Bayesian Deep Learning for Introspective Robot Perception

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KROS-Europe 2022

DLR

DLR Aerial Robotics: Aerial Manipulation

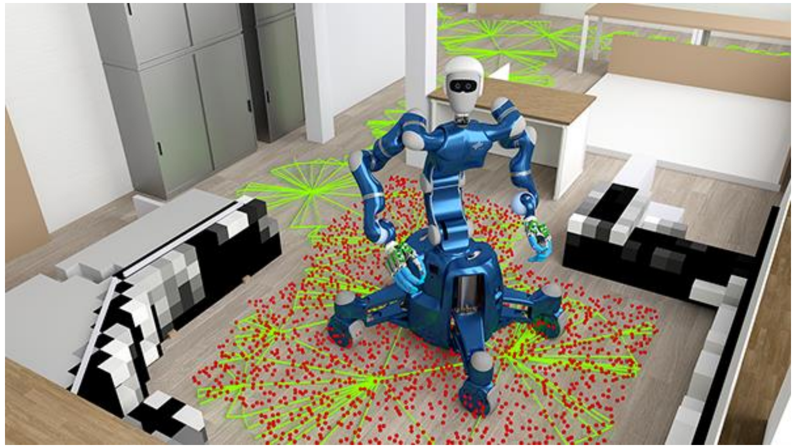
DLR Aerial Robotics: Planetary Exploration

DLR Aerial Robotics: Solar Powered UAVs

On Importance of Reliability and Robustness of a Perception System

- Field robotics applications – outdoor environments.
- Safety critical systems – both at research and industry levels.

How to leverage Deep Learning techniques from computer vision research to robotic perception?



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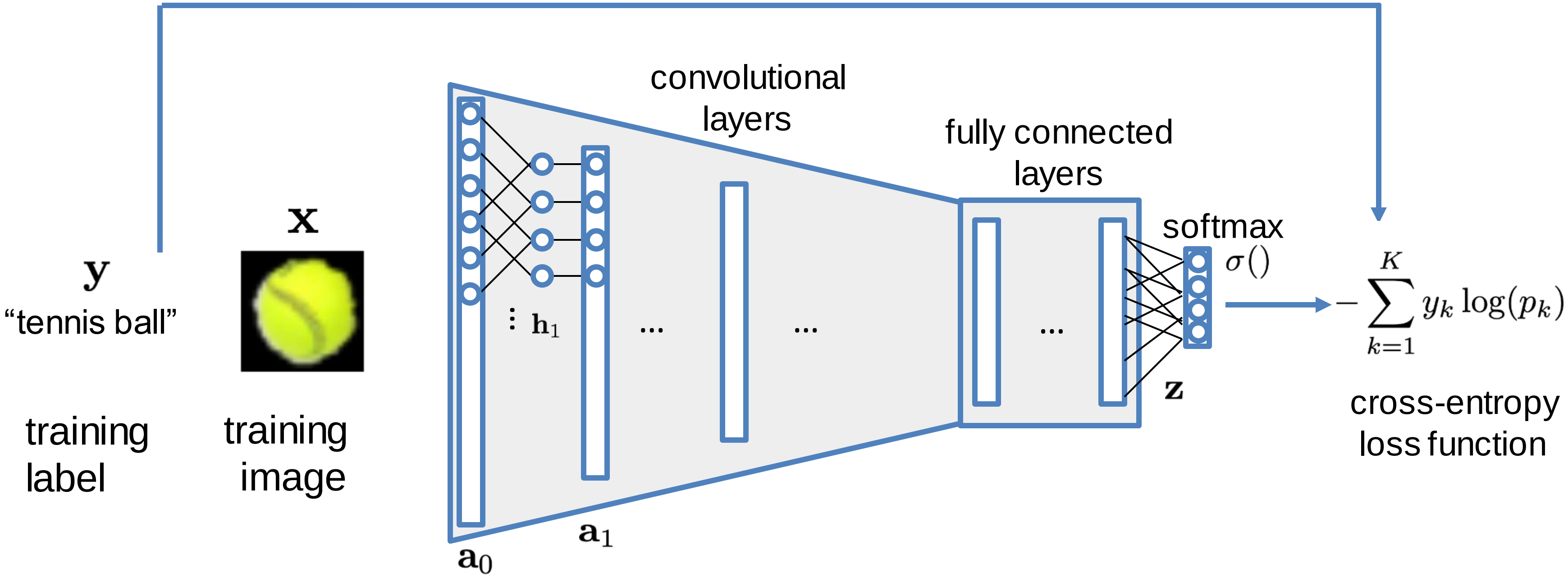
Returning Distributions Rather Than A Single, Most Likely Guess.

