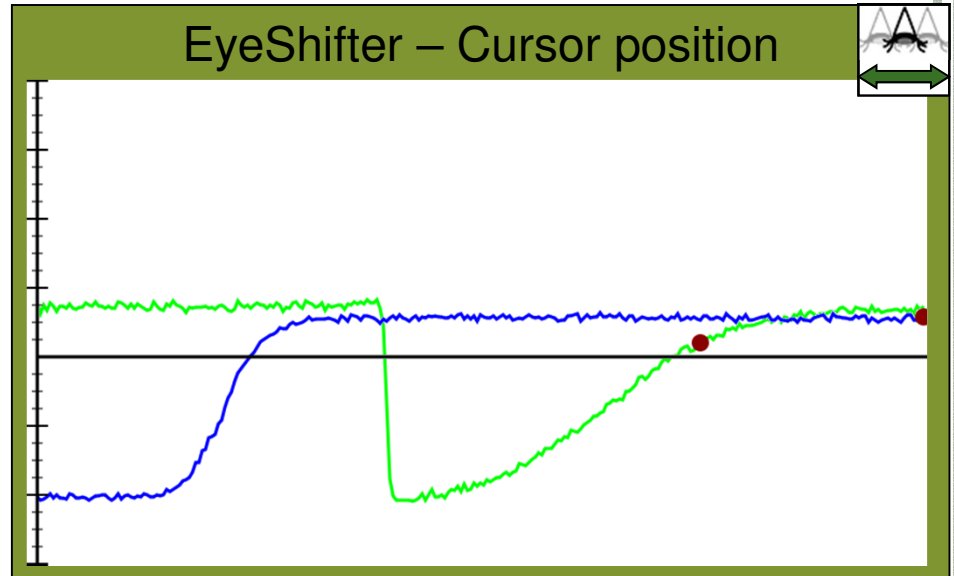
## ShiftTree



### Best split in node (so far)

ESO:	ESONextMax
CBO:	CBOSimple
Threshold:	-0,739969

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

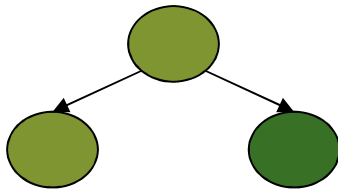
Best threshold by current dynamic attribute:	-0,739969
Score of the best split by current dyn. attribute :	0,805777
Best score in the node (so far)	0,805777
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

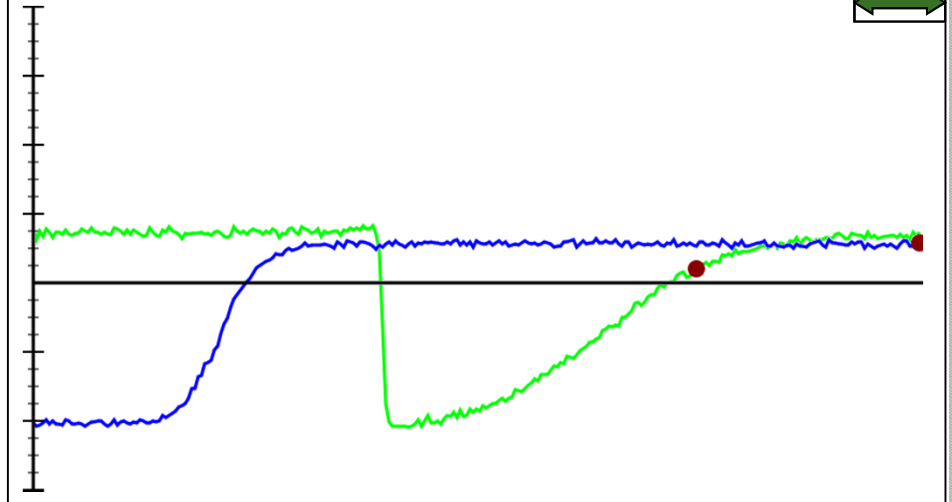
## ShiftTree



### Best split in node (so far)

ESO:	ESONextMax
CBO:	CBOSimple
Threshold:	-0,739969

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



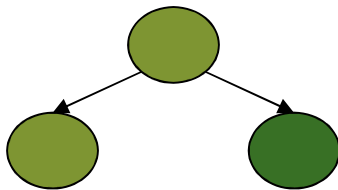
Best threshold by current dynamic attribute:	-0,739969
Score of the best split by current dyn. attribute :	0,805777
Best score in the node (so far)	0,805777
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

