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Autonomous Driving
& Intelligent Transport

UKRI Innovate UK

Centre for Connected
& Autonomous Vehicles

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Welcome to Oxford Brookes

& Our Related Research

December 2023: Connected, Automated Mobility & Future of Transport

Dr Andrew Bradley
abradley@brookes.ac.uk

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Oxford Brookes University

- Faculty of Social Sciences
- Faculty of Health Sciences
- Business Faculty
- **Faculty of Technology, Design and Environment**
  - School of Architecture
  - School of Arts
  - School of Built Environment
  - **School of Engineering, Computing and Mathematics**

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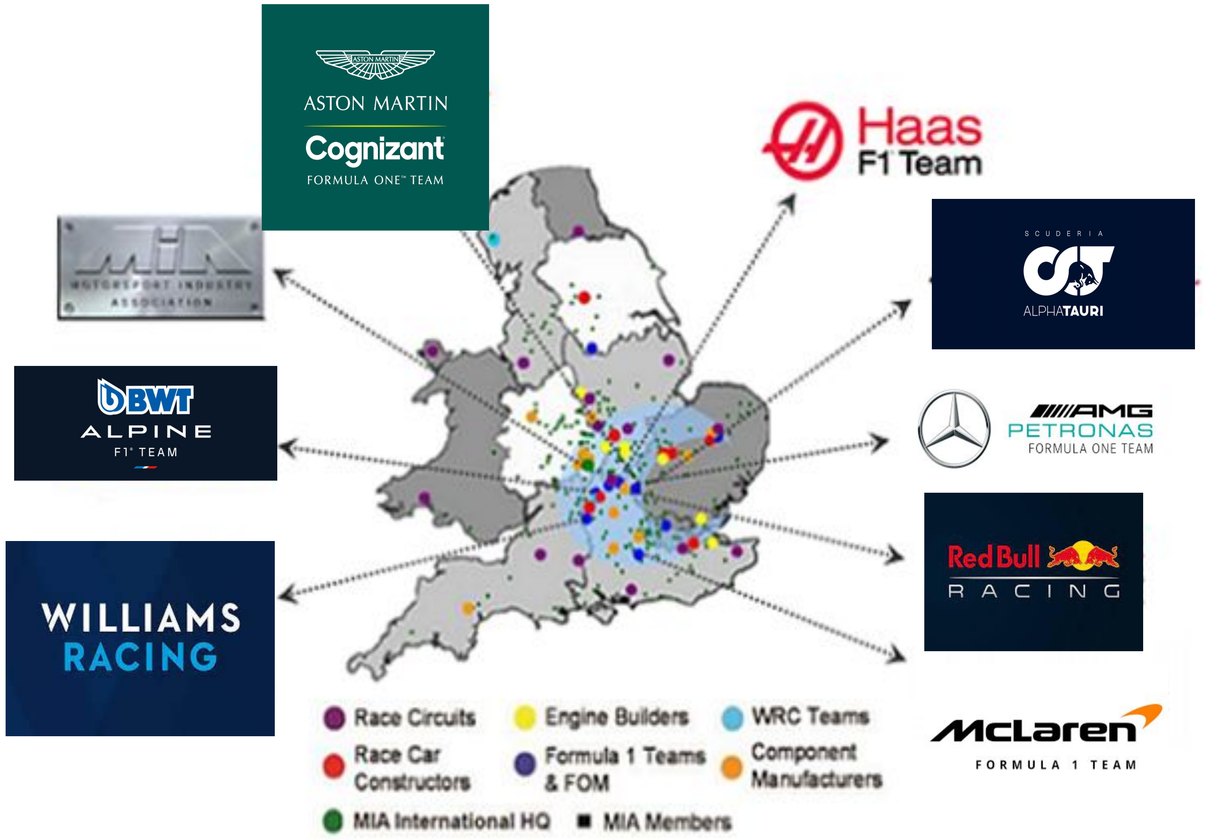
The UK motorsport valley and Oxford science park

- Culham Science Centre
- Culham Centre for Fusion Energy
- Rutherford Appleton Laboratory – Harwell Campus
- Begbroke Science Park
- Millbrook RACE AV test facility



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Our New Home - Campus move

Cutting edge, sustainable buildings on the Headington Hill site which will enhance STEM

The purpose-built workshop is dynamic, flexible space: industry-standard technical facilities with specialist engineering equipment

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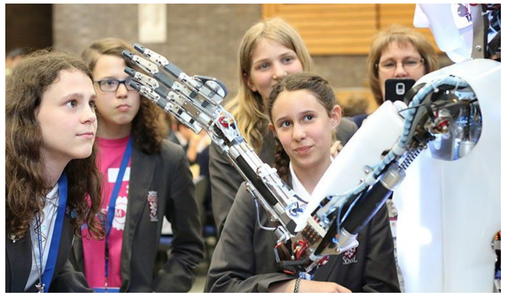
Taught Programmes - Postgraduate and Undergraduate

Engineering

- Mechanical
- Electro-Mechanical
- Automotive with EV
- Motorsport
- Racing Engine Systems

Computing

- Computer Science
- Cyber Security
- Artificial Intelligence
- Data Analytics
- IT for business



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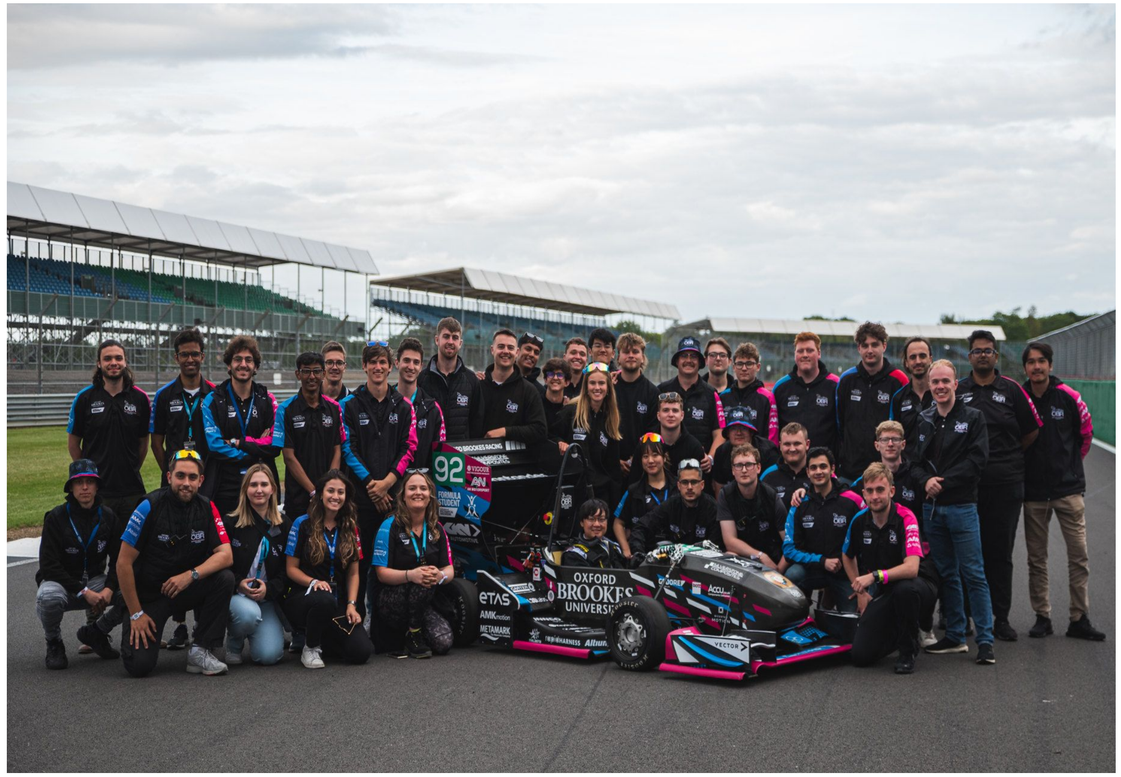
Award-Winning Electric and Autonomous racing teams

Formula Student Electric



OBR
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AUTONOMOUS

Formula Student Autonomous

Engineering Research

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Global Challenges
Environmental/Social/Political

Future of Transport
Electrification/ Autonomy/Clean power

Motorsport
Competitive Driven Innovation

Materials
Lightweight/Sustainability/Smart

Autonomous Driving & Intelligent Transport (ADiT)

Materials Processes and Modelling (MPM)

Powertrain & Pollution Modelling (PPM)

Mechanics

Centre for High Voltage Electronics & Energy Systems (HVEES)

Modelling Sustainable Futures (MSF)

High Voltage Systems

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High Voltage, Electronics and Energy Storage Lab (HVEES)

Equipment

HV BIDIRECTIONAL POWER SUPPLY

AVL Pack Tester

CELL / MODULE / PACK CHAMBER

Binder Cell Chamber

Arbin Cell Cycler

Power Supply

Oscilloscope

Temperature and Humidity Chart Recorder

Digital Multimeter

Gamry 5000P Potentiostat

HVES The High Voltage & Energy Storage Group at Oxford Brookes University

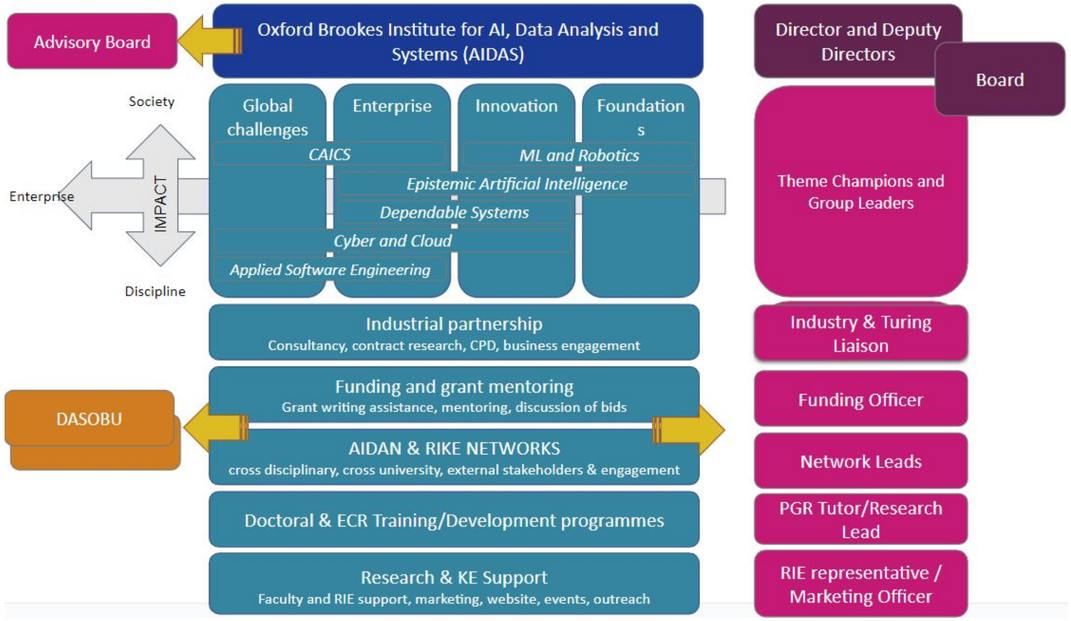
HVES Oxford Brookes University

Computing Research

5 research groups: Applied Software Engineering, Cybersecurity and Cloud, Dependable Systems, Epistemic AI, Machine Learning and Robotics

