AI Solutions for Biomedical and Industrial Data – From Data to Decisions

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From Data to Decision – Our Approach
I) Optimization in Machine Learning: Multi-dimensional Particle Swarm Swarm Optimization (MD-PSO)

Multidimensional Particle Swarm Optimization for Machine Learning and Pattern Recognition

Go to $d = 23$

$g_{best}(3)$

$7$

$xd_a(t) = 2$

Optimizing over dimensions

$9$

$xd_a(t) = 3$

MD PSO ($d_{best}$)

OK!

$d = 3$

Go to $d = 23$

$x_{d_a}(t) = 23$
How to deal with such complex functions?
Learn to Synthesize Optimal Features – Signal Processing and Optimization Approach

Feature engineering:
- Feature extraction
- Feature selection
- Feature synthesis

Network Architecture Design: Evolutionary Artificial Neural Networks

**Question:** How to design **optimal** neural networks? MD-PSO

Kiranyaz, *Neural Networks*, 2009. (top 5th downloaded paper from Elsevier Journal)

\[ xx_a^{kd}(t) = \begin{cases} 
  \{ w_{jk}^0 \}, \{ w_{jk}^1 \}, \{ \theta_{k}^1 \}, \{ w_{jk}^2 \}, \{ \theta_{k}^2 \} \\
  \ldots, \{ w_{jk}^{O-1} \}, \{ \theta_{k}^{O-1} \}, \{ \theta_{k}^{O} \} 
\end{cases} \]
Patient-specific Classification of ECG Data by Evolutionary ANNs

Advanced Patter Recognition and Machine Learning: Collective Network of Binary Classifiers

- Supervised semantic classifier
- Evolutionary classifier (deep rooted in mathematical optimization)
- Scalable wrt both classes and features (suitable for Big Data)
- Incremental as opposed to static classifiers

Kiranyaz, *Neural Networks*, 2012
EEG Classification by Incremental CNBC Evolution

Synthetic Aperture Radar (SAR) Data Analysis and Classification


The CNBC test-bed application GUI showing a sample user-defined ground truth set over San Francisco Bay area.
Lighthouse Stadium

Multimedia Group – Prof. S. Kiranyaz
Patient-Specific Seizure Detection Using Nonlinear Dynamics and Nullclides

Average sensitivity 91.15%; average specificity 95.16% on CHB-MIT Database

Zabihi, Journal of Biomedical and Health Informatics, 2018 (under review).
FACE SEGMENTATION IN THUMBNAIl IMAGES BY DATA-ADAPTIVE CONVOLUTIONAL SEGMENTATION NETWORKS

Some Initial Results on the Test dataset
Table 1: Mean performances of the FCN-32s VGG [9] and the proposed L2S with single and 5 CSNs.

<table>
<thead>
<tr>
<th>Method</th>
<th>Train (mean %)</th>
<th>Test (mean %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pix. Acc.</td>
<td>F1</td>
</tr>
<tr>
<td>L2S (1 CSN)</td>
<td>91.29</td>
<td>70.59</td>
</tr>
<tr>
<td>L2S (5 CSNs)</td>
<td>94.38</td>
<td>81.05</td>
</tr>
<tr>
<td>FCN-32s [9]</td>
<td>94.29</td>
<td>77.91</td>
</tr>
</tbody>
</table>

Combining Quantum Mechanics and Spectral Graph Theory: Quantum-Cut for Salient Object Detection

\[
H(i, j) = \begin{cases}
V(i) + |N_i| \frac{\hbar^2}{2m} & i = j \\
- \frac{\hbar^2}{2m} & j \in N_i \\
0 & e. w
\end{cases}
\]

\[
L(i, j) = \begin{cases}
\sum_k w_{i,k} & i = j \\
- w_{i,j} & j \in N_i \\
0 & e. w
\end{cases}
\]

- Aytekin **Pattern Recognition**, 2016
- Aytekin **Pattern Recognition Letters**, 2016
- Aytekin **ICPR 2014**. IBM Best Paper Award
- Aytekin, Best Nordic Thesis Award, 2017
Object Proposals and Labeling

