AstroCeNT's Scientific Computing & Information Technology Group Activities

AC Computing (G5)

Piotr Gawron

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Particle Astrophysics Science and Technology Centre
International Research Agenda
Nicolaus Copernicus Astronomical Center, Polish Academy of Sciences

CAMK PAN

AstroCeNT–APC Annual Meeting
Warsaw, 20 December 2023

European Funds Smart Growth

Republic of Poland

FNP Foundation for Polish Science

European Union
European Regional Development Fund

Group members

Researchers

- Piotr Gawron — leader
- Manish Gupta — post-doc
- Marek Bukowicki — post-doc
- Tomasz Rybotycki — post-doc
- Aleksandra Krawiec — post-doc
- Magdalena Wiercioch — technician (post-doc in waiting)
- Piotr Kalaczyński — technician (post-doc in waiting)

Students

- 2 undergrad students

Past members

- Mateusz Denys — post-doc

Section 1

Software engineering for data analysis

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Overview of current activities

Deap-3600

- Toy Monte Carlo (with M. Kuźniak group).
- Applications neural networks for event position reconstruction.

Einstein Telescope / Gravitational waves

- OSB, Division 10, Data Analysis Platform, Technology Tracking Group.
- GW signal reconstruction, sound field reconstruction.

Quantum computing

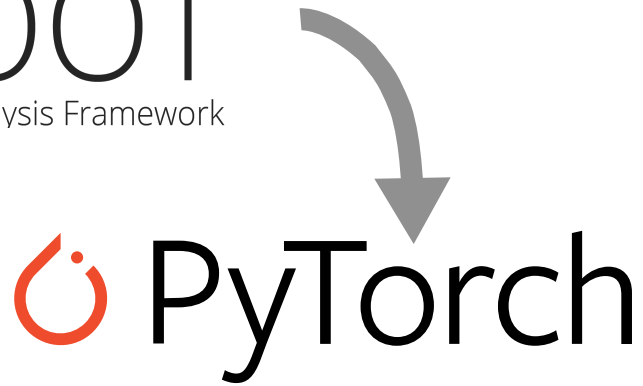
- Quantum Machine Learning models for Earth observations.

Toy MC-based full PSD model

Manish Gupta, Piotr Kalaczyński (for Deap-3600)

Highlights

- Use of faster, modern tool
- Speeding-up the computation by ≈ 2.5 orders of magnitude
- Continuous testing and preparing for deployement.