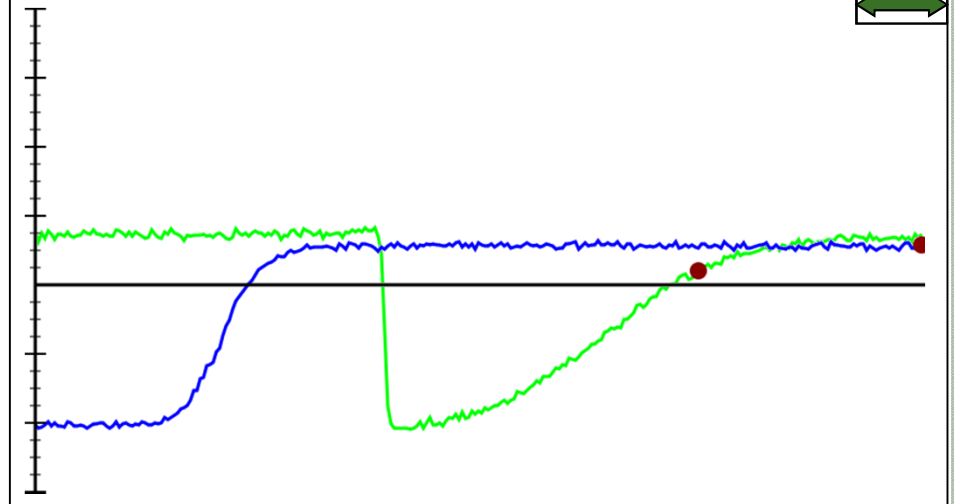
## ShiftTree



### Best split in node (so far)

ESO:	ESONextMax
CBO:	CBOSimple
Threshold:	-0,739969

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



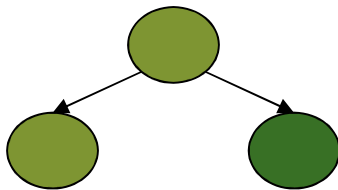
Best threshold by current dynamic attribute:	0,390093
Score of the best split by current dyn. attribute :	0
Best score in the node (so far)	0
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

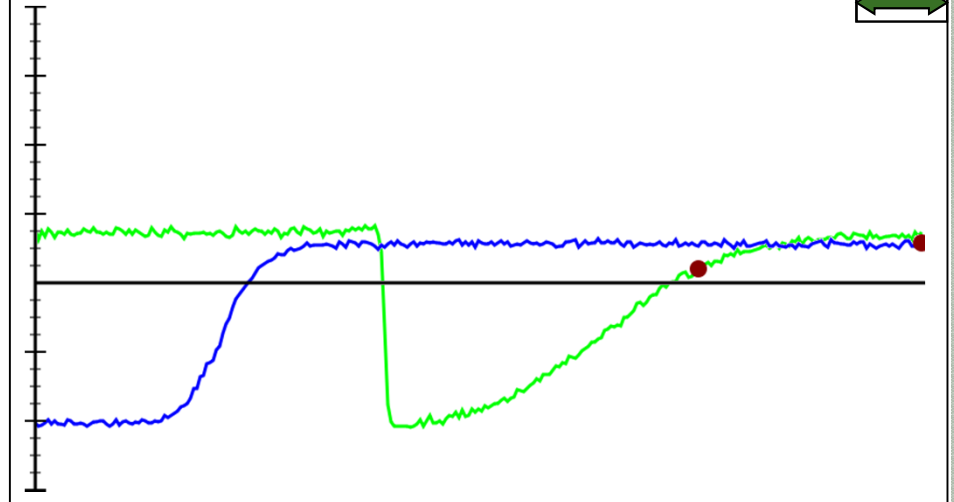
## ShiftTree



### Best split in node (so far)

ESO:	ESONext100
CBO:	CBOSimple
Threshold:	0,390093

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



Best threshold by current dynamic attribute:	0,390093
Score of the best split by current dyn. attribute :	0
Best score in the node (so far)	0
Best ordering:	

