SnT 2021

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO

PREPARATORY COMMISSION

Machine learning prospects for automatic SHI processing

Christos Saragiotis, Ronan Le Bras, Vera Miljanovic Tamarit, Megan Slinkard

(CTBTO IDC/SA & MDA)

Is6-454

ORAL PRESENTATION

Series of talks on 25 years of CTBT

C. Saragiotis, R. Le Bras, V. Miljanovic Tamarit, M. Slinkard (CTBTO IDC/SA)

- Background
- Machine learning in the IDC
- Future prospects

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Timeline of machine learning and the CTBTO

Era	Machine learning milestones	CTBT
1950s	Birth of ML research	
1960s	Bayesian methods introduced for probabilistic inference	
1970s	"AI winter"	
1980s -90s	SVM (Support Vector Machines) and RNN (Recurrent Neural Networks) become popular	**1996** The CTBT is signed
2000s	Unsupervised ML becomes widespread	**2000** Routine data analysis started at the IDC
2010s	Deep learning becomes feasible	

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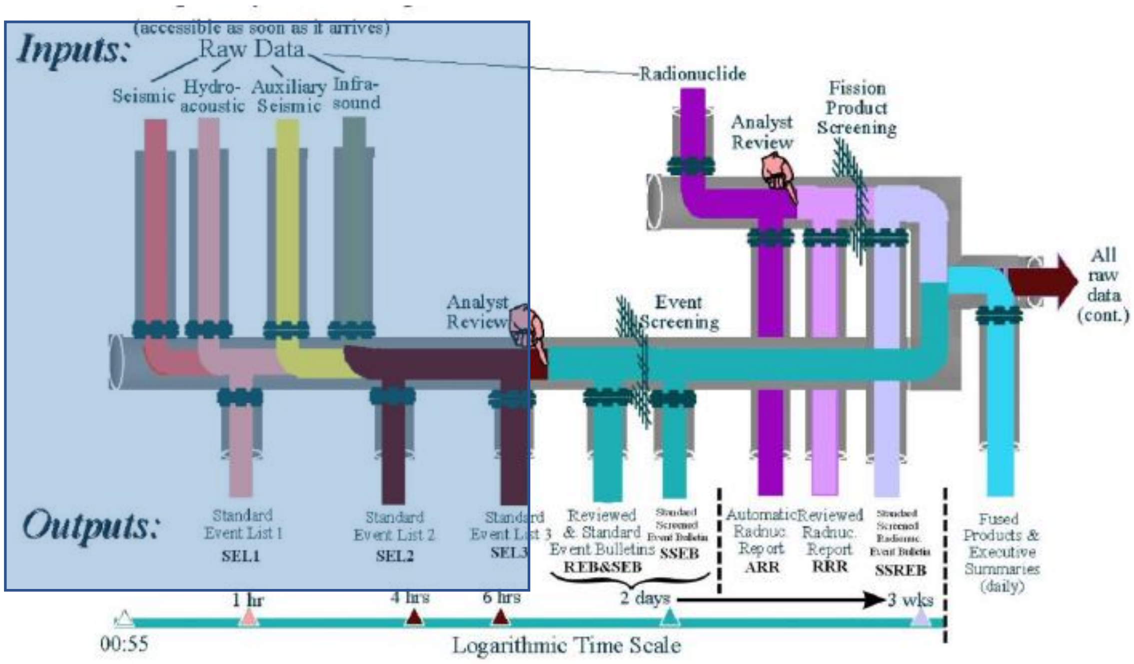
IDC processing pipeline



- SHI processing
  - Automatic
  - Interactive (analyst review)
- Event screening (automatic)
- Radionuclide processing
- Technology fusion

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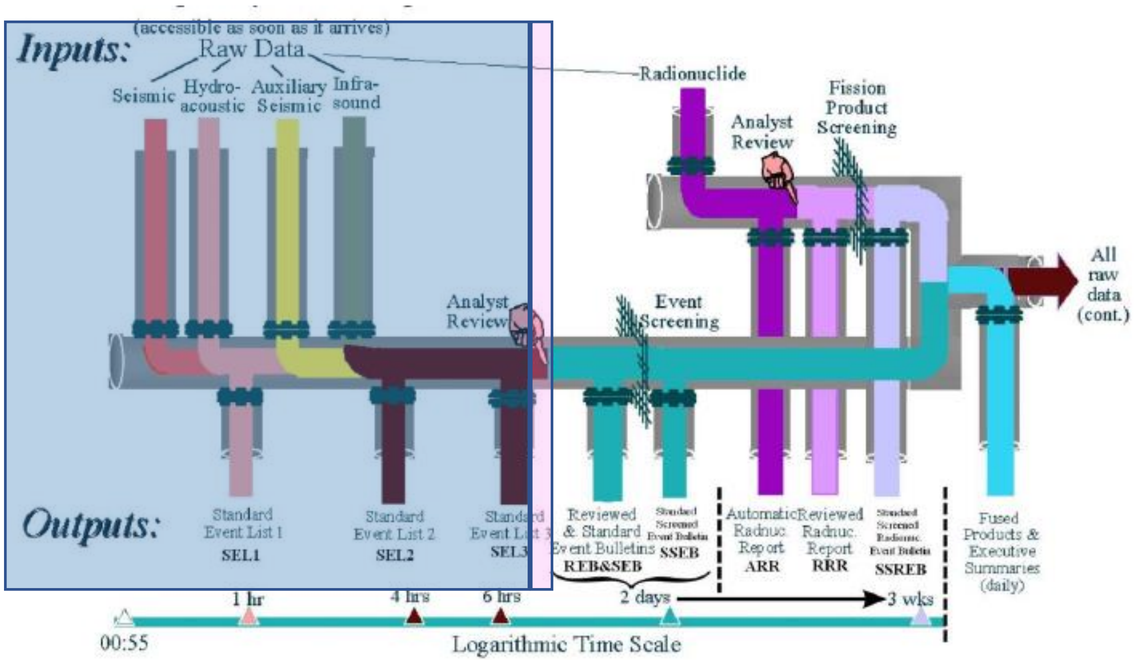
IDC processing pipeline



