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MultiSense: Fine-grained Multiplexing for Steerable Camera Sensor Networks

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Camera Sensor Network

- Network of Camera Sensors
  - Useful for remote monitoring
  - E.g., doorways, intersections, equipment

- Key Attribute: Programmable Actuation
  - Pan-tilt-zoom ("steer") camera's lens
  - Continuous loop: steer→sense→steer→sense
    - Sense == capture image, Steer == pan-tilt-zoom

Multi-user Camera Sensor Network

- Sharing is Advantageous
  - High deployment and maintenance cost
  - Per-user networks economically infeasible

- Sharing in today's camera networks
  - Actuation controlled by single user
  - Data sharing is the only option
    - E.g., live traffic cameras

- Need for multi-user "timeshared" camera networks

Outline

- Motivation
- Overview
  - Challenges of Shared Actuation
  - Virtualization-based Approach
- MultiSense Design
  - Camera-specific Optimizations
  - Proportional-share Scheduling
- Implementation and Evaluation
  - Xen-based using Sony PTZ
  - Synthetic Workloads + Case Study
- Conclusion

Sharing Actuation: Desirable Properties

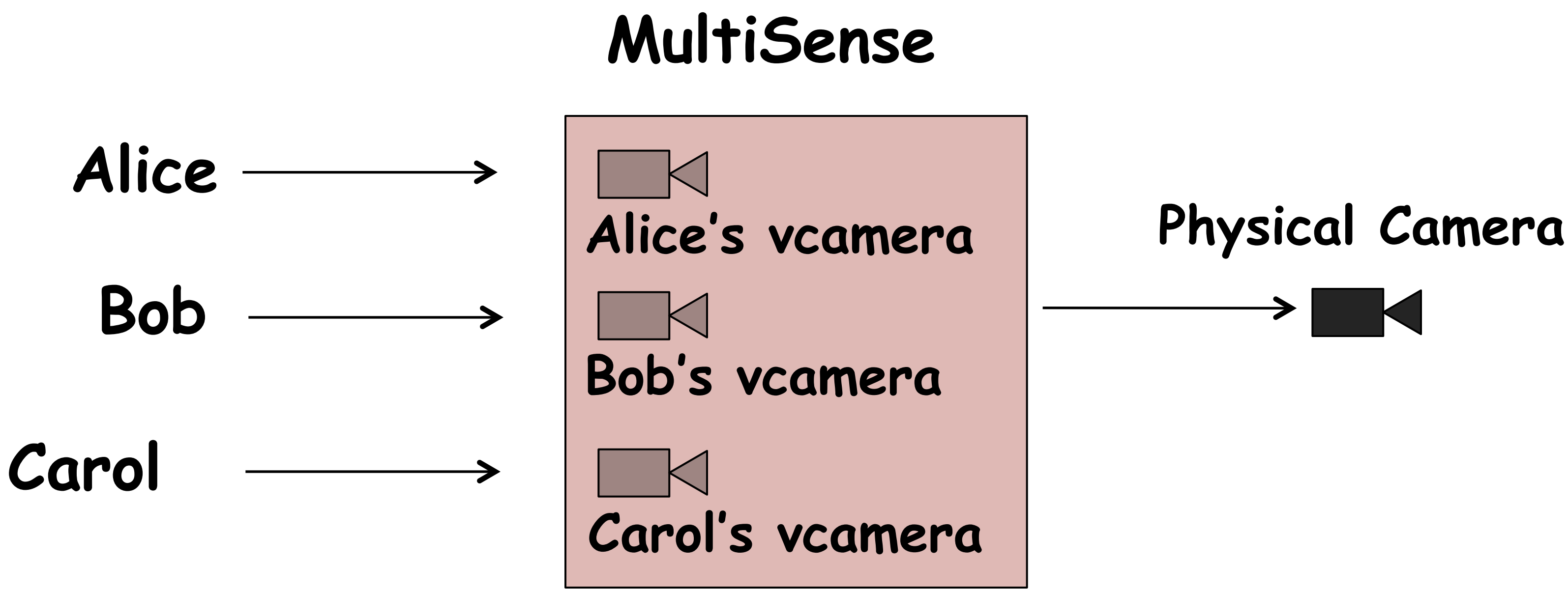
Challenge

How do we multiplex a camera network to efficiently service conflicting demands of competing users ?

