

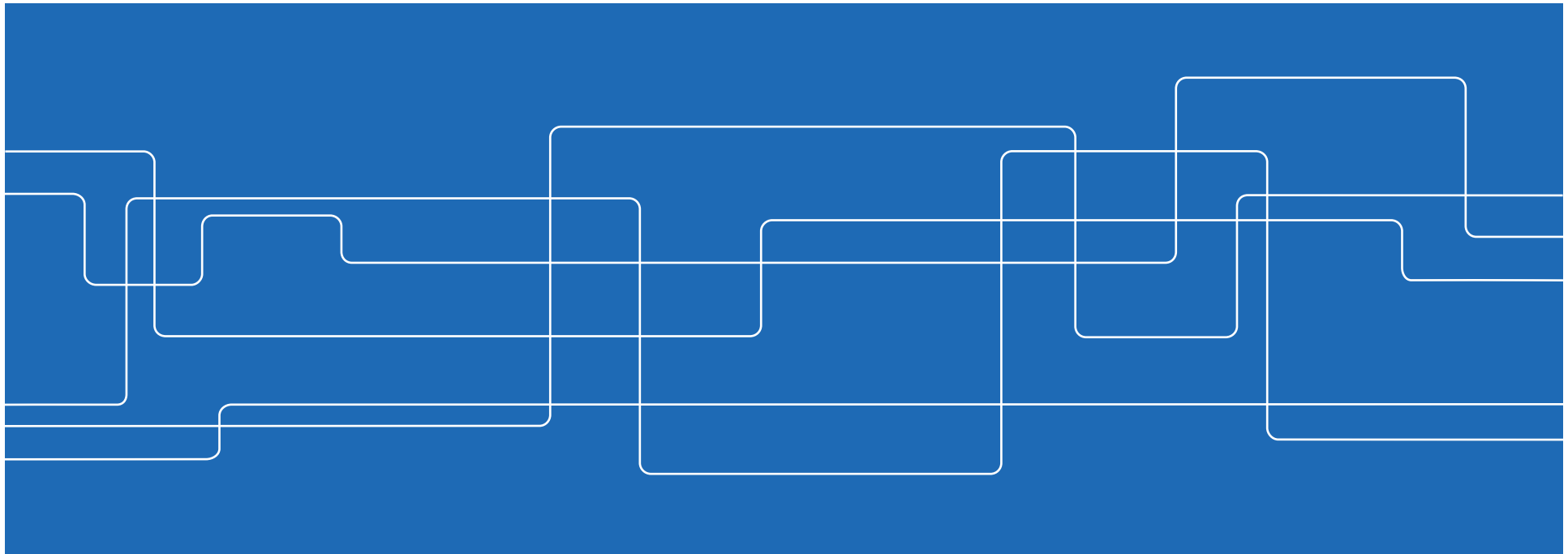


Internet of Reality: Challenges, Initial Results and the Road Ahead

Ericsson Research Lecture Series

James Gross

Dec 7th, 2020





James Gross



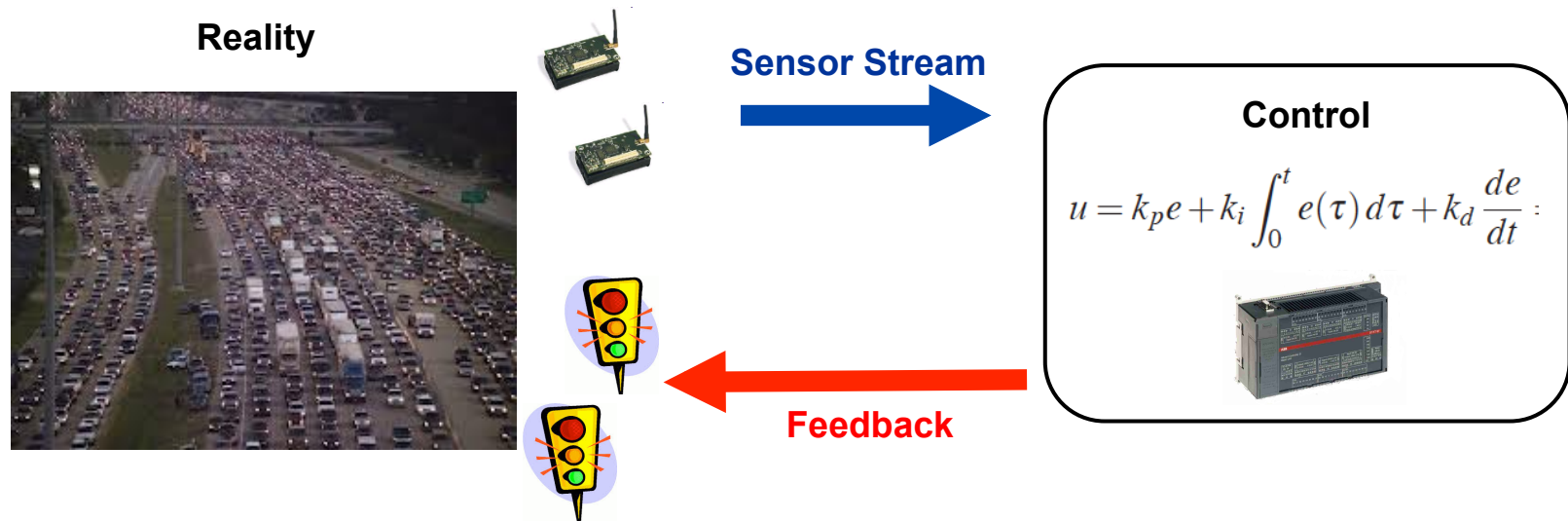
- Professor for Machine-to-Machine Communications
 - PhD from TU Berlin in 2006
 - Assistant Prof. at RWTH 2008 – 2012
 - Since 2012 at KTH
- Research focus:
 - Cellular networks, critical machine-to-machine communications
 - Network performance models
 - Edge computing for closed-loop applications
- Associate Director KTH Digital Futures
- Co-Director KTH Competence Center TECoSA
- Founder@R3 Communications (spin-off in industrial wireless)



