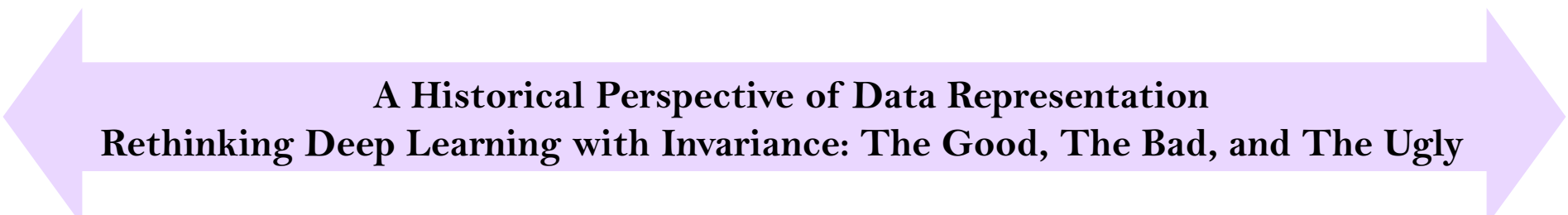


Tutorial Outline

- **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)
- *Q&A / Coffee Break (30 min)*
- **Part 5:** Invariance in the era of rethinking deep learning (50 min)
- **Part 6:** Conclusions and discussions (20 min)
- *Q&A (10 min)*

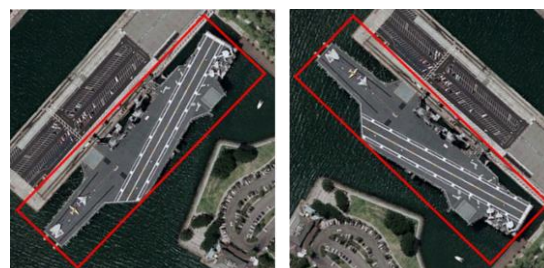


A Historical Perspective of Data Representation
Rethinking Deep Learning with Invariance: The Good, The Bad, and The Ugly

