Research on AI and networking at CNR-ISTI

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Consiglio Nazionale delle Ricerche

Institute of Information Science and Technologies (ISTI)

- Located in Pisa, Tuscany
- Largest CNR institute on **Computer Science** (around 300 staff, including fellows and PhD students)
- Pursues excellence in **scientific research**, technology **transfer** (Research Infrastructures), and **training/education** (PhD, master thesis)
- Active on **international** and national **projects** (95 active proj, external funds 5ME/y, EC funds are around 50%)
- >350 internat. publications per year
- Scientific activity is organized into 13 ***research laboratories***, covering several computer science topics

Research themes and trends at ISTI

- **AI**, both foundational (trust/explain) & applied, transversal to most of ISTI research labs;
- **Visual** tech: interactive and immersive, VR/XR, recognition, architectural design, structural assessment;
- **System design**: SW Engineering & formal methods, HCI, sensors & communications, autonomous driving;
- **Inform Retrieval**: optimized search, green AI, cross-modal (text+visual) search & recognition;
- **Networking**: resource and management optimization, AI-based networks automobilization, architecture design for wireless technologies integration;

Application domains:

- Health&Wellness, Cultural Heritage, Mobility, Ecology, Agriculture…

Exploring AI in different domains at ISTI

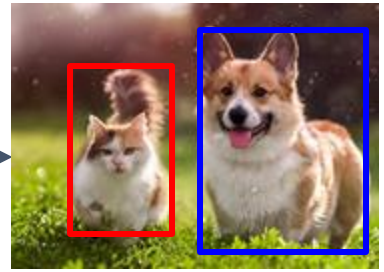
(all but networking)

AI-Supported Vision and Language Processing

Struggle to **understand fine-grained differences** (white dog vs black dog)

long fur cat, dog, colored parrot, drawer

Detection model



Struggle to **understand the prompt** (tend to count non-existent objects)

strawberries

Counting model

16

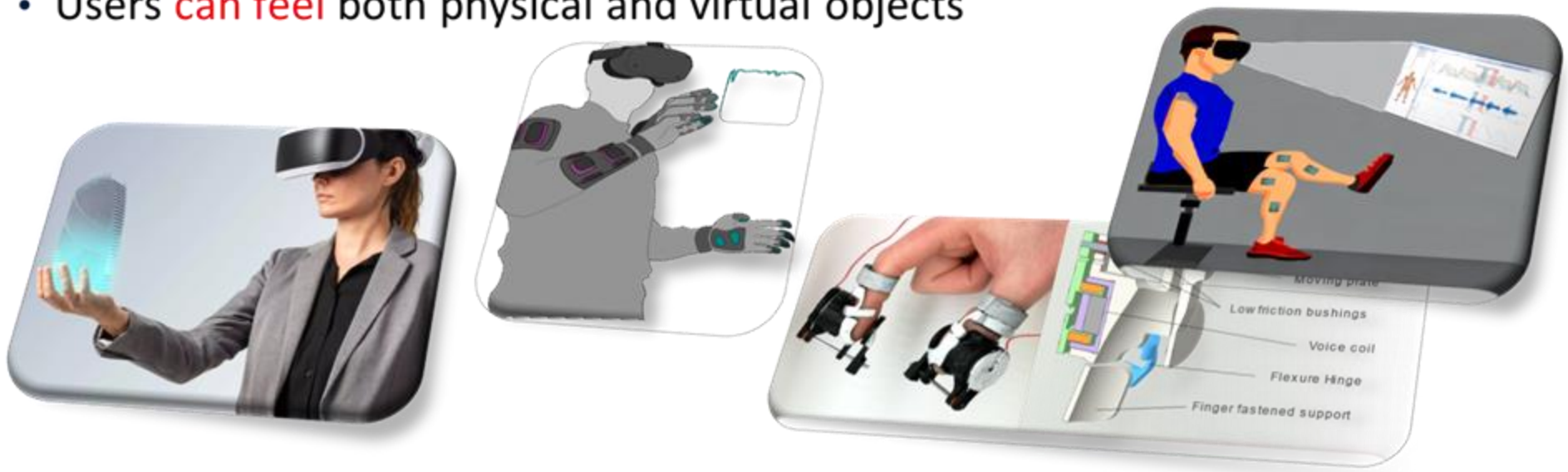
Cross-Modal Video Retrieval Syst.: system design for fast and effective video search on a large-scale dataset.

