Distributed Smart Cameras

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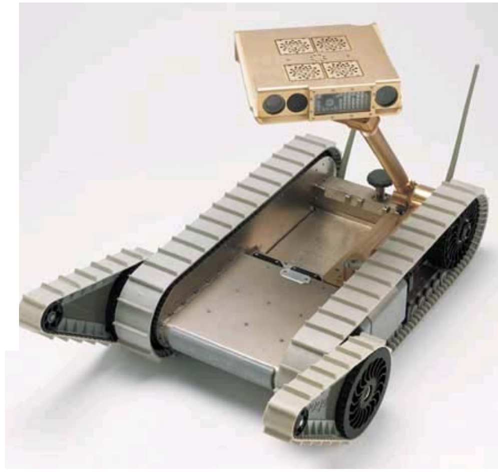
Cameras are ubiquitous …



… and are important for many Applications

- Entertainment
- Security
- Production
- Medical application
- Environment
- Automation
- Robotics
- Multimedia
- Biometric
- …

Agenda

1. Traditional Camera Networks
   Advantages & Challenges

2. Smart Cameras
   Principle & Architecture

3. Distributed Smart Cameras
   Research Challenges
   Distributed Computing
   Applications

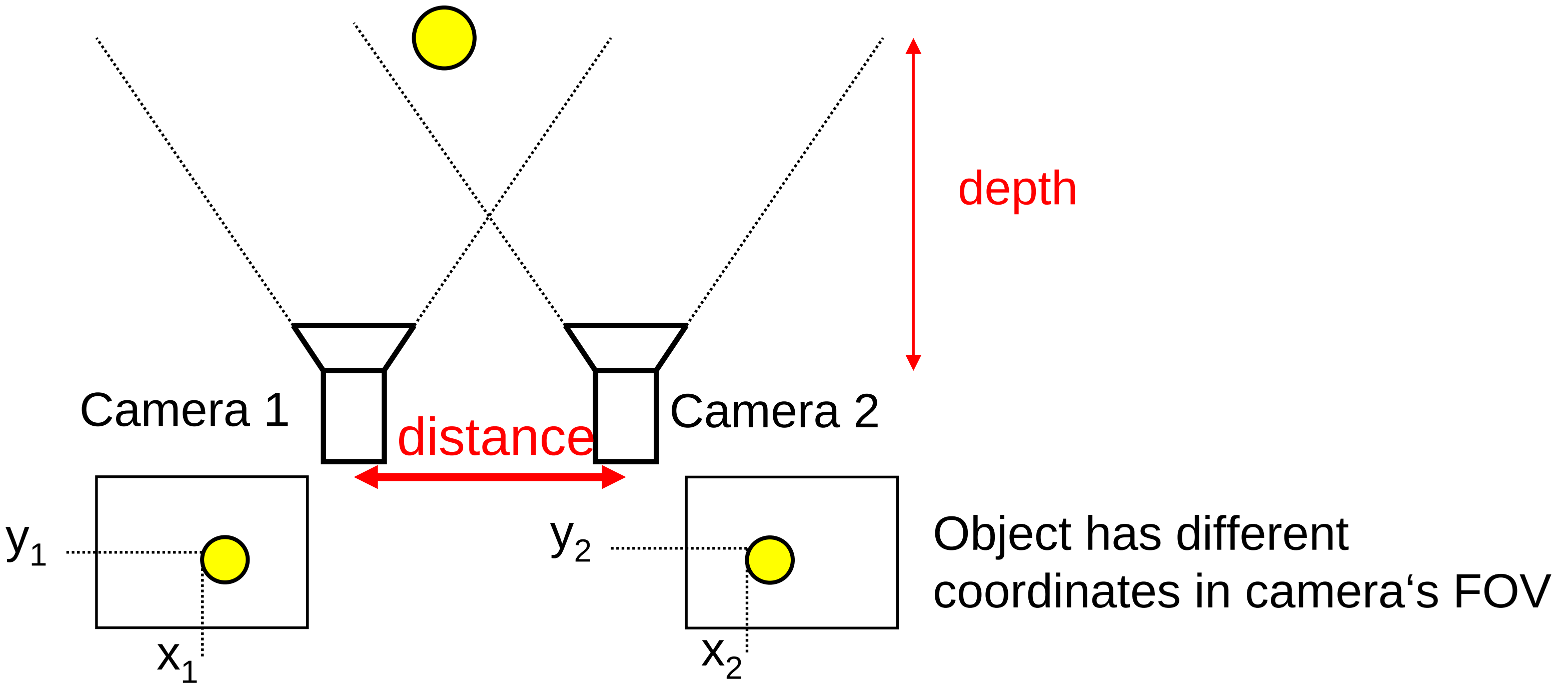
Traditional Camera Networks

Camera Networks

Advantages and challenges of multiple cameras

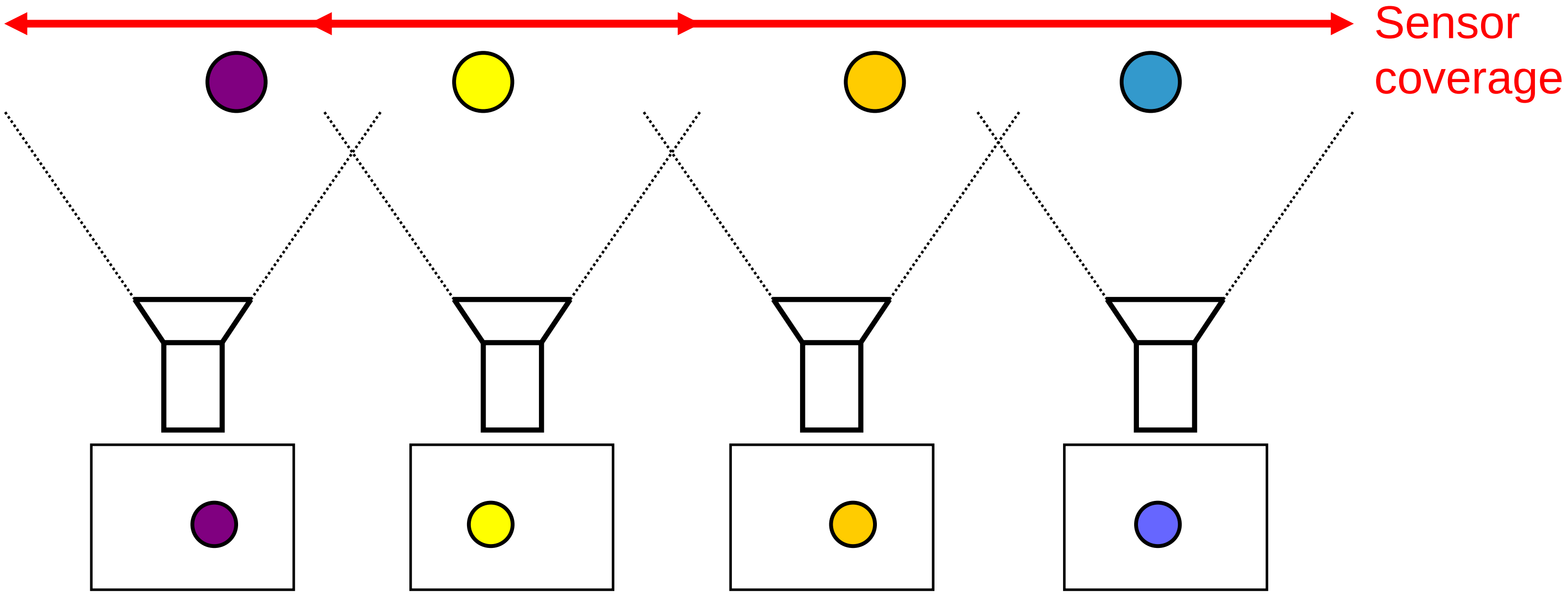
Advantage: 3D Information

- When we know the camera geometry
  - compute depth information based on different perspectives
  - stereo camera setup