Image Labeling

- Lighthouse tower
- Building
- Sky
- Door
- House

- Wall
- Table
- Chair
- Curtain
- Railing
- Shelves
- Sideboard
Combining Deep Learning and Signal Processing – Object Proposals

Object(s) Recognition & Localization

wall door window mirror building cabinet balcony column arch
bottles column door window
Real-Time Motor Fault Detection by 1-D Convolutional Neural Networks

Real-time Motor Condition Monitoring

Real-time Motor Fault Detection by 1D CNN

240 msec to detect and classify faults from a 2-sec signal sampled at 12.8kHz (5min for training)

Real-Time Patient-Specific ECG Classification by 1D CNN

Training (Offline)

Patient-specific data: first 5 min. beats

Common data: 200 beats

Training Labels per beat

Real-time Monitoring

Upload

Real-Time Patient-Specific ECG Classification by 1D CNN

Table II: VEB and SVEB classification performance of the proposed method and comparison with the four major algorithms from the literature. Best results are highlighted.

<table>
<thead>
<tr>
<th>Methods</th>
<th>VEB</th>
<th>SVEB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acc</td>
<td>Sen</td>
</tr>
<tr>
<td>Hu et al. [10]</td>
<td>94.8</td>
<td>78.9</td>
</tr>
<tr>
<td>Jiang and Kong [15]</td>
<td>98.8</td>
<td>94.3</td>
</tr>
<tr>
<td>Ince et al. [16]</td>
<td>97.9</td>
<td>90.3</td>
</tr>
<tr>
<td><strong>Proposed</strong></td>
<td><strong>98.9</strong></td>
<td><strong>95.9</strong></td>
</tr>
<tr>
<td>Jiang and Kong [15]</td>
<td>98.1</td>
<td>86.6</td>
</tr>
<tr>
<td>Ince et al. [16]</td>
<td>97.6</td>
<td>83.4</td>
</tr>
<tr>
<td><strong>Proposed</strong></td>
<td><strong>98.6</strong></td>
<td><strong>95</strong></td>
</tr>
<tr>
<td>Ince et al. [16]</td>
<td>98.3</td>
<td>84.6</td>
</tr>
<tr>
<td><strong>Proposed</strong></td>
<td><strong>99</strong></td>
<td><strong>93.9</strong></td>
</tr>
</tbody>
</table>

1 The comparison results are based on 11 common recordings for VEB detection and 14 common recordings for SVEB detection.
2 The VEB and SVEB detection results are compared for 24 common testing records only.
3 The VEB and SVEB detection results of the proposed system for all training and testing records.

Personalized Monitoring and Advance Warning System for Cardiac Arrhythmias

Serkan Kiranyaz, Turker Ince & Moncef Gabbouj

Kiranyaz, Scientific Reports, 2017. (Springer Nature)
a) Modelling common causes of cardiac arrhythmia in the signal domain.
b) Symbolic illustration of an abnormal S beat synthesis for Person-Y using the degrading system designed from the ECG data of several Patient(s)-X.
c) Illustration of the overall system, where a dedicated CNN is trained by Backpropagation over the training dataset created for Person-Y (top). Once the 1D CNN is trained, it can then be used as a continuous cardiac health monitoring and advance warning system (bottom) for Person-Y.
34 patients with 63,341 ECG beats were used in the evaluation.