Invariance/Symmetry is Ubiquitous in AI Tasks



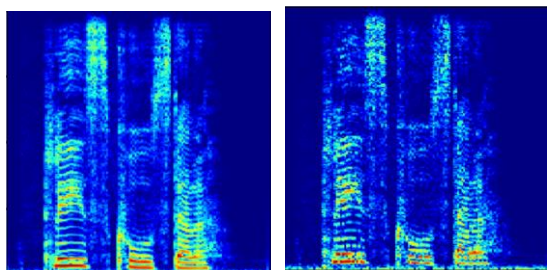
Image Classification
position



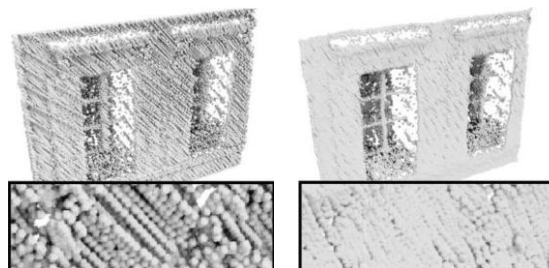
Remote Sensing
orientation



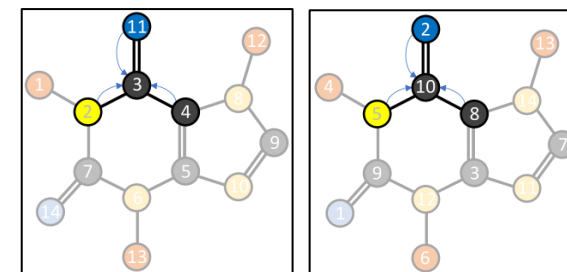
Self-driving Car
motion blurring



Speech Command
time warping



Point Cloud
Analysis
noise

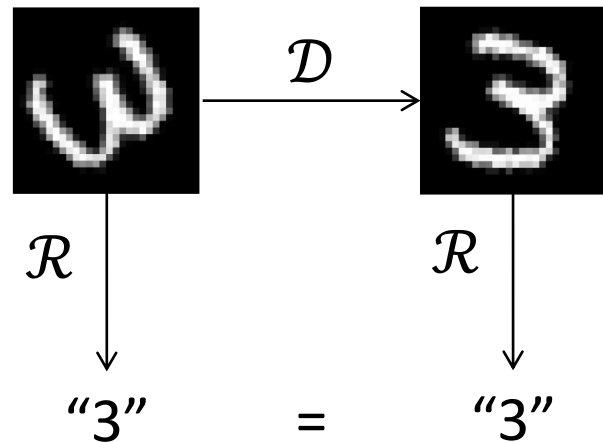


Prediction of
Molecular Properties
permutation

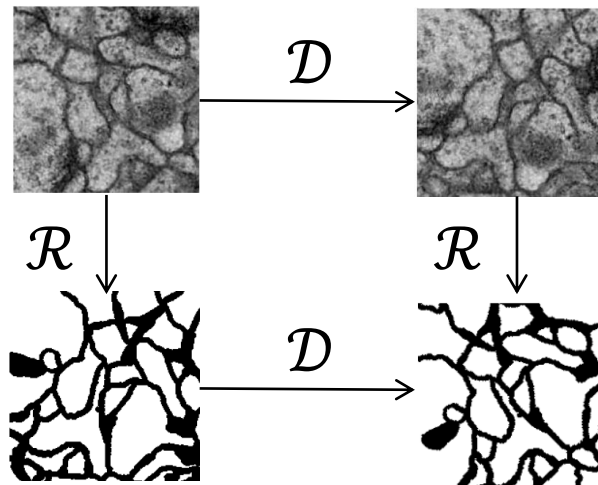
A Formalization of Invariance/Symmetry (in Representation)

- Invariance: $\mathcal{R}(\mathcal{D}(f)) \equiv \mathcal{R}(f)$
- Equivariance: $\mathcal{R}(\mathcal{D}(f)) \equiv \mathcal{D}(\mathcal{R}(f))$
- Covariance: $\mathcal{R}(\mathcal{D}(f)) \equiv \mathcal{D}'(\mathcal{R}(f))$
- $\mathcal{R}$ is a representation, $\mathcal{D}$ is a degradation, and invariance/equivariance is a special case of covariance with $\mathcal{D}' = \text{id}/\mathcal{D}$

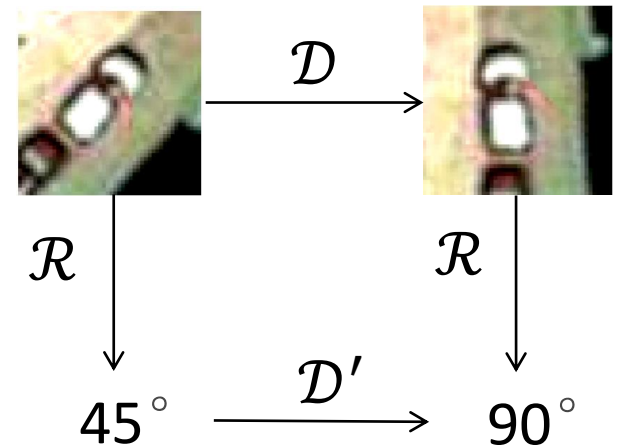
• K Lenc, A Vedaldi. Understanding image representations by measuring their equivariance and equivalence. CVPR, 2015.



Invariance
 $\mathcal{D} = \text{rotate}, \mathcal{R} = \text{classifier}$



Equivariance
 $\mathcal{D} = \text{rotate}, \mathcal{R} = \text{detector}$



Covariance
 $\mathcal{D} = \text{rotate}, \mathcal{R} = \text{estimator}$

A History of Invariance/Symmetry (in Representation)

