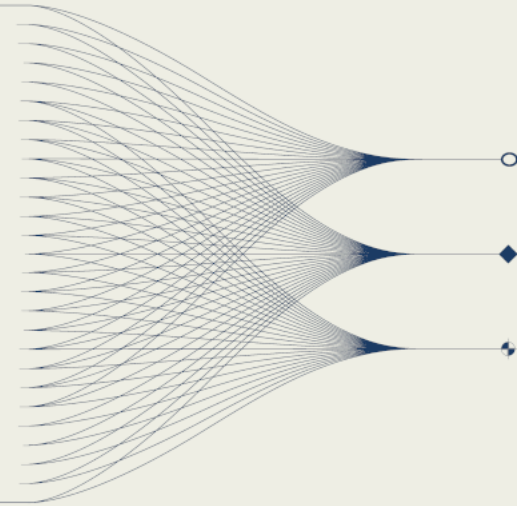
Ke05

ML, DL and HPC: Transforming CTBTO's operations in global monitoring and verification

Evgeny Burnaev

Professor, Head of AI center, Skoltech
Leading Researcher, AIRI



Presentation Date: 10 September 2025

Evgeny Burnaev

General Scheme

- **ARTIFICIAL INTELLIGENCE**

AI is the broadest term, applying to any technique that enables computers to mimic human intelligence, using logic, if-then rules, decision trees, and machine learning (including deep learning)

- **MACHINE LEARNING**

The subset of AI that includes abstruse statistical techniques that enable machines to improve at tasks with experience. The category includes deep learning

- **DEEP LEARNING**

The subset of machine learning composed of algorithms that permit software to train itself to perform tasks, like speech and image recognition, by exposing multilayered neural networks to vast amounts of data

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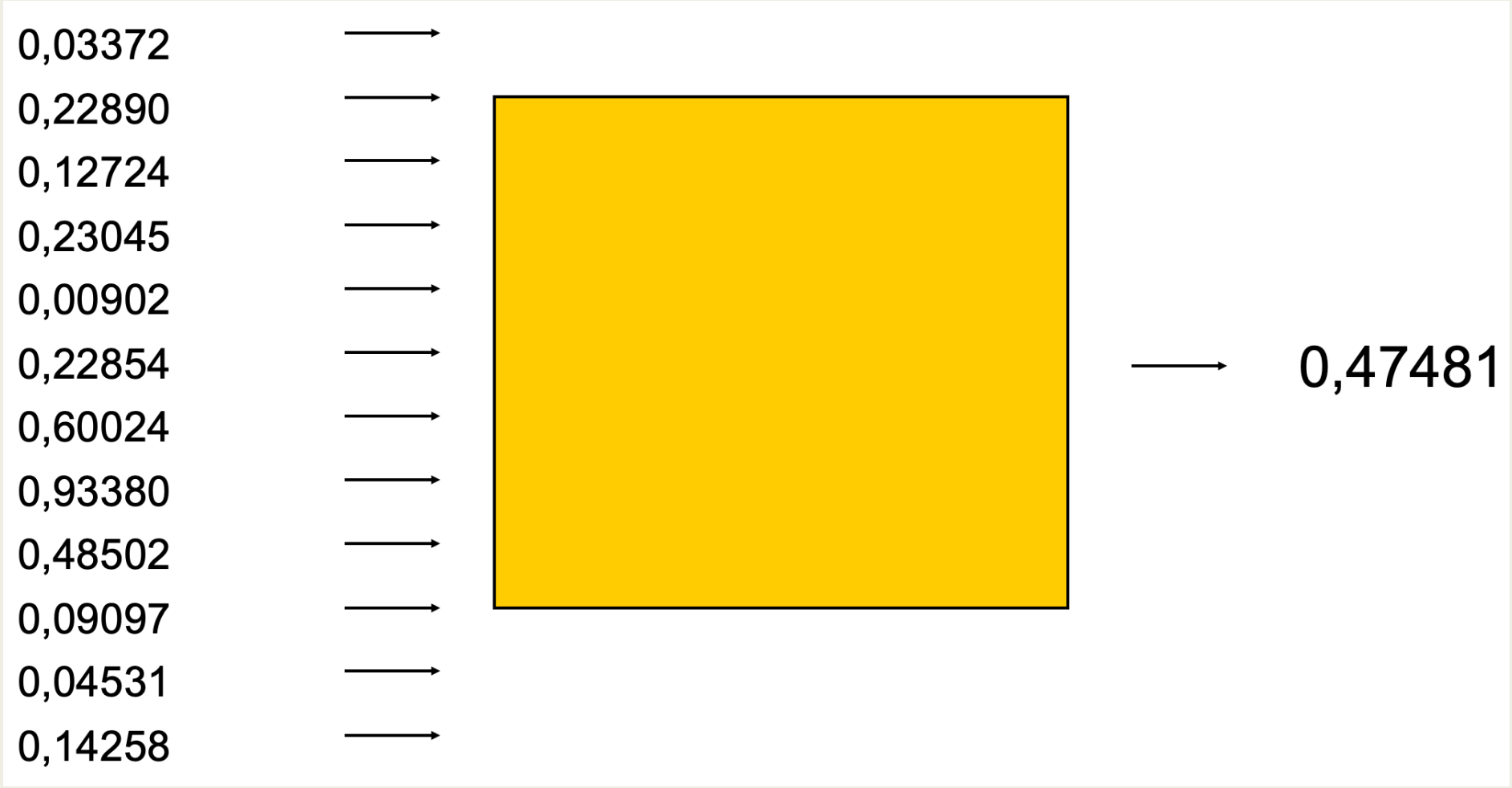
Schematic Diagram of AI



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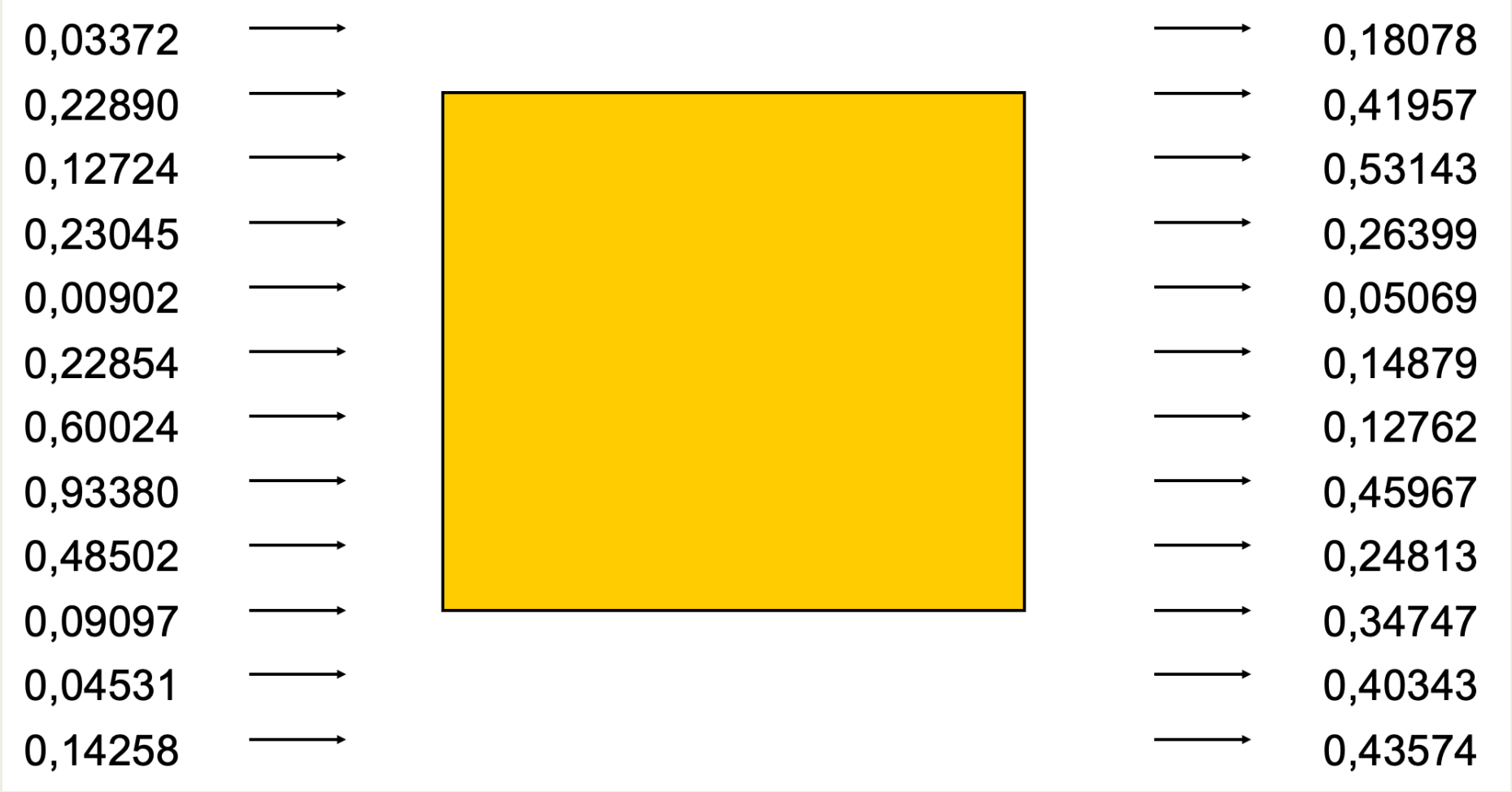
Schematic Diagram of AI



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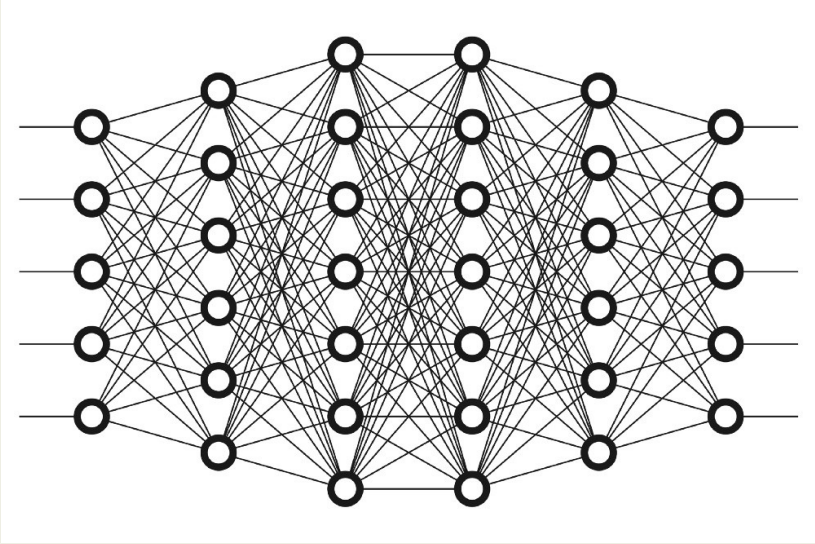
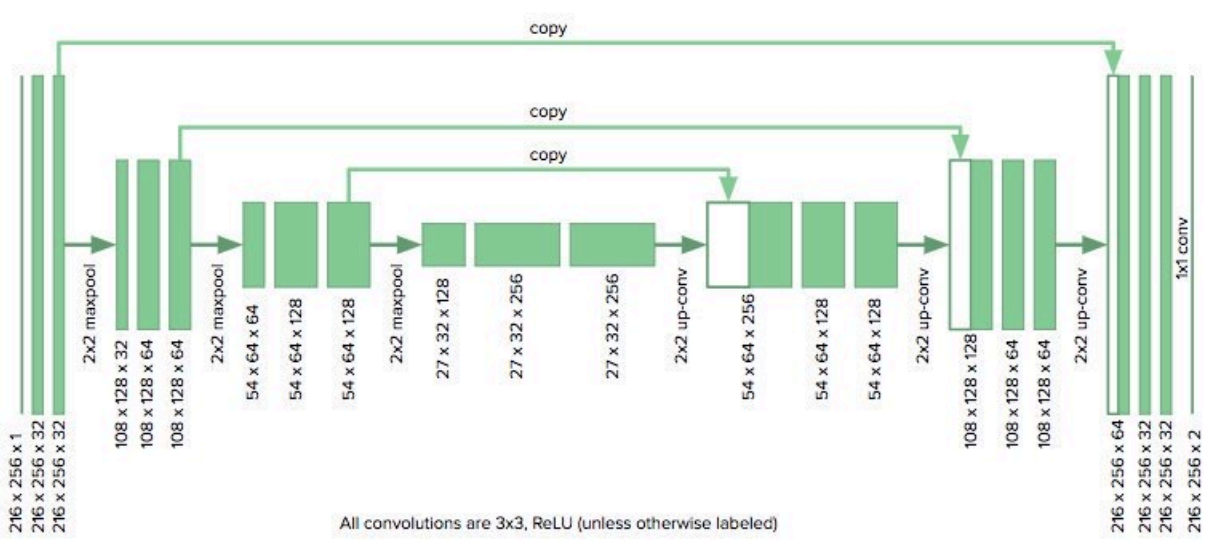
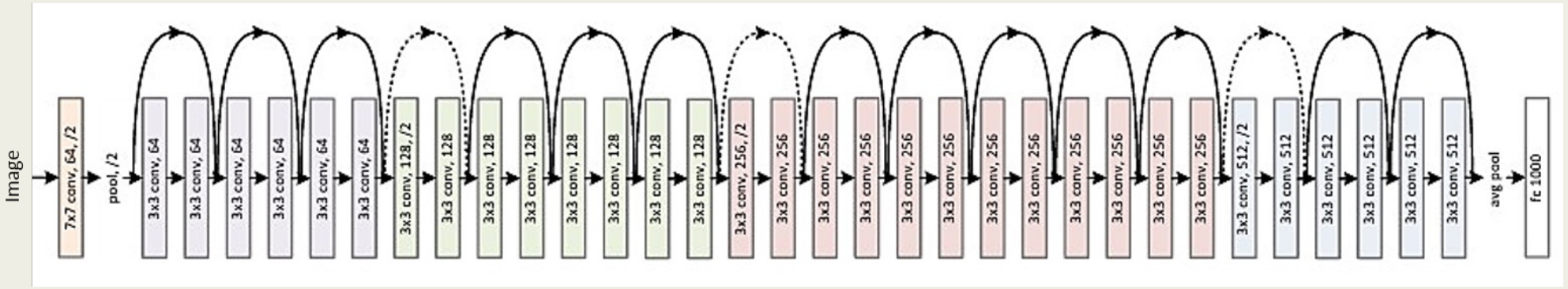
What is inside the Black Box?







