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Self-Organizing Cameras

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT | WIEN GRAZ

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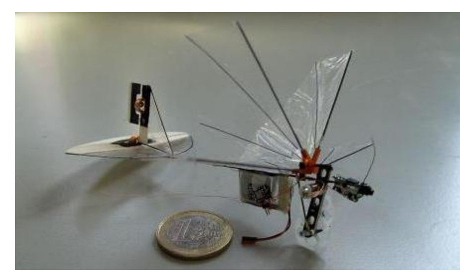
Ubiquitous Cameras

- We are surrounded by billions of cameras in public, private and business spaces
- Various well-known domains
  - Transportation
  - Security
  - Entertainment
  - Mobile
- Cameras serve a purpose and provide some utility
  - Providing documentation/archiving
  - Increasing security
  - Enabling automation
  - Fostering social interaction



Paradigma Shifts in Video Processing

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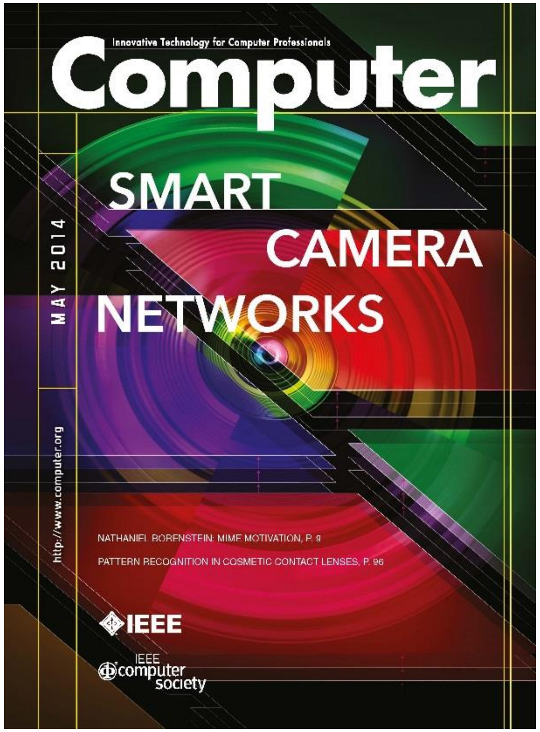
- Towards online/onboard processing
- Towards distributed, in-network analysis
- Towards ad-hoc deployment and mobile and open platforms
- Towards user-centric applications

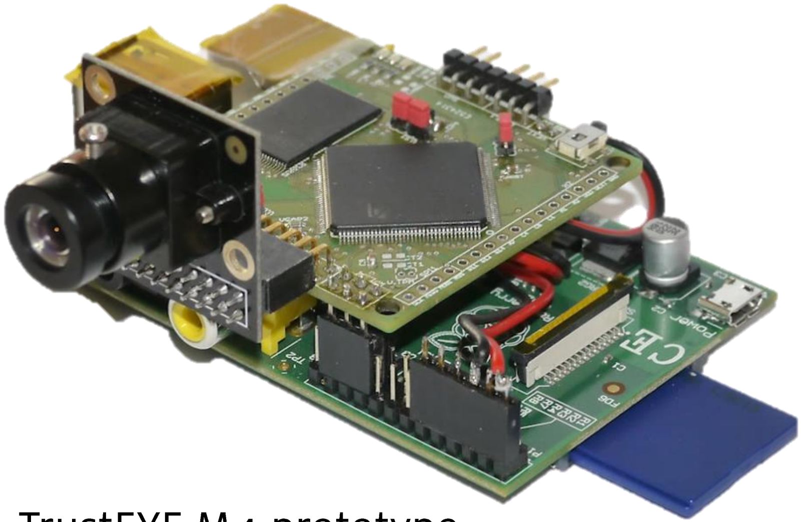


Emergence of Smart Camera Networks !

