AstroCeNT's Scientific Computing & Information Technology Group Activities

AC Computing (G5)

Piotr Gawron

ASTROCENT

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

CAMK PAN

CAMK PAN reporting meeting
Warsaw, 01 February 2024

European Funds Smart Growth

Republic of Poland

FNP Foundation for Polish Science

European Union
European Regional Development Fund

Group members

Researchers

- Piotr Gawron
- Manish Gupta
- **Tomasz Rybotycki**
- **Piotr Kalaczyński**
- *Marek Bukowicki*

Students

- *Mateusz Stępniak*
- *Emilia Kaczmarczyk*

Past members

- Mateusz Denys
- **Aleksandra Krawiec**
- **Magdalena Wiercioch**
- 6 students

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

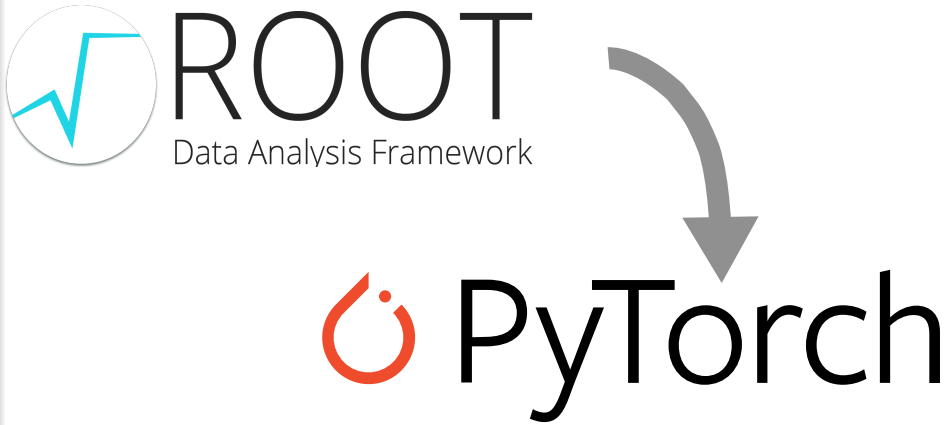
- Quantum Machine Learning models for Earth observations.

