TU WIEN Informatics

Introduction to Computational Sustainability

Ivona Brandić

Head of the Research Unit Computational Sustainability

TU Wien

ivona.brandic@tuwien.ac.at

MARIE CURIE ACTIONS chist-era WWTF cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY European Commission Stadt Wien FWF FFG Forschung wirkt.

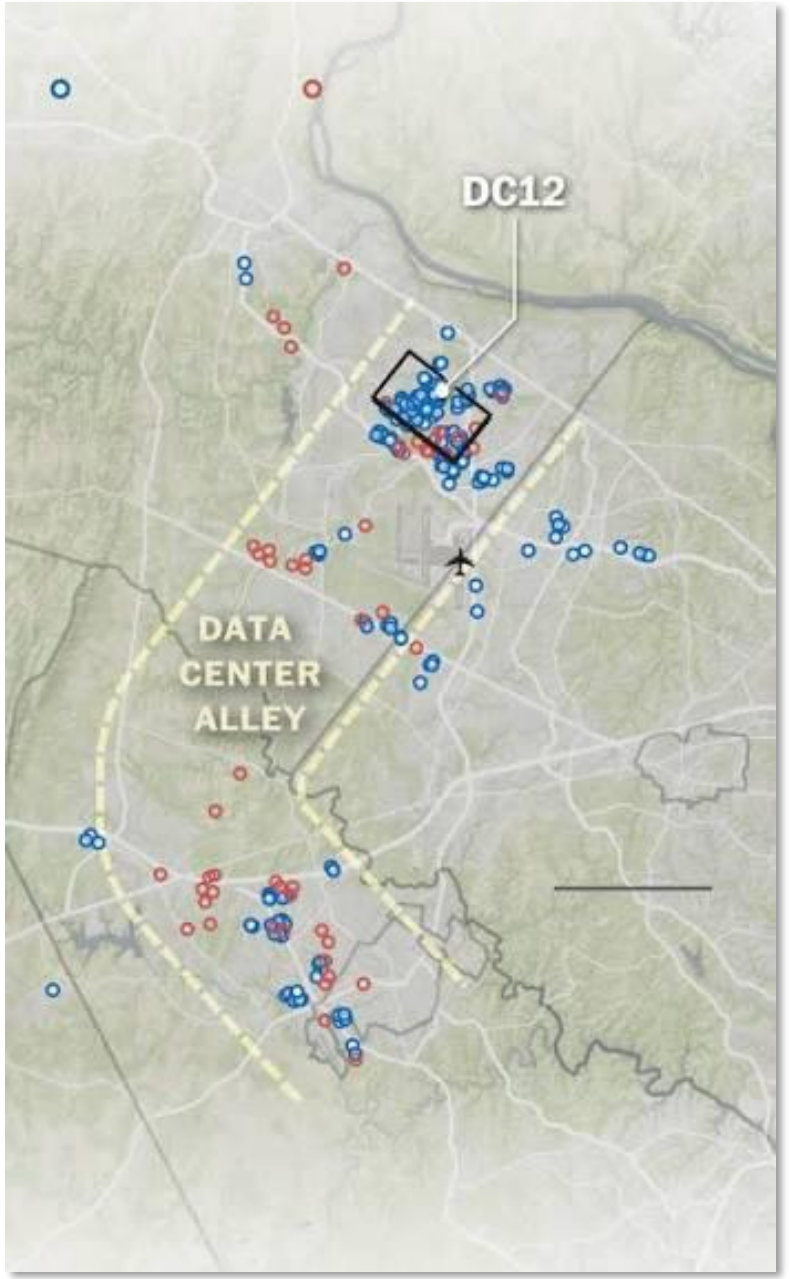


Google data Center in Kronstorf

Source: https://www.falter.at/zeitung/20260714/der-koloss-von-kronstorf



After tornado alley, bible belt, rust belt, sun belt etc - we have now **Data Center Alley**



Source: https://www.washingtonpost.com/dc-md-va/interactive/2024/data-centers-tour-northern-virginia/

BBC

How backlash against data centres could shape the US midterm elections

4 days ago

Share Save Add as preferred on Google

Kali Hays
Technology reporter, San Francisco



Watch: The BBC's Shaimaa Khalil is in Arizona to hear from residents about the expansion of data centres.

A year ago, a longtime US senator was not thinking much about data

ADVERTISEMENT

Source: https://www.bbc.com/news/articles/c0rezqpnekro



https://www.krone.at/4276414

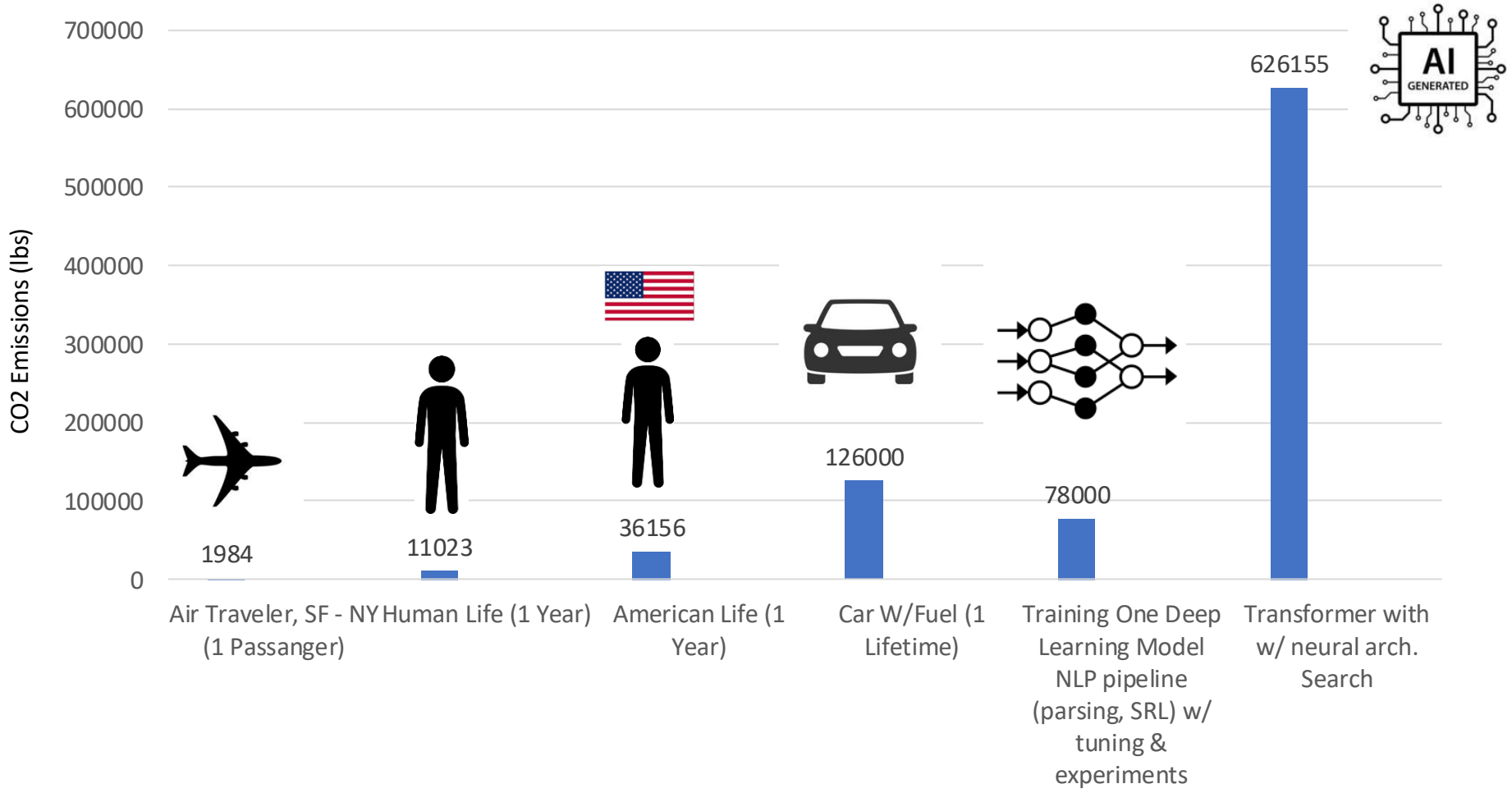
"In Deutschland sind 99 neue Rechtenzentren in Planung oder Bau, ein Drittel davon Hyperscaler."

Source: https://www1.wdr.de/mediathek/audio/wdr5/wdr5-morgenecho-interview/audio-nachhaltige-rechenzentren-wie-kann-das-gehen-100.html

Eine neue Gallup-Umfrage zeigt, wie groß der Widerstand gegen KI-Rechenzentren in den USA geworden ist: 71 % der Amerikaner lehnen solche Anlagen in ihrer Umgebung ab – vor allem wegen Energieverbrauch, Wasserbedarf und Umweltfolgen.

Source: https://www.forbes.at/artikel/widerstand-gegen-ki-rechenzentren

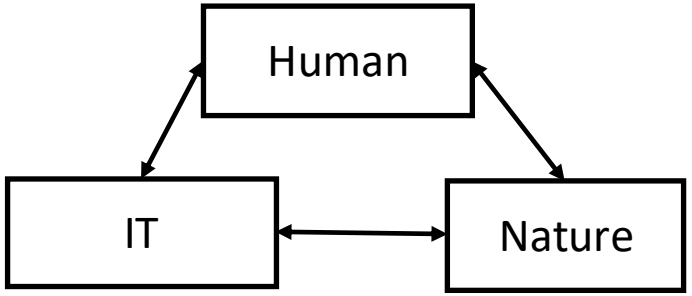
Problem: CO_2 Footprint of (generative) AI



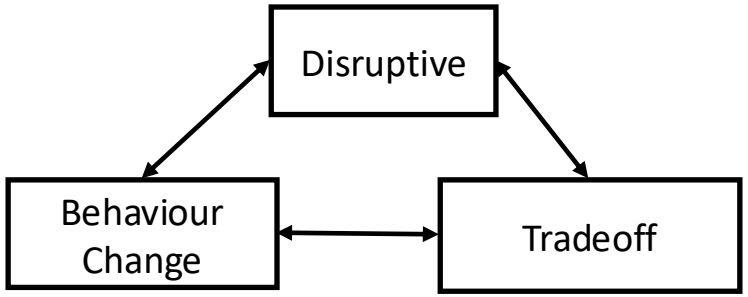
Source: Emma Strubell, Ananya Ganesh, Andrew McCallum: Energy and Policy Considerations for Deep Learning in NLP, ACL (1) 2019: 3645-3650
Inspiration for Visualisation: Keren Bergman, Multicore World 2023 https://2019multicoreworld.files.wordpress.com/2023/02/bergman-keren-23.pdf

