Predictive Process Monitoring
and an Example on Mental Healthcare

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Outline

Predictive Process Monitoring
and an Example on Mental Healthcare

1. Introduction
2. Statistical & Predictive process monitoring
3. Mental Healthcare application
4. Future research
5. Discussion

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Introduction

Dr. Leo C.E. Huberts

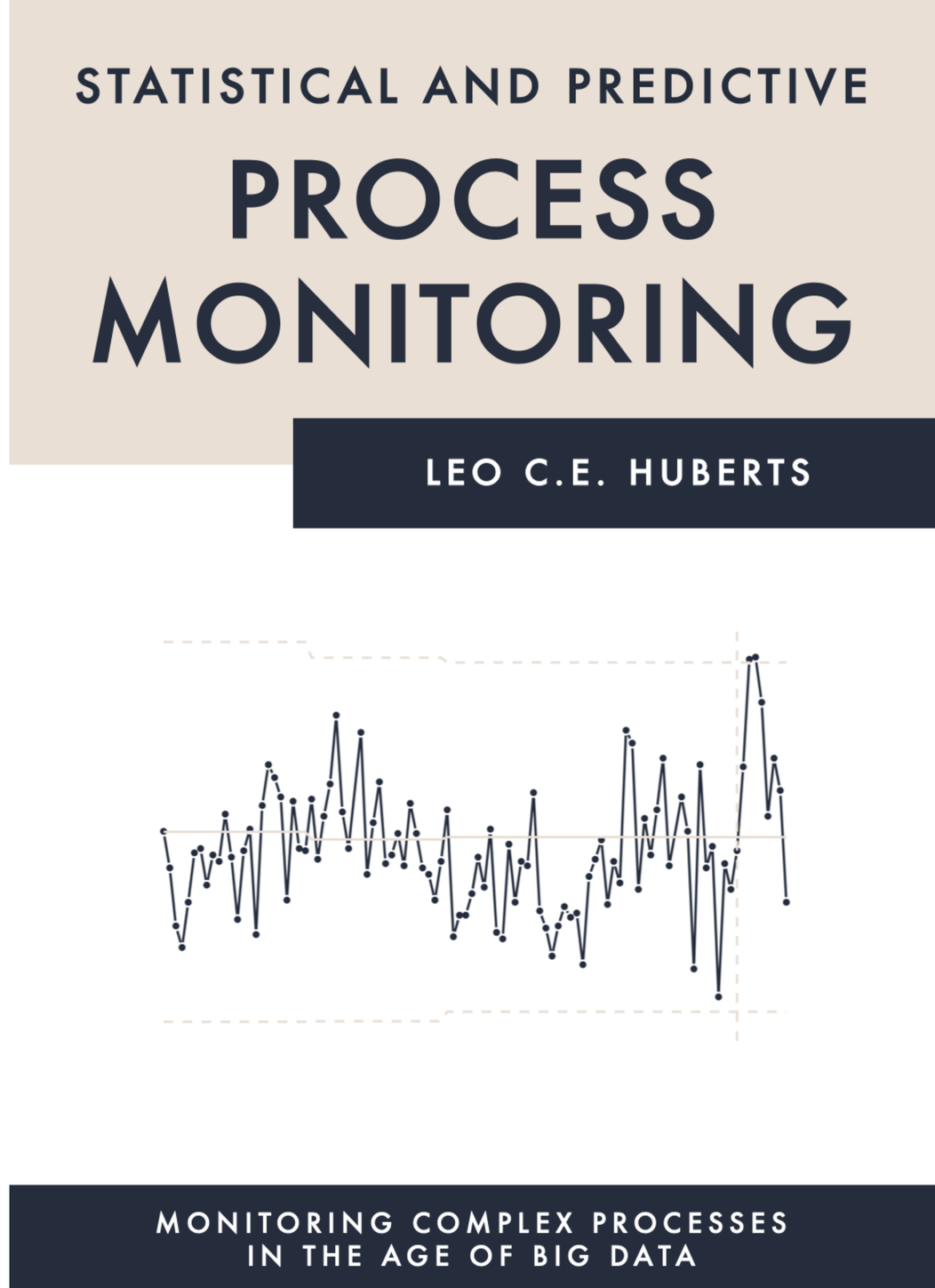
Assistant Professor Business Analytics University of Amsterdam

PhD Thesis Statistical and Predictive Process Monitoring

Monitoring of large streams of data, analytics for a better world, building early warning systems in education, healthcare and industry.