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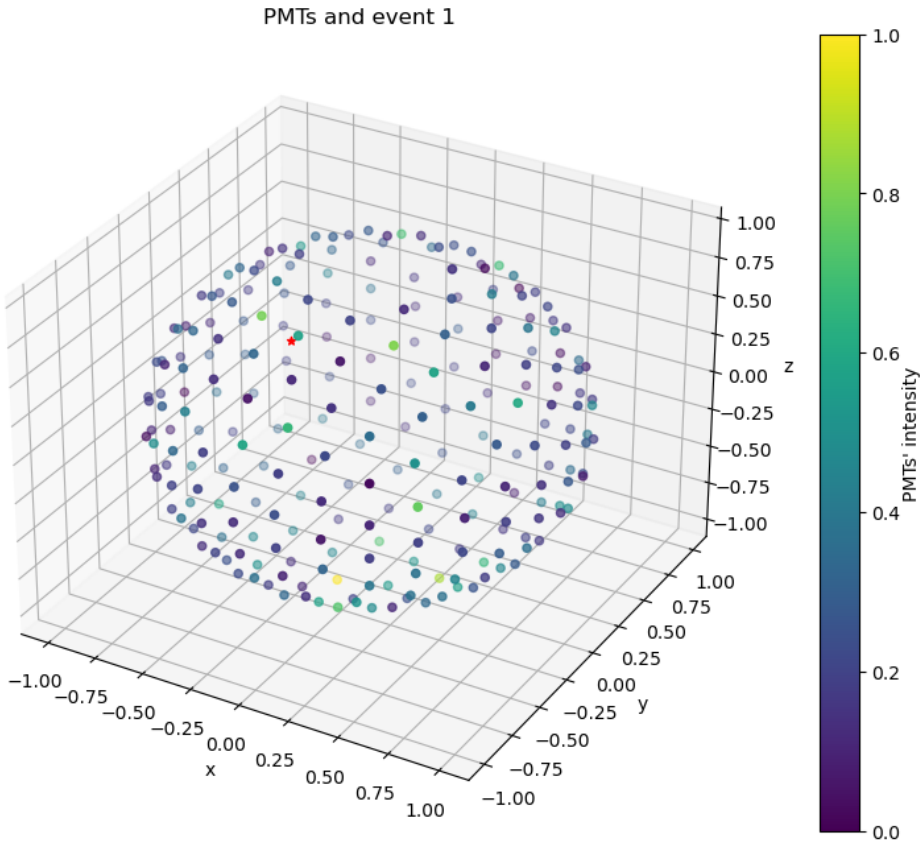
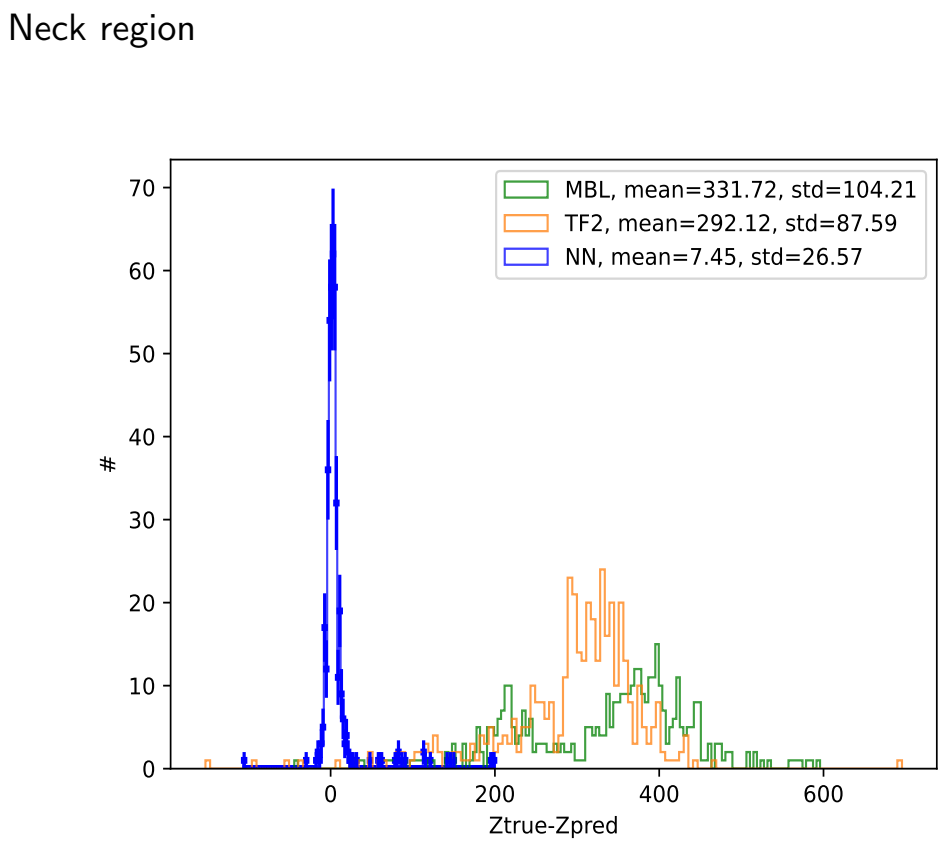
Position reconstruction in DEAP-3600 detector, generative models for data augmentation

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





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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 defended
- 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:

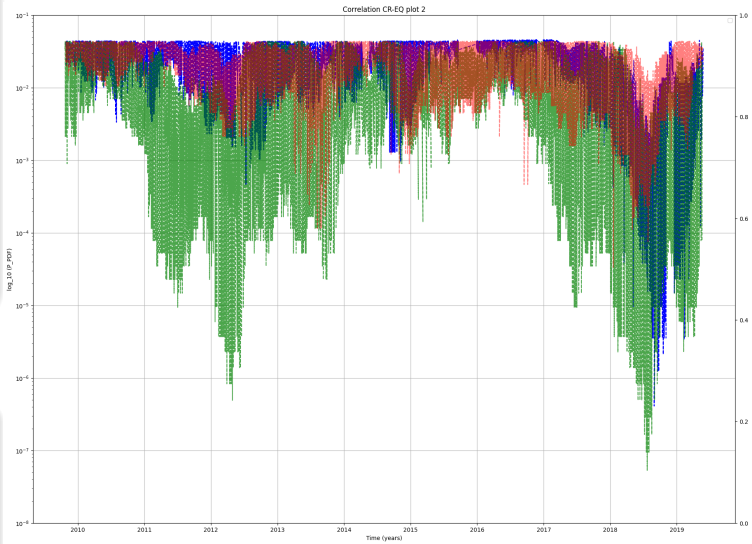
- underground particle physics labs in Wieliczka/Bochnia (CR simulations for IFJ PAN), paper in 2024
- collaboration with the space industry