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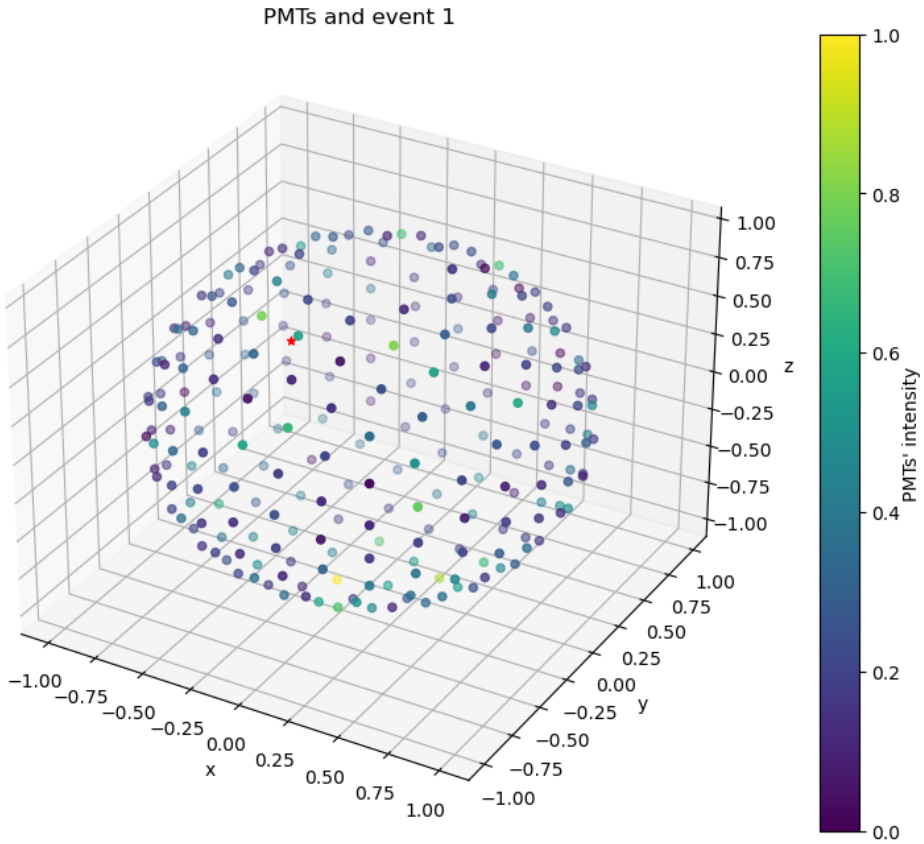
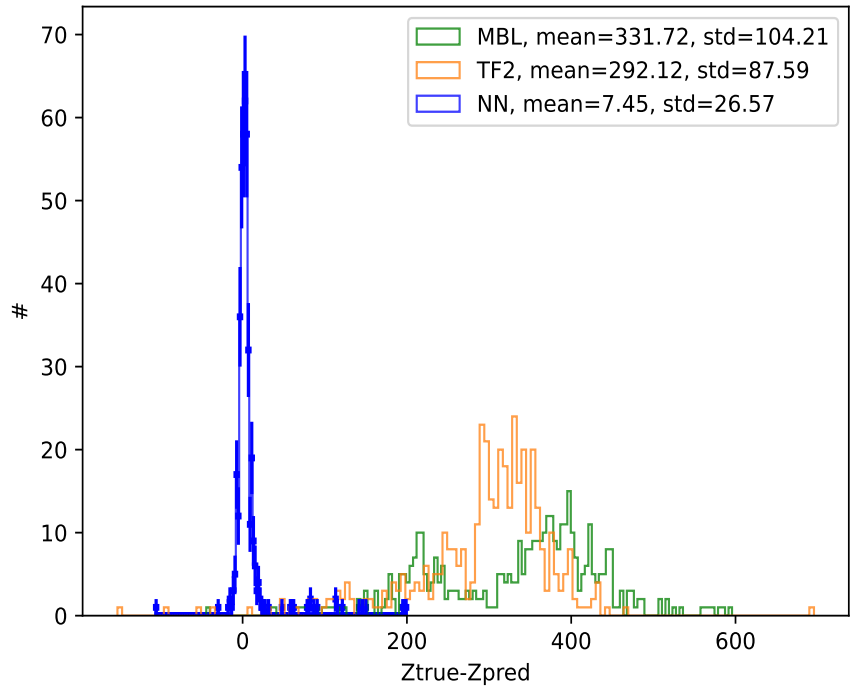
Position reconstruction in DEAP-3600 detector, generative models for data augmentation

Magdalena Wiercioch in collaboration with Luca Doria (Deap-3600 collaboration)



Neck region



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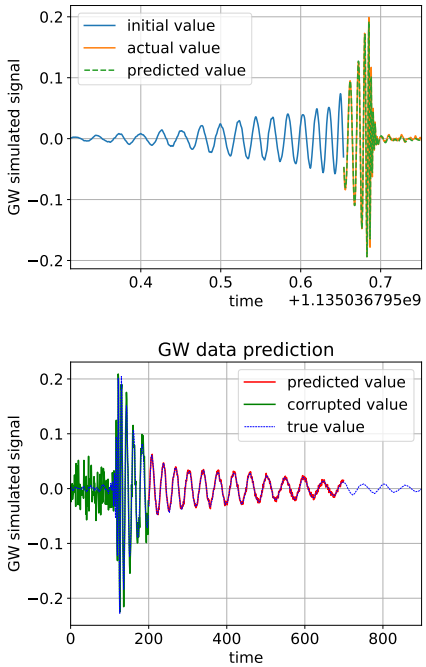
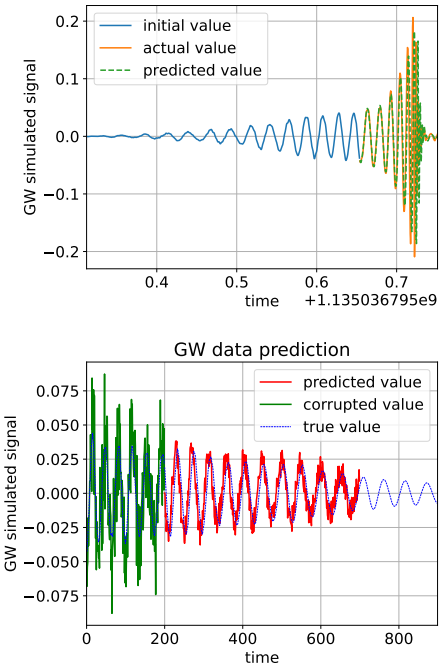
Gravitational waves prediction using RNNs