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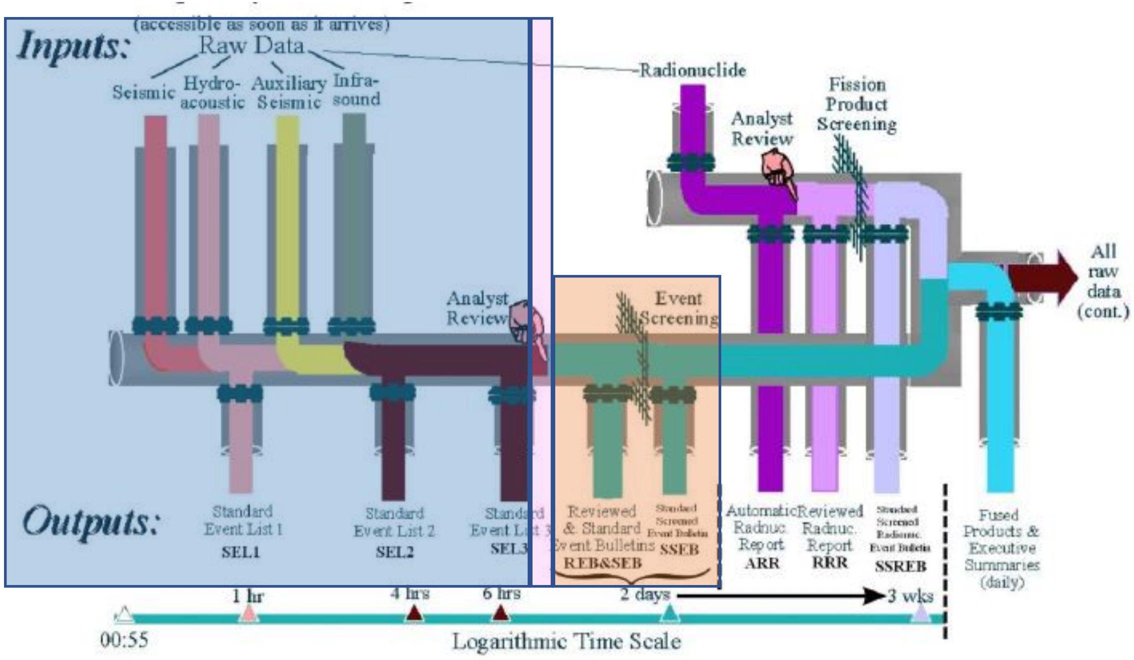

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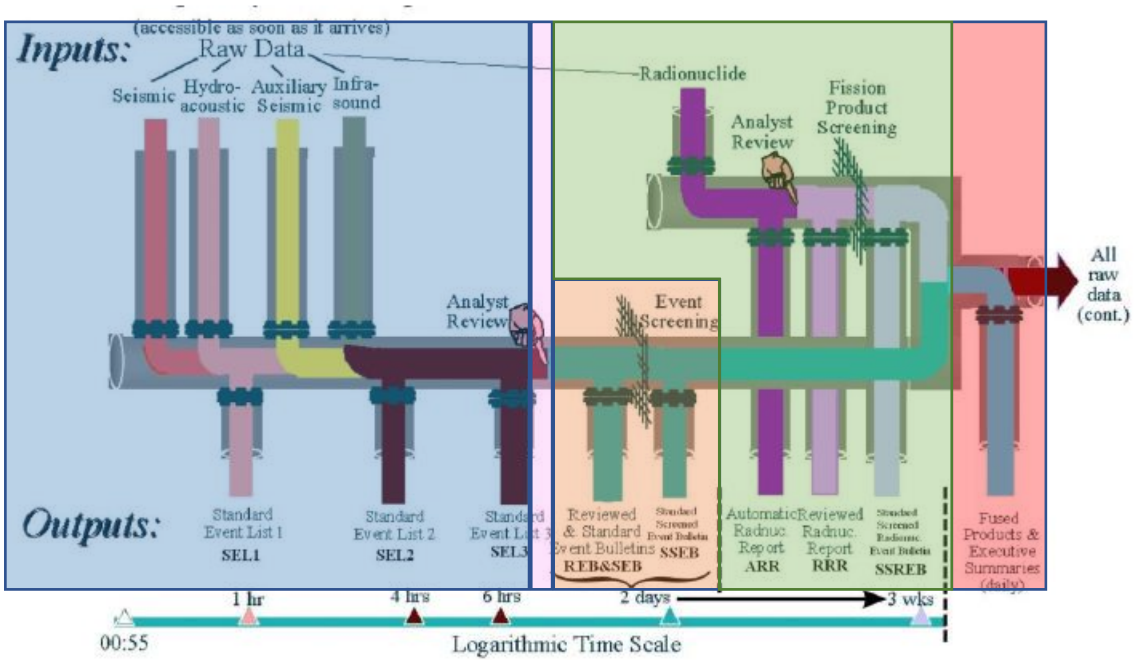

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Machine learning prospects for automatic SHI processing

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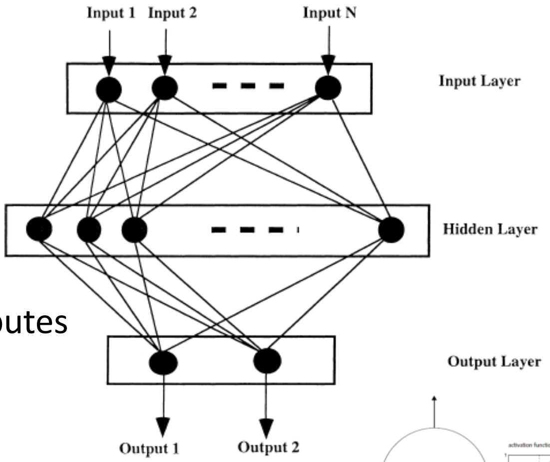
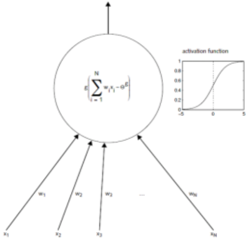
Machine learning in the early IDC system

Neural networks

- Multi-layer perceptron used in single-station 3C phase identification (station processing)
- Three cascaded NNs with three layers (15x6x2 nodes).
- 15 attributes (mostly polarization attributes but also Td, contextual attributes and spectral features (HtoV ratios).
- They identify N, T, and regional P and S (later split to P, PKP, Pn, Pg, Sn and Lg by other programs)

(Sereno & Patnaik (1993), Wang & Teng (1995, 1997), Wang, Israelsson and North (1997), Wang (2002),





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Machine learning in the early IDC system

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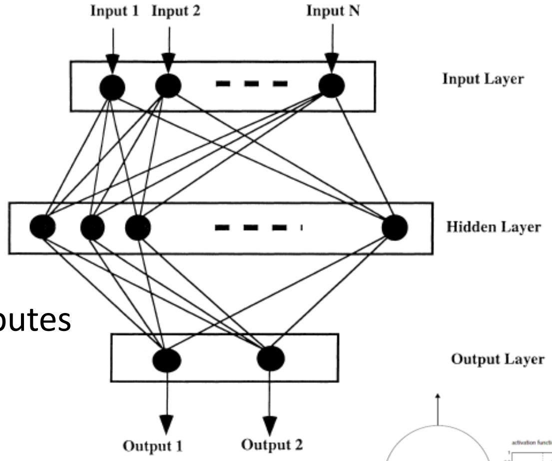

