



EdgeDroid:

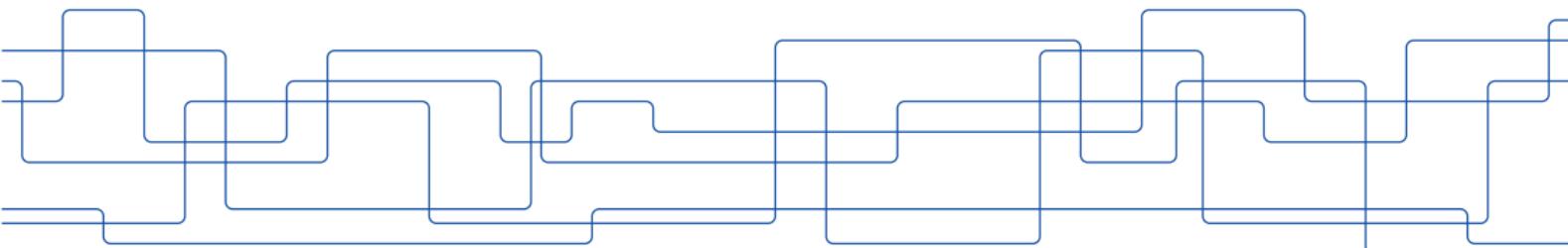
An Experimental Approach to Benchmarking Human-in-the-Loop Applications

M. Olguín Muñoz[†], J. Wang[‡], M. Satyanarayanan[‡] and J. Gross[†]

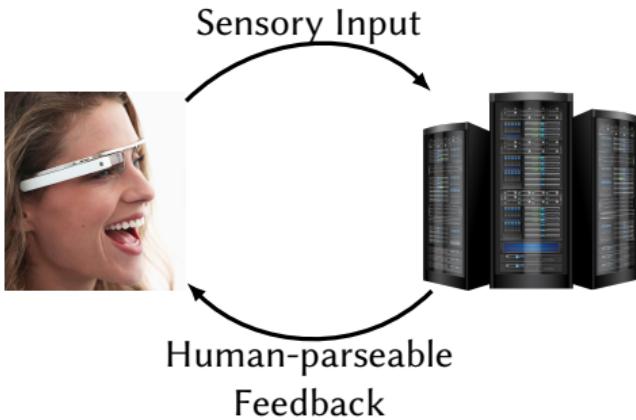
[†] KTH Royal Institute of Technology, Sweden

[‡] 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?

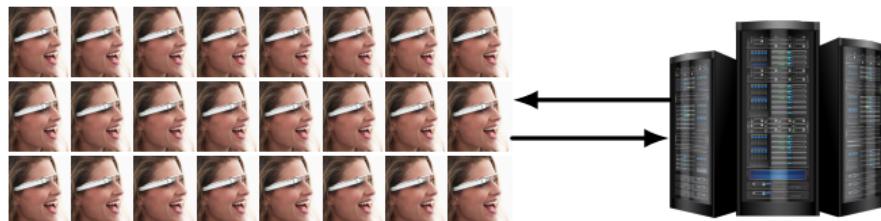


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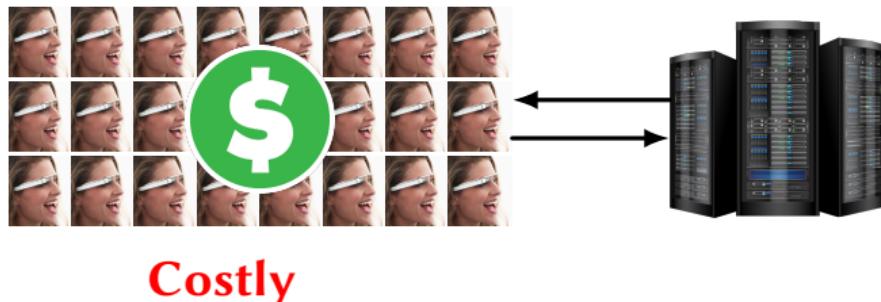


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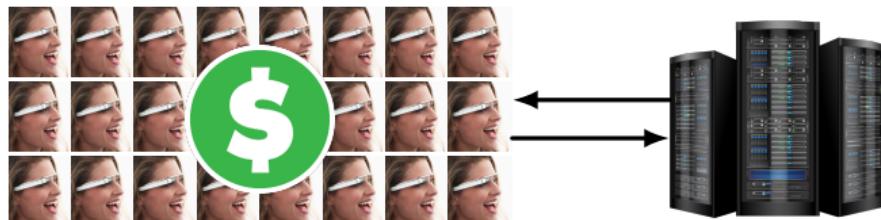