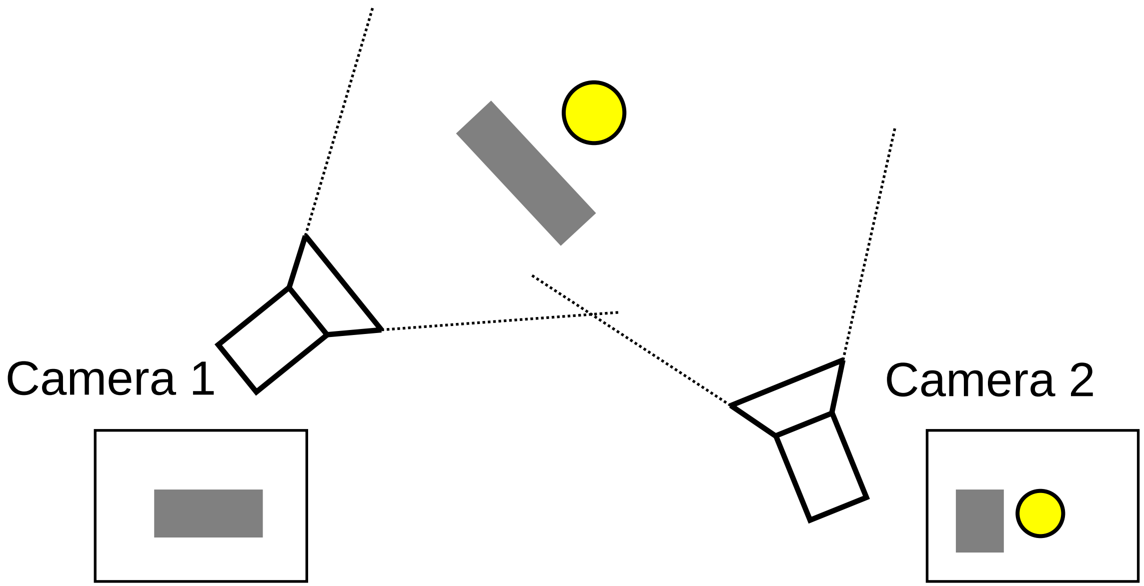
Advantage: Enlarged Field of View (FOW)

- Enlarge the sensor coverage
  - setup with overlapping or non-overlapping FOVs
  - at „constant“ resolution