- **Transparency**: users feel like they control dedicated cameras
- **Isolation**: users don't impact performance of other users
- **Arbitration**: control over each user's QoS

Virtualization-based Approach

- Our Approach: Virtualization
  - Virtual camera looks like physical camera
  - Extend VMM isolation mechanisms
  - **Goal:** hide + mitigate complexity of state transitions

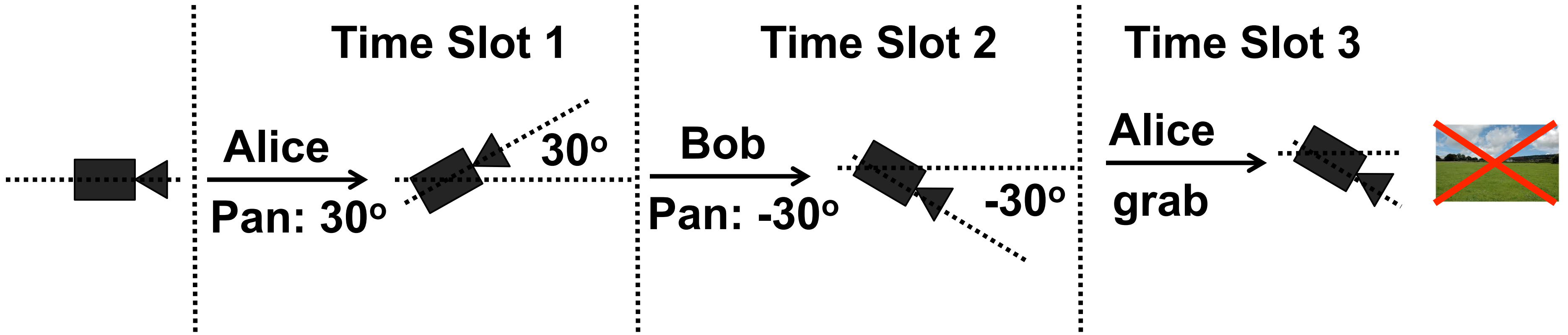


Design Overview

- Performance
  - Minimize slow mechanical actuation overhead
- Fairness
  - Proportionally partition sensing resources among users

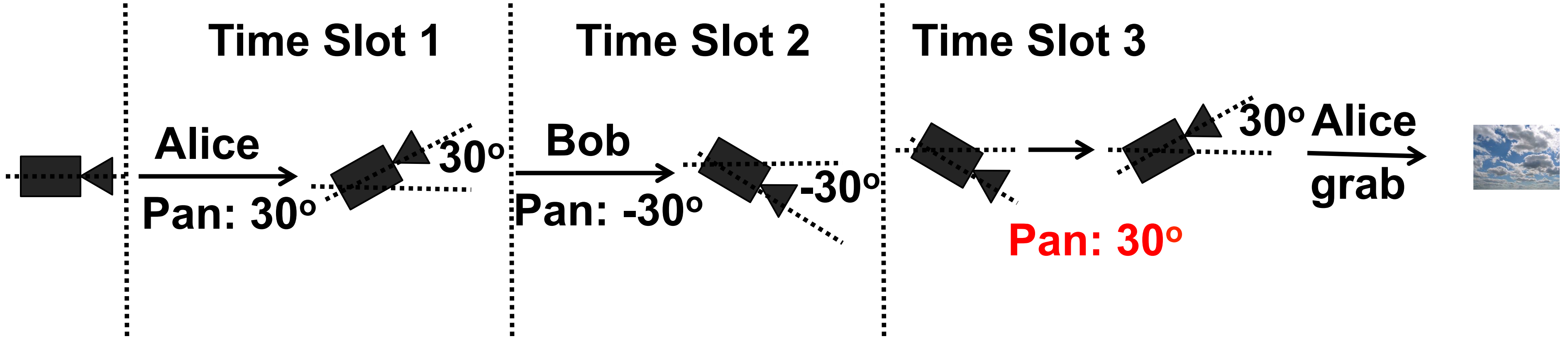
Naïve Time Sharing

- Divide time into slots
- Round-robin assign slots to users



- Naïve interleaving leads to wrong results!
  - Cameras are "stateful": PTZ position encodes state