Studying Human-in-the-Loop Applications

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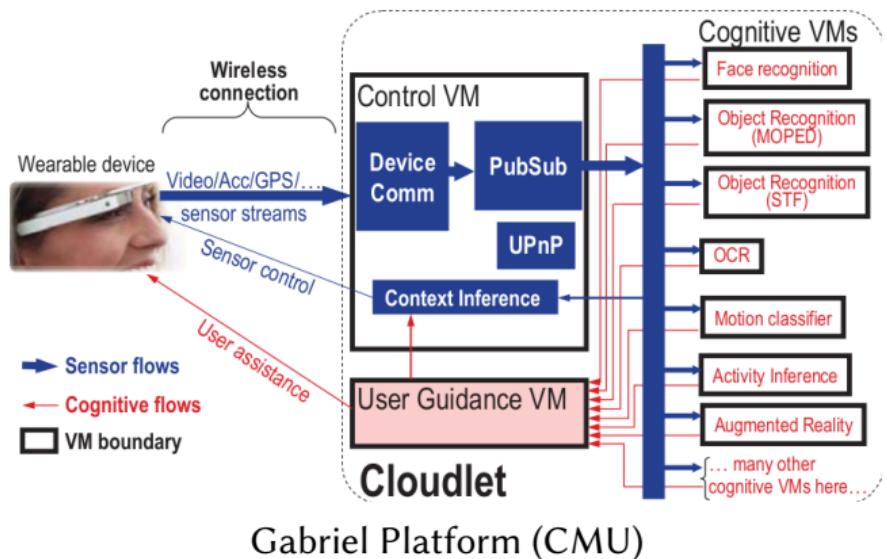
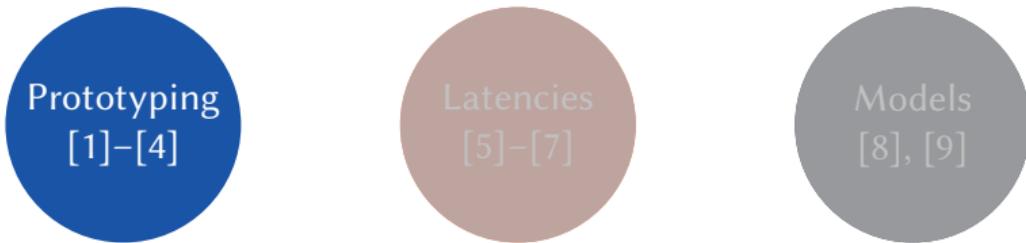
- ▶ How do they interact with each other?
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With which methodology can we study these behaviors?



Costly, poor repeatability

Previous & Related Work

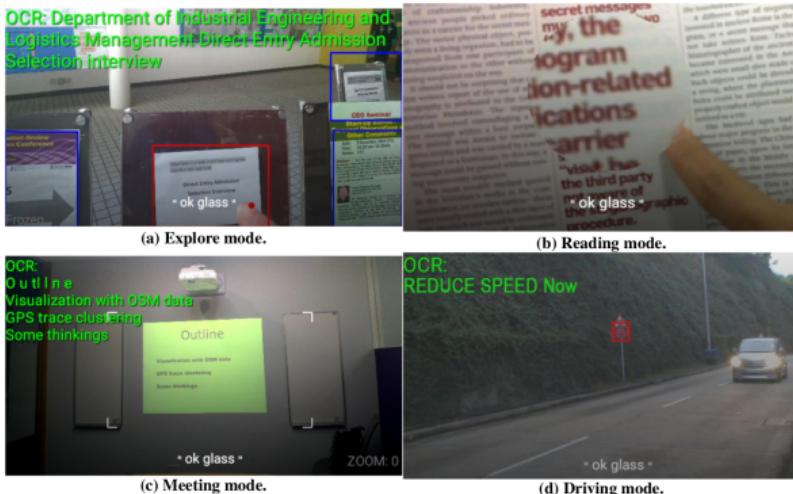


Previous & Related Work

Prototyping
[1]–[4]

Latencies
[5]–[7]

Models
[8], [9]



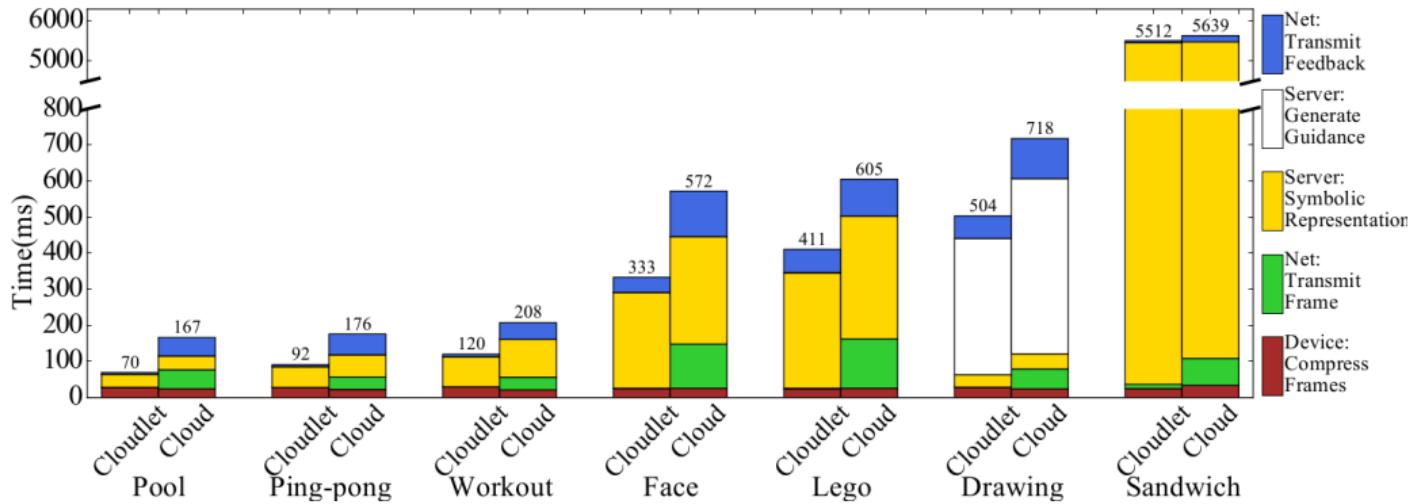
Hyperion Assistant (HKUST)

Previous & Related Work

Prototyping
[1]–[4]

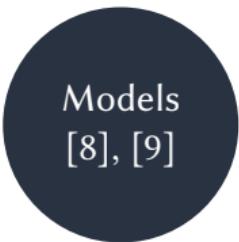
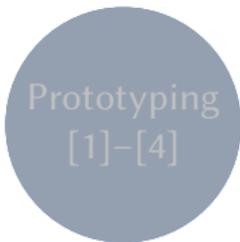
Latencies
[5]–[7]

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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- ▶ EdgeDroid: A synthetic workload generator for Human-in-the-Loop applications on Edge infrastructure.

