Universität St.Gallen

Challenges, Opportunities, and Projects in Embedded Sensing Systems

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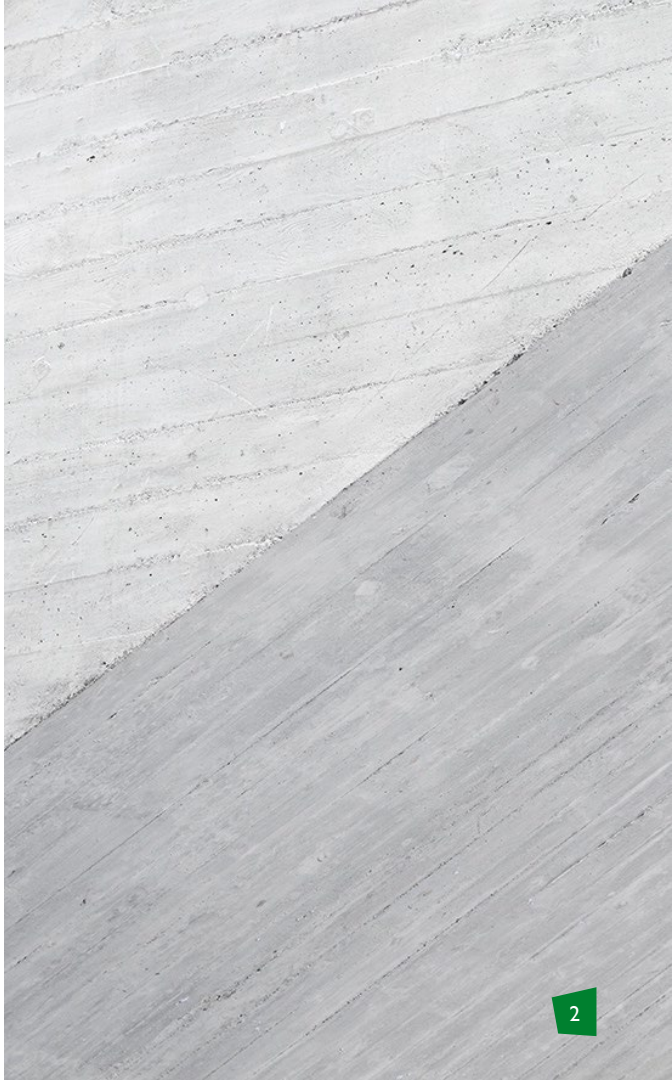
From insight to impact

Agenda

1. Perceiving and Reacting to the Real-world
2. Challenges – Finding the Solution Space
3. Opportunities in Embedded Sensing
4. Ongoing Projects
5. Summary and Takeaways



1. Introduction

Perceiving and Reacting to the Real-world

From **Perceiving** the Real-world...

TRANSLATING THE REAL-WORLD

Measure physical quantities and converts into digital signals, that can be read by an observer or instrument

APPLICATION RANGE

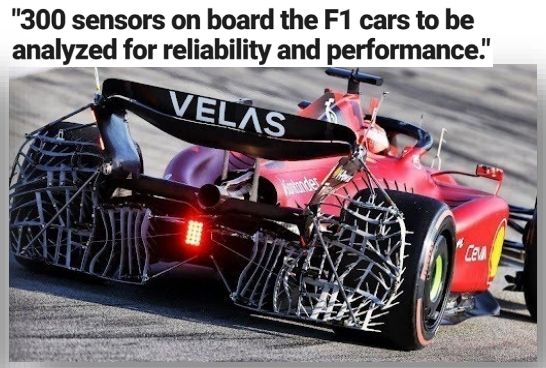
Diverse applications ranging from personal fitness tracking to life-critical industrial applications

SENSOR TYPES

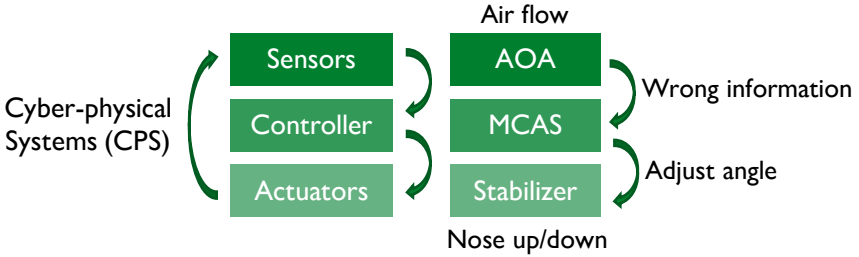
Active/passive, contact/non-contact, absolute/relative