Oxford Brookes Institute for Artificial Intelligence, Data Analysis and Systems (AIDAS)

- New flagship Computing research institute
- Director: Prof. Fabio Cuzzolin
- Coordinates activities across all Computing research groups
- Also incorporates Centre for AI, Culture and Society (ex. Institute for Ethical AI)
- 4 pillars:
  - Global Challenges
  - Enterprise
  - Innovation
  - Foundations



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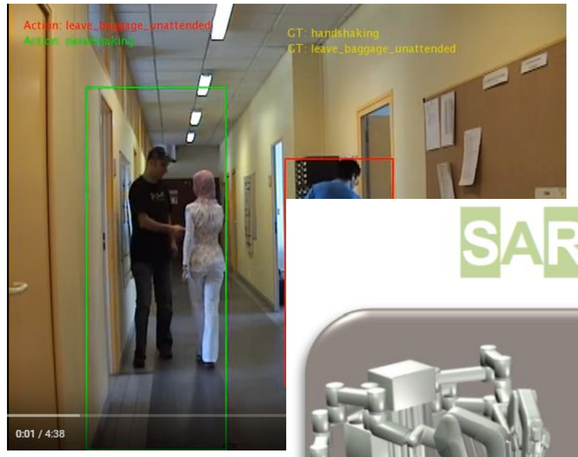
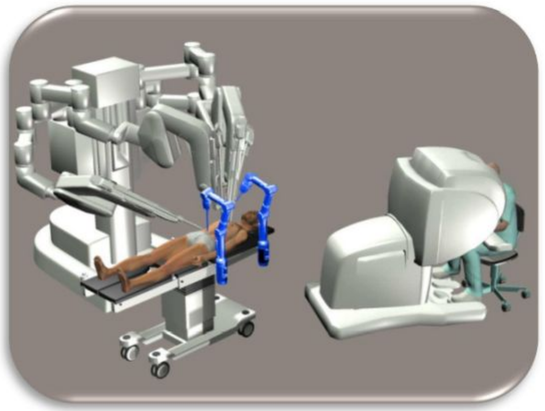
VISUAL ARTIFICIAL INTELLIGENCE LABORATORY

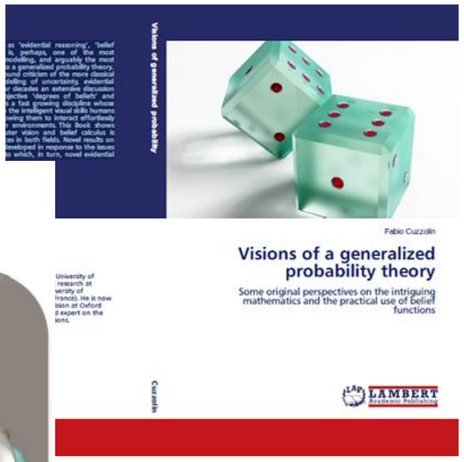
Research

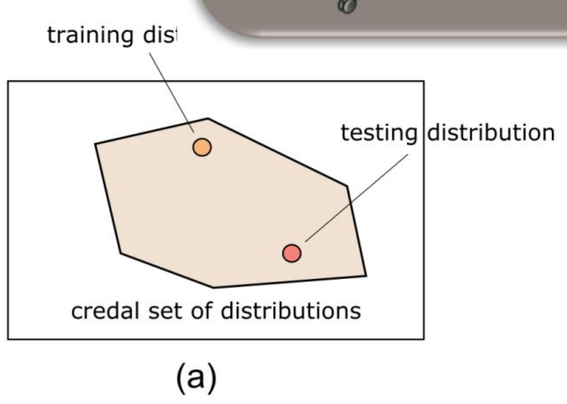
- **Computer Vision** (deep learning for action detection, video captioning, complex activities, future event prediction, scene understanding)
- **Machine Learning** (continual learning, federated learning, self-supervised learning)
- **Artificial Intelligence** (machine theory of mind, epistemic AI, neuro-symbolic reasoning)
- **AI for Healthcare** (audio-visual monitoring of people in a coma, empathetic AI)
- **Surgical Robotics** (SARAS, MAESTRO)
- **Autonomous Driving** (Formula Student AI, ROAD)
- **Uncertainty Theory** (random sets, belief functions, geometry of uncertainty)

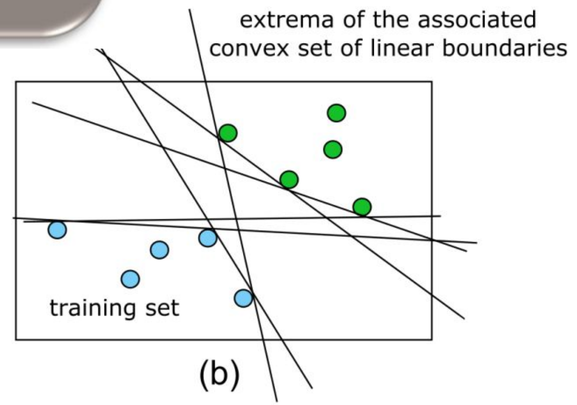


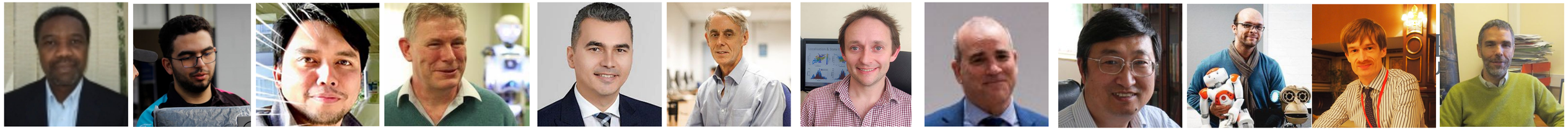
SARAS











Connected Vehicles

Communications & Cybersecurity

Transactions with Infrastructure & Vehicles

Safras Iqbal
Peter Ball
George Blumberg
Muhammad Hilmi Kamarudin
Fabio Iapaolo
Shadi Eltanani

Advanced Perception Systems

Road User Behaviour

Fabio Cuzzolin
Valentina Musat
Nabil Yassine
Izzeddin Teeti
Alex Rast
Ivan Fursa

Robust Perception in Challenging Conditions

Fabio Cuzzolin
Andrew Bradley
Maryam Sultana
Muhammad Mubashar
Shireen Kuddukil Manchingal
Youssoufa Alhadji

Epistemic AI

Testing Software & AI Systems

Hong Zhu
Thi Minh Tam Tran

Real-time Vehicle Control

John Durodola
Andrew Bradley
Ozdemir Ozerem
Marco Try Martos
Gerren Nitri
Aydin Azizi
Paul Allen

Autonomous Vehicle Simulation

Andrew Bradley
Can Hoke
Louise Bilous
Aydin Azizi

Driving Ethics

Nigel Crook
Fabio Iapaolo

Trajectory planning

Sam Garlick
Tamas Pinter
Abishaan Ravikumar

Localisation & Mapping

Alex Rast
Matthias Rolf
Andrew Bradley
Aduen Benjumea
Louise Bilous

Autonomous Racing

Aduen Benjumea
Thomas LeClaire
Mihir Gohad
Sebastian Donnelly
Lora Hernandez-Herrera

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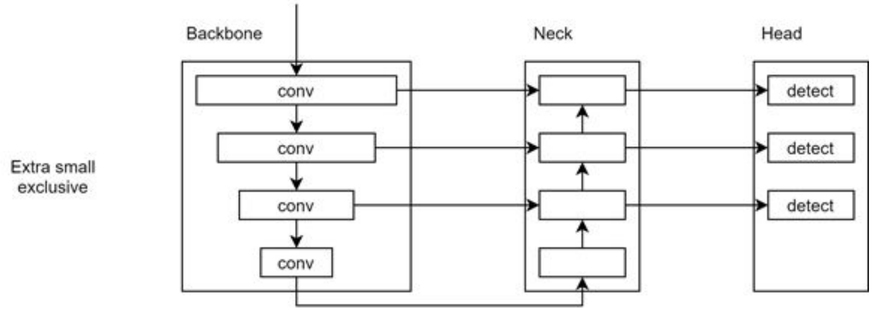
Seeing is Believing

Advanced Perception

- Perception: transforming sensor data into object information
- Usually involves very big machine learning models
- Many challenges:
  - Object/background separation
  - 2-D/3-D projection
  - Sensor fusion
  - Object identification
  - Sensor degradation (e.g. due to weather, darkness, etc.)
  - Real-time speed

Brookes groups (Visual AI Lab, Autonomous Driving and Intelligent Transport) are at the forefront of research in this area.



V. Musat, I. Fursa, P. Newman, F. Cuzzolin and A. Bradley, "Multi-weather city: Adverse weather stacking for autonomous driving," in 2021 IEEE/CVF International Conference on Computer Vision Workshops (ICCVW), Montreal, BC, Canada, 2021 pp. 2906-2915.
doi: 10.1109/ICCVW54120.2021.00325

Benjumea, A., Teeti, I., Cuzzolin, F., Bradley, A., (2021).
YOLO-Z: Improving small object detection in YOLOv5 for autonomous vehicles.
IEEE/CVF International Conference on Computer Vision (ICCV) ROAD challenge workshop, 2021.

