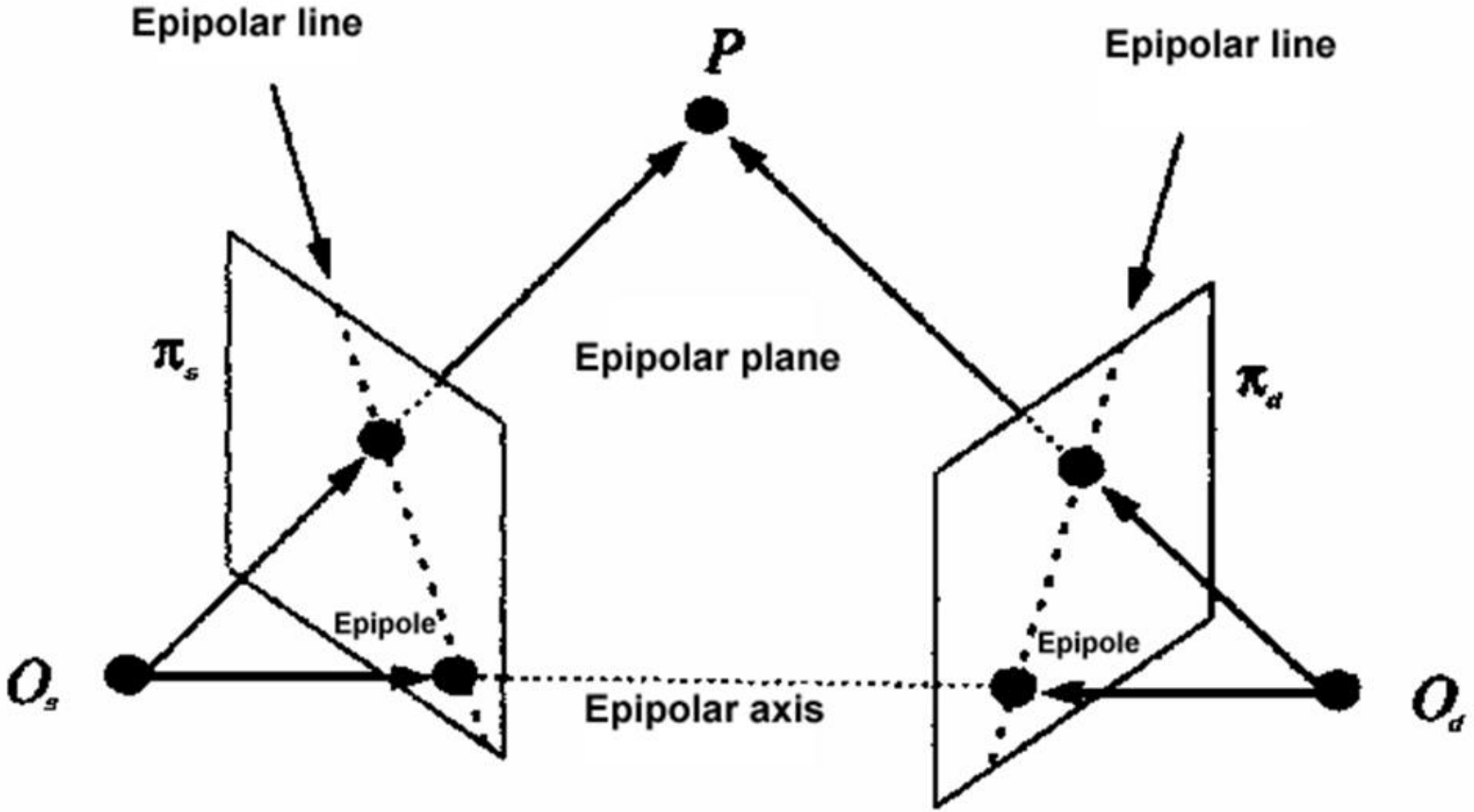
Data, science, mathematics

Massimo Ferri
Università di Bologna
massimo.ferri@unibo.it

Data, science, mathematics

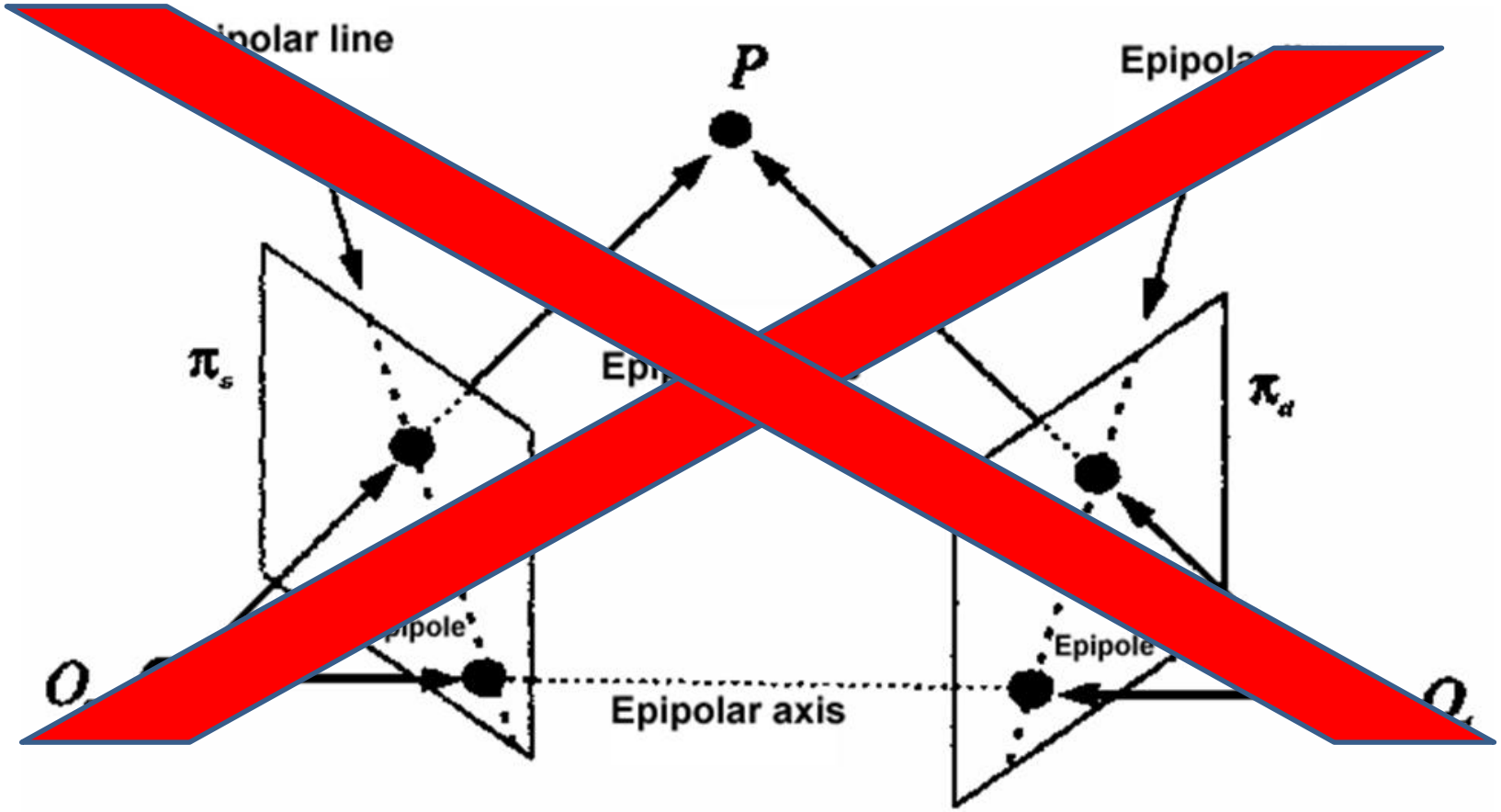
- **An example**
- Is an intellectual revolution at hand?
- Explainable AI
- The rôle of mathematics
- Conclusions

An example



The matching problem in stereovision finds a help in classical geometry: The *epipolar correspondence* is a projectivity between line pencils.