Our Contributions

- ▶ A methodology for benchmarking human-in-the-loop applications.
- ▶ EdgeDroid: A synthetic workload generator for Human-in-the-Loop applications on Edge infrastructure.
- ▶ 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?

Benchmarking... what?

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

Answer: Time

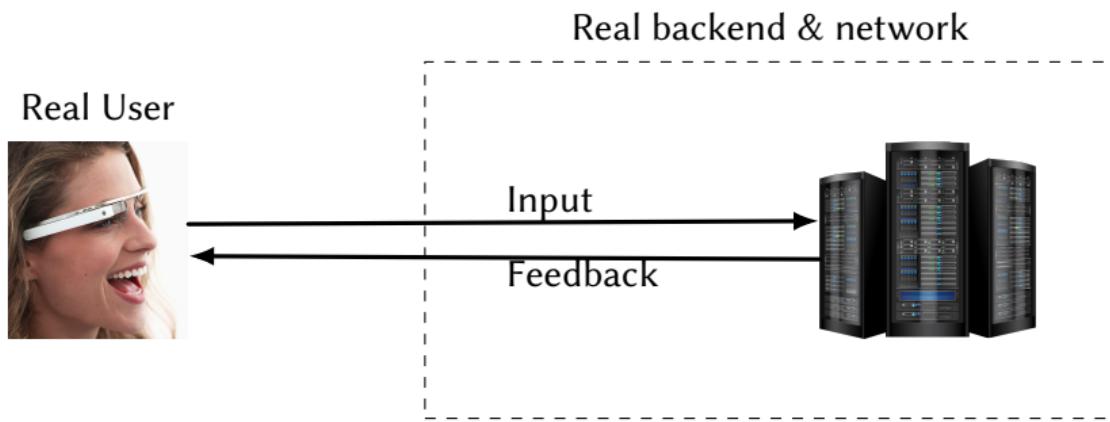
- ▶ Latency
- ▶ Jitter

Human time-perception is tail-driven...

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

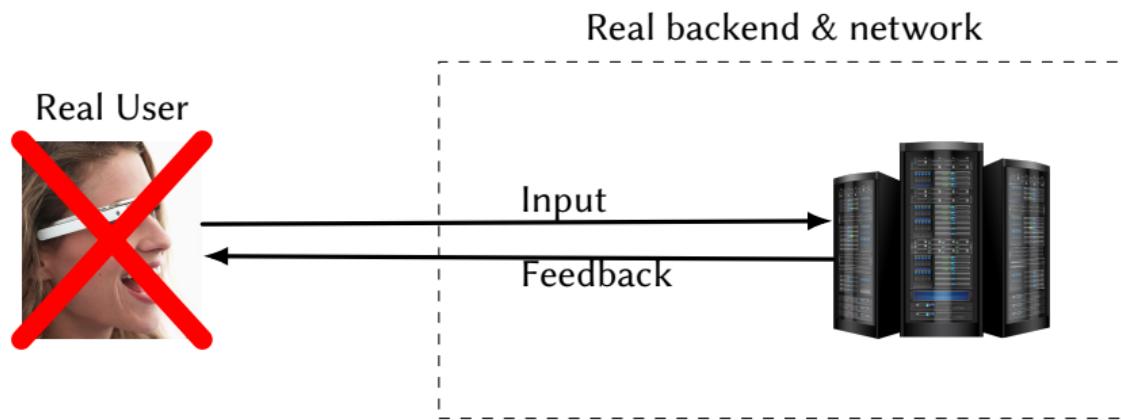
KPIs: Delays (total RTT and segment-wise)

Approach



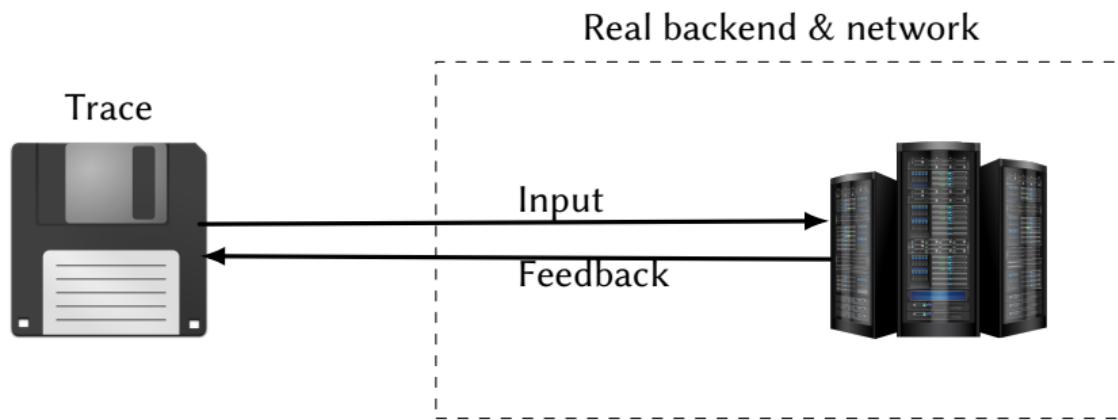
Benchmarking human-in-the-loop applications is HARD

Approach



What if we could do away with the human users?

