

# Apply machine learning to Performance trend analysis

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# Objectives

- Detect the state of the CPU utilization (degrading, improving or steady state)
- Detect whether there is any change in the test environment that effects the CPU utilization

# Markov switching model, [Hamilton, 1989]

- A technique used for describing the evolution of the process at different periods of time
- Model involves multiple structures that can characterize the time series behaviors in different states
- The switching mechanism between the states is assumed to be an unobserved Markov chain - a stochastic process which contains the probability of transition from one state to any other state

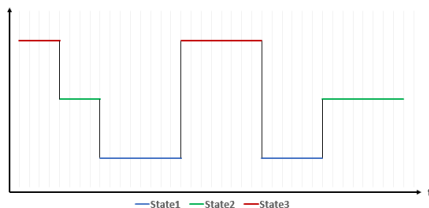


Figure: regime shift between states

# Markov switching model, [Hamilton, 1989]

Assuming that  $S_t$  denote an unobservable state variable

$$y_t = X_t' \beta_{S_t} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_{S_t}^2)$$

$y_t$  is the observed value of time series at time  $t$

$X_t$  are the predictor variables of time series at time  $t$

$\beta_{S_t}$  are the coefficients in state  $S_t$ , where  $S_t = 1, 2, \dots, k$

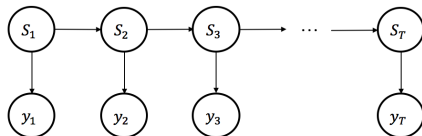


Figure: Model structure

# Markov switching model

Given dataset,

$$y_t = X_t' \beta_{S_t} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_{S_t}^2)$$

- $y_t$  is the CPU utilization
- $X_t$  are components which have an impact on the CPU utilization
- Assume there are three states ( $k = 3$ ): normal, good, bad

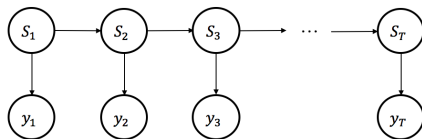


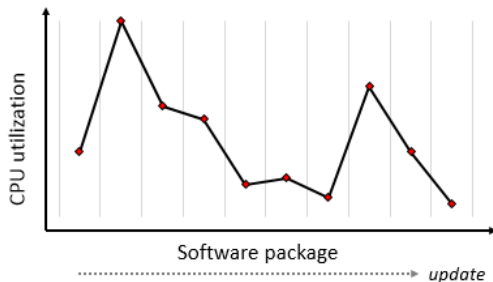
Figure: Model structure

# Markov switching autoregressive model

## Autoregressive model

$$y_t = c + \sum_{i=1}^p \phi_p y_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma^2)$$

where  $c$  is constant and  $\phi_p$  are parameters



# Markov switching autoregressive model

The observation are drawn from the first order autoregressive model, AR(1).

$$y_t = X_t' \beta_{S_t} + \phi_{1,S_t} y_{t-1} + \varepsilon_t$$

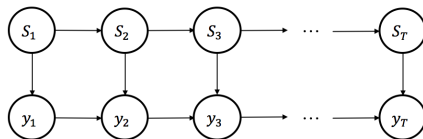


Figure: Model with additional dependencies at observation level



## Model Likelihood

$$L(\theta; y_t) = f(y_t|\theta) = \sum_{t=1}^T \sum_{j=1}^k f(y_t|S_t = j; \theta)P(S_t = j)$$

and  $S_t$  is non-observable variable

A weighted average of the likelihood function in each state where weights are given by state's probabilities.

# What has been done?

One software product  $\Rightarrow$  many software packages

One software package  $\Rightarrow$  many different types of test cases

## Data preprocessing

- Select a test case which has a minimum value of CPU utilization for each software package
- Multiple values separated by a tab character are stored together in column  $\Rightarrow$  split a tab-separated values to columns
- Remove incomplete test cases which are not executed properly

ID	Variable1	Variable2	ID	Variable1	A	B	C
1	X	A=2 B=1 C=5	1	X	2	1	5
2	Y	A=4 B=2 C=8	2	Y	4	2	8
3	Z	A=1 C=6	3	Z	1	0	6
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.

Figure: Data example

# What has been done?

Study and review source code in the R package in detail

- MSwM: An univariate autoregressive Markov switching model for linear and generalized model by using the E-M algorithm [Sanchez-Espigares, 2014]

# What has been done?

Implement and modify code in the package

- Small typo in the code when computing residual variance
- Solve non-invertible Hessian using generalized inverse procedure [Gill, 2004]
- Extension for categorical predictor variables
- Deal with NAs coefficients

# What has been done?

Implement and modify code in the package

- Deal with NAs coefficients

A function first initial coefficients with random subsets

- Continuous variable: contains same value in all observations

*Solution:* Reshuffle data

- Categorical variable: not contain all levels of variable

The function uses matrix multiplication to compute conditional means

⇒ NAs

*Solution:* Remove variables with NAs coefficient before performing matrix multiplication

# What has been done?

Results of fitting Markov switching autoregressive model

- Estimated parameters in each state
- For each observation,
  - State assignment
  - Probability assignment in each state
- Graphs show periods where the observation is in the specific state

# Next step

- Model selection: Compare several models (e.g., number of states, number of parameters which have switching effects)
- State prediction: Find the most probable state for the new observation
- Making a state inference
- Fit model for other software products



James D Hamilton (1989)

A new approach to the economic analysis of nonstationary time series and the business cycle

*Econometrica: Journal of the Econometric Society*, pages 357-384.



Jeff Gill and Gary King (2004)

What to do when your hessian is not invertible: Alternatives to model respecification in nonlinear estimation

*Sociological methods & research*, 33(1):54-87.



Josep A. Sanchez-Espigares and Alberto Lopez-Moreno (2014)

MSwM: Fitting Markov Switching Models

*CRAN R*.