Mateusz Denys, Magdalena Wiercioch in collaboration with Michał Bejger, Agata Trovato, Éric Chassande-Mottin



The **best** result in the test set



The **worst** result in the test set

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KM3NeT related activities

Piotr Kalaczyński

Tasks this year

- finishing the CORSIKA MC production and prompt muon analysis
- writing up the PhD thesis and the gSeaGen paper
- code maintenance & dev: corant, gSeaGen (KM3NeT)

Results

- PhD thesis completed (defence in January)
- Publication under the collaboration review: "gSeaGen code by KM3NeT: an efficient tool to propagate muons simulated with CORSIKA"

Future

Funding proposals to be submitted

- M2Tech (simulation of hybrid KM3NeT DOMs containing SiPMs)
- Copernican Academy Grants (acoustic simulation for KM3NeT)
- OSCARS (common neutrino telescope dataformat?)

Other ideas/involvement:

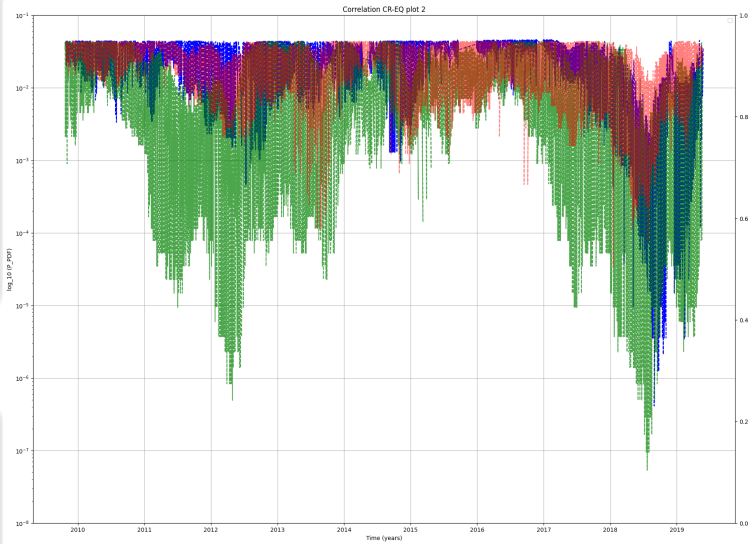
- underground particle physics labs in Wieliczka/Bochnia (CR simulations for IFJ PAN), paper in 2024
- collaboration with the space industry

Studying relations between cosmic rays detection rate and a global number of earthquakes

Aleksandra Krawiec Piotr Homola (Institute of Nuclear Physics, PAS: Project CREDO)

Task and results

- Replicating discovery using **proper software engineering** methods
- Finding and applying tools for optimizing hyperparameters



Future

Study the presence of causal relations between cosmic rays and number of earthquakes

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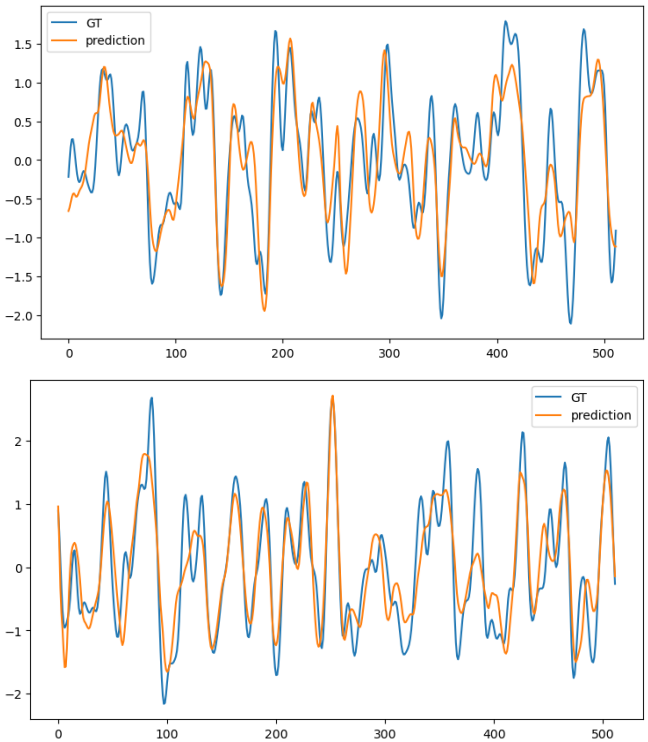
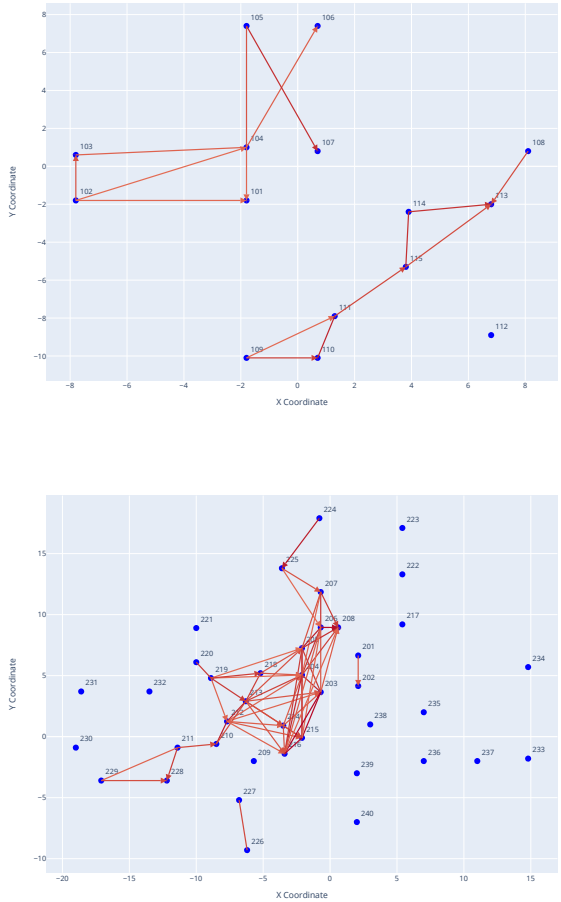
Missing channels reconstruction @ Virgo