Algebraic
Invariants

Geometric
Invariants

Moment
Invariants

Multiscale
and Wavelet

CNN to Geometry
Deep Learning

1840s

1960s

2000s

2010s

2020s

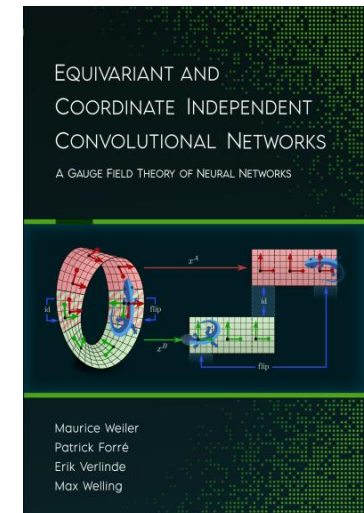
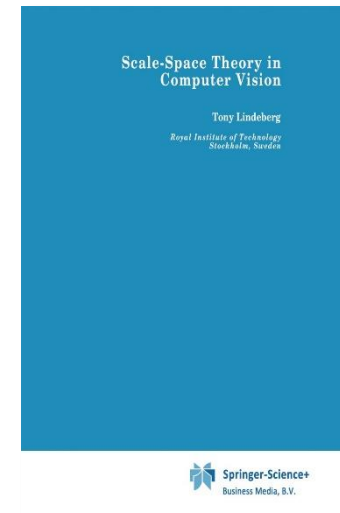
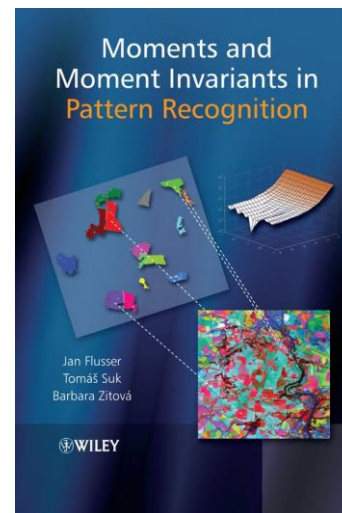
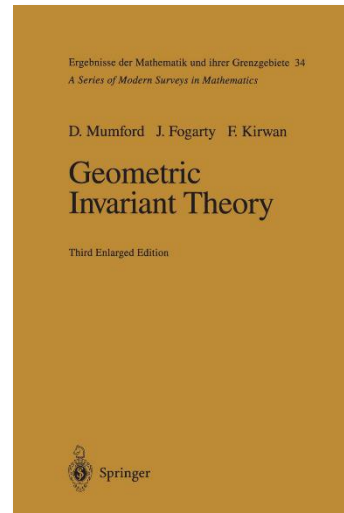
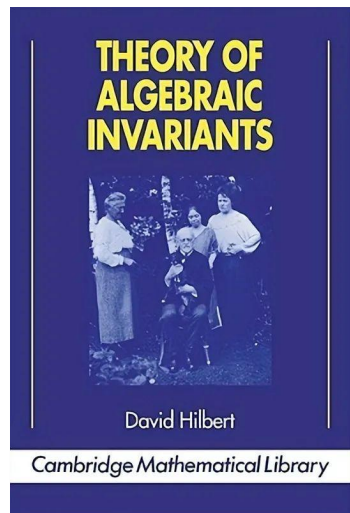
Hilbert Cayley Klein...

Mumford

Flusser

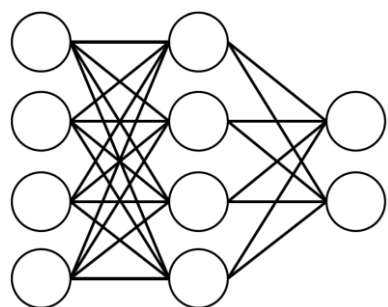
Lowe Lindeberg Mallat...

LeCun Bronstein...