VISIONE https://visione.isti.cnr.it

AI for Extended Reality

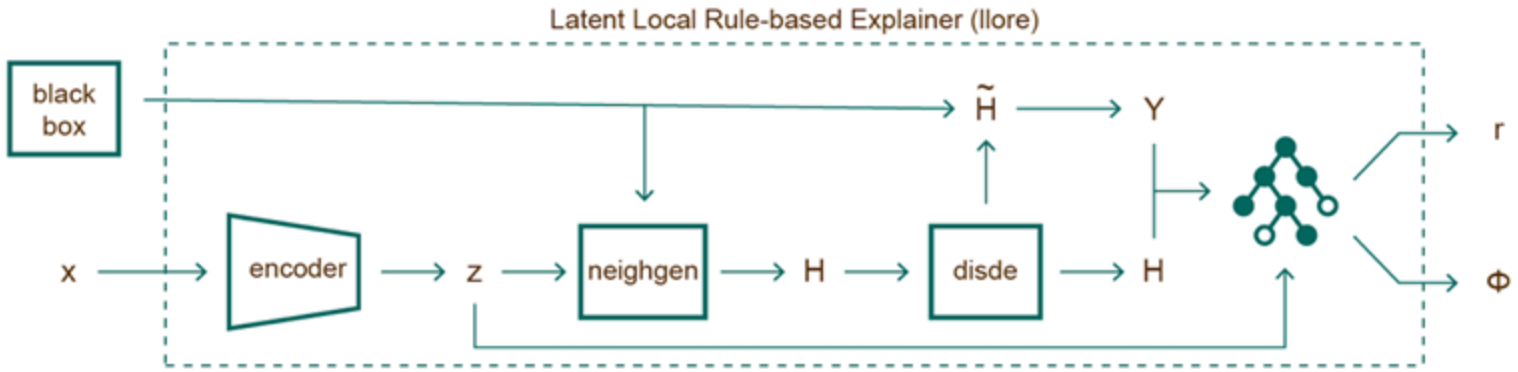
Social and hUman ceNtered XR

- Virtual objects have physical properties (material/weight/temperature…)
- Sensors transfer data from physical to virtual world
- Users can feel both physical and virtual objects