Outline

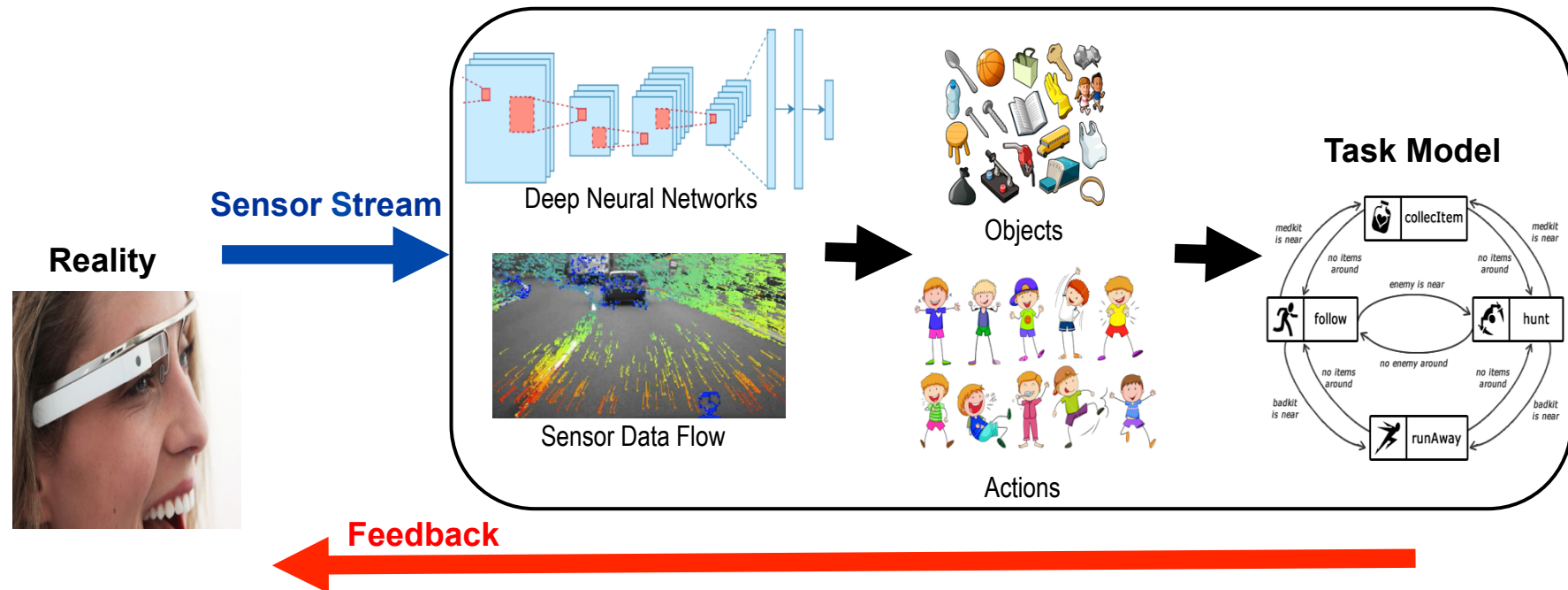
- **Towards an Internet of Reality?**
- Initial Challenges and Results
 - EdgeDroid and the quest for latency impact
 - Scheduling for closed-loop
- Upcoming Challenges & Outlook

Cyber-Physical System (CPS)



Traditionally in industrial automation, but broader use cases exist

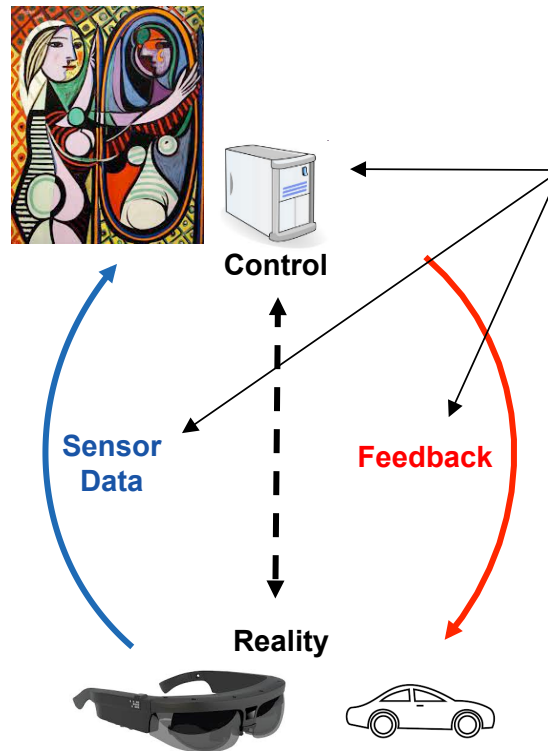
Wearable Cognitive Assistant (HITL)



Generalizes to human-in-the-loop (HITL), many different scenarios

Underlying Principles

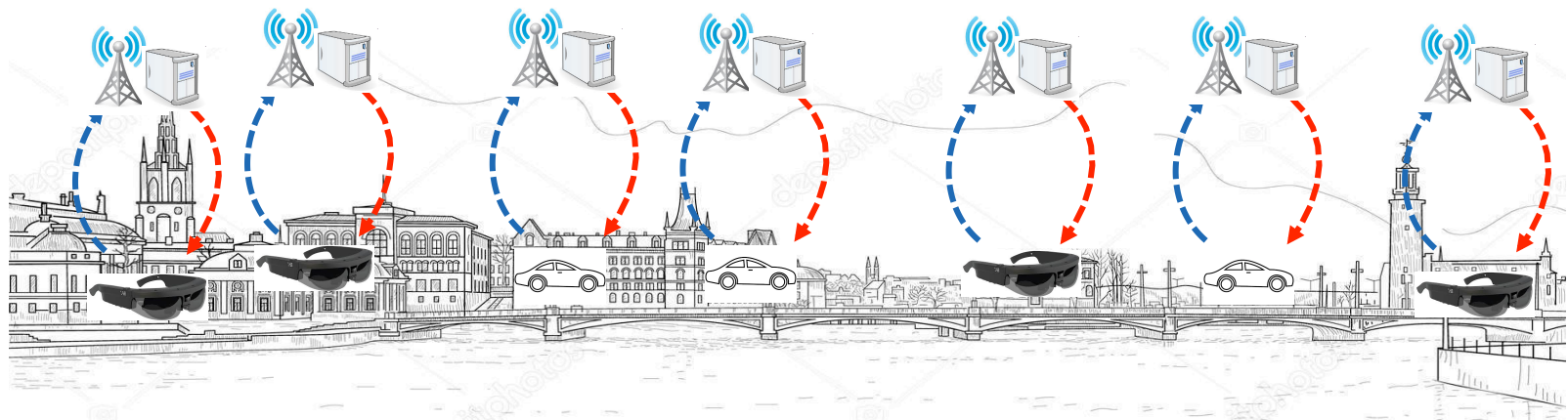
Representation of reality:
constant update of a
specific context



Feedback system:
loop set-up, dependable,
1-to-1 load ratio

Substantial utility of applications:
Automation gain, knowledge transfer, automated assistance

Ubiquitous Provisioning?



- Run over shared network infrastructure
- Efficient support of such applications?
- Interaction between applications and network?