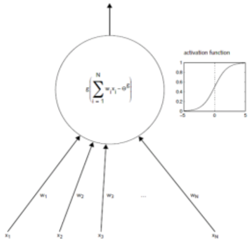

Bayesian inference

- Identification of regional S phases (Sn, Lg, Rg, Sx)
- $P\{phase|F,C\} = \frac{P\{F|phase,C\}}{P\{F|C\}}$
- F: features (S−P time, f, velocity, HtoV ratio)
- C: context (station specific)

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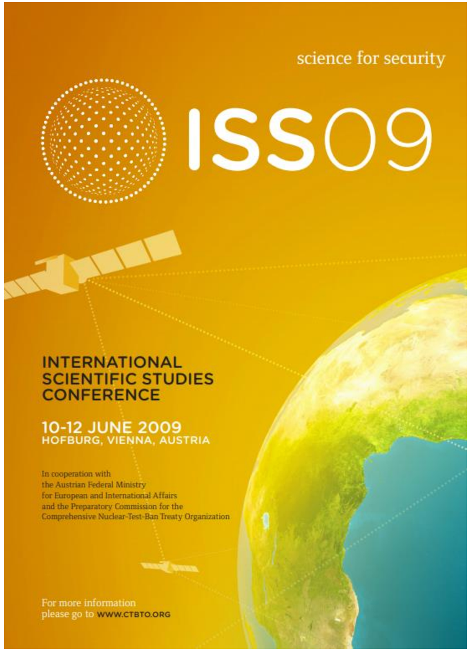
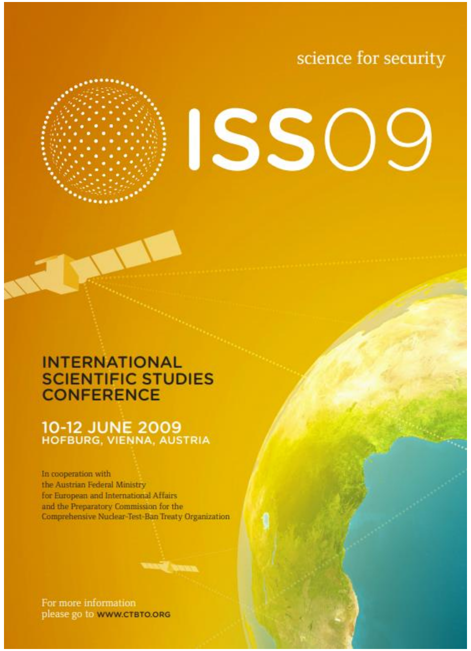
Conferences and symposia



International Scientific Studies 2009 conference

"[…] to identify scientific and technological developments that might enhance these capabilities as well as improve the cost-effectiveness of the CTBTO's products and services […]"



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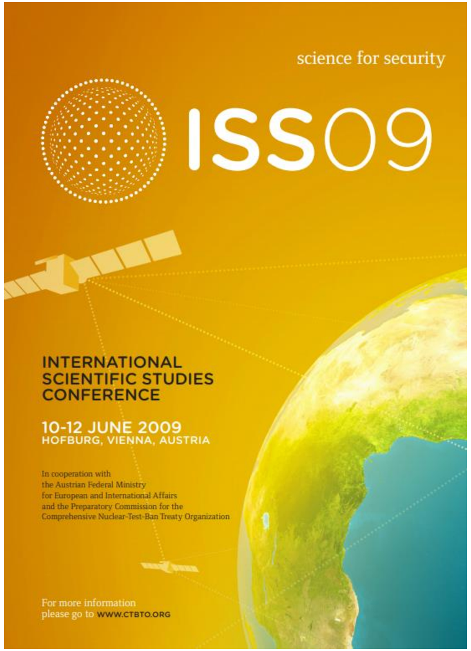
Data mining session

- Phase labelling and false association identification
- False event identification
- Vertically Integrated Seismological analysis (NetVisa)
- F detector
- BayesLoc
- vDEC
- and more



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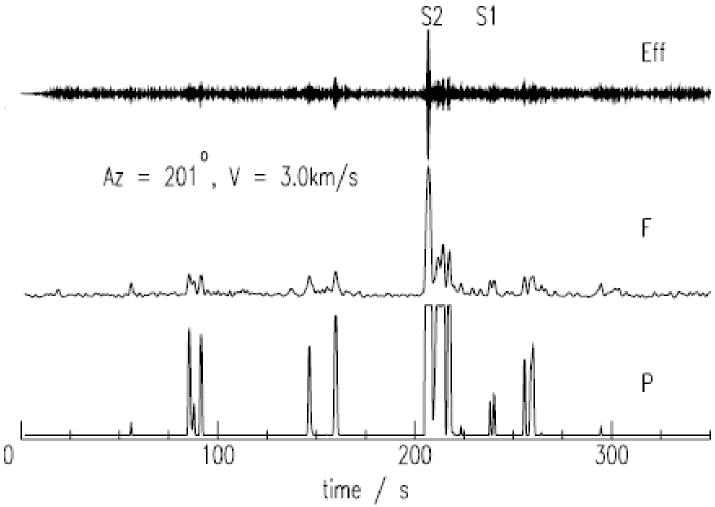
GenF detector

Uses prior information about

- the signal
  - source power spectrum
  - source scaling
  - path effects
  - …
- and noise
  - power spectrum
  - spatial correlation



From Selby (2008)

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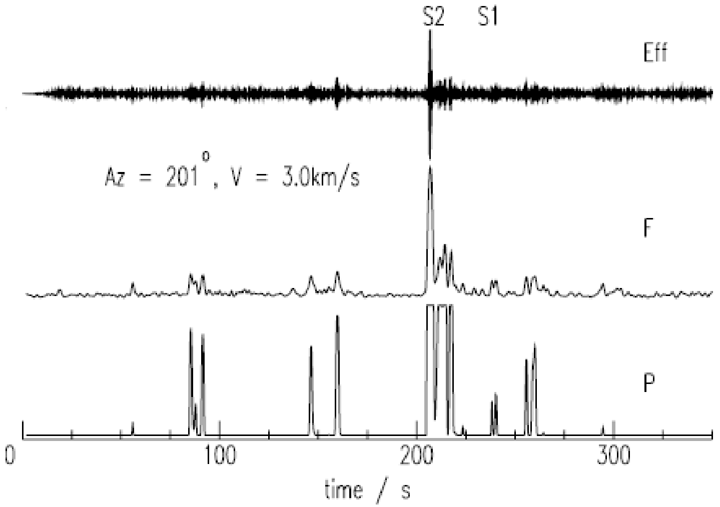