Open access:

- https://pure.uva.nl/ws/files/59618725/Thesis.pdf



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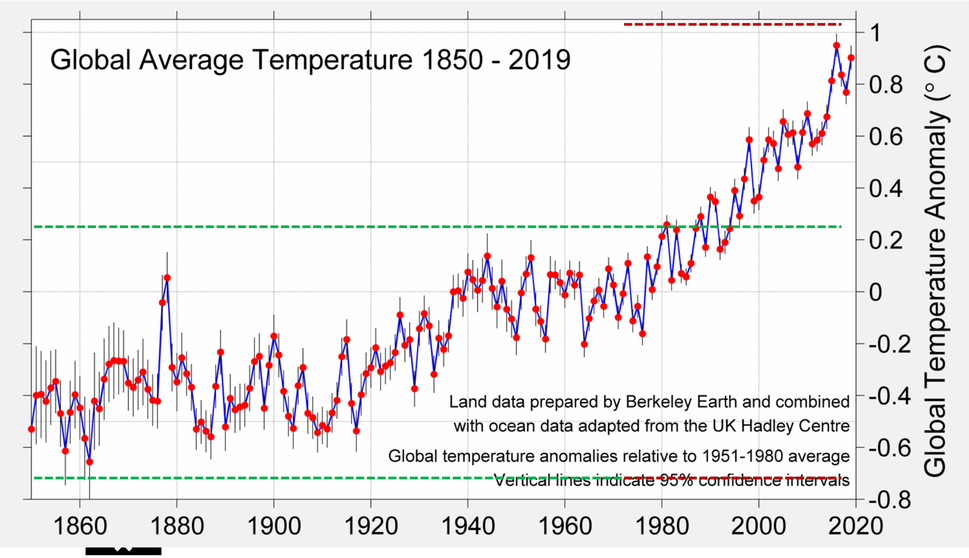
Statistical process monitoring

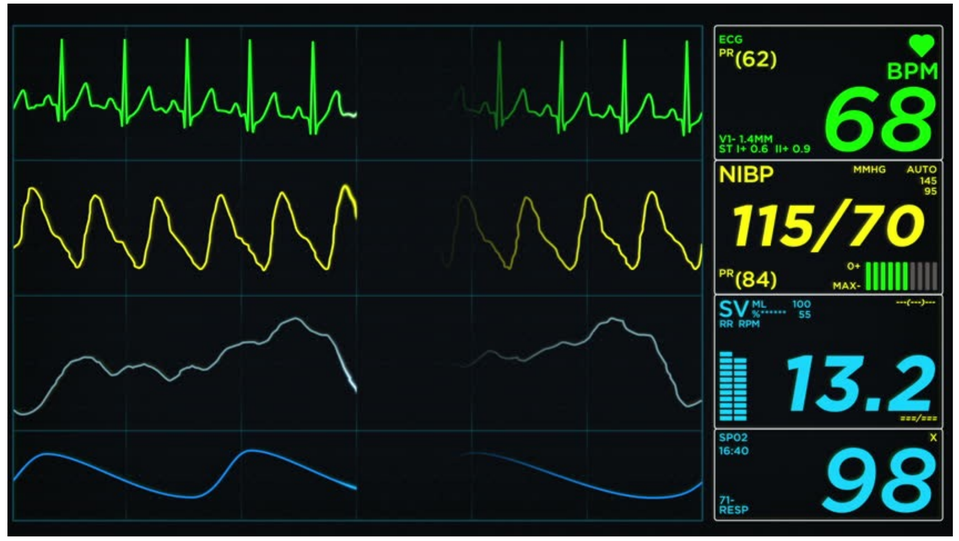
Are we in- or out-of-control?