Sharing with State Restoration

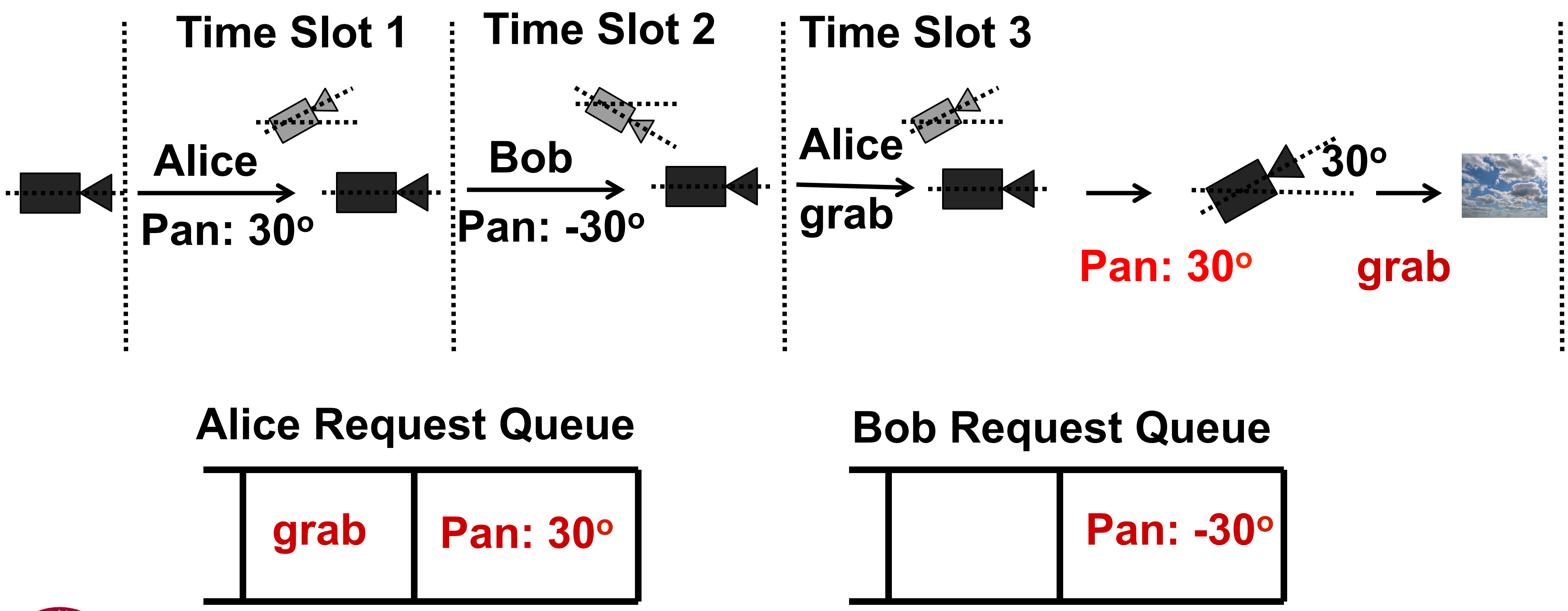


- Interleaving actuations can be wasteful

Insight: actuation without capturing an image does not change an application's control flow

Request Groups

- Prevent waste by grouping requests
  - All actuation requests grouped with a sense
  - Execute group atomically