Smart Cameras as Enabling Technology

- Smart cameras combine
  - sensing,
  - processing and
  - communication

  in a single embedded device



TrustEYE.M4 prototype
on top of RaspberryPI

- perform image and video analysis in real-time closely located at the sensor and transfer only the results
- collaborate with other cameras in the network

[Rinner, Wolf. A Bright Future for Distributed Smart Cameras. Proc. IEEE, 2008]

Autonomous In-Networking Analysis

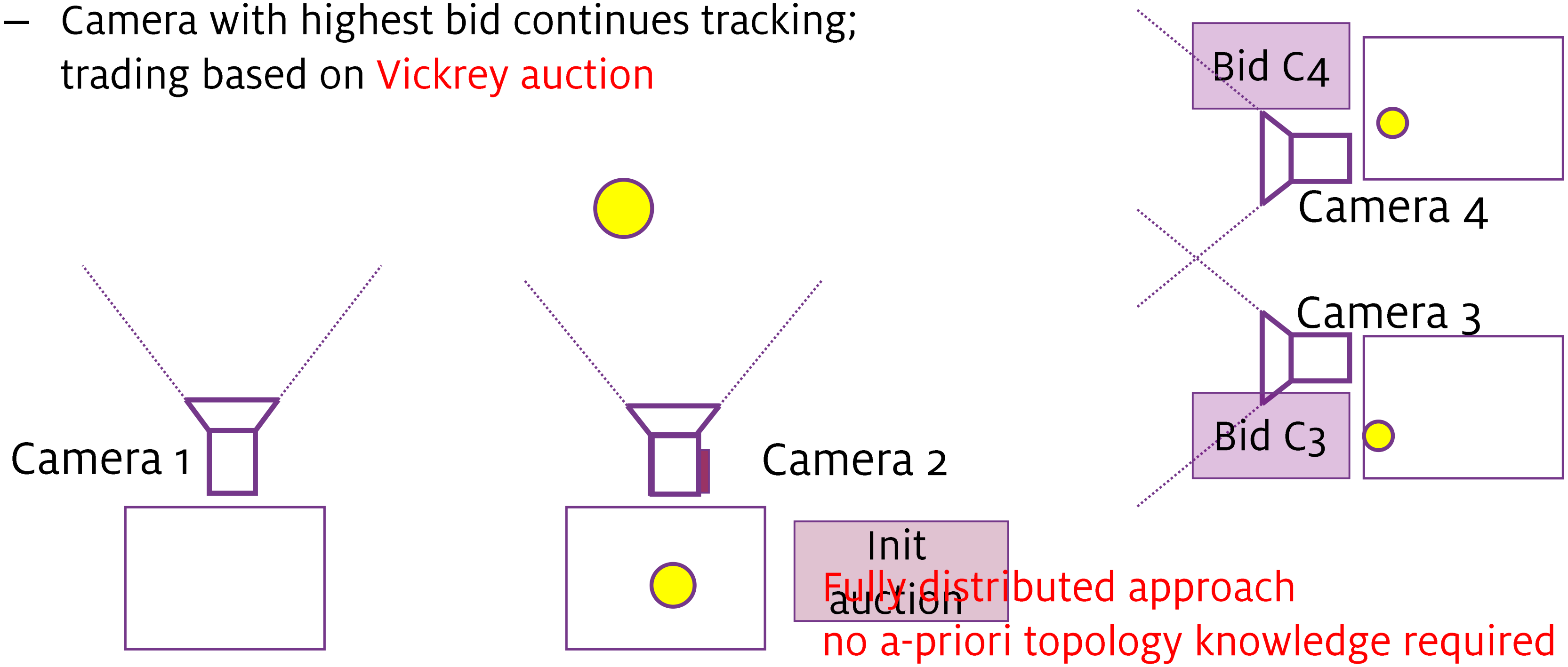
Self-organizing Camera Network

- Perform autonomous, decentralized and resource-aware network-wide analysis

- Demonstrate autonomous multi-object tracking in camera network
  - Exploit single camera object detector & tracker
  - Perform camera handover
  - Learn camera topology
- Key decisions for each camera
  - When to track an object within its FOV
  - When to initiate a handover
  - Whom to handover

Virtual Market-based Handover

- Initialize auctions for exchanging tracking responsibilities
  - Cameras act as self-interested agents, i.e., maximize their own utility
  - Selling camera (where object is leaving FOV) opens the auction
  - Other cameras return bids with price corresponding to “tracking” confidence
  - Camera with highest bid continues tracking;
    trading based on Vickrey auction