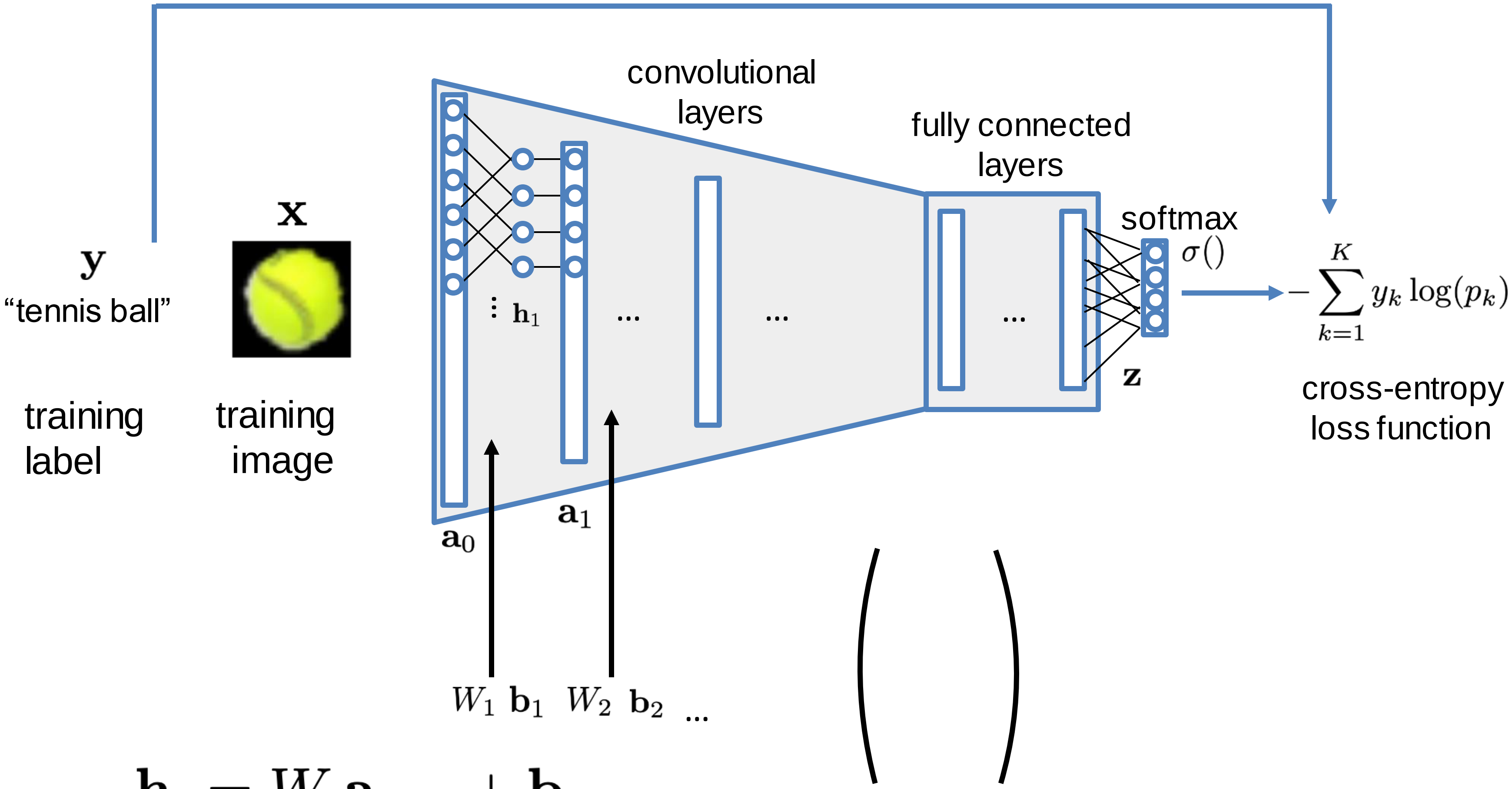
S. Thrun et al, “Probabilistic Algorithms and the Interactive Museum Tour-Guide Robot Mineva”, IJRR 2000.

- **Probabilistic robotics** at the age of **deep learning**.
- Major challenges lie in **uncertainty quantification** of **neural network.**