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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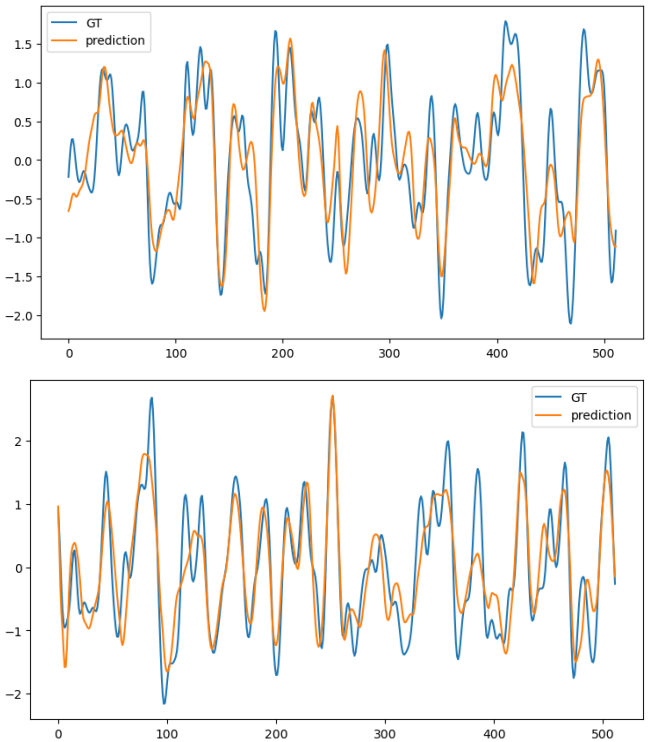
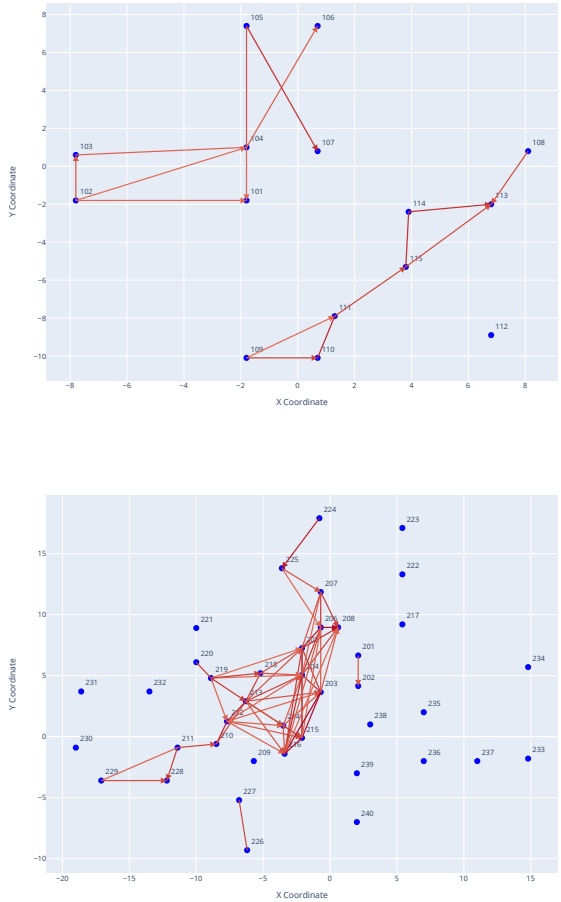
Missing channels reconstruction @ Virgo