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Example: Embeddings

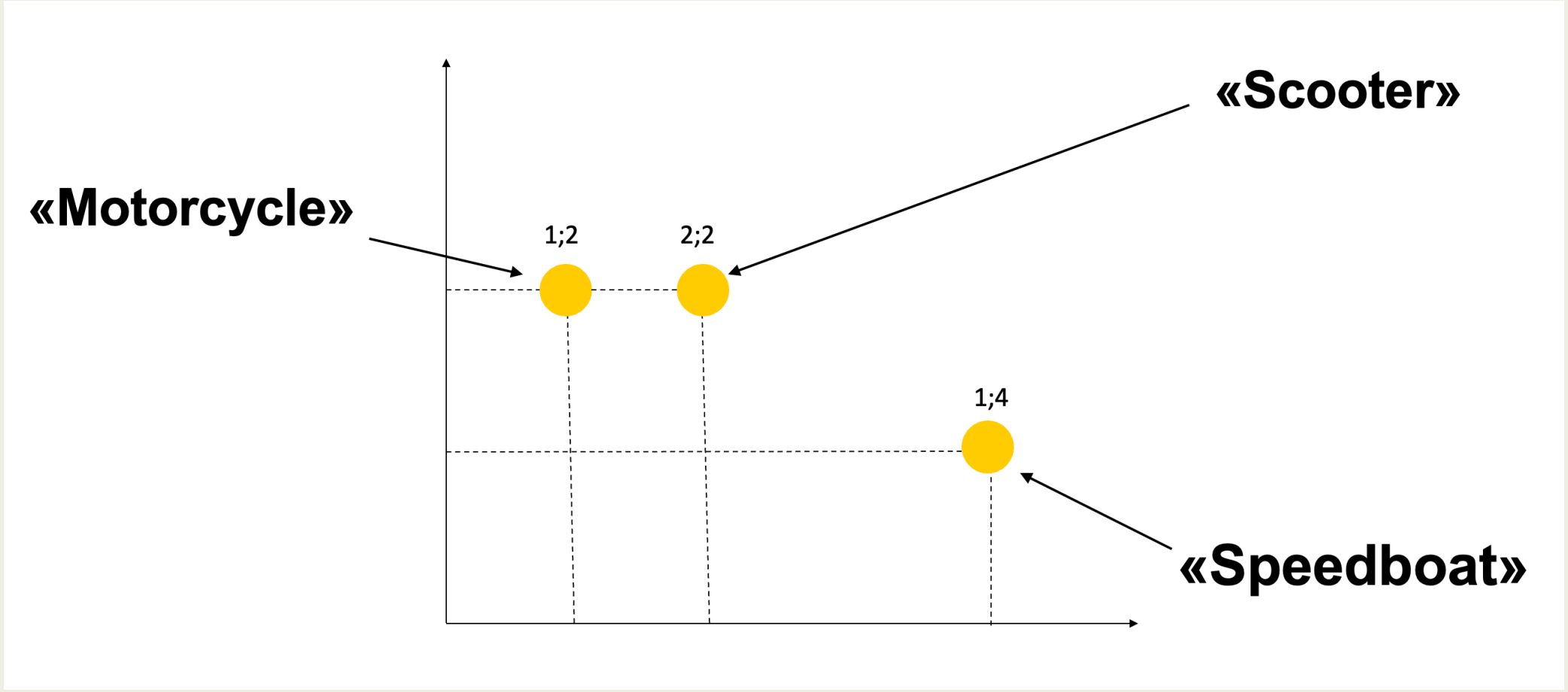

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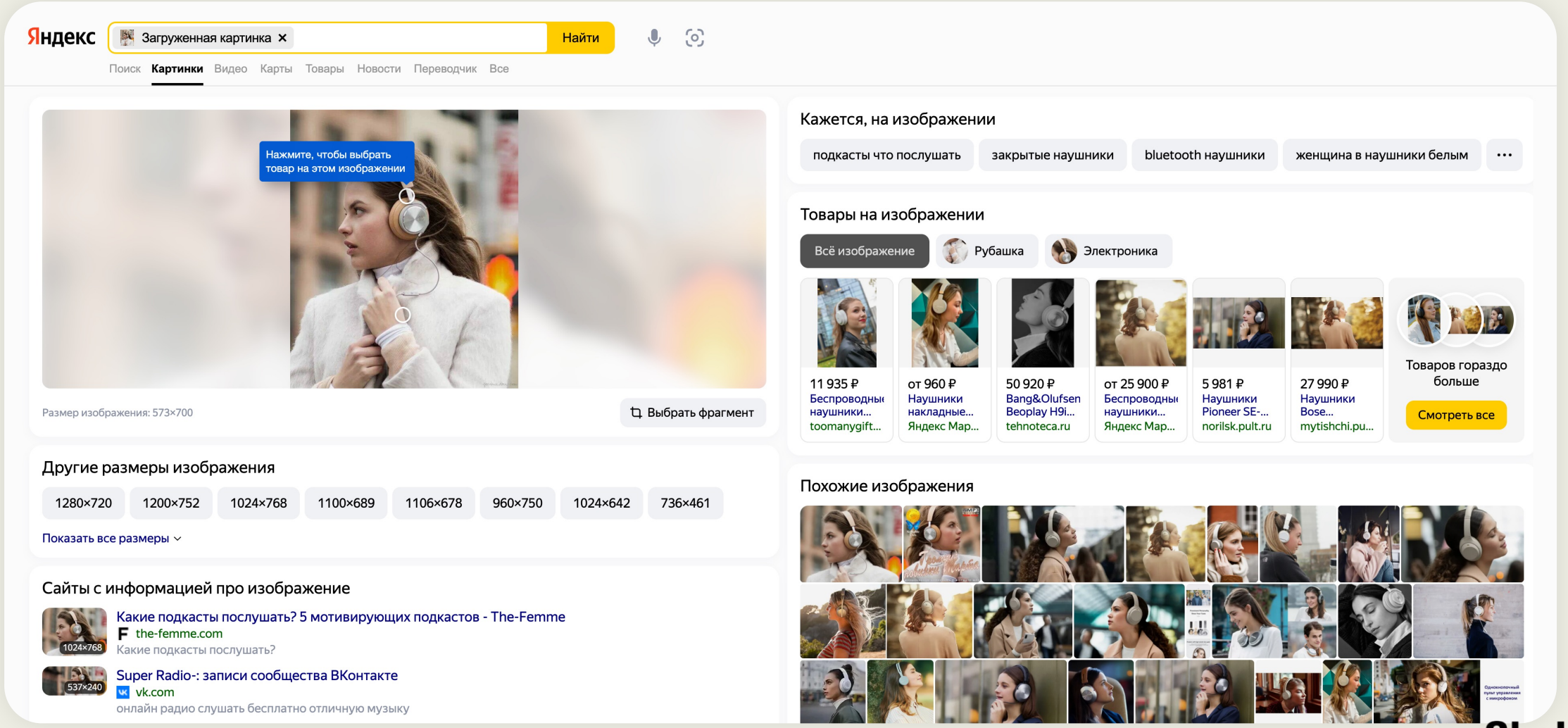
Image Search



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Training based on Data from Search Engine

[Motorcycle]

|1|0|1|0|0|1|0|0|….|1|

|1|0|1|0|0|0|0|1|….|1|

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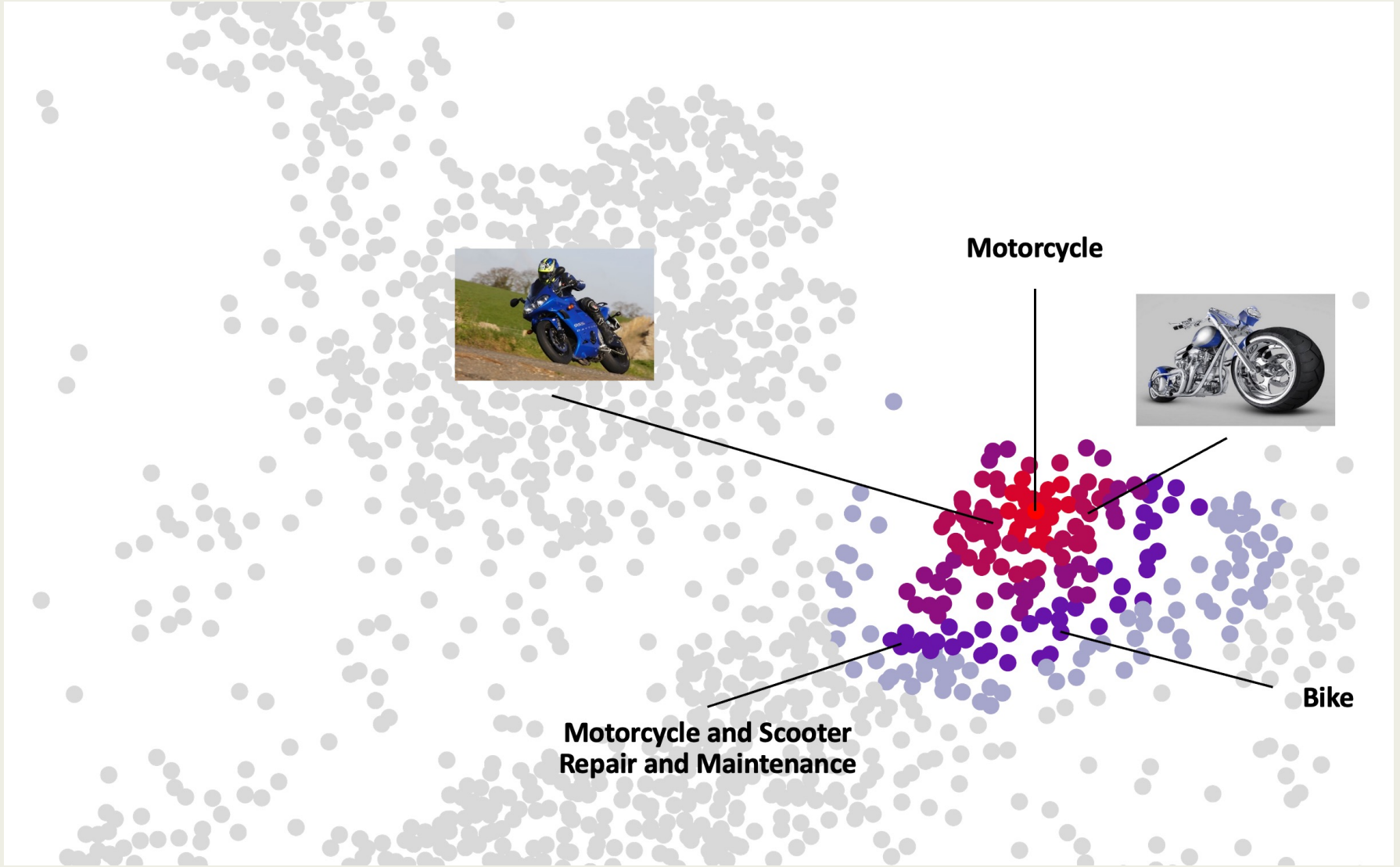
Common Semantic Spaces