Adverse Weather / Lighting

- Computer vision in good weather is (relatively) easy
- Driving in adverse weather is hard
- Night is particularly challenging
- The real world offers no weather guarantees
- Robust perception is essential for Level 5 autonomous vehicles

Oxford: Good vs. adverse lighting - Oxford RobotCar dataset - OBU Detections

W. Maddern, G. Pascoe, C. Linegar and P. Newman, "1 Year, 1000km: The Oxford RobotCar Dataset", *The International Journal of Robotics Research (IJRR)*, 2016.

Augmentation: Multi-weather city

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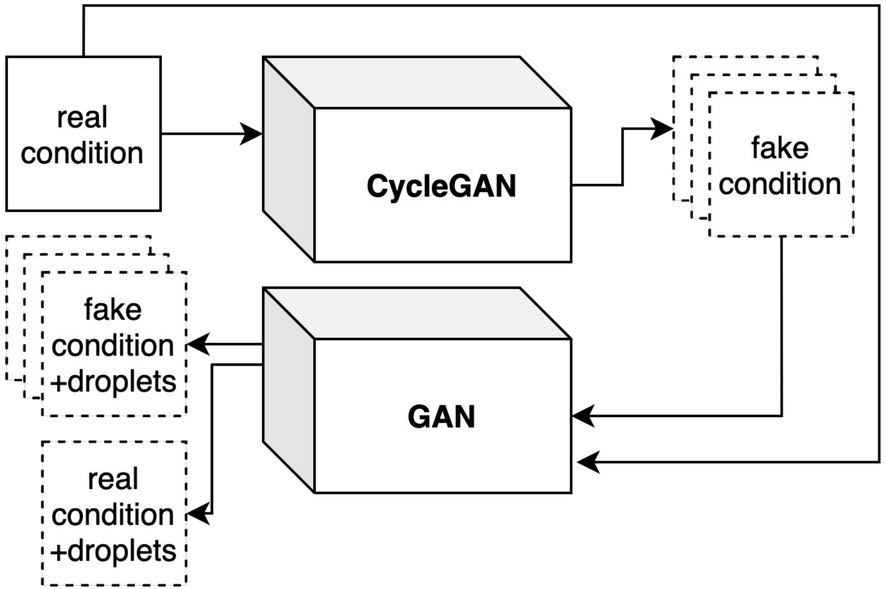
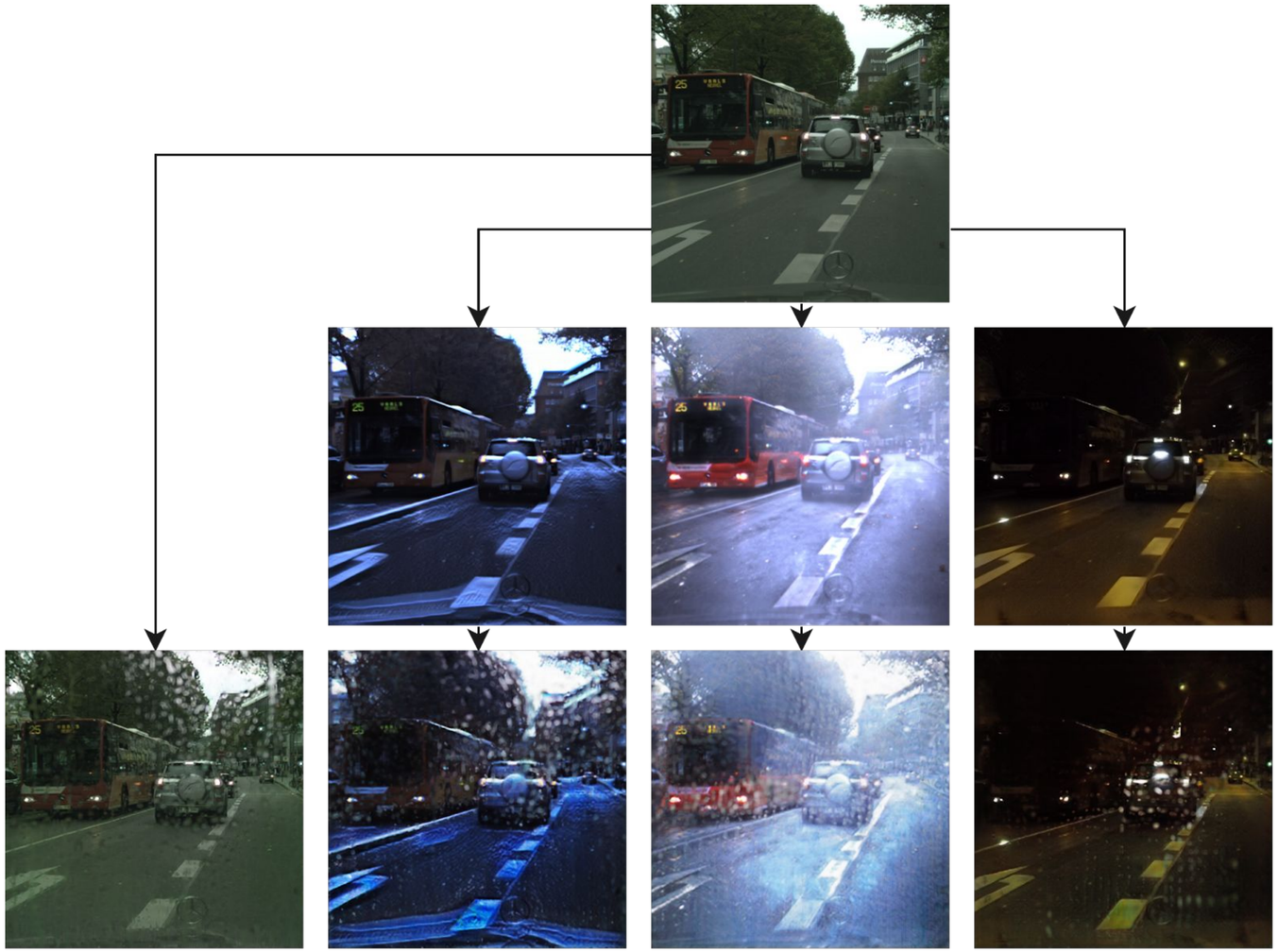
Adverse weather stacking for autonomous driving

- Use of GANs for style transfer
- Vast increase in the amount of training data





Musat, V., Fursa, I., Newman, P., Cuzzolin, F., Bradley, A. (2021). 'Multi-weather City: Adverse Weather Stacking for Autonomous Driving'. 2021 International Conference on Computer Vision.

VISUAL ARTIFICIAL INTELLIGENCE LABORATORY

Augmentation: Worsening Perception

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Deliberate worsening of camera imagery to emulate the effect of adverse weather upon the AV perception system

- Enables stress-testing of downstream subsystems

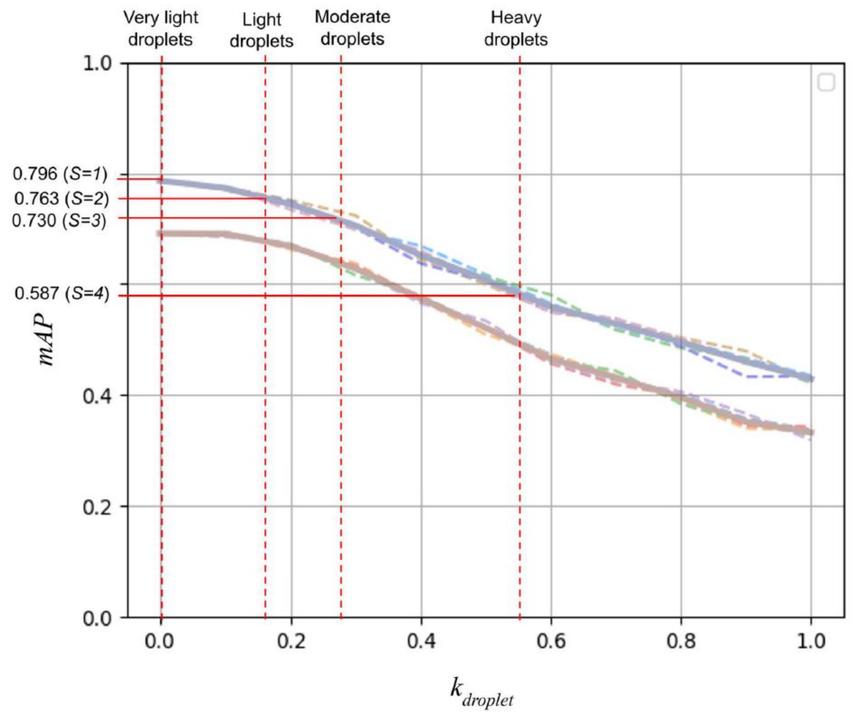
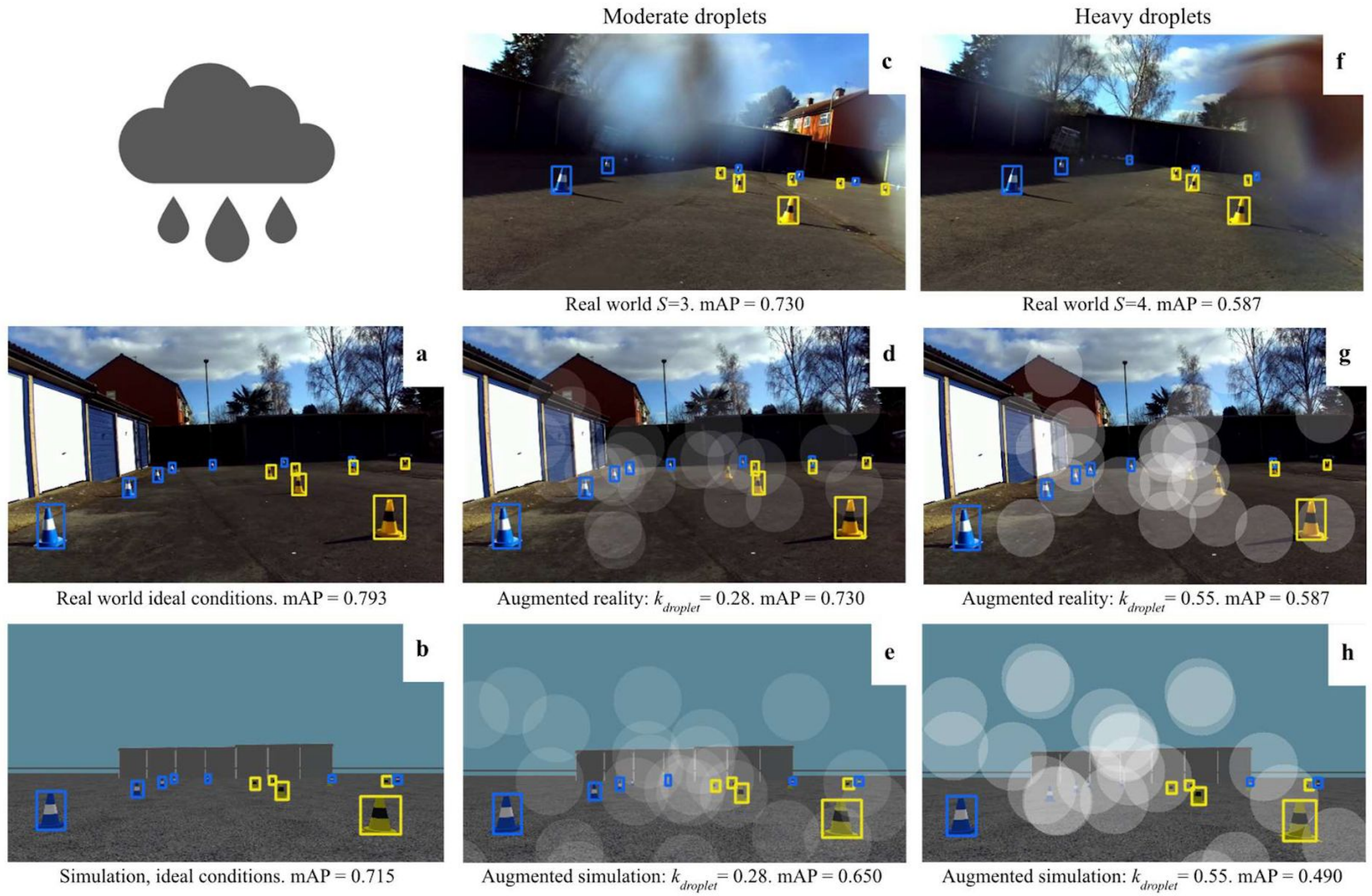