An example



Zhou, K., Meng, X., & Cheng, B. (2020). Review of stereo matching algorithms based on deep learning. *Computational intelligence and neuroscience, 2020*.

Data, science, mathematics

- An example
- **Is an intellectual revolution at hand?**
- Explainable AI
- The rôle of mathematics
- Conclusions

Is an intellectual revolution at hand?

A controversial article [1], backed by a successful book [2], proposed a paradigm shift in our way of thinking:

“The new availability of huge amounts of data, along with the statistical tools to crunch these numbers, offers a whole new way of understanding the world. Correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all.”

[1] Anderson, C. (2008). The end of theory: The data deluge makes the scientific method obsolete. *Wired magazine, 16*(7), 16-07.

[2] Mayer-Schönberger, V., & Cukier, K. (2013). *Big data: A revolution that will transform how we live, work, and think*. Houghton Mifflin Harcourt.

Is an intellectual revolution at hand?

I might be in the same position of a natural philosopher of the 16th century, opposing Galileo's scientific method, but I see terrible dangers in that position.

Are we going to abandon science in favour of the Big Data oracle?

For example, what would have decided Big Data as a model for the solar system?

Data, science, mathematics

- An example
- Is an intellectual revolution at hand?
- **Explainable AI**
- The rôle of mathematics
- Conclusions

Explainable AI

https://cs.stanford.edu/people/karpathy/deepimagesent/generationdemo/

a train is parked on the tracks near a platform

a cat is sitting on a toilet seat

Explainable AI

https://cs.stanford.edu/people/karpathy/deepimagesent/generationdemo/

a man riding a horse down a street next to a building

a group of people standing around a train

Explainable AI

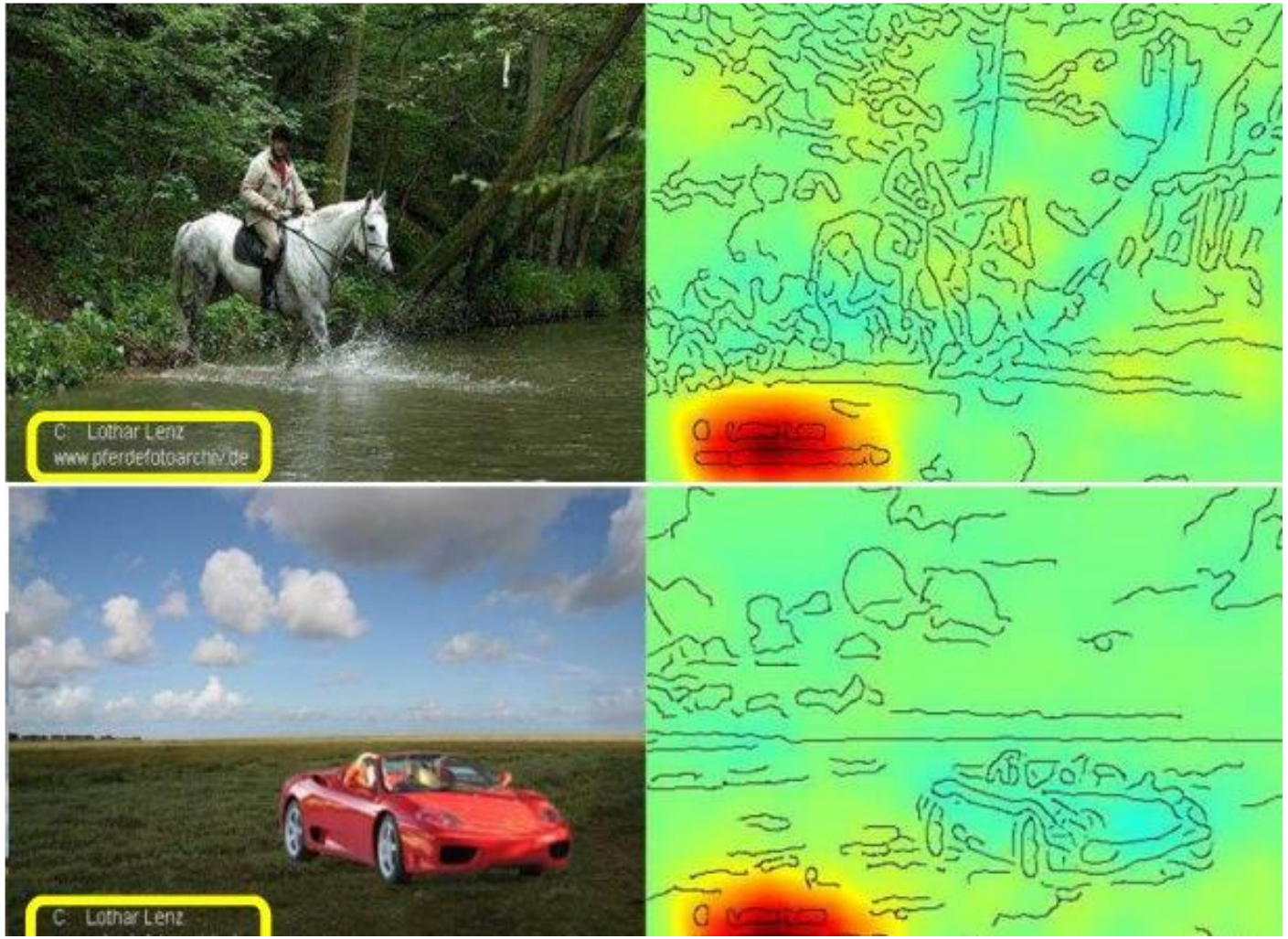
I don’t blame the mistakes. I do blame the black box!