https://www.sun-xr-project.eu/

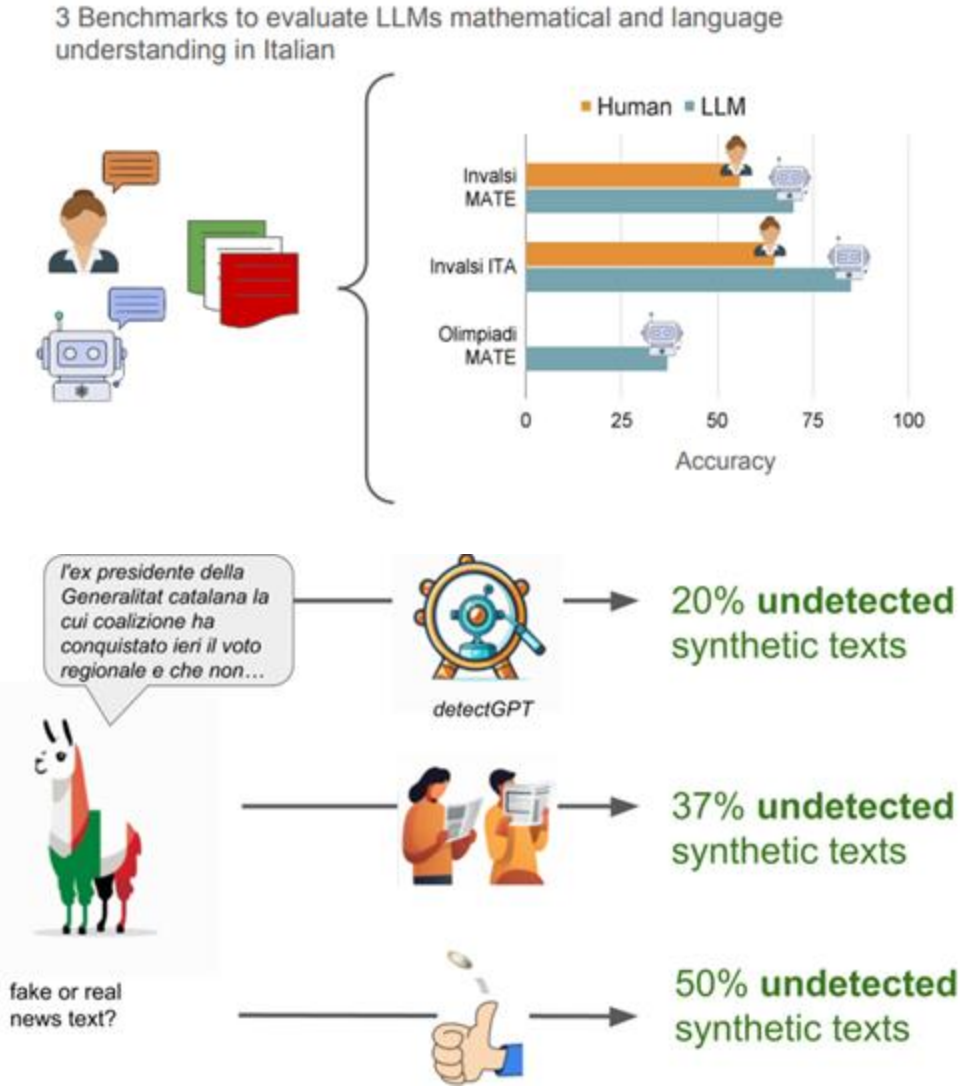
eXplainable AI to improve Trust in AI-DSSs



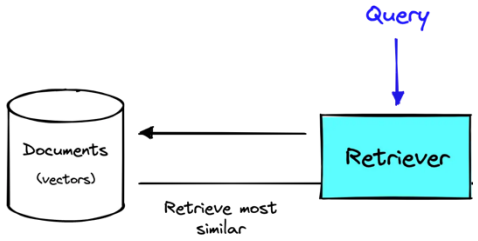
- Using Generative AI to create explanations in the form of exemplars and counter-exemplars.
- Rules are generated in a latent space to capture features relevant for the Black-Box
- Rules are used to generate synthetic images
- User study to assess how explanations improve trust towards AI model