Computational Sustainability

Actors:

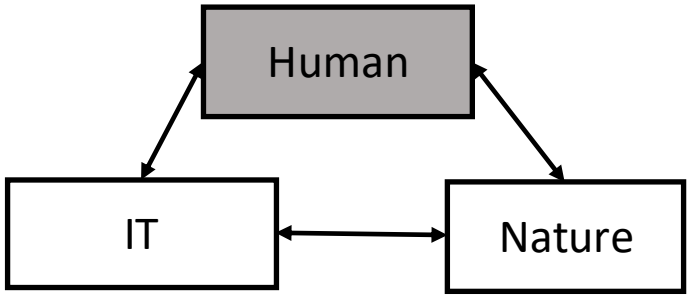


Methods:



Computational Sustainability

Actors:





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Sustainable Watershed Management Through IoT-Driven Artificial Intelligence

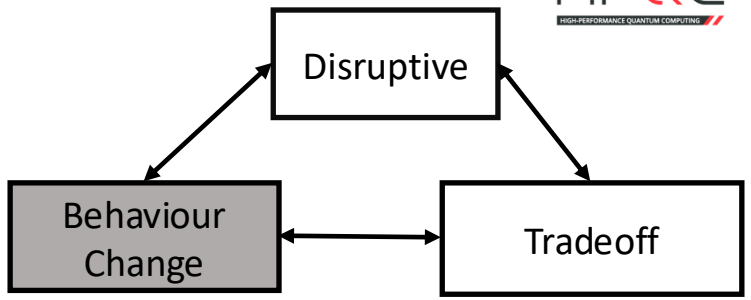
FFG Forschung wirkt.



Virtual Shepherd

TRUST! Explaining the increasing energy consumption of IT infrastructures

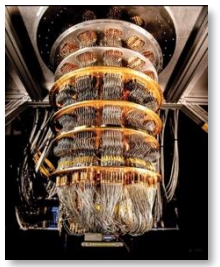
Methods:



HPQC HIGH-PERFORMANCE QUANTUM COMPUTING

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High Performance Integrated Quantum Computing



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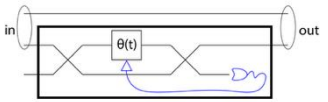
Quantum Algorithm Enginering COMET Module

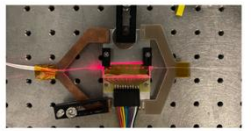
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ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

MARIE CURIE ACTIONS





WWTF



WWTF: AI-supported Holographic Environmental Water Monitoring

FWF

Themis: Trustworthy and Sustainable Code Offloading

FWF

Triton: Transprecise Edge

WWTF: Advancing learning paradigms for photonic quantum processors



ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN







Asking ChatGPT Qs with 5-50 prompts[1] ≈



500ml of water

Search on LLM vs Google Search[1] ≈



2.9 Wh/ Search or up to 20x expensive

A text-to-image generation[2] (1000 inferences) ≈



3 kWh or 3hr of dishwasher

1 min video (e.g., midjourney) ≈

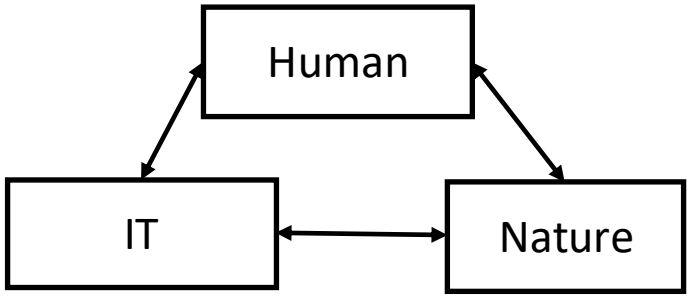


5,4 kWh or 36hr playing Playstation 4.0

Sources: https://www.youtube.com/watch?v=N4Ec_POLtes
https://www.youtube.com/shorts/O6QeeA6jbS0

Computational Sustainability

Actors:





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Sustainable Watershed Management Through IoT-Driven Artificial Intelligence

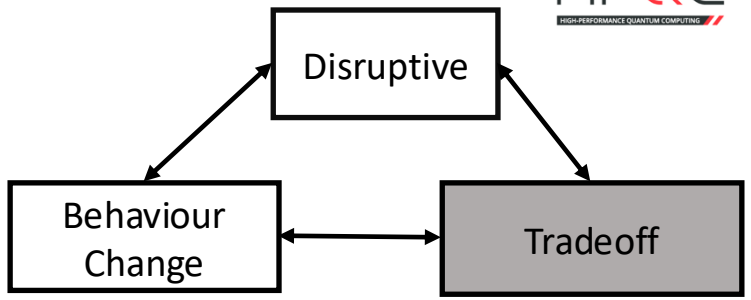
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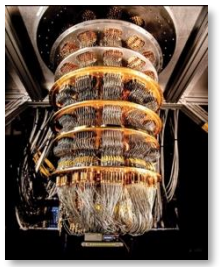
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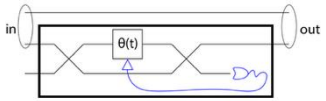
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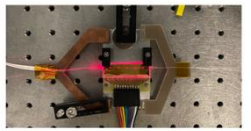
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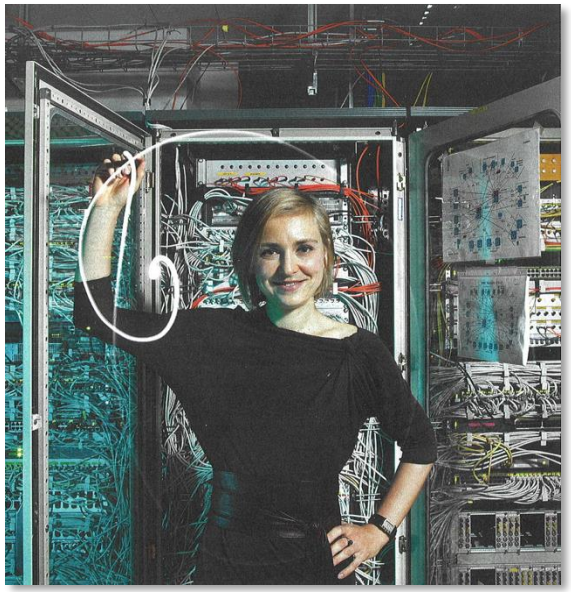
Triton: Transprecise Edge

WWTF: Advancing learning paradigms for photonic quantum processors

Data Centers once…



INRIA Rennes, 2012



TU Wien (VCS), 2011 (“Der Falter”)