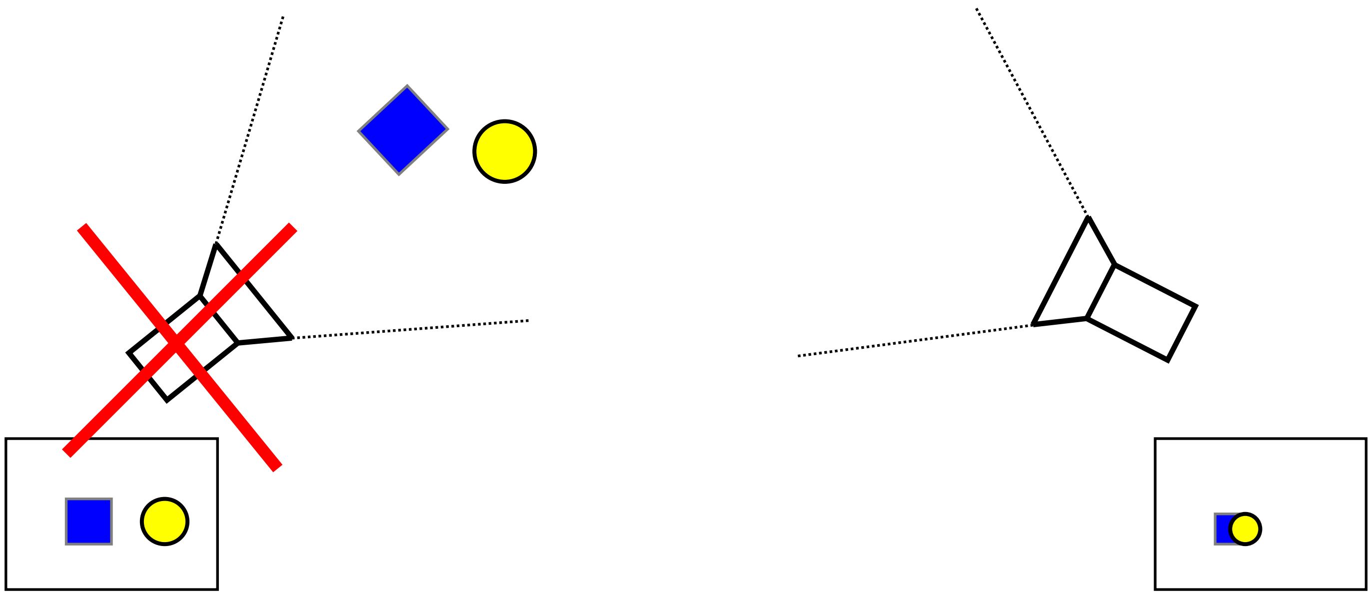
Advantage: Resolve Occlusions

- Alternate FOV may help to resolve occlusions
  - often in dynamic environments with moving objects



Advantage: Redundancy

- If a camera breaks down we may get useful information from another camera, typically with
  - different FOV
  - different resolution