Uncertainty Quantification of Neural Networks



Uncertainty Quantification of Neural Networks



$$\mathbf{h}_i = W_i \mathbf{a}_{i-1} + \mathbf{b}_i$$

$$\mathbf{a}_i = \phi(\mathbf{h}_i)$$

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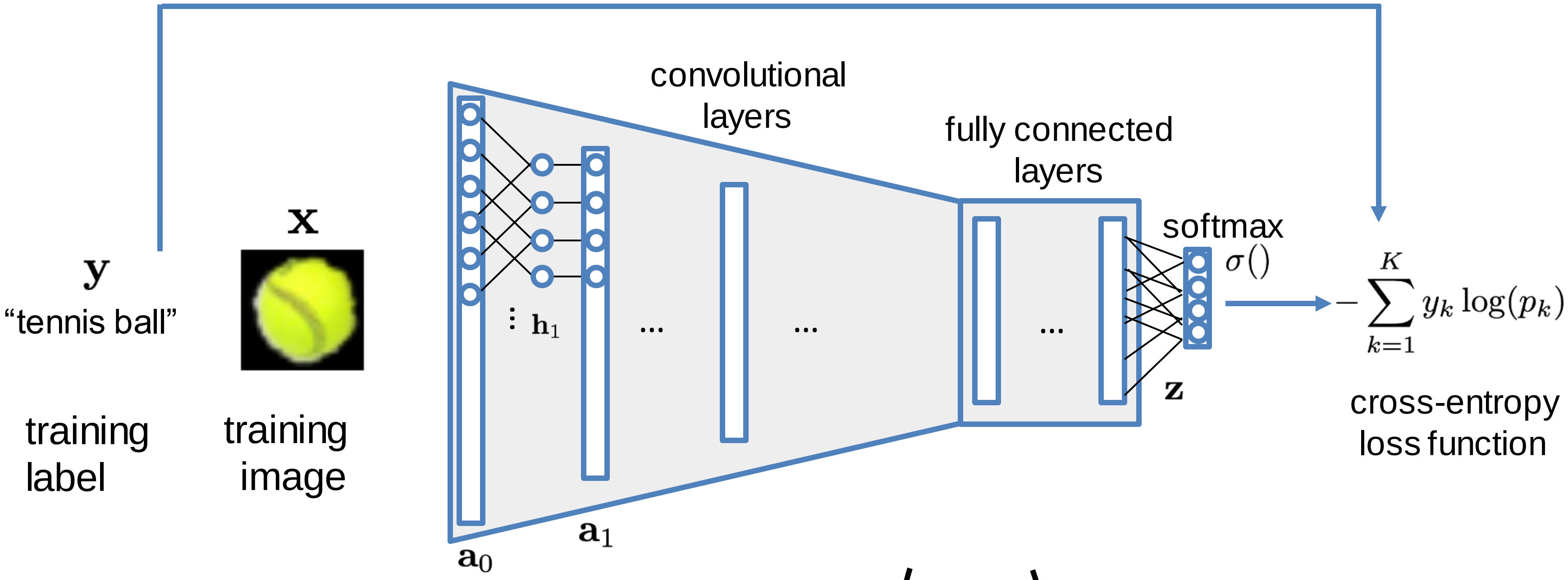
Uncertainty Quantification of Neural Networks



$$\mathbf{w} = \begin{pmatrix} W_1 & \mathbf{b}_1 \\ W_2 & \mathbf{b}_2 \\ \dots & \end{pmatrix}$$

$$\mathbf{h}_i = W_i \mathbf{a}_{i-1} + \mathbf{b}_i$$

$$\mathbf{a}_i = \phi(\mathbf{h}_i)$$

Standard training:

Find a single set of parameters that best fits my data

- Maximum likelihood principles

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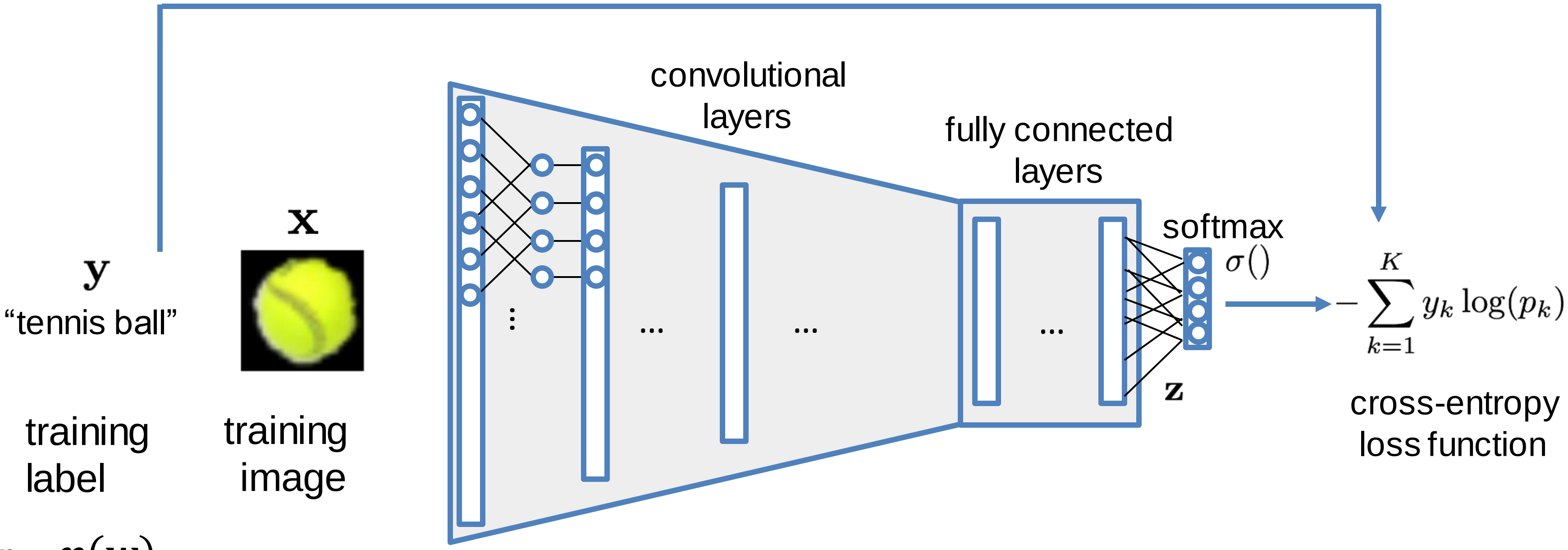
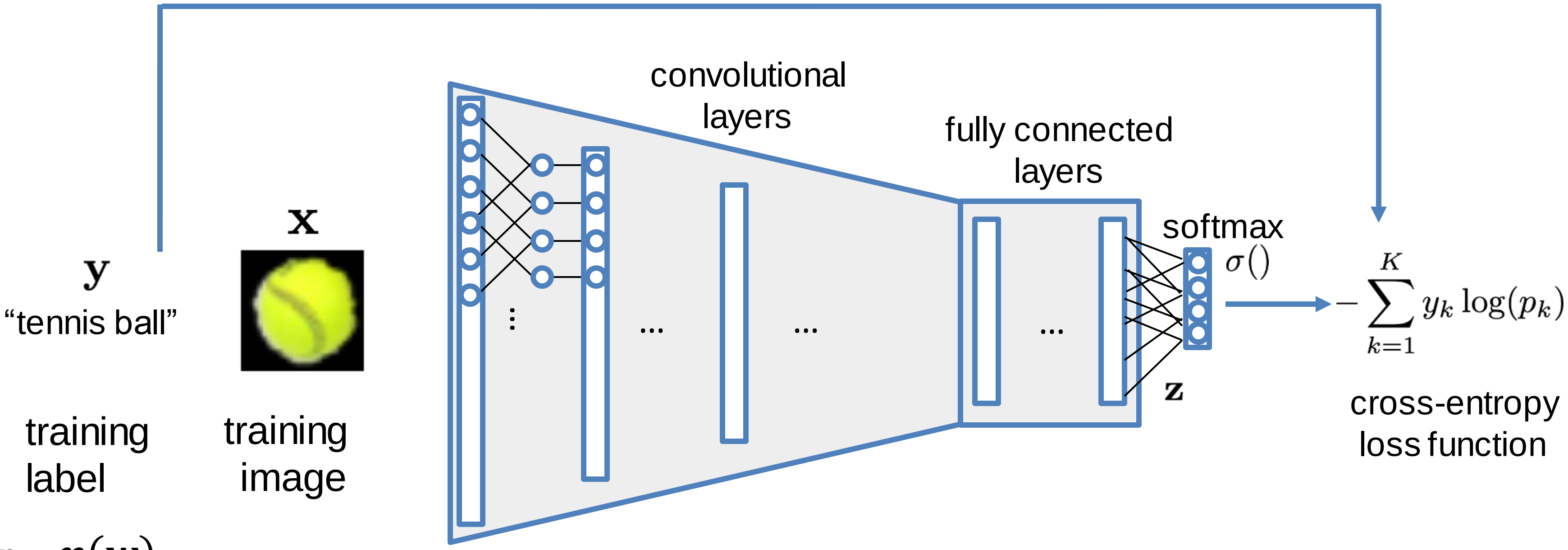
Uncertainty Quantification of Neural Networks



- **Define prior:** $p(w)$
- **Bayesian learning of posterior:** $p(w|X,Y) \propto p(y|X,w)p(w)$
- **Prediction:** $p(y^*|\mathbf{X},\mathbf{Y},x^*) = \int p(y^*|x^*,w)p(w|X,Y)dw$

Bayesian Neural Networks --Tishby et al "Consistent inference of probabilities in layered networks: Predictions and Generalization", 1989 IJCNN

Uncertainty Quantification of Neural Networks



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Major challenges in curse of high dimensionality!

Bayesian Neural Networks --Tishby et al “Consistent inference of probabilities in layered networks: Predictions and Generalization”, 1989 IJCNN