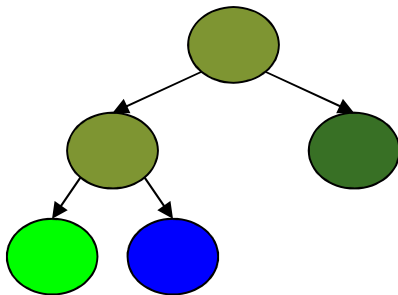


# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

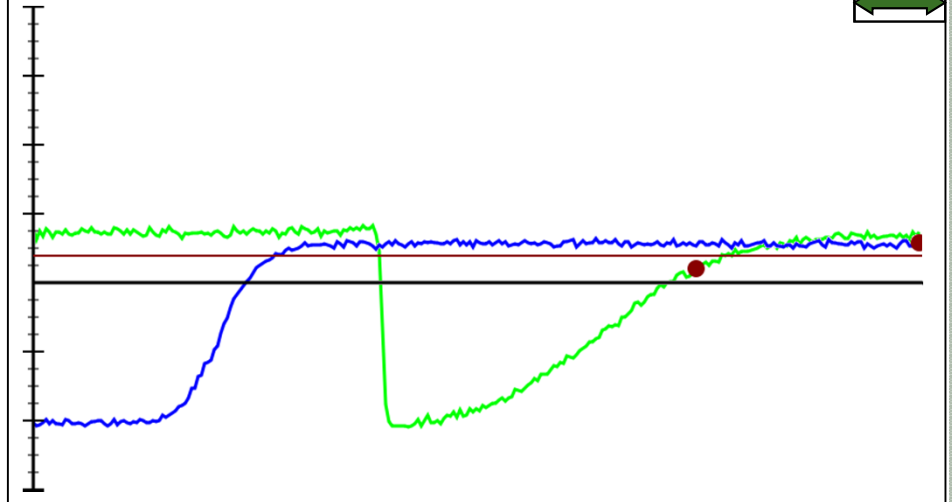
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection



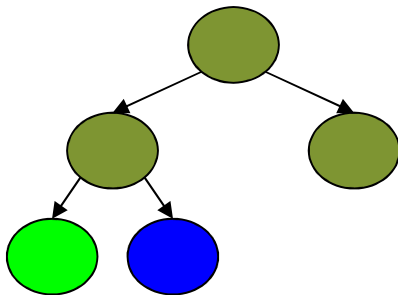
Best threshold by current dynamic attribute:	0,390093
Score of the best split by current dyn. attribute :	0
Best score in the node (so far)	0
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

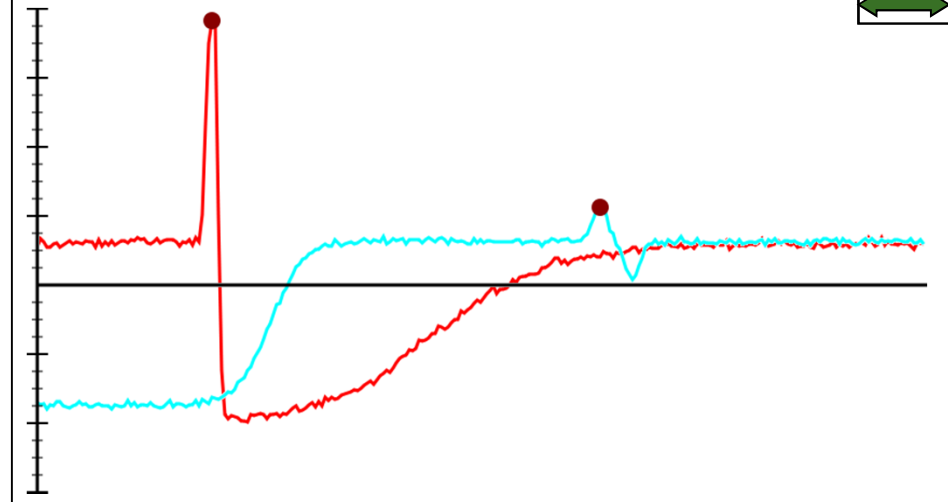
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