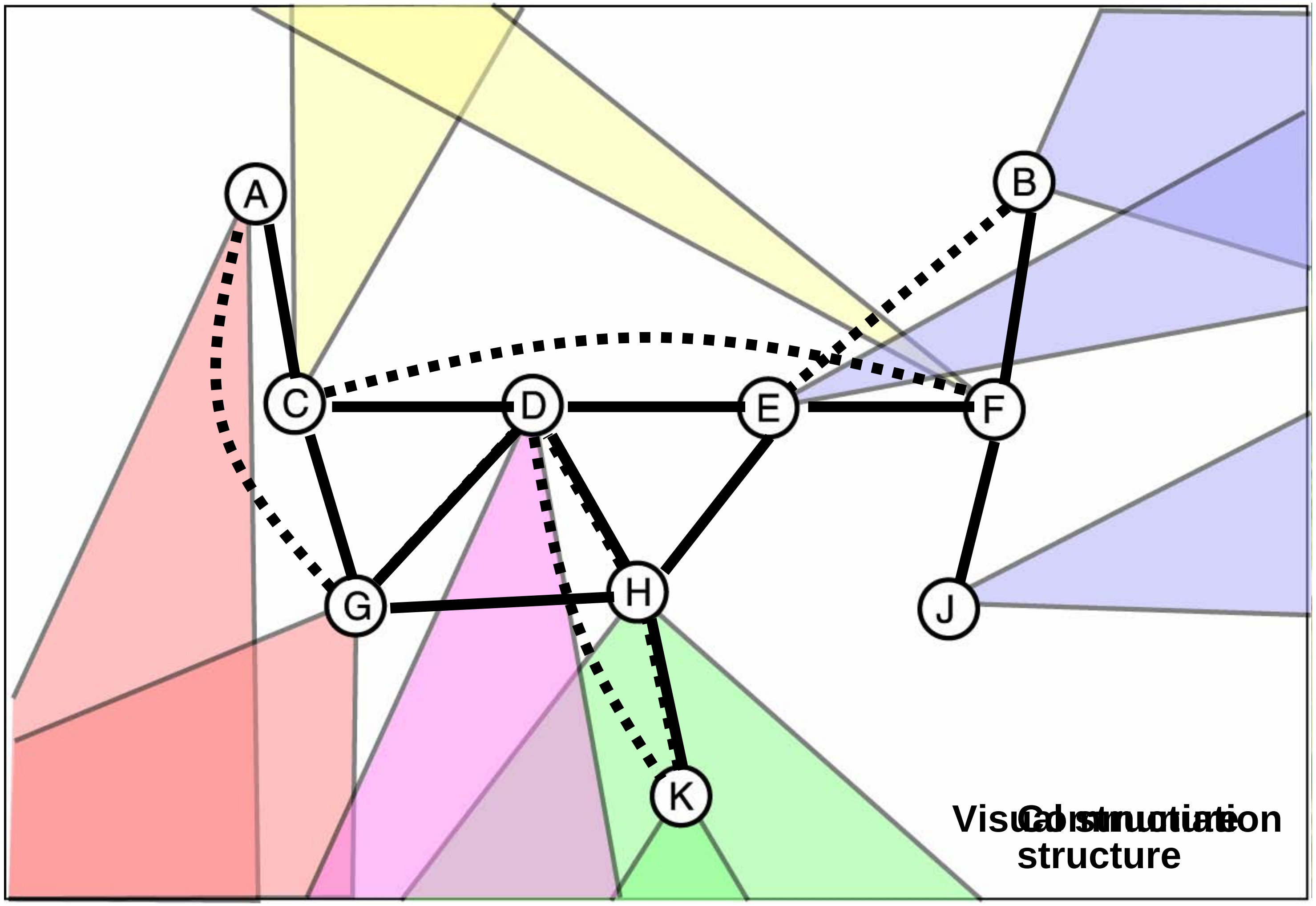
Challenge: Amount of Data

- A camera network produces a huge amount of data which has to be
  - transferred
  - stored
  - analyzed, processed, and „observed“, respectively
- Example: Subway in London with 40.000 cameras
  - single camera „generates“ approx. 260 Mbit/s (uncompressed)
  - requires extremely powerful network, storage and server!
- Video compression does not really help
  - compression rates in the range of 10 – 100
  - loss of image quality and large computational effort at camera

Challenge: Energy and Data Distribution

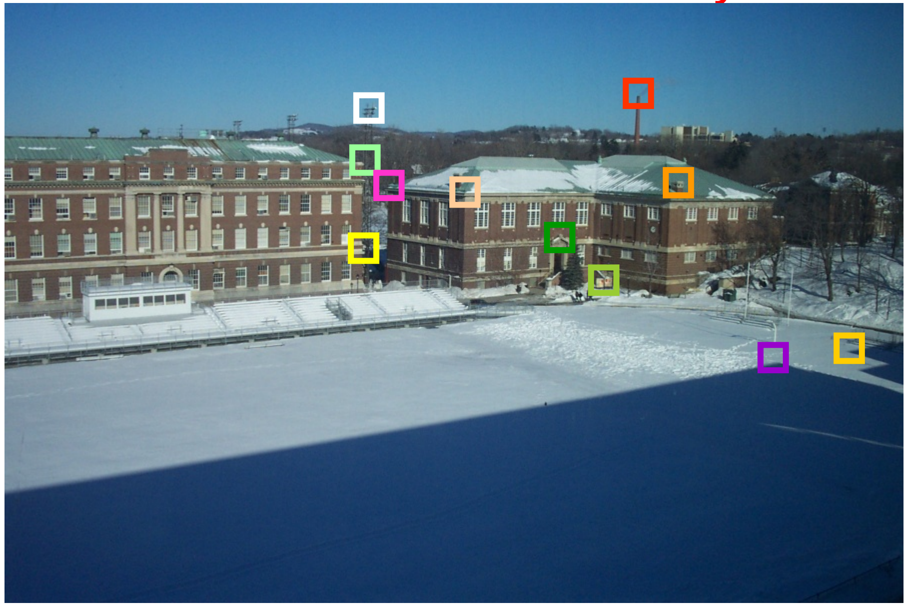
- Each camera requires energy and delivers data. Setting up the infrastructure for energy & data distribution is
  - tedious
  - expensive
  - and limits the applicability of multi-camera networks
- Reducing energy consumption and data transfer
  - battery-powered, energy harvesting
  - local processing, reduced bandwidth in wireless networks
- Dependency between energy consumption and data transfer
  - transferring data (much) more expensive than processing it