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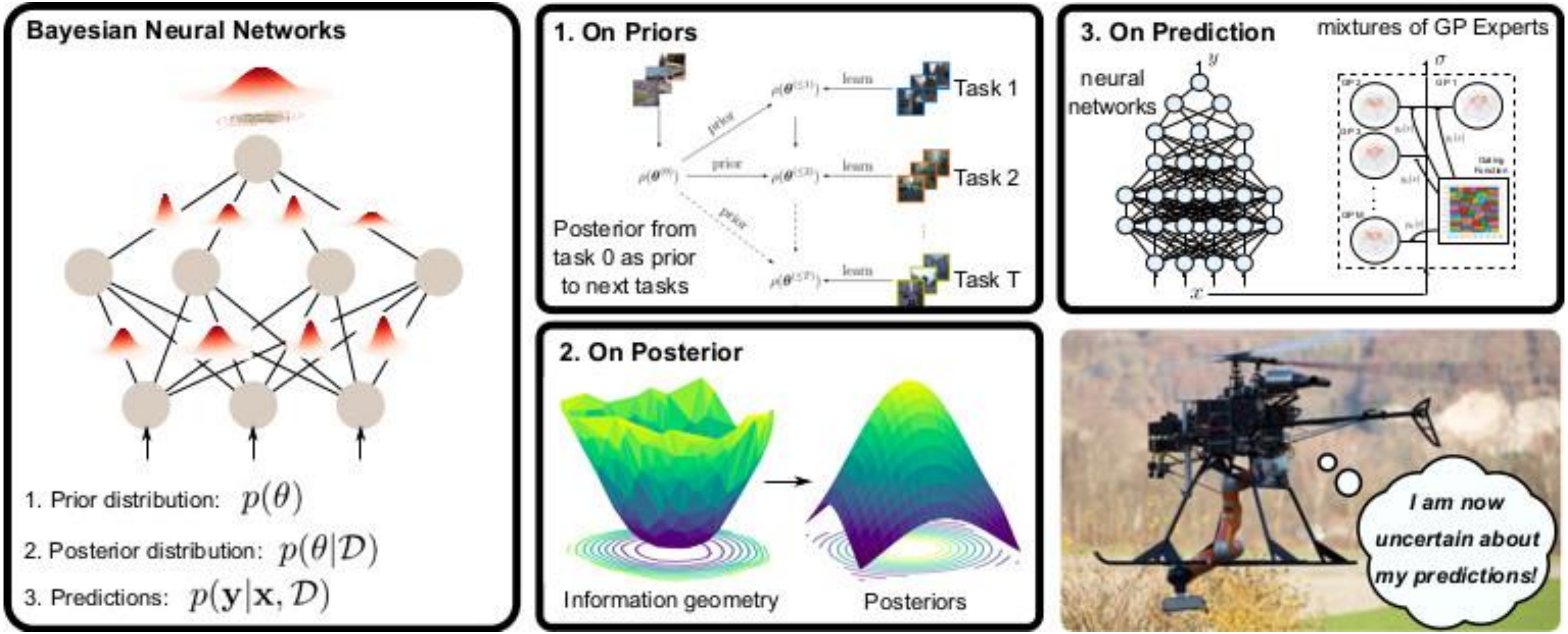
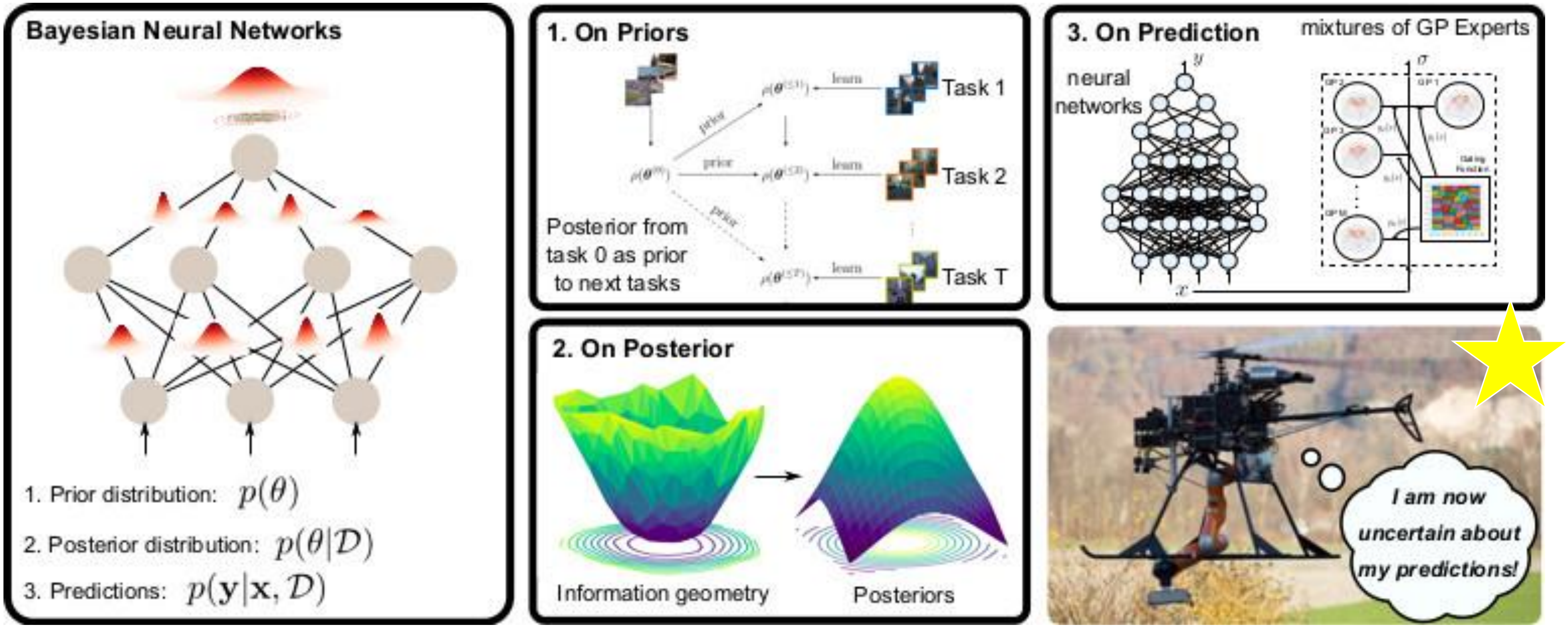
Overview of PhD Research