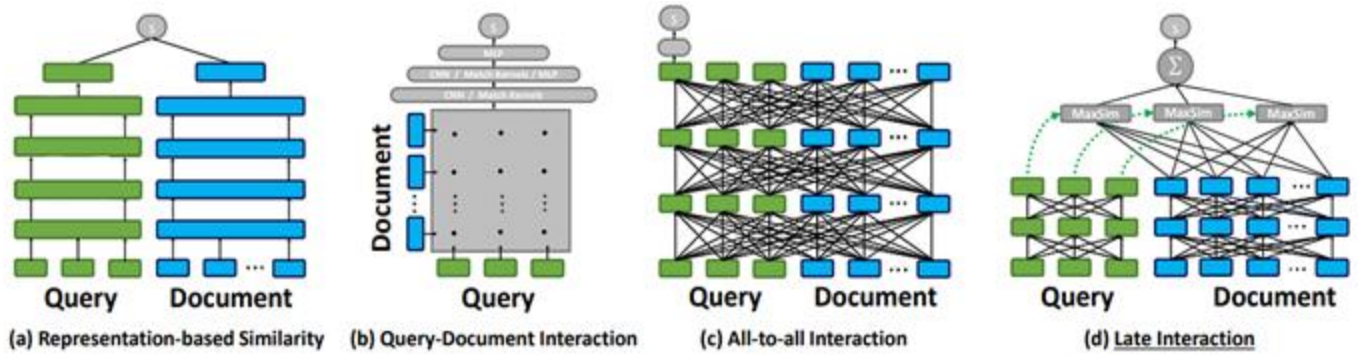
Large Language Models

- **Training**: methods for the adaptation of tokenizers to new languages/domain, with sensible speedup improvements in inference
- **Evaluation**: new datasets for the evaluation of language and mathematics skills of LLMs, linked to evaluation campaigns of students
- **Authorship Analysis** (cultural heritage, cybersecurity, computer forensics)



Efficient AI for Information Access and Retrieval



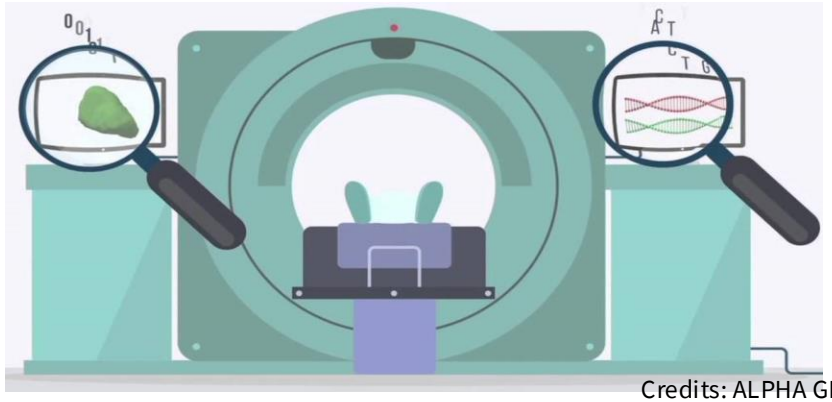


State-of-the-art neural retrieval models: **dense retrievers, late-interaction models, and sparse representation approaches.** They leverage deep encoders to achieve high effectiveness and address the vocabulary mismatch problem.
High-dimensional embeddings, leading to large indexes, high memory usage, and latency overhead.
Our research focuses on designing efficient, practical techniques for text IR, including compressed/distilled LLM-based models, compact learned representations, and advanced caching strategies.

- Dimensionality reduction of dense text representations for improved retrieval quality/efficiency
- Hybrid search with sparse representations (trading off slight effectiveness loss for substantial efficiency gains)
- Client-server solutions for conversational agents (trading off slight effectiveness loss for substantial efficiency gains)