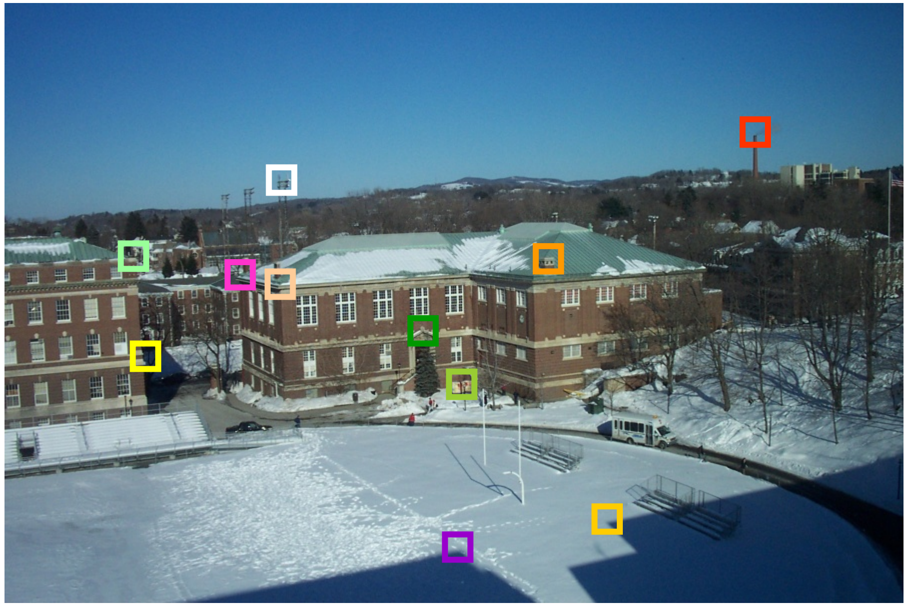
Challenge: Structure



Challenge: Spatial & Temporal Calibration

- Images of (overlapping) cameras must be „calibrated“ in space and time
  - complex procedure – only required during initialization (stationary cameras)
  - at different accuracy





Herausforderung: Registrierung (2)

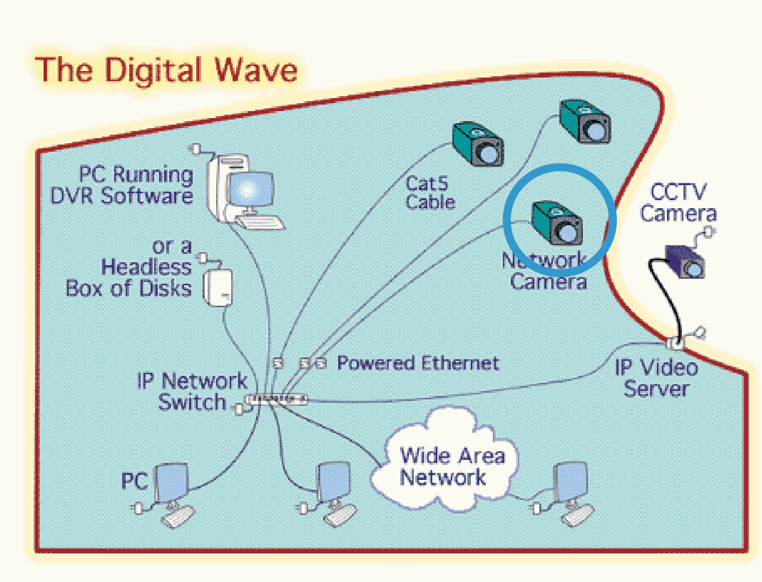
G. Yang, C.V. Stewart, M. Sofka, C. Tsai, PAMI 2007; http://www.vision.cs.rpi.edu/gdbicp/

Example: Surveillance Systems

- Large, complex system
  - many (wide spread) sensors/cameras
  - visualization at central monitoring station
  - 24/7 operation
- Characteristics
  - provides varied degrees of assistance to humans/operators, main focus: display & record
  - centralized system: computation takes place at monitoring station
  - static configuration: physical sensors & functionality
- Challenges for "intelligent" surveillance systems
  - increased functionality & flexibility; autonomous operation
  - standards, sensor integration, open systems
  - many non-technical issues, eg, privacy