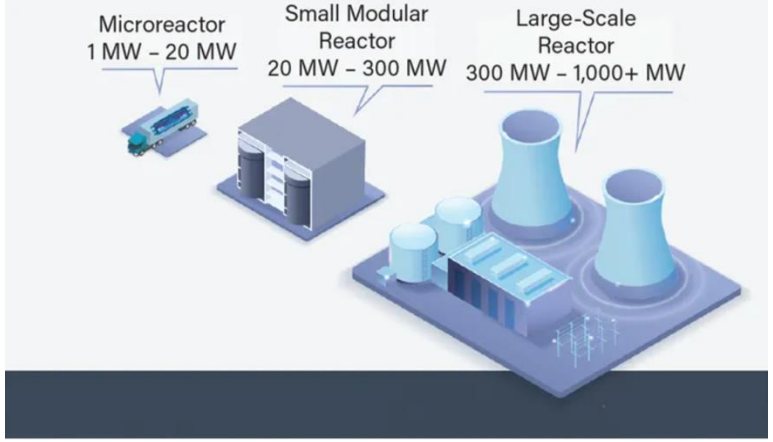


SuperMUC Munich, 2013

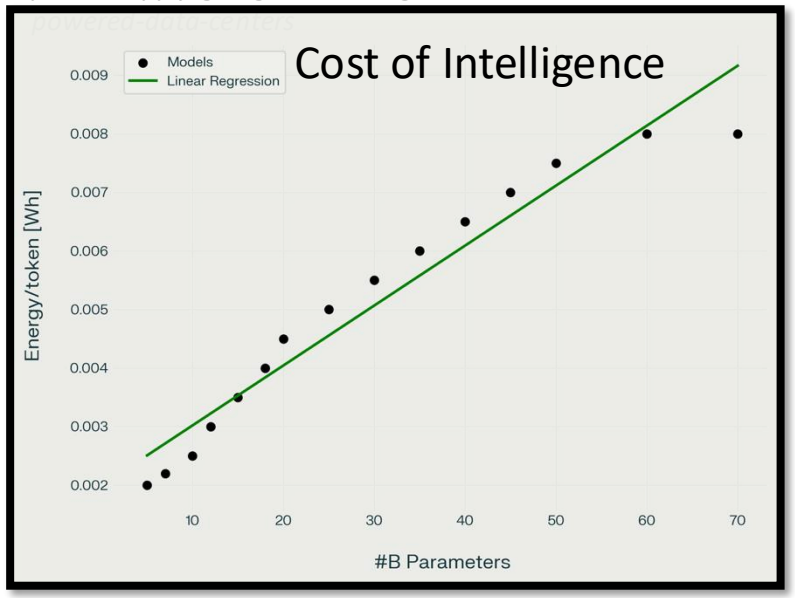


TU Wien, 2018

… Data Centers Now



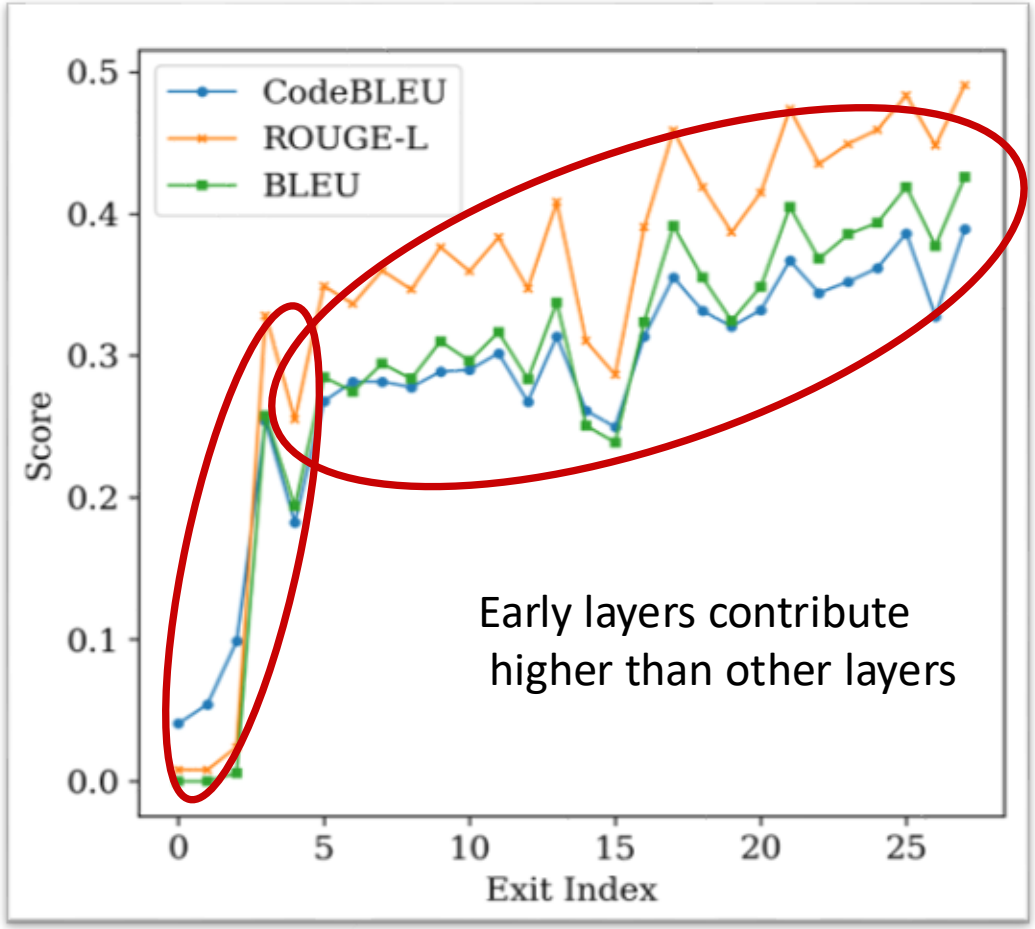
Source: https://www.datacenterknowledge.com/energy-power-supply/going-nuclear-a-guide-to-smrs-and-nuclear-powered-data-centers

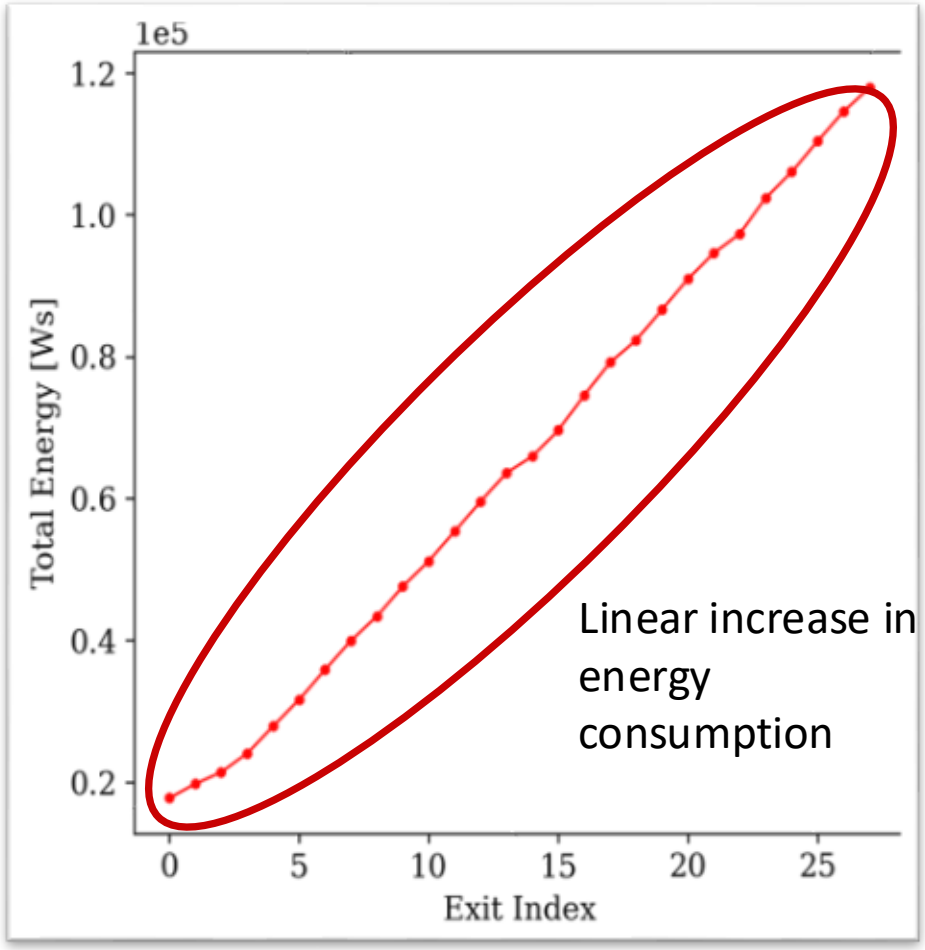




Source: https://www.datacenterdynamics.com/en/news/amazon-signs-deals-to-invest-in-nuclear-smrs-to-power-data-centers/

Exploiting LLM's Linear Increase in Energy Consumption





Performance vs energy-consumption Llama3.2-3B/Java, fixed exits

Triton: Transprecise Edge Grant-DOI: 10.55776/P36870

Themis: Trustworthy and Sustaianble Code Offloading Grant-DOI: 10.55776/PAT1668223



Slide: courtesy Shashi Ilager, University of Amsterdam

Source: Shashikant Ilager, Lukas Florian Briem and Ivona Brandic. GREEN-CODE: Learning Energy Efficient Code Generation in LLMs, 2025 IEEE 25th International Symposium on Cluster, Cloud and Internet Computing (CCGrid), May 19-22 2025, Tromso, Norway.

Where Static Placement Fails

Themis: Trustworthy and Sustainable Code Offloading Grant-DOI: 10.55776/PAT1668223

Triton: Transprecise Edge Grant-DOI: 10.55776/P36870



Smart Glasses / AR

On-demand visual querying with highly constrained batteries



Autonomous Robotics

Local perception now, cloud reasoning when needed.



Smart surveillance

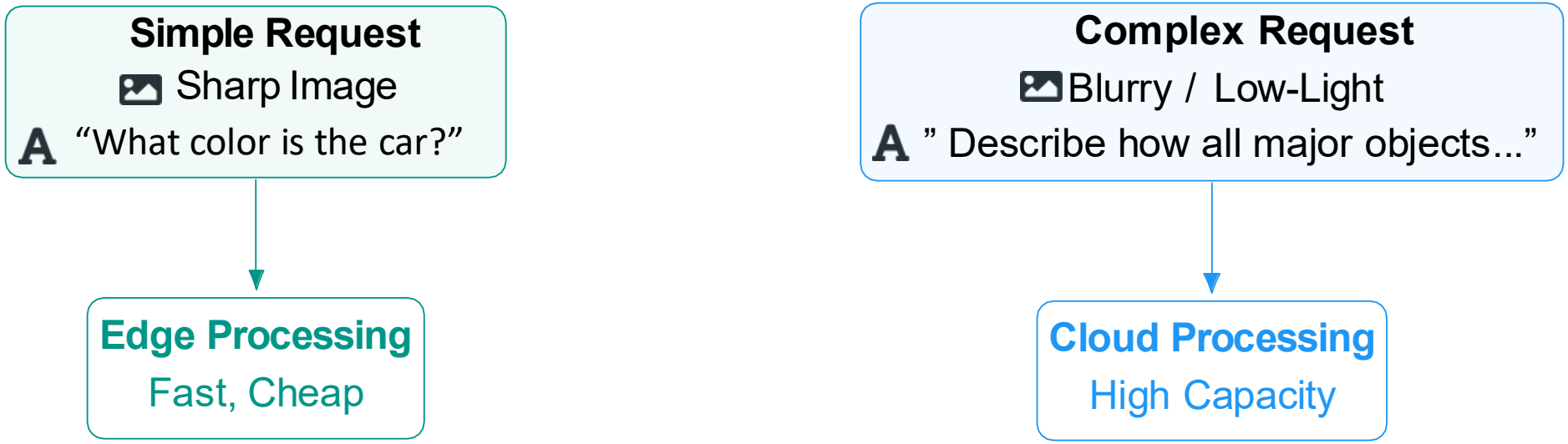
Unreliable links make adaptive offloading necessary



Slides courtesy Ahmed Šabanović (PhD student)
Based on paper „Ahmed Sabanovic, Paul Joe Maliakel, Ivona Brandic: INAR-VL: Input-Aware Routing for Edge-Cloud Vision-Language Inference. MobiSys Workshops 2026: 328-335"

Why Routing Matters

Multimodal inputs are highly variable.



The Problem: Static deployment or text-only routing ignores visual degradation, wasting edge resources on inputs that will fail anyway, or incurring unnecessary cloud latency on trivial tasks.

[Ding'24, Wang'24].

Typical VQAv2 question sets

Who is wearing glasses?

man



woman



Where is the child sitting?

fridge



arms



Is the umbrella upside down?

yes



no

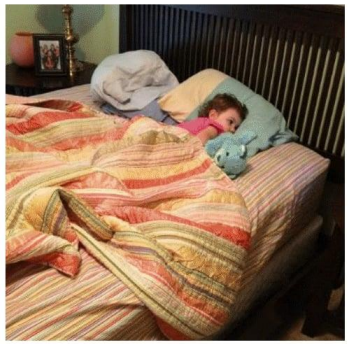


How many children are in the bed?

2



1



The Trade-off: Speed versus Accuracy

Edge-Only Execution*

~7.5 J **~820 ms**

- **Advantages:** Low latency, energy-efficient, fully local execution.
- **Limitations: Substantially Lower Accuracy** (~66.5%) on complex reasoning tasks and degraded images.

