



# EdgeDroid:

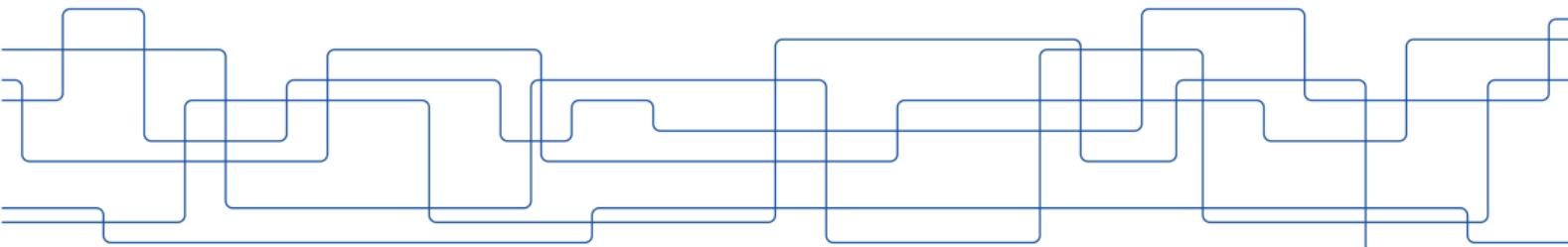
*An Experimental Approach to Benchmarking Human-in-the-Loop Applications*

M. Olguín Muñoz<sup>†</sup>, J. Wang<sup>‡</sup>, M. Satyanarayanan<sup>‡</sup> and J. Gross<sup>†</sup>

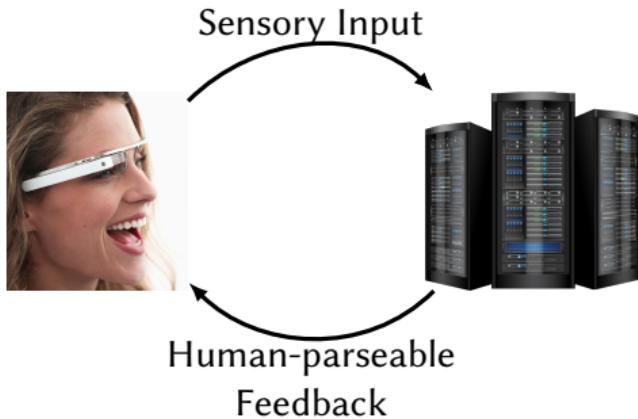
<sup>†</sup> KTH Royal Institute of Technology, Sweden

<sup>‡</sup> Carnegie Mellon University

*Spring 2019 OEC Workshop. May 9–10, Carnegie Mellon University, Pittsburgh, PA.*







# Studying Human-in-the-Loop Applications

Need to understand and optimize these applications:

- ▶ How do they interact with each other?
- ▶ How do they interact with infrastructure?
- ▶ How do they scale?

With which methodology can we study these behaviors?

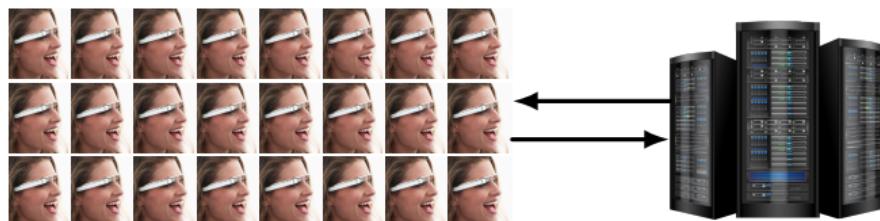


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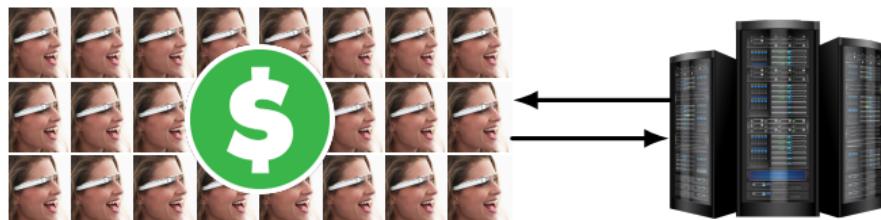


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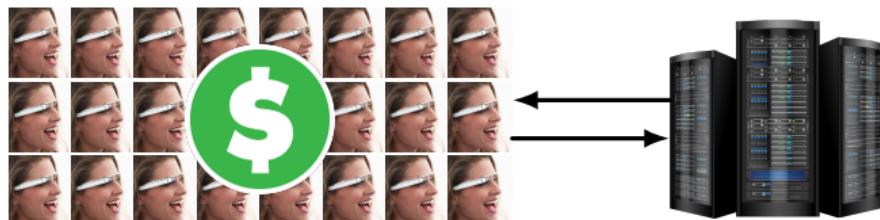
**Costly**