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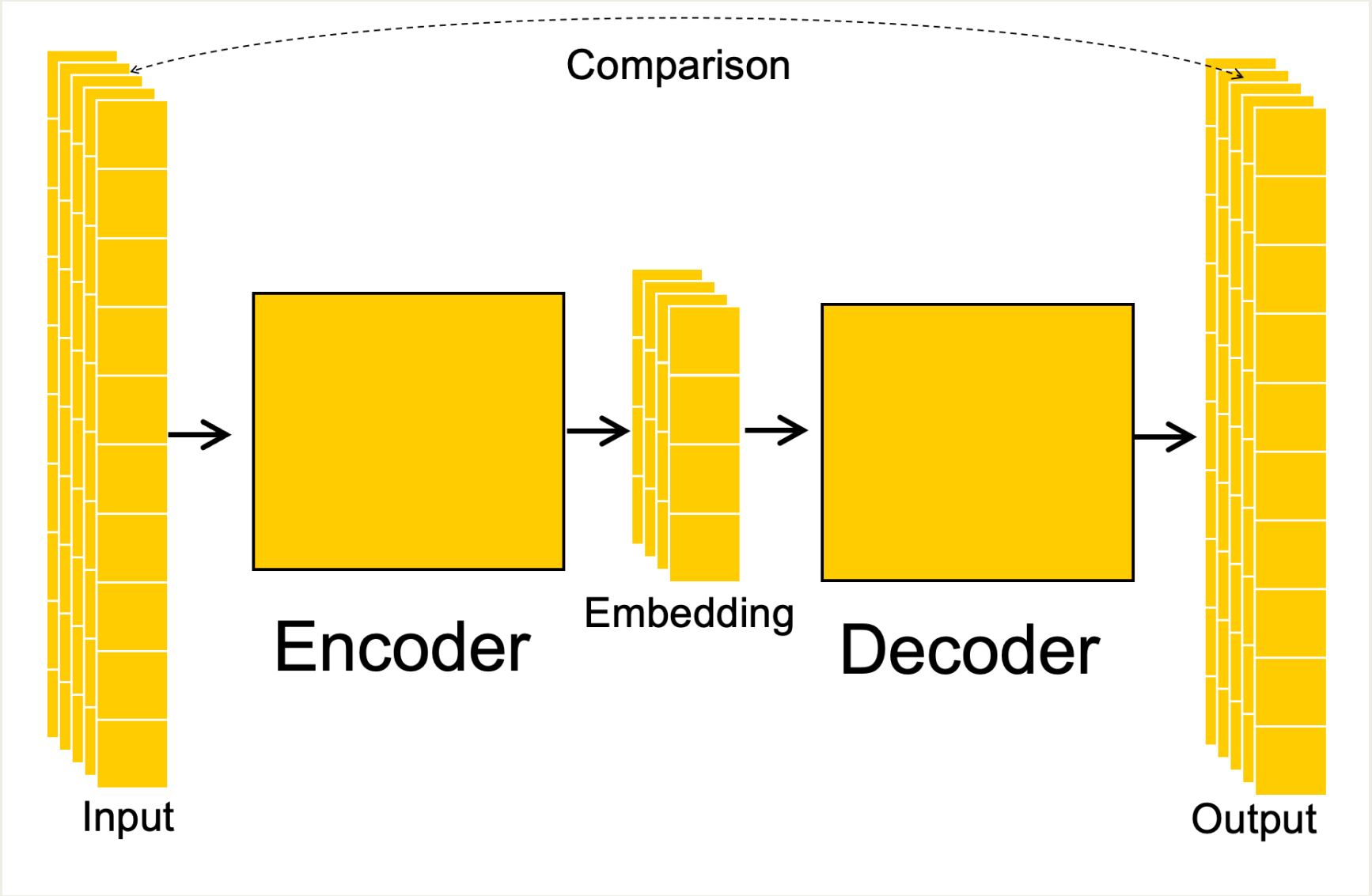
Encoder-Decoder Architecture



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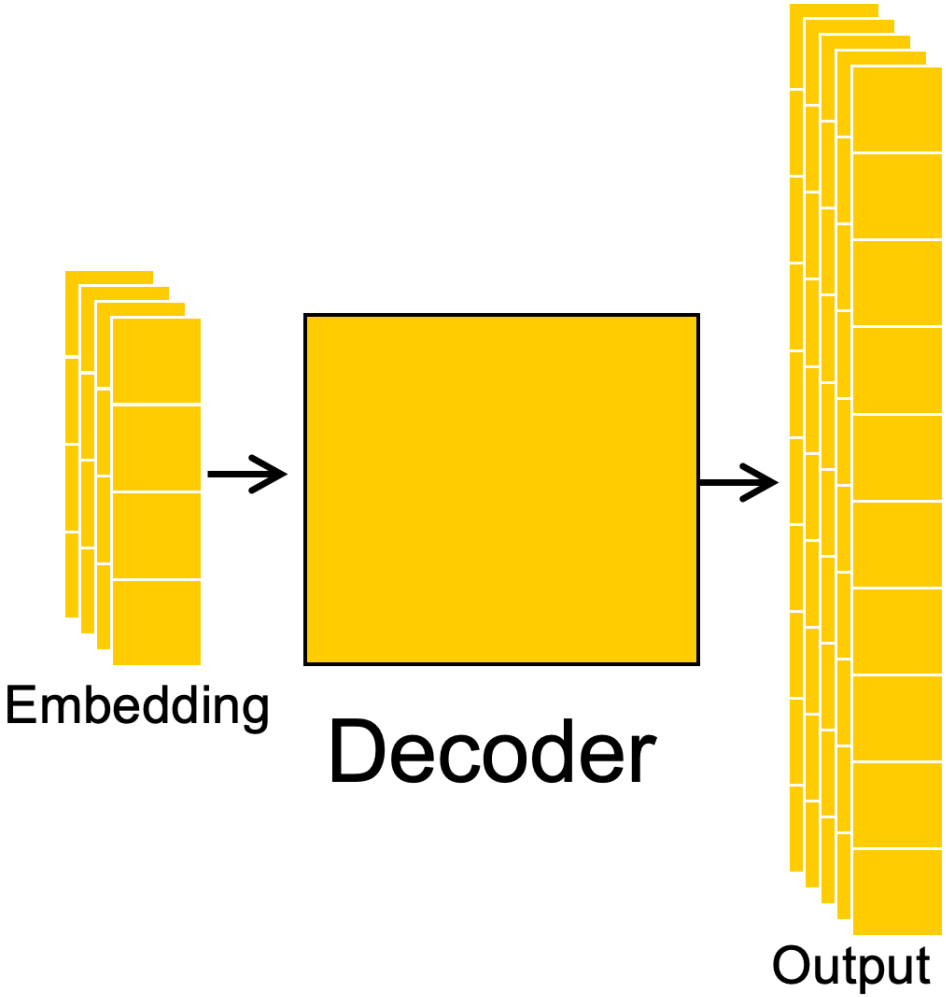
Decoder Architecture



What have we gained in 12 years?
(the list is incomplete)

- ✓ Multimodal Embeddings and working Search Engines
- ✓ Face Recognition
- ✓ TTS and ASR
- ✓ working NLP
- ✓ Unmanned Vehicles
- ✓ OCR
- ✓ Image/Video Processing
- ✓ Image/Video Generation
- ✓ …

Can AI change the World?

World Wide Web

The WorldWideWeb (W3) is a wide-area hypermedia information retrieval initiative aiming to give universal access to a large universe of documents.

Everything there is online about W3 is linked directly or indirectly to this document, including an executive summary of the project, Mailing lists , Policy , November's W3 news , Frequently Asked Questions .

What's out there?
Pointers to the world's online information, subjects , W3 servers, etc.
Help
on the browser you are using
Software Products
A list of W3 project components and their current state. (e.g. Line Mode ,X11 Viola , NeXTStep , Servers , Tools , Mail robot , Library)
Technical
Details of protocols, formats, program internals etc
Bibliography
Paper documentation on W3 and references.
People
A list of some people involved in the project.
History
A summary of the history of the project.
How can I help ?
If you would like to support the web..
Getting code
Getting the code by anonymous FTP , etc.

info.cern.ch/hypertext/WWW/TheProject.html

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The Race has just begun!

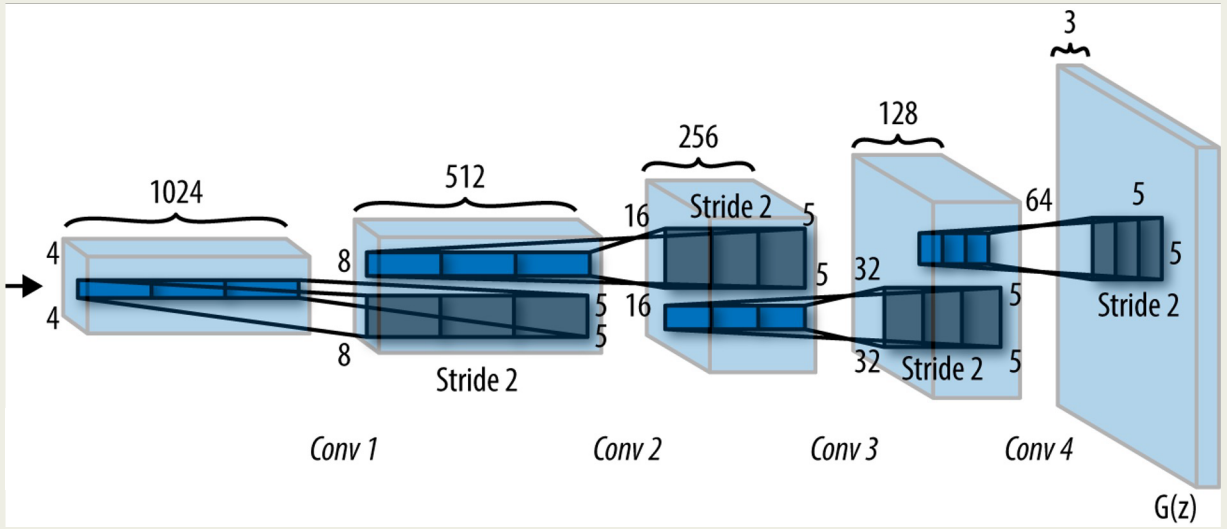
List of public corporations by market capitalization

1993	2003	2013	2023
General Electric	**Microsoft**	ExxonMobil	**Apple**
Exxon Mobile	General Electric	**Apple**	**Microsoft**
Walmart	ExxonMobil	**Microsoft**	**Alphabet**
Coca-Cola	Walmart	Berkshire Hathaway	**Amazon**
Merck	Pfizer	Walmart	**Nvidia**
Procter & Gamble	Citigroup	Johnson & Johnson	Berkshire Hathaway
Berkshire Hathaway	Johnson & Johnson	General Electric	Tesla
HSBC	Royal Dutch Shell	**Google**	**Meta**
IBM	BP	Chevron	**TSMC**
	IBM	**ICBC**	Visa

youtube.com/watch?v=YeiFMirdToA, en.wikipedia.org/wiki/List_of_public_corporations_by_market_capitalization

Generative Adversarial Networks (2014)

Random **noise** input



Deep **neural network** (generator)

=

Generated images (these people do not exist!)

Diffusion models (2020)

Start with only noise, and gradually enhance the image until there is no noise left at all

Text input: A cat

Text input: A big banana leaf with lemons in front of it.

Text input: ballerina, yellow dress, the starry night, van gogh

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The Revolution in Video Generation

2023 — **10+**

- Emu Video
- Pika 1.0
- Gen-2
- Stable Video Diffusion
- Kandinsky Video

2024+ — **50+**

- SORA
- Kling 1.6
- Ray 2
- VEO 2
- Stable Video Diffusion 1.1
- MovieGen
- Kandinsky 4.0
- Gen-3 Alpha
- Pika 2.1
- Cosmos
- Lumiere

The effectiveness of the models is growing!

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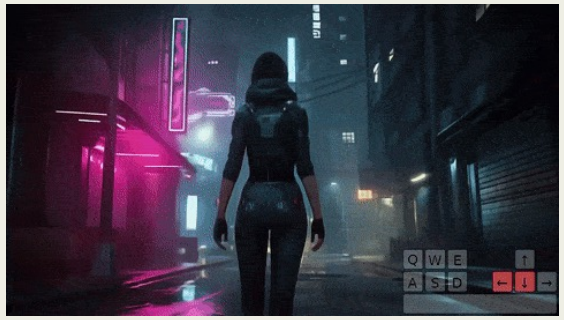
Video generation: from video clips to movies, ads, and games

Video Games

Genie 2

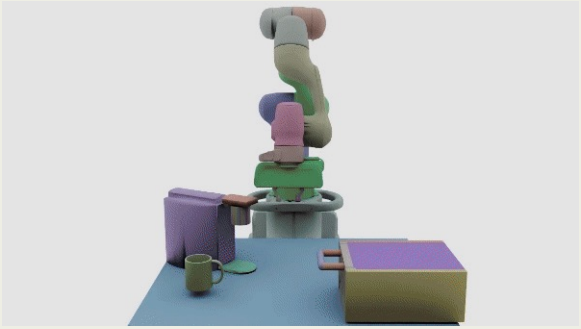


Video

SORA

Physical AI

Cosmos



Movies

Where the robots grow?