Cloud-Only Execution*

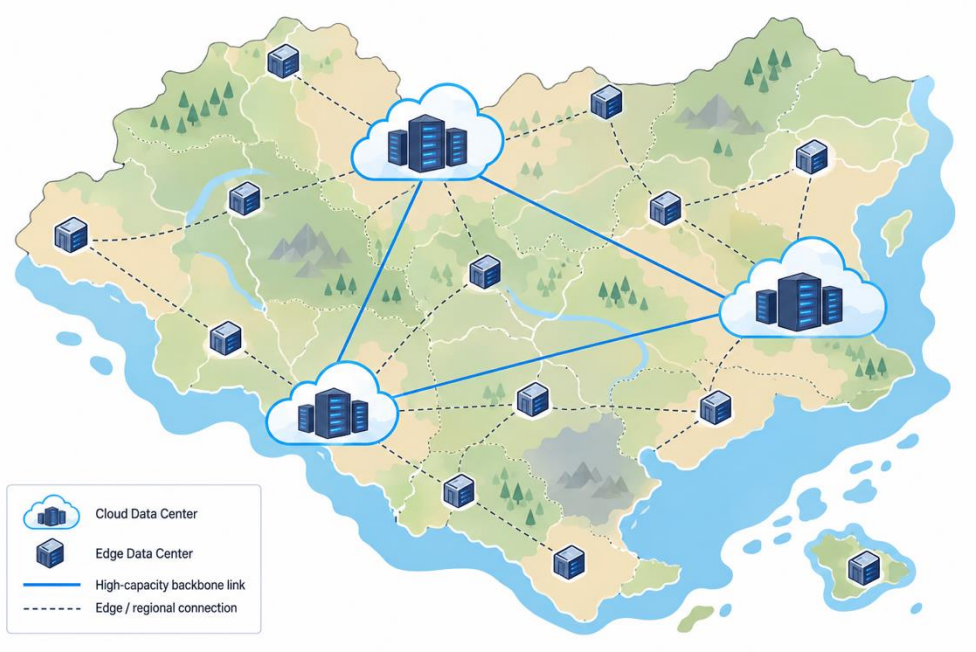
~26.0 J **~2400 ms**

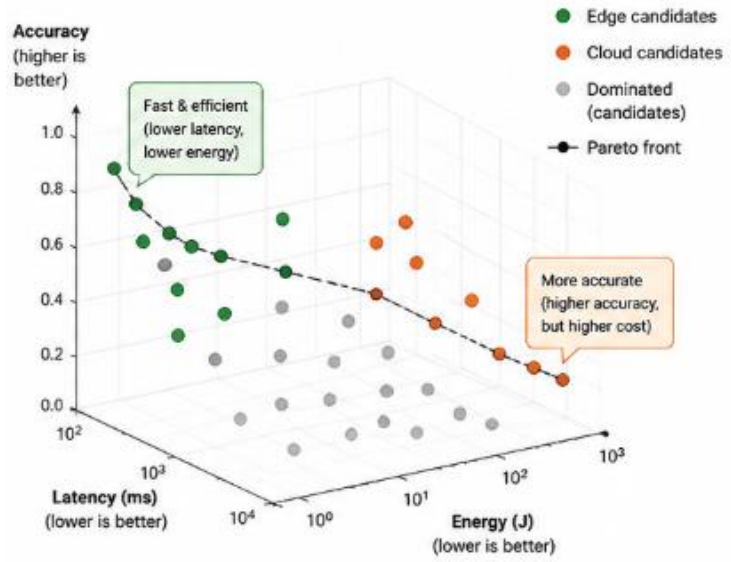
- **Advantages: Higher Accuracy** (~74.4%) from large-scale models.
- **Limitations:** Network-induced latency, elevated energy consumption, data transfer overhead.

Static placement forces a compromise. The goal is to recover both benefits.

**Evaluated on 2,000 samples across VQAv2, TextVQA, and GQA.*

Pareto Configuration Router





1. Query Complexity

Combines image degradation and text reasoning load.

2. Quality Estimate

Accounts for model capability mismatch and query difficulty.

3. Cost Estimate

Build Pareto frontier and select the lowest-cost configuration meeting quality requirements.

Whats next?









- Marie Curie Network **AEGIS — Adaptive Grid-Interactive Edge Datacenter Fleets**
- **Transform Data Centers from passive energy consumers to active gird stabilisation actors**
- through batteries, cooling, and adaptable computing — and that coordinate many sites into one **Virtual Power Plant**.

- https://aegis-dn.eu/positions/





ERICSSON

Imperial College London



LUNDS UNIVERSITET

DELL Technologies





tdc net

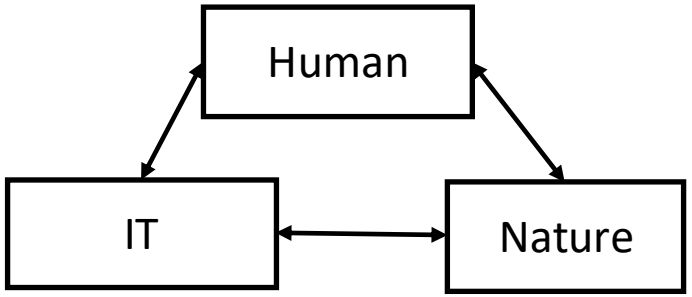
The 15 positions

DC	Project	Host	Country	Status
DC1	Grid Interface Control and Runtime Verification	Technical University of Denmark	Denmark	open
DC2	Grid-Interactive Thermal Flexibility for EDCs	École Polytechnique Fédérale de Lausanne	Switzerland	open
DC3	FPGA-Based AI Accelerator Options for Ultra-Low-Carbon Inference	École Polytechnique Fédérale de Lausanne	Switzerland	open
DC4	Carbon-Aware Digital Twins for Flexible EDCs	TU Wien	Austria	open
DC5	Privacy-Preserving Energy Flexibility Quantification for EDCs	Imperial College London	United Kingdom	open
DC6	Flexibility Modeling and Forecasting for EDC Fleets	Technical University of Denmark	Denmark	open
DC7	Carbon-Aware Neural Architecture Search (NAS)	Technical University of Denmark	Denmark	open
DC8	Grid-Aware AI Workload Mobility for the Computing Continuum	Technische Universität Berlin	Germany	open
DC9	Intent-Driven Power Management and Facilities Control	Lund University	Sweden	open
DC10	Privacy and Safety for Carbon-Aware Site-Level Workload Management	Dell Technologies (degree: Imperial College London)	Ireland	closed
DC11	End-to-End Energy Modeling for Distributed AI Services	Aalto University	Finland	open
DC12	Agentic Verification for Trusted Autonomous Operations	Technische Universität Berlin	Germany	open
DC13	Fleet-Level Workload Shaping with Live Grid Signals	Technical University of Denmark	Denmark	open
DC14	Energy-Efficient Full-Stack Development Toolchain for Energy-Aware AI Apps	Ericsson (degree: Aalto University)	Finland	open
DC15	Responsive Telecom Edge Sites Aggregated as Virtual Power Plants	TDC NET (degree: Technical University of Denmark)	Denmark	open

https://aegis-dn.eu/positions/

Computational Sustainability

Actors:





chist-era

Sustainable Watershed Management Through IoT-Driven Artificial Intelligence

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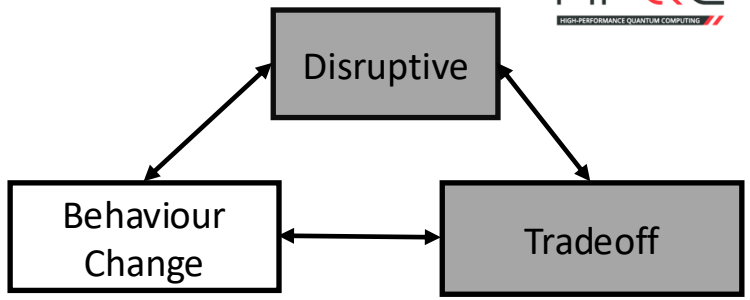


Virtual Shepherd



TRUST! Explaining the increasing energy consumption of IT infrastructures

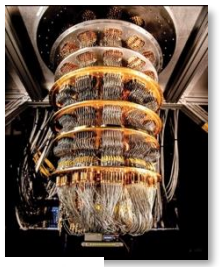
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FFG Forschung wirkt.

High Performance Integrated Quantum Computing



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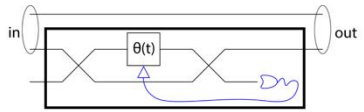
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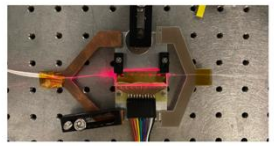
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WWTF: AI-supported Holographic Environmental Water Monitoring

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Themis: Trustworthy and Sustainable Code Offload

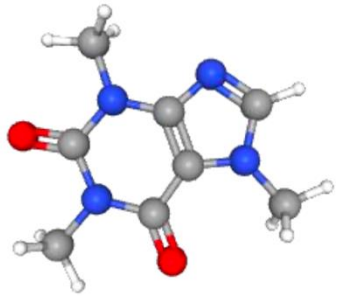
FWF

Triton: Transprecise Edge

WWTF: Advancing learning paradigms for photonic quantum processors

A cup of coffee?



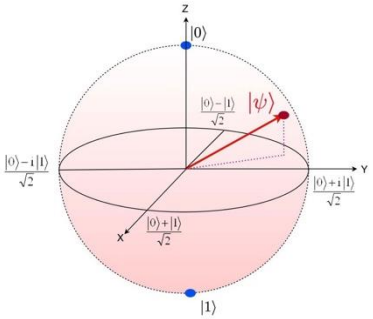




"Every time you add a qubit, you double your possible outcomes, With 20 qubits there are a million possible outcomes. With 100 qubits, you have more possibilities than there are bits in all the hard drives in the world. With 300 qubits—that's more possibilities than there are particles in the universe."

- Representing the energy configuration of a single caffeine molecule at a single instant requires approximately 10^{48} bits in a classical computer
- Can be done using 160 logical qubits on a quantum machine

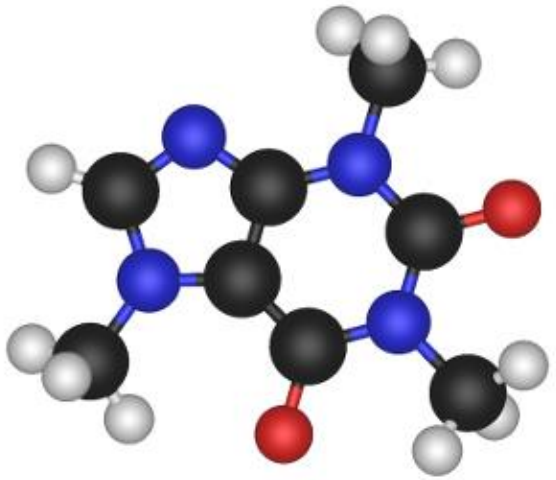
1 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 vs. 160



Courtesy Nico Einsiedler (IBM), TU Wien
Quantum Fall Fest 2022

https://quantum.duke.edu/2020/10/16/more-possibilities-than-there-are-particles-in-the-universe/

What can I do with quantum computer?