Figure 3: Effect of adherent droplet augmentation upon perception performance on real-world camera (blue) and simulator output (brown) - Solid line shows the mean of all sweeps. Horizontal and vertical lines indicate the experimental mAP from the corresponding severity (in real-world testing).



Fursa, I., Fandi, E., Musat, V., Culley, J., Gil Esteller, E., Bilous, L., Vander Sluis, I., Rast, A., Bradley, A. (2021). 'Worsening Perception: Real-time Degradation of Autonomous Vehicle Perception Performance for Simulation of Adverse Weather Conditions'. SAE Journal of Connected & Automated Vehicles. arXiv:2103:02760.

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“We’ll see”… Isn’t good enough

Road Understanding

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Weather conditions

Roadside Infrastructure

Road user behaviour

Robust perception

Autonomous system & vehicular integration

Vehicle control

Vehicle state, Position, localisation & Mapping

ROAD: ROad event Awareness Dataset

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World's first dataset for road awareness in autonomous driving

- 122k frames, 1.7M labels
- Annotation layer on videos from the Oxford RobotCar Dataset

- ROAD Workshop at ICCV'21

- IEEE PAMI publication:

Singh, G., Akrigg, S., Di Maio, M., Fontana, V., Alitappeh, J.R., Saha, S., Jeddisavari, K., Yousefi, F., Culley, J., Nicholson, T., Omokeowa, J., Khan, S., Grazioso, S., Bradley, A., Di Gironimo, G., Cuzzolin, F. (2021). 'ROAD: The ROad event Awareness Dataset for Autonomous Driving'. IEEE Transactions on Pattern Analysis and Machine Intelligence.

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Action Detection & Prediction

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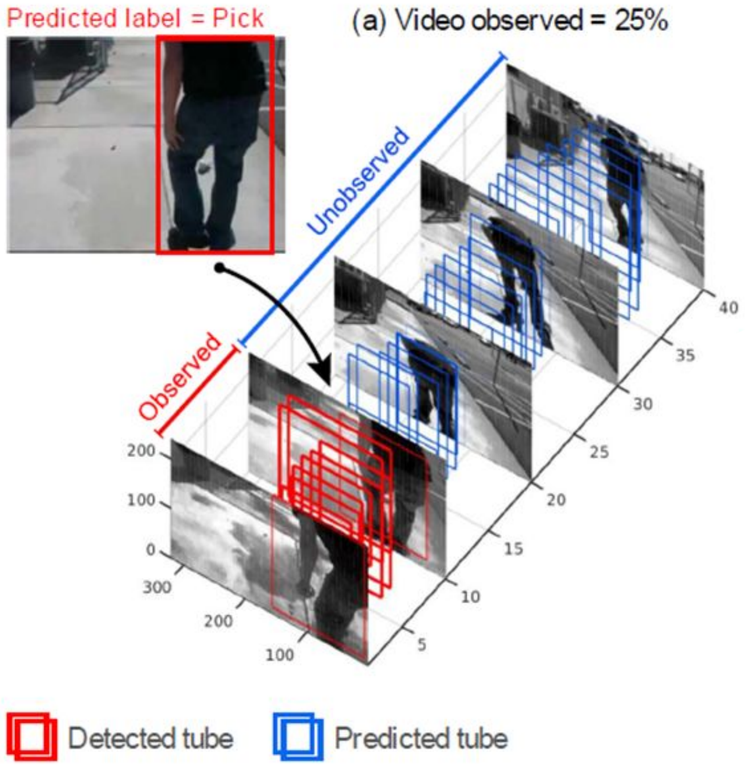
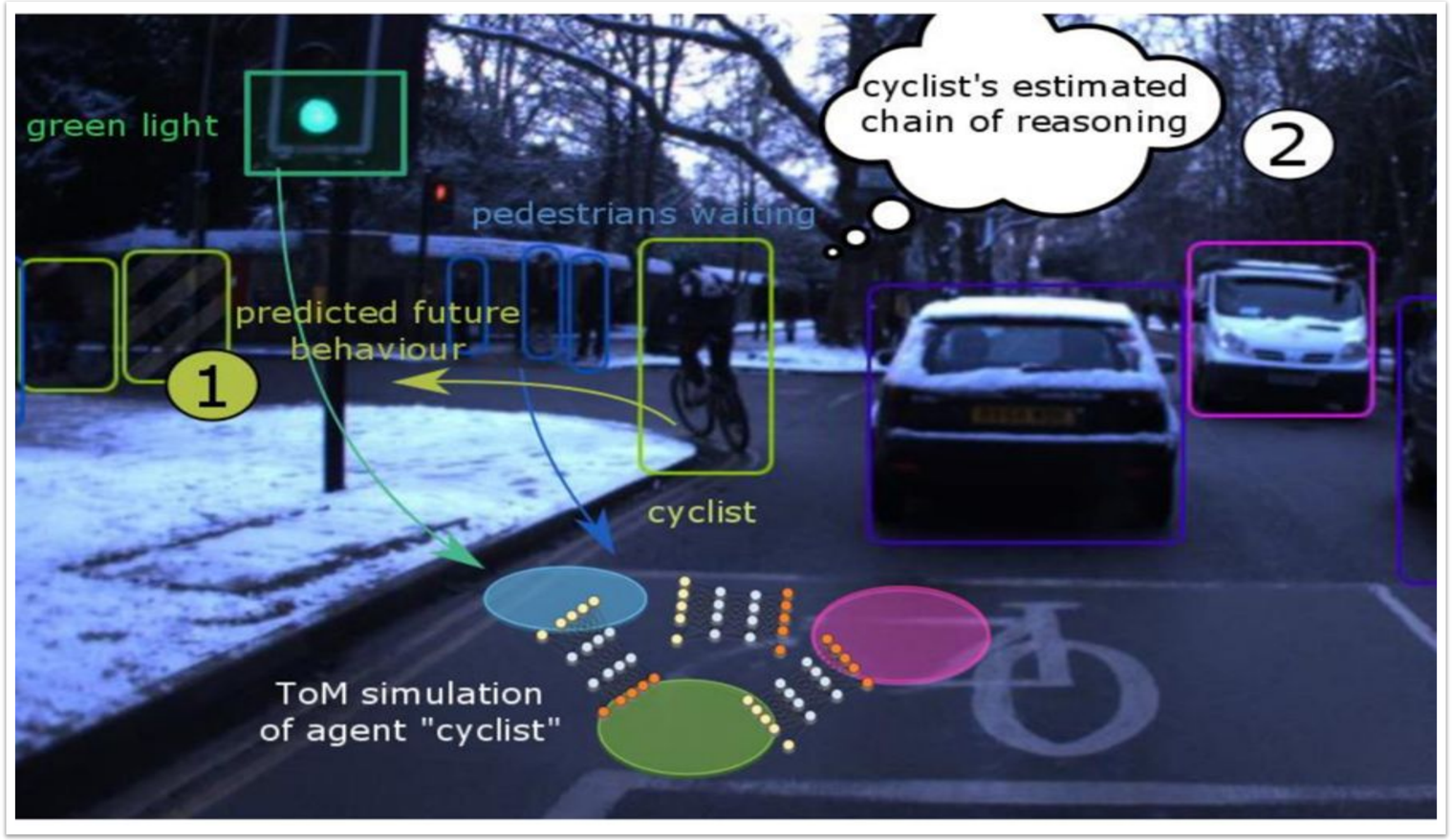
- Time series predictions of evolution of actions
- Theory of Mind (ToM) simulations
- Essential for unstructured environments





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Epistemic AI for Autonomous Driving