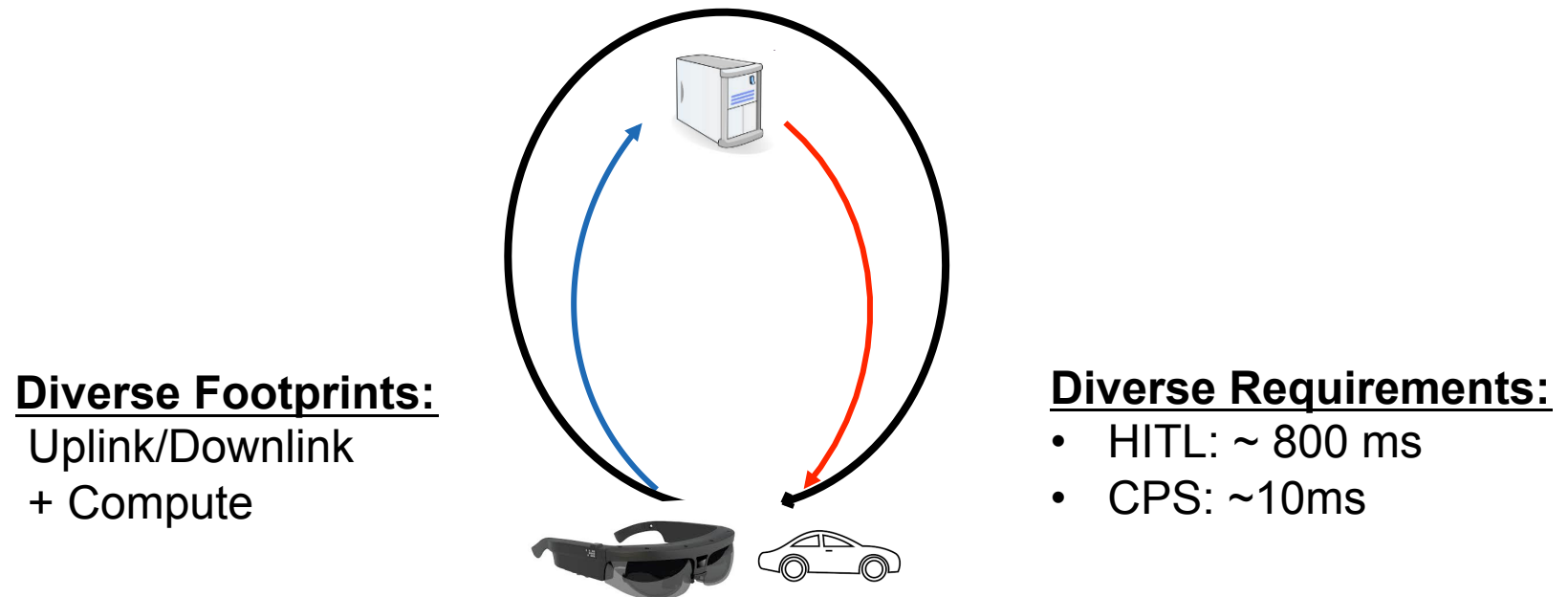


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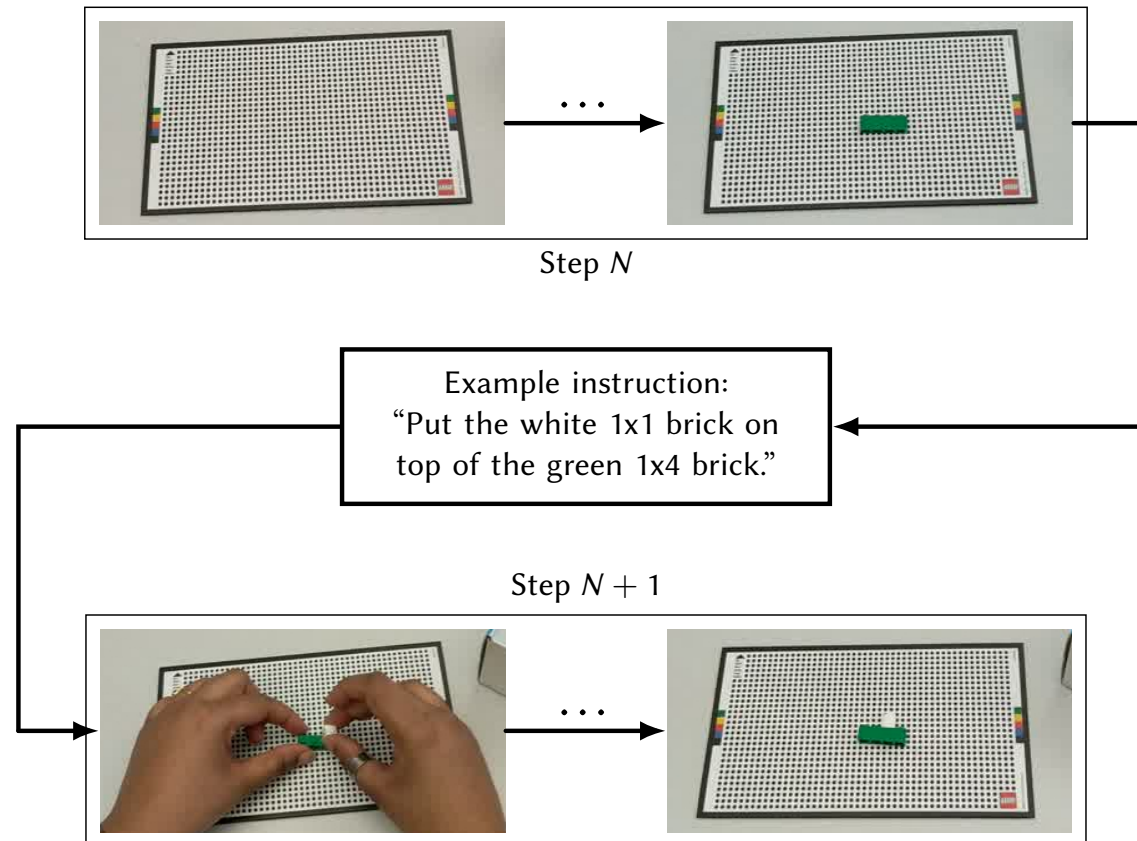
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Application Characteristics