TRENDS

Ongoing trend to produce **smaller sensors**, which are more **resource-efficient, accurate**, and **reliable**



... To **Reacting** to The Real-world



ACCURACY AND PRECISION

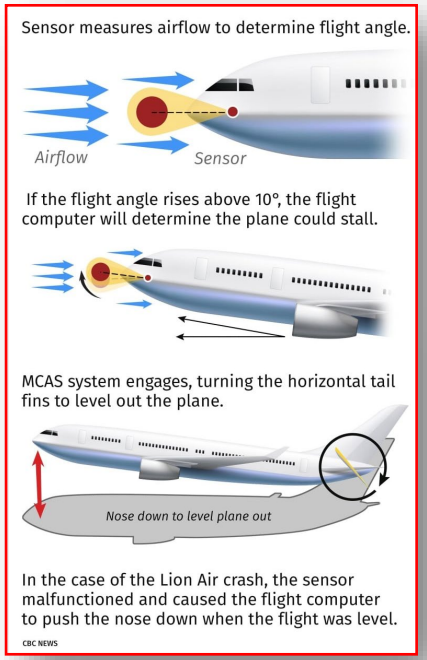
- Key enablers of any Cyber-physical System
- Accuracy is how close a measured value is from the real value and precision refers to the reproducibility of measurements

PERFORMANCE AND RELIABILITY

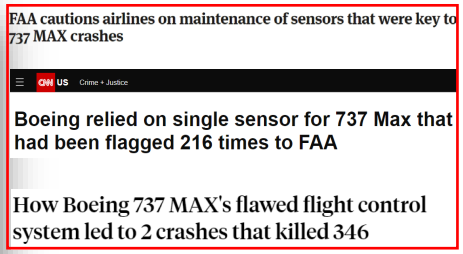
- Accurate information in a timely manner
- Certain decision-making systems requires extremely reliable information (e.g., healthcare, aviation)

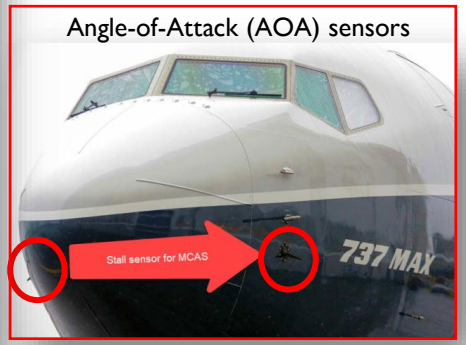
SAFETY, **SE**CURITY, AND **PR**IVACY

- Preventing accidental failures harmful to humans
- Preventing malicious users
- Preventing misuse of information



https://www.seattletimes.com/business/boeing-aerospace/preliminary-report-due-today-on-737-max-crash-in-ethiopia/