Vectors — lists of values

Matrices — tables of relationships

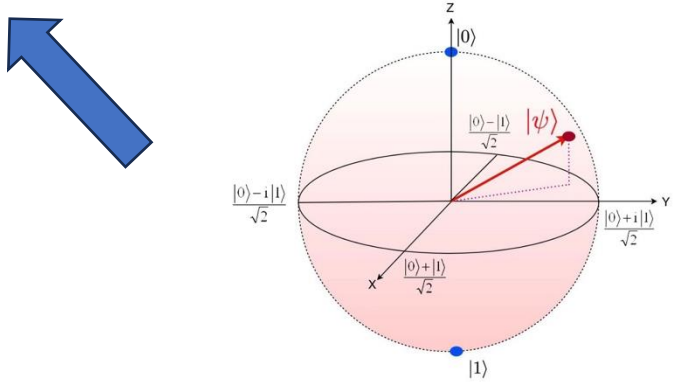
Tensors — multidimensional arrays

Matrix multiplication — transforming things

Eigenvectors and eigenvalues

3-d native modeling and computation

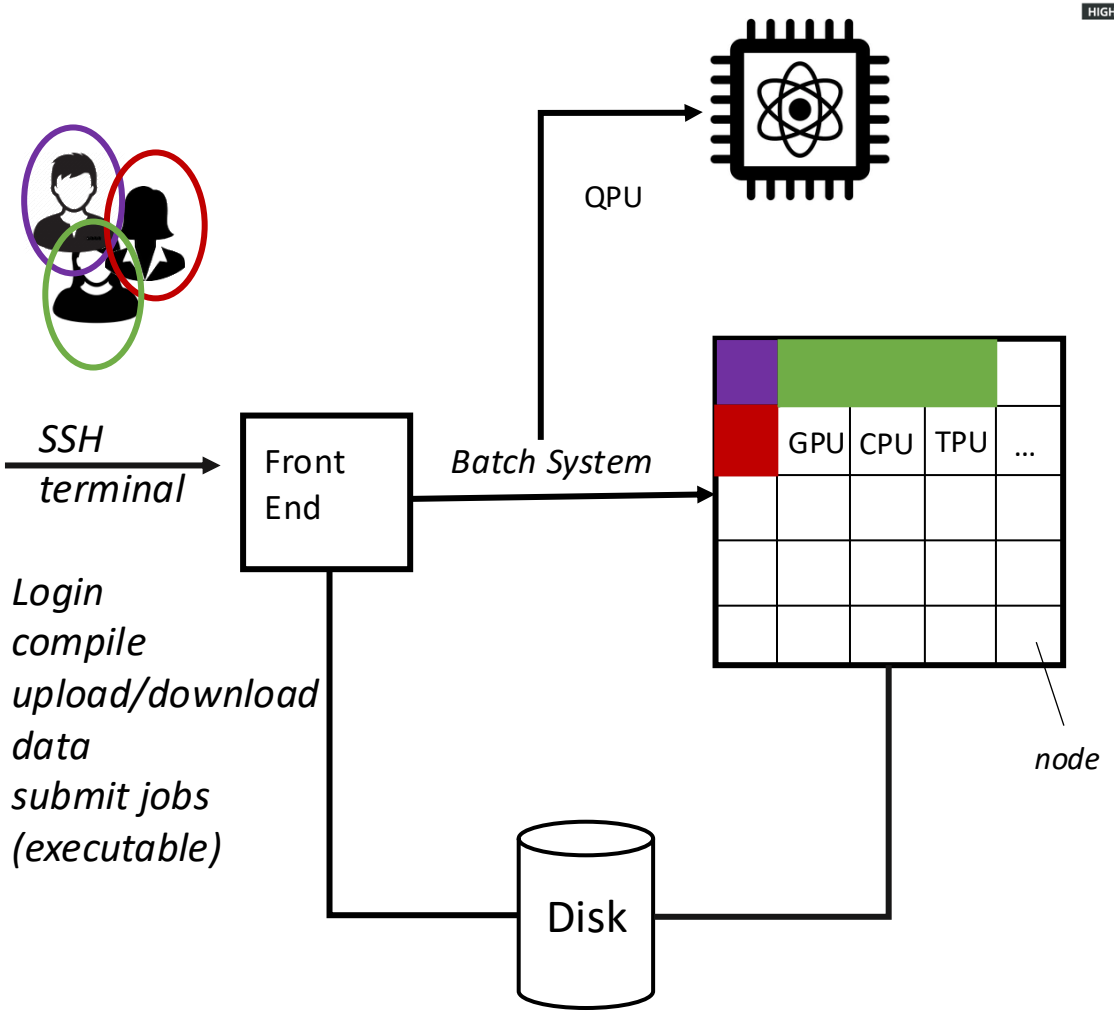
Linear Algebra



HPC Cluster



- Each “node” has its own operating system
- Nodes are interconnected with a network cable
- Higher performance demand more processors
- Accessed via front-end node/computer
- Shared with may users



- *Login*
- *compile*
- *upload/download data*
- *submit jobs (executable)*

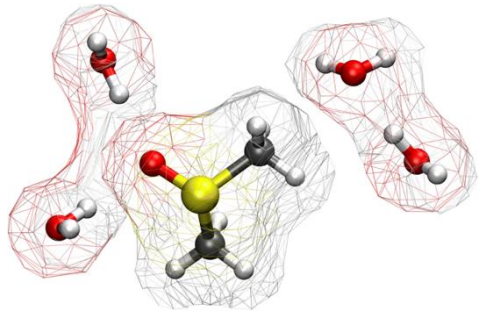
HPQC Cluster

FFG High Performance Integrated Quantum Computing
Grant ID: #4562957

HPQC HIGH-PERFORMANCE QUANTUM COMPUTING

- Improve QC performance
- Complement QEC capabilities
- Extend QC research with HPC

- Implement Hybrid Q-Libs
- **Benchmark PoC use-cases in hybrid infrastructure (HPC TU Wien)**





Direct access

Login console

HPC node

QC system



Circuit API



Offloading API

aconet



QML



S. Herbst



V. De Maio



M. Kanatbekova



F. Zilk

- → Best Paper Award at ISVLSI 2025
- → FGCS2024 Fall Editor's Choice Award
- → Dieberger-Skalicky Prize 2025
- → NetIdee Scholarship 2024
- → DISCOVER US Scholarship 2026

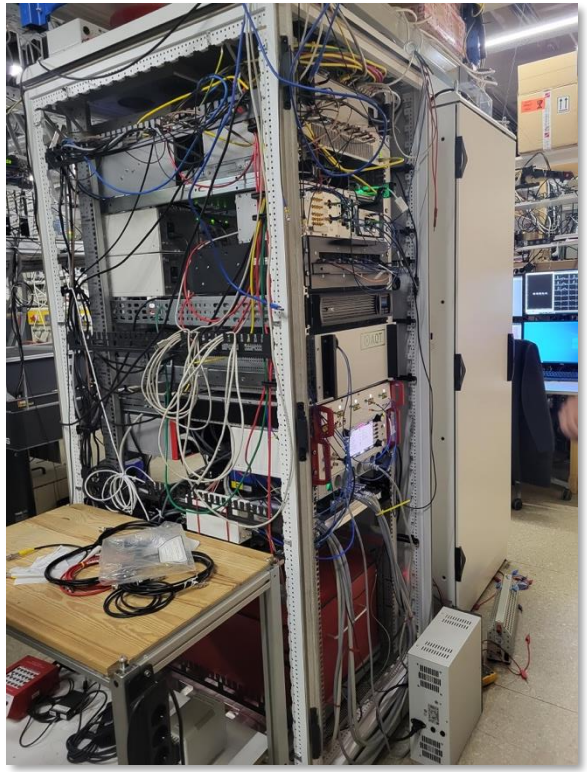
AQT JKU JOHANNES KEPLER UNIVERSITÄT LINZ universität innsbruck IBM MATH+TEC TU WIEN FFG Forschung wirkt.

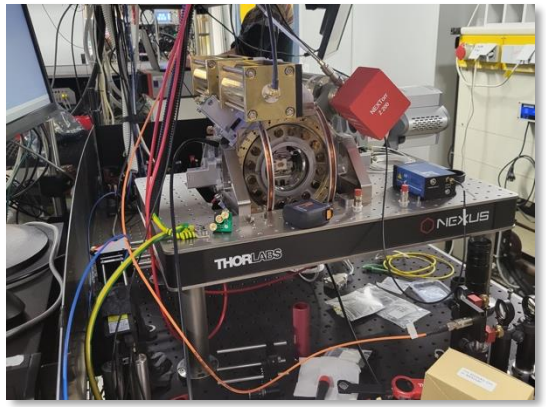
Assembly of a Quantum Processing Unit (QPU)