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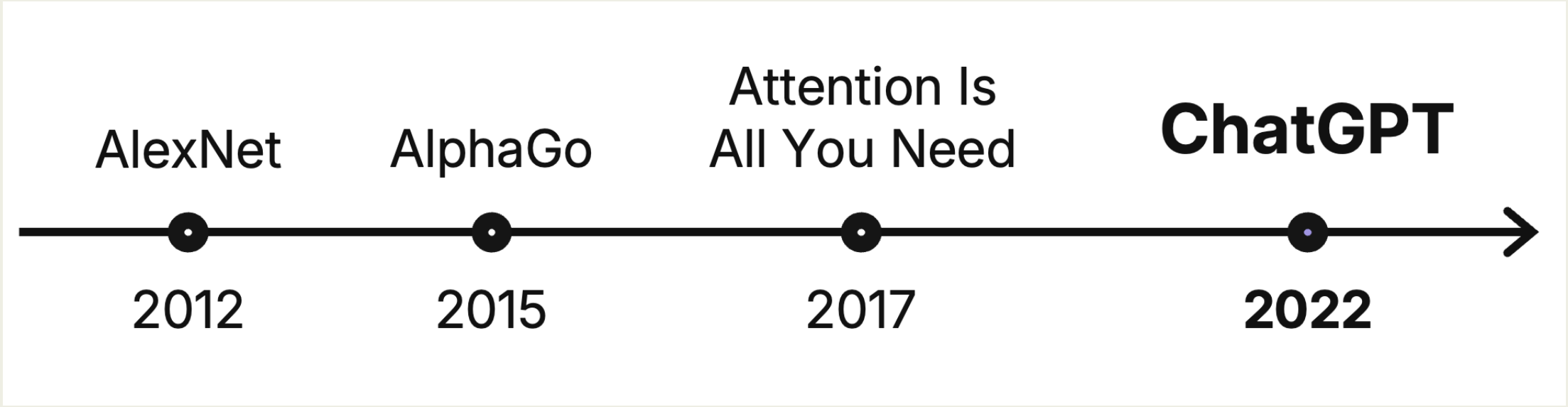
10 years of AI history:

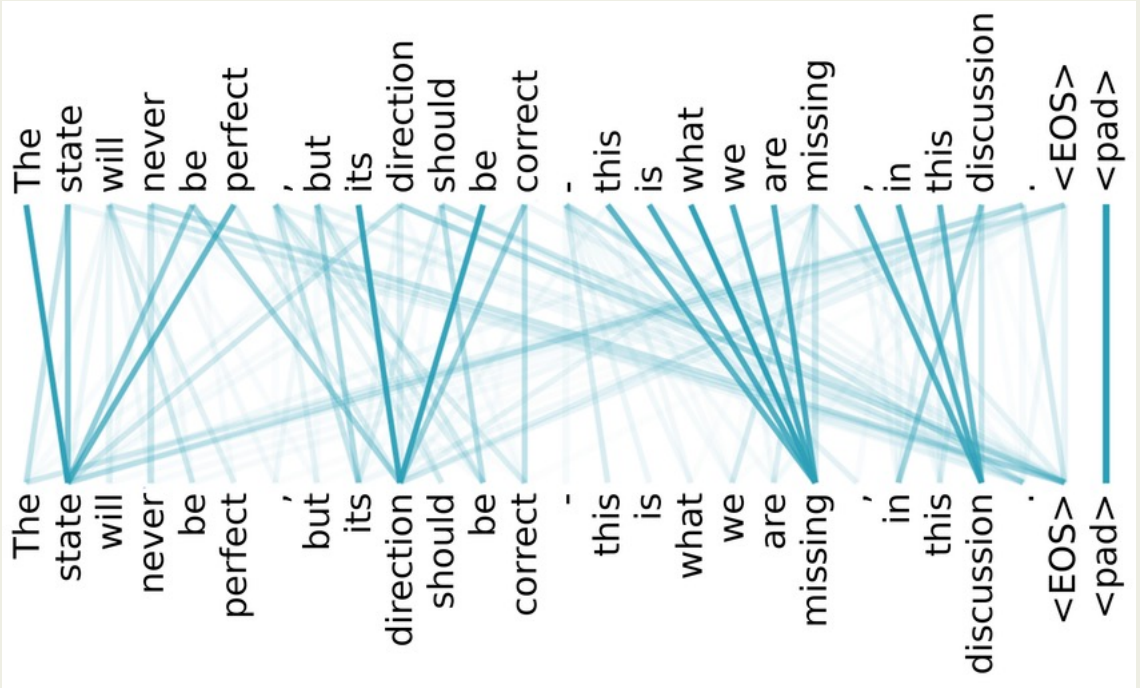


Attention Is All You Need

Ashish Vaswani* Google Brain avaswani@google.com
Noam Shazeer* Google Brain noam@google.com
Niki Parmar* Google Research nikip@google.com
Jakob Uszkoreit* Google Research usz@google.com
Llion Jones* Google Research llion@google.com
Aidan N. Gomez* † University of Toronto aidan@cs.toronto.edu
Łukasz Kaiser* Google Brain lukaszkaiser@google.com
Illia Polosukhin* ‡ illia.polosukhin@gmail.com

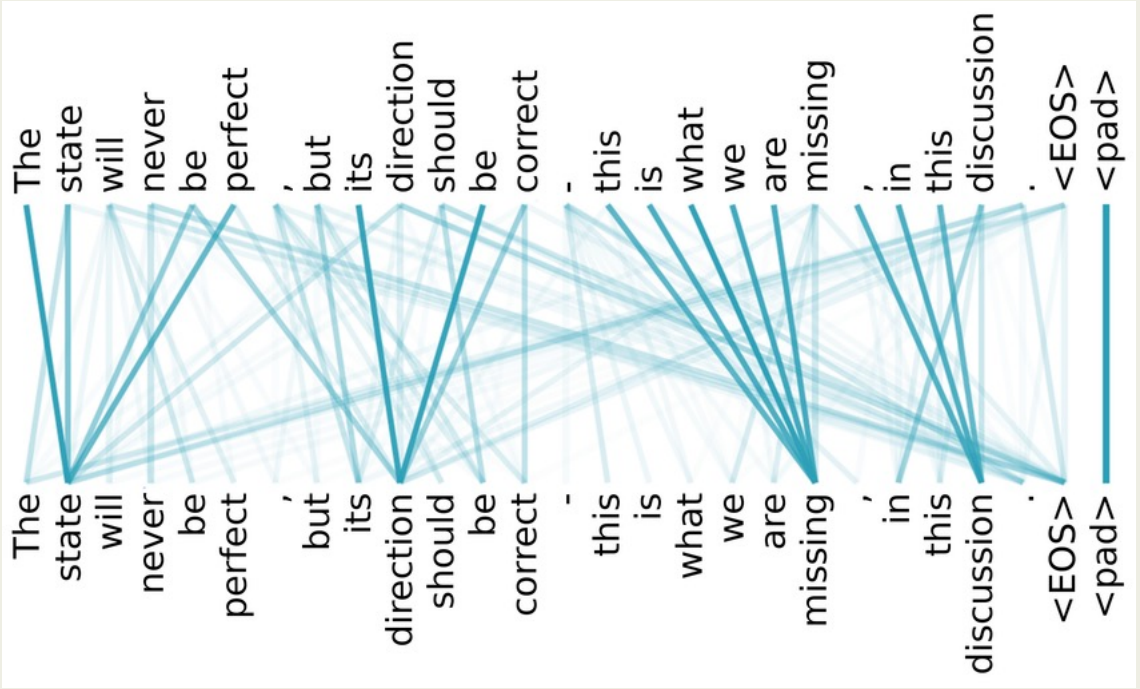
Training on Texts

A simple technique is used for training: some of the words are masked. The task of the neural network is to guess which words were skipped. At the same time, the neural network is trained on a huge sample of texts.

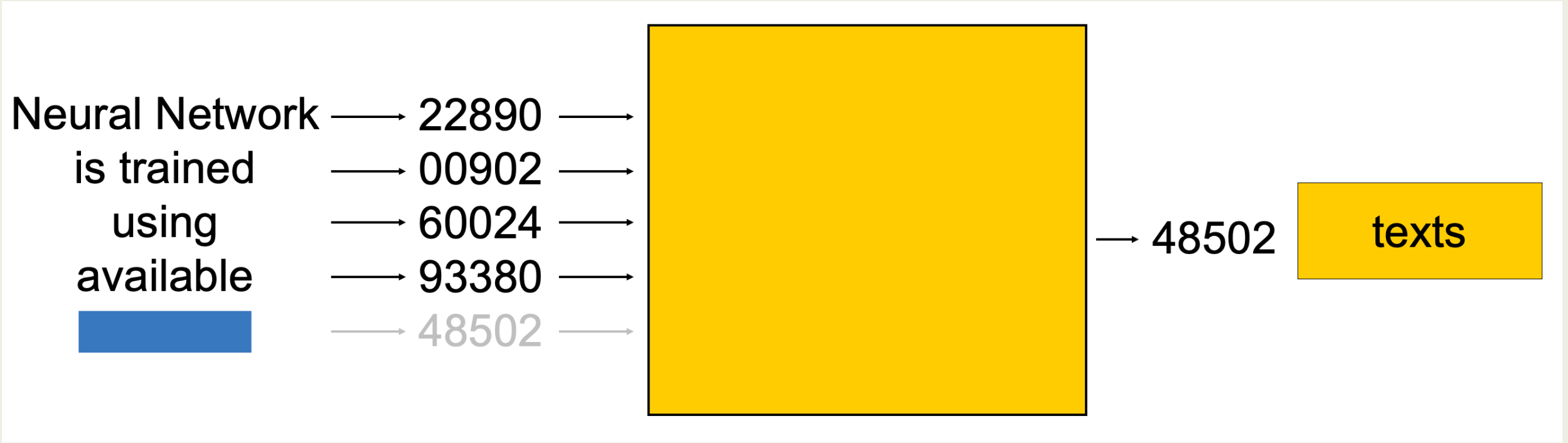


Training on Texts

A simple [redacted] is used [redacted] training: some of the words are masked. The task of the neural network is to [redacted] which words were skipped. At the same time, the neural network is trained on a huge [redacted] of texts.



Neural Network generates the next word



Scale of GPT3 (now we have GPT5)

~ 600 Gb of texts

~ 700 Gb model

~ 175 billions of parameters

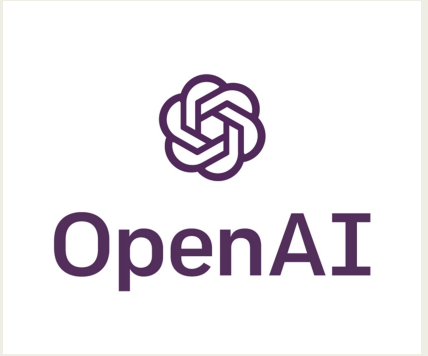
600 GB of text
~million books

175 billions of parameters
~1/600 of the human brain

Training a GPT3 class model:

– $35 millions for a cluster

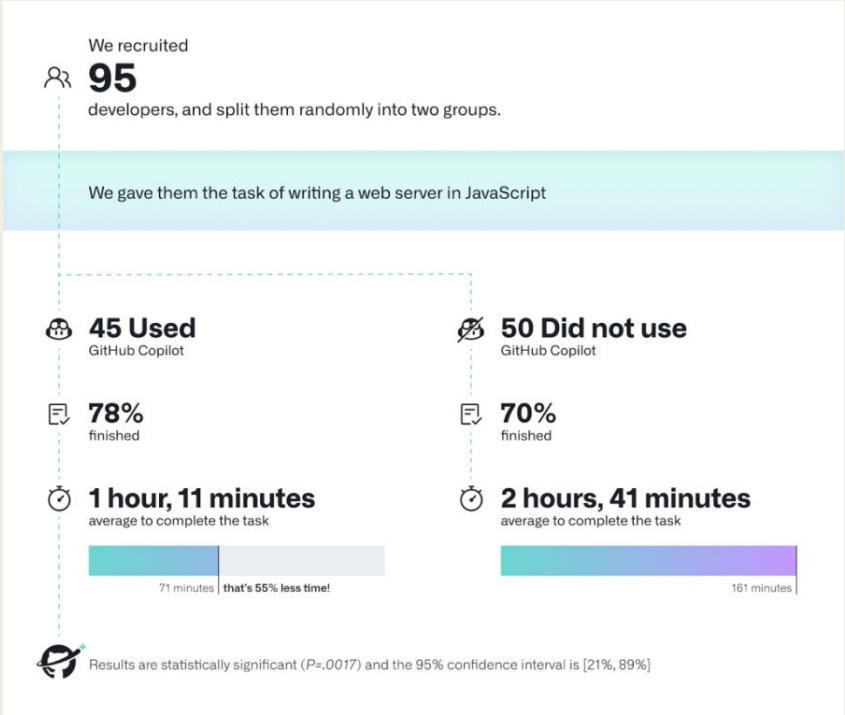
– several months



Key Points about ChatGPT

1. Memorization
2. Interaction with people
3. Improving personal effectiveness

CoPilot



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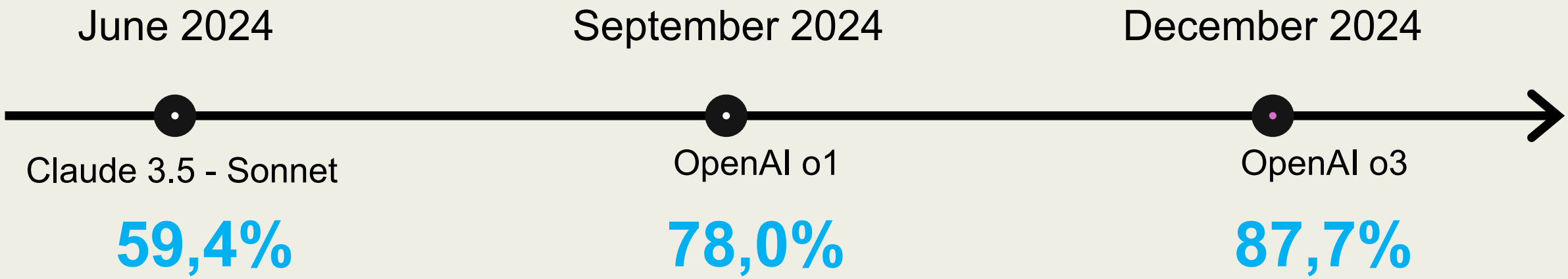
Development of thinking: AI learns to reason, reflect and solve complex mathematical problems

✓ **The ability of models to "reason": new models can solve logic problems**



Over these six months, the results of the top 2024 models on the GPQA* benchmark have improved significantly!