Marek Bukowicki, with support of Tomasz Bulik



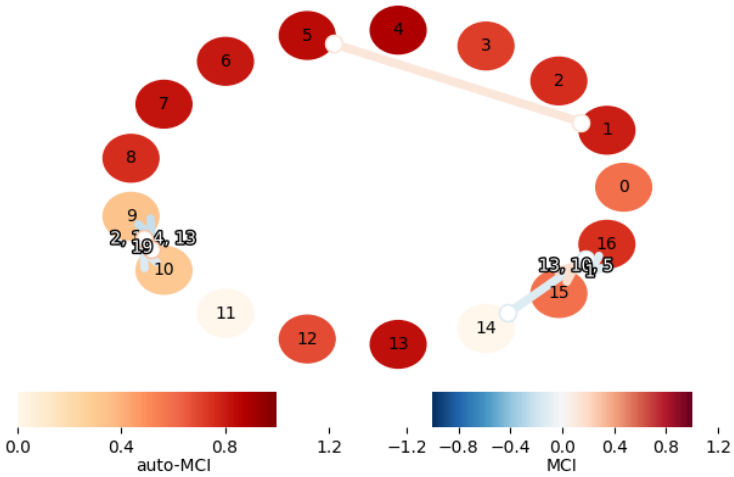
Reconstructions of the acceleration measured by one seismometer based on signal from another seismometer



Correlations between seismometers signals on the floors of Virgo

Detecting causality in time series containing data from environmental gravitational wave sensors

Emilia Kaczmarczyk



Partial correlation-based causality detection in Ligo seismic sensors data (preliminary results)

Section 2

Quantum computing

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LUMI-Q

European quantum computers, EUROHPC-2022-CEI-QC-01

Goal of the project

Quantum computing environment integrated with the HPC infrastructure.

AstroCeNT's tasks

High performance computing + quantum machine learning techniques for:

- GW signal processing from Einstein Telescope,
- EO data processing from Sentinel satellites.

- *Funding for AstroCeNT:* 4×12 *PM* — likely to happen but not secured yet.
- New quantum computer delivery in 2024.