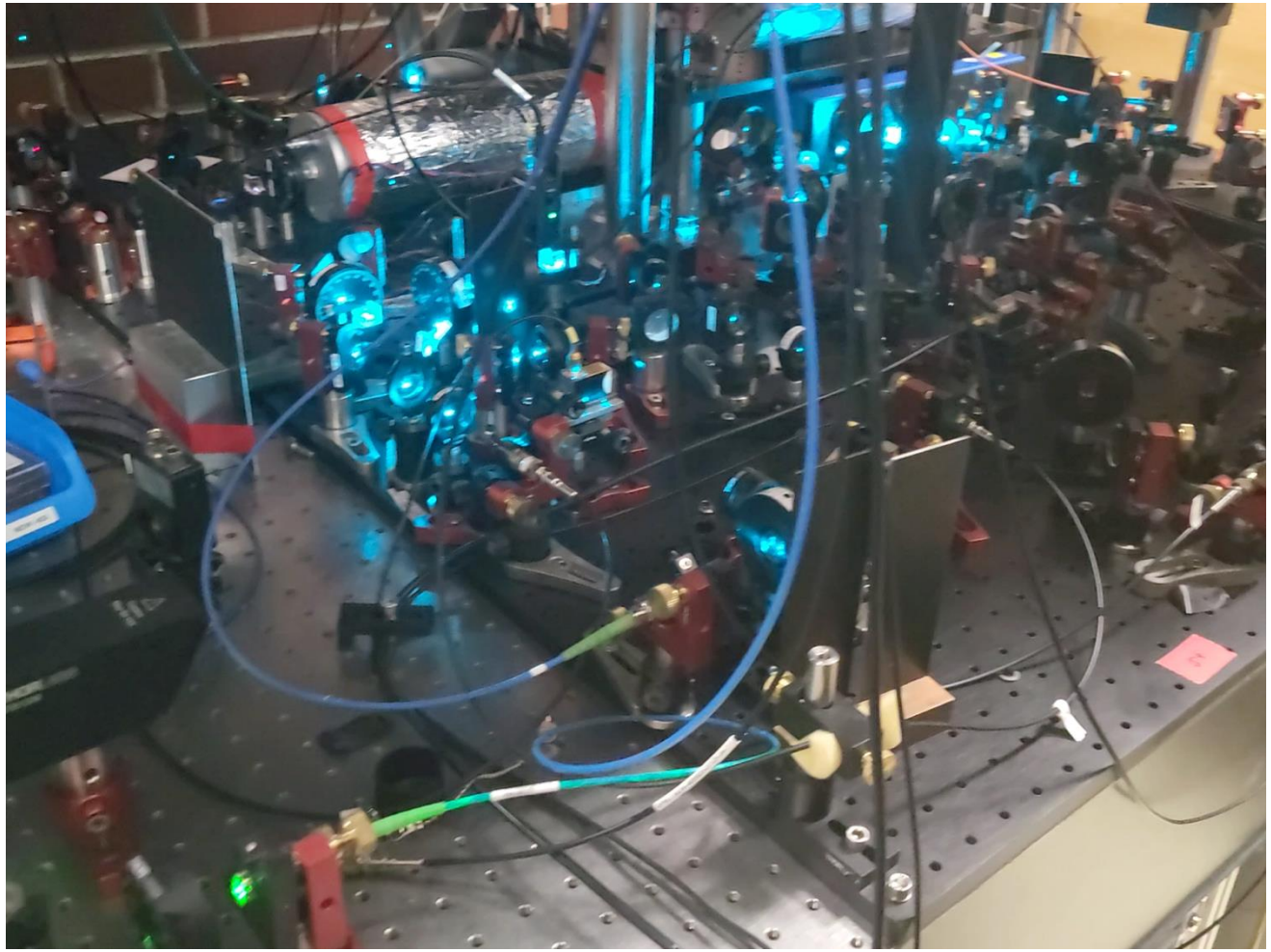
- Move from Ca+ to Ba+
- New system with
  stage 1: 10x higher T_1
  stage 2: infinit. Higher T_1
- 2q error rate:
  legacy: < 10^{-2}
  target: < 10^{-3}
- Init error
  legacy: < 10^{-3}
  target: < 10^{-4}
- Readout error
  legacy: < 10^{-3} -> ~ 10^{-4}
  target: < 10^{-5}

Picture: Courtesy AQT; Uni Innsbruck



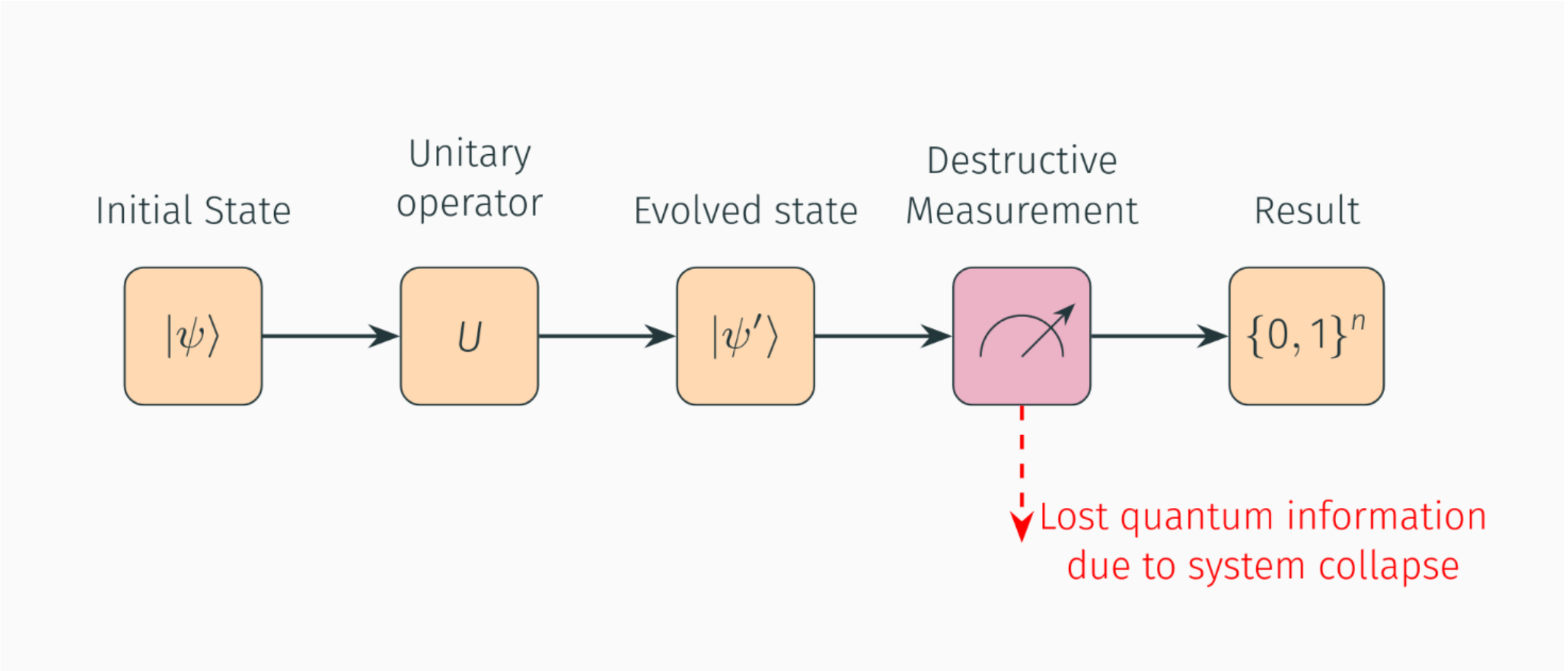


Ion-trap quantum computer



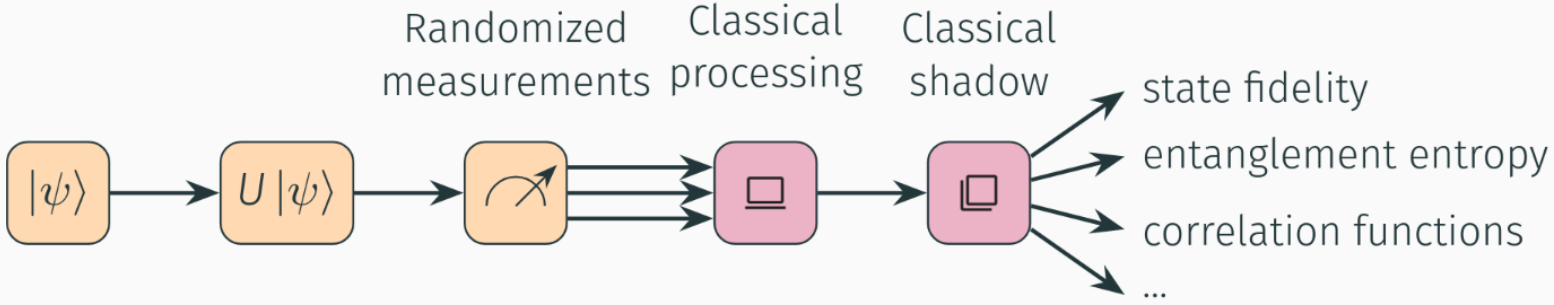
Courtesy Experimentalphysik, Univ. Innsbruck
Pictures, video: courtesy Vincenzo de Maio