- In-control process: all is well
- Out-of-control process: sound the alarm

Monitoring average temperatures



Monitoring vitals



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Statistical process monitoring

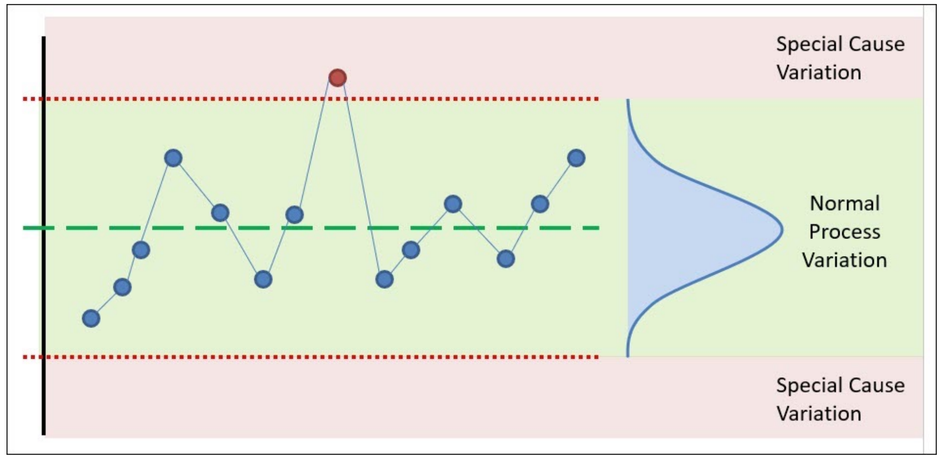
Are we in- or out-of-control?

1. Estimate the *normal situation (phase I)*
2. Monitor one or more indicators for deviations from *normal situation (phase II)*
3. Signal if the indicator deviates *too much*

- *What is normal?*
- *What is too much deviation?*

=> *Minimize false alarms*

=> *Maximize detection*



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Predictive process monitoring

Are we going to be in- or out-of-control?

- Early warning system
- Preventive care/interventions
- Utilize increase in data/computing power
- Predicting is hard!
- Case studies
  - Huberts, LCE, Does, RJMM, Ravesteijn, B, Lokkerbol, J. (2021) **Predictive monitoring using machine learning algorithms and a real-life example on schizophrenia.** *Quality Reliability Engineering International*. https://doi.org/10.1002/qre.2957
  - Leo C. E. Huberts, Marit Schoonhoven & Ronald J. M. M. Does (2020) **Multilevel process monitoring: A case study to predict student success or failure**, *Journal of Quality Technology*. https://doi.org/10.1080/00224065.2020.1828008

Measuring the predictability of life outcomes with a scientific mass collaboration

Matthew J. Salganik, Ian Lundberg, Alexander T. Kindel, Caitlin E. Ahearn, Khaled Al-Ghoneim, Abdullah Almaatouq, Drew M. Altschul, Jennie E. Brand, Nicole Bohme Carnegie, Ryan James Compton, Debanjan Datta, Thomas Davidson, Anna Filippova, Connor Gilroy, Brian J. Goode, Eaman Jahani, Ridhi Kashyap, Antje Kirchner,

INSIGHTS PREDICTION ARTIFICIAL INTELLIGENCE BIAS RESEARCH

AI can't predict a child's future success, no matter how much data we give it

Swing and a miss!

*We investigated this question with a scientific mass collaboration using the common task method; **160 teams built predictive models** for six life outcomes using data from the Fragile Families and Child Wellbeing Study, a high-quality birth cohort study. Despite using a rich dataset and applying machine-learning methods optimized for prediction, the best predictions were **not very accurate** and were only slightly better than those from a **simple benchmark model.***

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Trimbos instituut
Netherlands Institute of Mental Health and Addiction

The monitoring steps

Monitor the **probability of event E**

1. Define event E and threshold C
2. Specify the model for y_i
3. Estimate the parameters to obtain model parameters $\hat{\theta}_I$ at time t_I
4. Calculate $P(E)_t$ using the newly available observations at time $t > t_I$
5. Signal if $P(E)_t > C$
6. Re-estimate the parameters to obtain $\hat{\theta}_t$ using all available data at time t (including interventions) and go back to step 4 for a new timepoint.

