

# EdgeDroid

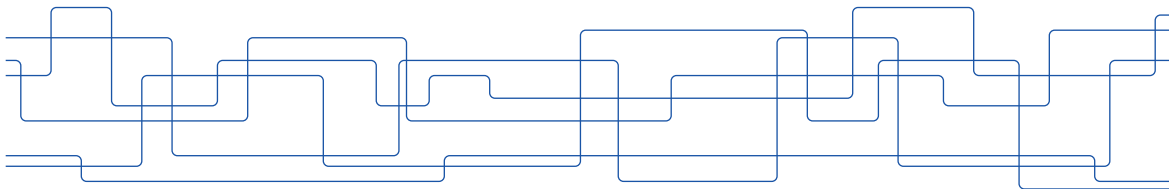
*An Experimental Approach to Benchmarking Human-in-the-Loop Applications*

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

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Sensory Input



Human-parseable  
Feedback



# 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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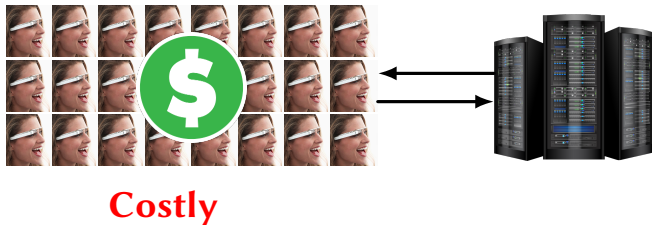


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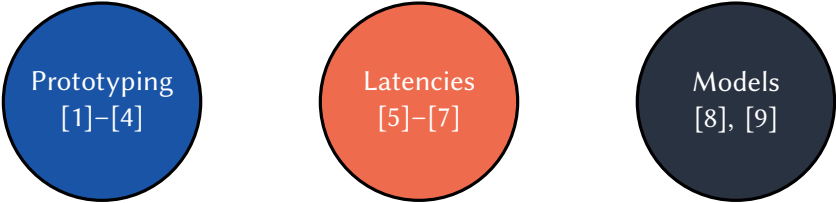
- ▶ How do they interact with each other?
- ▶ How do they interact with infrastructure?
- ▶ How do they scale?

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**Costly, poor repeatability**

## Previous & Related Work



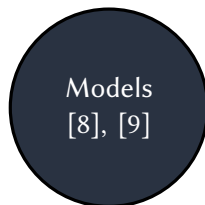
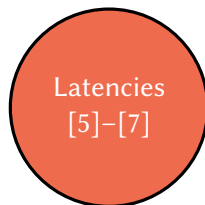
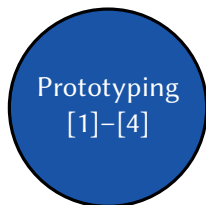
Prototyping  
[1]–[4]

Latencies  
[5]–[7]

Models  
[8], [9]



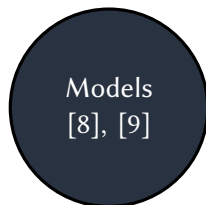
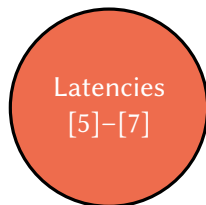
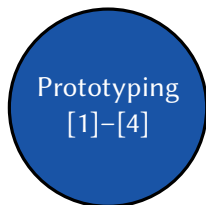
## Previous & Related Work



## Our Contributions

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

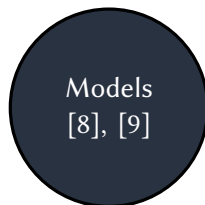
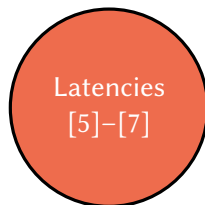
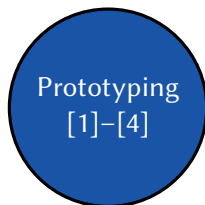
## Previous & Related Work



## Our Contributions

- ▶ A methodology for benchmarking human-in-the-loop applications.
- ▶ EdgeDroid: A benchmarking tool-suite.