Fully distributed approach
no a-priori topology knowledge required

Camera Control

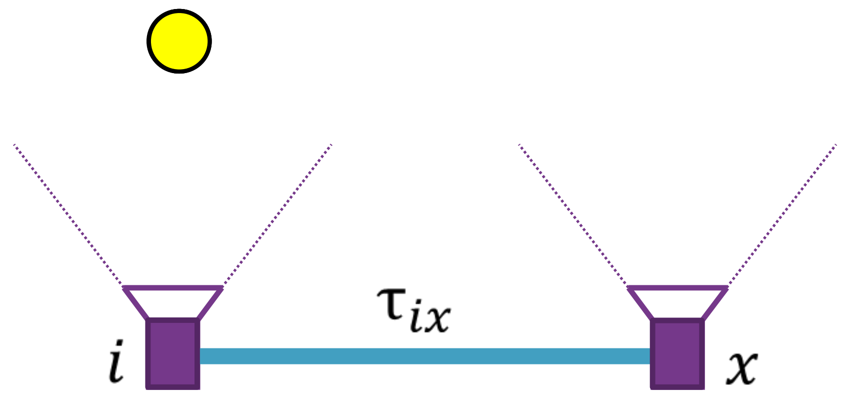
- Each camera acts as agent maximizing its utility function

$$U_i(O_i) = \sum_{j \in O_i} [c_j \cdot v_j \cdot \Phi_i(j)] - p + r$$

- Local decisions
  - When to initiate an auction (at regular intervals or specific events)
  - Whom to invite (all vs. neighboring cameras)
  - When to trade (depends on valuation of objects in FOV)
- Learn neighborhood relations with trading behavior (“pheromones”)
  - Strengthen links to buying cameras
  - Weaken links over time