From Selby (2008)

GenF at the IDC

- Has been tested extensively
- Is merged in the IDC codebase but not activated.
- Is part of the Reengineered software and testing planned to start again in 2021 Q3

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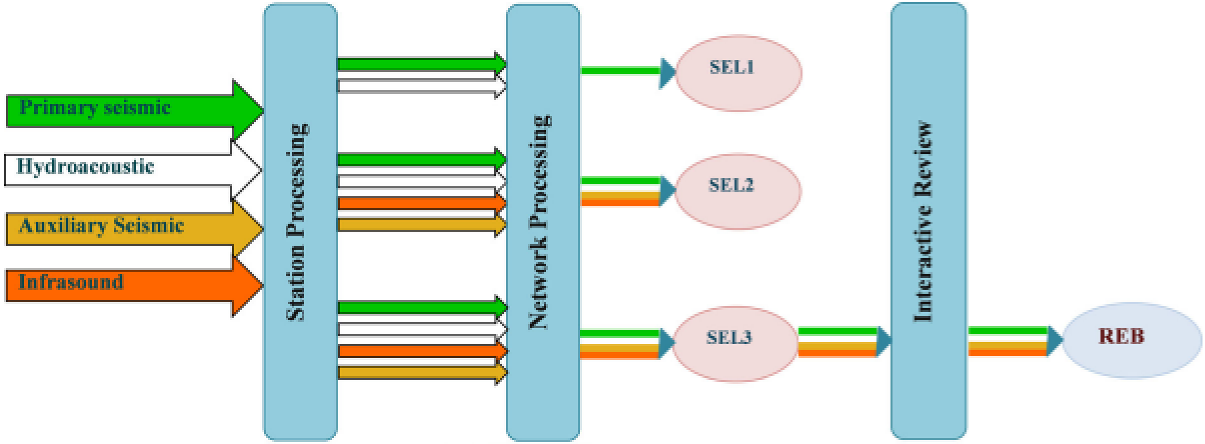
NetVISA

- Uses a Bayesian approach in the network processing step (Arora et al, 2013)
- Probability Density Function (PDF) is built with analysts' reviewed data



Le Bras etal (2020)

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Period	Features	Testing and Ops
2012-13	Original paper	2013 Initial tests begin
2014-15	Support for hydro	
2015-17	Support for Infrasound	Off-line testing of 1 yr of data
2016-17	Analyst interface	VSEL3 in Ops
2017-19	Improvements in regional velocity model	2018 VSEL3 systematically reviewed by analysts
2019-21	Improvements for hydro and error ellipses	2020 RSTT used in NetVISA Le Bras etal (2020)

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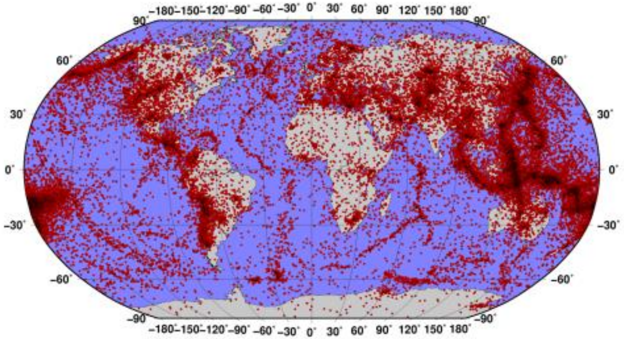
NetVISA

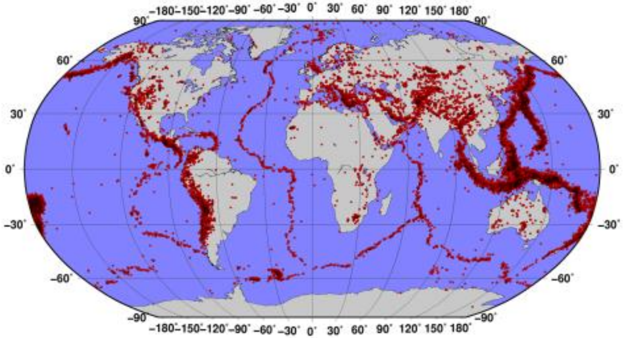
- Yields improved automatic event list
- Reduces analyst workload

- Since Jan 2018, it is part of OPS (analysts can switch back and forth the GA pipeline and the NetVisa one)
- Is expected to replace current associator (GA) soon.

SEL3 events



Events after analyst review



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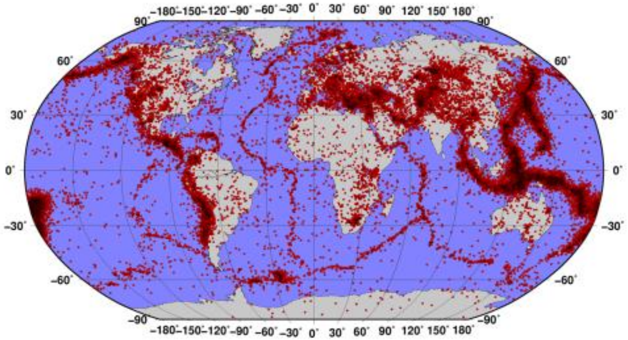