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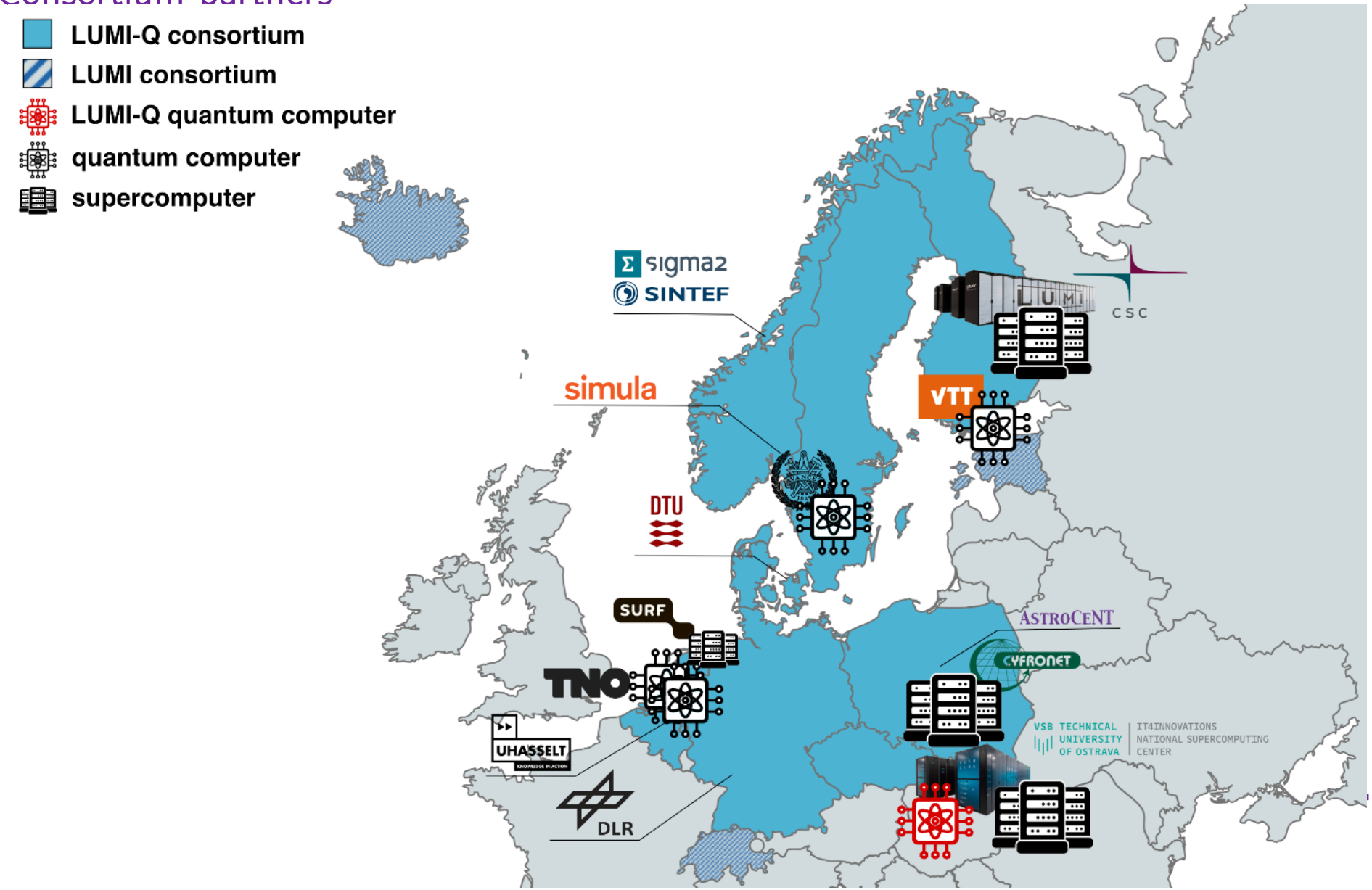
LUMI-Q

Consortium partners

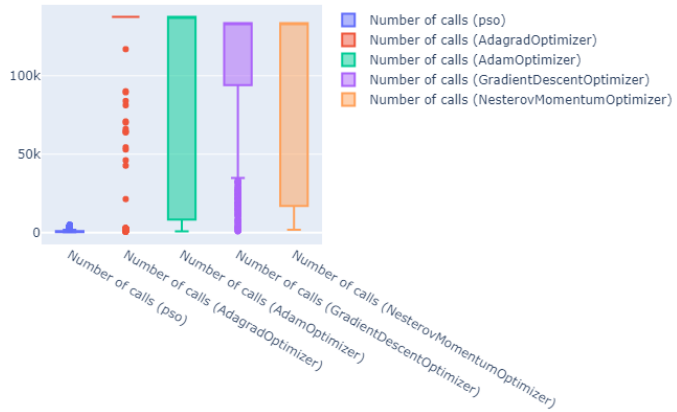


Investigate performance of metaheuristics as QNN training methods

Tomasz Rybotycki, Piotr Gawron

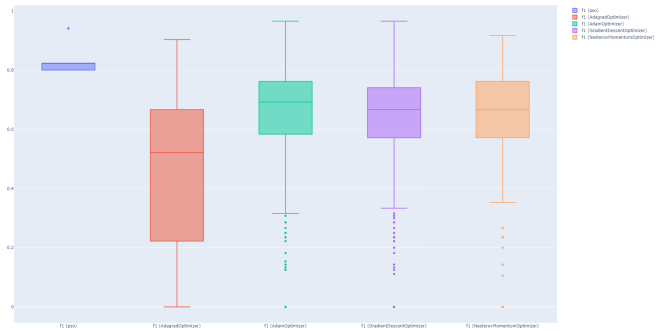
Results

- Performance metrics comparable (or better) to gradient-based techniques
- Significant cost reduction (# of quantum device calls)