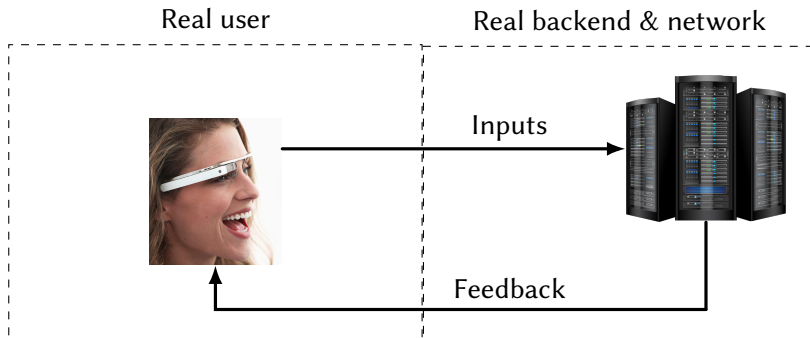
## Previous & Related Work



## Our Contributions

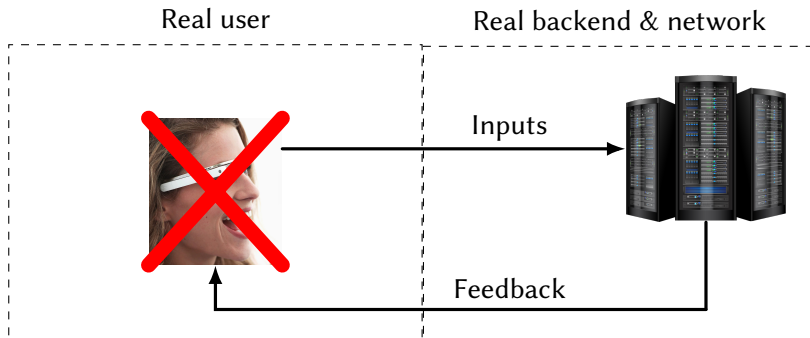
- ▶ A methodology for benchmarking human-in-the-loop applications.
- ▶ EdgeDroid: A benchmarking tool-suite.
- ▶ Experiments and measurements which show the effectiveness of the approach.

# Approach



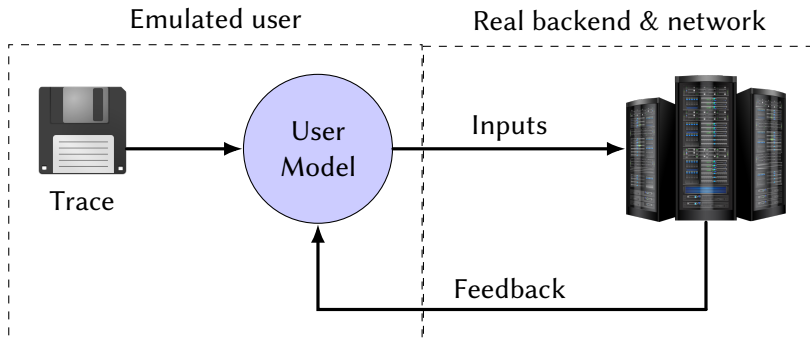
Benchmarking human-in-the-loop applications is HARD

# Approach



What if we could do away with the human users?