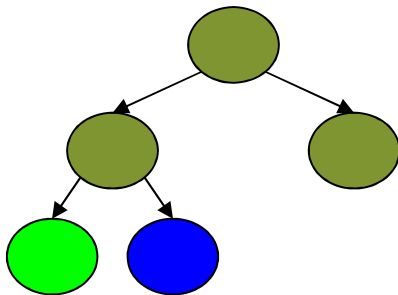
Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far):	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	<b>ESONextMax</b>	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

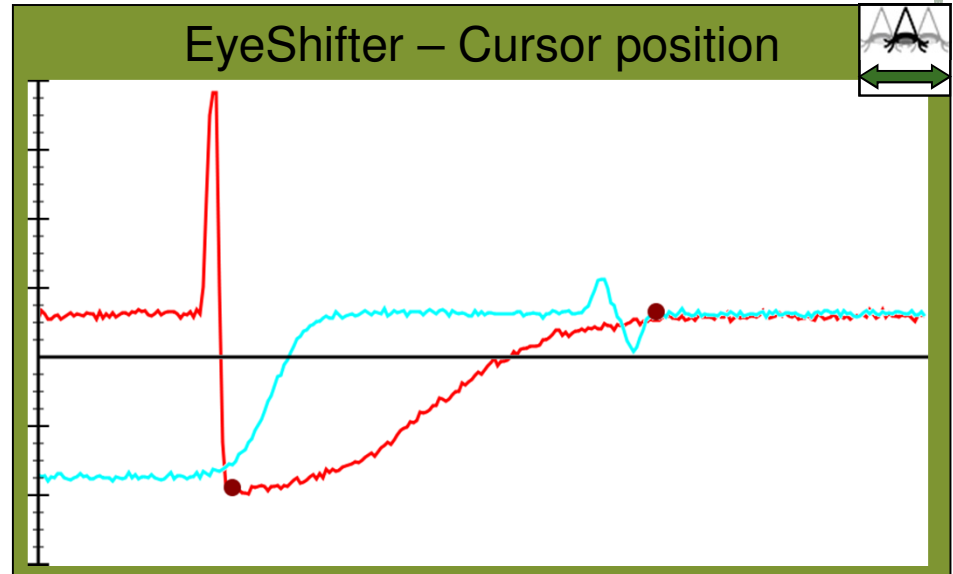
## ShiftTree



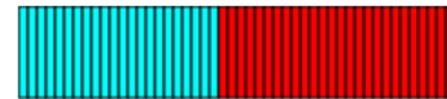
### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

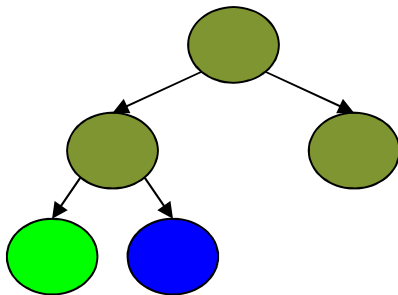
Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far):	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