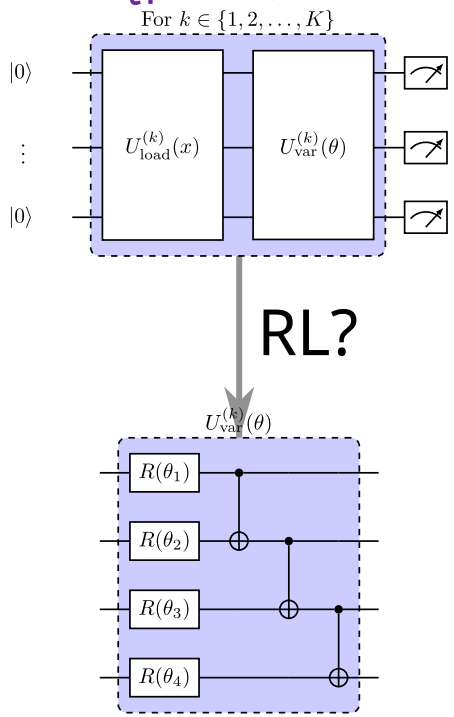
Future

- Extensive experiments on diverse circuits structures
- Different metaheuristics (types / kinds)
- Metaheuristic training for barren-plateaus problem



RL4QC — Variational Quantum Circuit structure search using Reinforcement Learning

Mateusz Stępniak, Tomasz Rybotycki, Justyna Zawalska (AGH), Piotr Gawron




```python
# DQN Agent
class DQNAgent:
    def __init__(self, input_dim, output_dim, learning_rate=0.001):
        self.q_network = DeepQNetwork(input_dim, output_dim)
        self.optimizer = optim.Adam(self.q_network.parameters(), lr=learning_rate)
        self.criterion = nn.MSELoss()

    def select_action(self, state, epsilon):
        if np.random.rand() < epsilon:
            return np.random.choice([0, 1])  # Random action
        else:
            state = torch.FloatTensor(state).unsqueeze(0)
            q_values = self.q_network.forward(state)
            return torch.argmax(q_values).item()
```

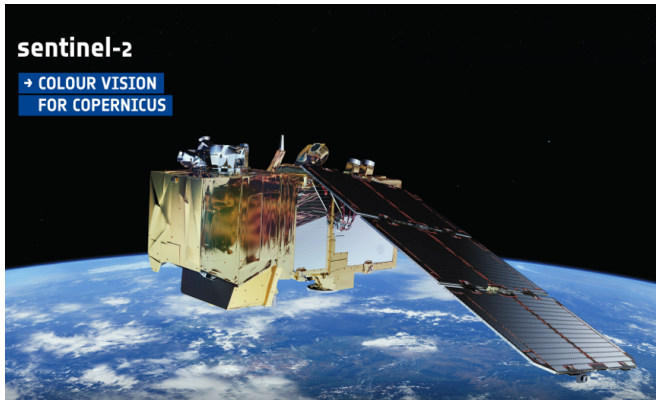
An RL python library for quantum circuit structure finding