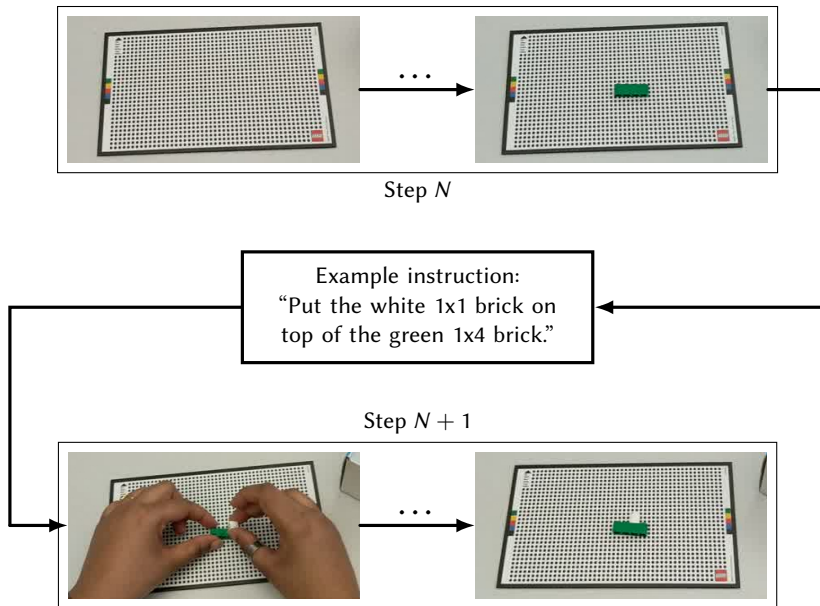
# Approach



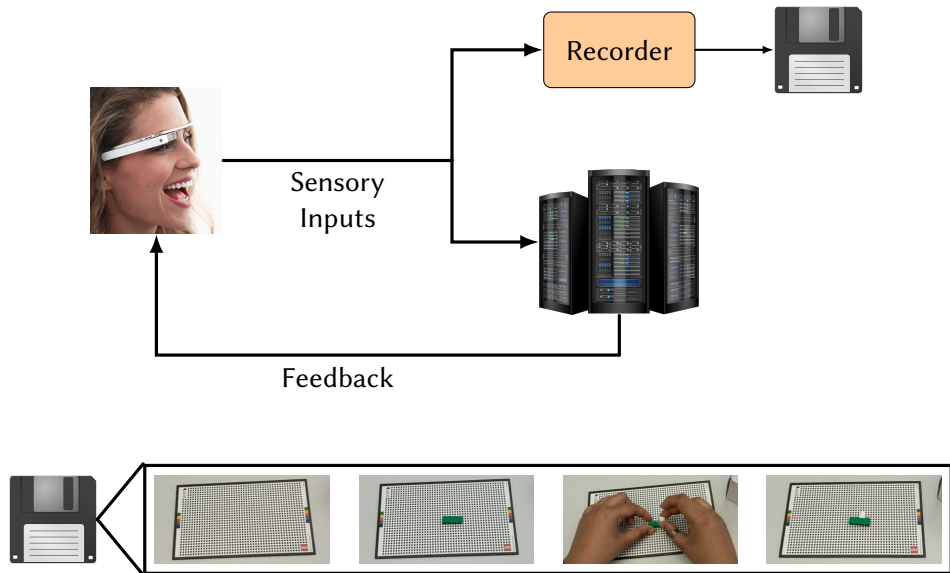
What if we could do away with the human users?

**Repeatable, scalable!**

## Example: Task Guidance WCA, LEGO Assistant [1]



# Tracing





# Trace Replay

## Non-trivial Challenge

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

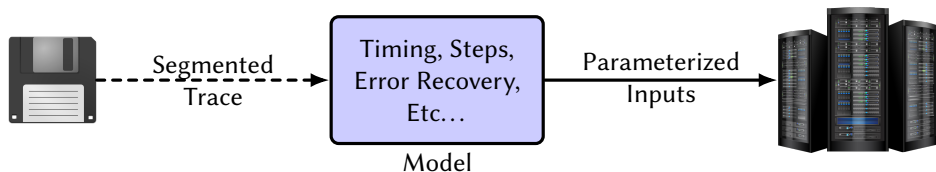
# Trace Replay

## Non-trivial Challenge

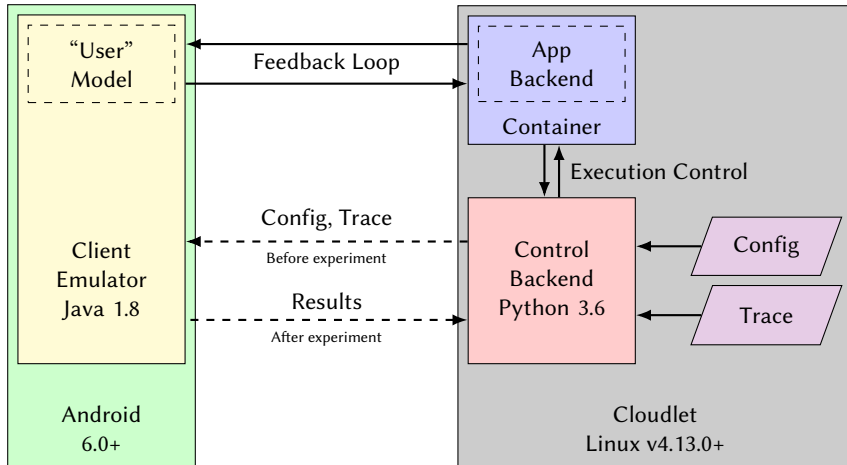
- ▶ Changes in system responsiveness require adapting trace.
- ▶ System delays affect user behavior as well.