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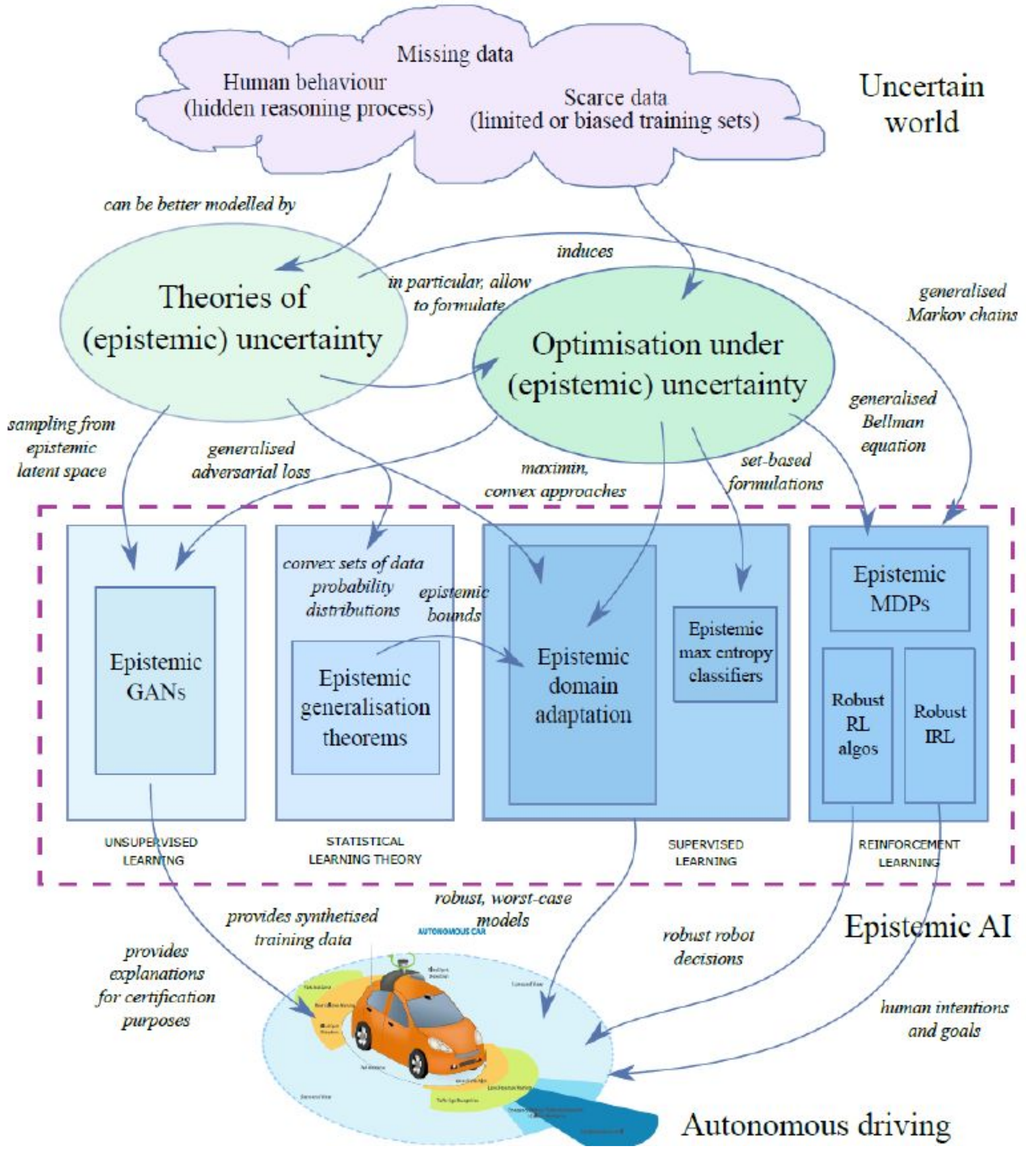
- €3 M (€1,209,000 to Brookes) EU Horizon 2020 Project
- Oxford Brookes is the lead and coordinator of the project
- Epistemic AI: Quantifying 'unknown unknowns'
  - Model uncertainty
  - Out-of-distribution events
  - Missing data

- Learn the space of models, not just a model
- Robust to unreliable/constantly changing data
- A movement towards explainable AI
- Rapid, 'single shot' learning
- A more reliable approach for unstructured environments



Epistemic AI

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Ethical Autonomous Vehicles

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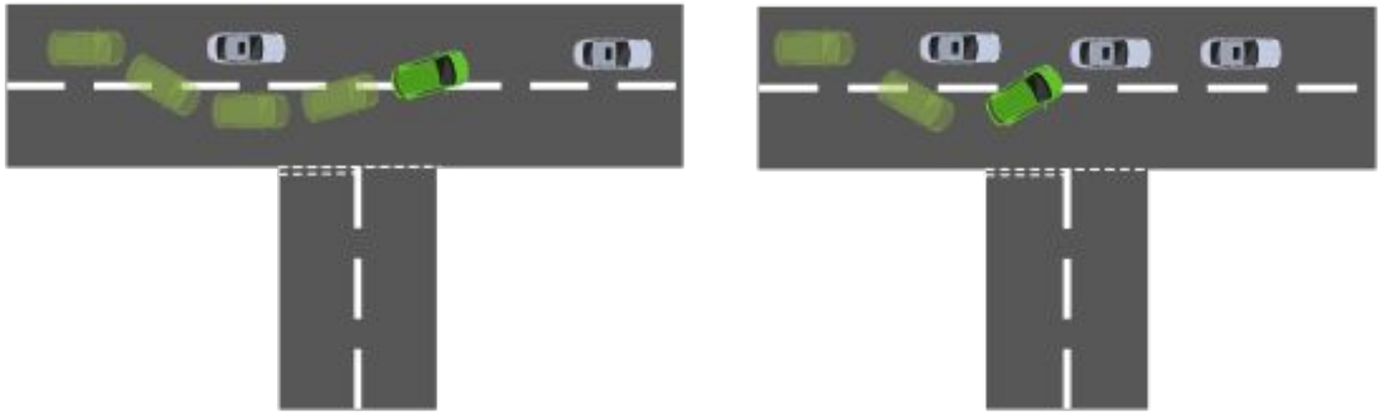
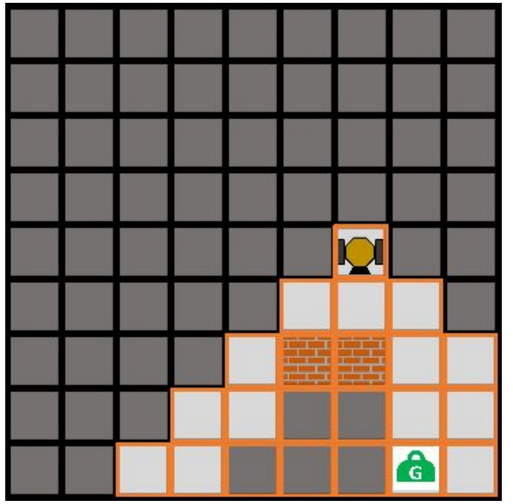
- Development of machines with moral competence
- Ethical Alignment of the behaviour of autonomous robots with user/societal moral norms (e.g. acceptable driving behaviours)
- Mitigation of the discovery of inappropriate robot behaviour through exploratory learning (i.e. Reinforcement learning)
- Enabling robots to learn virtues



Overtaking Scenarios



The Institute for Ethical AI

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Testing Times

Simulating Autonomous Vehicles

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Vehicle dynamic modelling

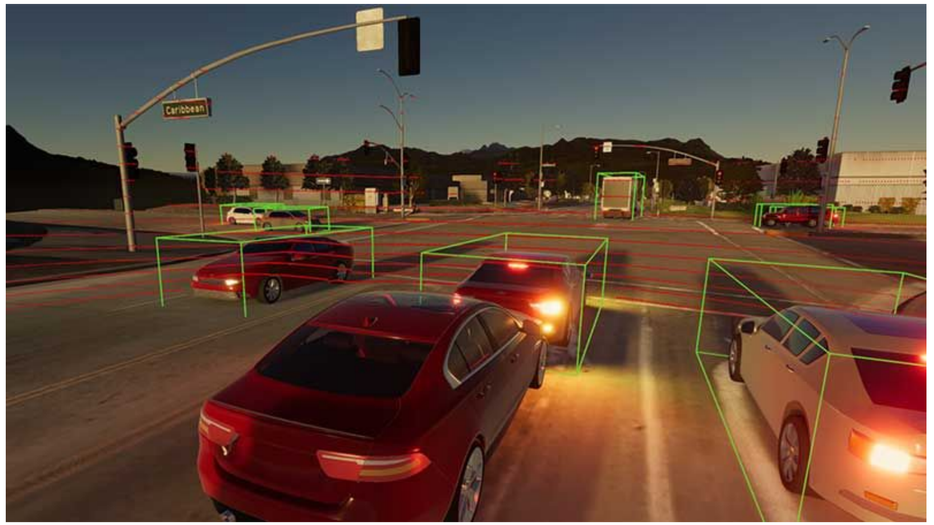
Driver-in-Loop Simulation

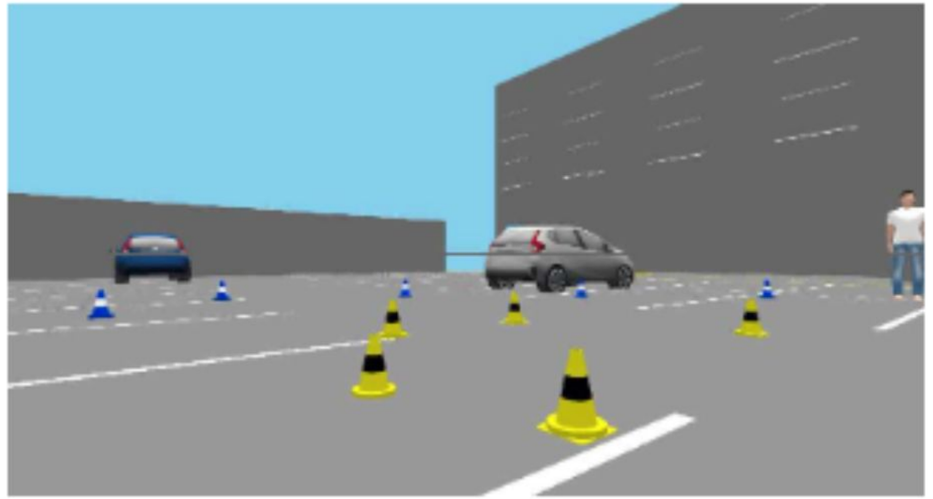
Sensor modelling

HiL testing

Augmented-Reality testing

- Enables targeted use of augmented data to enhance dataset
- Stress-testing perception systems
- Building better prior knowledge about the world





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Augmented-Reality Testing

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A real vehicle drives in real-world ...