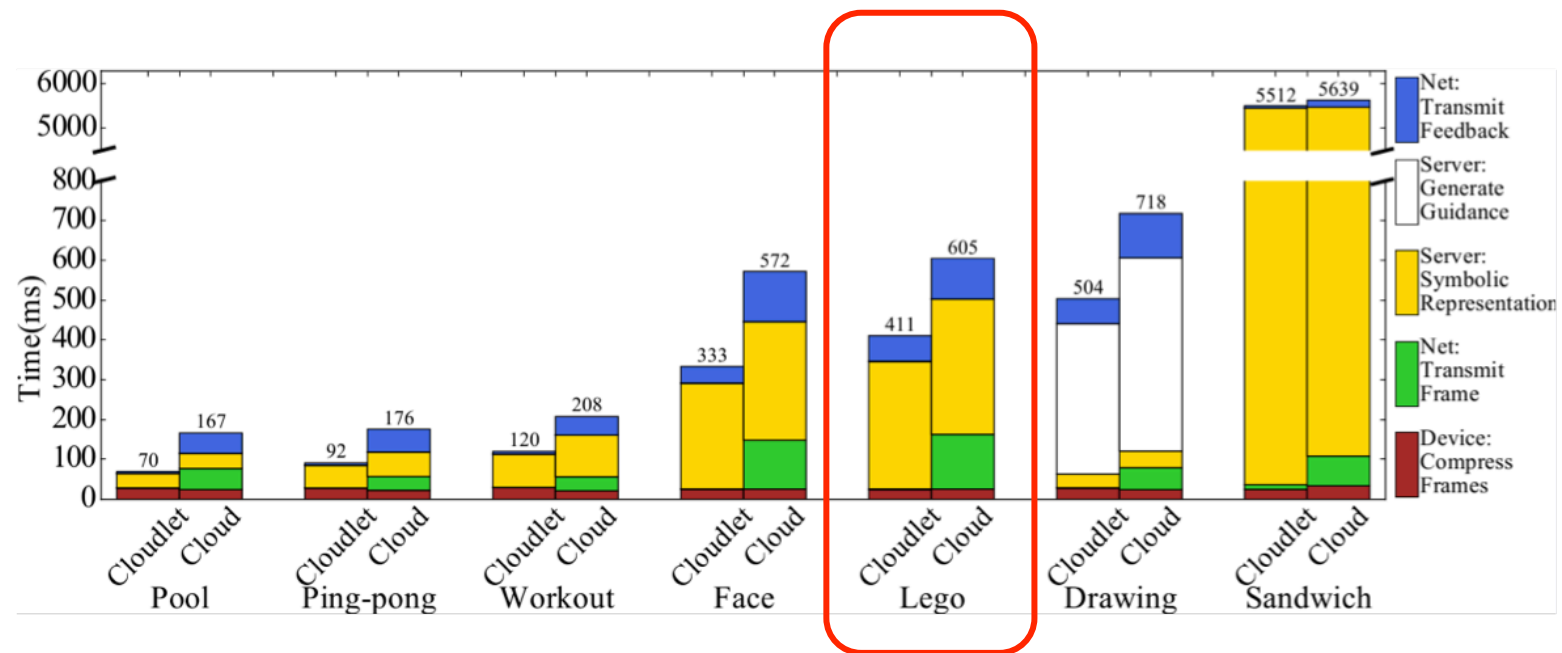
End-to-end latency over the loop is the central metric!



Example HITL: LEGO Assistant



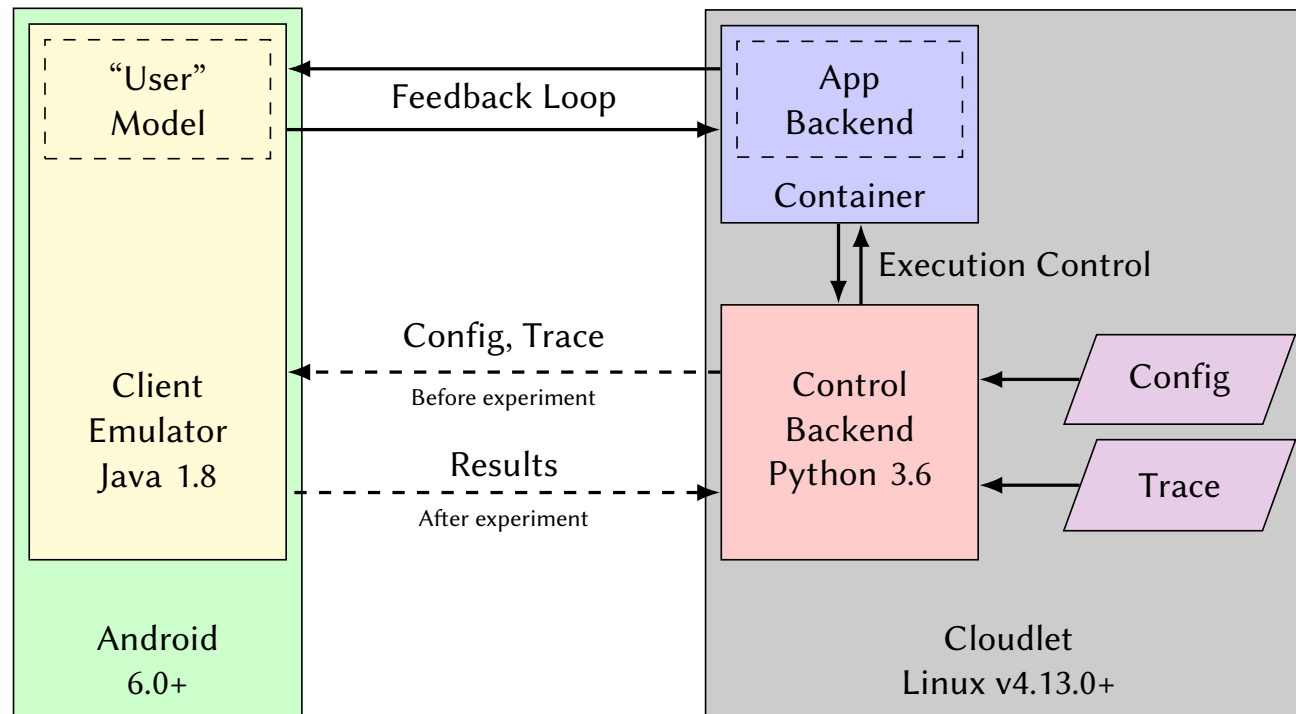
LEGO Footprint & Latency Requirement



QoE determined by latencies $t_{low}=600$ ms, $t_{up} = 2.7$ s !

Chen et al. "An empirical study of latency in an emerging class of edge computing applications for wearable cognitive assistance," *IEEE SEC* 2017.