## Our Approach

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



# Implementation

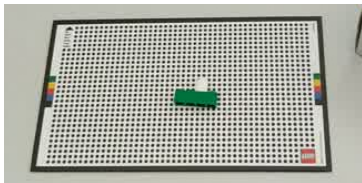


 <https://github.com/molguin92/EdgeDroid>

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

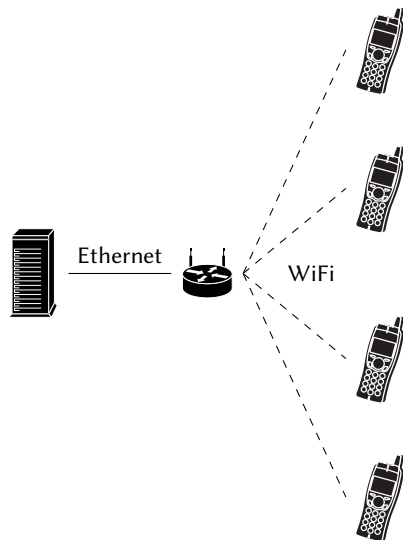
# Evaluation: Setup

## Application & Scenarios



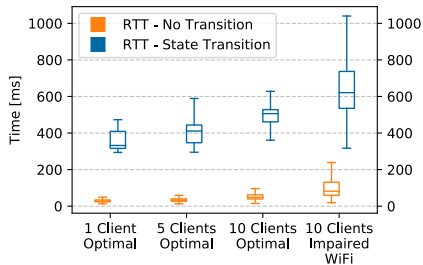
LEGO Assistant

- ▶ Three *optimal* scenarios with 1, 5 and 10 devices.
- ▶ Weakened wireless link with 10 devices.
- ▶ KPI: Round-Trip Time (RTT).

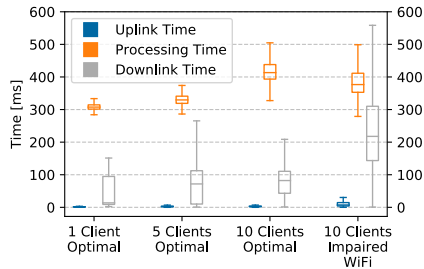


# Use Cases

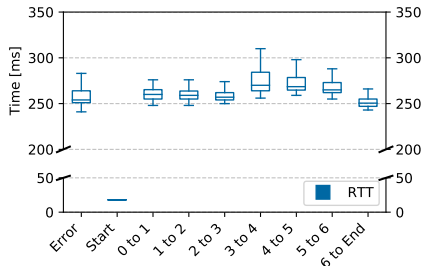
State change vs. no state change.



Times by pipeline segments.



RTT by task step.



Reference latency bounds for LEGO  
(Chen *et al.* [5])

Latency [ms]	Quality
< 600	Excellent
600 – 2700	Impaired
> 2700	Unusable

# Conclusions

## Future Work

- ▶ User Model.
- ▶ Other types of Applications.

## 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.



# Thank you.

## Contact

**Manuel Olguín Muñoz**

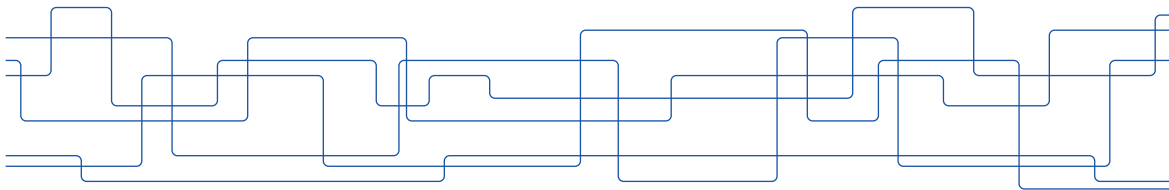
Division of Information Science and Engineering

KTH EECS

Malvinas väg 10, 100-44 Stockholm, SWEDEN

Email: [molguin@kth.se](mailto:molguin@kth.se)