- \( Sen = 82.51\% \), \( Spe = 99.55\% \), \( Ppr = 95.55\% \), \( Acc = 97.75\% \) and \( FAR = 0.45\% \),
- Average probability of missing the first abnormal beat is 0.174
- The average probability of missing three consecutive abnormal beats is around 0.0053.
- Therefore, detecting one or more abnormal beat(s) among the first three occurrences is highly probable (>99.4%)

**Table 1.** Cumulated CM for the test dataset over 10 runs.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>S</th>
<th>V</th>
<th>F</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>564118</td>
<td>1443</td>
<td>7447</td>
<td>2721</td>
<td>60</td>
</tr>
<tr>
<td>S</td>
<td>1362</td>
<td>12913</td>
<td>9752</td>
<td>447</td>
<td>17</td>
</tr>
<tr>
<td>V</td>
<td>856</td>
<td>217</td>
<td>28145</td>
<td>210</td>
<td>20</td>
</tr>
<tr>
<td>F</td>
<td>224</td>
<td>16</td>
<td>1254</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Q</td>
<td>120</td>
<td>11</td>
<td>2032</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 2.** 2 × 2 confusion matrix deducted from the CM in Table 1.
Advanced Network Architecture Design: Generalized Operational Perceptrons (GOPs)

We proposed a Progressive Operational Feedforward Neural network learning approach

\[ x_k^l = b_k^l + \psi_k^l(y_{i-1}^l, w_{ik}^l), \]
\[ y_k^l = f_k^l(x_k^l) \]
\[ p_k^l \in \{P\}, \psi_k^l \in \{\Psi\}, f_k^l \in \{F\} \]

Efficient CNN Design (Deep Learning)

Tensor-based CNN:
- Employing multilinear projection as the primary feature extractor
- Lower number of network parameters (reduced memory footprint)
- Faster classification (reduced computational cost)


LR: Low-Rank Regression, Tai arXiv 2015
Temporal-aware NN BoF model for time-series data analysis

Fig. 1: Pipeline of the proposed financial forecasting model

Attention in Multi-linear Networks (AMLN)

AMLN architecture incorporates:

- Bilinear projection
- An attention mechanism to detect and focus on temporal information.

AMLN is highly interpretable, able to highlight the importance and contribution of each temporal instance.

Two-hidden-layer network achieves state-of-the-art performance on a large-scale Limit Order Book (LOB) dataset.


Fig. 3. Average attention of 10 temporal instances during training in 3 types of movement: decrease, stationary, increase. Values taken from configuration A(TABL) in Setup2, horizon $H = 10$. 

Alexandros Iosifidis
28.11.2018
Multimodal and Cross-modal Learning


Moncef Gabbouj  
14.12.2018
IEEE NER 2015 BCI CHALLENGE 2015: (3rd PLACE)

OBJECTIVE:
❖ P300-Speller is a well-known brain-computer interface paradigm and has great potential to help individuals with neuromuscular disabilities to communicate. The goal of this challenge was to detect errors during the spelling task by analyzing the subjects’ EEG recording.

METHODOLOGY:
❖ The BCI challenge@NER2015 dataset is used.
❖ 56 EEG channels are used.
❖ 13 different features of approximation coefficients of Daubechies 4 wavelets in 5-level decomposition are extracted (base-level features).
❖ The base-level features are classified by 56 different linear discriminant analysis (LDA) classifiers (for each channel) to obtain the meta-level features which are the posterior probabilities (of the LDA classifiers).
❖ For classification of (56-dimension) feature vectors a feedforward neural network with two hidden layers; 15 neurons in the first and 7 neurons in the second hidden layer is used.

RESULTS:
❖ The area under the ROC curve of 0.78 was achieved for the proposed approach (this was 0.69 in the private leaderboard).
PHYSIONET CHALLENGE 2016: (2nd PLACE AMONG 48 TEAMS)

OBJECTIVE:
❖ Heart sound has a great potential to be used as a diagnostic test in ambulatory monitoring. The goal was to detect heart anomalies by analyzing the subject's heart sound waves.

METHODOLOGY:
❖ The Physionet challenge 2016 PCG dataset is used.
❖ 18 features is selected among 40 features from time, frequency, time-frequency domains.
❖ Wrapper-based feature selection scheme using sequential forward selection search algorithm is used for feature selection.
❖ 20 ANN were used with two hidden layers in each, and 25 hidden neurons at each layer.