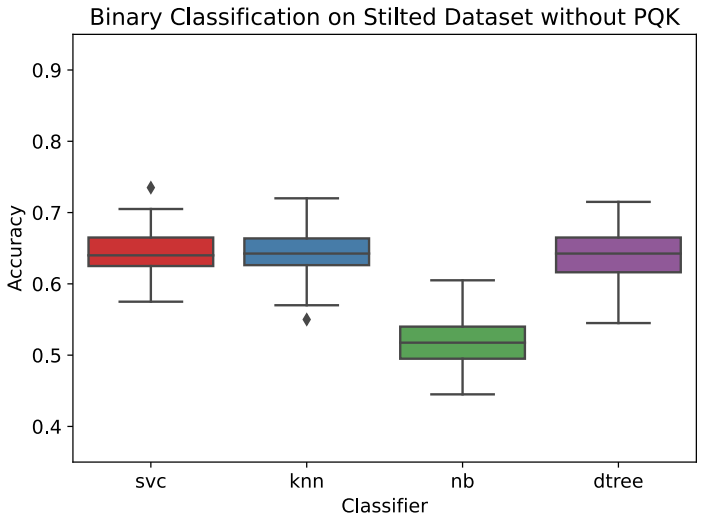
Future

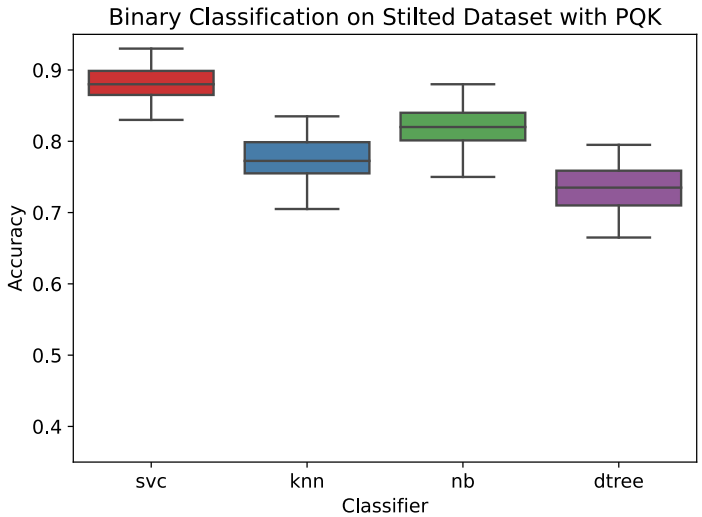
- Comparisons with related methods
- VQC optimization with RL + ZX-calculus techniques

Spectral information processing with quantum neural networks

Manish Gupta, Piotr Gawron, Co-operation ESA's Φ-Lab — AstroCeNT







Unsupervised quantum machine learning for Earth observations

Piotr Gawron with IITiS PAN, CSGroup and CNES

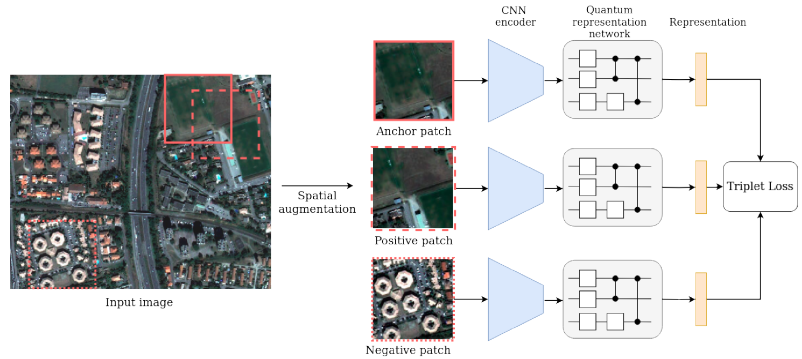
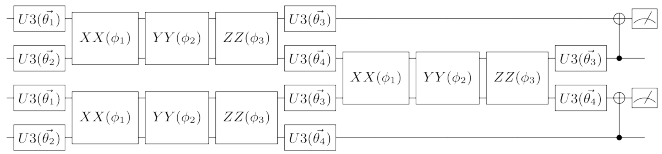
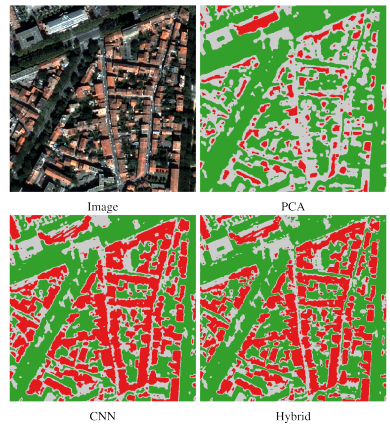


Fig. 1. Illustration of the proposed hybrid contrastive learning framework.