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Predictive process monitoring

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Boosted Predictive Process Monitoring in Mental Health

- Data on all 17 million Dutch citizens through Statistics Netherlands and Trimbos Institute
- Income, housing etc.
- (Mental) healthcare appointments/diagnoses
- Focus on **crises** in people diagnosed with schizophrenia
  - Affects almost 1 percent of people
  - Top 15 causes of disability
  - Mortality rates 3.7 times higher
  - Suicide rate almost 400 times higher
  - The overwhelming majority of people suffering from schizophrenia will relapse into crisis care

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Predicting crises

- What method should we use to predict a crisis?
- Logistic regression

$$p_{i,t} = \frac{exp(\beta_0 + \beta' x_{i,t})}{1 + exp(\beta_0 + \beta^T x_{i,t})},$$

- Hierarchical regression

$$log\left(\frac{p_{it}}{1 - p_{it}}\right) \sim N(X_{it}\alpha_i, \sigma^2), \text{ for } t = 1, \dots, M \text{ (Week level)},$$

$$\alpha_i \sim N(\gamma W_i', \Sigma), \text{ for } i = 1, \dots, N \text{ (Individual level)},$$

FIGURE 3 Two-level structure of the case study data with individuals ($i = 1, \dots, N$) as the top level. Weeks in the data ($t = 1, \dots, M$) belonging to individual i are the bottom level

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Predicting crises

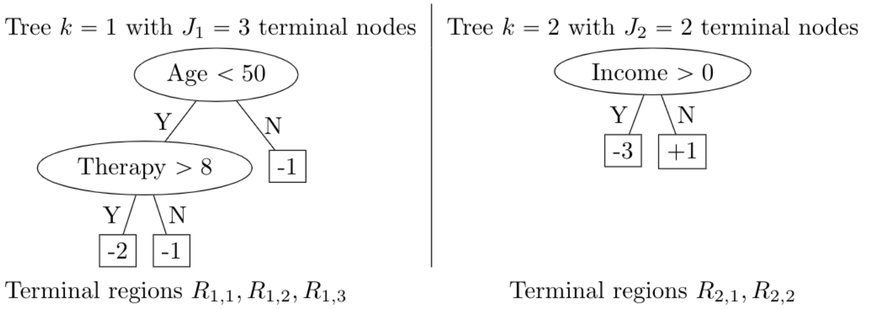
- What method should we use to predict a crisis?
- Gradient Boosting (XGBoost)
  - Efficient & Highest precision

Table 5.2 – Table of the mean estimated probabilities for the three methods, aggregated by the binary crisis outcome variable

Model	$P_{t\|y=0}$	$P_{t\|y=1}$	r_t	AUC
Logistic regression*	0.0021	0.0026	1.2260	0.6130
Hierarchical regression*	0.0021	0.0030	1.4370	0.5856
XGBoost	0.0017	0.0062	3.5440	0.6533

*Using 50% of the persons in the data due to limited memory size

Figure 4 – An example of a tree ensemble model for the risk of a mental health crisis using two trees ($K = 2$) and three variables. The Therapy variable contains hours of therapy in the past 4 weeks, the Income variable the amount in Euros earned over the past 4 weeks. The learning rate is $\eta = 0.3$. The initial prediction equals $p_0 = 0.5$.



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The monitoring steps

Monitor the **probability of a crisis**

1. Define event E (*crisis*) and threshold C
2. Specify the model for y_i (*gradient boosting*)
3. Estimate the parameters to obtain $\hat{\theta}_I$ at time t_I
4. Calculate $P(E)_t$ using the newly available observations at time $t > t_I$
5. Signal if $P(E)_t > C$
6. Re-estimate the parameters to obtain $\hat{\theta}_I$ using all available data at time t and go back to step 4 for a new timepoint.