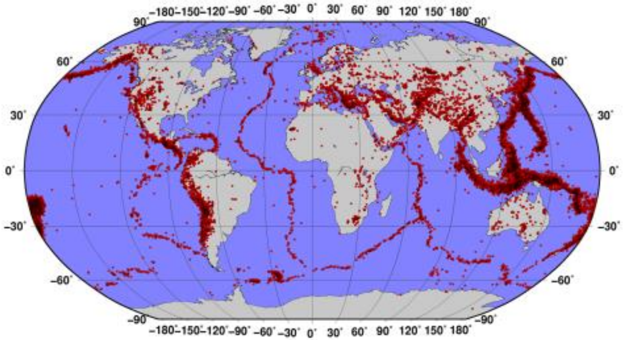

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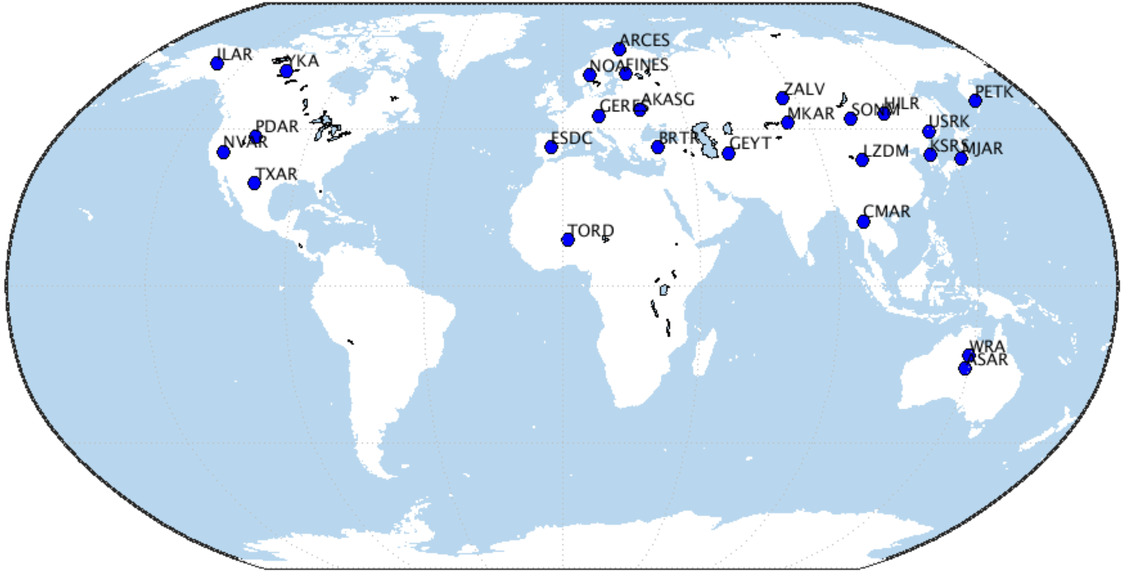
Single-station backazimuth prediction for 3C stations

- Accurate from array stations (beamforming)
- Unstable from 3C stations; polarization analysis (Jurkevics, 1988)

- Most stations in the IMS seismological network are single-station 3C

Array stations of the IMS primary seismic network



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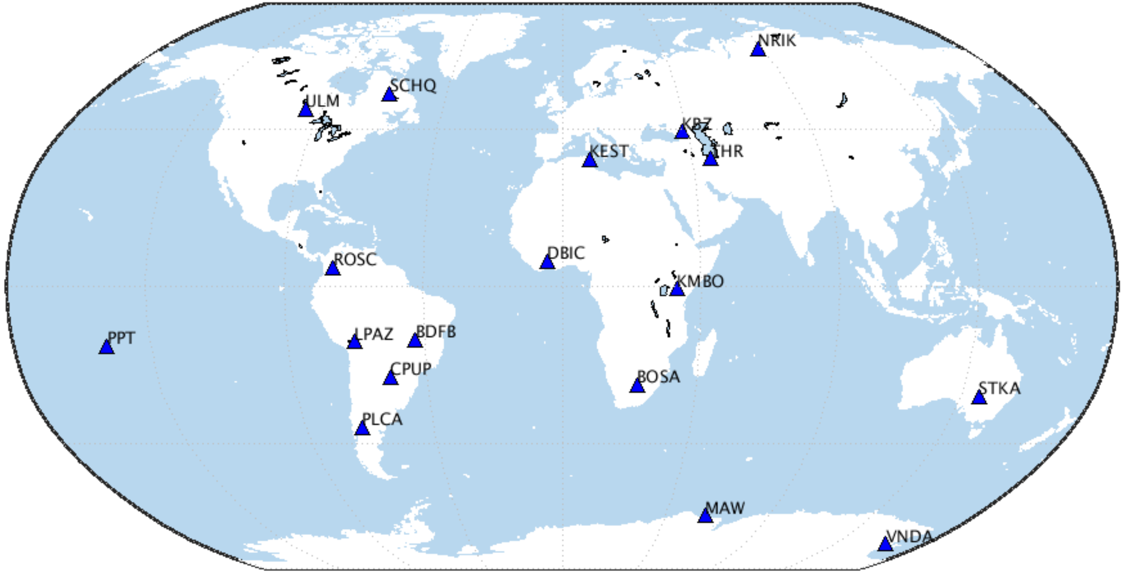

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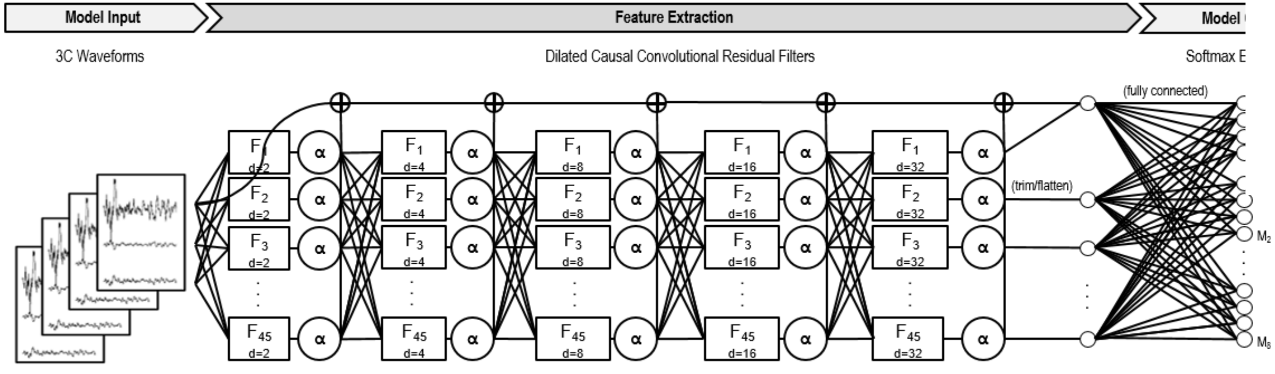
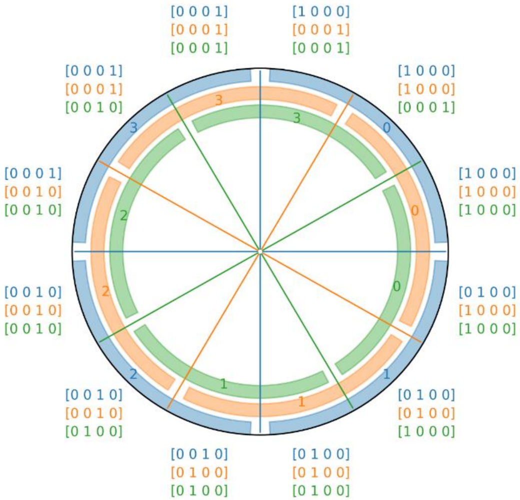
Single-station backazimuth prediction for 3C stations

- BazNet (Dickey et al, 2020) has been used within the IMS to predict backazimuth for 3C single-stations
- Provides uncertainty that correlates well with the prediction error
- Integration with NetVISA (P3.6-706)



From Dickey etal (2020)