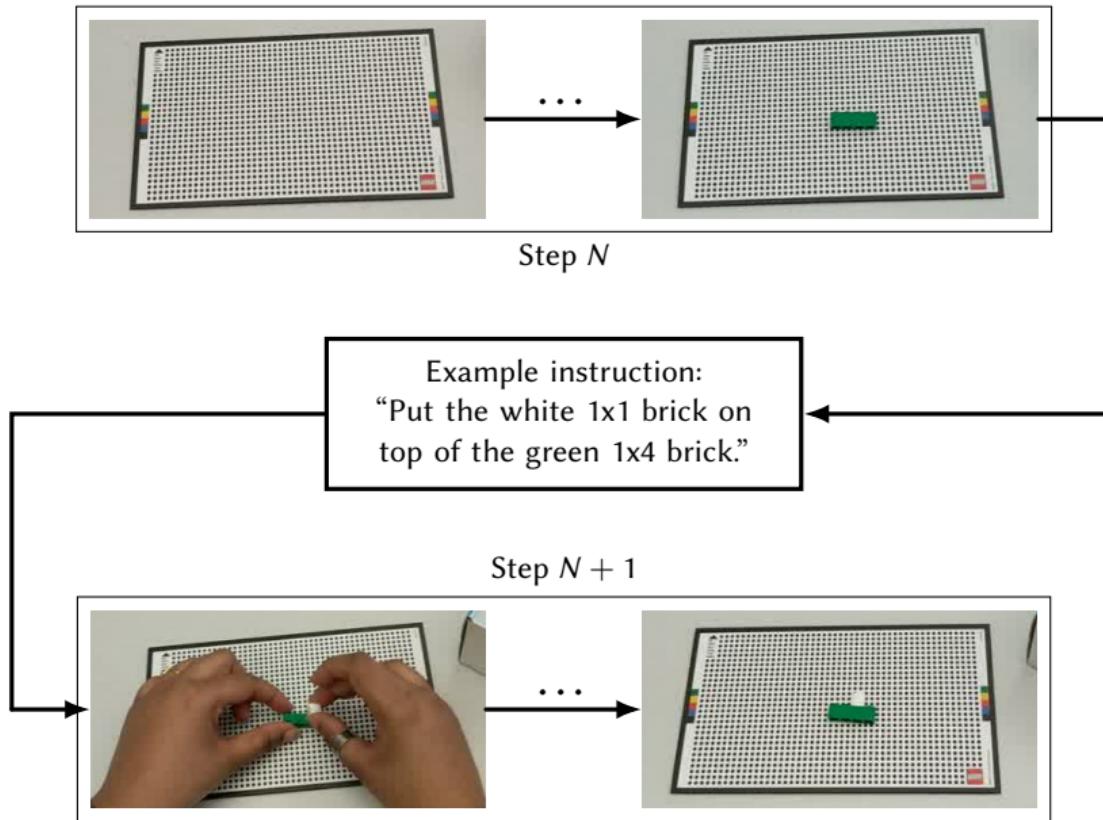
Approach



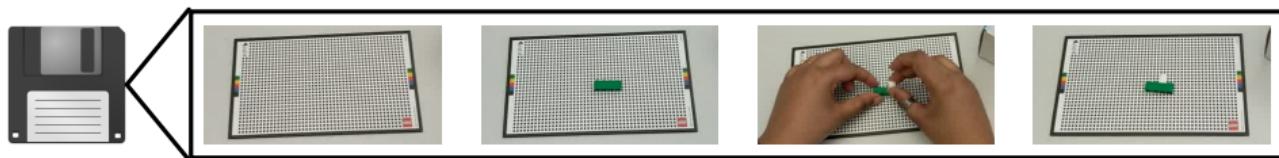
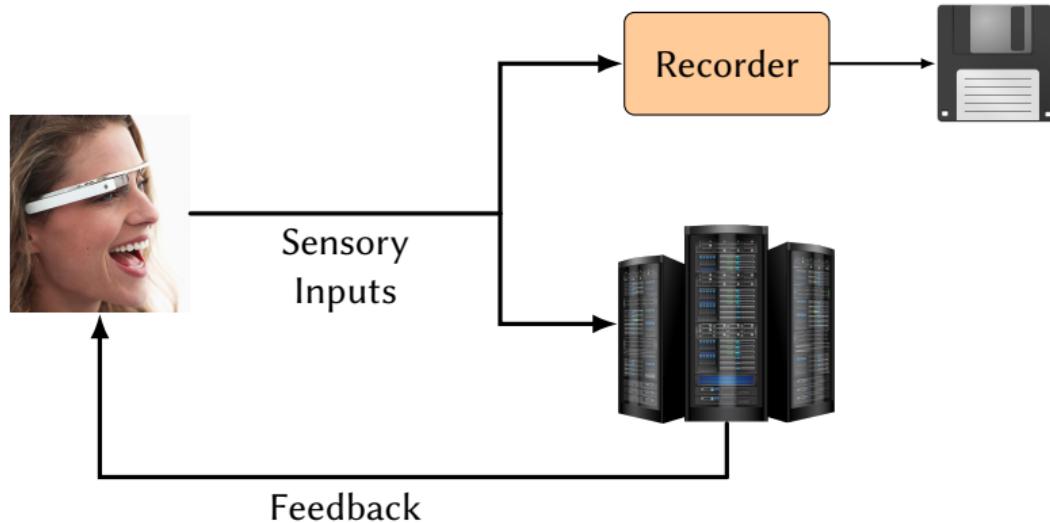
What if we could do away with the human users?