Website: <https://olguin.se>



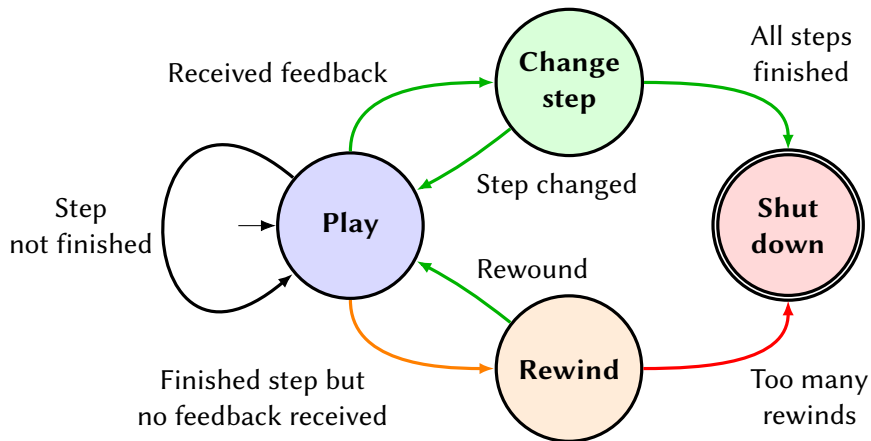


# Requirements

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

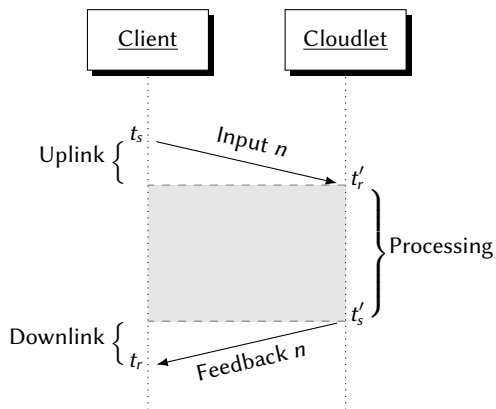
**Trace of pre-recorded inputs  
& a model of user behavior**

# User Model



Future work: more elaborate models.

# Timestamping



Clocks are synchronized previous to the experiment.

Timestamps at key points to obtain:

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

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

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

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

# References I

- [1] K. Ha *et al.*, “Towards wearable cognitive assistance,” in *Proceedings of the 12th Annual International Conference on Mobile Systems, Applications, and Services*, ser. MobiSys '14, Bretton Woods, New Hampshire, USA: ACM, 2014, pp. 68–81, ISBN: 978-1-4503-2793-0. DOI: 10.1145/2594368.2594383. [Online]. Available: <http://doi.acm.org/10.1145/2594368.2594383>.
- [2] Z. Chen *et al.*, “Early implementation experience with wearable cognitive assistance applications,” in *Proceedings of the 2015 Workshop on Wearable Systems and Applications*, ser. WearSys '15, Florence, Italy: ACM, 2015, pp. 33–38, ISBN: 978-1-4503-3500-3. DOI: 10.1145/2753509.2753517. [Online]. Available: <http://doi.acm.org/10.1145/2753509.2753517>.
- [3] D. Chatzopoulos *et al.*, “Hyperion: A wearable augmented reality system for text extraction and manipulation in the air,” in *Proceedings of the 8th ACM on Multimedia Systems Conference*, ser. MMSys'17, Taipei, Taiwan: ACM, 2017, pp. 284–295, ISBN: 978-1-4503-5002-0. DOI: 10.1145/3083187.3084017. [Online]. Available: <http://doi.acm.org/10.1145/3083187.3084017>.
- [4] S. Jalaliniya *et al.*, “Designing wearable personal assistants for surgeons: An egocentric approach,” *IEEE Pervasive Computing*, vol. 14, no. 3, pp. 22–31, 2015, ISSN: 1536-1268. DOI: 10.1109/MPRV.2015.61.