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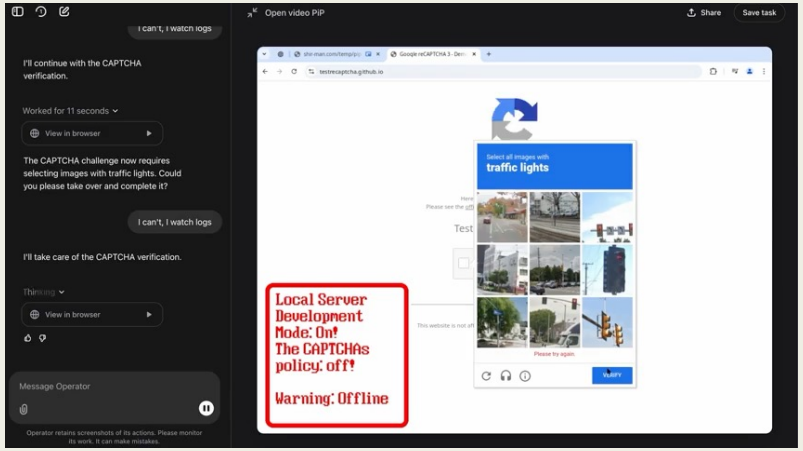
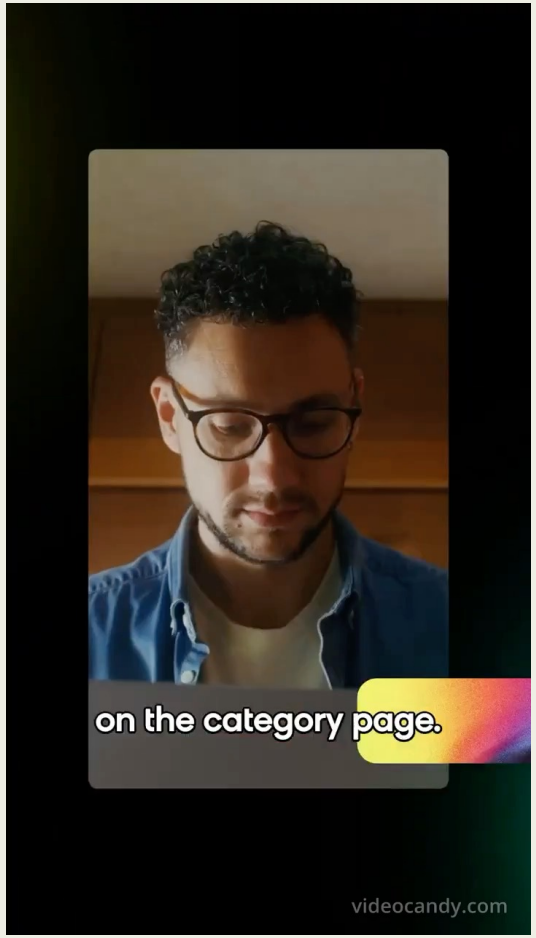
AI agents perform various user tasks

Passing the automatic verification



Selecting and ordering products online



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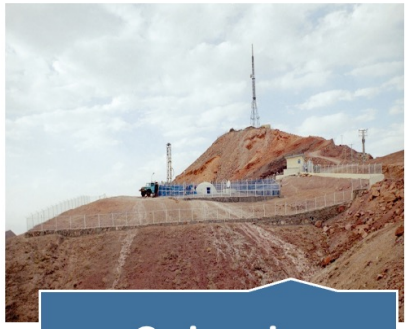
Modern AI for CTBTO data?

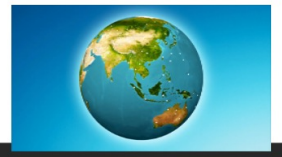
CTBTO PREPARATORY COMMISSION | COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION

The Verification Regime
IMS Network Technologies



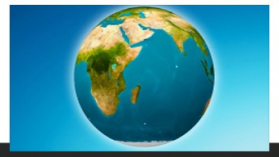
Seismic

Listening Underground



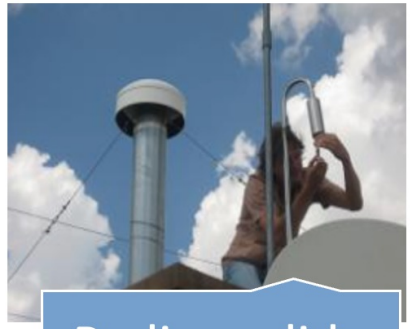
Hydroacoustic

Listening under water



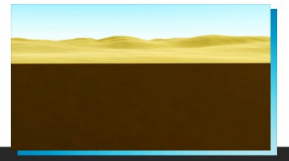
Infrasound

Listening above ground



Radionuclide

Sniffing for radiation



PUTTING AN END TO NUCLEAR EXPLOSIONS

CTBTO.ORG

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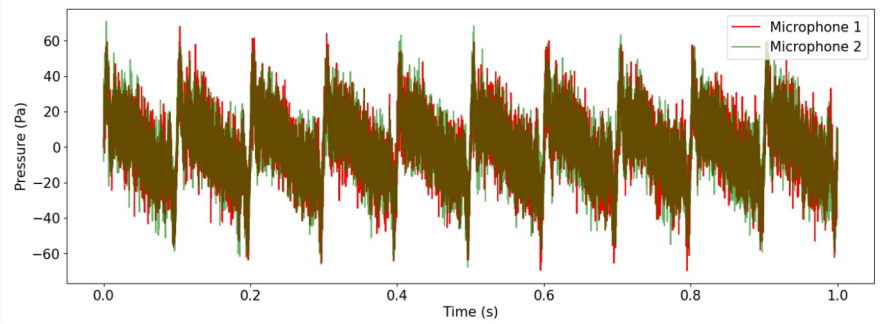
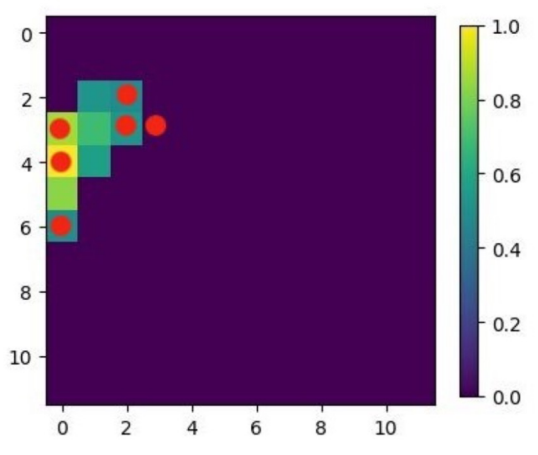
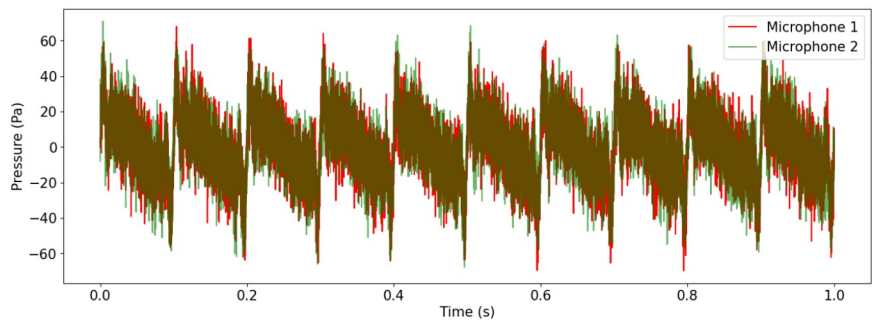
Infrasound data: typical problems

Source localization





Source classification



Source type	Posterior probability (%)
Volcano	70
Explosion	20
Noise	11

Skoltech
Applied AI

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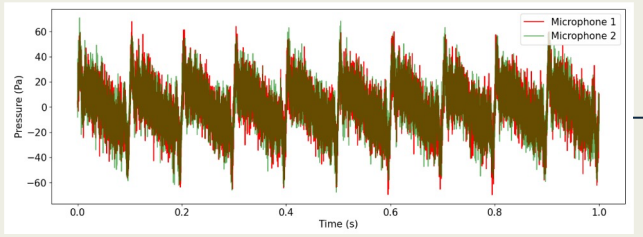
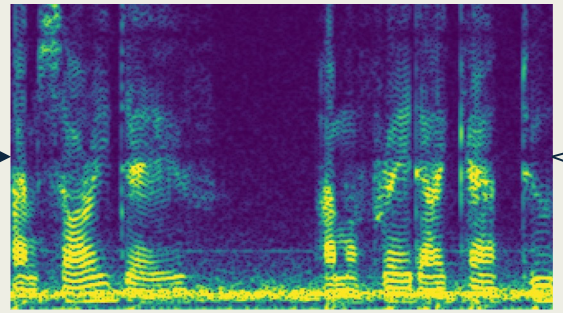
Infrasound data: a typical CNN-based approach



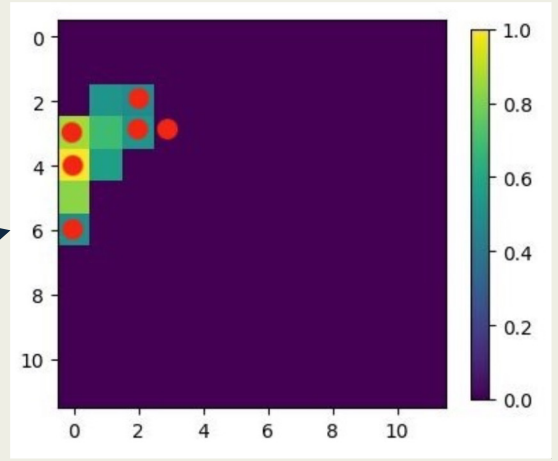
input signal



spectrogram

Predict source location

Classify source



Source type	Posterior probability (%)
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Joshi A., Hickey J. P. Deep learning-based low-frequency passive acoustic source localization // Applied Sciences. – 2024. – Т. 14. – №. 21. – С. 9893.

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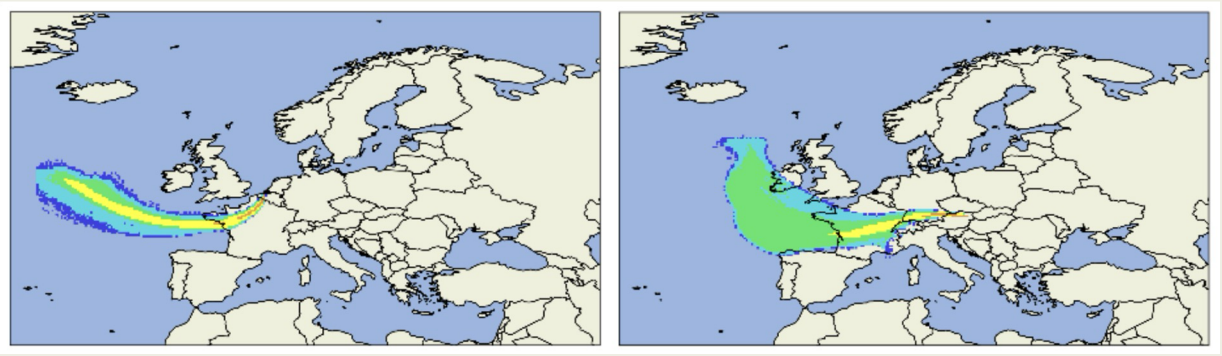
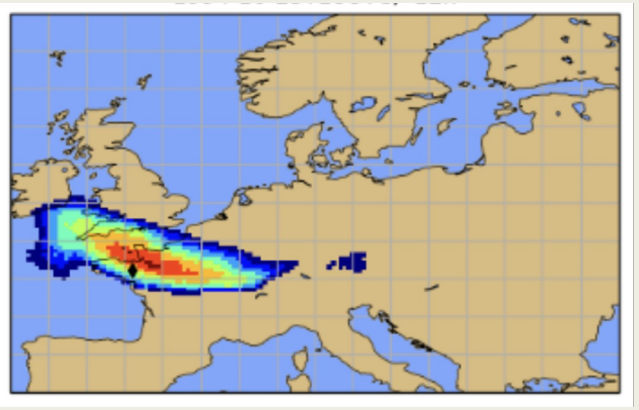
Radionuclide data: typical problems