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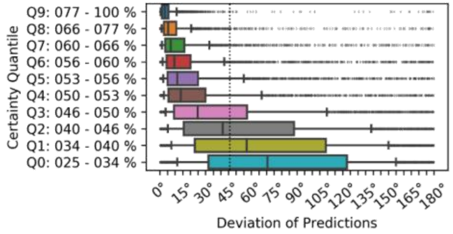

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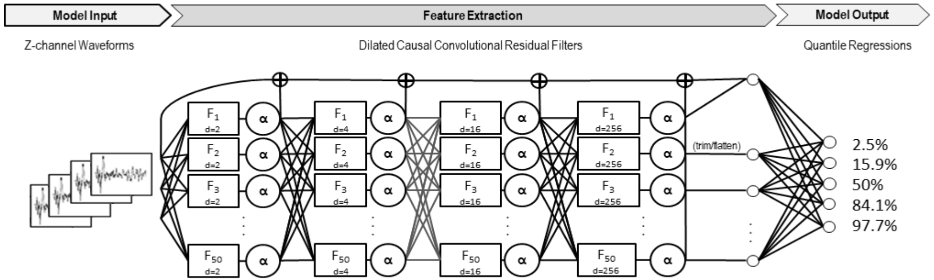
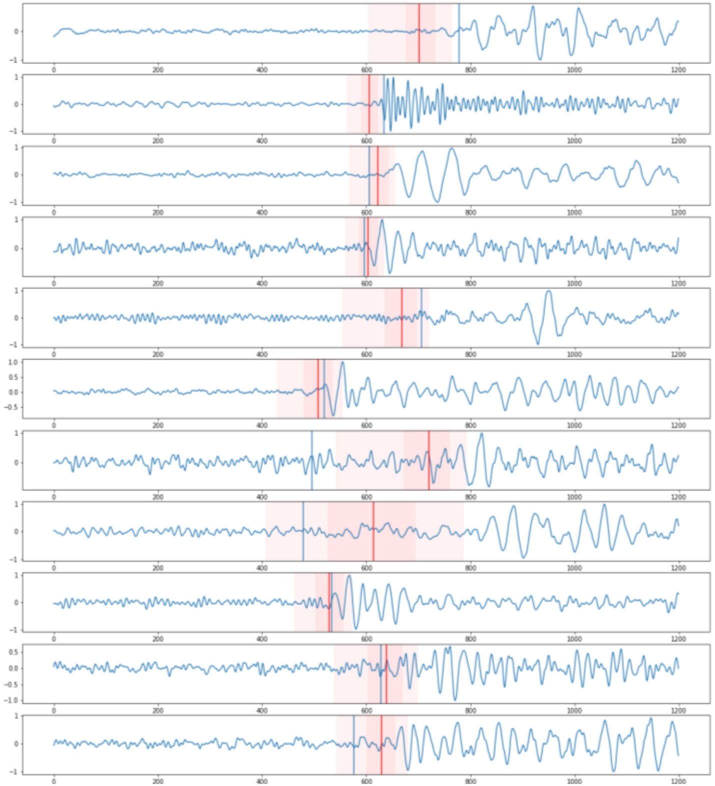
Refinement of automatically picked arrival times

- In 2020 more than 300,000 arrivals (73% of total) of automatically picked seismic phases were retimed by our analysts
- Some require fk analysis (very time consuming)
- Assuming 10 sec retiming effort per arrival → 875 person days, which is about ½ a person-year.
- ArrNet (P3.6-707)





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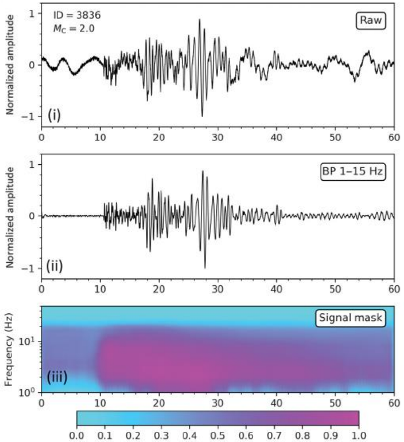
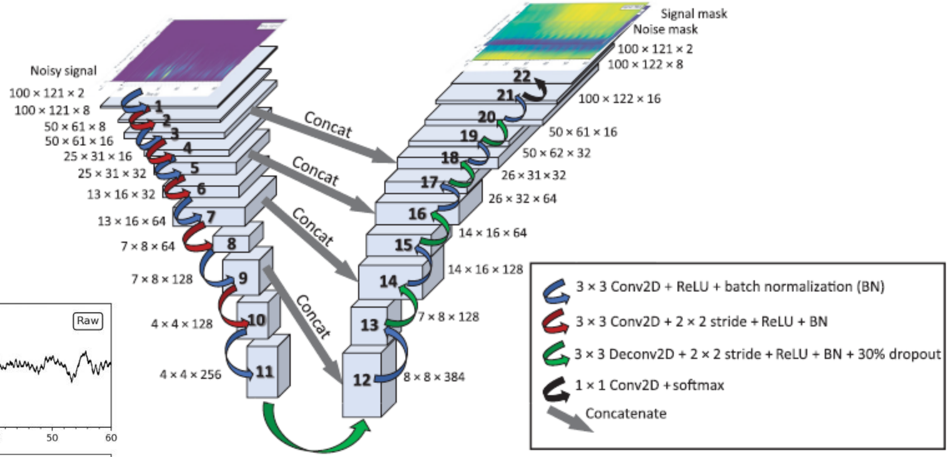
Waveform denoising

- Inspired by source separation studies for music information retrieval
- Deep convolutional neural network that decomposes waveforms signal and noise.
- Requires training per station.
- Expected to enhance the SNR in stations with inherently low SNR





From Tibi etal 2(021)