2. Challenges

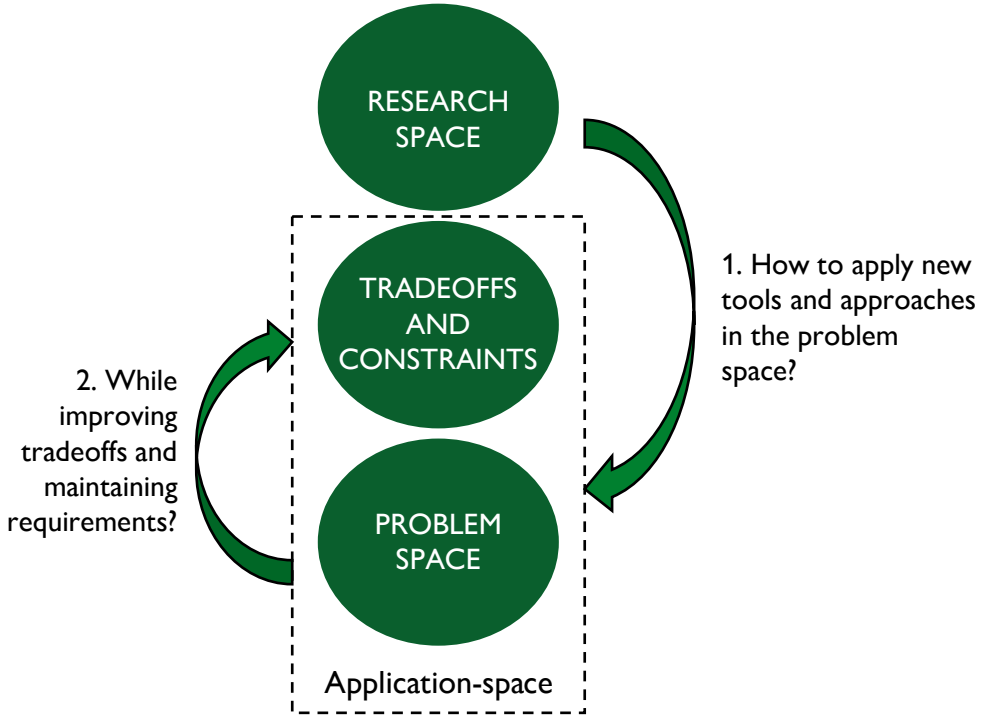
Research-, problem-, and solution-space

Challenge: Finding the Solution-space

RESEARCH SPACE
- Innovation: incremental contribution to existing applications, or approaches
- Invention: novel applications or approaches

TRADEOFFS AND CONSTRAINTS
- Accuracy and Precision
- Performance and Reliability
- Safety, security, and privacy
- Energy efficiency
- Usability
- Costs

PROBLEM SPACE
- Balancing tradeoffs while ensuring application requirements
- Real-world applications



Example: *Farming Analytics*

SCENARIO
Farm owner desires to track machines and workers in the field to improve efficiency

RESEARCH SPACE
Wearable technology, edge computing, (big) data analytics

CONSTRAINTS AND TRADEOFFS
++ accuracy/precision, **++** consumption, **--** privacy
++ performance and reliability, **++** consumption
++ safety, security, and privacy, **++** consumption
++ consumption, solution **--** cost-effective

PROBLEM-SPACE
How would **you** use the research space to balance these constraints?

Food for thought:
- Do we need a privacy-oriented solution?
- Is it possible to achieve fine-grained analytics preserving privacy?

3. Opportunities

Trends in Embedded Sensing

Intelligence on the Edge

EDGE COMPUTING

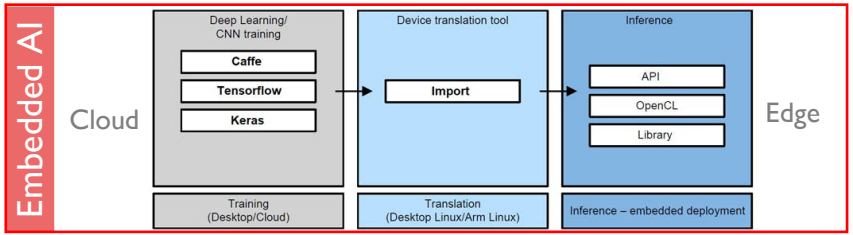
- Moves compute and storage closer to the edge of the network
- **Less data, more information**
- Significant impact on energy efficiency of mobile sensors

EMBEDDED AI

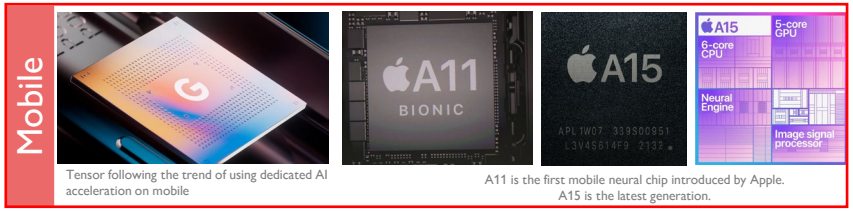
- Requires dedicated AI-chips (AI-accelerators) with focus on energy optimization
  - Example 1 (mobile): Apple's Bionic chips A11-A15 (iPhones), Google Tensor (Pixel phone)
  - Example 2 (IoT) : "TinyML" project enable AI on resource-constrained devices (wereable, IoT)
- You do not train models on the edge, rather apply them

KEY QUESTIONS

- What are the tradeoffs?
- Which type of applications allows it?