The dynamic Vehicle-in-the-Loop Simulation System in this project will be fitted into a real StreetDrone vehicle.

Multiple virtual vehicles will be injected in order to test vehicle control systems and decision making capabilities in a controlled, repeatable, cost-effective and configurable way.

... and interacts with surrounding virtual vehicles

Main strengths of the proposed test system:

- Testing on high integration level
- Experience of dynamic system behaviour
- Significant reduction in testing effort, cost and timescale
- Flexibility in test case variation

PROJECT ATRIUM

AuTonomous DRiving SImUlation and Modelling

zeta MILLBROOK OXFORDSHIRE COUNTY COUNCIL OXFORD BROOKES UNIVERSITY STREETDRONE

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Is the world ready for AVs?

Infrastructure Readiness for CAVs

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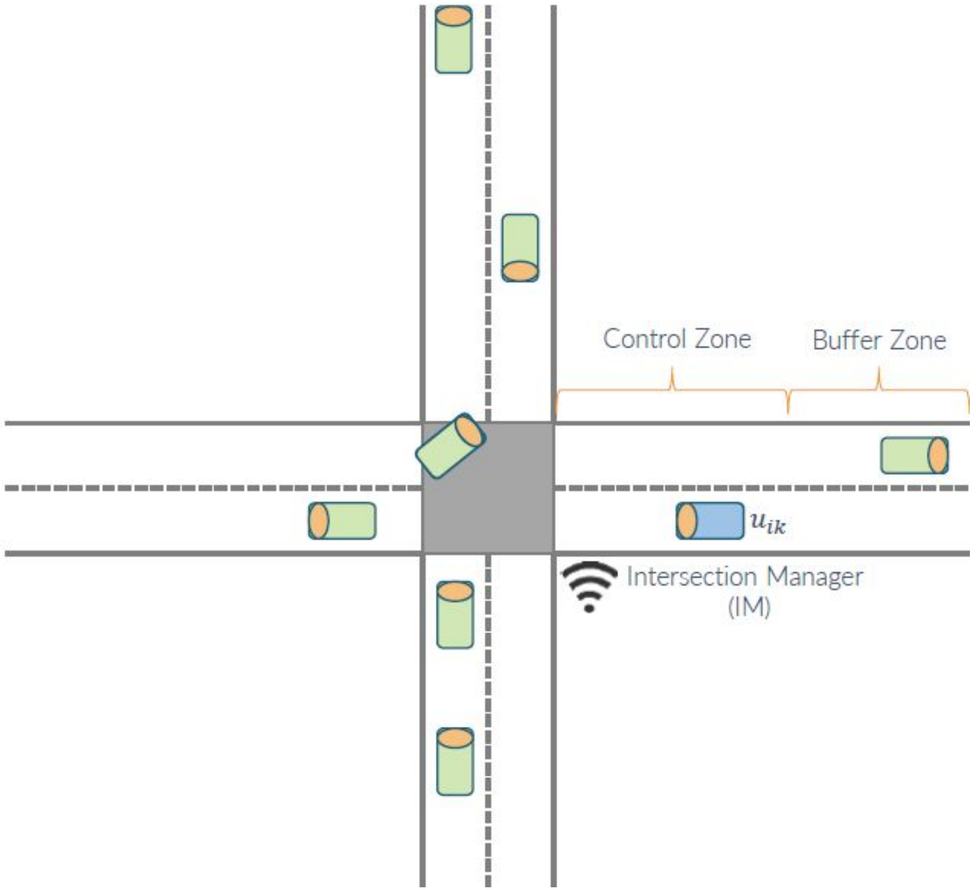
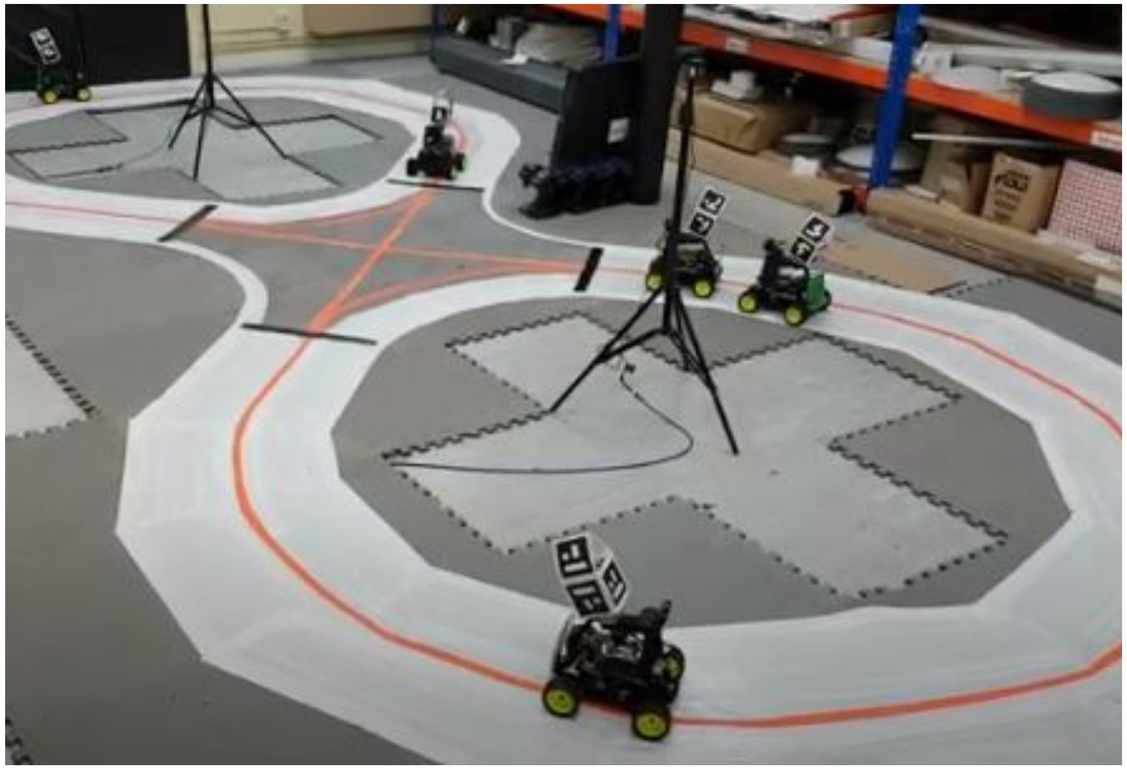
Structures	Roads	Communications	Drainage	Geotechnical
Parking facilities	Autonomy-enabled roads	Roadside communication	Water and flooding	Platooning and convoys – tunnels, vegetation
Fuelling and power distribution	Maintenance	Multiple traffic signals		
Segregated infrastructure	Road geometry	Construction plans		
Street lighting		Clarity of road markings and signage		
Roundabouts		Handling tolls		

One of the most important requirements for creating CAV-enabled road systems is achieving **maximum predictability** in the traffic environment.

AI Intersection Management





- **Reinforcement Learning (RL)** defines the objective
- **Deep Learning (DL)** gives the mechanism
- RL + DL = General Intelligence

Budan, G., 2021. *Connected and automated vehicle enabled traffic intersection control with reinforcement learning* (Doctoral dissertation, Oxford Brookes University).