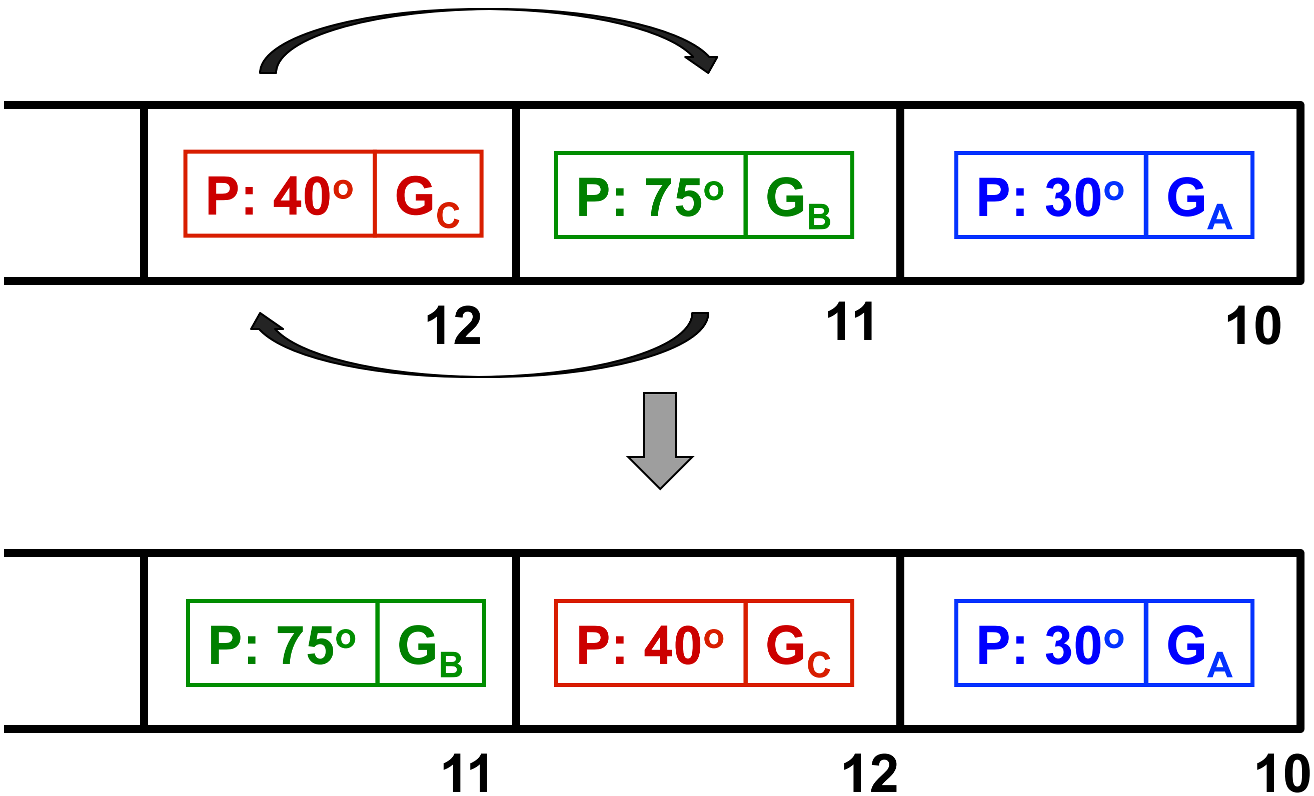


Actuator Fair Queuing

- Adapt Start-time Fair Queuing
  - Well-known algorithm from networks/CPUs
    - Partition actuation time based on weights
  - Direct adaptation is wasteful
    - Schedules based on fairness not performance
- Use request batching to adjust tradeoff between fairness and performance