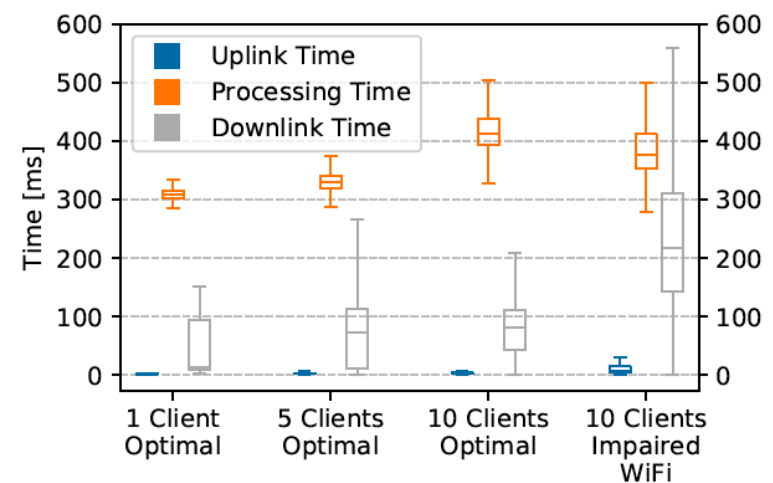
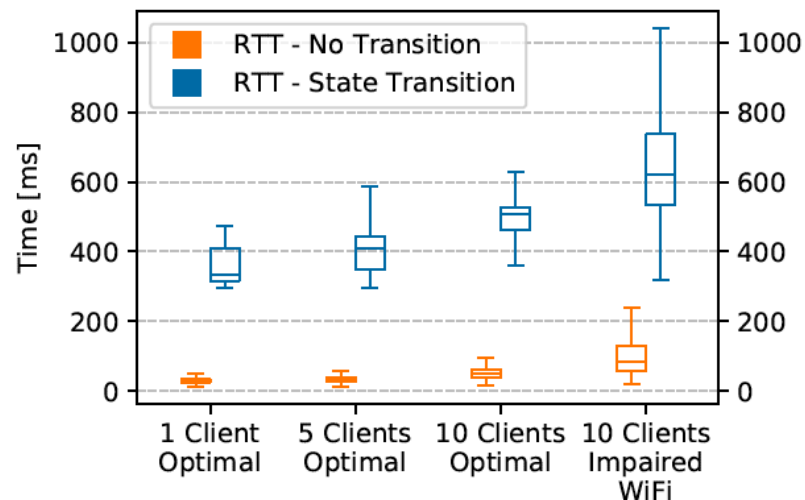
HITL Emulation: EdgeDroid



Muñoz et al. "EdgeDroid: An experimental approach to benchmarking human-in-the-loop applications," *ACM HotMobile* 2019.

Infrastructure Impact

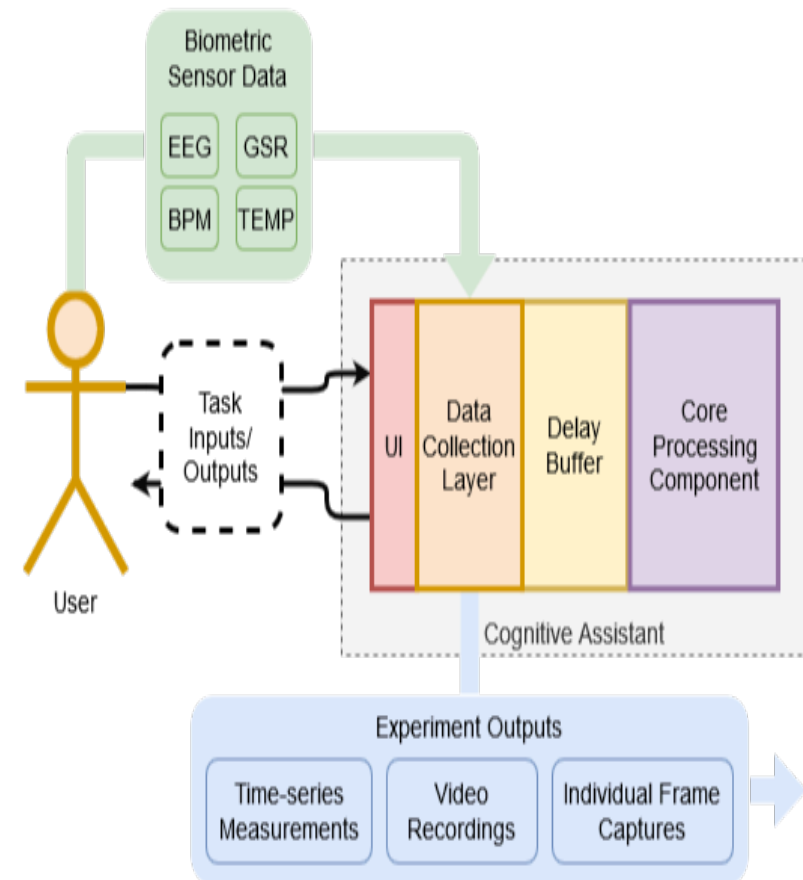
IEEE 802.11n & simple cloudlet set-up, office environment



- Exponential latency scaling, various contributing factors
- Load easily pushes latencies beyond t_{down} , **impact?**

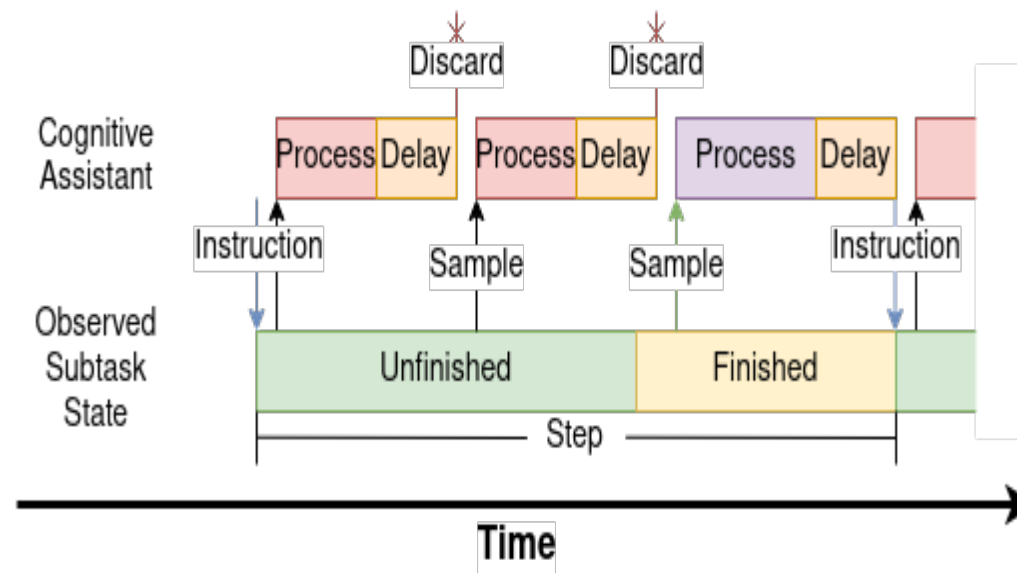
User Study on Delayed Feedback

- User study at CMU in fall 2019
- Modified assistant to control latencies
- Tracking of various outputs
- 40 participants, mostly students from CMU