Marek Bukowicki, with support of Tomasz Bulik



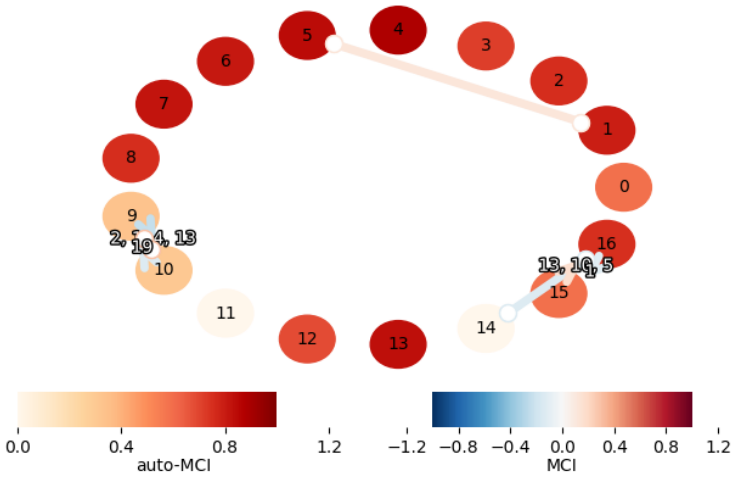
Reconstructions of the acceleration measured by one seismometer based on signal from another seismometer

