Machine Learning Applications at a Storage Ring

Tobias Boltz, Miriam Brosi, Erik Bründermann, Florian Rämisch, Patrik Schönfeldt, Markus Schwarz, Minjie Yan and Anke-Susanne Müller | July 20, 2017
Motivation

Why use Machine Learning Techniques?

- increasing data rates at particle accelerators (reaching TB per day)
- data reduction $\Rightarrow$ information loss?
- fast (maybe even online), but precise data analysis required
- make use of large statistics to get higher precision
- machine learning offers options to process large data rates
- can model multivariate and non-linear dependencies
Machine Learning

Overview

- emerged as a sub-field of computer science in the 1950s
- explores algorithms that enable computers to learn from data without being explicitly programmed\(^1\)
- separated into two main categories: supervised learning and unsupervised learning
- variety of different methods for both categories exists
- typical examples are classification (supervised) and clustering (unsupervised) methods

Supervised Learning

Classification: Autom. Identification of New Object’s Category

⇒ e.g. neural networks, decision trees, support vector machines, ...
⇒ simple evaluation measures, e.g. accuracy score
Unsupervised Learning

Clustering: Exploratory Tool of Data Analysis

⇒ e.g. $k$-means, DBSCAN, gaussian mixture models, . . .
⇒ evaluation generally requires more effort
Machine Learning Applications at ANKA
CSR and Micro-Bunching Instability
Studies at ANKA

- operation of synchrotron light sources with short electron bunches increases coherent synchrotron radiation (CSR) power
- leads to complex dynamics in the longitudinal phase space and the formation of micro-structures within the bunch
- indirect measurement: resulting fluctuations in the emitted CSR power
- direct measurement: electron distribution, difficult due to the small scale of the micro-structures

⇒ See posters by M. Brosi and B. Kehrer this afternoon!
ML Applications at ANKA
Master’s Thesis: Spectrogram Classification

- Title: Analysis of Bursting Spectrograms using Machine Learning Techniques
- Author: Florian Rämisch
- Date: January 2017
- Processed data: order of TB, measured at ANKA
ML Applications at ANKA
Master’s Thesis: Spectrogram Classification

- Title: Analysis of Bursting Spectrograms using Machine Learning Techniques
- Author: Florian Rämisch
- Date: January 2017
- Processed data: order of TB, measured at ANKA
Bursting Spectrogram Classification
Automated Identification of Marked Bursting Regimes

Fill 4922 - Bunch 156

CSR fluctuation frequency

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Bursting Spectrogram Classification

Potential Tool for Multi-Bunch Studies

Title: Comprehensive Analysis of Micro-Structure Dynamics in Longitudinal Electron Bunch Profiles

Author: Tobias Boltz

Date: March 2017

Processed data: order of TB, simulated using Inovesa²

Published in KITopen:
https://publikationen.bibliothek.kit.edu/1000068253

ML Applications at ANKA

Master’s Thesis: Clustering of Micro-Structures

- Title: Comprehensive Analysis of Micro-Structure Dynamics in Longitudinal Electron Bunch Profiles
- Author: Tobias Boltz
- Date: March 2017
- Processed data: order of TB, simulated using Inovesa
- Published in KITopen: https://publikationen.bibliothek.kit.edu/1000068253

Clustering of Micro-Structures

Micro-Structures on the Longitudinal Bunch Profiles

\[ t \left( T_s \right) \]

\[ z / c \left( \text{ps} \right) \]

\[ \rho(z) \left( \text{pC/ps} \right) \]

micro-structures
Clustering of Micro-Structures

Analysis of Micro-Structures

\[ \rho(z) \text{ (pC/ps)} \]

\[ z/c \text{ (ps)} \]
Clustering of Micro-Structures

Analysis of Micro-Structures

\[ \Delta \rho(z) \left( 10^{-1} \text{ pC/ps} \right) \]

vs.

\[ \frac{z}{c} \text{ (ps)} \]

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Clustering of Micro-Structures

Correlation to CSR Power

\[ P_{\text{csr}} \text{ (arb. unit)} \]

\[ t (T_s) \]

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Clustering of Micro-Structures

Correlation to CSR Power

$P_{csr}$ (arb. unit)

$t (T_s)$
Summary and Outlook

Machine Learning at a Storage Ring

- Machine learning provides tools to handle large data sets, e.g.:
  - classification: automated identification of new object’s category
  - clustering: exploratory tool of data analysis

- Increasing data rates at particle accelerators yield new possibilities for the application of machine learning techniques

- First applications at ANKA have already proven successful
Thank you for your attention!
### Clustering of Micro-Structures: Simulation Parameters

<table>
<thead>
<tr>
<th>Physical parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF voltage $U_0$</td>
<td>1 MV</td>
</tr>
<tr>
<td>revolution frequency $f_{\text{rev}}$</td>
<td>9 MHz</td>
</tr>
<tr>
<td>synchrotron frequency $f_s$</td>
<td>30 kHz</td>
</tr>
<tr>
<td>damping time $\tau_d$</td>
<td>5 ms</td>
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<tr>
<td>harmonic number $h$</td>
<td>50</td>
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<tr>
<td>parallel plates distance $g$</td>
<td>3.2 cm</td>
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<tr>
<td>initial electron distribution $\varphi(z, E, t_0)$</td>
<td>2-dim. Gaussian</td>
</tr>
<tr>
<td>simulation time $t$</td>
<td>$250 \ T_s$</td>
</tr>
<tr>
<td>bunch current $I_{\text{bunch}}$</td>
<td>0.5 mA to 2.0 mA</td>
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</table>

<table>
<thead>
<tr>
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<td>time steps $n_{\text{steps}}$</td>
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</tr>
</tbody>
</table>