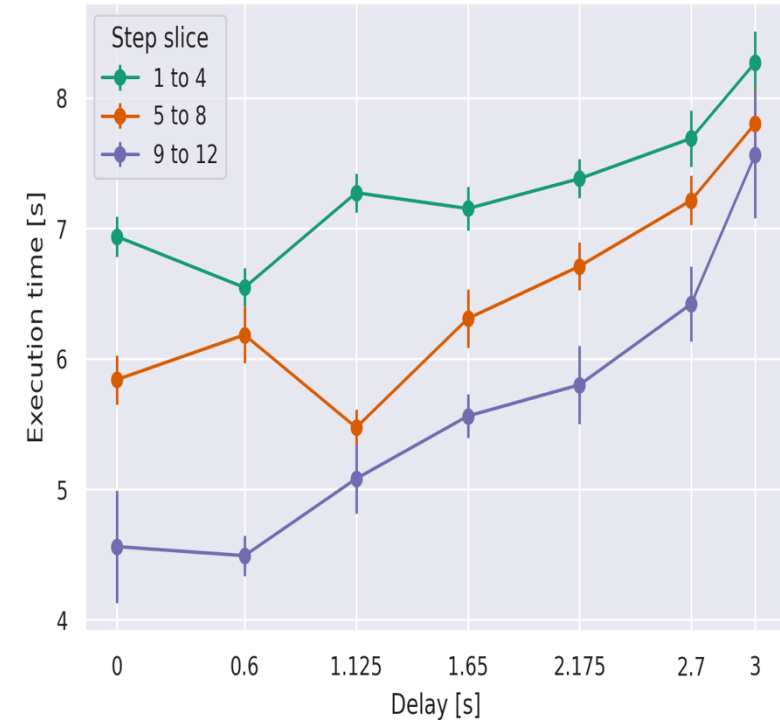
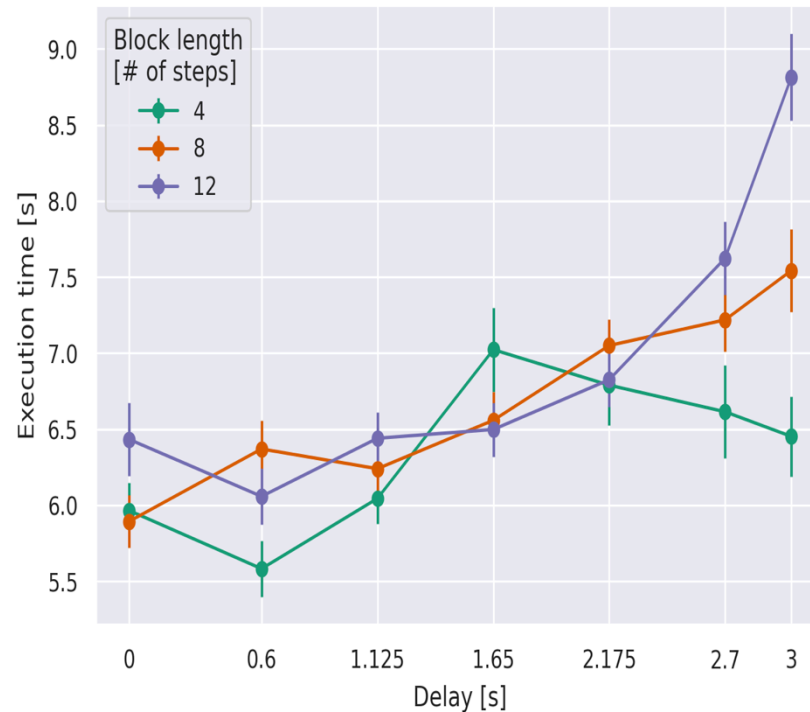


Muñoz et al. "Impact of delayed response on wearable cognitive assistance," *ArXiv 2020*

Experimental Set-up



Key Results



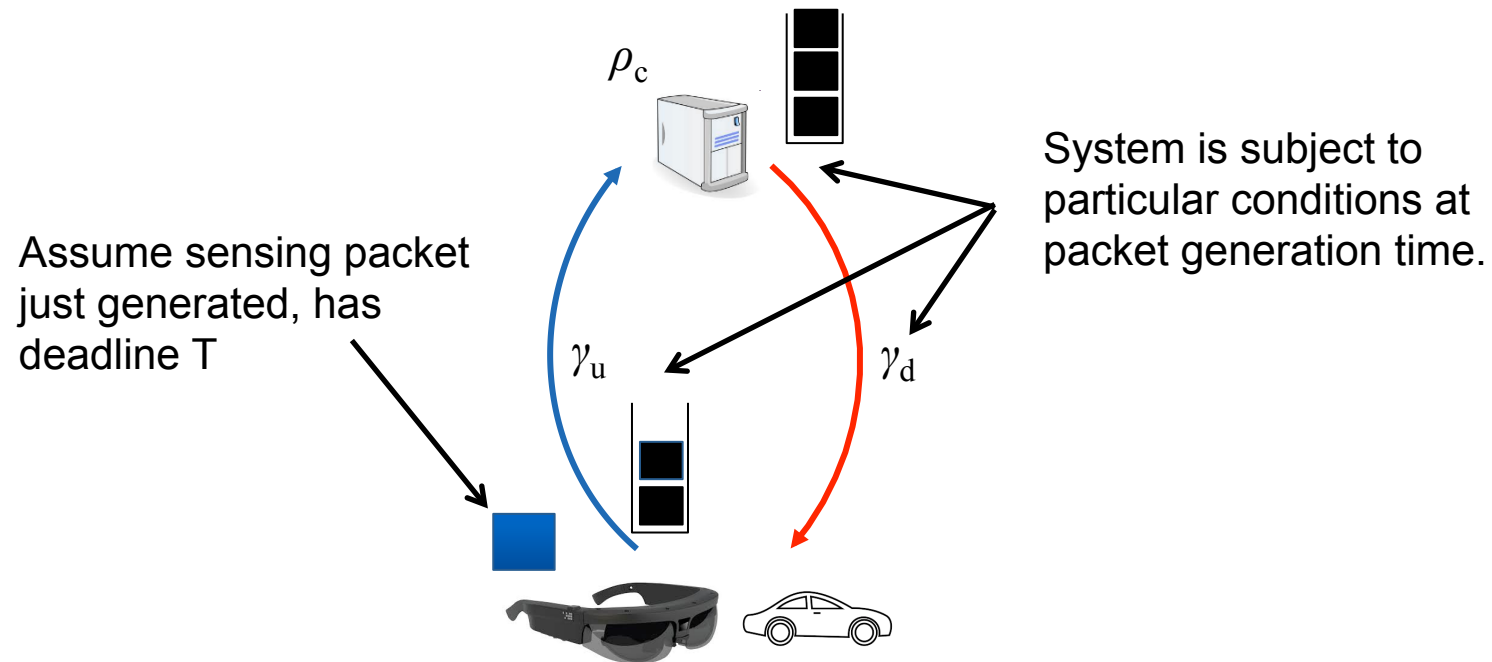
Normalized execution delay increases with delay, delay also prevents task execution acceleration.