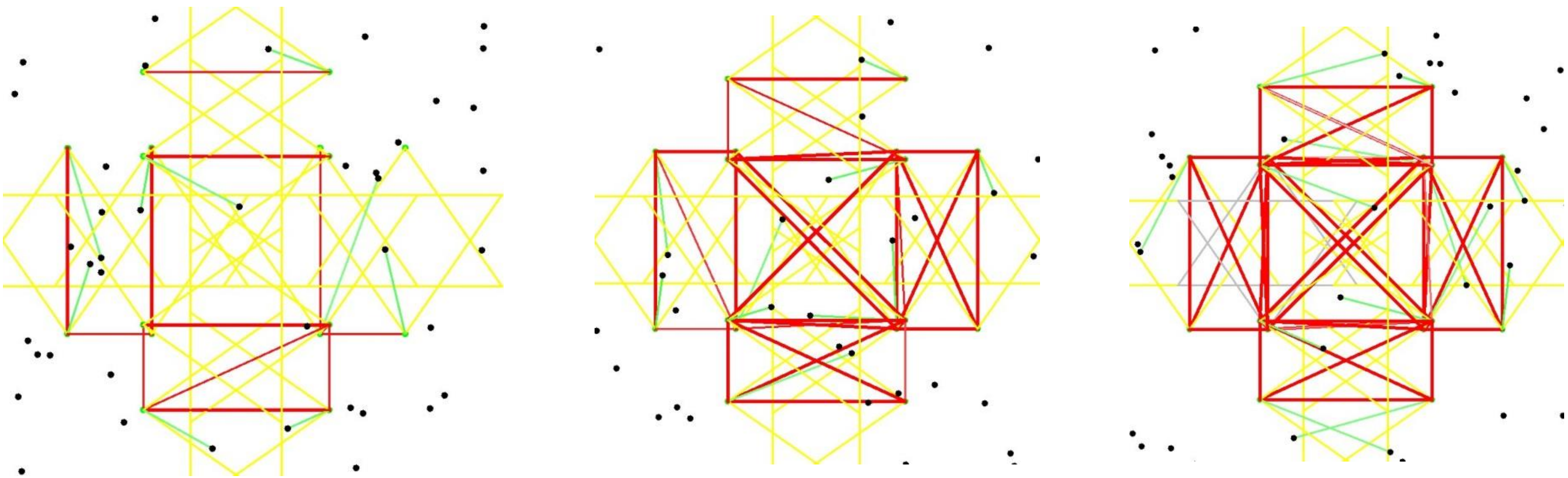
Learn the Camera Topology

- Artificial pheromones inspired by the ant foraging process
- The selling camera i creates a link τ_ix to the buying camera x for future trading purpose.
- Local vision graph for each camera representing the local neighborhood.
- Multiple trades with the same camera strengthens the link between cameras.
- Decay pheromone level when no trade occurs



Learn Neighborhood Relationships

- Gaining knowledge about the network topology (vision graph) by exploiting the trading activities
- Temporal evolution of the vision graph



Exploit the Camera Topology

- In addition to broadcast auctions to all cameras, we define two multicast communication policies

- STEP

  Probability to communicate with another node is based on the strength of the link. All others have only a small probability to get the invitation as well.

$$P_{STEP(i,x)} = \begin{cases} 1 & if\ \tau_{ix} > \varepsilon \\ \eta & otherwise \end{cases}$$

- SMOOTH

  Probability to communicate with another node is based on the strength of the link relative to strongest link.