Communications & Cyber Security

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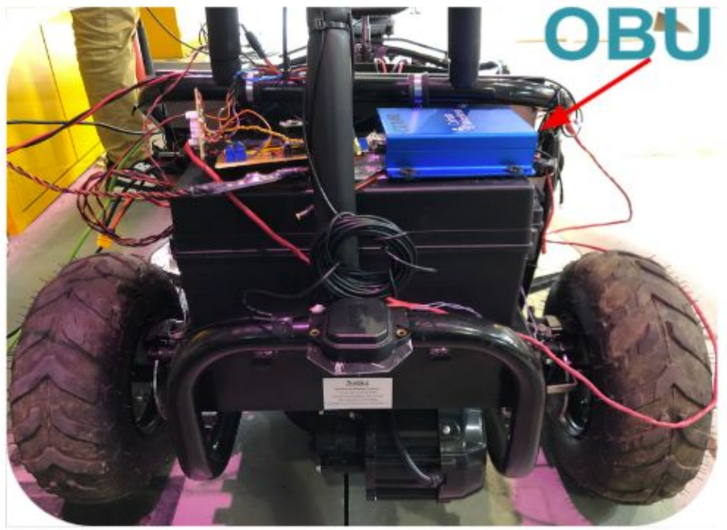
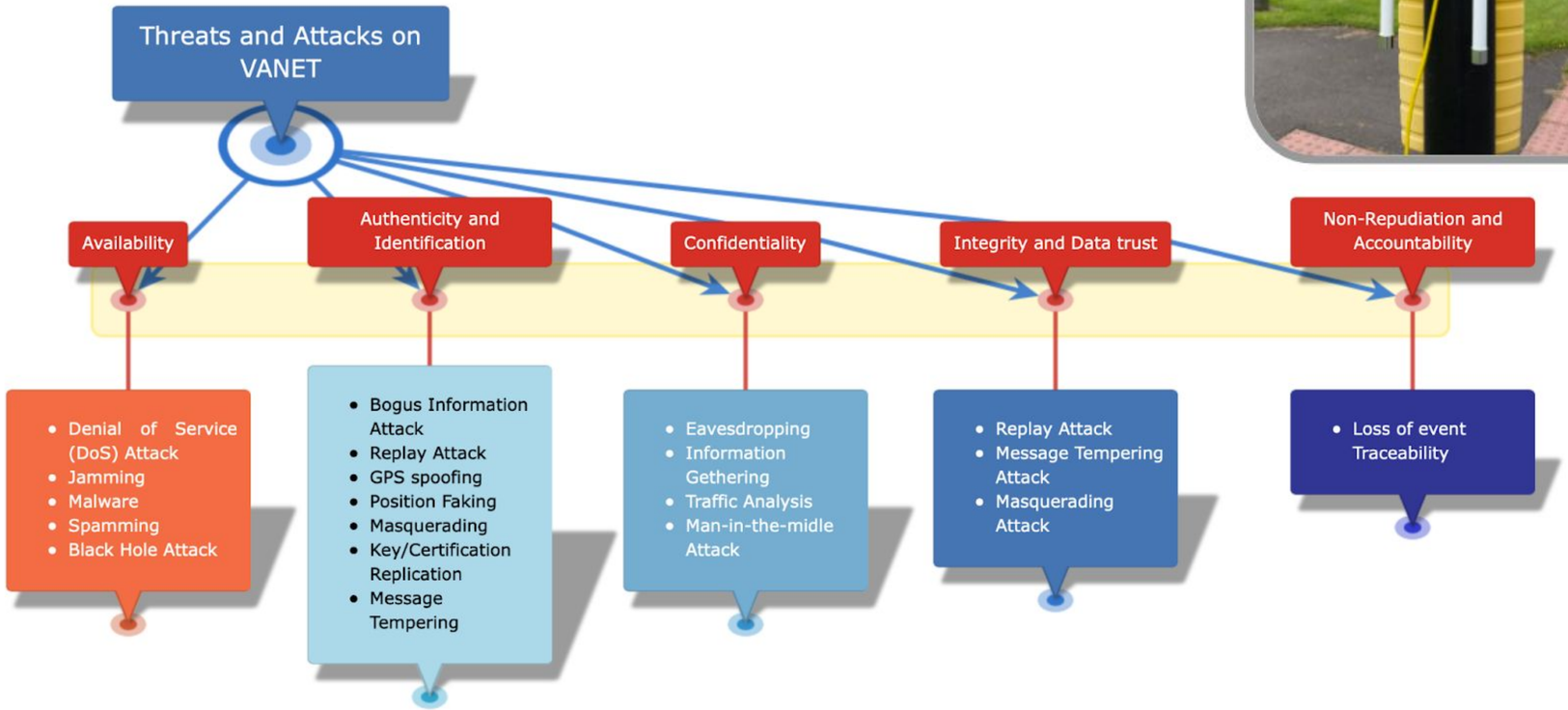
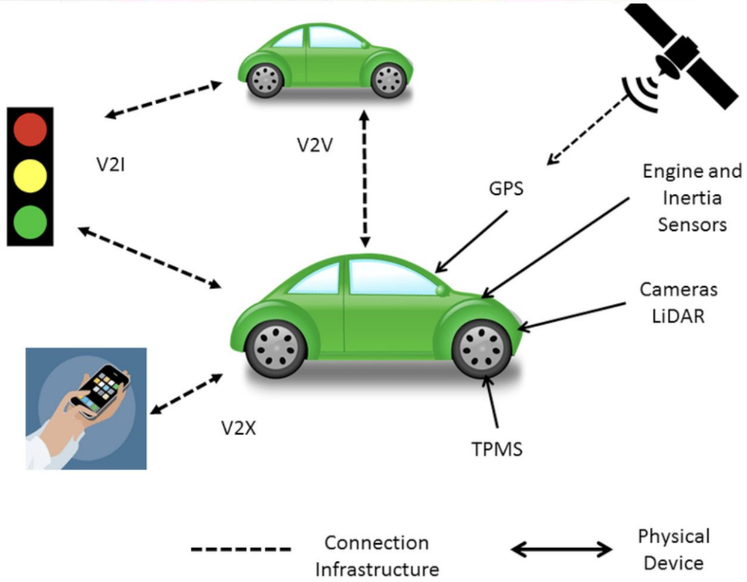
- Risk of exploiting communication layer on CAVs with many potential cyber-attacks
- Machine Learning approaches for anomaly detection and mitigation techniques for cyber threat on CAVs

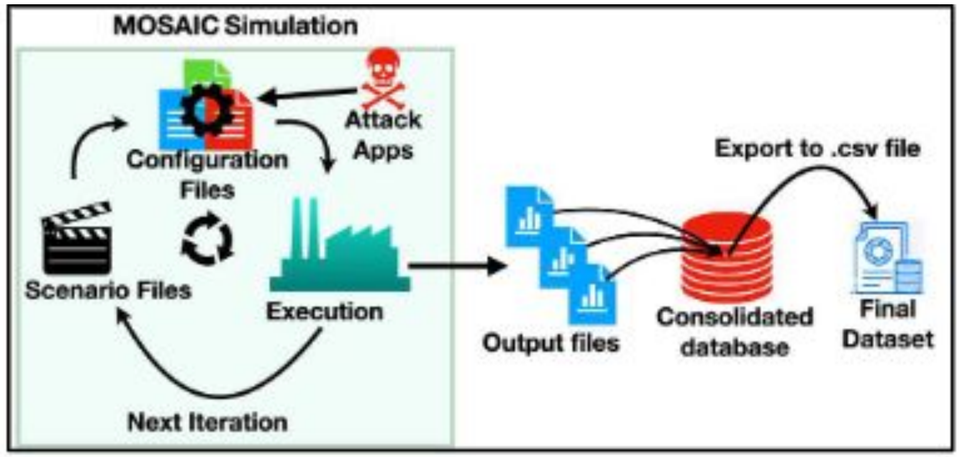


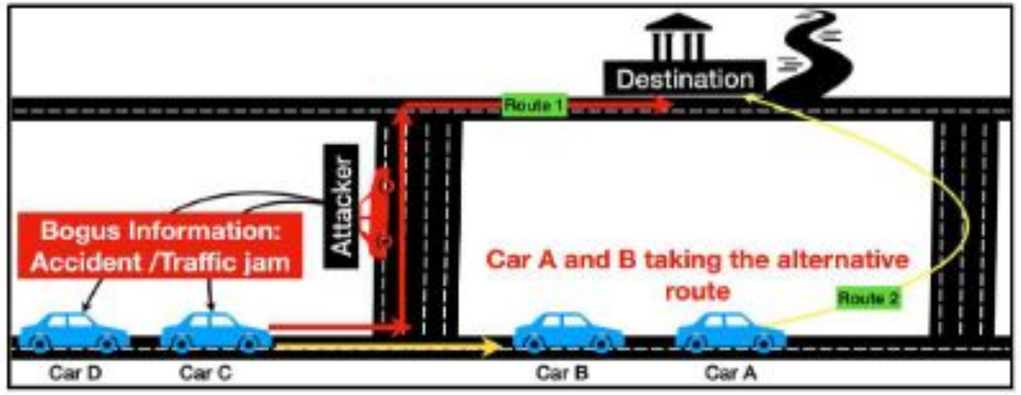




Cyber Security

- Simulate cyber attacks on CAVs to generate a dataset
- Train a Machine learning model for threat detection
- ….ongoing work on attack detection and mitigation using AI methods





Iqbal, S., Ball, P., Kamarudin, M.H., Bradley, A., (2021). Simulating Malicious Attacks on VANETs forConnected and Autonomous Vehicle Cybersecurity:A Machine Learning Dataset. CSNDSP 2022

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Motorsport accelerates innovation

Formula Student: Artificial Intelligence

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Annual international competition held at Silverstone racetrack

Two classes:

- ADS Class – Design and build (or retrofit) your own autonomous racing car
- DDT Class – Use competition-provided car with your own software and sensors

Static Events:

Business Plan Presentation	100
Real World AI	100
Engineering Design	150
Simulation Development	100
	45%

Dynamic Events:

Skid Pad	100
Acceleration	100
Autocross/Sprint	100
Trackdrive	250
	55%

Institution of MECHANICAL ENGINEERS

Achievements

AD IT Autonomous Driving & Intelligent Transport

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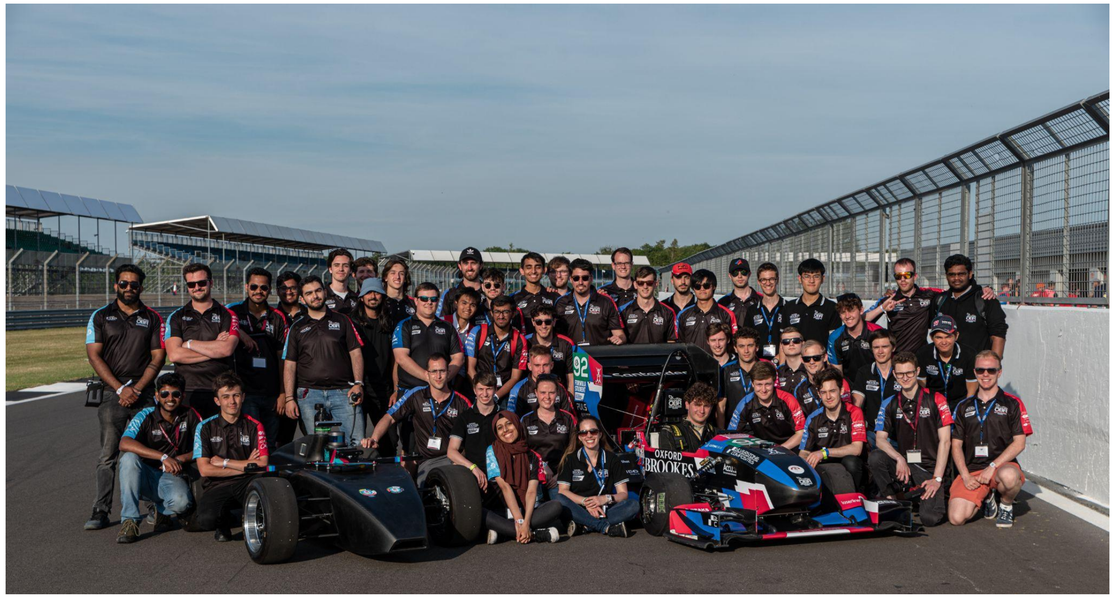


2019

- First place Real World Autonomous event
- Completed 10 laps of the track drive event fully autonomously

2020

- 1st place overall (DDT Class)