Request Batching Example

Batch of size 3



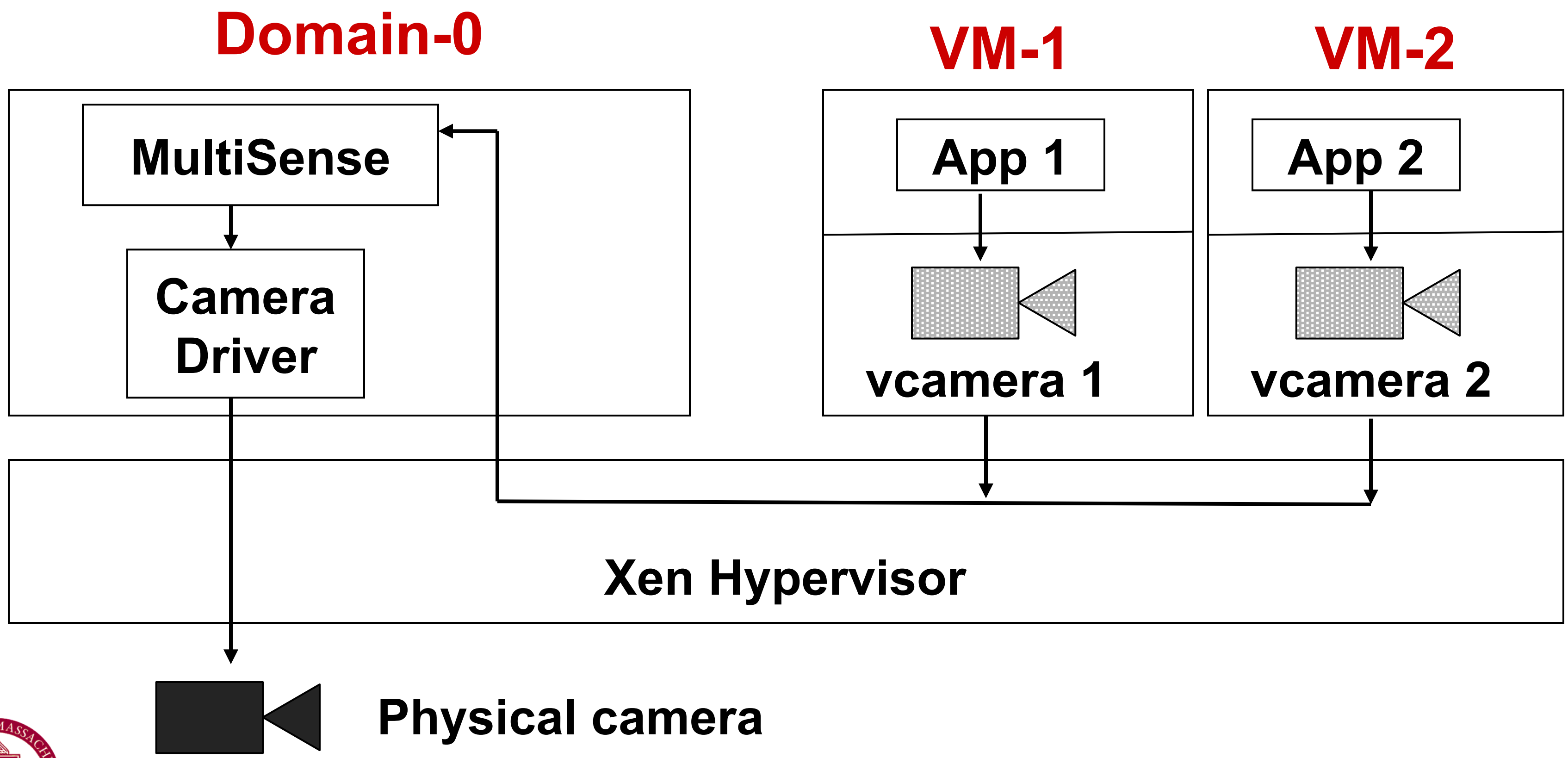
Actuation

30° -> 75° -> 40° = 80°

30° -> 40° -> 75° = 45°

MultiSense Implementation

- Leverage Xen Hypervisor
  - Augment VMs with virtual cameras
  - Write split-drivers for camera