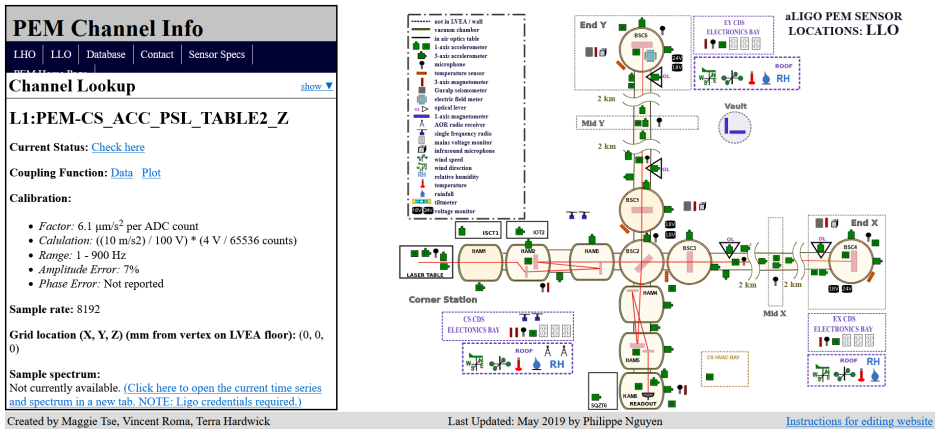


Correlations between seismometers signals on the floors of Virgo

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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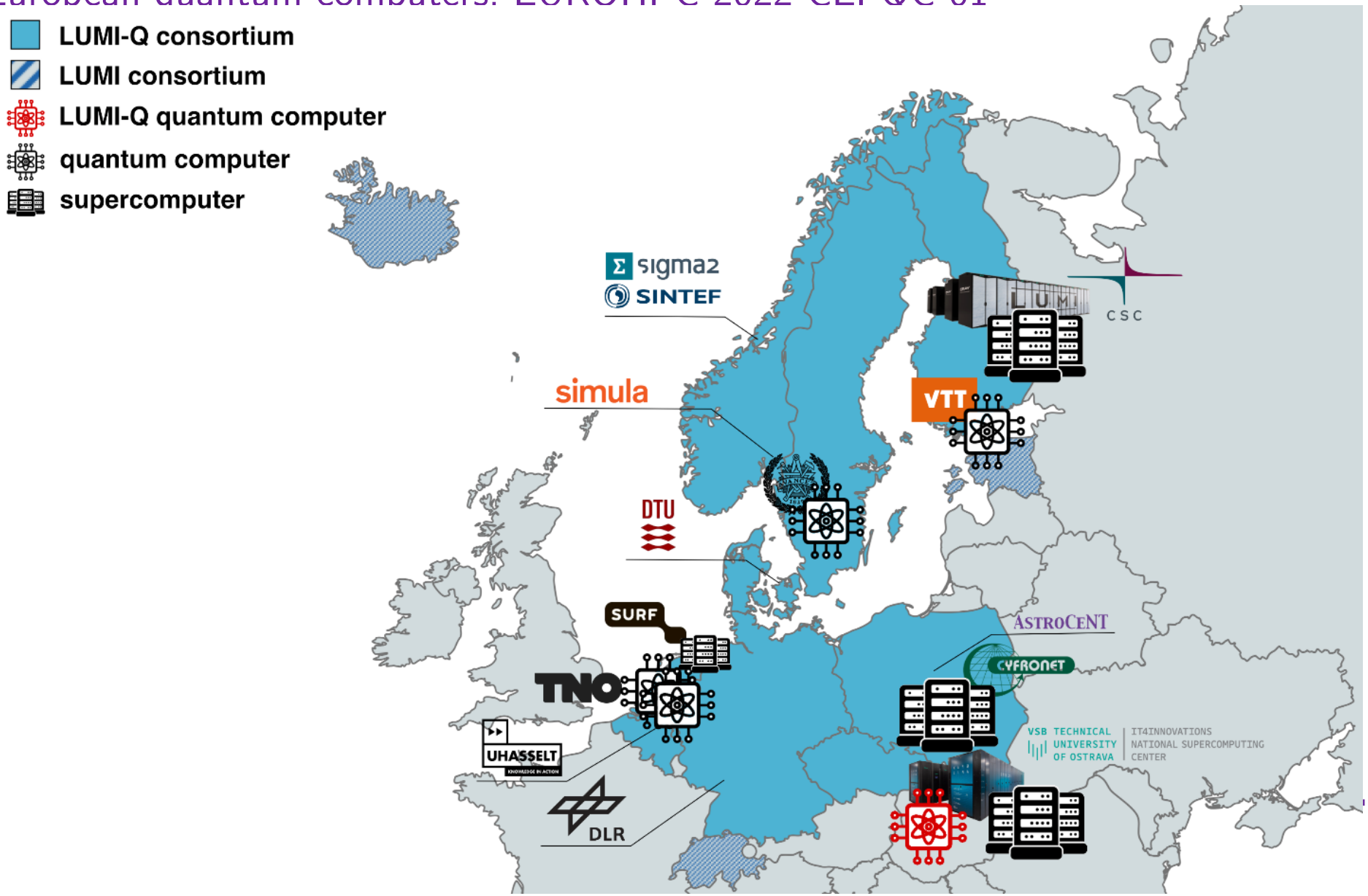
LUMI-Q