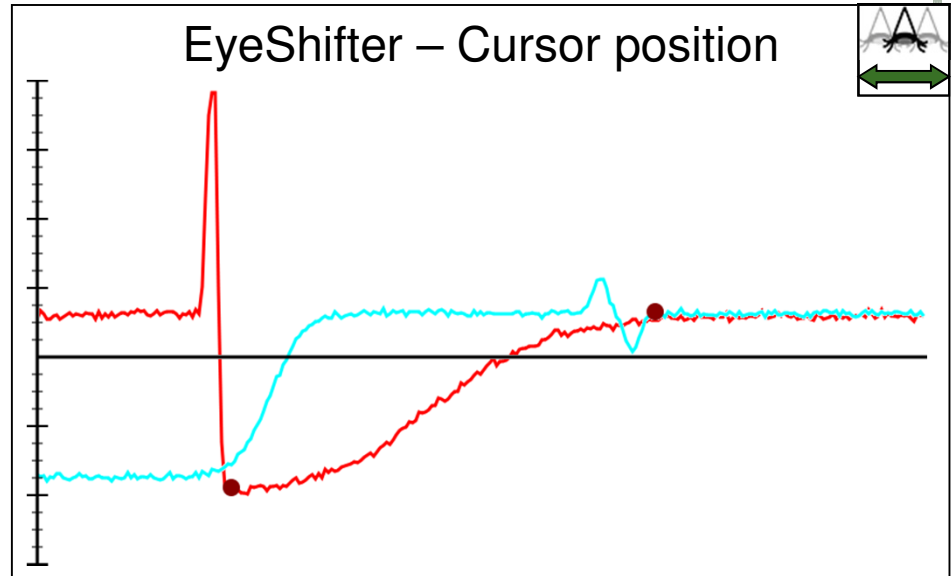
## ShiftTree



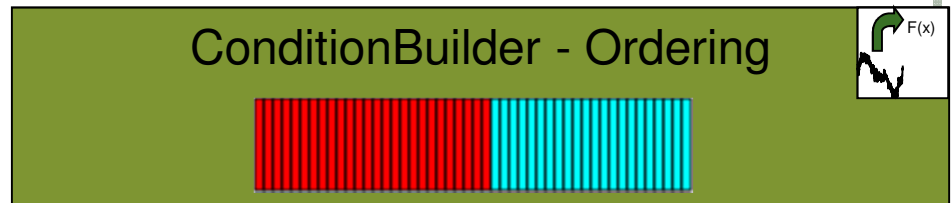
### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

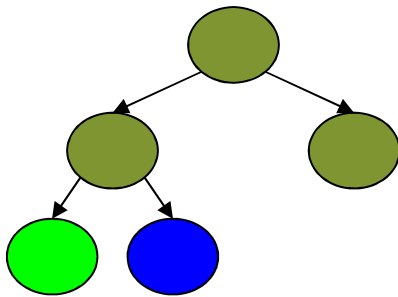
Best threshold by current dynamic attribute:	-
Score of the best split by current dyn. attribute :	Inf
Best score in the node (so far):	Inf
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

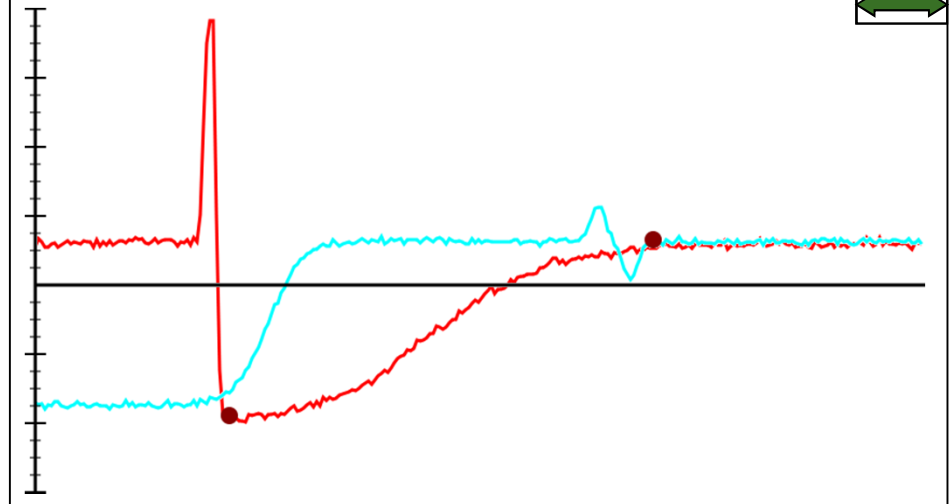
## ShiftTree



### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

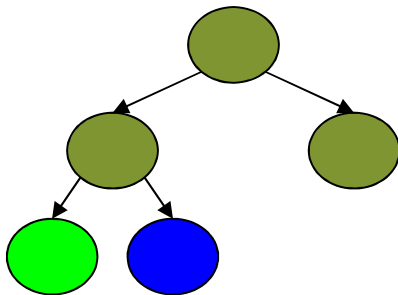
Best threshold by current dynamic attribute:	-0,700739
Score of the best split by current dyn. attribute :	0
Best score in the node (so far):	0
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