Overview of PhD Research



Lee et al, "Bilateral Teleoperation of Aerial Manipulators with Virtual Reality from Robotic Perception and Active Learning" (Under Review at Field Robotics)

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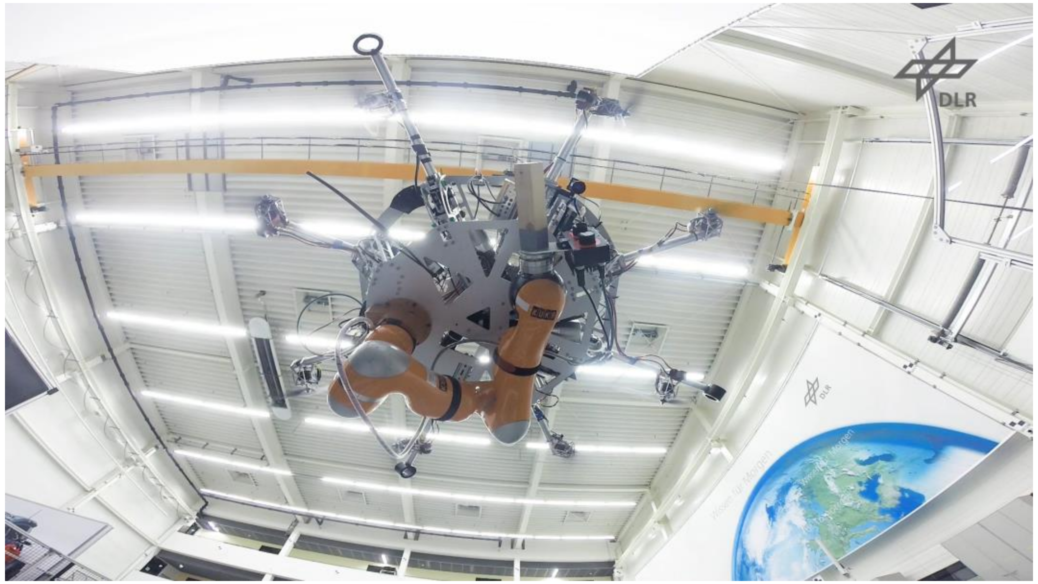
SAM – The Latest Generation of DLR Aerial Manipulators

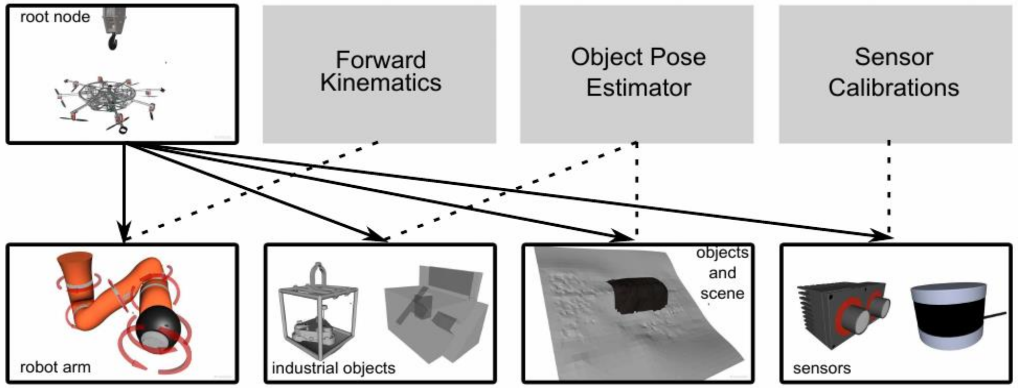
Deployment and Retrieval of Inspection Robotic Crawler [1]

Valve Closing in Air [2]

[1] Lee et al, "Visual-Inertial Telepresence for Aerial Manipulation" ICRA 2020.
[2] Balachandran et al, "Shared Controller for Aerial Manipulation" (in preparation)