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

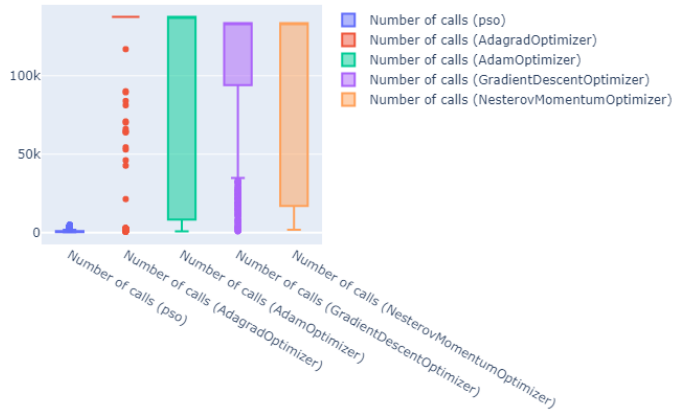


Investigate performance of metaheuristics as QNN training methods

Tomasz Rybotycki, Piotr Gawron

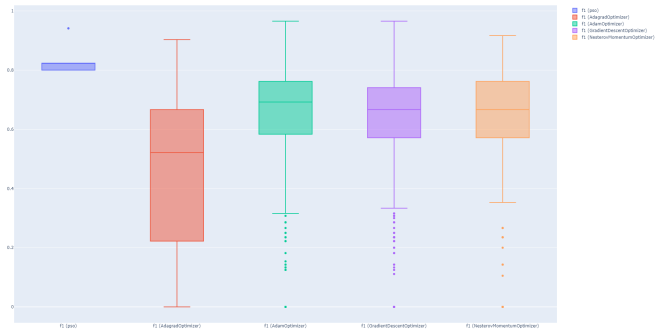
Results

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



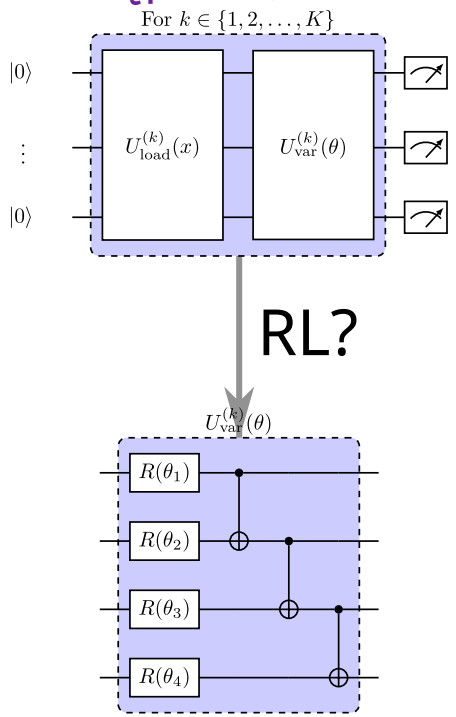
Future

- 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()
```

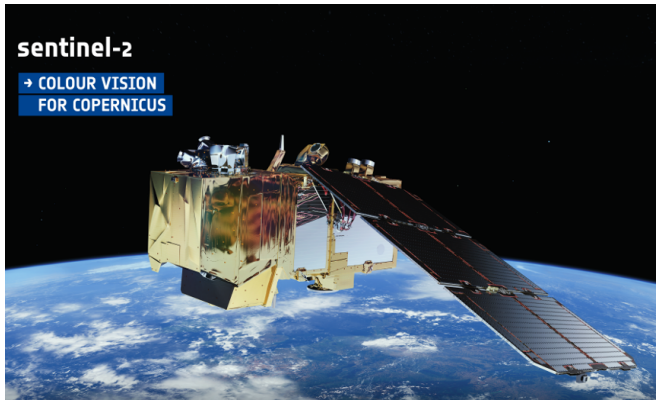
An RL python library for quantum circuit structure finding

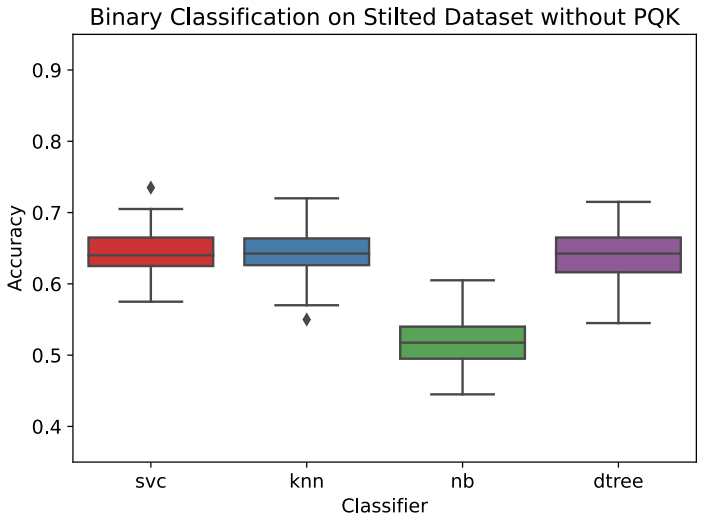
Future

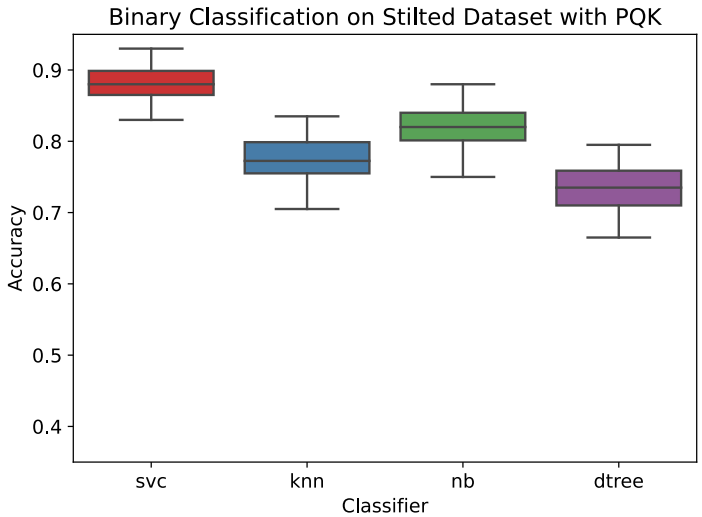
- Comparisons with related methods
- VQC optimization with RL + ZX-calculus techniques

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

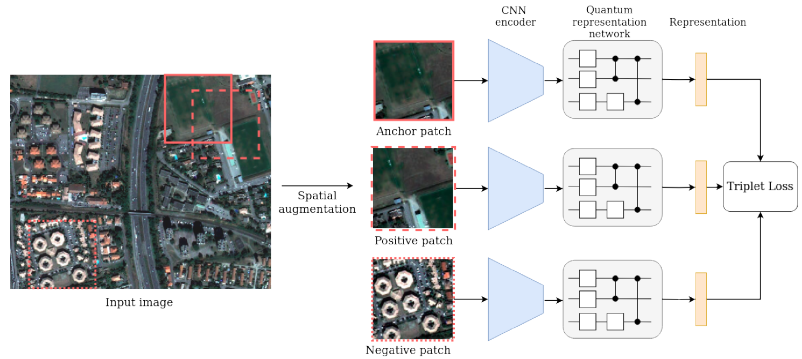
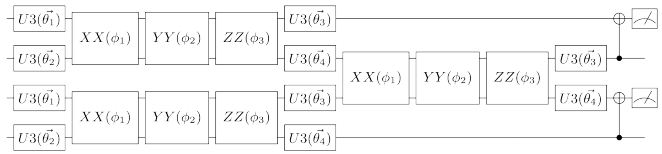
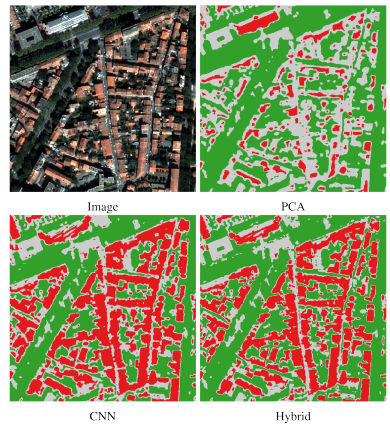


Fig. 1. Illustration of the proposed hybrid contrastive learning framework.