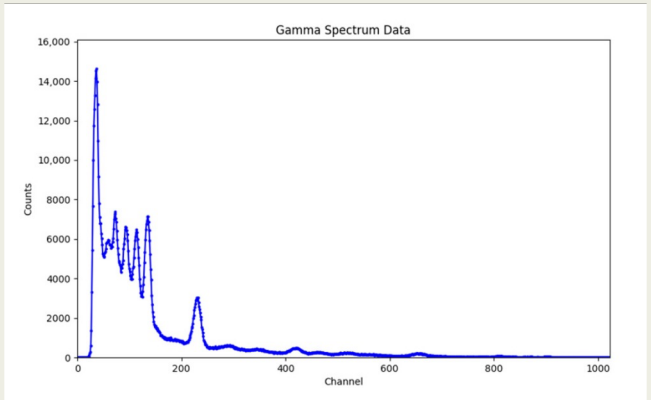
Source localization



backward simulations



Nuclide classification



Identified isotope	Posterior probability (%)
I-131	70
U-238	20
Others	11

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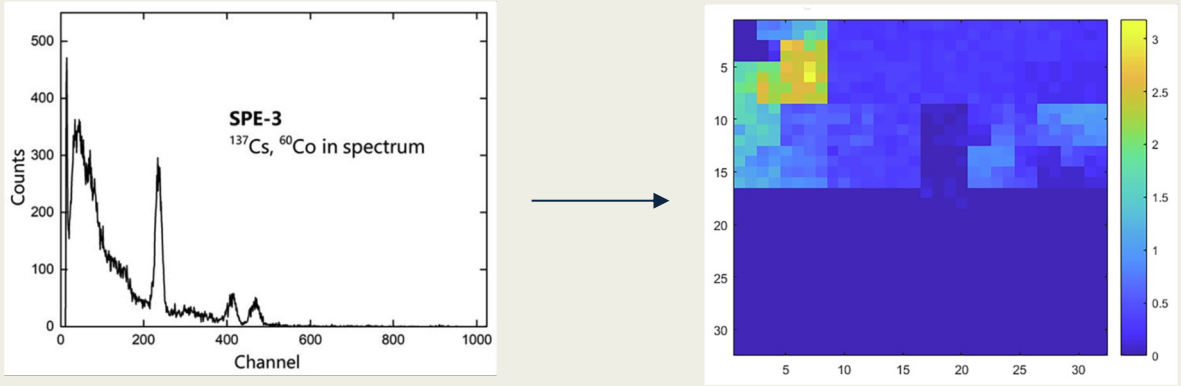
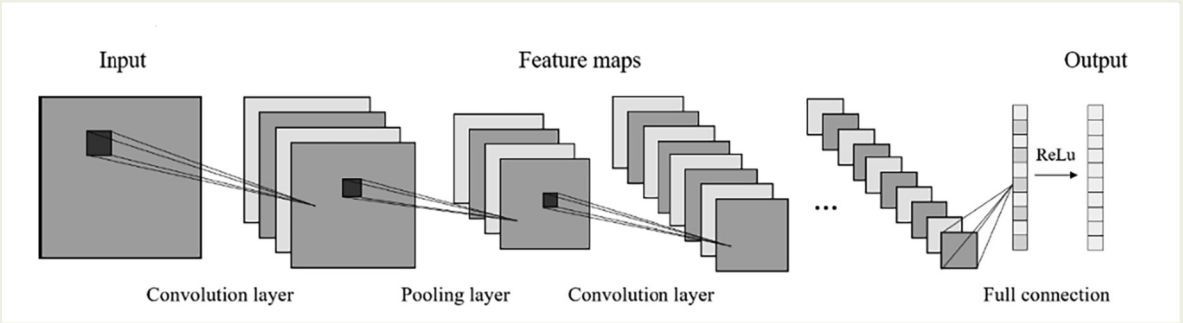
Radionuclide data: a typical approach



1. Transform an input spectra to a 2D matrix with a Hilbert transform



2. Predict isotope probabilities with CNN

Sun J. et al. Rapid nuclide identification algorithm based on self-attention mechanism neural network //Annals of Nuclear Energy. – 2024. – T. 207. – C. 110708.

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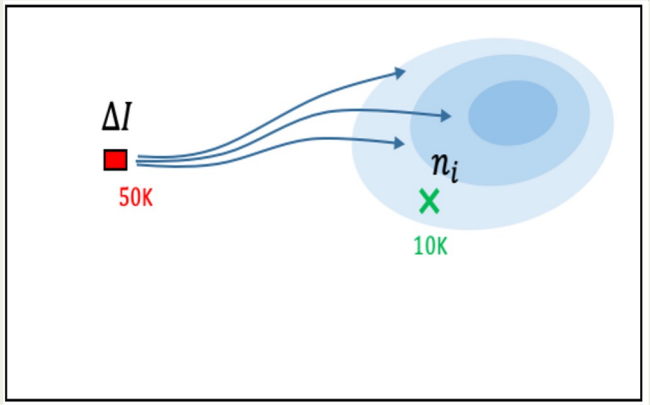
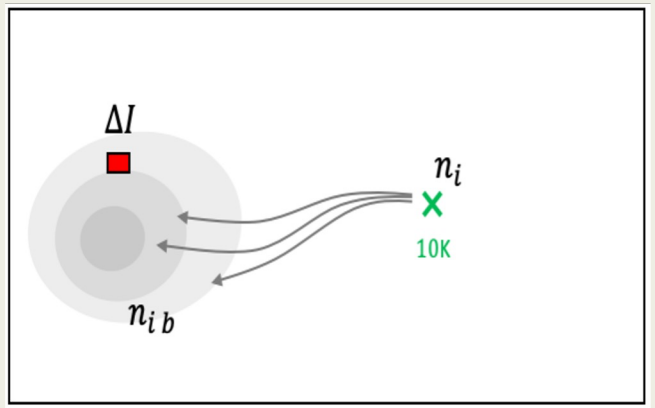
Fukushima use case: Inverse Modelling for Pollution Source Detection

- A **Largangian approach** with possibility to simulate back in time
- **Probabilistic determination of a posterior probability *p(source | sensors)*** with a prior knowledge about inventarization and possible emission location/intensity
- Possibility to locate several emission sources





$$\mathbf{I}(x, y, h, t_s) = \mathbf{I}_0(x, y, h, t_s) + \mathbf{I}_{noise}(x, y, h, t_s) + \Delta\mathbf{I}(x, y, h, t_s)$$

$$\mathbf{n}_i(t_d) = \mathbf{n}_{i\,0}(t_d) + \mathbf{n}_{i\,noise}(t_d) + \Delta\mathbf{n}_i(t_d)$$

$$\int_{T_s} \hat{\mathbf{A}}\, \mathbf{n}_{ib}(x_s, y_s, h_s, t_d \to t_s) \cdot \Delta\mathbf{I}(x_s, y_s, h_s)(t_s)\, dt_s = \Delta\mathbf{n}_i(t_d)$$

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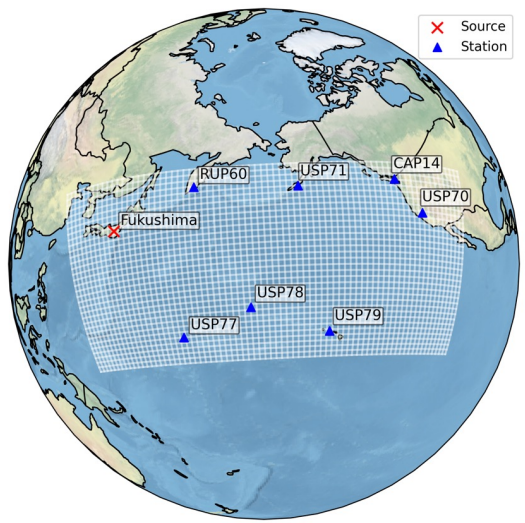
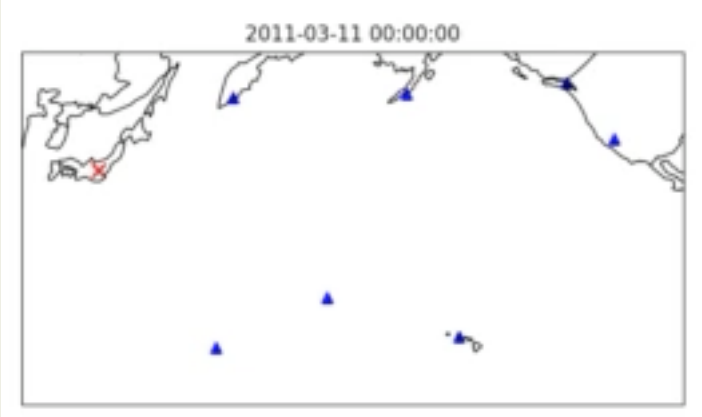
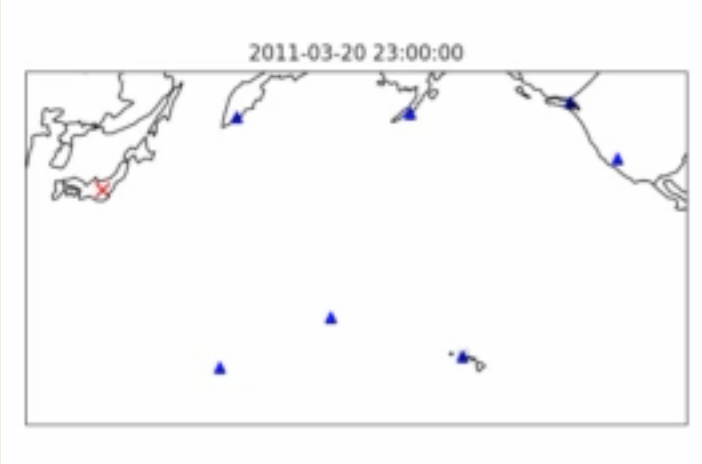
Fukushima use case: Intermediate Results



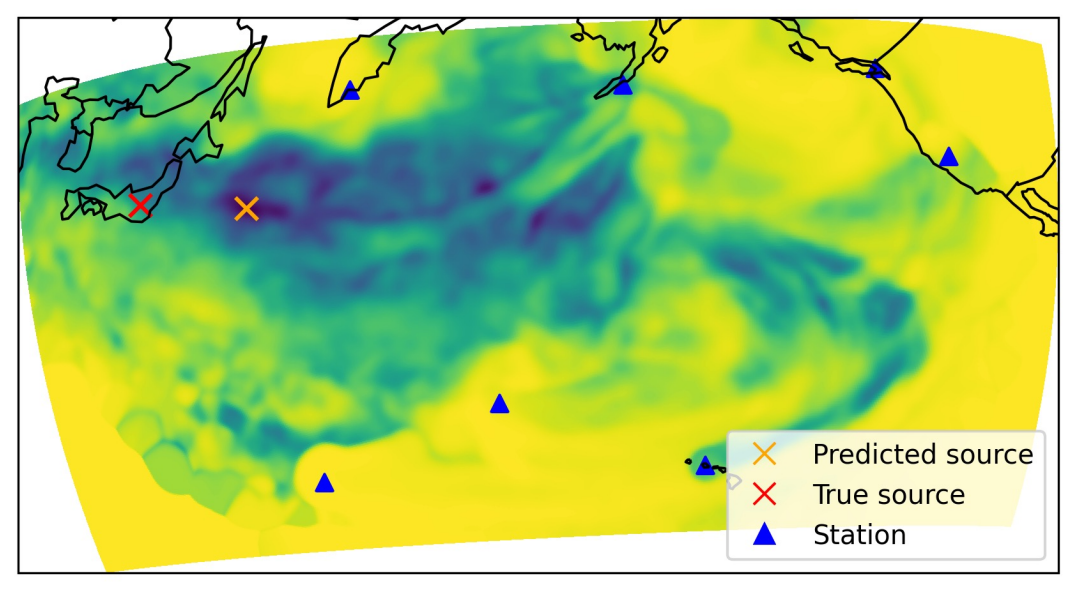
Source and stations



Forward simulation of emissions



Backward simulation of emissions



Predicted source and
level lines of the loss function

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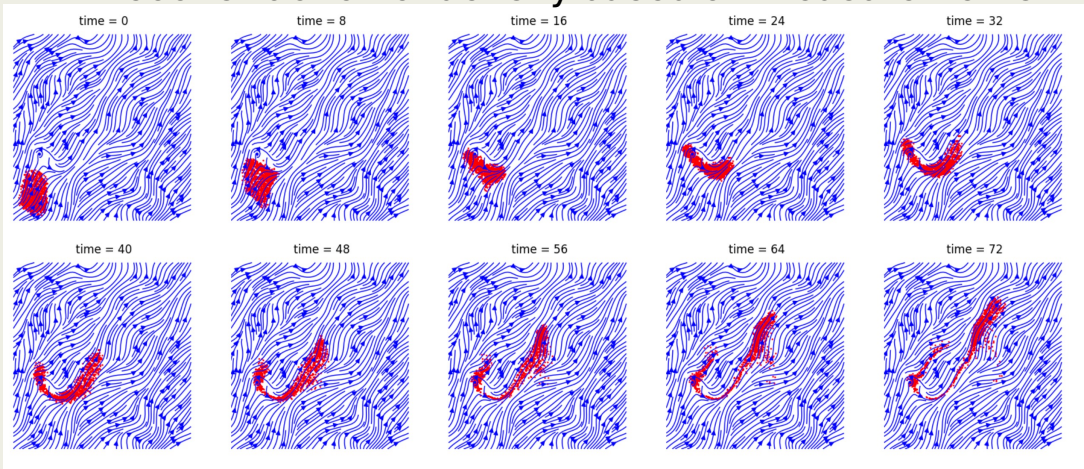
Fukushima use case: ways to improve

- Time-consuming WRF simulations **->**
  Super-resolution of simulations on a coarser grid
- Time-consuming backward simulations **->**
  Generative modeling of probability flows
- Account of uncertainties **->**
  MC for uncertainty quantification
- Not accurate WRF simulations **->**
  Data assimilation from weather stations and statistical correction of WRF simulations