Repeatable, but is it 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.

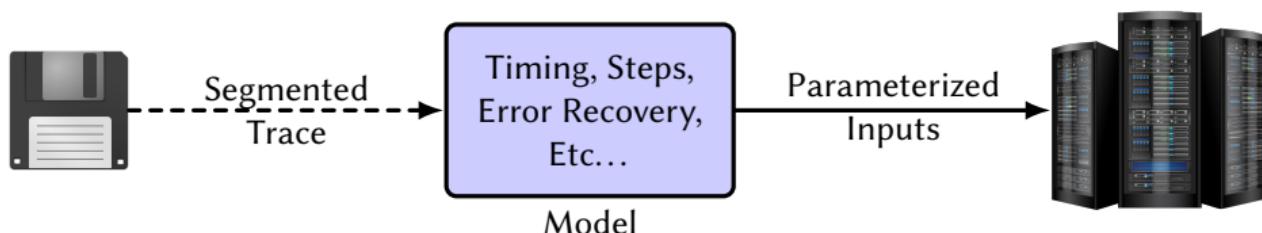
Trace Replay

Non-trivial Challenge

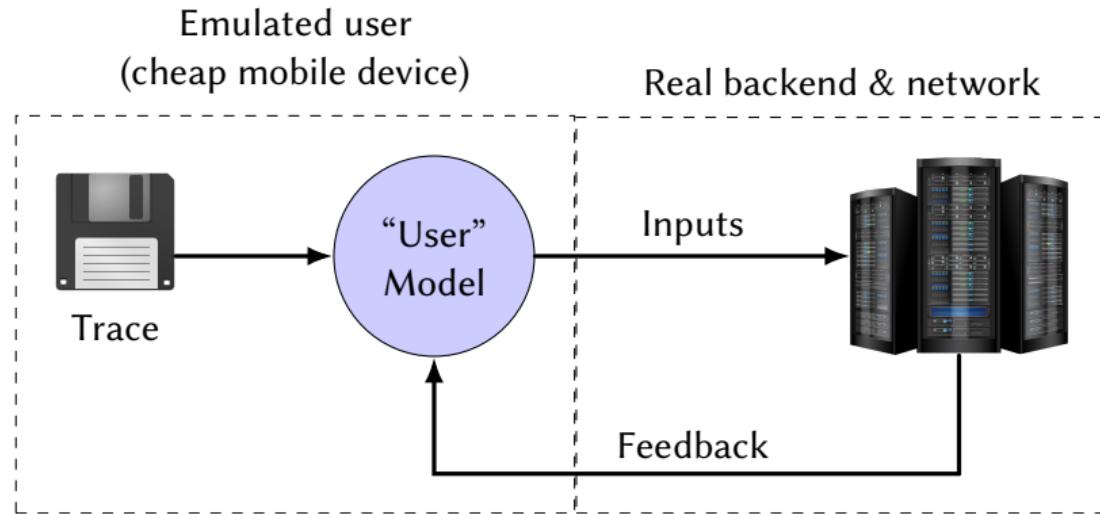
- ▶ Changes in system responsiveness require adapting trace.
- ▶ System delays affect user behavior as well.