Virtual Reality from Robotic Perception



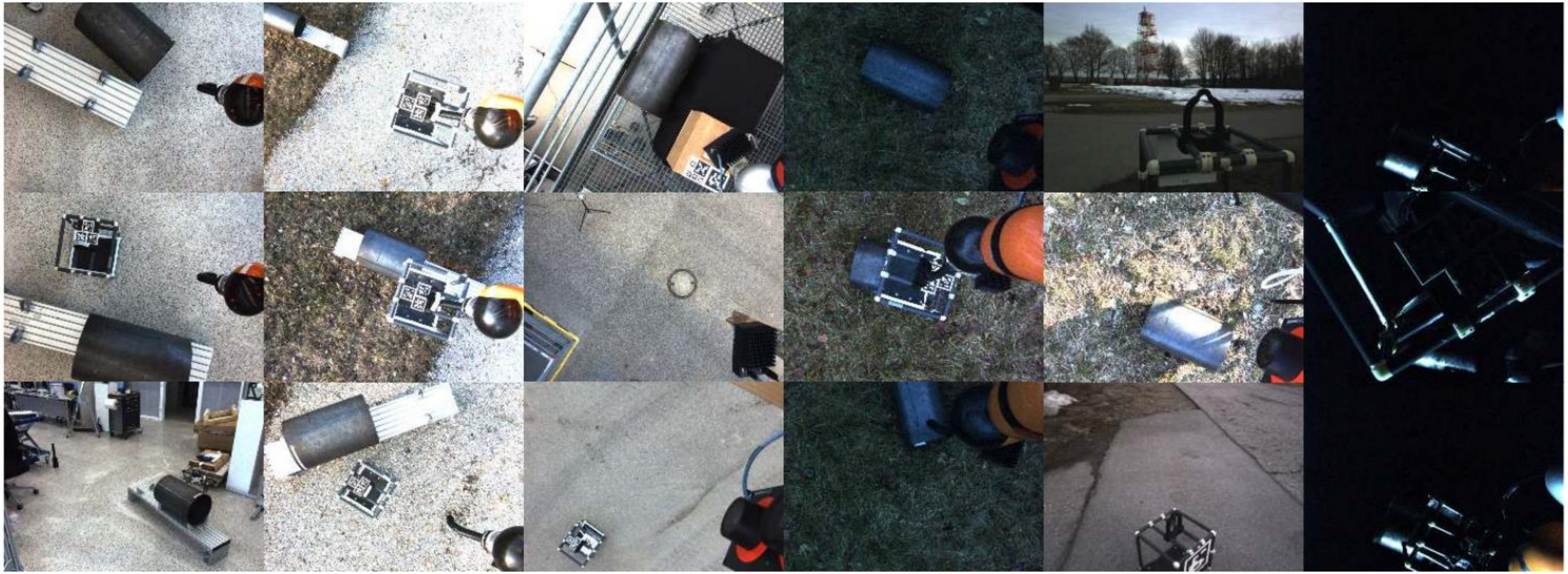


(a) scene graph with flat hierarchy

- If **known geometry**: combination of marker tracking and visual-inertial SLAM.
- If **unknown geometry**: combination of surface reconstruction and dynamic Lidar SLAM.

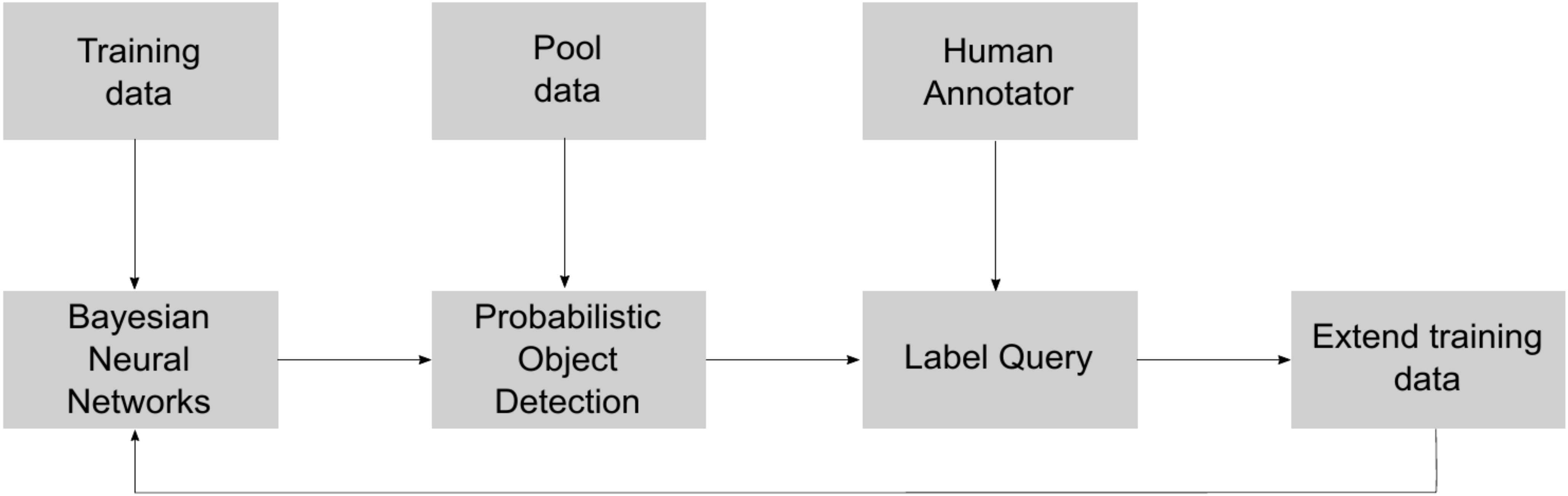
\- **Object detector** is based on deep learning.