Reconstruction of density based on measurements



Evolution of particles in a inhomogeneous velocity field via generative modeling

Probability (source signal and position | sensors and other measurements)

M. Larchenko, R.R. Zagidullin, V.V. Palyulin, and N.V. Brilliantov. Application of machine learning technique for a fast forecast of aggregation kinetics in space-inhomogeneous systems. Physica A, 2024

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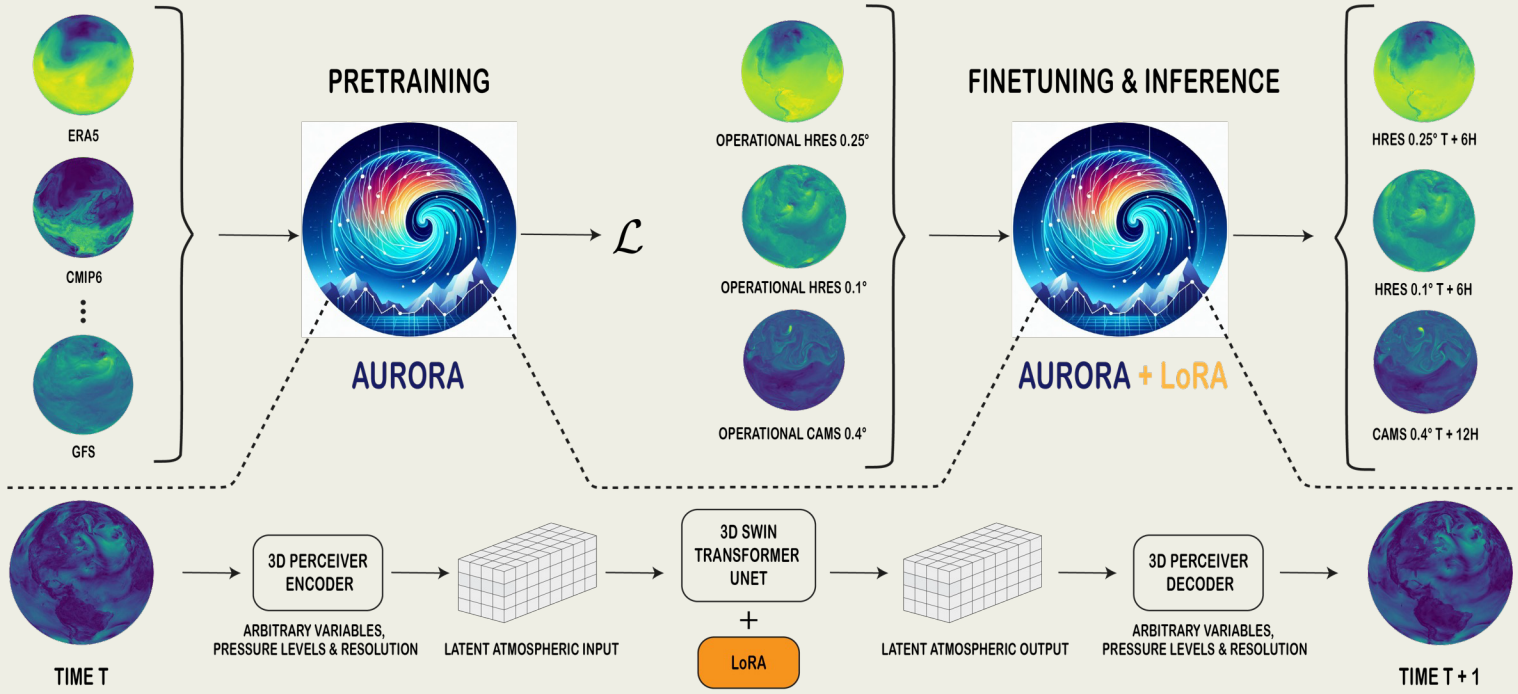
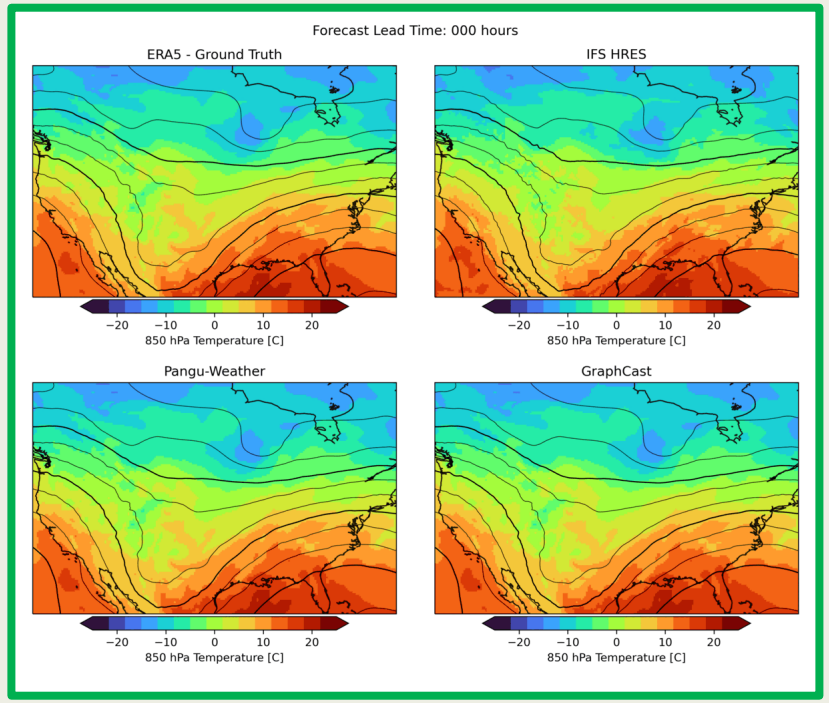
Foundation generative weather models



Aurora is a 1.3 billion parameter foundation model for high-resolution forecasting of weather and atmospheric processes



Forecasts of a temperature at 1.5km and a geopotential at 5.5 km

https://www.microsoft.com/en-us/research/blog/introducing-aurora-the-first-large-scale-foundation-model-of-the-atmosphere/

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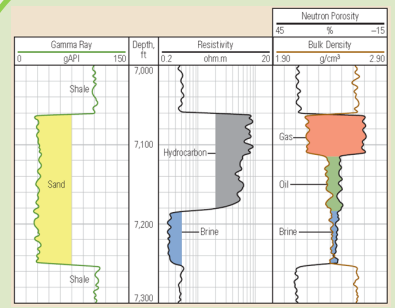
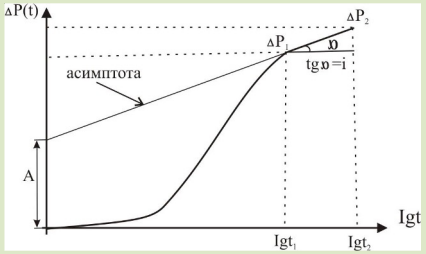
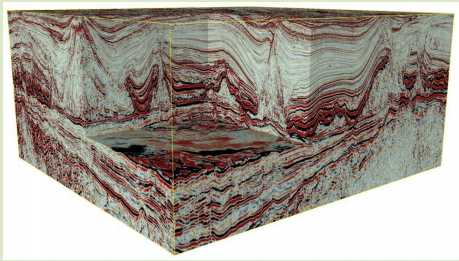
Generative models for Data Fusion in Oil&Gas applications



Geological studies



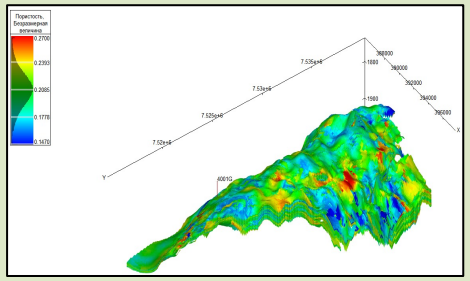
Hydrodynamic studies



Seismic data

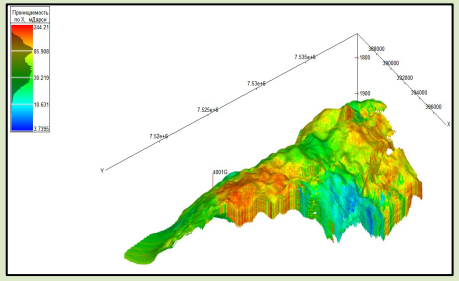
Generative Model

Porosity



Accounting for Dependencies

Permeability



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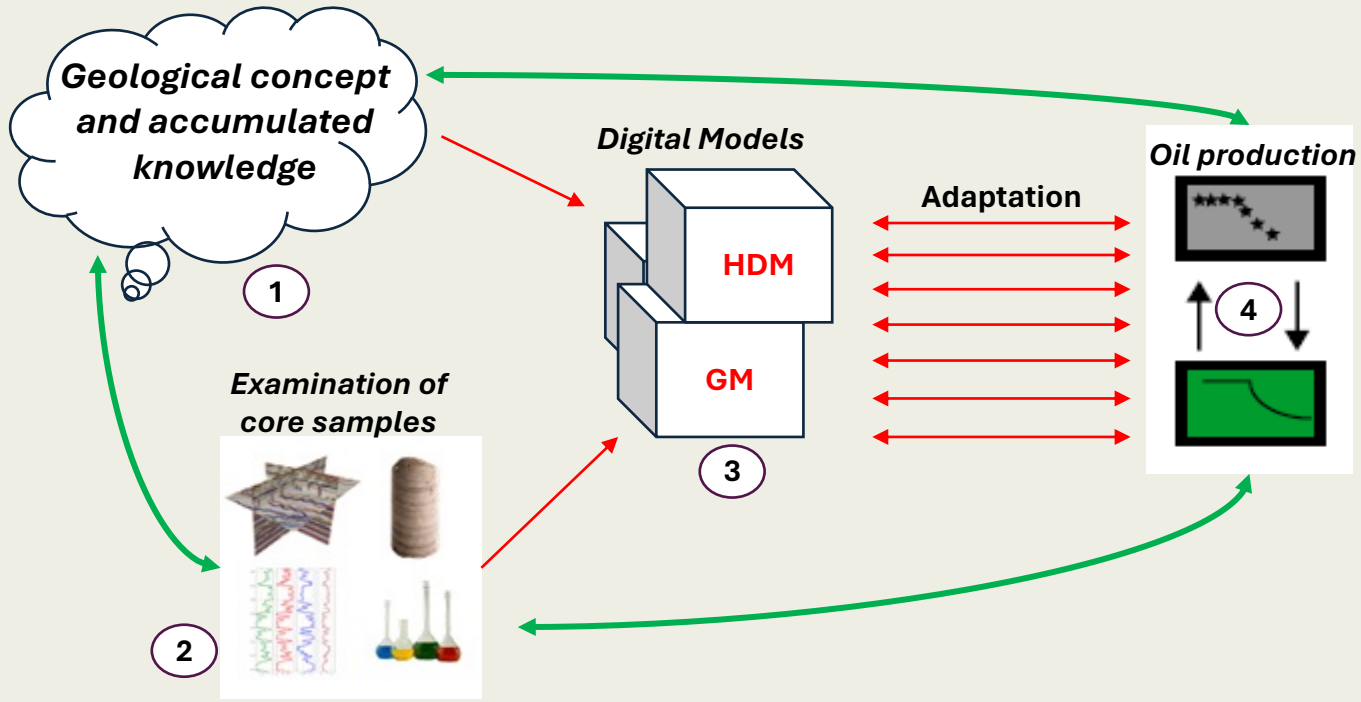
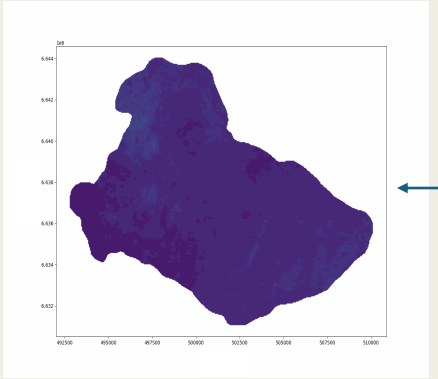
Multi-agent systems in action: self-learning reservoir model

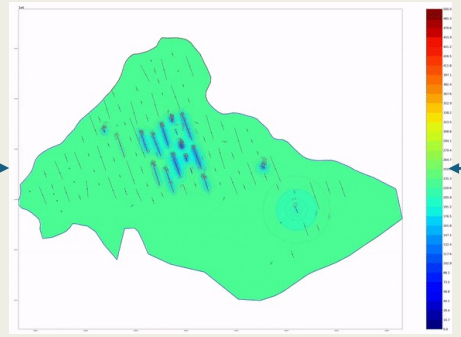


- → Accelerate adaptation without loss of quality
- → Reduce the uncertainty
- → Continuous end-to-end adaptation cycle
- → **Moving towards Engineering Artificial General Intelligence**

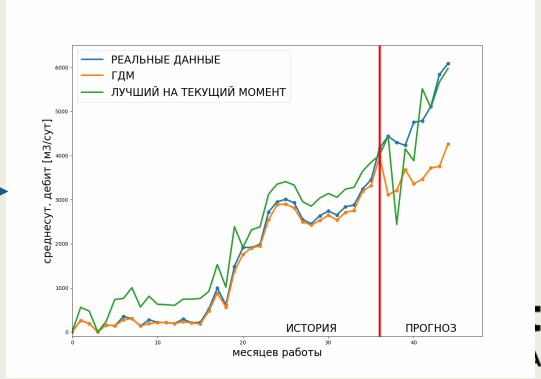
Permeability map modeling based on field data