2021

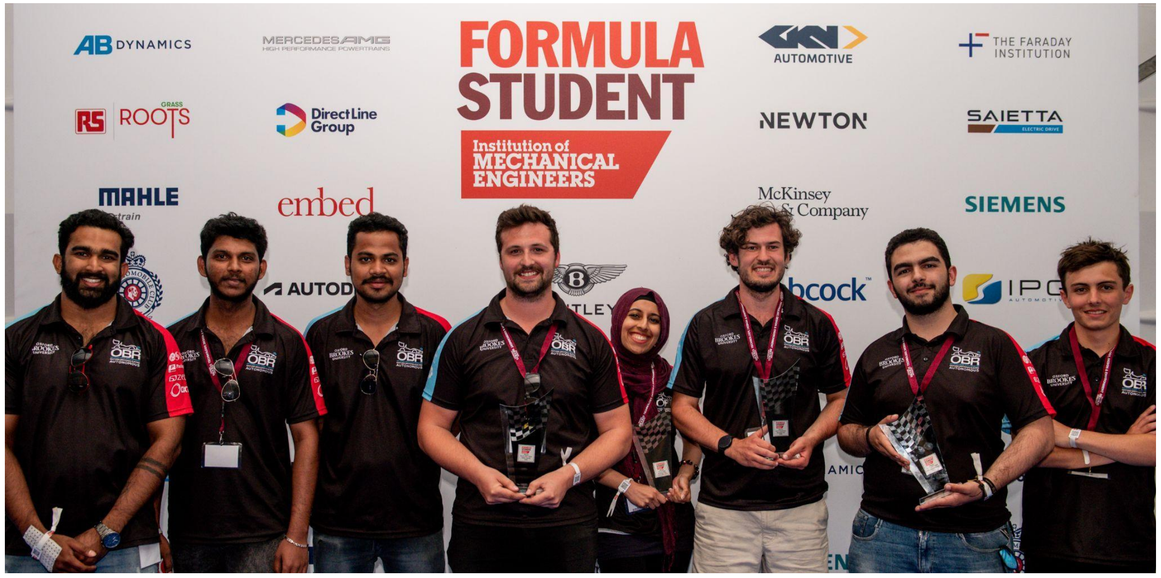
- 2nd place overall (DDT Class)

2022

- 1st place statics
- 3rd place overall (DDT Class)

2023

- 1st place statics
- 2nd place overall (DDT Class)



✔Publications resulting from student work

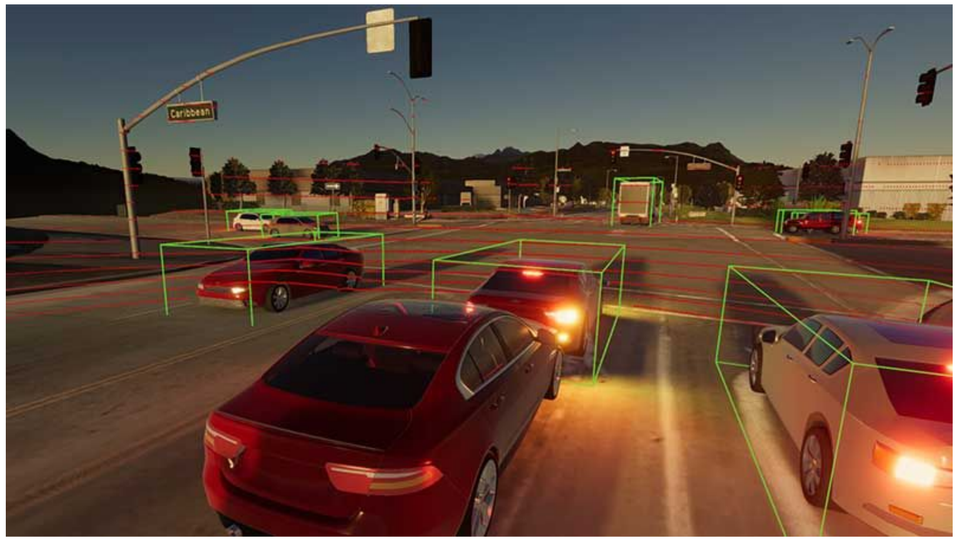
- S. Garlick & A. Bradley (2022) Real-time optimal trajectory planning for autonomous vehicles and lap time simulation using machine learning, Vehicle System Dynamics, 60:12, 4269-4289, DOI: 10.1080/00423114.2021.2011929
- Singh, G., Akrigg, S., Di Maio, M., Fontana, V., Alitappeh, J.R., Saha, S., Jeddisavari, K., Yousefi, F., Culley, J., Nicholson, T., Omokeowa, J., Khan, S., Grazioso, S., Bradley, A., Di Gironimo, G., Cuzzolin, F. (2022). 'ROAD: The ROad event Awareness Dataset for Autonomous Driving'. IEEE Transactions on Pattern Analysis and Machine Intelligence. arXiv: 2102.11585.
- Fursa, I., Fandi, E., Musat, V., Culley, J. et al., "Worsening Perception: Real-Time Degradation of Autonomous Vehicle Perception Performance for Simulation of Adverse Weather Conditions," SAE Intl. J CAV 5(1):87-100, 2022, https://doi.org/10.4271/12-05-01-0008.
- Benjumea, A., Teeti, I., Cuzzolin, F., Bradley, A., (2021). YOLO-Z: Improving small object detection in YOLOv5 for autonomous vehicles. IEEE/CVF International Conference on Computer Vision (ICCV) ROAD challenge workshop, 2021.
- Ravi, S., Bradley, A., Collier, C. (2020). 'MPC Controller for Autonomous Formula Student Vehicle'. SAE Technical Paper Series 2020-01-0089.
- Budan, G., Hayatleh, K., Morrey, D., Ball, P., Shadbolt, P. (2018). '*An analysis of vehicle-to-infrastructure communications for nonsignalised intersection control under mixed driving behaviour*'. Analog Integrated Circuits and Signal Processing.

Summary

AD IT Autonomous Driving & Intelligent Transport

OXFORD BROOKES UNIVERSITY

- Leading institution for automotive & motorsport education
- Specialist facilities for High Voltage Energy Systems for EVs
- Expertise in AI
- Highly active, industry-linked CAM research community including:
  - Perception in challenging conditions
  - Prediction of road user behaviour
  - Low-power embedded computing
  - Connected vehicles
  - Cybersecurity for CAVs
  - Explainable and transparent AI
- Award-winning human and autonomous racing teams
- *OBR Autonomous* team: Training students to be the next generation of autonomous vehicle engineers & developers



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https://www.brookes.ac.uk/research/units/tde/groups/autonomous-driving-and-intelligent-transport

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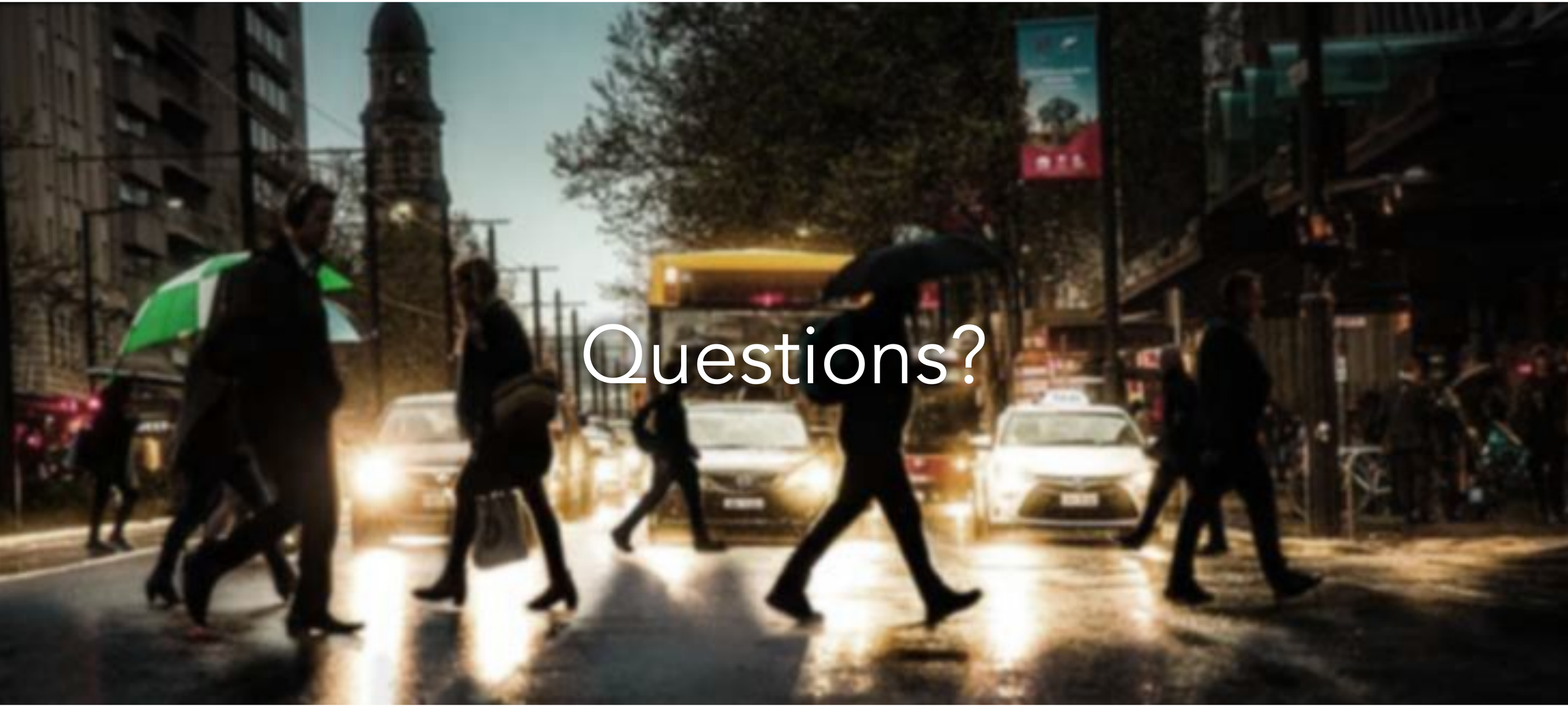

UKRI Innovate UK

Centre for Connected & Autonomous Vehicles