$$P_{SMOOTH(i,x)} = \frac{1 + \tau_{ix}}{1 + \tau_{im}}$$

$$m = \underset{y}{argmax}\ \tau_{iy}, \forall y$$

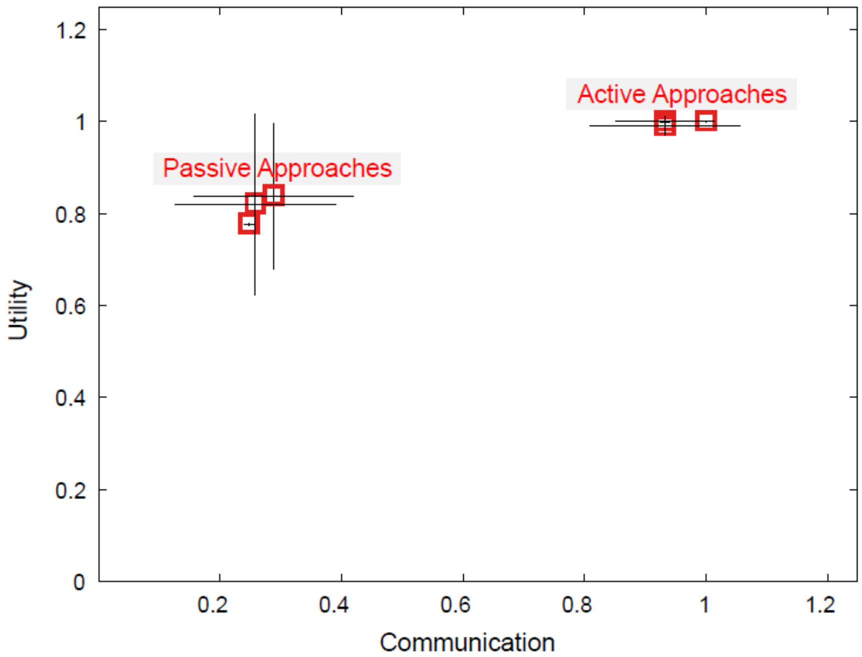
Six Camera Strategies

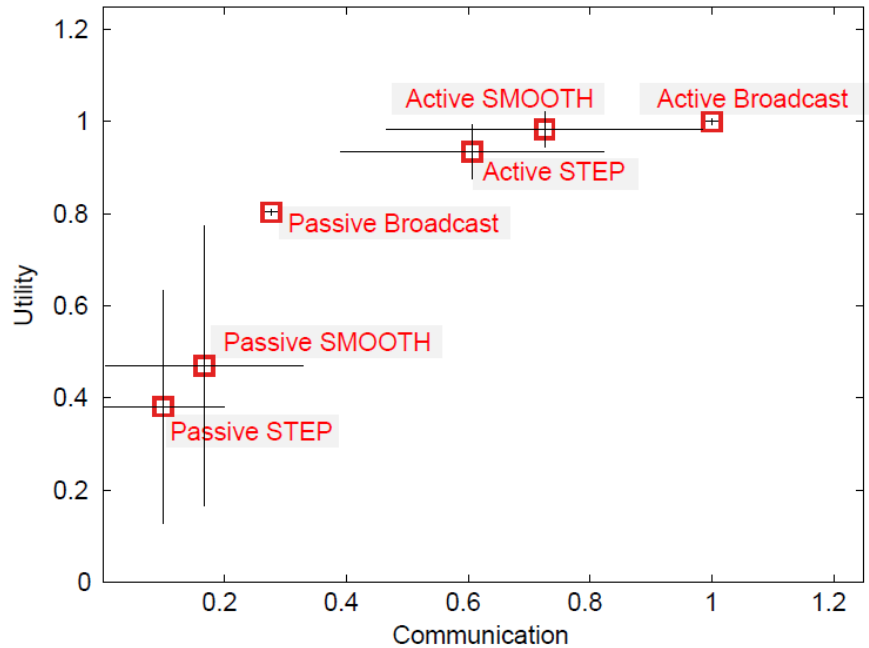
- Auction initiation
  - "Active": at regular intervals (at each frame)
  - "Passive": only when object is about to leave the FOV
- Auction invitation
  - "Broadcast": to all cameras
  - "Smooth": probabilistic proportional to link strength
  - "Step": to cameras with link strengths above threshold (and rest with low probability)

- Selected strategy influences network performance (utility) and communication effort

Tracking Performance

- Tradeoff between utility and communication effort





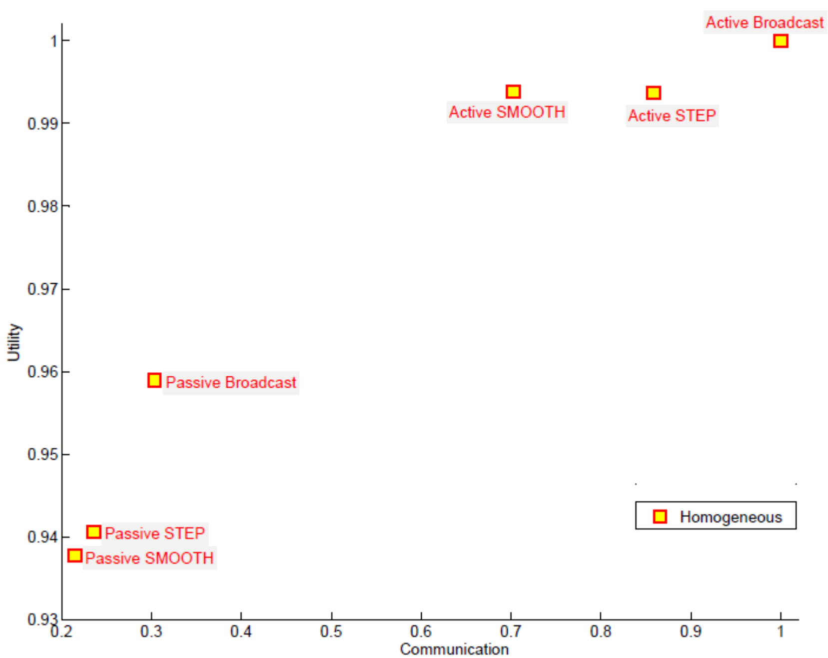
Scenario 1 (5 cameras, few objects) Scenario 2 (15 cameras, many objects)