AI for Health and Wellbeing

Visual Intelligence to support **image-based diagnosis and prognosis**



Credits: ALPHA GRID

Assistive technologies for **computational physiology** and **healthy living**

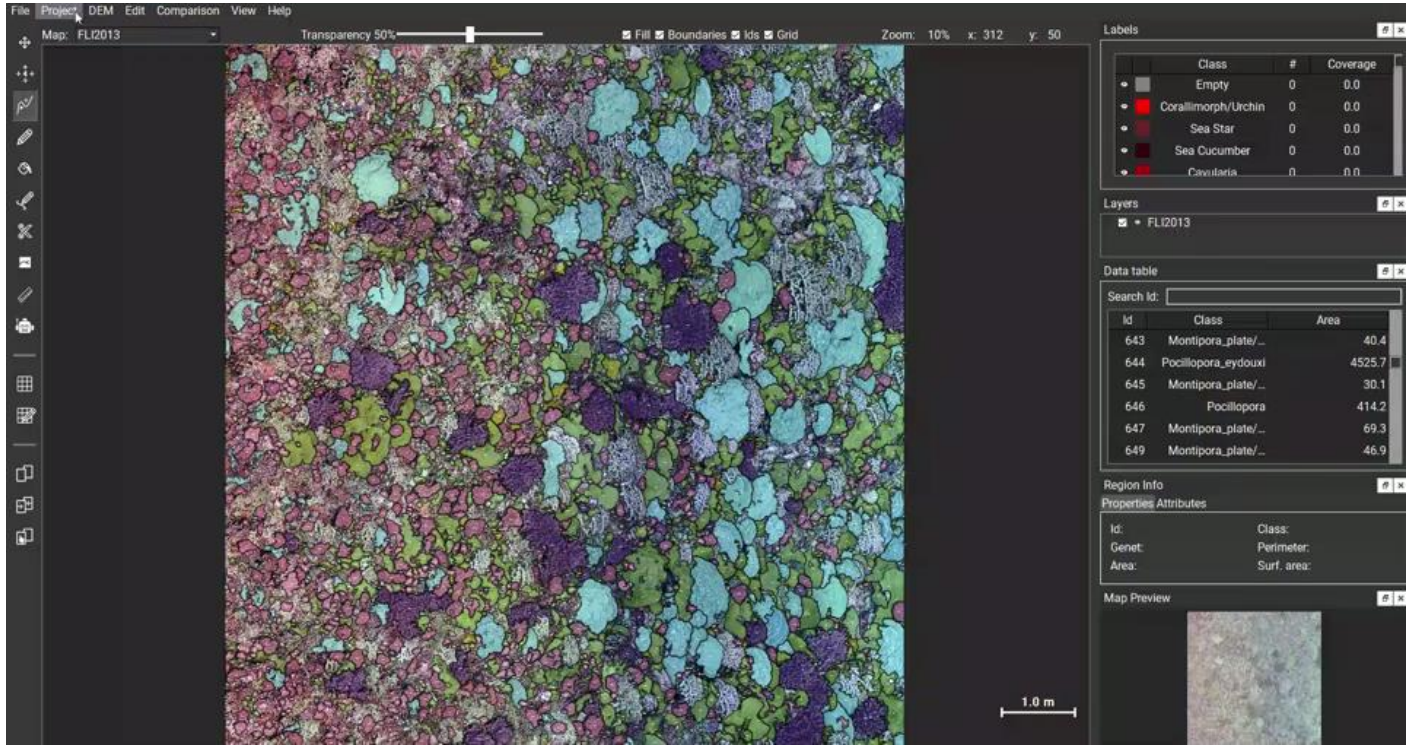
Providing **quantitative & repeatable** support to radiologists toward the so-called **precision radiology, personalized medicine**

Personal devices to **self-monitor** or **remotely monitor vital parameters** for a long-lasting wellbeing and quality of life of individuals

AI for Environmental Monitoring

- Automatic and semi-automatic solutions to enable **large-scale image sampling (remote sensing, drones)**

- Our solutions are based on:
  - Intelligent interactive systems (Human-centric AI)
  - Geometry processing
  - Computer Graphics and Computer Vision
  - Computational Physiology
  - Computational Biology



TagLab: an interactive AI-based solution for understanding and characterizing large image samplings (ex. of coral reefs) http://taglab.isti.cnr.it

Research on AI for Networking

AI for Networking

ISTI - Wireless Network lab active on:

- **Networking Paradigms Design**

  Paradigms design for distributed networks, distributed computing, and telemetry infrastructures

- **NTK for Analysis and Design of AI-Powered Networking**

  Application of theoretical tools for the analysis and design of the stability and trainability of NN-based networking systems

- **Intent-Based Networking**

  Algorithm design for automatic operational control and maintenance operations of the network based on human prompts