A model for following, understanding, possibly correcting an AI judgement is necessary: **Explainable AI** (XAI) [3]

A positive example: *heat maps*.

[3] Miller, T., Hoffman, R., Amir, O., & Holzinger, A. (2022). Special issue on explainable artificial intelligence (XAI). *Artificial Intelligence*, 103705.

Explainable AI



A horse

A horse?

Lapuschkin, S., Wäldchen, S., Binder, A., Montavon, G., Samek, W., & Müller, K. R. (2019). Unmasking Clever Hans predictors and assessing what machines really learn. *Nature communications*, *10*(1), 1096.

Data, science, mathematics

- An example
- Is an intellectual revolution at hand?
- Explainable AI
- **The rôle of mathematics**
- Conclusions

The rôle of mathematics

- Mathematics is ubiquitous in AI.
- For example, computer vision is permeated with geometries of all kinds.
- Deep Learning is based of the search for a minimum of a loss function, by following its antigradient.
- Mathematics - and topology first and foremost - will be central as a tool for Explainable AI and to rationalize the answers of Big Data.

The rôle of mathematics

Topology is present at least in:

- The shape of data and of data sets [4]
- Dimension reduction of data (Mapper) [5]
- Persistent Homology
  - Qualitative understanding of natural images [6]
  - Guessing the shape of sampled objects (Stanford flavour) [7]
  - Extracting features out of data (Bologna & Genova flavour) [8]
- Inserting the observer in Deep Learning (GENEOs) [9].

The rôle of mathematics

[4] Ferri, M. (2018). Why topology for machine learning and knowledge extraction? *Machine Learning and Knowledge Extraction, 1*(1), 115-120.

[5] Singh, G.; Mémoli, F.; Carlsson, G.E. Topological methods for the analysis of high dimensional data sets and 3D object recognition. In *SPBG 2007; The Eurographics Association (*2007), 91–100.