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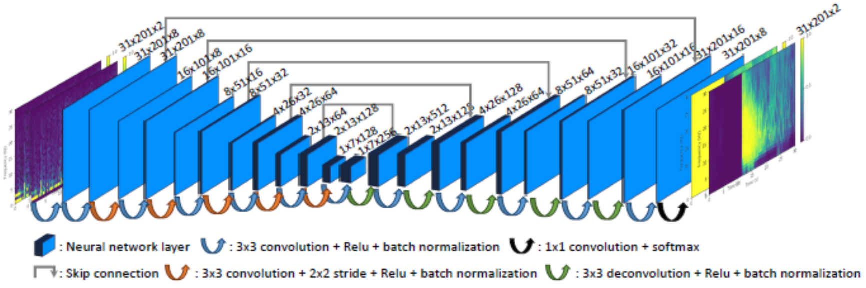
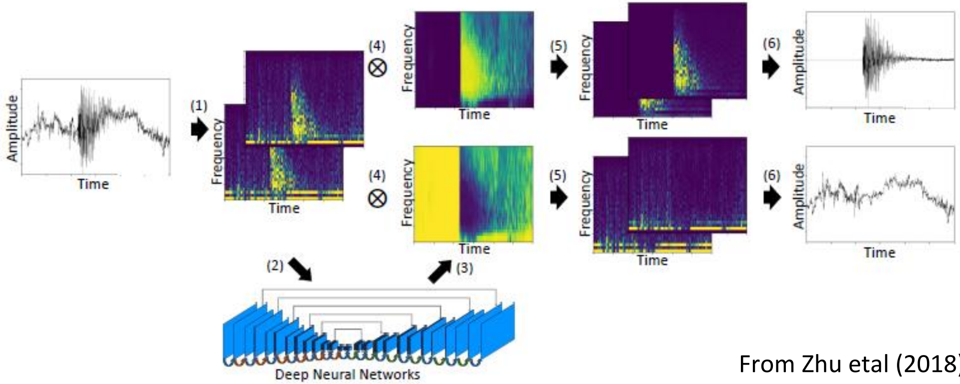
Other prospects

- Denoising (Zhu et al, 2018)
- Arrival time picking (Zhu & Beroza, 2018)
- Simultaneous detection and phase picking (Mousavi et al, 2020)
- Clustering signals and noise in continuous data (Seydoux et al, 2020)





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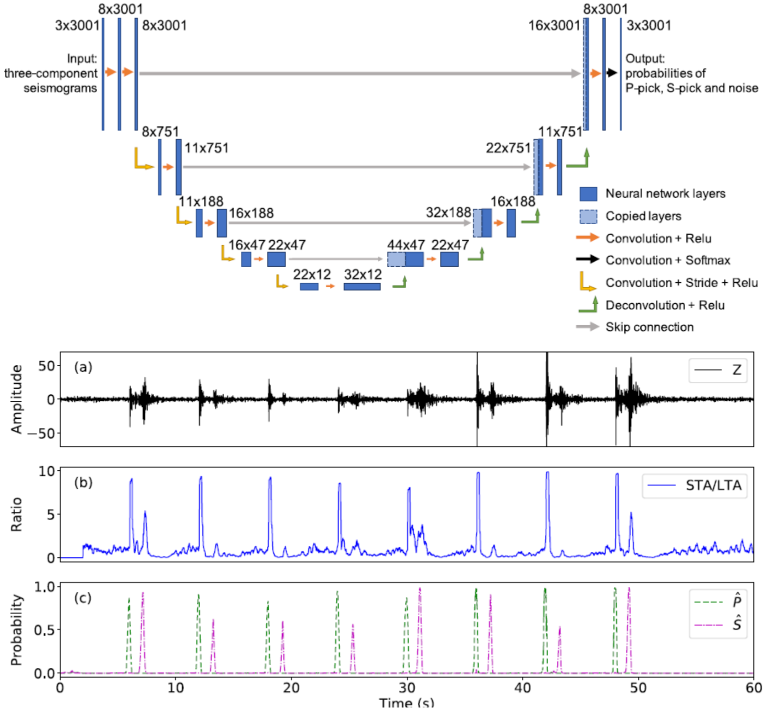

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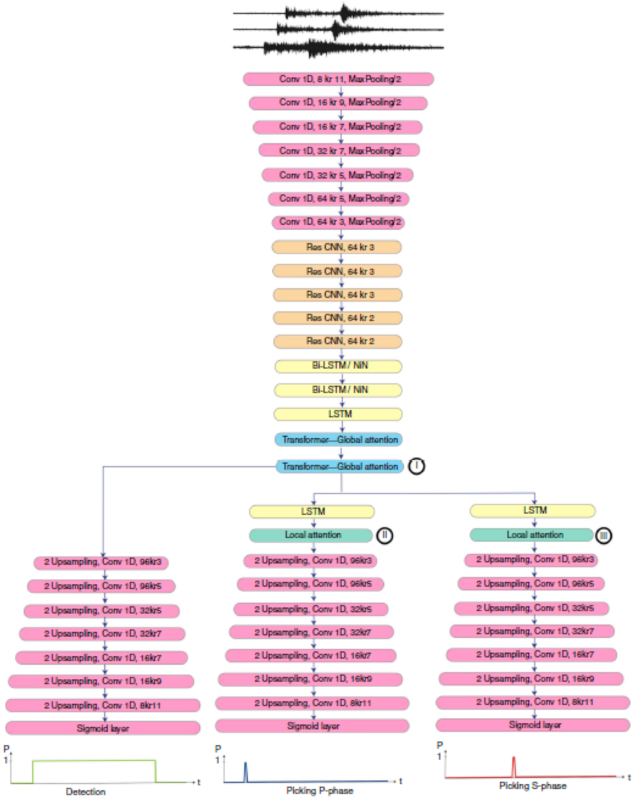

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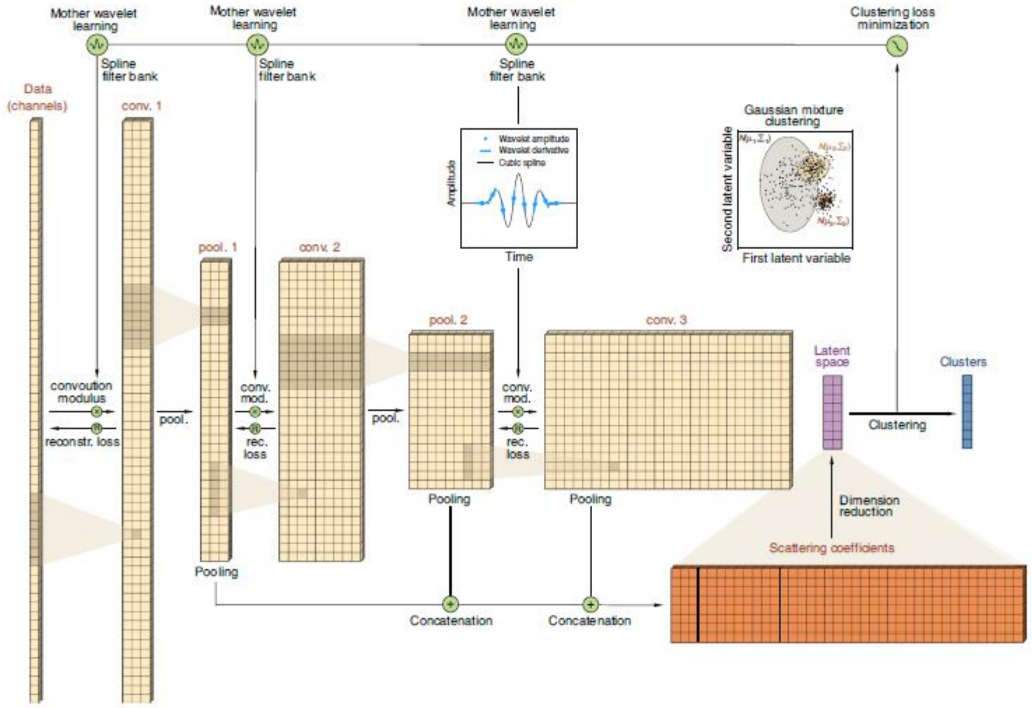