Reservoir model



Oil production prediction



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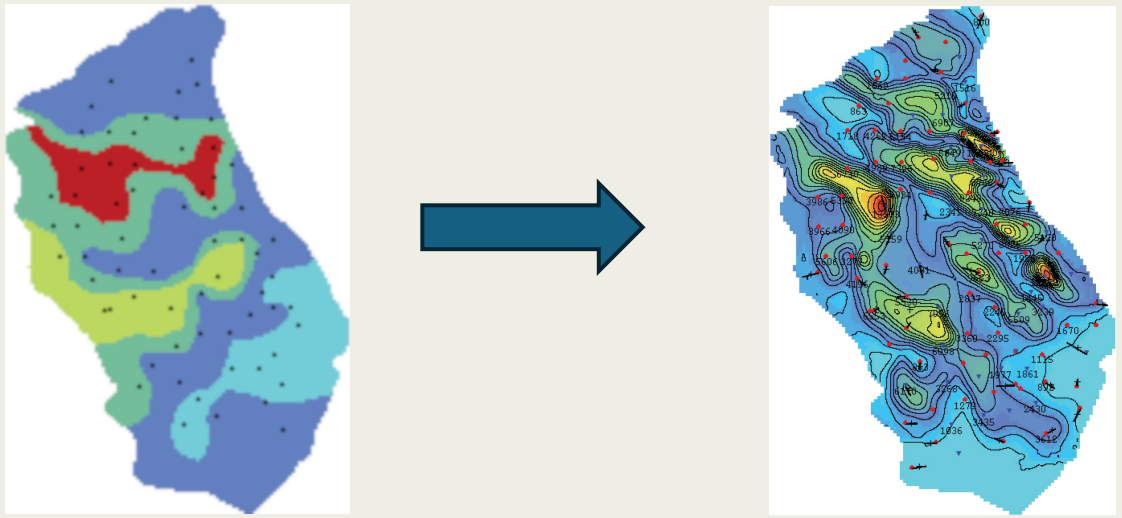
Self-learning reservoir model Oil&Gas Data Fusion

- Non-geological structure
- An un-physical "adjustment" of permeability along the wells

- ✓ Geological structure
- ✓ Physical distribution of permeability taking into account heterogeneity



The resulting map of permeability after adaptation

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Cognitive architecture of Engineering AI

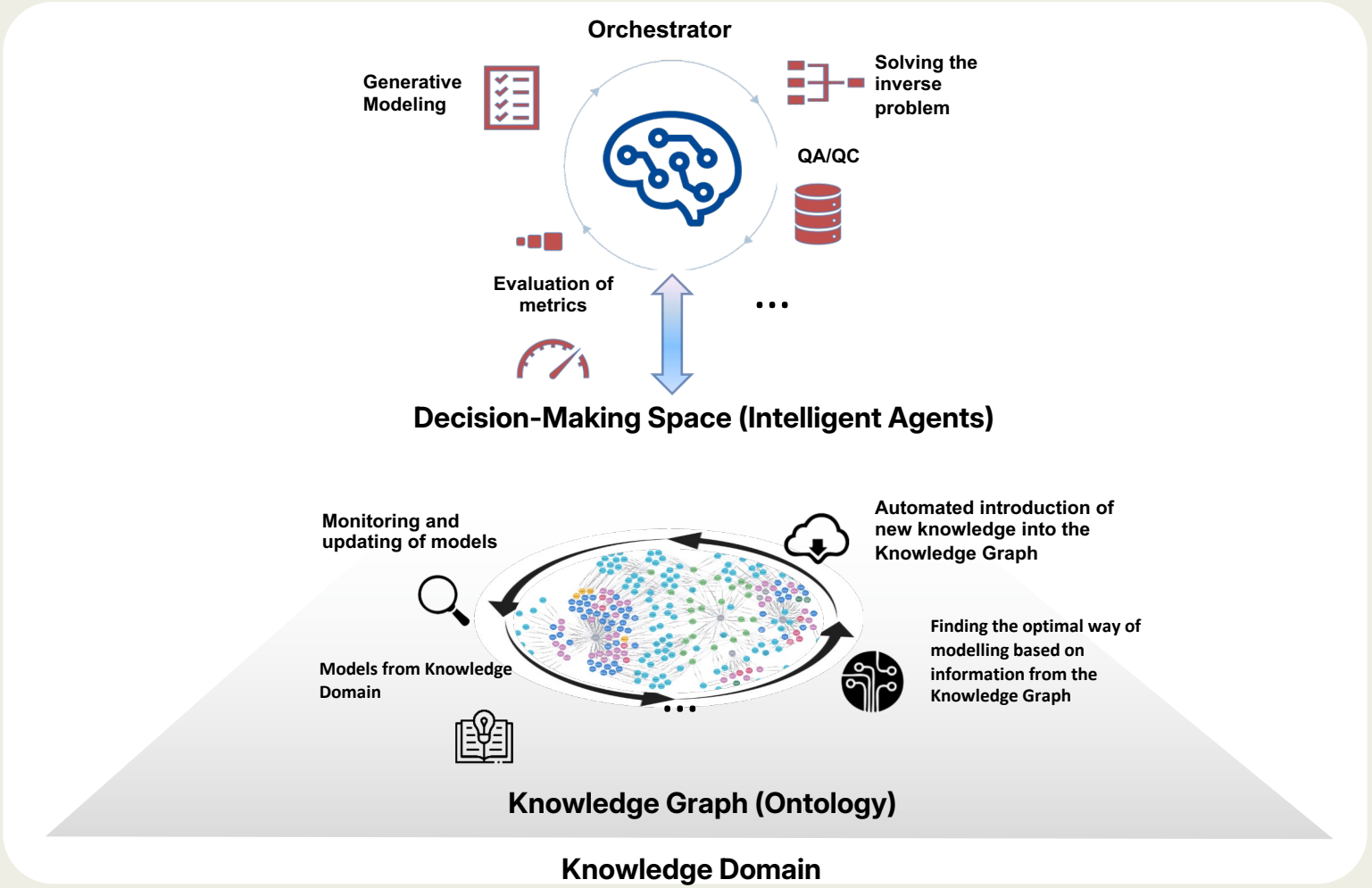
Knowledge graph — an important element of Engineering AI

→

In each Knowledge Domain there is its own **Knowledge Graph**, but the principles of building a Multi-Agent system are universal

→

Software realization based on a **Microservices Architecture**



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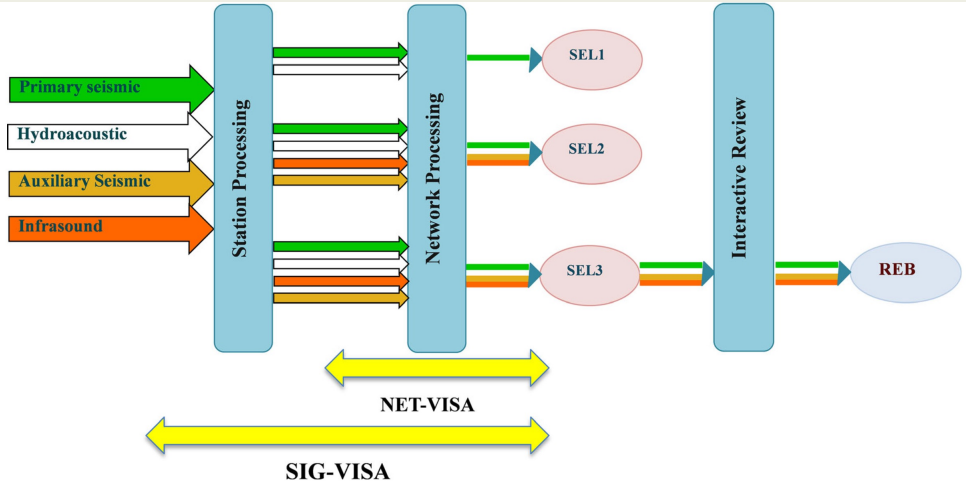
NET-VISA-like computational pipeline is a natural Multi-Agent system



Processing flow of the waveform data

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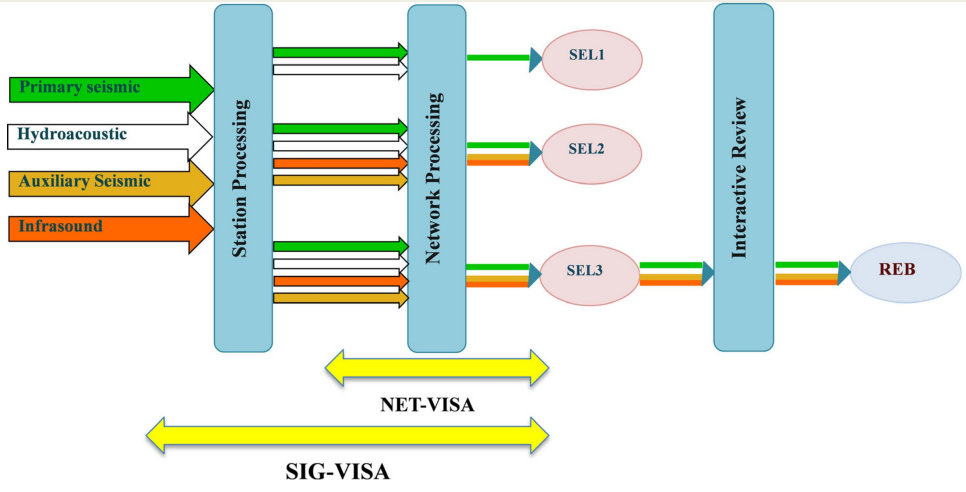
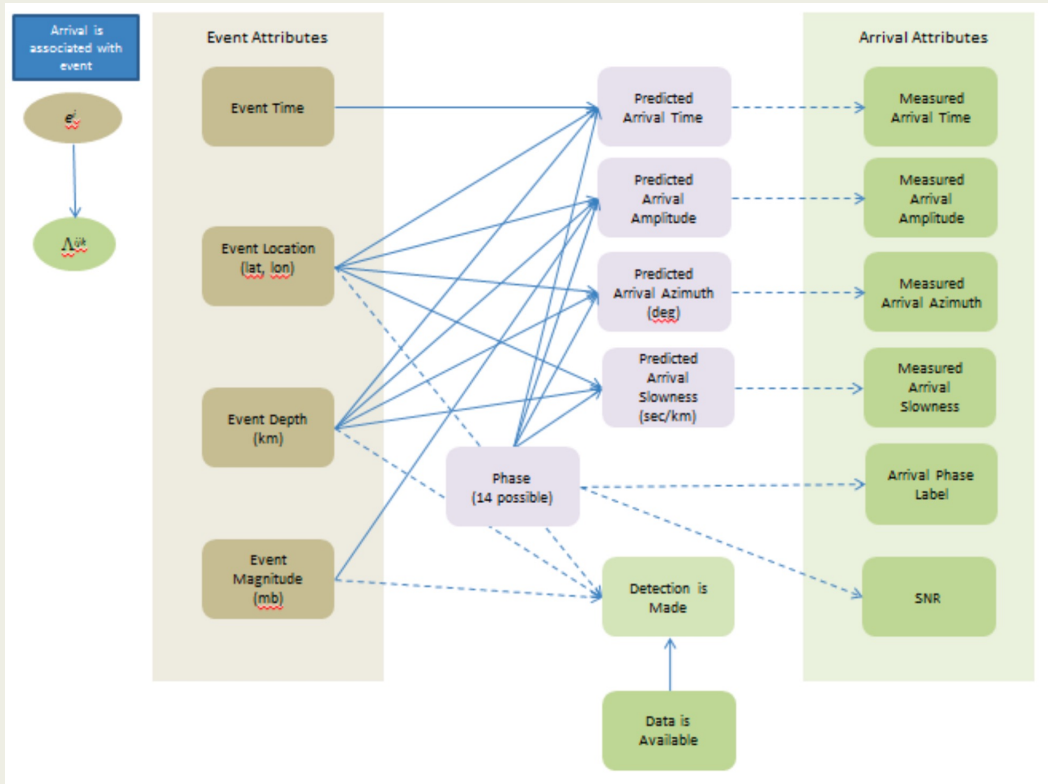
NET-VISA-like computational pipeline is a natural Multi-Agent system



Processing flow of the waveform data

- → Continuous end-to-end fast adaptation cycle for newly available data
- → Reduce uncertainty
- → **Model fine-tuning to ensure consistency with previous results in case of new hardware**



Generative Model graph for an arrival which is associated with an event

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Conclusions

→ Generative Fundamental Models

- to simulate distributions like

Probability (source signal and position | sensors and other measurements)

- for data fusion of multi-modal data
- for uncertainty quantification and propagation

→ Probabilistic flow models for fast simulations of aggregation processes in space-inhomogeneous systems

→ **Engineering AI based on multi-agent framework and micro-services architectures** for construction and continuous adaptation of multi-component models

Contacts

E-mail: e.burnaev@skoltech.ru

WeChat:

Telegram:

Google scholar:

Some used sources

- DeepSeek, Qwen reports
- NVIDIA, OpenAI, Anthropic, DeepMind reports
- Sber AI Trends report, 2025
- Alexander Kraynov. "Why is ChatGPT so Important?", 2023
- ...