Network Intelligence Lab

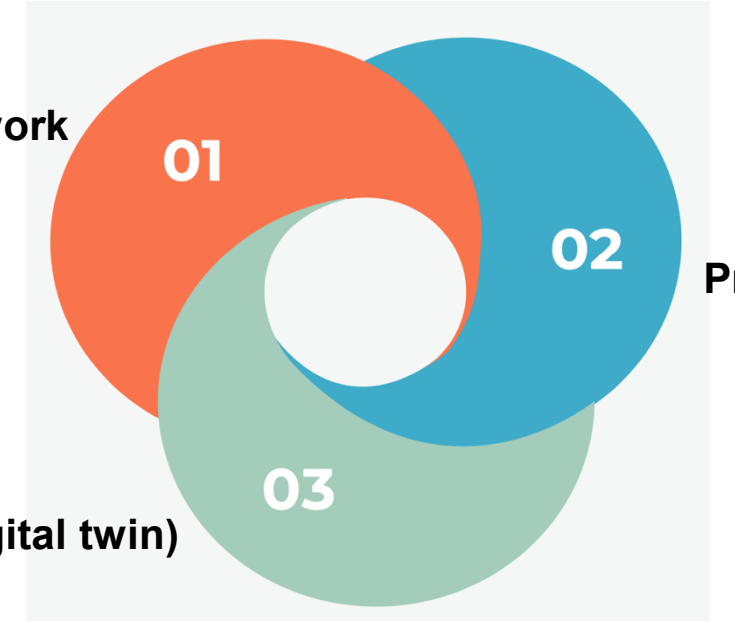
AI for Networking: Network Evolution

- ✓ The telecommunications industry is evolving with the development of **high-speed** wireless communication networks based on **multi-technology integration**, such as 5G and NTN
- ✓ The Third Generation Partnership Project (3GPP) is spending much effort on the standardization of new 5G core functionalities and features
- ✓ Features include service-based architecture, improved quality of service, enhanced machine-to-machine communications, cloud-native technologies, and access to edge computing

AI for Networking: Advantages and Challenges

- ✓ A notable feature of new generation networks is **AI for Networking**
- ✓ The telecommunication industry is expected to **invest heavily** in AI for network management and optimization now, and until the next decade
- ✓ AI offers benefits such as:

Proactively improving network performance



Prediction of the network state

Providing models of the infrastructure behavior (digital twin)

AI for Networking: The Role of the Analytics

AI needs data ➔ analytics

How analytics could help us?

- ✓**Traffic generated by services running over the network can be analyzed to produce reliable models which could reduce the overhead associated with data collection**
- ✓**Generative AI methods like Generative Adversarial Networks (GANs) and Variational AutoEncoders (VAEs) can be used to learn characteristic patterns and reproduce them synthetically (approximating digital twins)**

Challenges in Data Collection:

- ✓ **Capturing high-volume and high-velocity data in the core network involves non-negligible costs**
- ✓ **Data collection can perturb user data traffic (threshold among completeness and minimizations)**
- ✓ **Information coming from heterogeneous infrastructures such as the 5G Control Plane and User Plane**

AI for Networking: Support from the Architectural Design

Networking Paradigms Design & AI

- **SRv6-enabled data plane** for scalable and programmable network architectures
- **Latency-aware communication mechanisms** to optimize interaction among distributed network resources
- **In-band and out-of-band telemetry frameworks** for efficient monitoring of large-scale distributed systems (**IFIT** protocol)
- **Interoperability** and **integration** with heterogeneous technologies (e.g., **5G, Non-Terrestrial Networks**)

AI for Networking: Model Analysis

Neural Tangent Kernel - NTK for Analysis and Design of AI-Powered Networking

- Simpler (linearization) is the neural network, better is the investigation of **trainability, stability, and efficiency** in learning dynamics involving resource-constrained systems
- Application to the analysis of distributed autonomous control and optimization systems guided by **“information metrics”**
- NTK-guided modeling allows easier development of **digital twins** of complex networked systems

AI for Networking: Intent-Based Networking

Intent-Based Networking:

- **Policy abstraction and synthesis** into machine-interpretable network rules (QoS, Slicing)
- **Automated provisioning and configuration** of distributed data plane resources
- **Closed-loop orchestration** (optimizing use of resources) leveraging LLM-driven reasoning for adaptive control
- Enabling **scalable, self-managing, and intent-aware network infrastructures**

Contacts

AI for Networking

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THANKS FOR LISTENING!

QUESTIONS?

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