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Finding the threshold

- What threshold *C* should be used to signal a ‘high’ probability of a crisis?
- Propose a tuning algorithm
  - Determine a desired False Alarm Rate (FAR_0)
  - Use cross-validation + grid search to find *C* that achieves a $FAR_{observed}$ close to, but less than FAR_0

FAR_0	C_{tuned}	$FAR_{observed}$	Precision	Recall
0.50000	0.001961	0.233681	0.003285	0.451351
0.10000	0.006116	0.029413	0.006130	0.106306
0.05000	0.008648	0.014699	0.007784	0.067568
0.01000	0.017988	0.003014	0.014247	0.025526
0.00100	0.051656	0.000327	0.064516	0.013213
0.00010	0.139054	0.000060	0.180556	0.007808
0.00001	0.333604	0.000009	0.400000	0.003604

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Results and summary

- Prediction is hard!
- Results are promising, but hardware insufficient
- Proposed tuning procedure to achieve desired false alarm rate (FAR)
  - Cross validation + grid search
  - Something for (more) future research

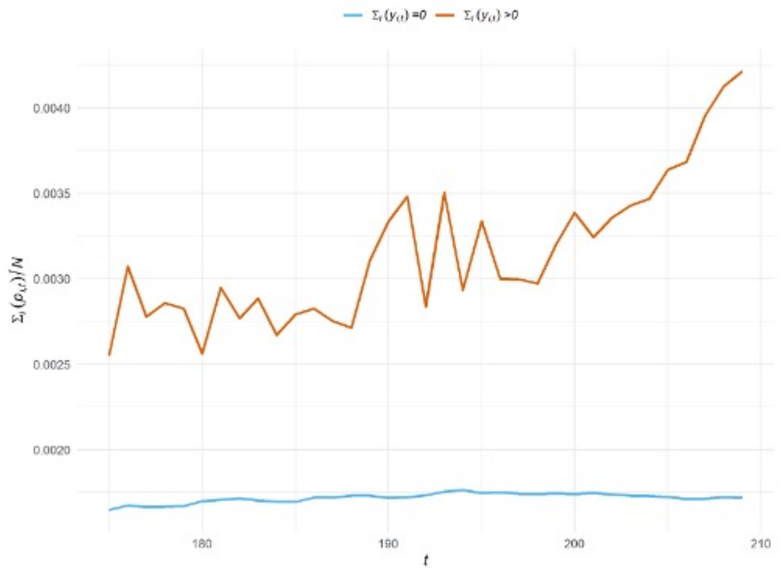

Table 5.5 – Precision and recall values using the XGBoost estimated probabilities of a crisis within 10 weeks and various values for threshold C

	C	Precision	Recall
1	0.0001	0.0148	1.0000000
2	0.0010	0.0183	0.8244052
3	0.0100	0.0438	0.0265457
4	0.1000	0.1603	0.0010674
5	0.5000	0.5000	0.0001685
6	0.7500	1.0000	0.0000281

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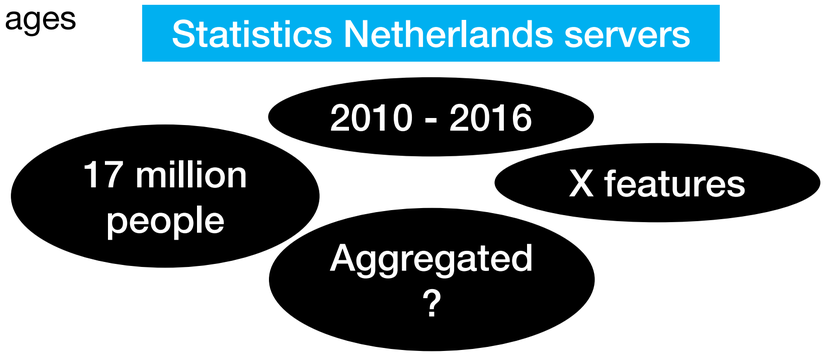
Future research

Predictive process monitoring in mental health

- Using Statistics Netherlands Data on all Dutch citizens
- Access to supercomputer
- Focus on **depression** and other mental health diagnoses
  - Affects around 5 percent of people
  - Depression is the leading cause of disability in the United States among people between the ages of 15 and 44
  - Early detection is critical for rapid intervention
  - Lifetime risk of suicide among people with untreated depression ranges from 2.2-15%
- Further analyses of what threshold *C* should be used to signal a 'high' probability of an event *E*?
- How often to re-estimate the parameters to obtain $\hat{\theta}_t$



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Thank you! 😇

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