Our Approach

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

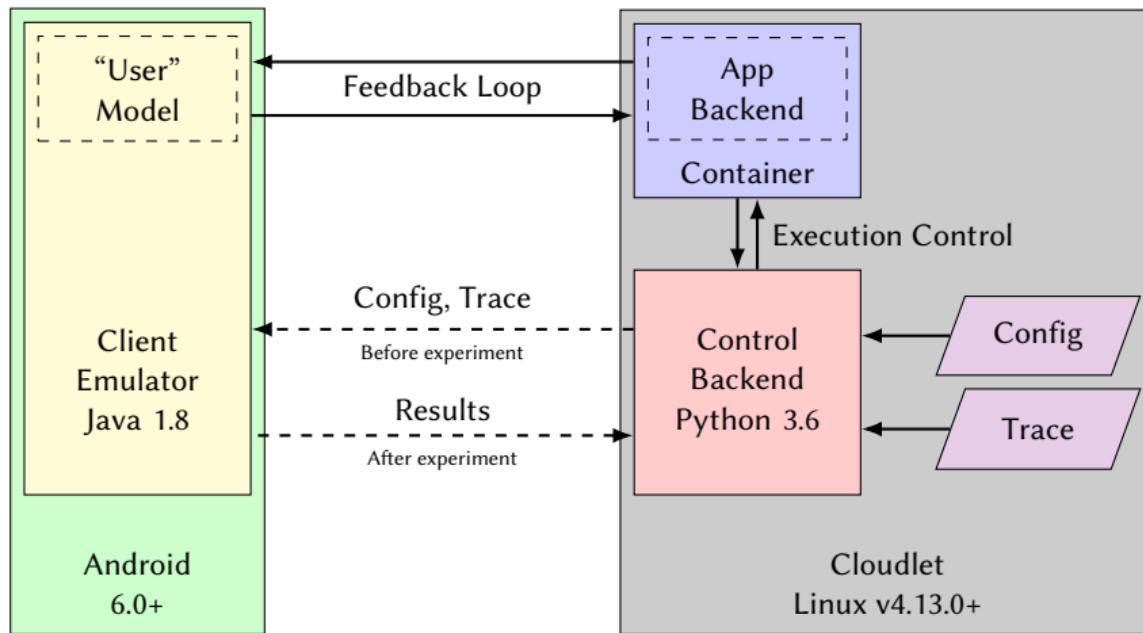


Approach



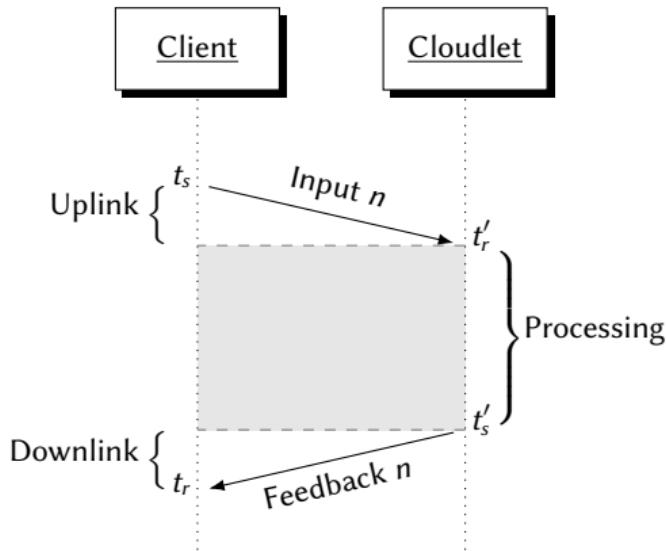
Repeatable, scalable!

Implementation: EdgeDroid



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

Timestamping



Clocks are synchronized previous to the experiment.

Timestamps at key points to obtain:

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

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

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

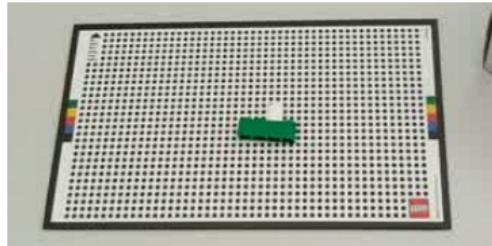
$$\Delta T_{\text{total}} = \Delta T_{\text{up}} + \Delta T_{\text{proc}} + \Delta T_{\text{down}} = t_r - t_s \quad (4)$$

Evaluation

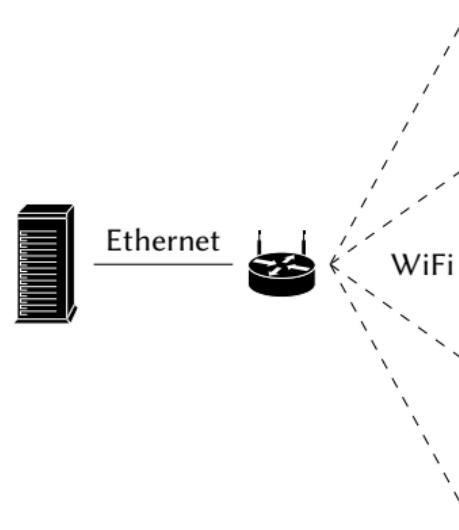
Key purpose:
Demonstrate utility of EdgeDroid.

Evaluation: Setup

Application & Scenarios



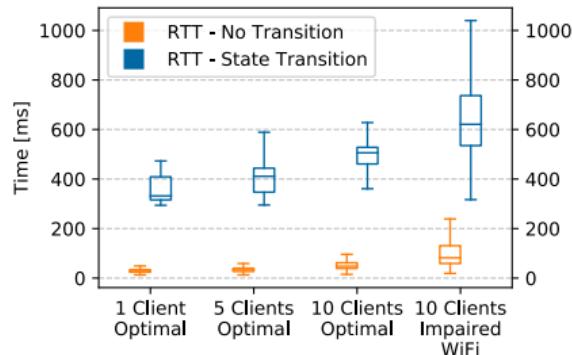
LEGO Assistant



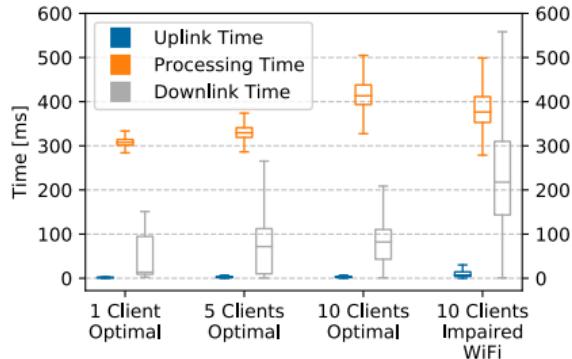
- ▶ Three *optimal* scenarios with 1, 5 and 10 devices.
- ▶ Weakened wireless link with 10 devices.

Use Cases

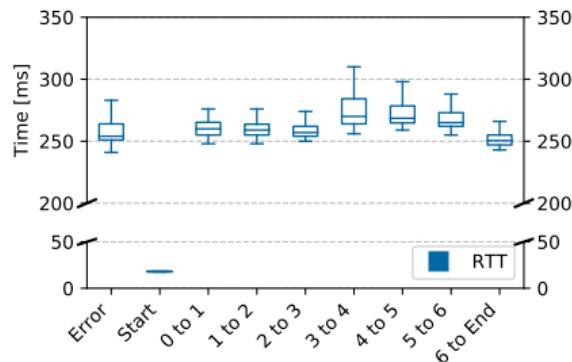
State change vs. no state change.