- Emerging Pareto front

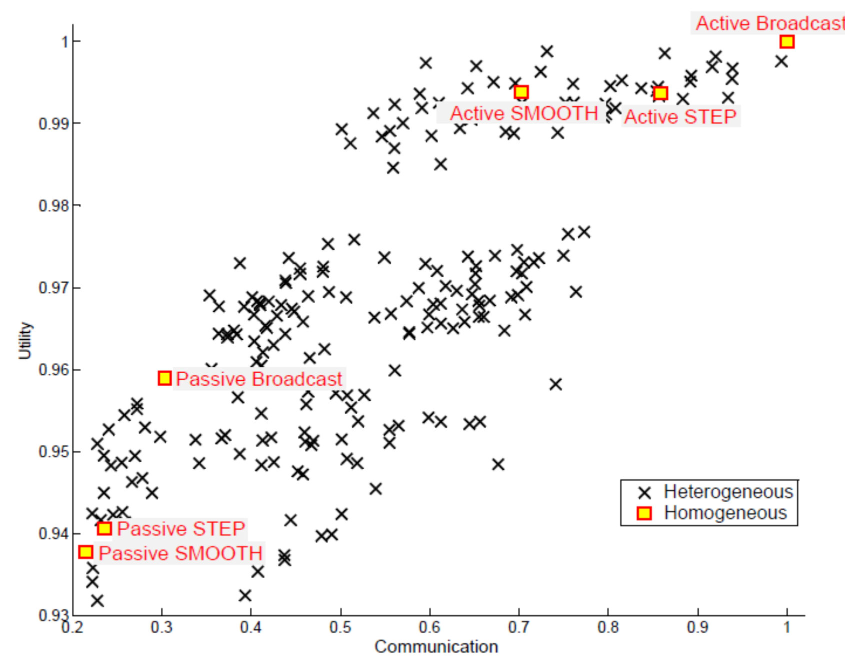
[Esterle et al. Socio-Economic Vision Graph Generation and Handover in Distributed Smart Camera Networks. ACM Trans. Sensor Networks. 10(2), 2014]

Assigning Strategies to Cameras

- Identical strategy for all cameras may not achieve best result



Homogeneous strategies (3 cameras)

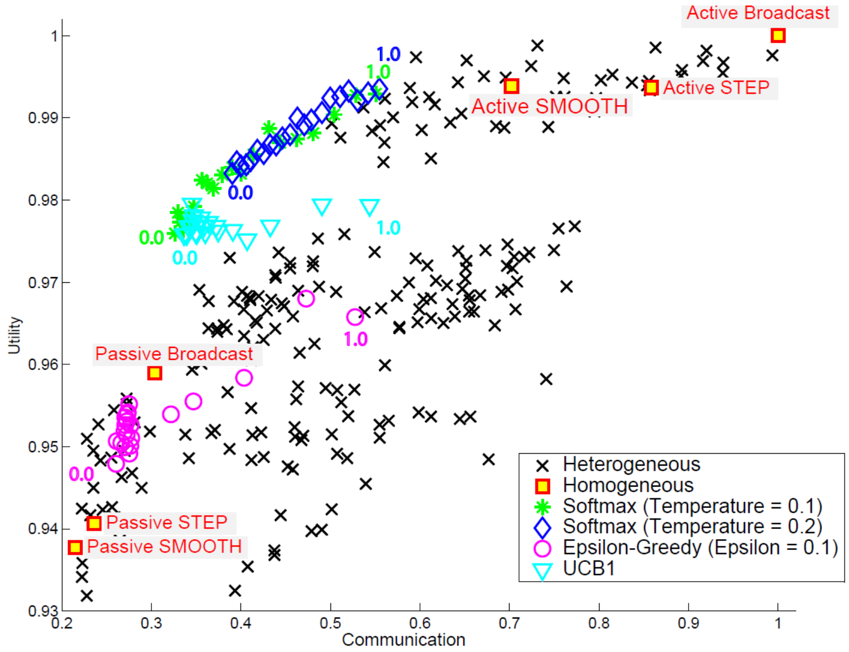


Heterogeneous strategies (3 cameras)

- Strategy depends on various parameters (FOV, neighbors, scene …)
  - Let cameras learn their best strategy