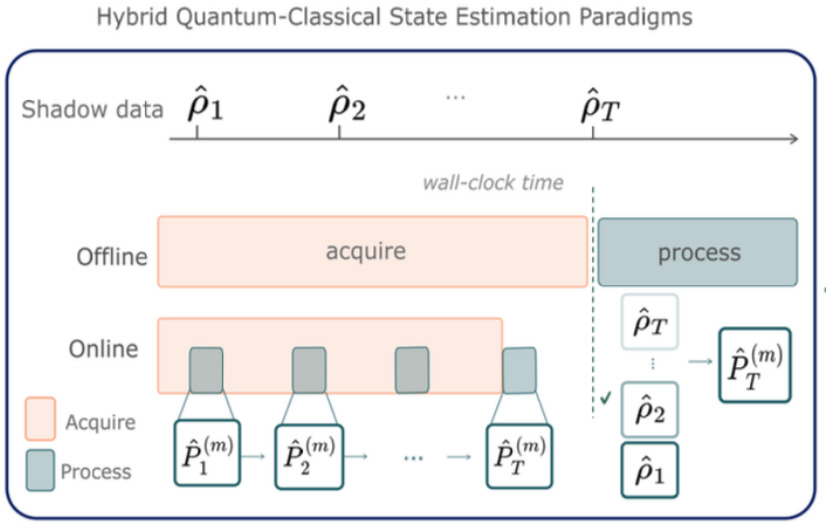
Destructive Measurements



Slide courtesy: S. Herbst

(Online) Classical Shadows



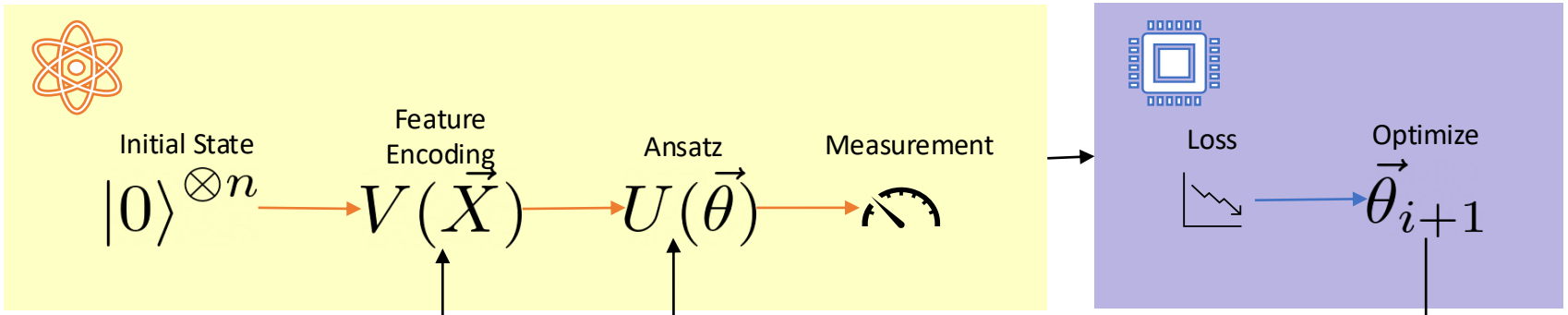


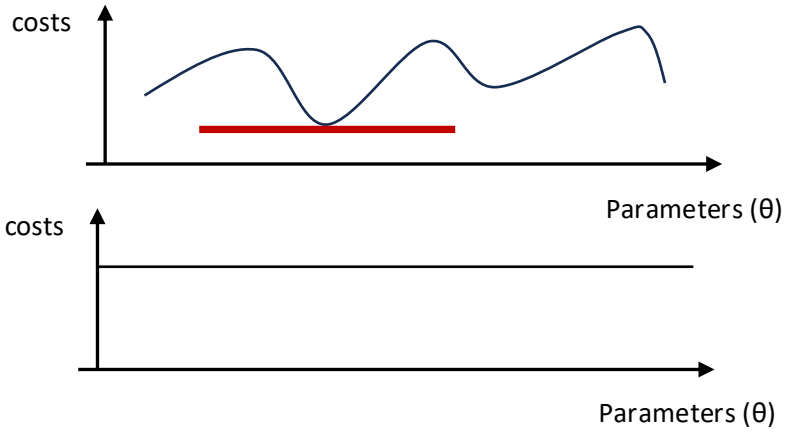
→ *turning entanglement detection from a purely offline diagnostic into a protocol that runs concurrently with the experiment*

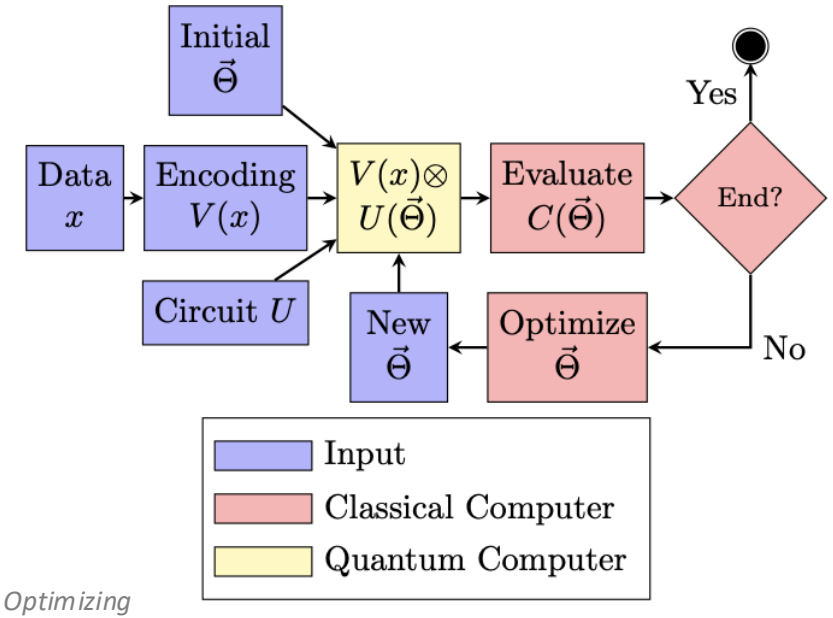
Source: Huang, HY., Kueng, R. & Preskill, J. Predicting many properties of a quantum system from very few measurements. Nat. Phys. 16, 1050–1057 (2020).

Source: Marwa Marso, Sabrina Herbst, Jadwiga Wilkens, Vincenzo De Maio, Ivona Brandić and Richard Kueng. "An Online Approach for Entanglement Verification Using Classical Shadows" https://arxiv.org/pdf/2603.26602

Quantum Neural Network (QNN)



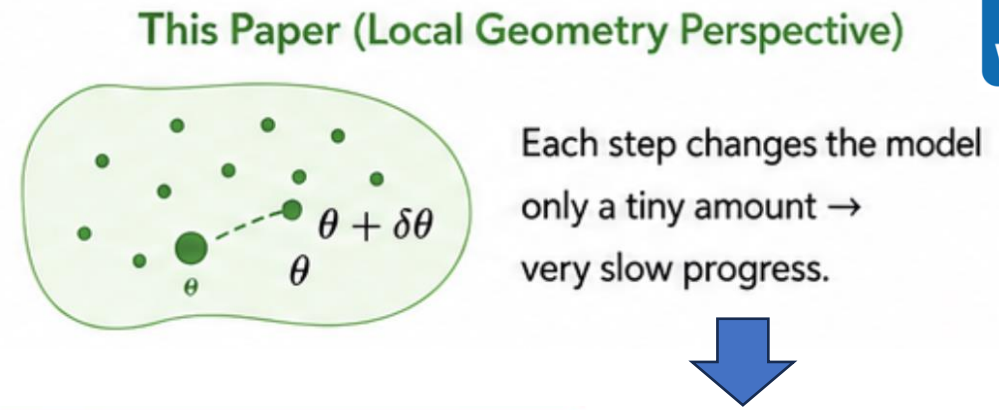


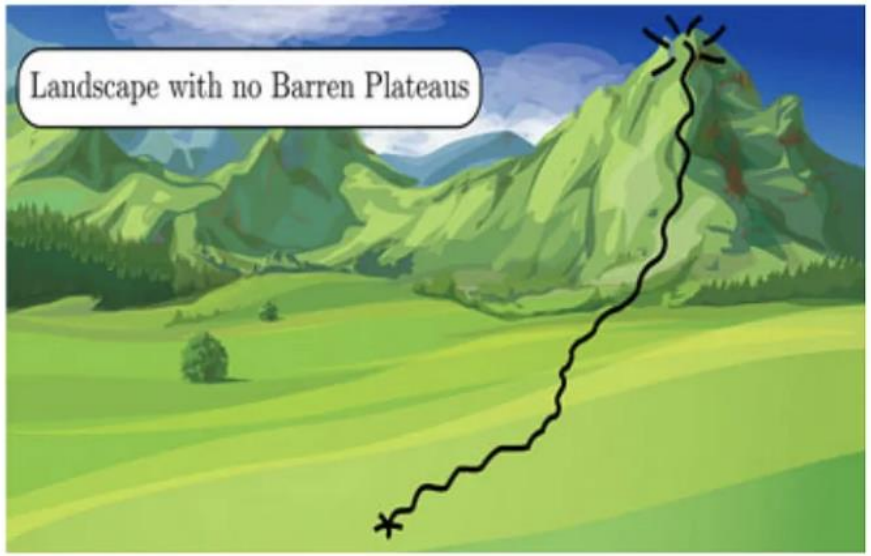


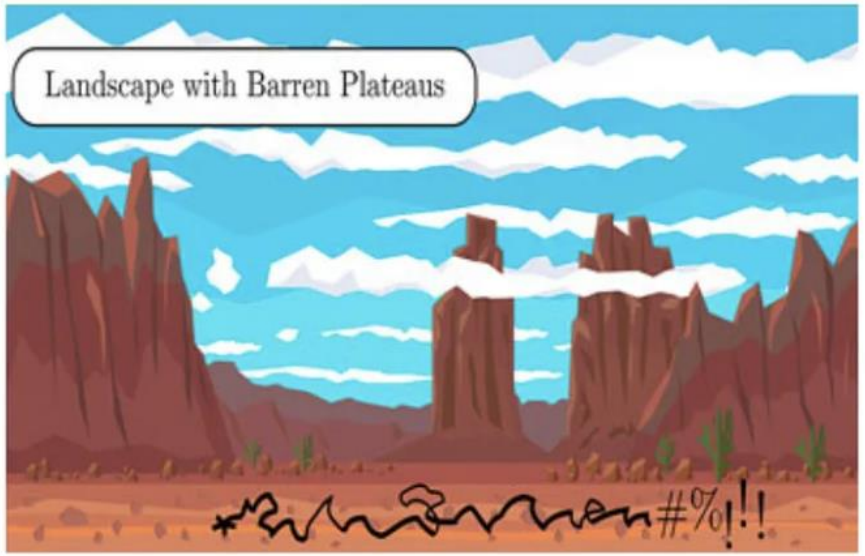
*Source: **Sabrina Herbst**, Vincenzo De Maio, Ivona Brandic: On Optimizing Hyperparameters for Quantum Neural Networks. QCE 2024: 1478-1489*

Slide courtesy: S. Herbst

Barren Plateau







Source: https://medium.com/@deltorobarba/can-quantum-computing-accelerate-generative-ai-b1df36398ac5

*Source: **Sabrina Herbst**, Sandeep Suresh Cranganore, Vincenzo De Maio, Ivona Brandic: Exploring channel distinguishability in local neighborhoods of the model space in quantum neural networks. ICLR 2025*



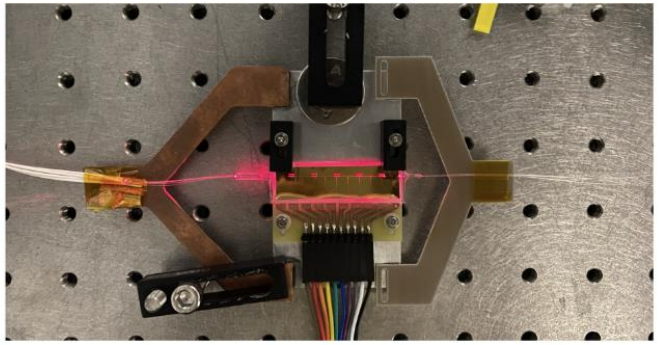
Sabrina Herbst

optimization landscape

- gradient of the cost function with respect to the circuit parameters becomes **exponentially small** as the system size increases.
- **training the model extremely difficult**, as gradient-based optimization essentially stalls—similar to being stuck on a flat, featureless desert with no clear direction to go.

Whats next?

