Tutorial Outline

- **Part 1:** Background and challenges (20 min)
- **Part 2:** Preliminaries of invariance (20 min)
- *Q&A / Break (10 min)*
- **Part 3:** Invariance in the era before deep learning (30 min)
- **Part 4:** Invariance in the early era of deep learning (10 min)
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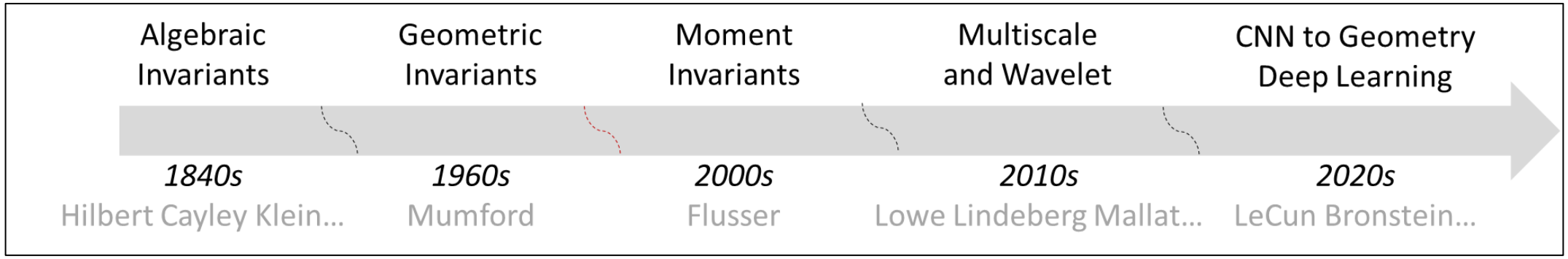
- **Part 6:** Conclusions and discussions (20 min)
- *Q&A (10 min)*

A Historical Perspective of Data Representation
Rethinking Deep Learning with Invariance: The Good, The Bad, and The Ugly

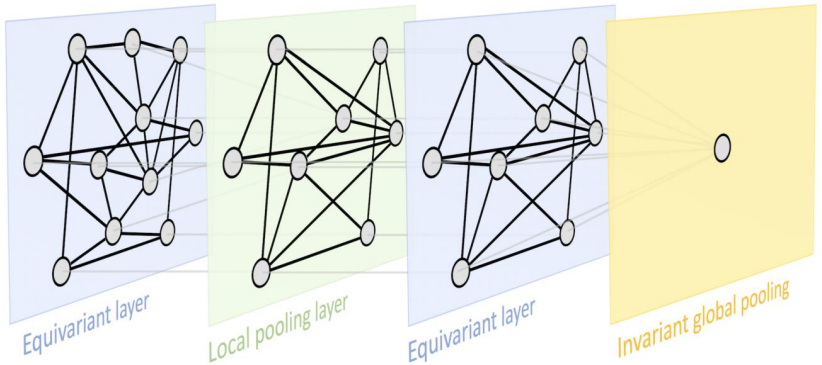
Conclusion 1: A Historical Perspective of Invariance

- A long history, from group theory, geometry, and physics
- In the era before deep learning: cornerstone
  - globally for the whole image (moment invariants), or locally for local parts of image (SIFT, DAISY, …).
- In the early era of deep learning: largely ignored
  - CNN vs. perceptron.
- In the era of rethinking deep learning: returned, geometric deep learning
  - locally and hierarchically (CNN, equivariant CNN, equivariant NN for group set, graph…).

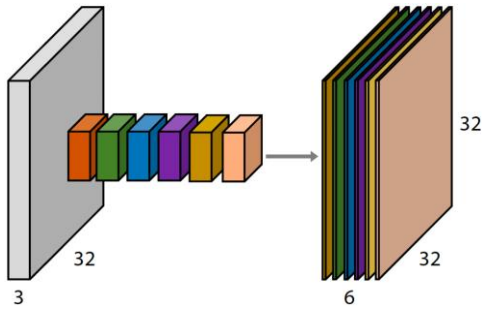


Conclusion 2: Rethinking Deep Learning by Invariance

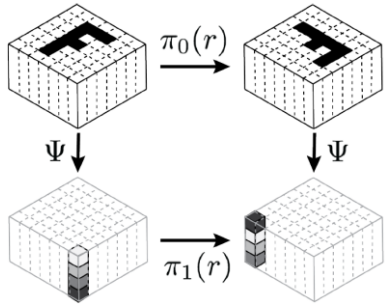
- Robust, interpretable and efficient (representation) learning
  - Perfect robustness, interpretable concept, and structural efficiency.
- CNN vs. perceptron on image data
  - Translation equi/in-variance.
- Geometric Deep Learning
  - For different transformations: wavelet scattering networks, group equivariant networks.
  - For different architectures and data types: deep sets/pointnet, graph networks, transformers.



Geometric deep learning blueprint

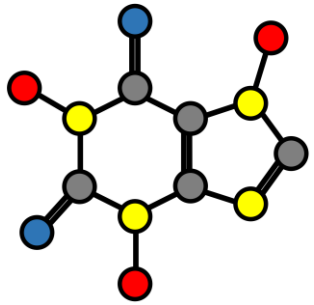


CNNs
translation



Group-CNNs
translation+rotation

DeepSets /Transformers
permutation



GNNs
permutation

Conclusion 3: Our Works for Invariance

Trustworthy AI as background

Symmetry priors in the natural world as principles

Expanding invariant representations at theoretical and practical levels

Invariant Representation

Invariant Theory
CSUR'23

Moment Invariants	Multiscale and Wavelet	Geometric Deep Learning
Refining global invariants TPAMI'24	**Designing local invariants** TPAMI'23	**Exploring hierarchical invariants** Submission B

Forensic Tasks

AIGC Detection
Submission C

AIGC Watermarking
Submission A

AIGC Hashing
USENIX Security'25

Open Problem 1:
Exploring the Limits of Handcrafted Invariants

- **The Good:**
  - Embedding knowledge; good interpretability, robustness, and efficiency.
- **The Bad and The Ugly:**
  - Discriminability, adaptivity.
- **Open Problem:**
  - Upper bound of discriminability?
  - Data-driven learning, a must?
  - If for a specific task, handcrafted invariants always sufficient?
- **Research Opportunity:**
  - Overcomplete designs of invariants, e.g., time-frequency, multi-scale, hierarchical.
  - Feature selection and explanation, from over-complete to task-discriminative.

Open Problem 2:
More Flexible Designs for Learning Invariants

- **The Good:**
  - Discriminability, adaptivity.
- **The Bad and The Ugly:**
  - Limited invariance, inefficient implementation, especially for joint invariance.
- **Open Problem:**
  - Group convolution (symmetry sampling), uniformly good?
  - Element-wise operations and global pooling, sufficient for graphs/sets?
- **Research Opportunity:**
  - Continuous and high-order designs for local-equivariant and global-invariant representations.
  - Specific designs of equi/in-variance for different data types.

Open Problem 3:
Real-world Impact and Application Considerations

- **The Good:**
  - Many low-level processing, some high-level tasks; AI for Science, e.g. AlphaFold.
- **The Bad and The Ugly:**
  - Real-world impact in broader applications.
- **Open Problem:**
  - Invariance, somewhat limit adaptivity?
  - Invariance, designed for generic tasks?
- **Research Opportunity:**
  - Designing high-performance invariants for specific tasks, i.e., specific data assumptions and knowledges.
  - Easy-to-use software, environment, and document.

There Is No Royal Road To Geometry

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§ Thank you!

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