Towards Industrial Applications



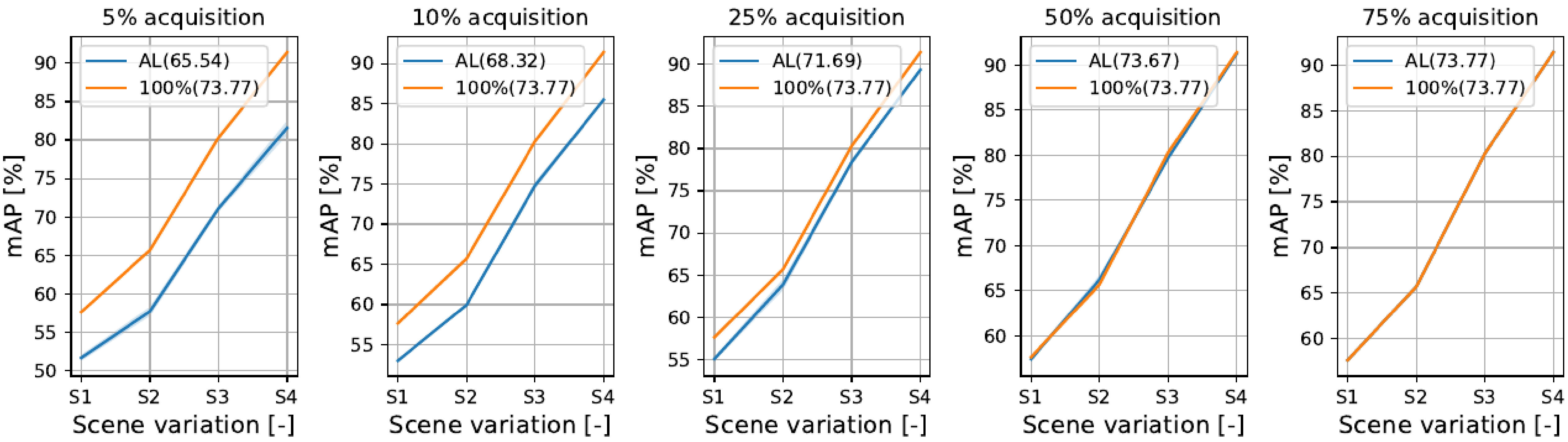
- **What could be the practical problem in this context?**

Active Learning using Bayesian Neural Networks



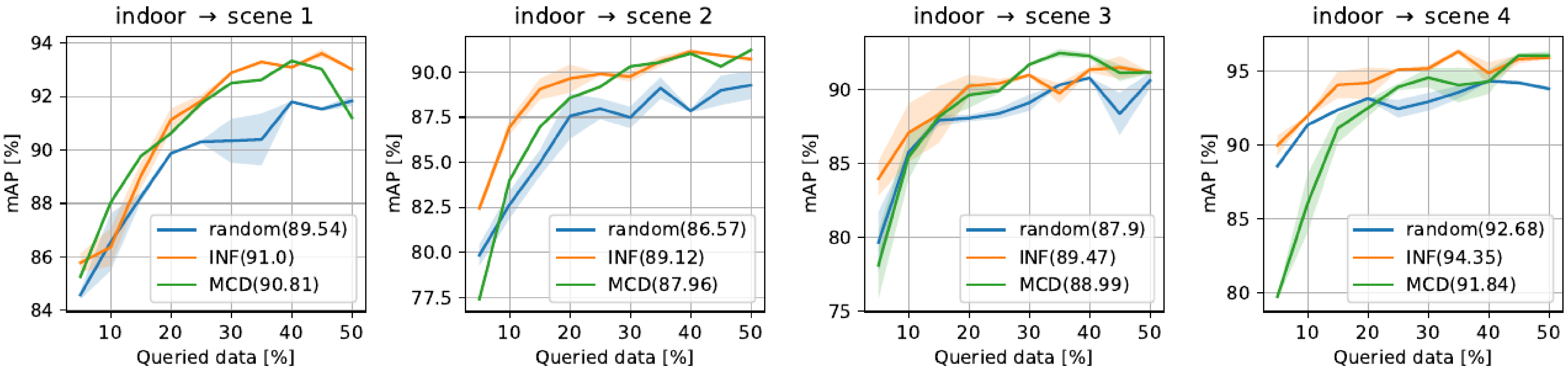
[1] Ren et al, “A Survey of Deep Active Learning” ACM Computing Surveys 2022. *Optimal Experiment Design
[2] Lee et al, “Estimating Model Uncertainty of Neural Networks in Sparse Information Form” ICML 2020.

Active Learning Results: Redundancy in the Data



- **Main Take-Away**: **Lots of redundancy in the data; Only 25% could be good enough.**

Active Learning Results: Uncertainty Estimates



- **Well-calibrated uncertainty estimates** matters for performance of active learning in practice.

Outdoor Flight Experiments and Operations at Night

- Over 68 successful experiments in different locations, users, seasons and lightning.
- Between 1.82-1.83 faster task execution time with the VR system when compared to only camera.

Conclusion

- Uncertainty quantification in neural network predictions for robotic perception.

- Bayesian Deep Learning = Bayesian reasoning applied to neural networks.
- Challenging due to high dimensional weight space.

- Overview of my PhD – priors, posteriors and predictions, designed for robotic perception.

- Active learning applied to VR-based teleoperation system for aerial manipulation.

Main take-away: data preparation is a practical problem, and probabilistic approach through uncertainty modelling can help in obtaining a solution with active learning.

Thank you for listening!


PhD Advisors


DLR Supervisors

Mobile Robots Team

Perception and Cognition department

EU2020 AEROARMS and SAM Team

Many other colleagues