- **Non-linearities**
  - Occur very often in ML
  - **Activation functions in neural networks (e.g sigmoid)**
  - Kernel methods
  - Attention mechanisms and transformers
- Solution: photonic memristors



Picture courtesy: Philip Walther (Uni Wien) & team



Philip Walther, Uni Wien



Ivona Brandic, TU Wien



Vincenzo de Maio, TU Wien & Uni Leicester



Martin Mauser, Uni Wien



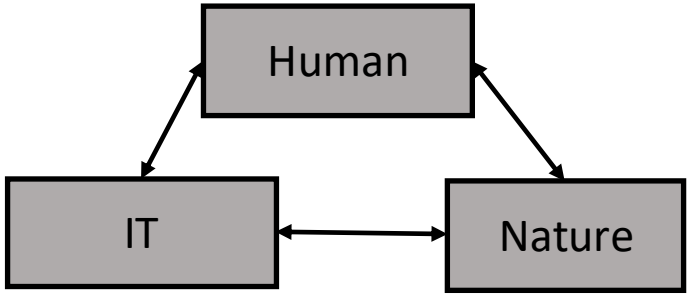
Iris Agresti, Uni Wien

ALPAQA: Advancing learning paradigms for photonic quantum processors

https://www.wwtf.at/funding/programmes/ict/ICT25-062/

Computational Sustainability

Actors:



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Sustainable Watershed Management Through IoT-Driven Artificial Intelligence

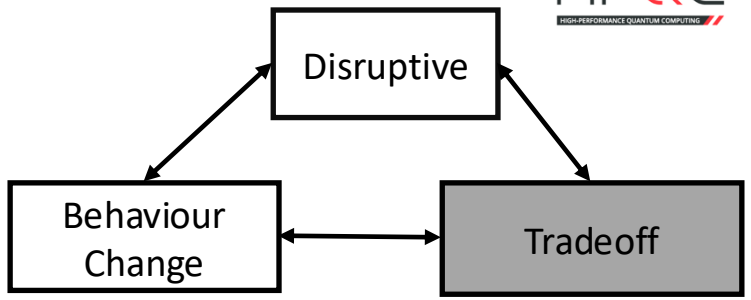
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Virtual Shepherd

TRUST! Explaining the increasing energy consumption of IT infrastructures

Methods:



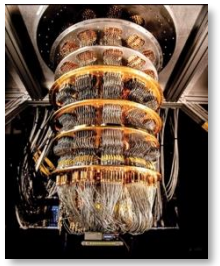
Doctoral College Computational Sustainability

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

HPQC HIGH-PERFORMANCE QUANTUM COMPUTING

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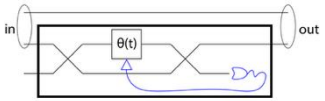
High Performance Integrated Quantum Computing

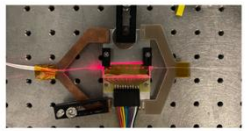


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Quantum Algorithm Enginering COMET Module

MARIE CURIE ACTIONS





W|W|T|F

WWTF: Advancing learning paradigms for photonic quantum processors



W|W|T|F

WWTF: AI-supported Holographic Environmental Water Monitoring

FWF

Themis: Trustworthy and Sustainable Code Offloading

FWF

Triton: Transprecise Edge

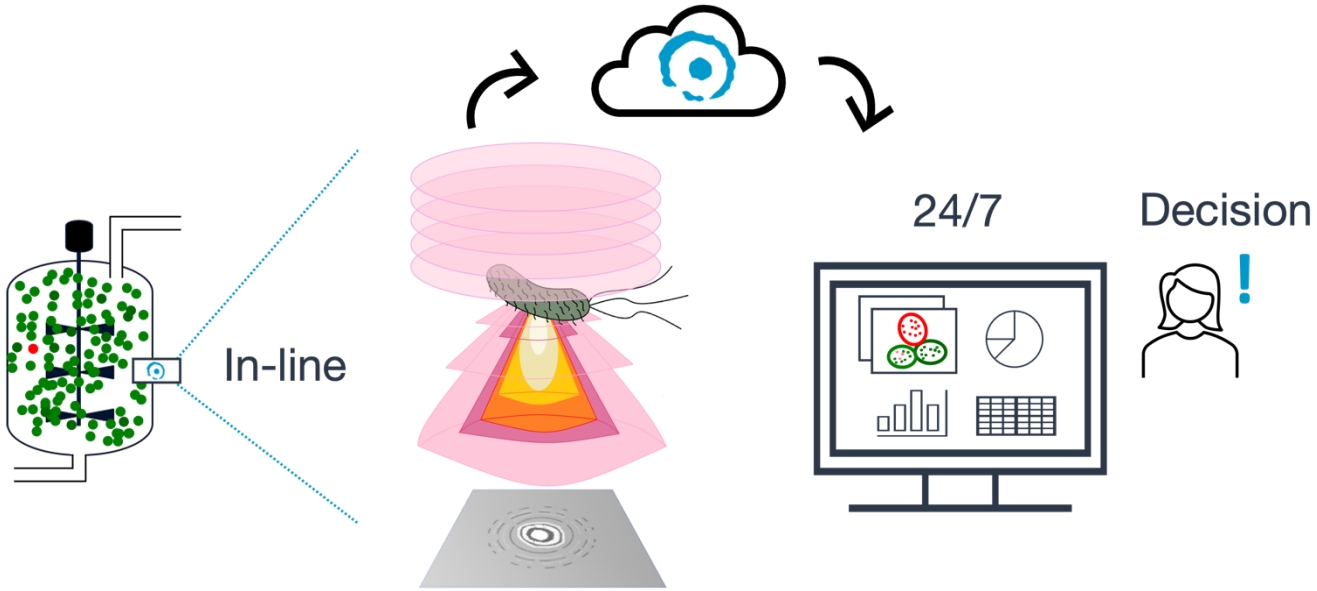

Wasserversorgung der Stadt Wien
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Wasserwerk Nußdorf
WIEN
Wasserwerk Lobau
St. Pölten
II. Wiener Hochquellenleitung
Mödling
III. Wiener Wasserleitung
Wasserwerk Moosbrunn
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Wasserleitungen
Schutz- und Schongebiet
Grafik-Wiener Wasserwerke

Holographic microscopy

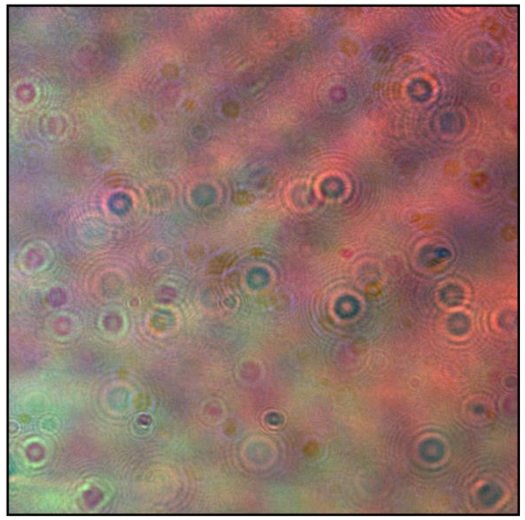


WWTF

 # ESR24-053
AI-supported Holographic Environmental Water Monitoring



- Our device has the size of a shoebox
- It collects liquids and shines light through them
- Some light is scattered by any particles inside
- The illuminating and scattered light interfere forming holograms that are recorded by a camera
- The preprocessed images and sent to the cloud
- The light in the volume is numerically reconstructed to ~500 images in a stack
- The total volume of view is ~1M times that of a conventional microscope
- Proprietary algorithms boost the contrast and resolution
- The whole platform provides real time microscopic monitoring



Slide: courtesy Peter van Oostrum, Holloid, BOKU Wien

Holloid
Big data on small things

universität wien
Faculty of Earth Sciences, Geography and Astronomy

Department of Geography and Regional Research
Digital Transformation
SSDT HUB

Sustainability and Digital Transformation Lecture (VO 290605)

Join this lecture to explore how sustainability and digitalization shape our world through geographical perspectives, interdisciplinary insights, and engaging talks by experts.

Mondays 16:45 - 18:15 - Link to join



Date	Speaker	Topic
19 Oct 2026	**Tanja Spennlingwimmer** AWS - Austria Wirtschaftsservice Gesellschaft mbH	Beyond Sustainability? Digital Transformation as a Driver for Change
09 Nov 2026	**Caroline Michellier** Royal Museum for Central Africa in Belgium	Citizen Science - Data Collection with Citezens in Data-Scarce Context
16 Nov 2026	**Rodrigo Conde-Jimenez** AIT – Austrian Institute of Technology	Ethics and the Regulation of Artificial Intelligence in a European context
23 Nov 2026	**Jonathan Donges** PIK - Potsdam Institute for Climate Impact Research in Germany	Earth System Modelling Focusing on Tipping Elements in the Earth System and Human-Earth System Interactions
30 Nov 2026	**Lina Stein** Rheinland-Pfälzische Technical University Kaiserslautern-Landau	Knowledge Accumulation in Science (LLM use)
07 Dec 2026	**Aydoğan Avcıoğlu** BRGM - French Geological Survey	Data Extraction Validation From Grey Literature
14 Dec 2026	**Ivona Brandic** TU Wien – Vienna Technical University	Sustainable Computing
11 Jan 2027	**Liuhuaying Yang** Complexity Science Hub	Creating Interactive Data Visualization for Communicating Scientific Results
18 Jan 2027	**Norbert Marwan** PIK - Potsdam Institute for Climate Impact Research	Complex Systems Methods for Analysis of Spatial Data
25 Jan 2027	**Emilia M. Bruck** TU Wien – Vienna Technical University	Planning and Sustainability Considerations of Data Centers as Critical Infrastructure of Digitization

Join us!



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Start
30 November 2026

End
1 December 2026

Category
Symposium

Venue
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More Information
https://www.h-its.org/research/cme/

- Ivona Brandic, Technical University of Vienna, Austria
- Sophie Cerf, Inria Center of the University of Grenoble Alpes, France
- Florina M. Ciorba, University of Basel, Switzerland
- Thaleia Dimitra Doudali, IMDEA Software Institute in Madrid, Spain
- Loïc Lannelongue, University of Cambridge, UK
- Matteo Mendula, Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT), Turin, Italy
- August Ning, Swiss Federal Technology Institute of Lausanne (EPFL), Switzerland
- Emma Strubell, School of Computer Science, Carnegie Mellon University, USA
- Klervie Toczé, Vrije Universiteit Amsterdam, The Netherlands

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cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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QUANTUM AUSTRIA

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SFG

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Bundesministerium Frauen, Wissenschaft und Forschung

MARIE CURIE ACTIONS