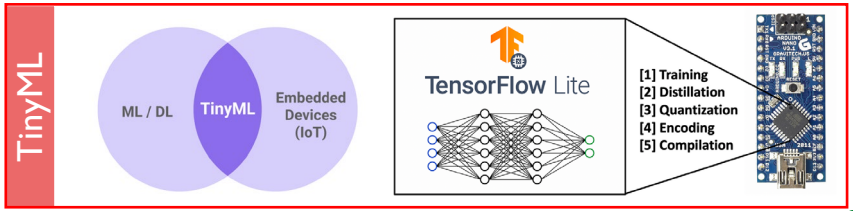


https://www.electronicdesign.com/markets/automation/article/21808380/bring-deep-learning-inference-to-embedded-applications

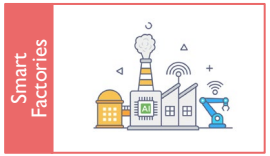


Tensor following the trend of using dedicated AI acceleration on mobile

A11 is the first mobile neural chip introduced by Apple.
A15 is the latest generation.



Our Research



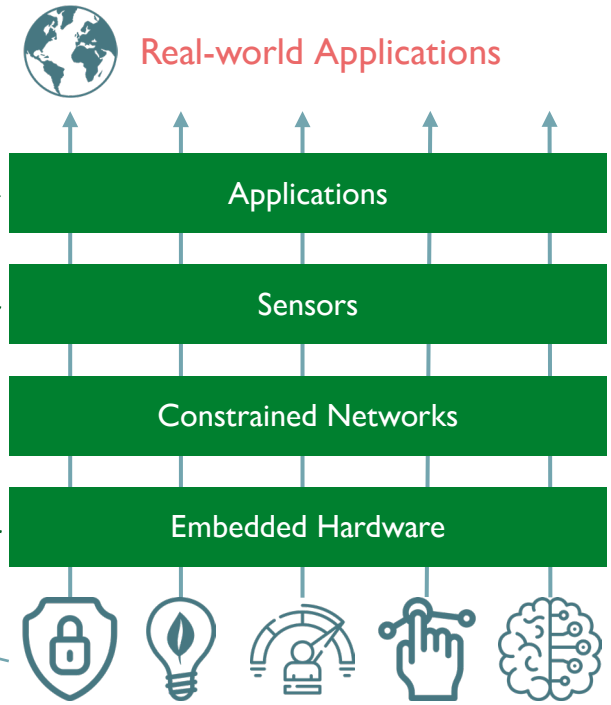
INDUSTRY APPLICATIONS
How to explore **new** (invention) and **existing** (innovation) use cases?

SENSING THE REAL WORLD
How to track and trace the **analogic, real-world** into the **digital space**?

CONSTRAINED NETWORKING
How to **communicate to/from sensors** observing constraints?

EMBEDDED HARDWARE/REAL-TIME OPERATING SYSTEMS
How to explore new/existing **hardware architectures** to **optimize transversal areas**?

TRANSVERSAL AREAS
How to explore tradeoffs and optimizations given application constraints such as **accuracy, security, energy efficiency, performance/scalability, usability**



4. Projects & Ideas

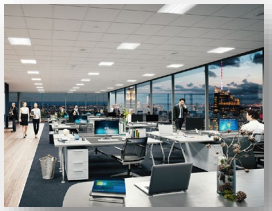
Overview

An Online Game Theory Approach to Optimize Charging Station Turnover During Peak Demand

Spectral-temporal Anomaly Detection for High-altitude Pumped Storage Hydroelectric Power Plants

Context-aware Adaptive Lighting for Office Spaces

Task-level Collaborative Ad-hoc Autonomous Guided Vehicles (AGV) for Efficient Warehouse Logistics