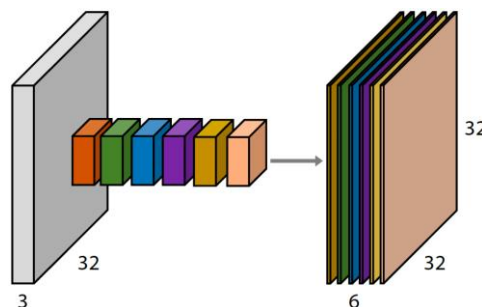


Rethinking Representations by Invariance/Symmetry

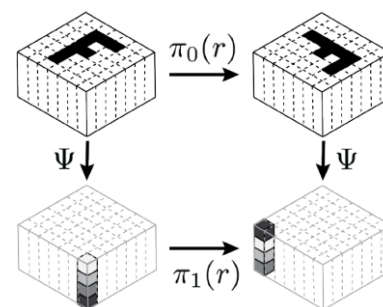
Geometric Deep Learning



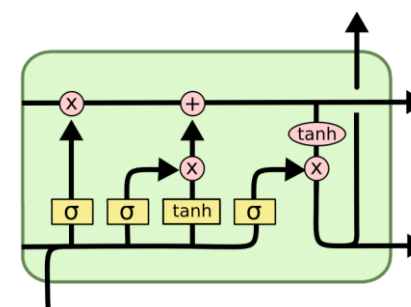
Perceptrons
function regularity



CNNs
translation



Group-CNNs
translation+rotation



LSTMs
time warping



DeepSets /Transformers
permutation



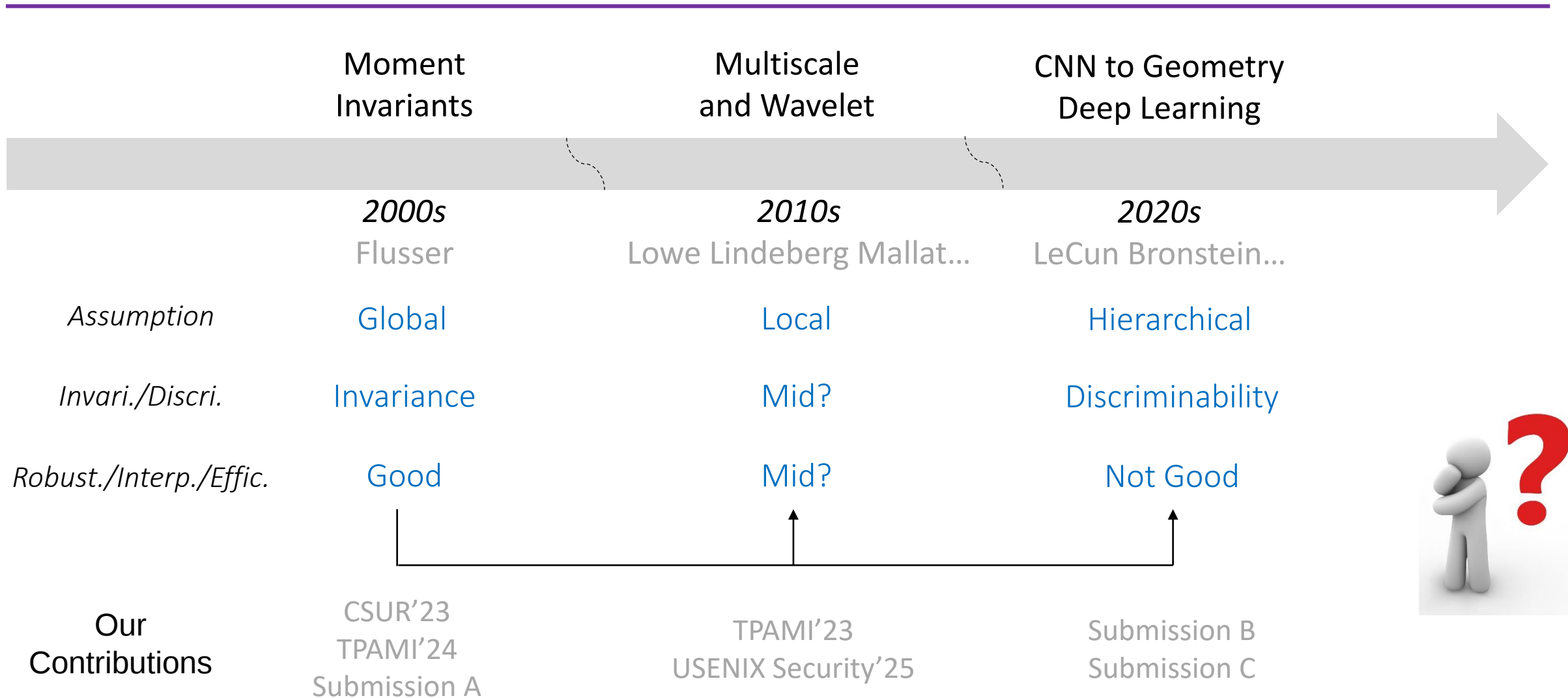
GNNs
permutation



Intrinsic CNNs
isometry/gauge choice

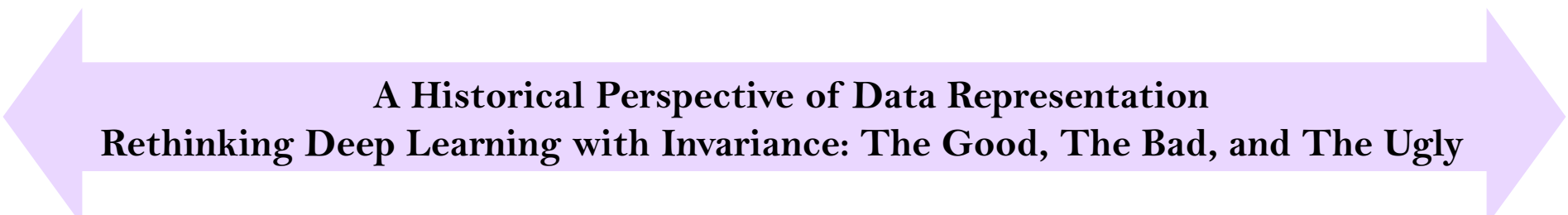
What I Did With My Collaborators
In The Process Of Invariance?

Our Contributions



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)
- *Q&A / Coffee Break (30 min)*
- **Part 5:** Invariance in the era of rethinking deep learning (50 min)
- **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



Time for
a Break!!