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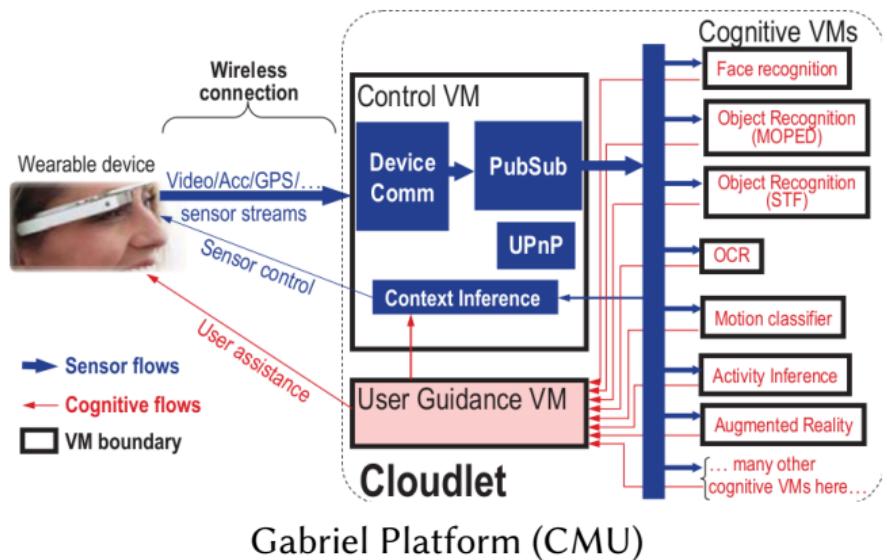
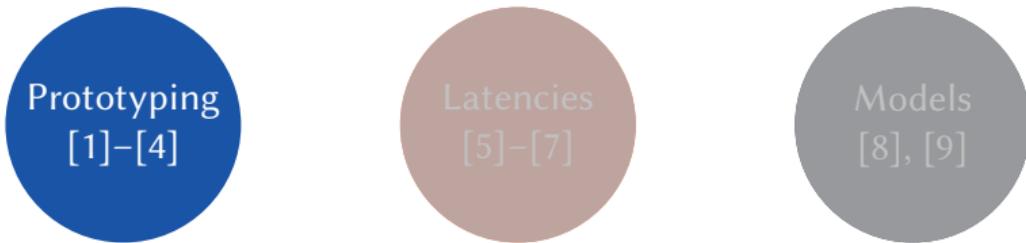
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With which methodology can we study these behaviors?



**Costly, poor repeatability**

# Previous & Related Work

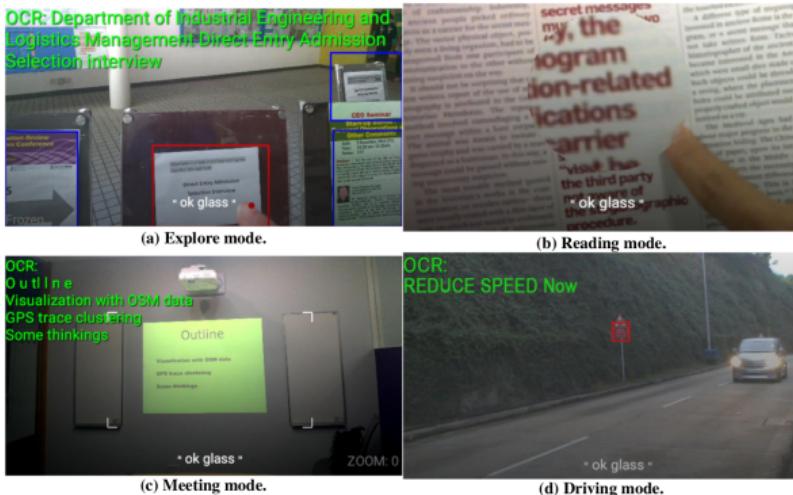


# Previous & Related Work

Prototyping  
[1]–[4]

Latencies  
[5]–[7]

Models  
[8], [9]



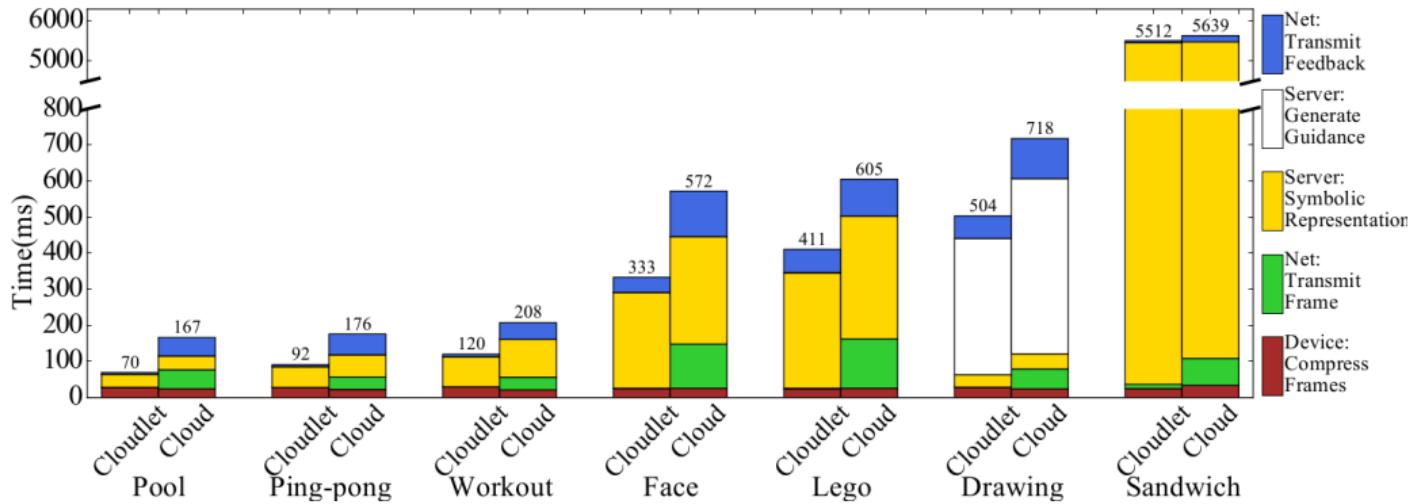
Hyperion Assistant (HKUST)

# Previous & Related Work

Prototyping  
[1]–[4]

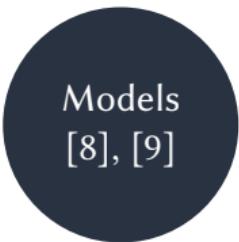
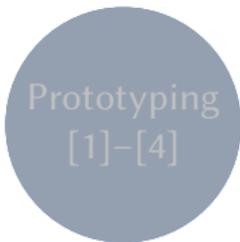
Latencies  
[5]–[7]

Models  
[8], [9]



Source: Chen *et al.* [5]

## Previous & Related Work



- ▶ H. Al-Zubaidy *et al.*, “Performance of in-network processing for visual analysis in wireless sensor networks,” in *Proceedings of the IFIP Networking Conference*, ser. IFIP NETWORKING’15, 2015
  
- ▶ S. Schiessl *et al.*, “Finite-length coding in edge computing scenarios,” in *Proceedings of the International Workshop on Smart Antennas*, ser. ITG WSA ’17, 2017

# Our Contributions

- ▶ A methodology for benchmarking human-in-the-loop applications.