Decentralized Multi-Agent Learning

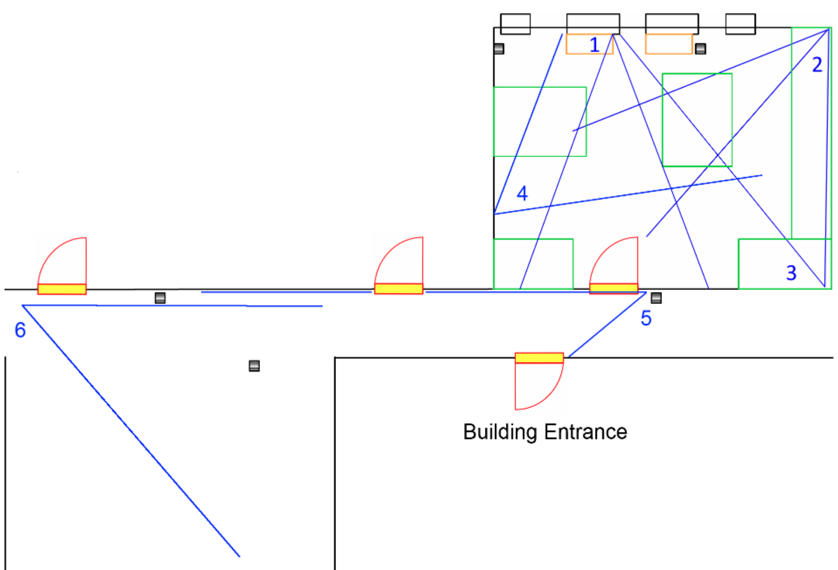
- Exploit bandit solver framework to maximize global performance
  - Co-dependency among agents' performance
  - Complex relationship between local reward global performance

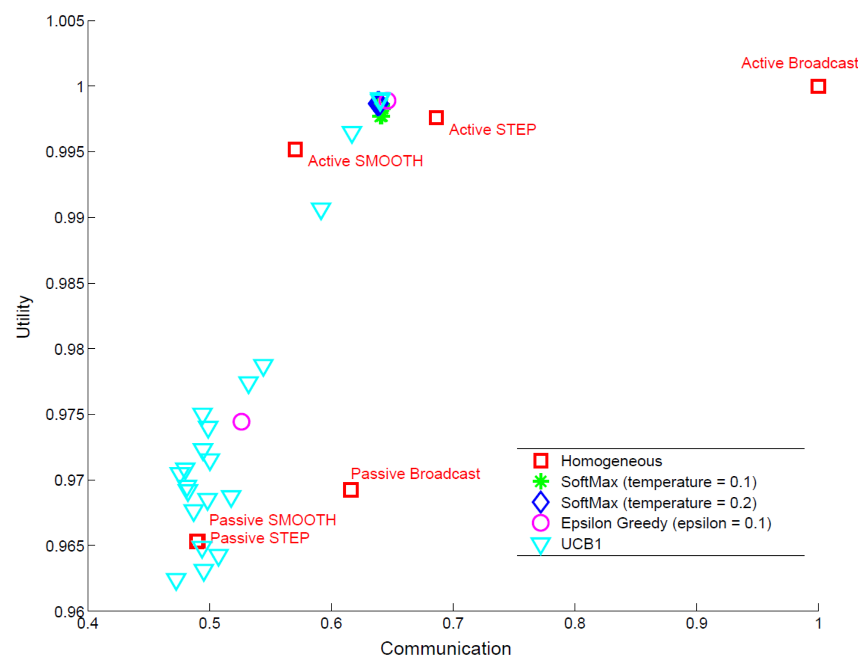


[Lewis et al. Learning to be Different: Heterogeneity and Efficiency in Distributed Smart Camera Networks. In Proc. SASO 2013]

Multi-camera Experiment

- Indoor demonstrator with 6 cameras tracking 6 persons
- Each camera performs
  - Color-based tracking
  - Fixed or adaptive handover strategies (bandit solvers)
  - Exchange of color histograms for person re-identification





Conclusion

- Smart cameras process video data onboard and collaborate autonomously within the network
- Our cartooning approach protects image data “at the sensor” but stills provides reasonable utility with low resource usage
- We apply socio-economic techniques to learn control strategies for autonomous multi-camera tracking
  - Global configurations emerge from local decision using local metrics
  - Adaptive strategies extend Pareto front of best static configurations
- Techniques applicable to various decentralized networked systems (e.g., Internet of Things)

Acknowledgements & Further Information

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