Times by pipeline segments.



RTT by task step.



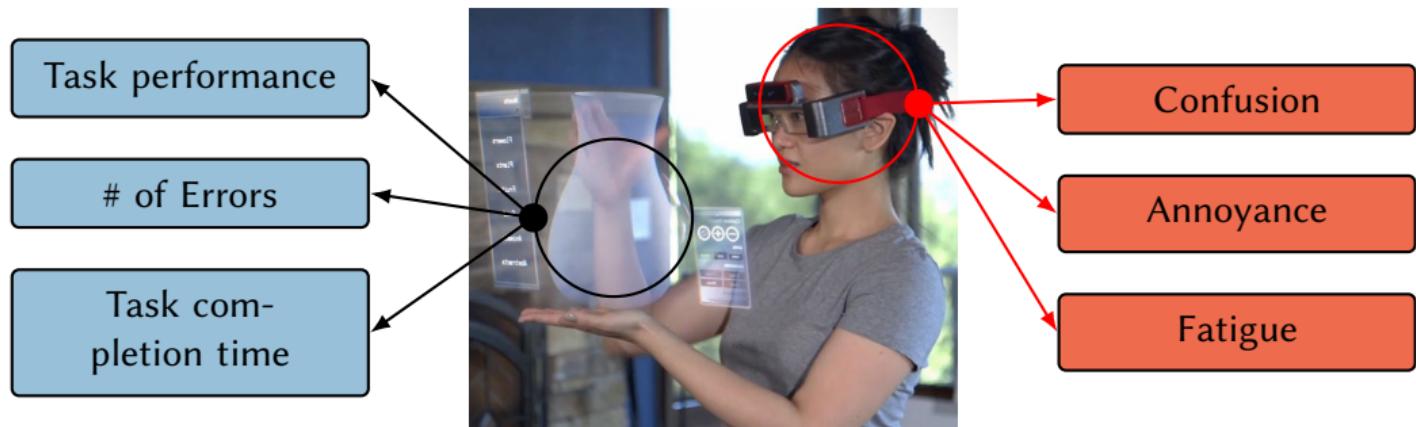
Future Work

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

Characterizing human behavior...

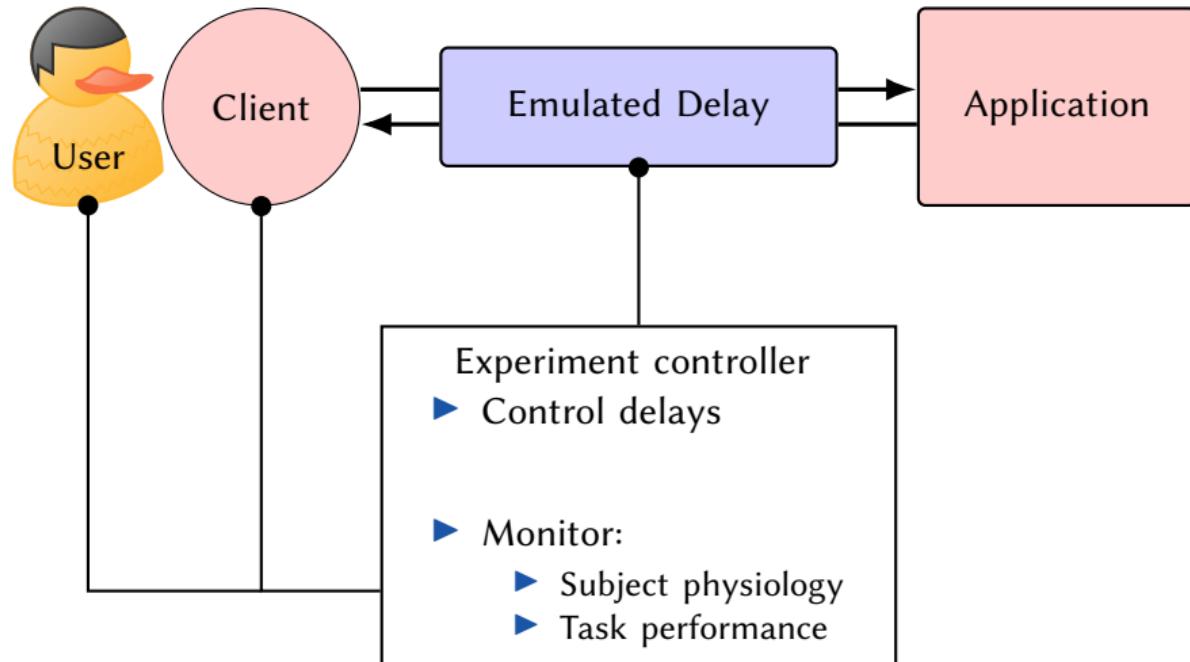
... in the presence of delays in human-in-the-loop applications.

Open research question: how do these delays affect users?