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- ▶ A methodology for benchmarking human-in-the-loop applications.
- ▶ EdgeDroid: A benchmarking tool-suite.
- ▶ Experiments and measurements which show the effectiveness of the approach.

# Benchmarking... what?

Key question:

In what way is system performance reflected in terms of user experience?

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In what way is system performance reflected in terms of user experience?

Answer: Time

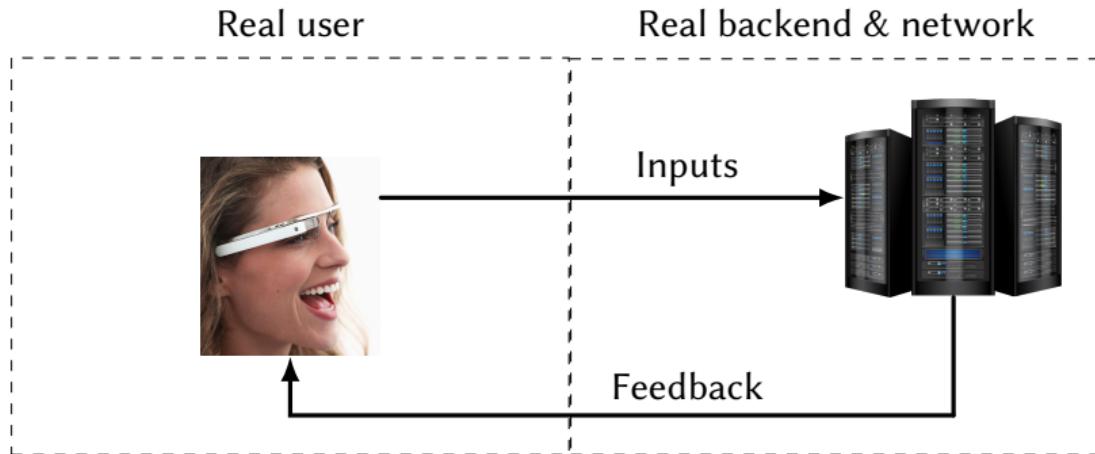
- ▶ Latency
- ▶ Jitter

Human time-perception is tail-driven...

Users tend to remember worst-case occurrences rather than averages.

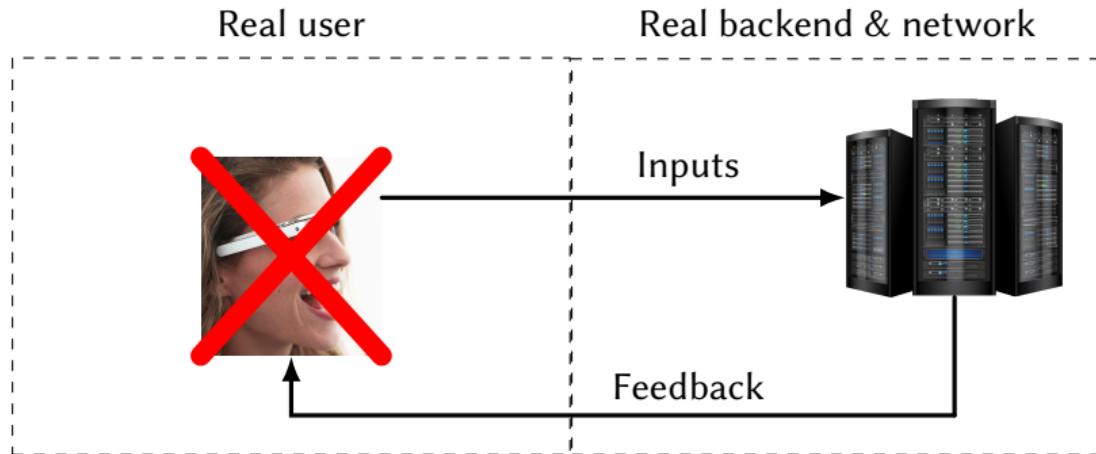
KPIs: Delays (total RTT and segment-wise)

# Approach



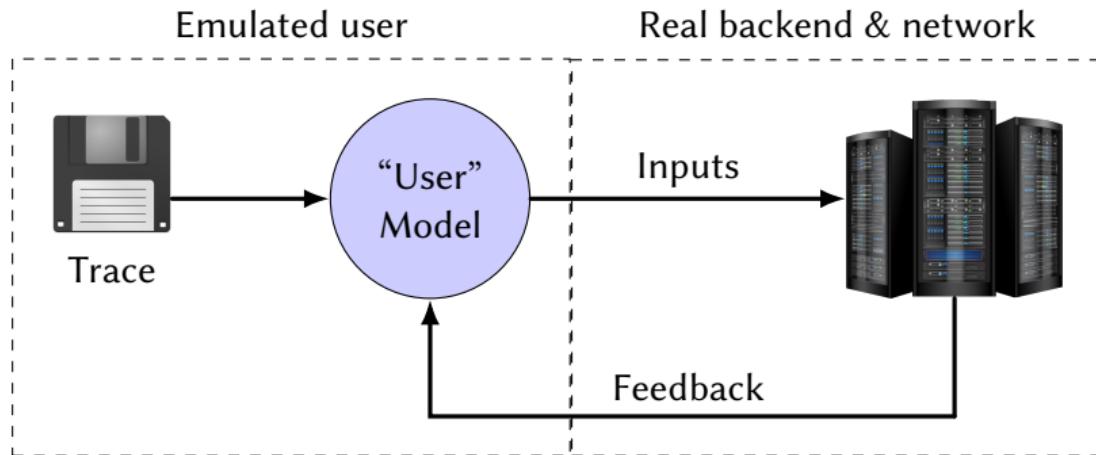
Benchmarking human-in-the-loop applications is HARD