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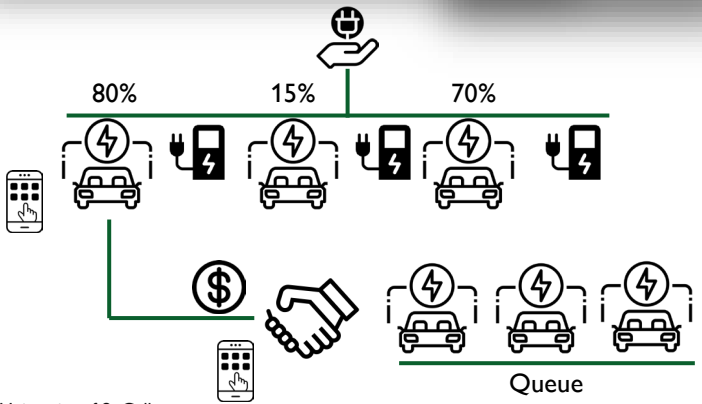


SCENARIO

Increasing demand for Electric Vehicle (EV) charging stations (CS)
Charging rate is inversely proportional to the level of the battery's charge

PROBLEM

Provider perspective: low CS turnover at peak demand
Customer perspective: dissatisfied due to waiting queues

APPROACH

Map the scenario as a game where Nash equilibrium is obtained by:

- EV1 at the queue: provide incentives to use CS
- EV2 using CS: release CS satisfied with incentives
- Provider: increase CS turnover, therefore, income

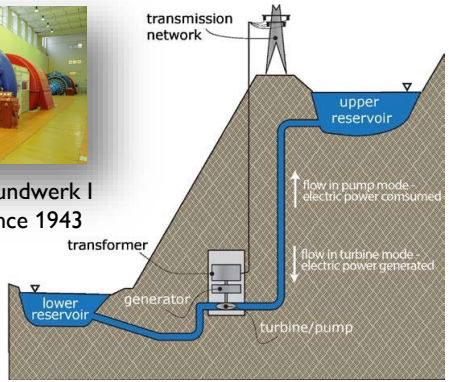
CHALLENGES

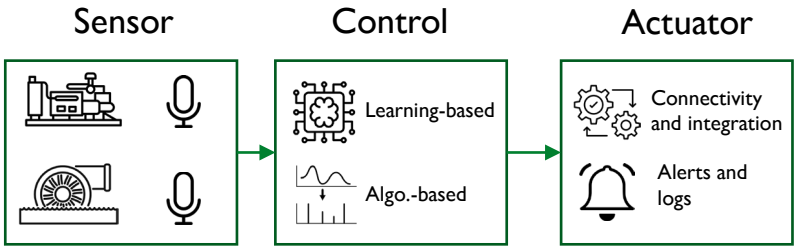
Proof of commitment, user privacy, malicious users, latency and scalability, queue management

Spectral-temporal Anomaly Detection for High-altitude Pumped Storage Hydroelectric Power Plants

Machine room at Lünerseewerk, since 1970

Turbines at Rodundwerk I in operation since 1943





SCENARIO

Access for regular maintenance operations is not straightforward in high-altitude pumped storage hydropower plants.

PROBLEM

- Access in certain periods of the year for regular maintenance operations
- Early detection of anomalies in legacy equipment (turbine, generator).
- Continuous real-time monitoring with limited connectivity.

APPROACH

- Data Collection: Evaluation of infrastructure, sensors (types and configuration), and positioning
- Data Analysis: Algorithimic. (Fourier) vs. Learning-based approach.
- Real-world: connectivity (alerting) and integration

CHALLENGES

- Limited connectivity
- Limited processing for edge learning approaches
- Signal noises, multipath propagation and interferences

Context-aware Adaptive Lighting for Office Spaces

SCENARIO

Individual/shared office environment whose objective is to adapt lightning levels according to occupants sensed mood/states (e.g., inactive, focused, relaxed, customized)

OPPORTUNITIES

- Optimizing energy consumption
- Potential impact in productivity
- Improve office layout and resource-allocation