Conclusions & Interpretation

- Increased infrastructure delay leads to:
 - Slowing in execution, prevented from acceleration
 - Execution slow-down lingers even if delay recovers!
- ➔ **Delay causes disruption of cognitive task automation, while making it hard to re-automate one happened!**
- System consequence: Significantly longer application execution, higher load, higher resource consumption!

How to Prevent Delays?

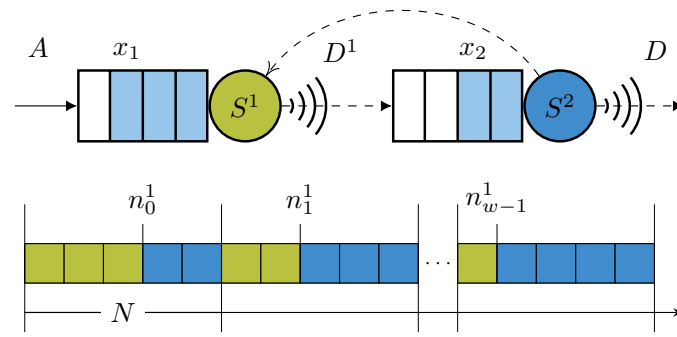


How to schedule the system to minimize likelihood of violating the deadline?

Zoppi et al. "Scheduling of Two-hop lossy wireless networks for time-critical feedback systems," *ArXiv* 2020.

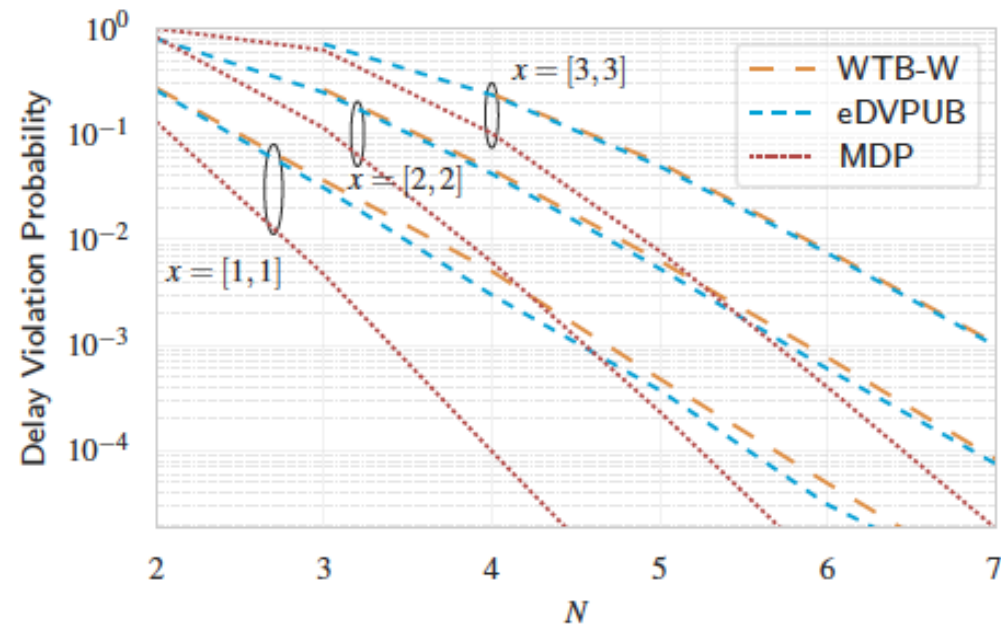
Model and Scheduling Choices

- Two-hop queuing model with joint slots for up-/down-link



- Scheduling variants:
 - Static allocation of slots
 - Allocate slots for the time until deadline, don't change
 - Constantly reallocate slots up until deadline

Results



- Substantial performance differences
- Fully adaptive approaches outperform all other schemes
- Load disbalance, underutilization most important factors



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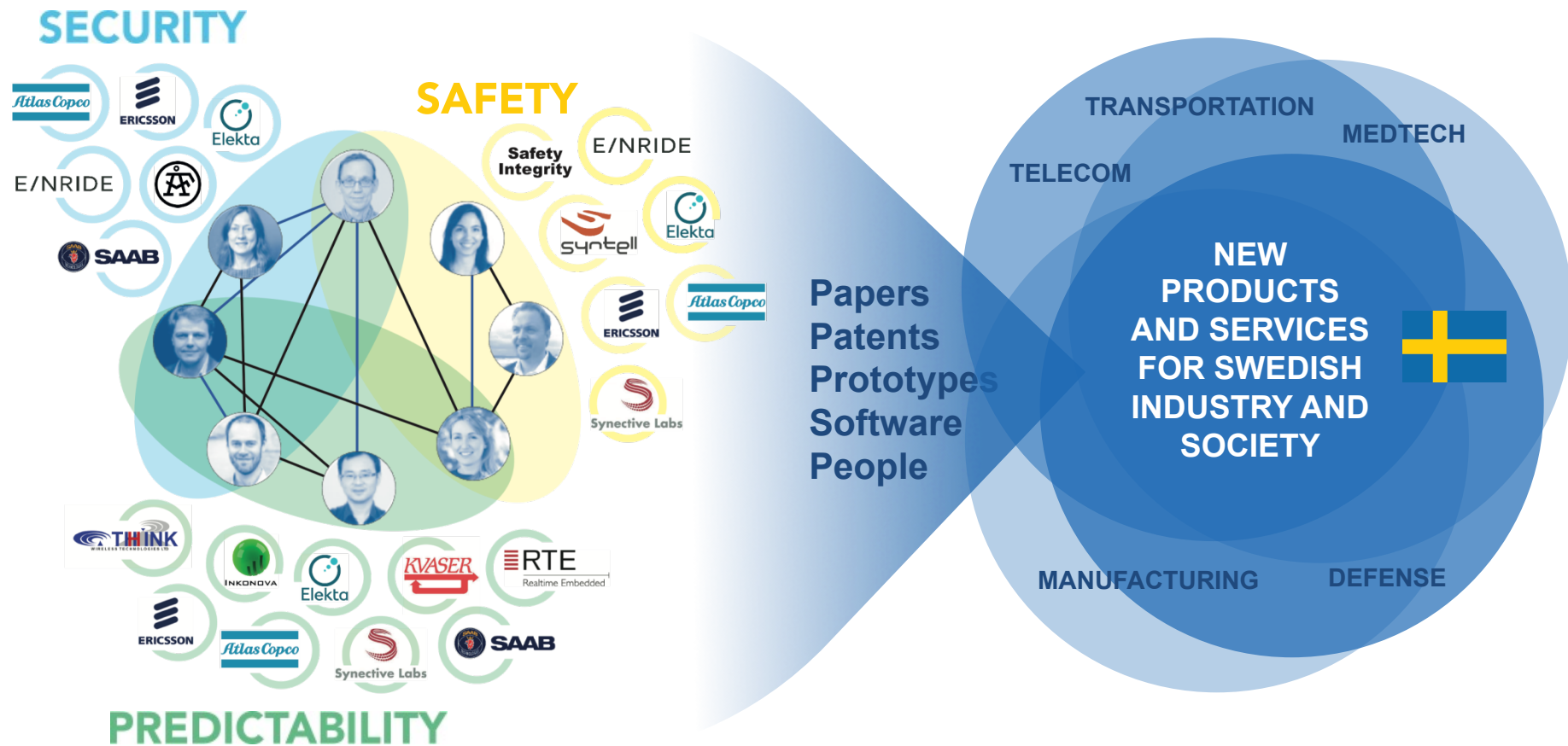