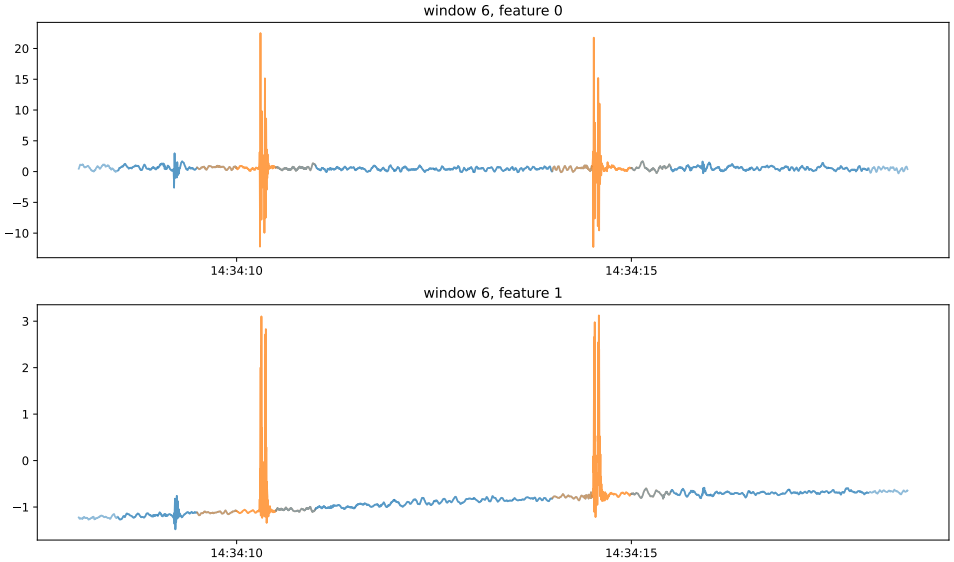


Section 3

Collaboration with industry

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

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] 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.

[3] Gupta, M. K., Romaszewski, M., and Gawron, P.

Potential of quantum machine learning for processing multispectral earth observation data.

[4] Otgonbaatar, S., Nurmi, O., Johansson, M., Mäkelä, J., Gawron, P., Puchała, Z., Mielzcarek, J., Miroszewski, A., Dumitru, C. O., et al.

Quantum computing for climate change detection, climate modeling, and climate digital twin.

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.

Thank you

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European Funds
Smart Growth

Republic of Poland

FNP Foundation for Polish Science

European Union
European Regional Development Fund