RESULTS:

<table>
<thead>
<tr>
<th>Evaluation Metrics</th>
<th>Sen (%)</th>
<th>Spe (%)</th>
<th>Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave.</td>
<td>94.2</td>
<td>88.8</td>
<td>91.5</td>
</tr>
</tbody>
</table>

Train Dataset 10-fold cross-validation
PHYSIONET CHALLENGE 2017: (1st PLACE AMONG 75 TEAMS)

OBJECTIVE:
- The goal of this challenge was to detect Atrial Fibrillation (AF) rhythm using hand-held ECG monitoring devices, in addition to three other classes: normal or sinus rhythm, other rhythms, and too noisy to analyze.

METHODOLOGY:
- The Physionet challenge 2017 ECG dataset is used.
- 491 hand-crafted multi-domain features are extracted.
- 150 features are selected using random forest.
- Hybrid classification (base-level + meta-level) learning

RESULTS:

<table>
<thead>
<tr>
<th>Evaluation Metrics</th>
<th>Ave. on Train Dataset (%)</th>
<th>Ave. on Test Dataset (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1n (Normal)</td>
<td>90.49</td>
<td>81.85</td>
</tr>
<tr>
<td>F1a (AF)</td>
<td>79.43</td>
<td>83</td>
</tr>
<tr>
<td>F1o (Other)</td>
<td>75.64</td>
<td></td>
</tr>
<tr>
<td>F1p (Noisy)</td>
<td>61.11</td>
<td></td>
</tr>
<tr>
<td>F1 (Total)</td>
<td>81.85</td>
<td>83</td>
</tr>
</tbody>
</table>

COMPUTING IN CARDIOLOGY

AF Classification from a short single lead ECG recording

Morteza Zabihi, Ali Bahrami Rad, Aggelos K. Katsaggelos, Serkan Kiranyaz, Susanna Narkilahti, and Moncef Gabbouj
tied for First Place

this certificate of merit for participation with distinction in the 18th annual Computing in Cardiology/PhysioNet Challenge

Rennes, France: September 27, 2017
NSF-Business Finland-IUCRC-CVDI

Industry Advisory Board (IAB)

Financial Support, Research Direction, Guidance

Collaborative Research Approach

Research Expertise & Institutional Support (Infrastructure, Students, etc.)

Core and Supplemental Funds, IUCRC Governance

Research Projects

Areas of Focus

Data Cleaning

Predictive Analytics

Data Summarization

Social Media Analytics

Research Technology Portfolio

Value Created

Innovations in Big Data and Analytics

Machine and Artificial Intelligence

Cooperative Technology Transfer
- Royalty Free Licenses
- Publication Access
- Technology Breakthroughs

Collaborative Results
- University Alignments
- Faculty/Student Access
- Industry Partnerships

Investment in Future
- Trained Workforce
- Recruitment Opportunities
- Professional Development

Value Return
- Research Cost Savings
- 90% funds dedicated to research
- >40:1 Return on Investment

University Partners

Funding Agencies

Cooperative Technology Transfer
- Royalty Free Licenses
- Publication Access
- Technology Breakthroughs

Collaborative Results
- University Alignments
- Faculty/Student Access
- Industry Partnerships

Investment in Future
- Trained Workforce
- Recruitment Opportunities
- Professional Development

Value Return
- Research Cost Savings
- 90% funds dedicated to research
- >40:1 Return on Investment

Founded in 2012

www.nsfcvdi.org
Recent books in the field

- Multidimensional Particle Swarm Optimization for Machine Learning and Pattern Recognition
  - Serkan Kiranyaz
  - Turker Ince
  - Moncef Gabbouj
  - Springer

- Nonlinear Digital Filtering with Python
  - An Introduction
  - Ronald K. Pearson • Moncef Gabbouj
Summary

- Novel methods and algorithms for artificial intelligence deeply rooted in signal processing and pattern recognition,

- New machine learning techniques developed based on the specific properties of the problems at hand,

- Data-to-Decision Research Community in TUT gathered a critical mass to make sizeable contributions to the field of AI,