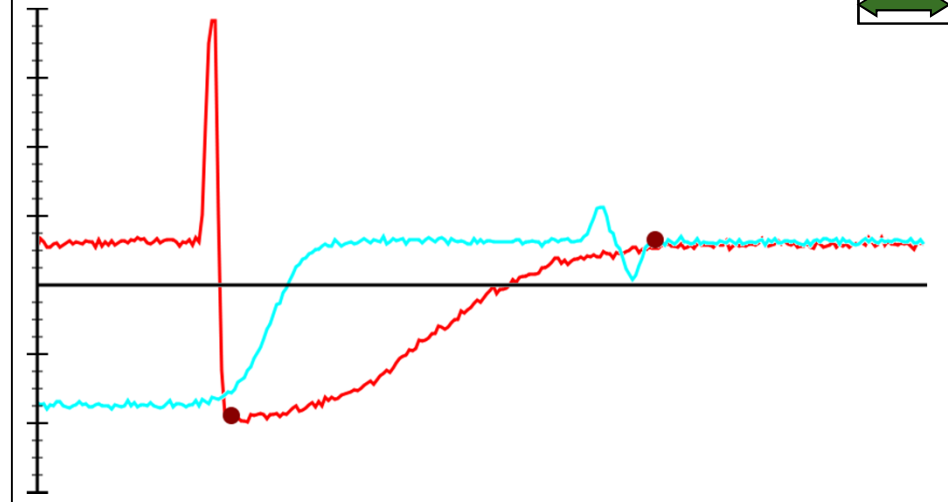
## ShiftTree



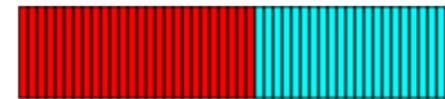
### Best split in node (so far)

ESO:	ESONextMax
CBO:	CBOSimple
Threshold:	-0,700739

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

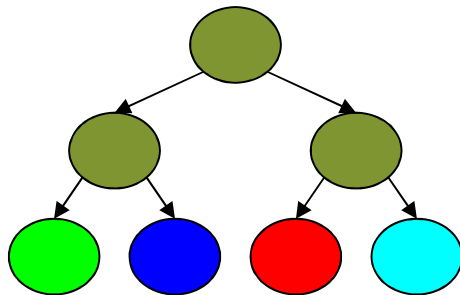
Best threshold by current dynamic attribute:	-0,700739
Score of the best split by current dyn. attribute :	0
Best score in the node (so far):	0
Best ordering:	

# LEARNING THE MODEL

## Defined operators

<b>ESO</b>	ESONextMax	To the next local maxima
	ESONext100	Step forward 100
	ESOMax	To the global maxima
<b>CBO</b>	CBOSimple	Value at cursor position

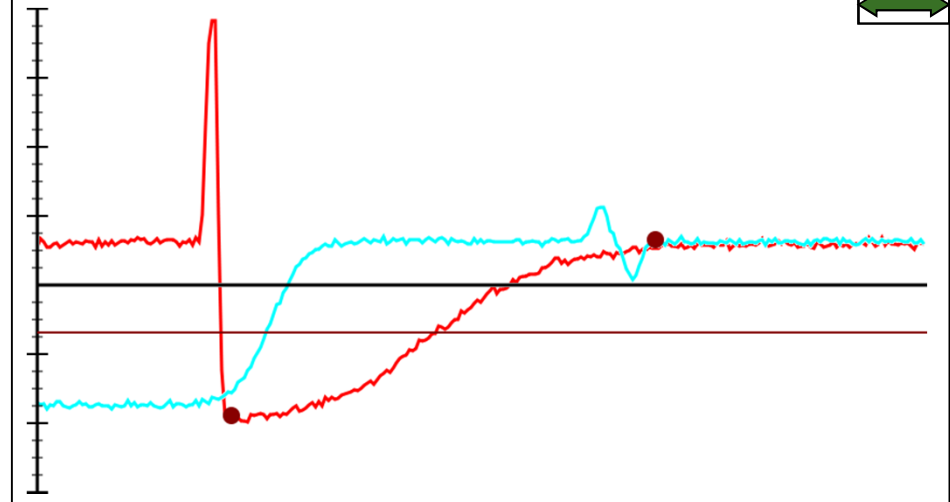
## ShiftTree



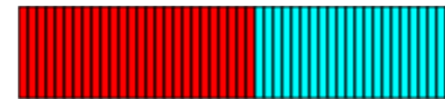
### Best split in node (so far)

ESO:	-
CBO:	-
Threshold:	-

## EyeShifter – Cursor position



## ConditionBuilder - Ordering



## Dynamic attribute selection

Best threshold by current dynamic attribute:	-0,700739
Score of the best split by current dyn. attribute :	0
Best score in the node (so far):	0
Best ordering:	