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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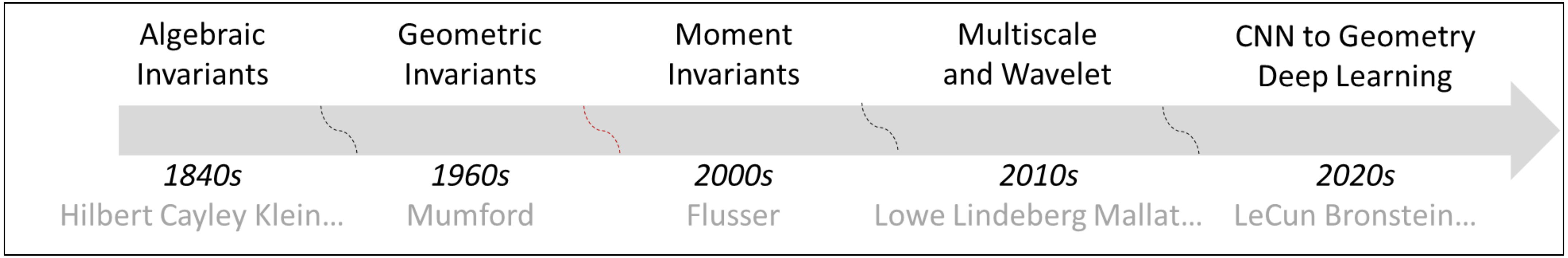
- **Part 6:** Conclusions and discussions (20 min)
- *Q&A (10 min)*

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

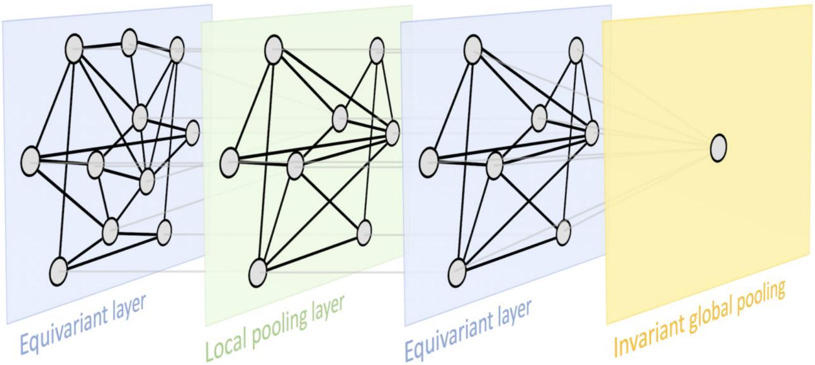
Conclusion 1: A Historical Perspective of Invariance

- 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…).

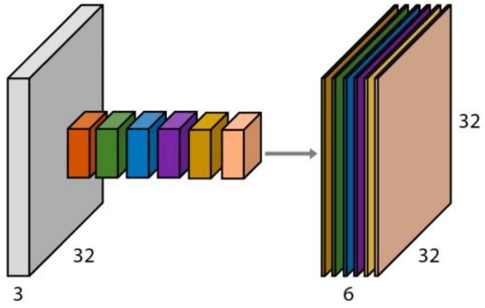


Conclusion 2: Rethinking Deep Learning by Invariance

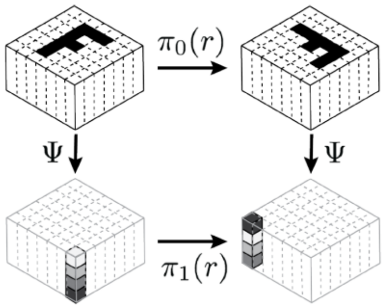
- Robust, interpretable and efficient (representation) learning
  - Perfect robustness, interpretable concept, and structural efficiency.
- CNN vs. perceptron on image data
  - Translation equi/in-variance.
- Geometric Deep Learning
  - For different transformations: wavelet scattering networks, group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



Geometric deep learning blueprint

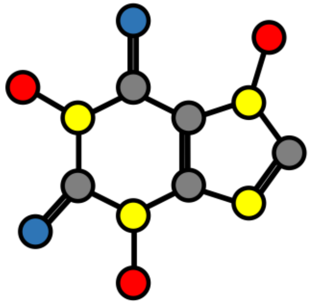


CNNs
translation



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 → **Refining global invariants** TPAMI'24
- Multiscale and Wavelet → **Designing local invariants** TPAMI'23
- Geometric Deep Learning → **Exploring hierarchical invariants** ICCV'25

Forensic Tasks

AIGC Detection
TIP'25

AIGC Watermarking
TIP'25, TIFS review

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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