APPROACH

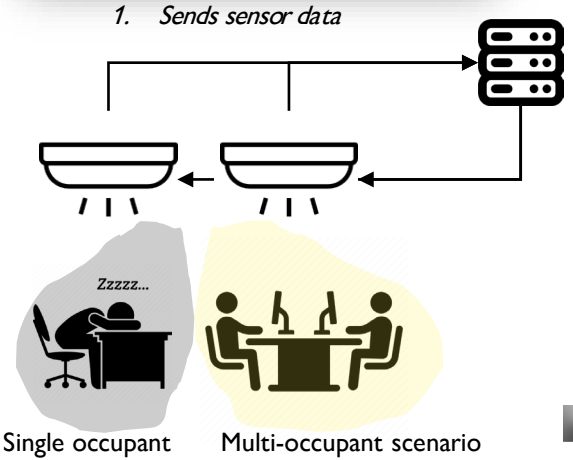
- Multi-modal sensing (PIR, audio, light-level)
- EdgeAI based on local customized policies

CHALLENGES

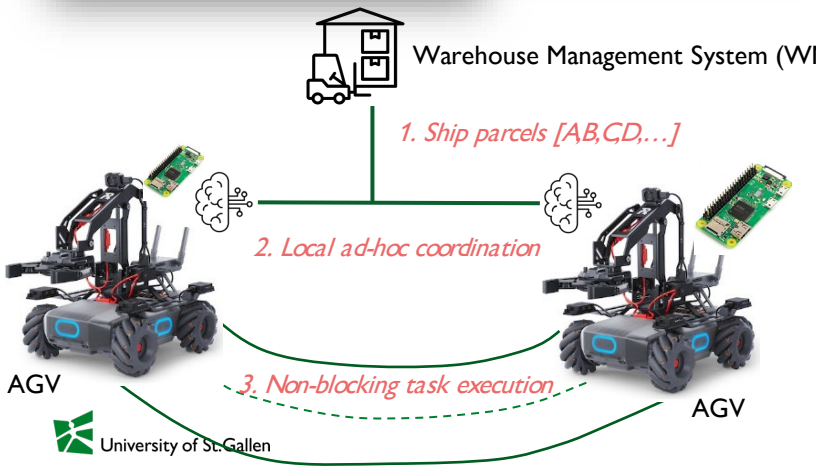
- Accurately determine occupant moods, sentiment analysis
- Adjust lightning levels in a timely manner (low response-time)
- Behavior on multi-occupant environments
- Occupancy data is privacy-sensitive

FUSION OF SENSORS

- Passive Infrared (PIR)
- Ambient light sensors
- Directional microphones



Task-level Collaborative Ad-hoc Autonomous Guided Vehicles (AGV) for Efficient Warehouse Logistics



SCENARIO

AGV robots operating in sliding rails typically do not cooperate at a task-level (e.g., picking and delivering parcels)

PROBLEM

- AGVs are coordinated at the routing level to avoid blocking tasks
- Not optimal when items are concentrated on single shelves distant from a delivering point

APPROACH

- Allow AGVs to operate on the same rail introducing task-level ad-hoc cooperation (and associated mechanisms)
- Hypothesis: two or more AGVs can be faster than a single AGV

CHALLENGES

- Recreate setup for research and experimentation
- Two or more AGVs can introduce complexity for certain tasks
- Performance and scalability of local coordination messages
- Task synchronization with WMS

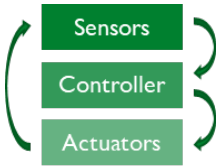
5. Closing

Summary and Takeways

Summary and Takeaways

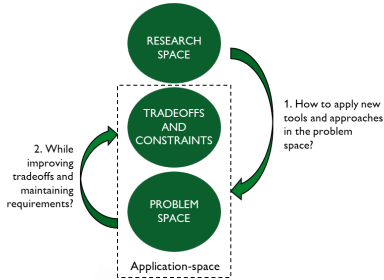
SENSORS AND SENSING

- Relevant for any CPS: Sensing provide input for decision systems at the control layer
- Not only data collection, but the **system at the edge**



CHALLENGES AND OPPORTUNITIES

- Application tradeoffs must always consider **cost/benefit ratio** in applied-research
  - However…. cost/benefit is limiting factor to explore wild research ideas
- **Look beyond the hype**: research/Innovation cannot, in any-case, overlook trending topics
  - EdgeAI on mobile phones and embedded systems (e.g., TinyML)



PROJECTS

- Receptive and open environment to innovation is key… and are finding it!
- **Mind the gap**: we try to look at least 5 years ahead
- Still, more projects to come!

Questions?

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