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The SnT conference: A forum of ideas exchange

Session O3.6 Artificial Intelligence and machine learning (Tuesday)

- Markov chain Monte Carlo estimate of origin error for SHI in NET-VISA (Arora etal)
- Emulation of seismic-phase travel times using the Deep Learning Travel Time (DeLTTa) method (Myers etal)
- Identification of repeating seismic events using non-linear dimensionality reduction (Bregman etal)
- Using machine learning to detect and characterize long-range infrasound signals from high explosives (Witsil etal)

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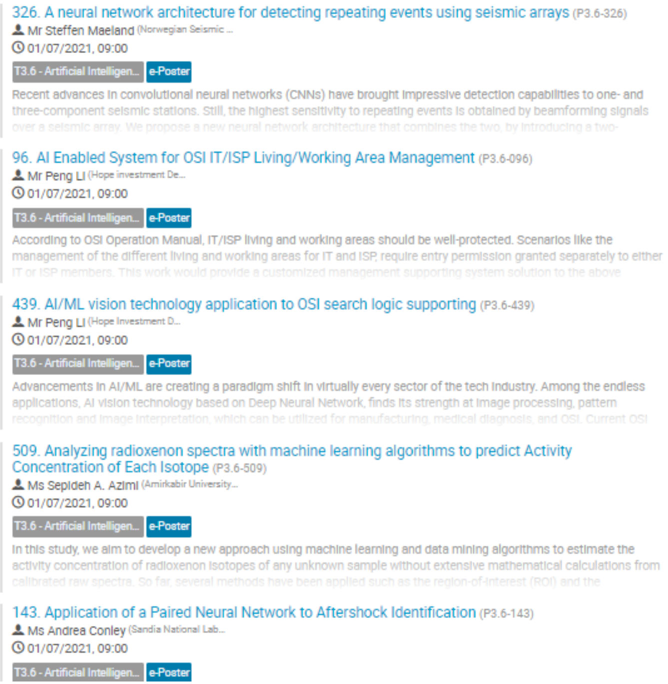
e-poster session P3.6 (Thursday)


326. A neural network architecture for detecting repeating events using seismic arrays (P3.6-326)
Mr Steffen Maeland (Norwegian Seismic ...
01/07/2021, 09:00
T3.6 - Artificial Intelligen... e-Poster
Recent advances in convolutional neural networks (CNNs) have brought impressive detection capabilities to one- and three-component seismic stations. Still, the highest sensitivity to repeating events is obtained by beamforming signals over a seismic array. We propose a new neural network architecture that combines the two, by introducing a two-

96. AI Enabled System for OSI IT/ISP Living/Working Area Management (P3.6-096)
Mr Peng LI (Hope investment De...
01/07/2021, 09:00
T3.6 - Artificial Intelligen... e-Poster
According to OSI Operation Manual, IT/ISP living and working areas should be well-protected. Scenarios like the management of the different living and working areas for IT and ISP, require entry permission granted separately to either IT or ISP members. This work would provide a customized management supporting system solution to the above

439. AI/ML vision technology application to OSI search logic supporting (P3.6-439)
Mr Peng LI (Hope Investment D...
01/07/2021, 09:00
T3.6 - Artificial Intelligen... e-Poster
Advancements in AI/ML are creating a paradigm shift in virtually every sector of the tech industry. Among the endless applications, AI vision technology based on Deep Neural Network, finds its strength at image processing, pattern recognition and image interpretation, which can be utilized for manufacturing, medical diagnosis, and OSI. Current OSI

509. Analyzing radioxenon spectra with machine learning algorithms to predict Activity Concentration of Each Isotope (P3.6-509)
Ms Sepideh A. Azimi (Amirkabir University...
01/07/2021, 09:00
T3.6 - Artificial Intelligen... e-Poster
In this study, we aim to develop a new approach using machine learning and data mining algorithms to estimate the activity concentration of radioxenon isotopes of any unknown sample without extensive mathematical calculations from calibrated raw spectra. So far, several methods have been applied such as the region-of-interest (ROI) and the

143. Application of a Paired Neural Network to Aftershock Identification (P3.6-143)
Ms Andrea Conley (Sandia National Lab...
01/07/2021, 09:00
T3.6 - Artificial Intelligen... e-Poster

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Vision

An environment where integration/testing of such methods is easy.

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Vision

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Solutions

- vDEC
- Containerization of the IDC pipeline (Re-engineering project)

https://www.ctbto.org/specials/vdec/

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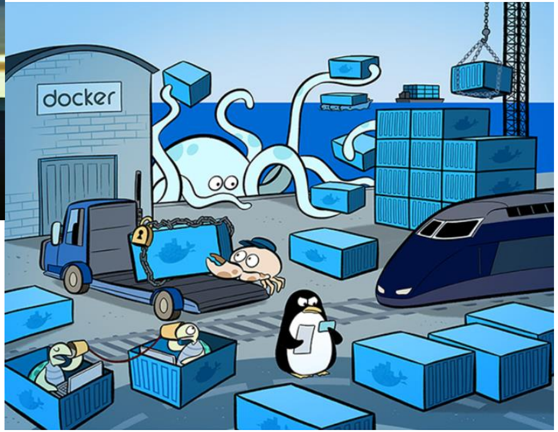
- Containerization of the IDC pipeline (Re-engineering project)

https://www.ctbto.org/specials/vdec/



from docker.com

C. Saragiotis, R. Le Bras, V. Miljanovic Tamarit, M. Slinkard (CTBTO IDC/SA)

Recap

- The CTBTO has been using ML algorithms since the beginning (the presentation is not exhaustive)
- Application of ML algorithms has been limited due to computational limitations.
- Improvements in computer hardware (processing power and storage) have made it possible to test and use algorithms that were once unattainable.

- The IDC has already started testing ML and DL algorithms and plan to test more.
- Possibilities exist in enhancing automatic processing:
  - signal detection
  - phase identification
  - phase association and
  - other subprocesses that could improve the above
  - event screening (?)

- Containerisation of the IDC pipeline will allow for simultaneous testing!