# Approach



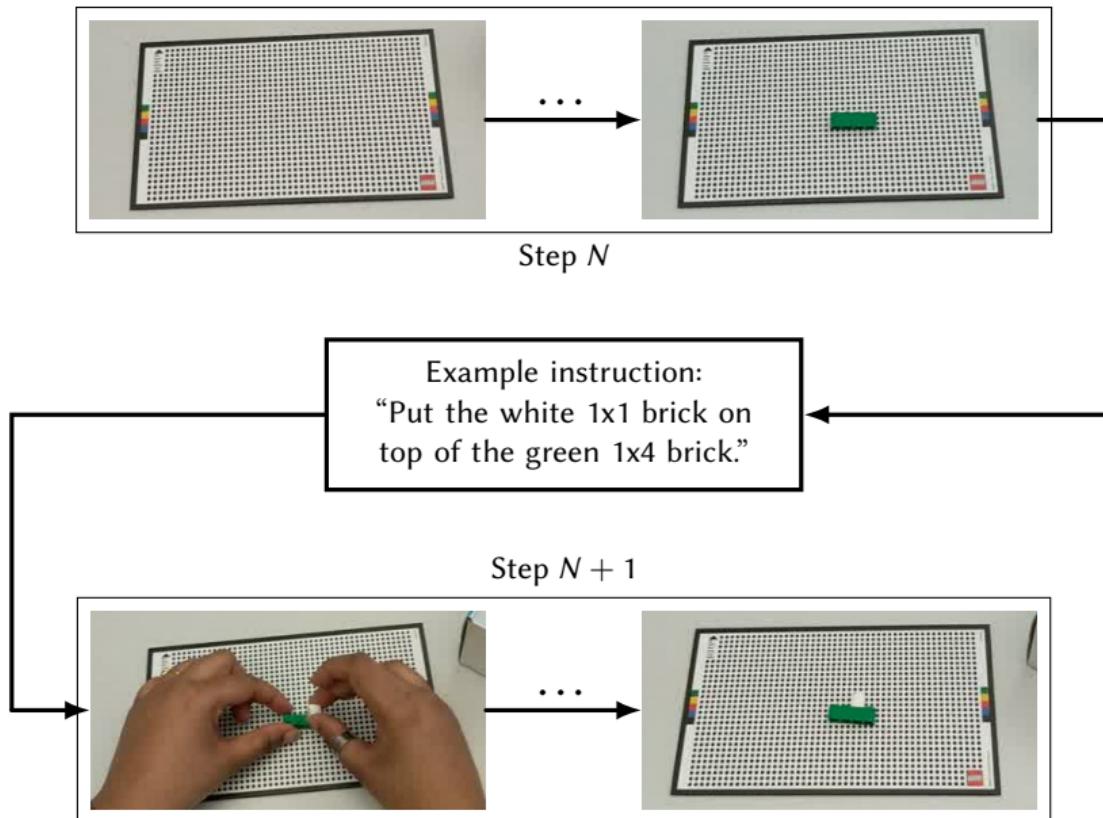
What if we could do away with the human users?

# Approach

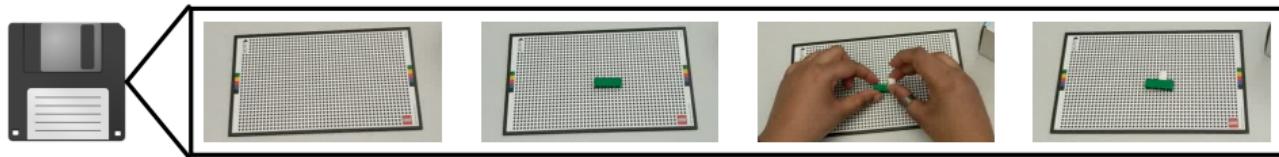
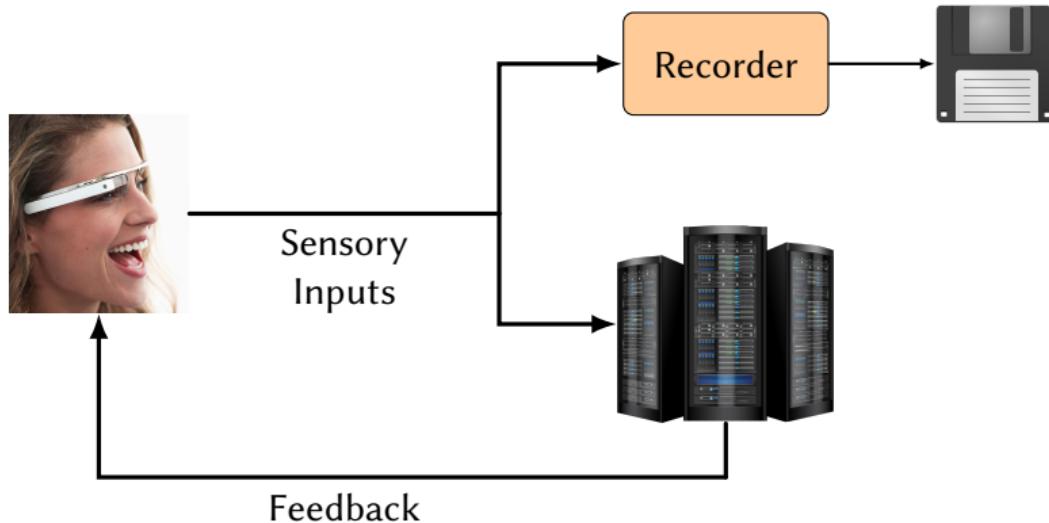