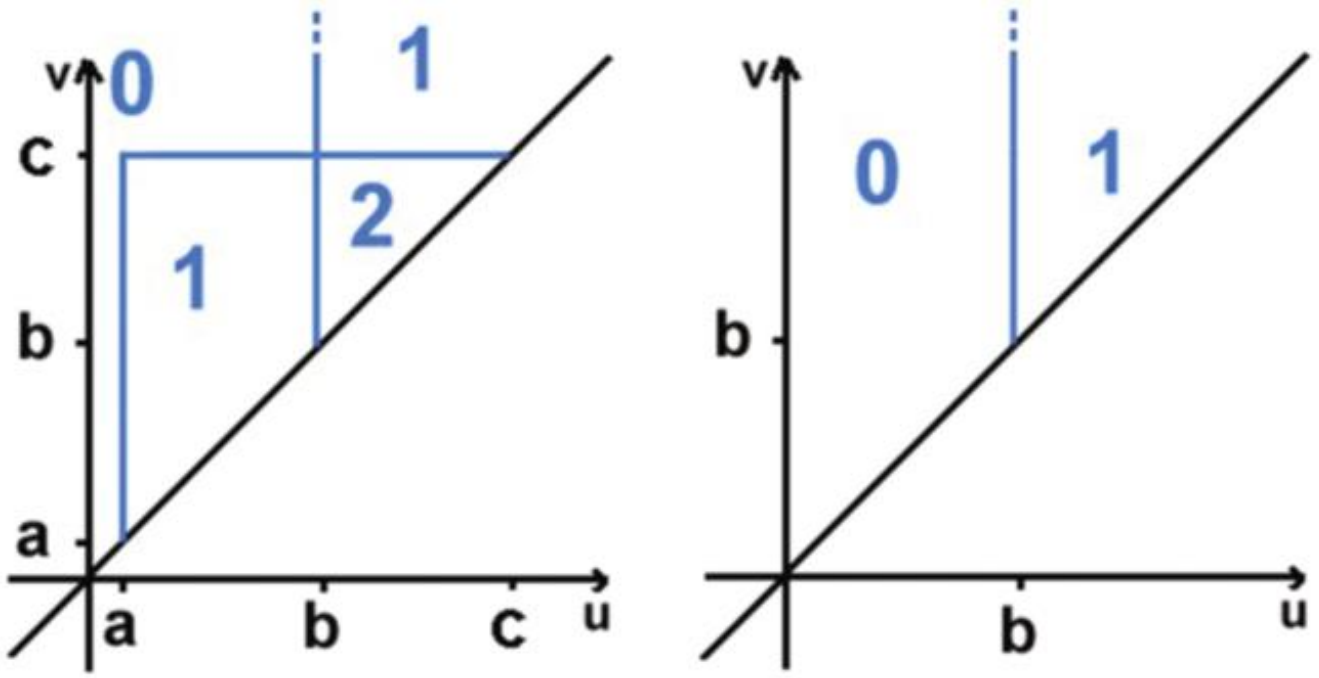
[6] Ferri, M. Persistent topology for natural data analysis—A survey. In *Towards Integrative Machine Learning and Knowledge Extraction; Springer* (2017), 117–133.

[7] Carlsson, G. Topological pattern recognition for point cloud data. *Acta Numer.* 23 (2014), 289–368.

[8] Frosini, P. Measuring shapes by size functions, *Proc. of SPIE, Intelligent Robots and Computer Vision X: Algorithms and Techniques, Boston, MA 1607* (1991), 122-133.

[9] Bergomi, M. G., Frosini, P., Giorgi, D., Quercioli, N. Towards a topological–geometrical theory of group equivariant non-expansive operators for data analysis and machine learning. *Nature Machine Intelligence*, *1* (2019), 423-433.

The rôle of mathematics



Data, science, mathematics

- An example
- Is an intellectual revolution at hand?
- Explainable AI
- The rôle of mathematics
- **Conclusions**

Conclusions

- AI algorithms and powerful computing tools enable us to deal with huge amounts of data
- This gives us unprecedented possibilities
- Still, there is the danger of blindly entrusting decisions to oracles
- A possible remedy is Explainable AI
- Mathematics is a way to keep understanding what AI tells us
- Topology provides formal, computable tools to capture qualitative aspect of reality, so will be – and already is – a perfect tool for integrating observers in the process.

THANKS FOR YOUR ATTENTION !