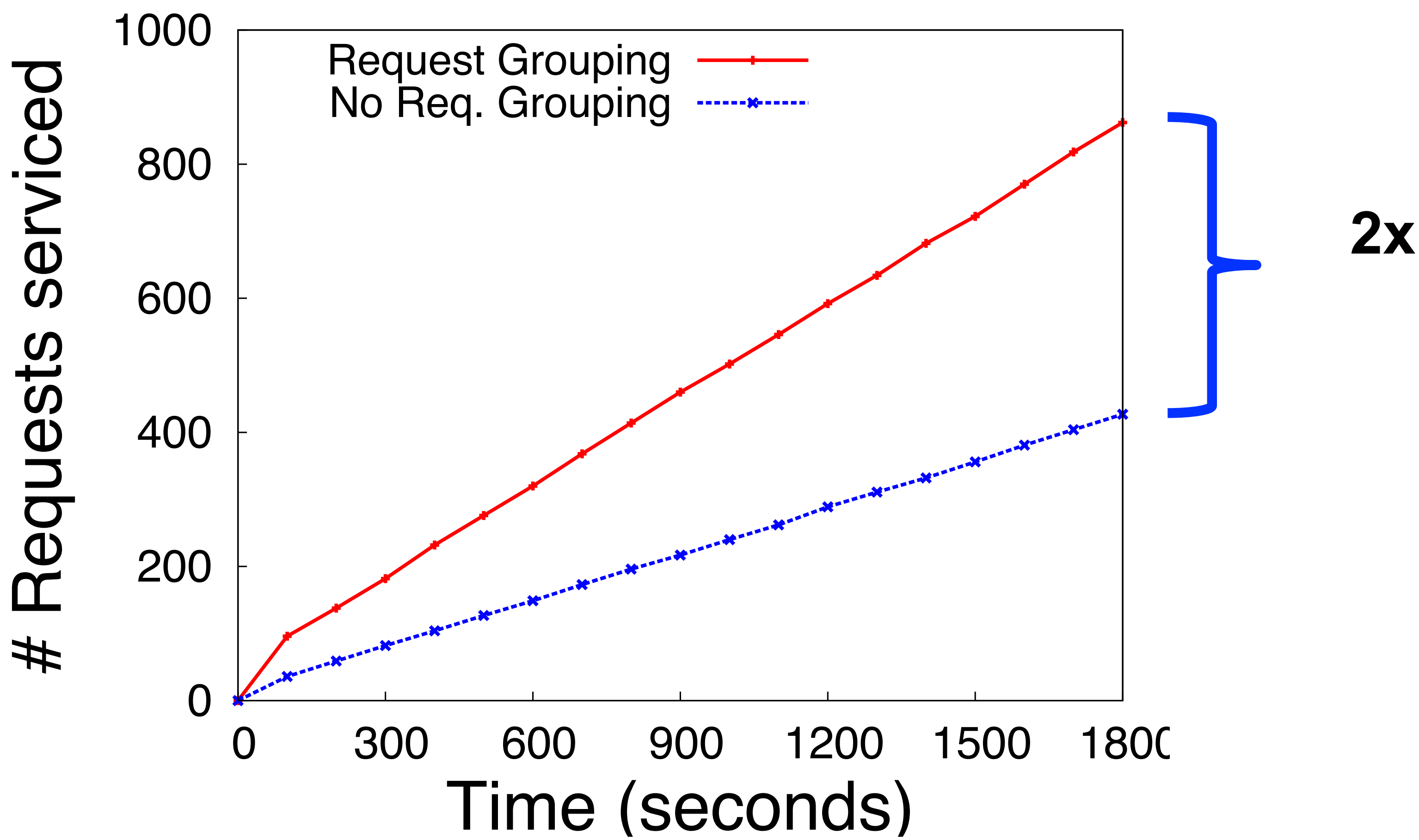


Evaluation: Setup

- Network of 2 Sony RZ50N PTZ Cameras
  - Attached to nodes running Xen
  - Each node runs 5 VMs with virtual cameras
- Workloads
  - Synthetic: Random actuations and senses
  - Case Study: Tracking and monitoring requests