What if we could do away with the human users?  
**Repeatable, scalable!**

# Example: Task Guidance Wearable Cognitive Assitance, LEGO [1]



# Tracing



# Trace Replay

## Non-trivial Challenge

- ▶ Changes in system responsiveness require adapting trace.
- ▶ System delays affect user behavior as well.

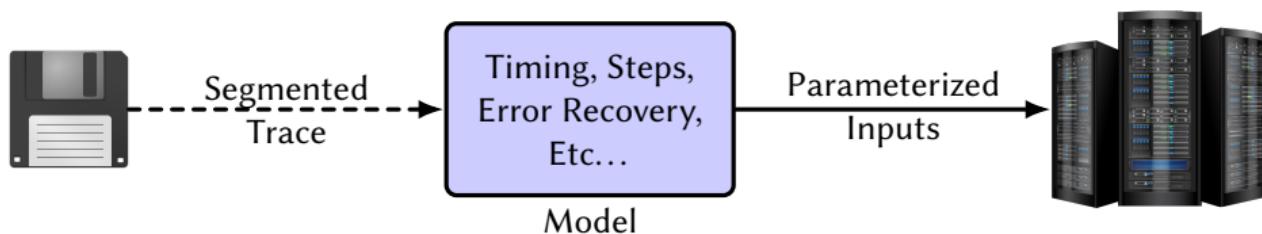
# Trace Replay

## Non-trivial Challenge

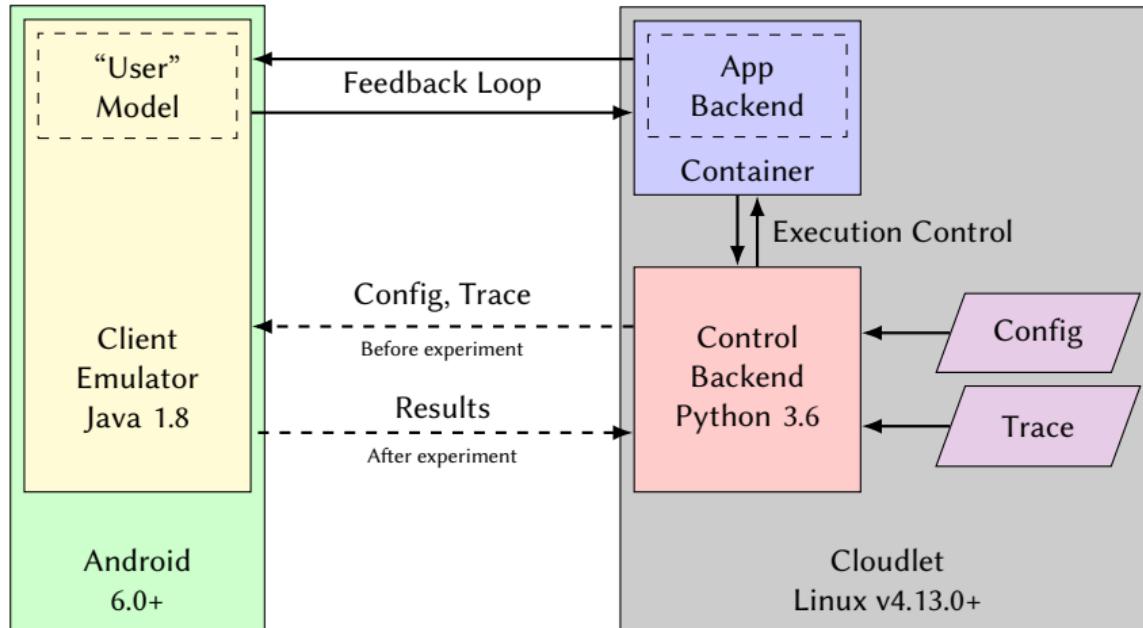
- ▶ Changes in system responsiveness require adapting trace.
- ▶ System delays affect user behavior as well.

## Our Approach

- ▶ Segment trace into logical “steps”.
- ▶ Controlled replay of steps.

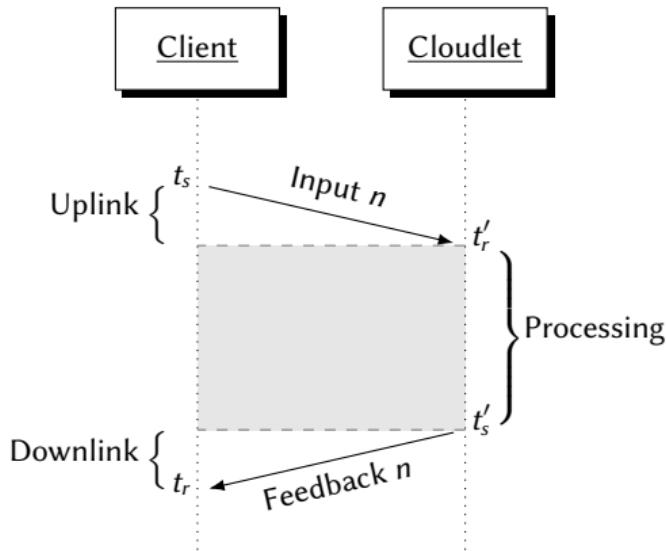


# Implementation: EdgeDroid



<https://github.com/molguin92/EdgeDroid>

# Timestamping



Clocks are synchronized previous to the experiment.