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

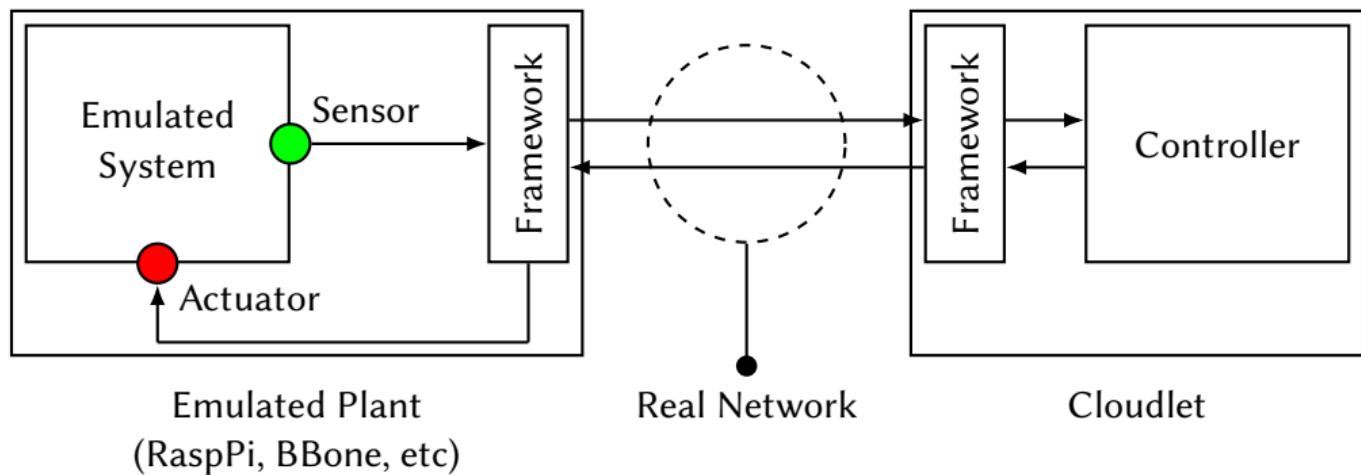
Proposed Experiment Setup



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 TUM¹[11].



¹<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

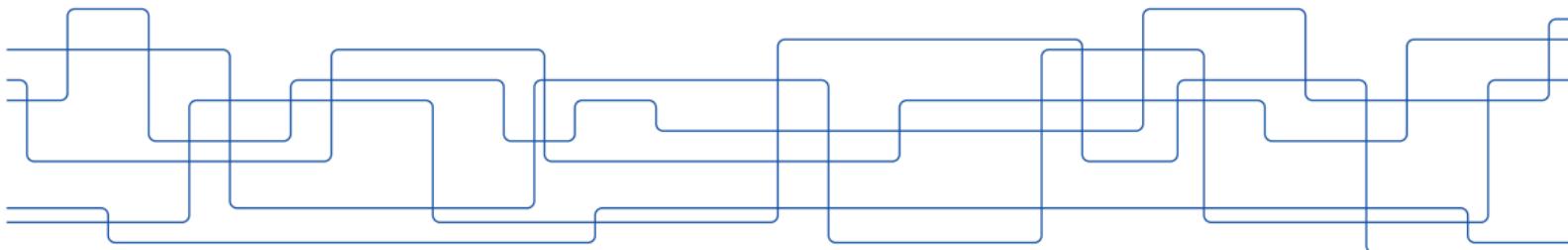
Part of an ongoing collaboration with the Elijah Group at Carnegie Mellon University, led by Prof. Mahadev Satyanarayanan.



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



Extra Slides



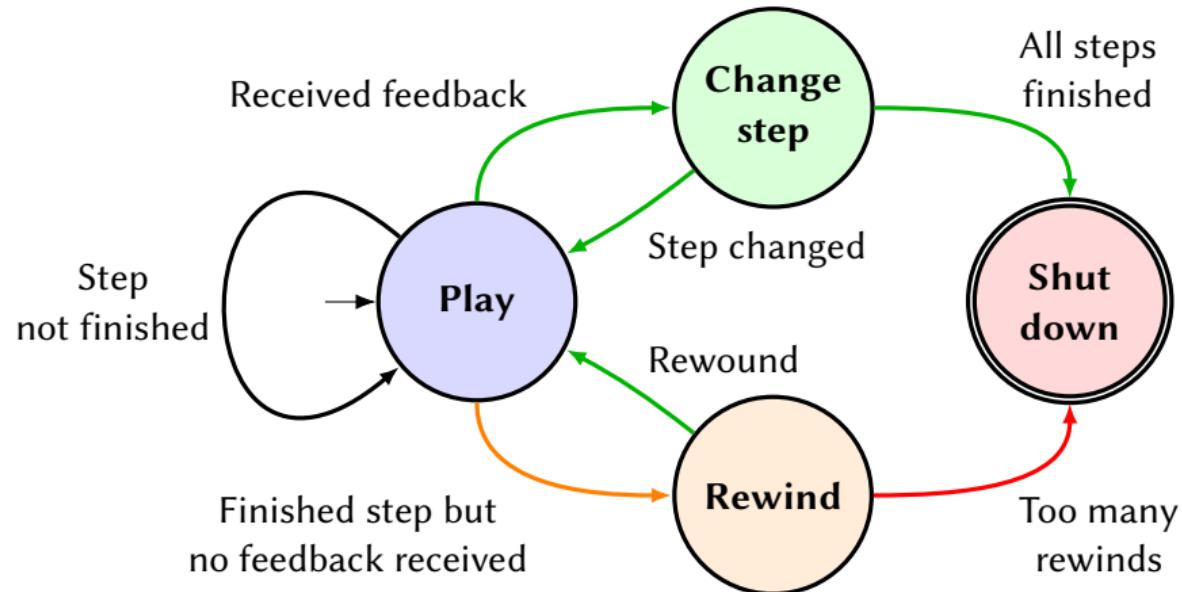
Requirements

- ▶ 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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