## References II

- [5] Z. Chen *et al.*, “An empirical study of latency in an emerging class of edge computing applications for wearable cognitive assistance,” in *Proceedings of the Second ACM/IEEE Symposium on Edge Computing*, ser. SEC '17, San Jose, California: ACM, 2017, 14:1–14:14, ISBN: 978-1-4503-5087-7. doi: 10.1145/3132211.3134458. [Online]. Available: <http://doi.acm.org/10.1145/3132211.3134458>.
- [6] J. Dolezal *et al.*, “Performance evaluation of computation offloading from mobile device to the edge of mobile network,” in *2016 IEEE Conference on Standards for Communications and Networking (CSCN)*, 2016, pp. 1–7. doi: 10.1109/CSCN.2016.7785153.
- [7] D. Chatzopoulos *et al.*, “Mobile augmented reality survey: From where we are to where we go,” *IEEE Access*, vol. 5, pp. 6917–6950, 2017, ISSN: 2169-3536. doi: 10.1109/ACCESS.2017.2698164.
- [8] 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.
- [9] 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.
- [10] M. Satyanarayanan *et al.*, “The case for VM-based cloudlets in mobile computing,” *IEEE Pervasive Computing*, vol. 8, no. 4, 2009.

## References III

- [11] J. Flinn, “Cyber foraging: Bridging mobile and cloud computing,” *Synthesis Lectures on Mobile and Pervasive Computing*, vol. 7, no. 2, pp. 1–103, 2012.
- [12] K. Sasaki *et al.*, “Vehicle control system coordinated between cloud and mobile edge computing,” in *2016 55th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE)*, 2016, pp. 1122–1127. DOI: 10.1109/SICE.2016.7749210.
- [13] —, “Layered vehicle control system coordinated between multiple edge servers,” in *2017 IEEE Conference on Network Softwarization (NetSoft)*, 2017, pp. 1–5. DOI: 10.1109/NETSOFT.2017.8004199.
- [14] T. Bittmann, “The edge will eat the cloud,” *Gartner Research*, no. G00338633, 2017.
- [15] K. Kumar *et al.*, “Cloud computing for mobile users: Can offloading computation save energy?” *IEEE Computer*, vol. 43, no. 4, pp. 51–56, 2010.
- [16] E. Cuervo *et al.*, “Maui: Making smartphones last longer with code offload,” in *Proceedings of the International Conference on Mobile Systems, Applications, and Services*, ser. ACM MOBISYS’10, 2010.
- [17] K. Ha *et al.*, “The impact of mobile multimedia applications on data center consolidation,” in *2013 IEEE International Conference on Cloud Engineering (IC2E)*, 2013, pp. 166–176. DOI: 10.1109/IC2E.2013.17.

## References IV

- [18] K. Ha *et al.*, “Just-in-time provisioning for cyber foraging,” in *Proceeding of the 11th Annual International Conference on Mobile Systems, Applications, and Services*, ser. MobiSys ’13, Taipei, Taiwan: ACM, 2013, pp. 153–166, ISBN: 978-1-4503-1672-9. DOI: 10.1145/2462456.2464451. [Online]. Available: <http://doi.acm.org/10.1145/2462456.2464451>.
- [19] (2018). Docker, [Online; accessed 14. Aug. 2018], [Online]. Available: <https://www.docker.com>.
- [20] (2018). Network Time Protocol, [Online; accessed 24. Sep. 2018], [Online]. Available: <https://www.eecis.udel.edu/~mills/ntp/html/index.html>.
- [21] (2018). TOML, [Online; accessed 25. Sep. 2018], [Online]. Available: <https://github.com/toml-lang/toml>.
- [22] K. Kim *et al.*, “Workload synthesis: Generating benchmark workloads from statistical execution profile,” in *2014 IEEE International Symposium on Workload Characterization (IISWC)*, 2014, pp. 120–129. DOI: 10.1109/IISWC.2014.6983051.
- [23] E. Deniz *et al.*, “Minime: Pattern-aware multicore benchmark synthesizer,” *IEEE Transactions on Computers*, vol. 64, no. 8, pp. 2239–2252, 2015, ISSN: 0018-9340. DOI: 10.1109/TC.2014.2349522.

# References V

- [24] M. Olguín *et al.*, “Demo: Scaling on the Edge – A Benchmarking Suite for Human-in-the-Loop Applications,” in *Proceedings of The Third ACM/IEEE Symposium on Edge Computing*, ser. SEC ’18, Accepted Submission, Extended Abstract, 2018. [Online]. Available: <https://olguin.se/files/demo-scaling-edge.pdf>.