Timestamps at key points to obtain:

$$\Delta T_{\text{up}} = t'_r - t_s \quad (1)$$

$$\Delta T_{\text{proc}} = t'_s - t'_r \quad (2)$$

$$\Delta T_{\text{down}} = t_r - t'_s \quad (3)$$

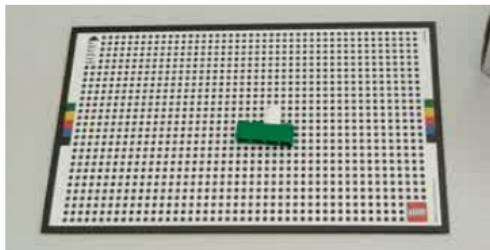
$$\Delta T_{\text{total}} = \Delta T_{\text{up}} + \Delta T_{\text{proc}} + \Delta T_{\text{down}} = t_r - t_s \quad (4)$$

# Evaluation

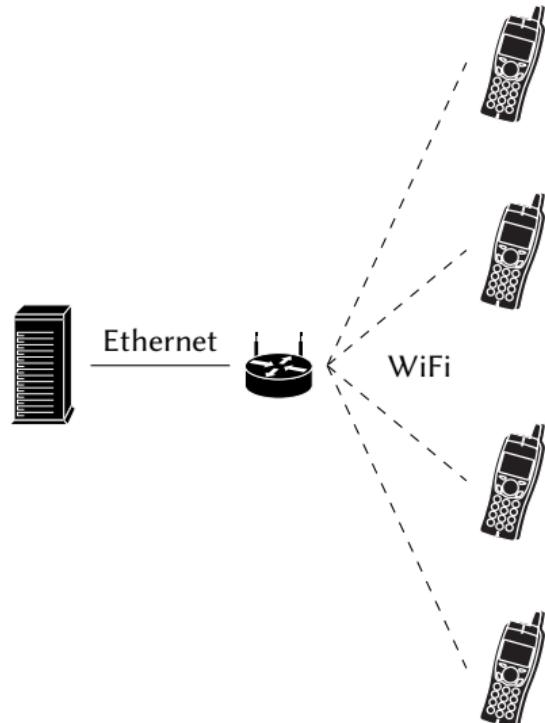
**Key purpose:**  
Demonstrate utility of EdgeDroid.

# Evaluation: Setup

## Application & Scenarios



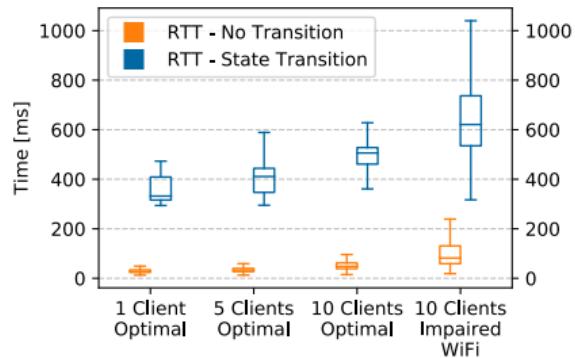
LEGO Assistant



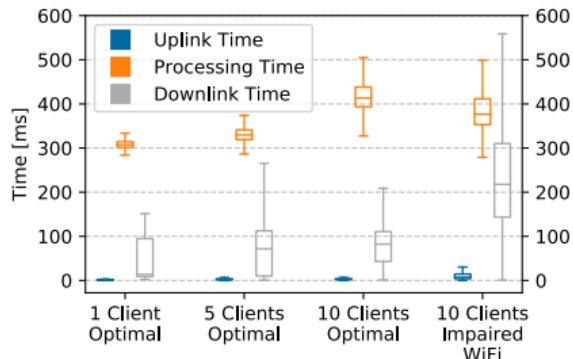
- ▶ Three *optimal* scenarios with 1, 5 and 10 devices.
- ▶ Weakened wireless link with 10 devices.

# Use Cases

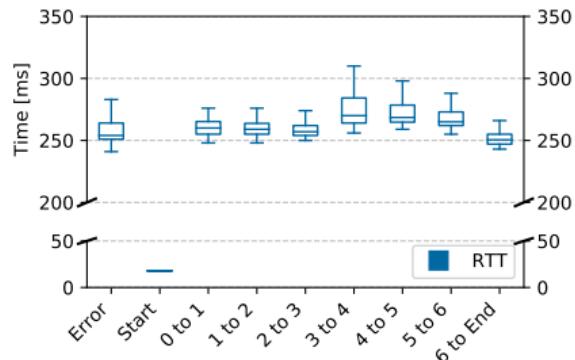
State change vs. no state change.



Times by pipeline segments.



RTT by task step.



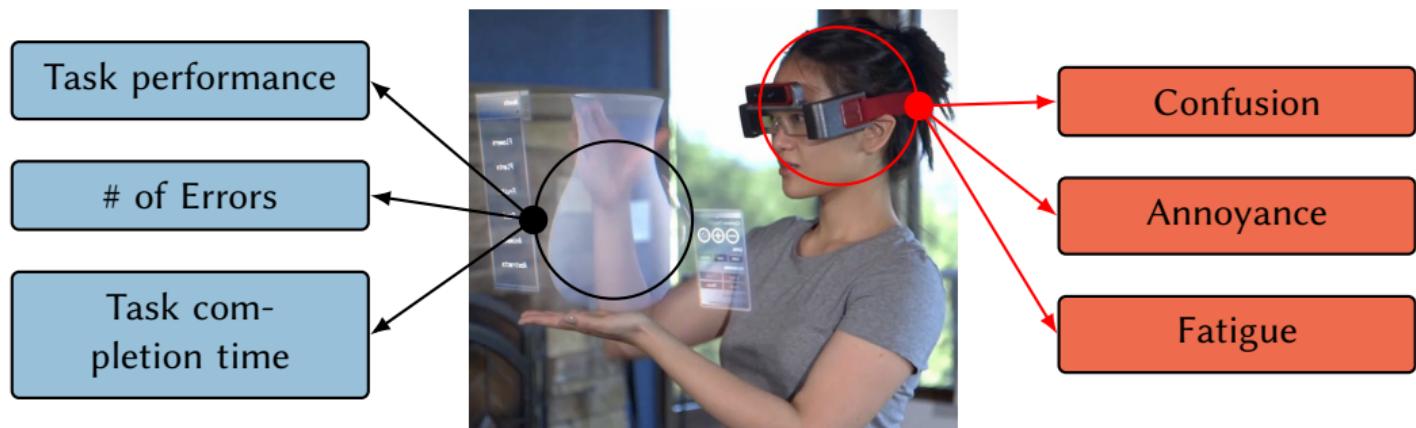
## Future Work

- ▶ Extending EdgeDroid
  - ▶ Characterizing human behavior
  - ▶ Extending to other types of applications
- ▶ Characterizing Control Performance on Edge Computing Infrastructure

# Characterizing human behavior...

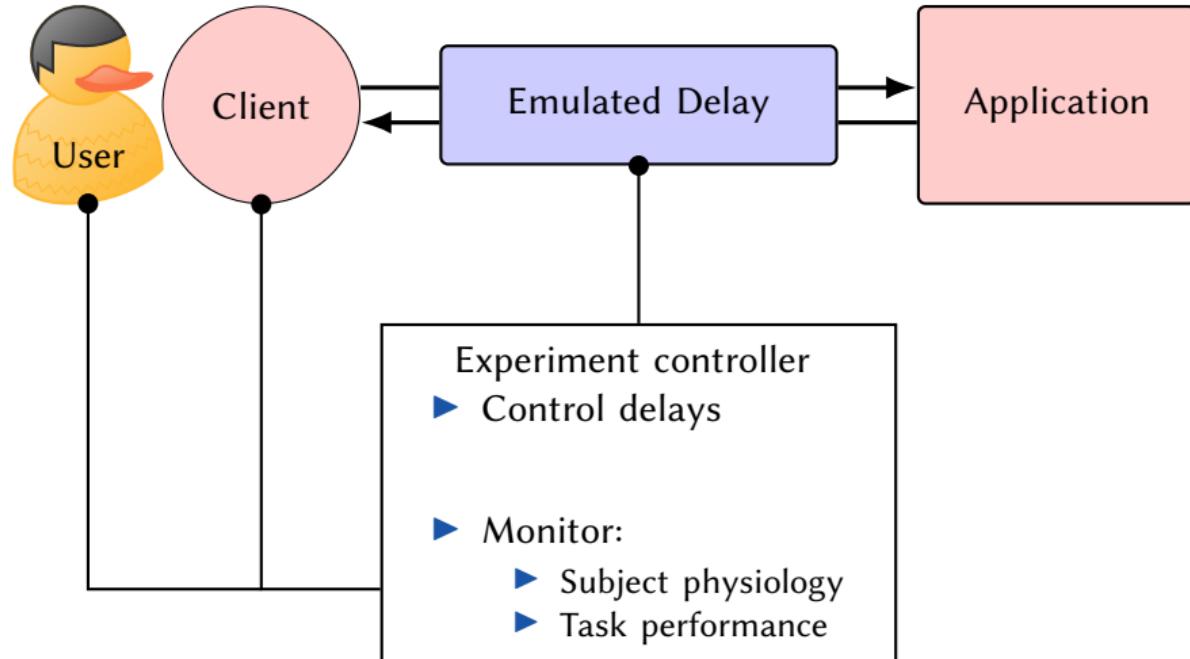
... in the presence of delays in human-in-the-loop applications.

Open research question: how do these delays affect users?



Dabrowski and Munson, “40 Years of Searching for the Best Computer System Response Time” [10]

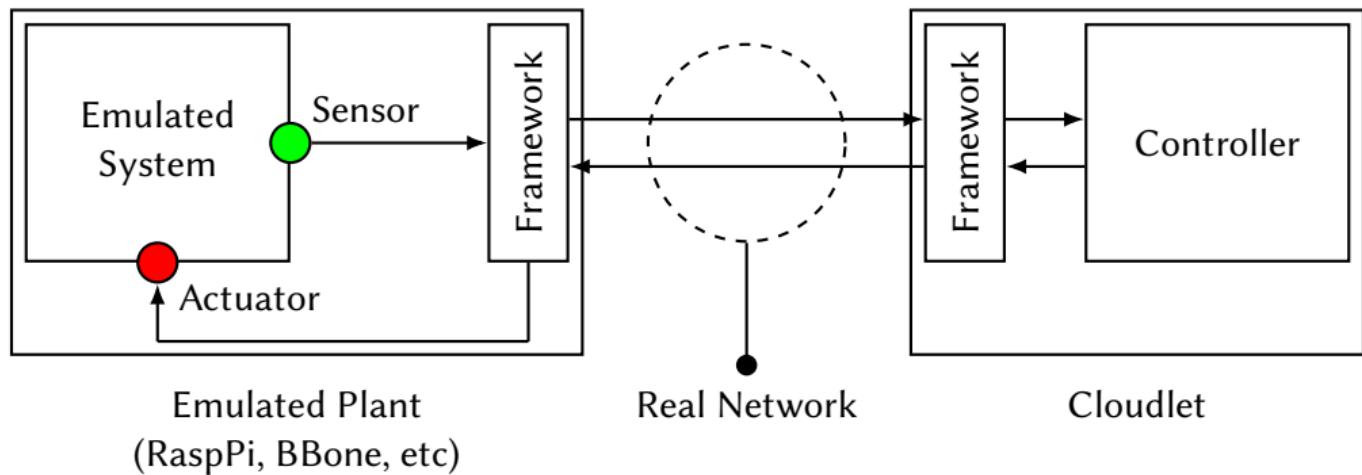
# Proposed Experiment Setup



# Control Performance on Edge Computing

## EdgeDroid for Control Applications

Main focus: study achievable latencies and reliability with off-the-shelf infrastructure.  
Similar to the NCSBench platform developed at TUM<sup>1</sup>[11].



<sup>1</sup><https://github.com/tum-lkn/NCSbench/>

# Conclusions

## Summary

- ▶ Need to study the scaling of Human-in-the-Loop applications.
  - ▶ Difficult due to human users.
- ▶ Methodology + tool suite for benchmarking:
  - ▶ **EdgeDroid**
  - ▶ Trace based.
  - ▶ Model of human behavior.
- ▶ Results which show the utility of EdgeDroid.

## Future Work

- ▶ Extending EdgeDroid
  - ▶ Characterizing human behavior
  - ▶ Extending to other types of applications
- ▶ Characterizing Control Performance on Edge Computing Infrastructure

## Acknowledgements

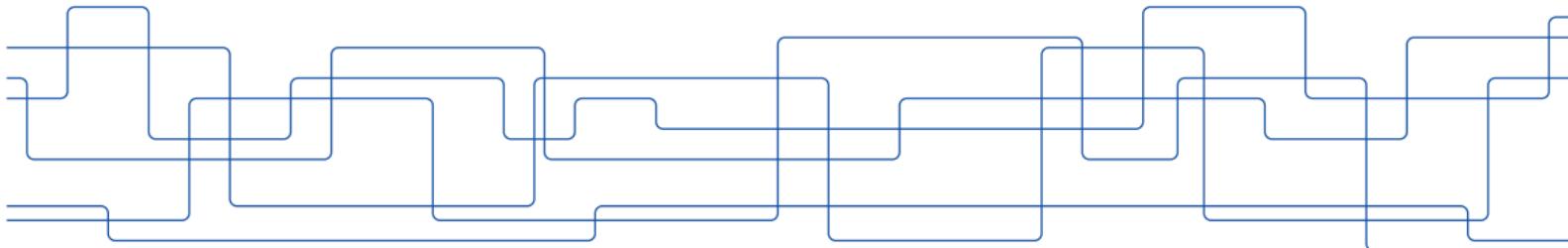
Part of an ongoing collaboration with the Elijah Group at Carnegie Mellon University, led by Prof. Mahadev Satyanarayanan.



This work was recently presented at HotMobile'19 [12].



## Extra Slides



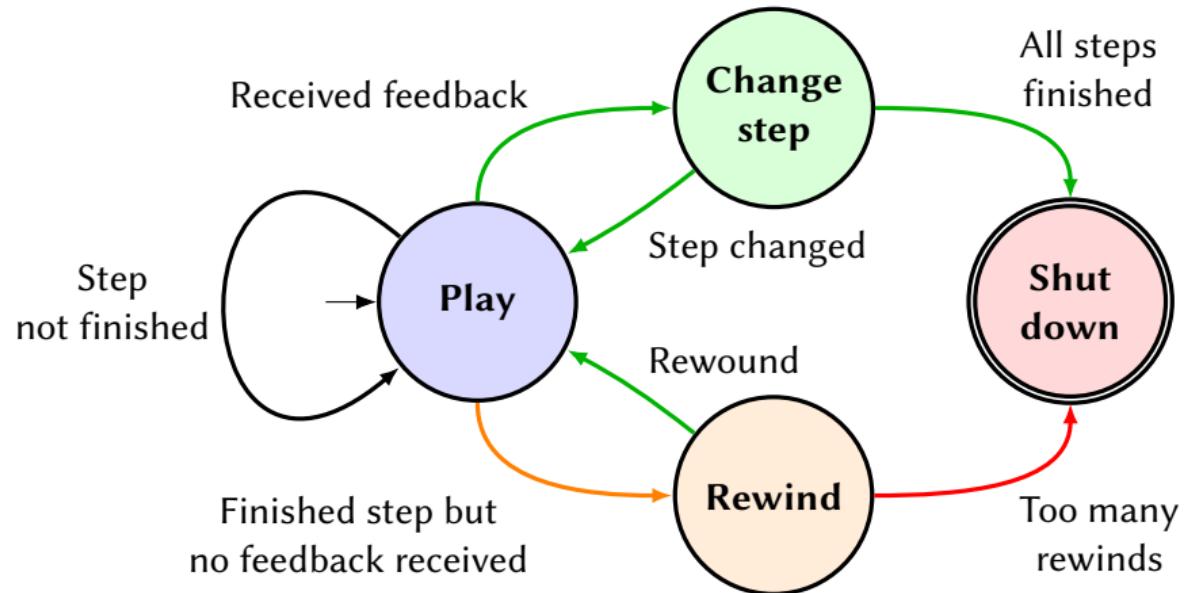
# Requirements

- ▶ Generate realistic, high-dimensional, real-time inputs.
- ▶ Correctly and realistically react to feedback.
- ▶ KPI: Delays.



**Trace of pre-recorded inputs  
& a model of user behavior**

# User Model



Future work: more elaborate models.

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