Current Activities

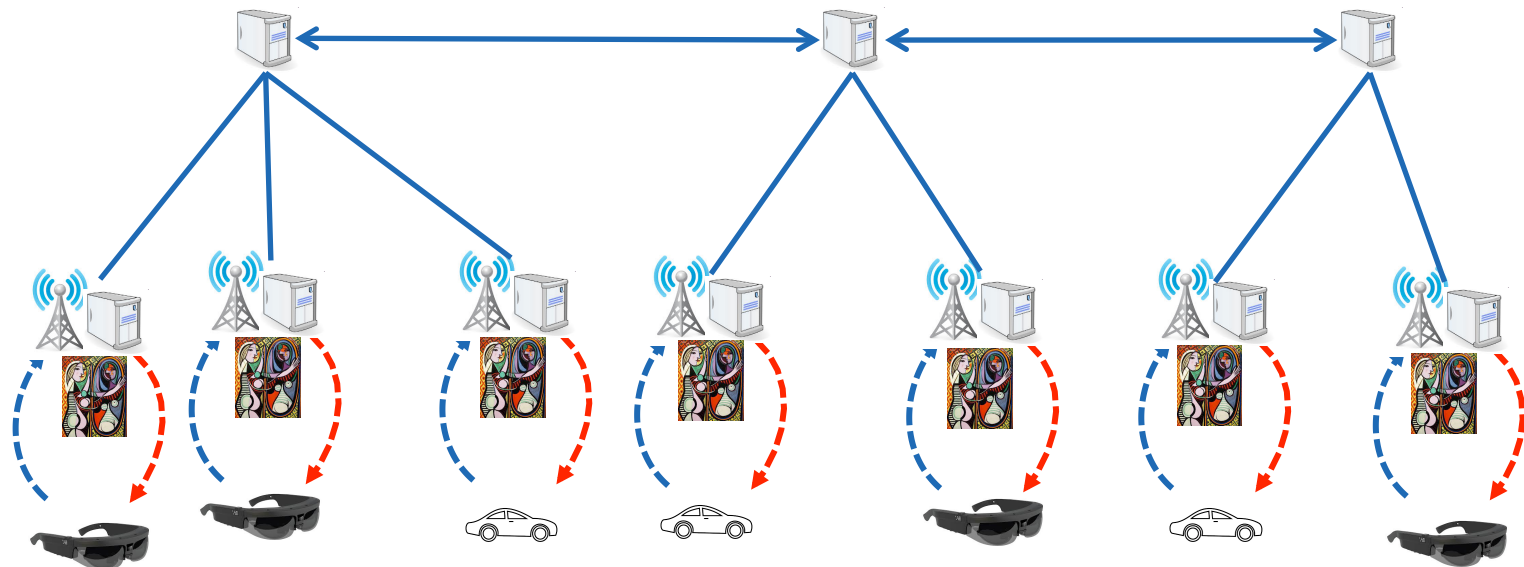
- Automated models of human reaction in HITL
- Latency & quality of control trade-offs: Cleave
 - <https://github.com/KTH-EXPECA/CLEAVE>
- Optimal sampling & semantics: When to sense reality?
- Predicting loop end-to-end latencies for real systems



VINNOVA Competence Center TECoSA



What to do with the Representations?



- Build a fabric that tracks the representations/ part of them?
- How to universally represent reality?
- Human footprint in such a fabric?



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Digital Futures inauguration

"Digital Futures opens up all areas of digitalisation. Cooperation is a key factor. It's not just about technical solutions, we need more perspectives and that's what Digital Futures will bring." – Sigbritt Karlsson, President KTH Royal Institute of Technology

Digital technologies to bring solutions to societal challenges

– Digital Futures is a cross-disciplinary research center that explores and develops digital technologies. We bring solutions to great societal challenges, in Sweden and globally. We generate knowledge, innovations and future leaders of high industrial relevance and strategic importance.

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Events & seminars

Inaugurated
one of the world's centres of its kind. The

DF seminar: Decision Making in Critical Societal Infrastructures
Oct 20 2020
In this talk, Carlo Fischione will overview the objectives of the Democritus project, and present the recent results on machine learning over wireless networks...


DF Seminar: Which clicks and ties matter?
Oct 22 2020
Mohammed Saqr will present four threads; 1) methodological innovation in learning and teaching; secondly, 2) replicability and validity to deliver reproducible impact; 3) the use and contribution to learning theory and educational frameworks; 4) use of big data for better inferences...

Distinguished lectures
Distinguished lecture: Moshe Y. Vardi
Nov 2 2020
Moshe Y. Vardi joins us from Rice University to tell more on how we can shift the focus in



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People





Summary & Conclusions

- Upcoming feedback systems that process reality
 - Powerful application class!
 - Novel footprints and requirements
 - End-to-end latency is key metric
- Mastering communication & compute interaction is key
 - Severe consequences if not
 - Still, complex scheduling task, mostly still open
- Towards an Internet of Reality? More research needed ...