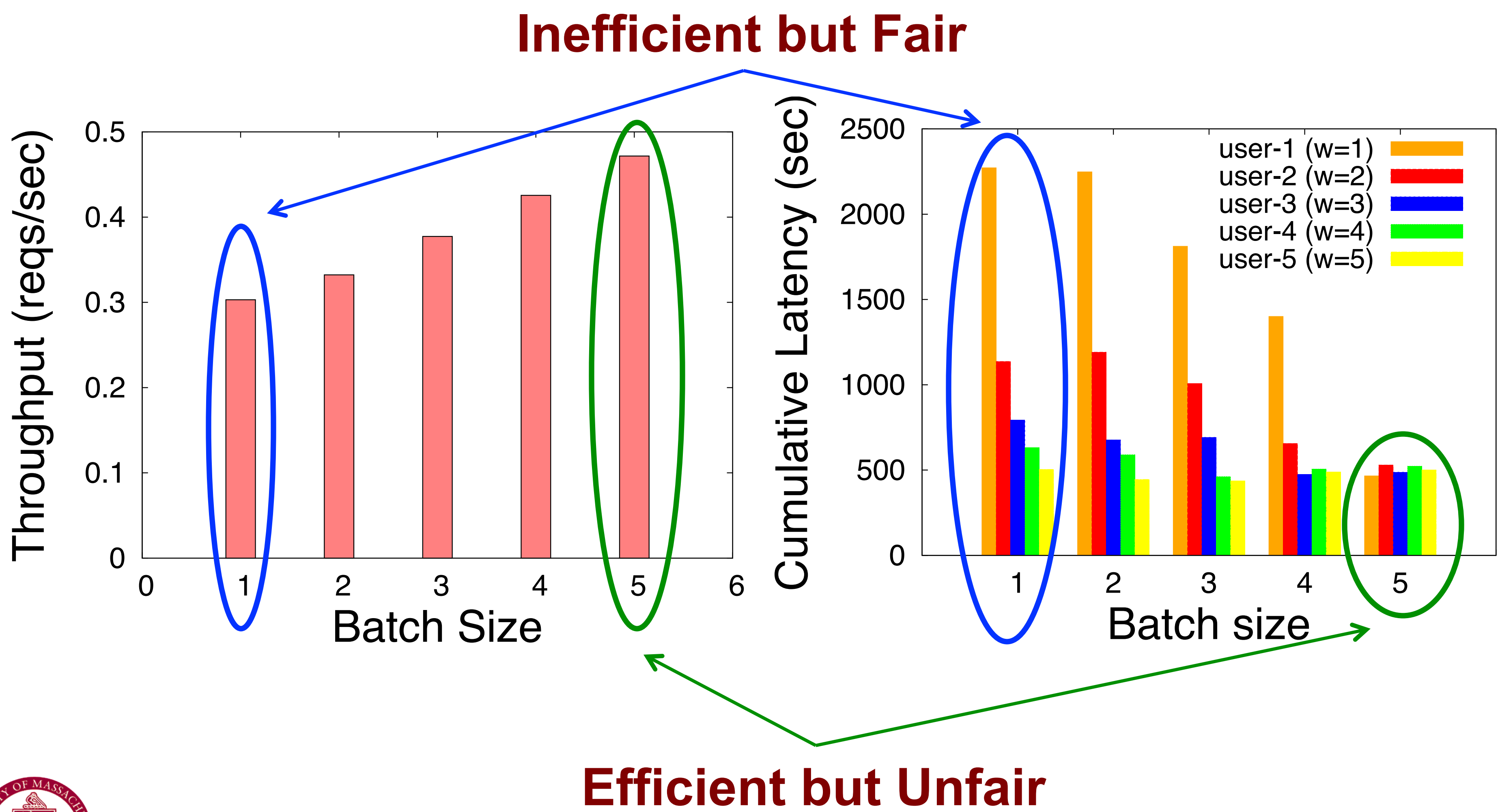
Benefits of Request Grouping

- AFQ Scheduling with Batch Size of 5



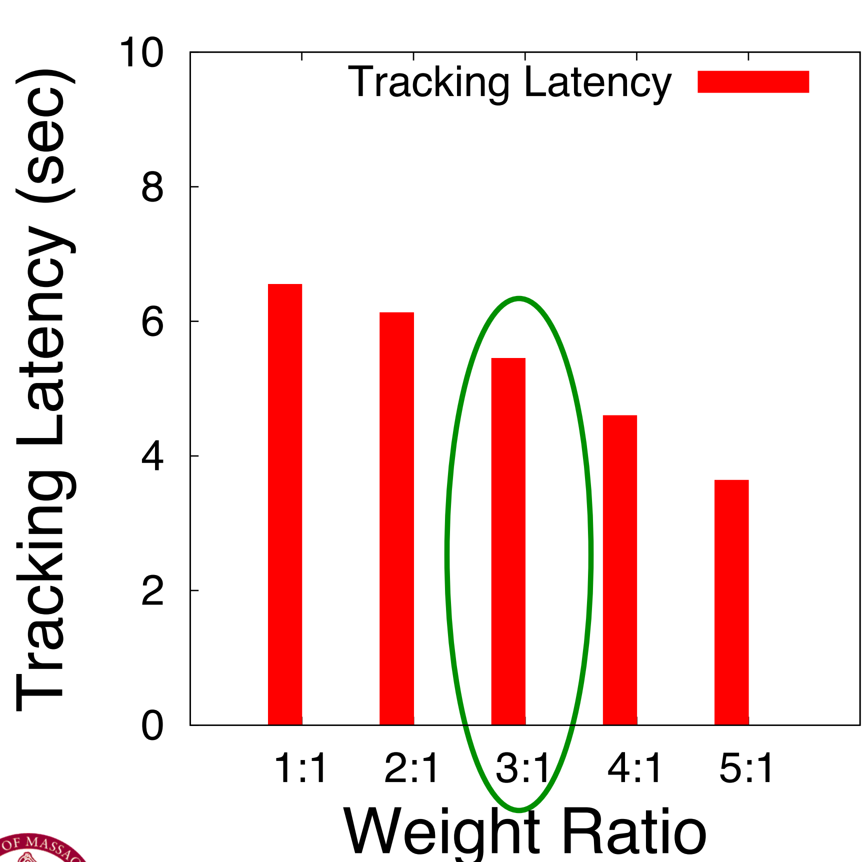
Actuator-Fair Queuing

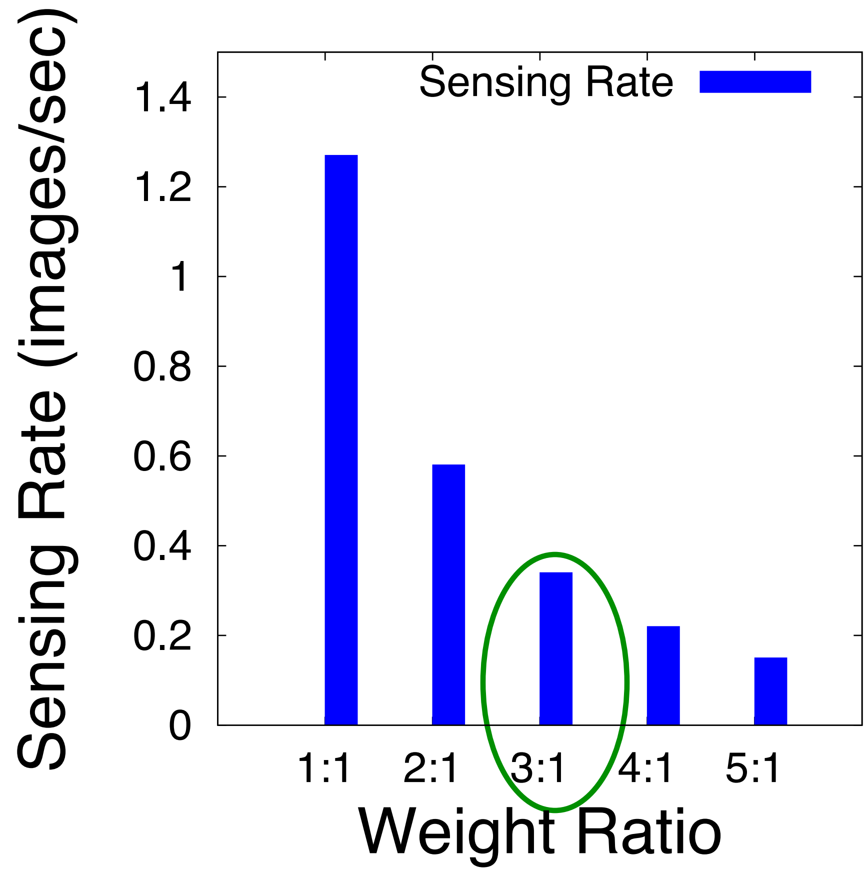
- 5 Users with different weights



Case Study: Tracking and Monitoring

- **Tracking**: scan path and capture image every 10°
- **Monitoring**: Continuously capture image at fixed-point





Case Study: Tracking and Monitoring

- Tracking
  - For object at 300ft away…
  - …capture image of object every 23 feet
  - …equates to object moving at 2.66mph or a walking person
- Monitoring
  - Concurrently capture image of fixed point every 3 sec.

Refer to the paper for results on camera coordination

Related Work

- Virtualization
  - Extend Xen hypervisor
  - Virtualizing I/O devices
- Proportional-share Scheduling
  - Adapt SFQ for cameras
  - Combine with camera-specific optimizations
- Sensor Networks
  - Focus on high-power steerable sensors
  - Orthogonal to low-power sensor networks

Conclusion

- Cameras capable of supporting multiple concurrent applications
  - Challenges
    - Slow mechanical actuation, stateful actuators
  - Key techniques for steerable cameras
    - Request grouping, AFQ, and batching

- Future Work
  - Extend to other steerable sensors
  - E.g., weather radars