Section 3

Collaboration with industry

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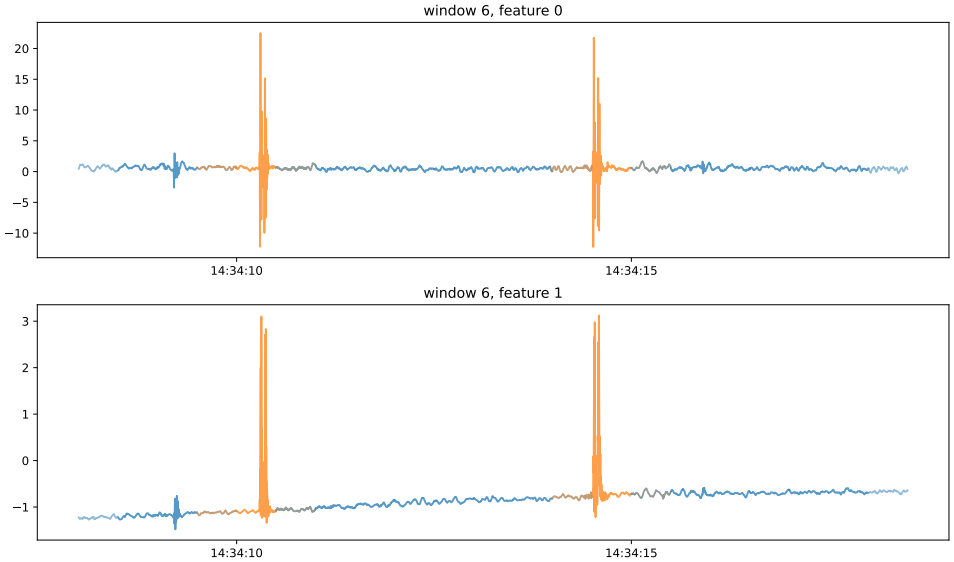
Geophone-based measurement of ground penetrator and unsupervised event detection

Piotr Gawron, Marek Bukowicki, Mariusz Suchenek and Astronika



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Section 4

Summary

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Papers

[1] Defonte, V., van Waveren, M., Pasero, G., Savinaud, M., Gawron, P., Brunet, P.-M., and Faucoz, O.
Quantum contrastive learning for semantic segmentation of remote sensing images.
In *Proceedings of the 2023 conference on Big Data from Space (BiDS'23): from foresight to impact: 6–9 November 2023, Austrian Center, Vienna.* (2023), E. C. J. R. Centre., Ed., EU Publications Office.

[2] Denys, M.
Model of cunning agents.
Physica A: Statistical Mechanics and its Applications 574 (Jul 2021), 125987.

[3] Gardas, B., Głomb, P., Sadowski, P., Puchała, Z., Jałowiecki, K., Pawela, Ł., Faucoz, O., Brunet, P.-M., Gawron, P., Van Waveren, M., et al.
Hyper-spectral image classification using adiabatic quantum computation.
In *IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium* (2023), IEEE, pp. 620–623.

[4] Gawron, P., and Lewiński, S.
Multi-spectral image classification with quantum neural network.
In *IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium* (Sep 2020), p. 3513–3516.

[5] Gupta, M. K., Beseda, M., and Gawron, P.
How quantum computing-friendly multispectral data can be?
In *IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium* (Kuala Lumpur, Malaysia, Jul 2022), IEEE, p. 4153–4156.

[6] Szymko, R., Denys, M., Bulik, T., Idźkowski, B., Kutynia, A., Nikliborc, K., and Suchiński, M.
Application of spatio-temporal spectral analysis for detection of seismic waves in gravitational-wave interferometer.
Galaxies 9, 33 (Sep 2021), 50.

[7] van Waveren, M., Savinaud, M., Pasero, G., Defonte, V., Brunet, P.-M., Faucoz, O., Gawron, P., Gardas, B., Puchała, Z., and Pawela, Ł.
Comparison of quantum neural network algorithms for earth observation data classification.
In *IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium* (2023), IEEE, pp. 780–783.

Outlook

Frame from my interview by ISC in Sep 2019

Main research tasks — proposed during interview

- 50% High performance computing using modern programming languages
- 20% Neural networks based speed-up of large data processing and automatic discovery
- 30% Quantum computation and quantum machine learning support for scientific computing

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Successes and failures

Group successes

- Successfully embedding my group into AstroCeNT activities.
- Establishing European collaboration in the areas of QC and EO.
- Supporting DEAP-3600, KM3NeT, CREDO, Virgo, ET with scientific computing skills.

My failures

- Not enough papers published (some in pipeline).
- Not enough grants secured.
- Collaboration with industry only semi-successfull.
- Future of the group is uncertain.

Future

CEAI@AGH

- We (PG, PK, TR) are partially joining part-time Center of Excellence in Artificial Intelligence @ AGH — project ArtiQ.

CAMK PAN

- MG, PK, TR will be supported by ESA-MEiN project.
- PG will be supported by another ESA consultancy project.
- LUMI-Q and access to a quantum computer should help us obtain grants.
- EuroQHPC-Integration should help us support the group for 4 years.

Thank you

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European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund