Introduction to Machine Learning and Geometric Deep Learning

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Oscar Carlsson, Department of Mathematical Sciences

WASP | WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

CHALMERS UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF GOTHENBURG

Outline

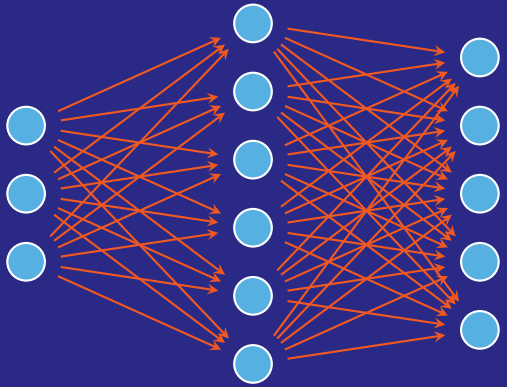
1. Machine learning
2. Geometry and symmetries in machine learning
3. My contributions

Introduction to ML

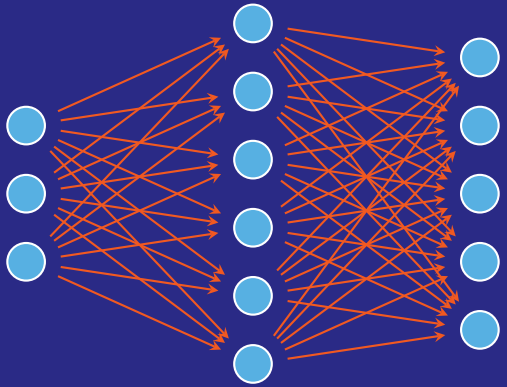
Examples of machine learning applications

- Language models
  - ChatGPT
  - Claude
  - Gemini
- AlphaFold
- Generative models
- Image analysis
  - Object detection
  - Semantic segmentation
  - Depth estimation
  - Classification

Machine learning models



Deep machine learning models



How humans and models differ in conceptualisation

Machine learning models are dumb!

How humans and models differ in conceptualisation

How humans and models differ in conceptualisation

Training a neural network

Training a neural network

Coffee cup

Training a neural network

Coffee cup

Training a neural network

Coffee cup

Goal

Use geometry and symmetry to improve and make networks more efficient

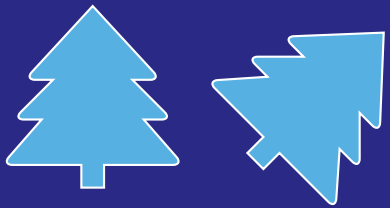
Geometry and symmetries in the real world

Tree

Geometry and symmetries in the real world

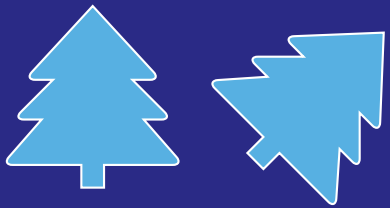
Tree

Geometry and symmetries in the real world



Invariant property

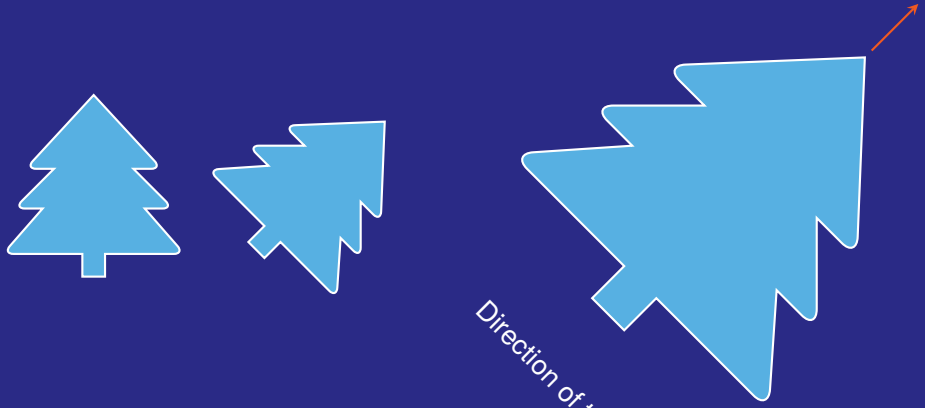
Geometry and symmetries in the real world



Invariant property

Direction of tree

Geometry and symmetries in the real world



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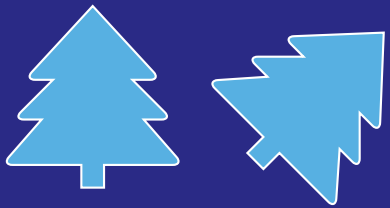
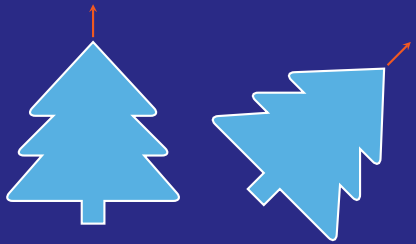


Invariant property



Equivariant property

Mathematics: Groups

- Set of transformations acting on some object
- Any two transformations can be combined into a single in the set
- One can undo transformations

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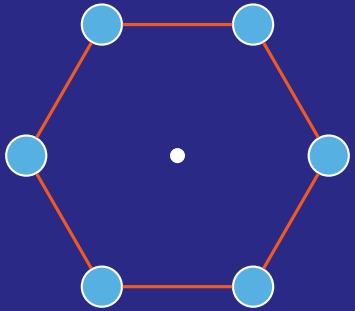
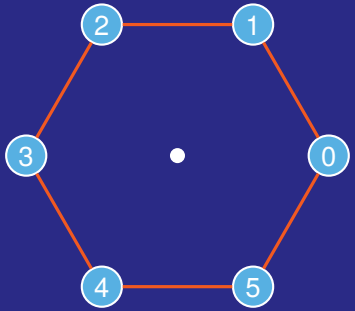
Often used to describe symmetries of objects

Example of a group



Example of a group



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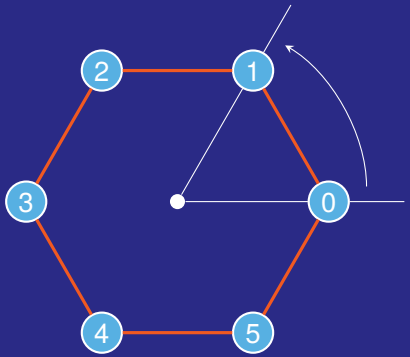

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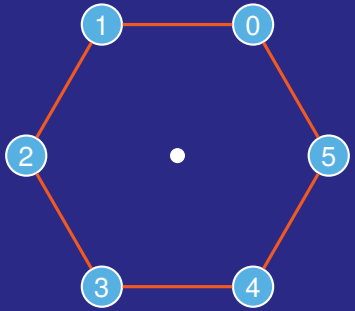

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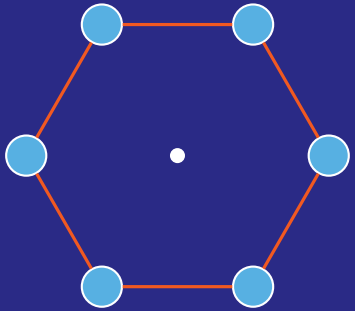

Mathematics: continuous groups, Lie groups

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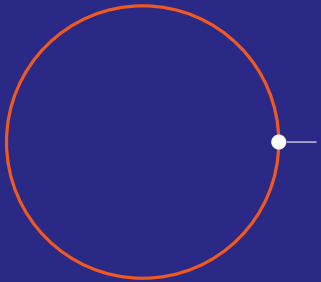

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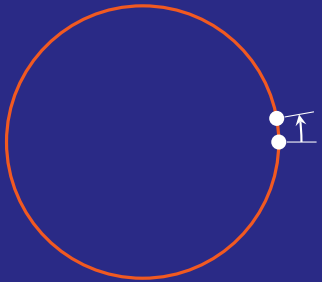

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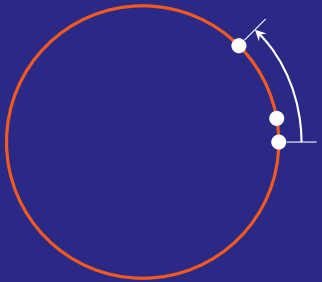

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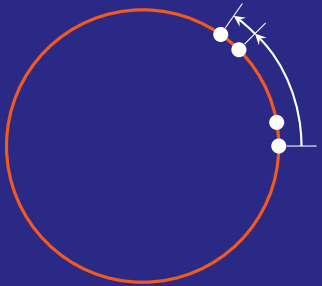

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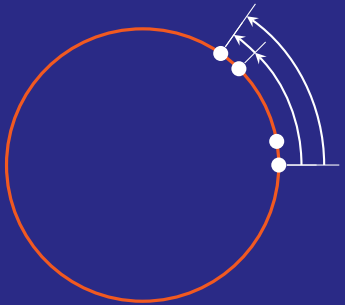

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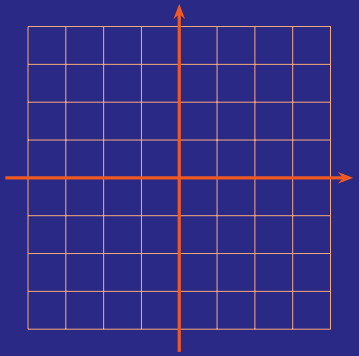

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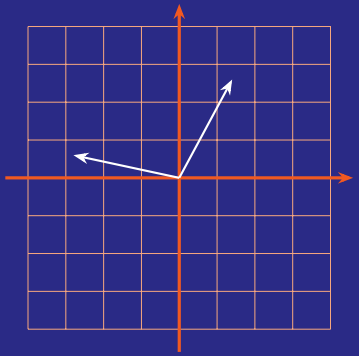

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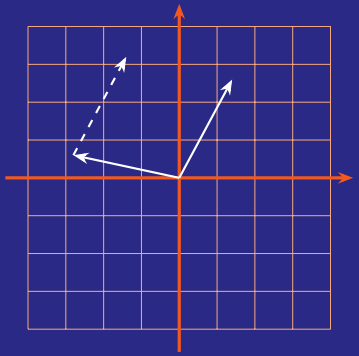

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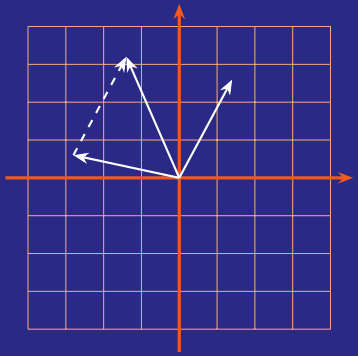

Reoccurring problems: differing positions

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Reoccurring problems: differing poses

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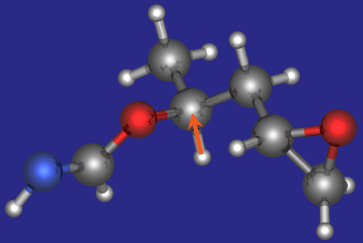
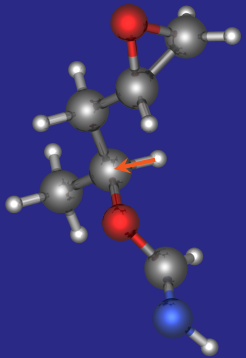




Dealing with geometry and symmetries in ML

Dealing with geometry and symmetries in ML:

Data augmentation

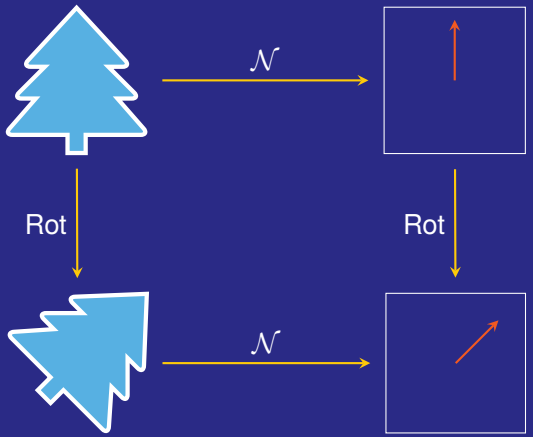
Dealing with geometry and symmetries in ML:

Data augmentation

Equivariance

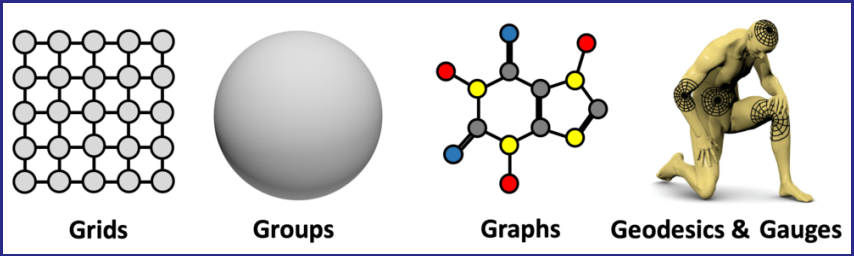
Data augmentation

Equivariant networks



$\mathcal{N}(g \triangleright_X x) = g \triangleright_Y \mathcal{N}(x)$ for all $g \in G$

Geometric Deep Learning



("Geometric Deep Learning: Grids, Groups, Graphs, Geodesics, and Gauges", Bronstein et al. 2021)

Questions

Data augmentation $\overset{?}{\longleftrightarrow}$ Equivariance

Questions

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How does one deal with data on curved spaces?

Questions

Data augmentation $\overset{?}{\longleftrightarrow}$ Equivariance

How does one deal with data on curved spaces?

Enconding symmetries mathematically?

Papers

- **Paper I.**: Jan E. Gerken, Jimmy Aronsson*, **Oscar Carlsson***, Hampus Linander, Fredrik Ohlsson, Christoffer Petersson, and Daniel Persson “Geometric deep learning and equivariant neural networks”. In: *Artificial Intelligence Review* (June 2023)
- **Paper II.**: Jan Gerken, **Oscar Carlsson**, Hampus Linander, Fredrik Ohlsson, Christoffer Petersson, and Daniel Persson “Equivariance versus Augmentation for Spherical Images”. In: *Proceedings of the 39th International Conference on Machine Learning* (June 2022), pp. 7404-7421
- **Paper III.**: **Oscar Carlsson***, Jan E. Gerken*, Hampus Linander, Heiner Spieß, Fredrik Ohlsson, Christoffer Petersson, and Daniel Persson Daniel “HEAL-SWIN: A Vision Transformer on the Sphere”. In: *2024 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)* (June 2024), pp. 6067-6077
- **Paper IV.**: Elias Nyholm*, **Oscar Carlsson***, Maurice Weiler, and Daniel Persson “Equivariant non-linear maps for neural networks on homogeneous spaces”. *Submitted* (April 2025)

Papers: Mathematical foundations

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Papers: Vision applications

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End of general introduction