Example: Video Surveillance Systems

- 1st and 2nd generation
  - primarily analog frontends
  - backend systems are digital



- 3rd generation
  - all-digital systems
- 3^{+} generation
  - smart cameras
  - surveillance tasks run on-site on smart cameras, e.g.,
    - video compression
    - accident detection
    - stationary vehicles (tunnels)
    - traffic statistics
    - wrong-way drivers
    - vehicle tracking

Smart Cameras

Basic Principle of Smart Cameras

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

  in a single embedded device

- 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

Differences to traditional Cameras

Traditional Camera

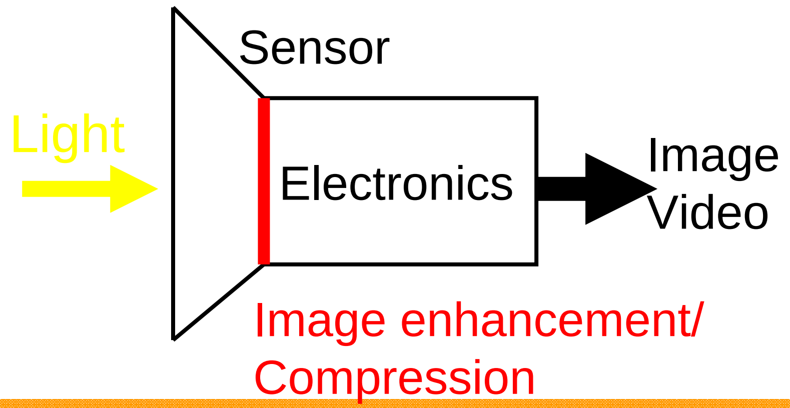
- Optics and sensor
- Electronics
- Interfaces

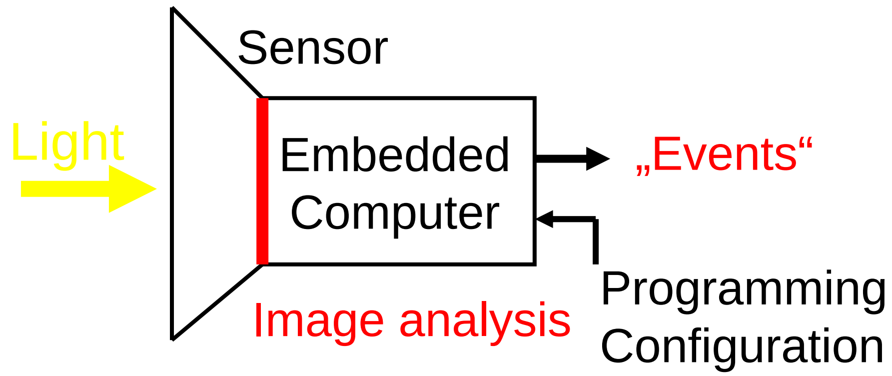
delivers data in form of (encoded) images and videos, respectively

Smart Camera

- Optics and sensor
- onboard computer
- Interfaces

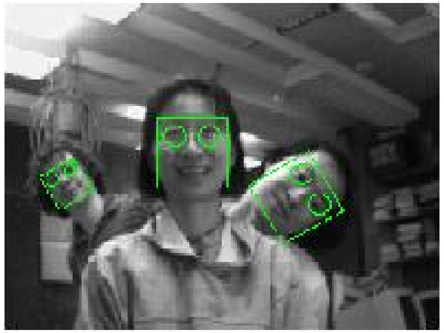
delivers abstracted image data is configurable and programmable

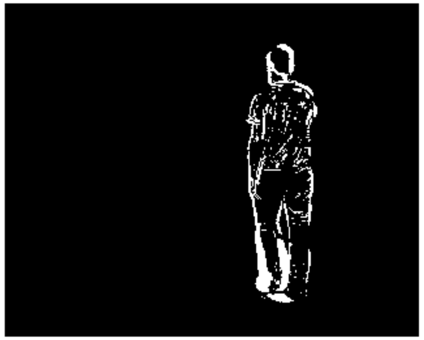




Smart Cameras look for important things

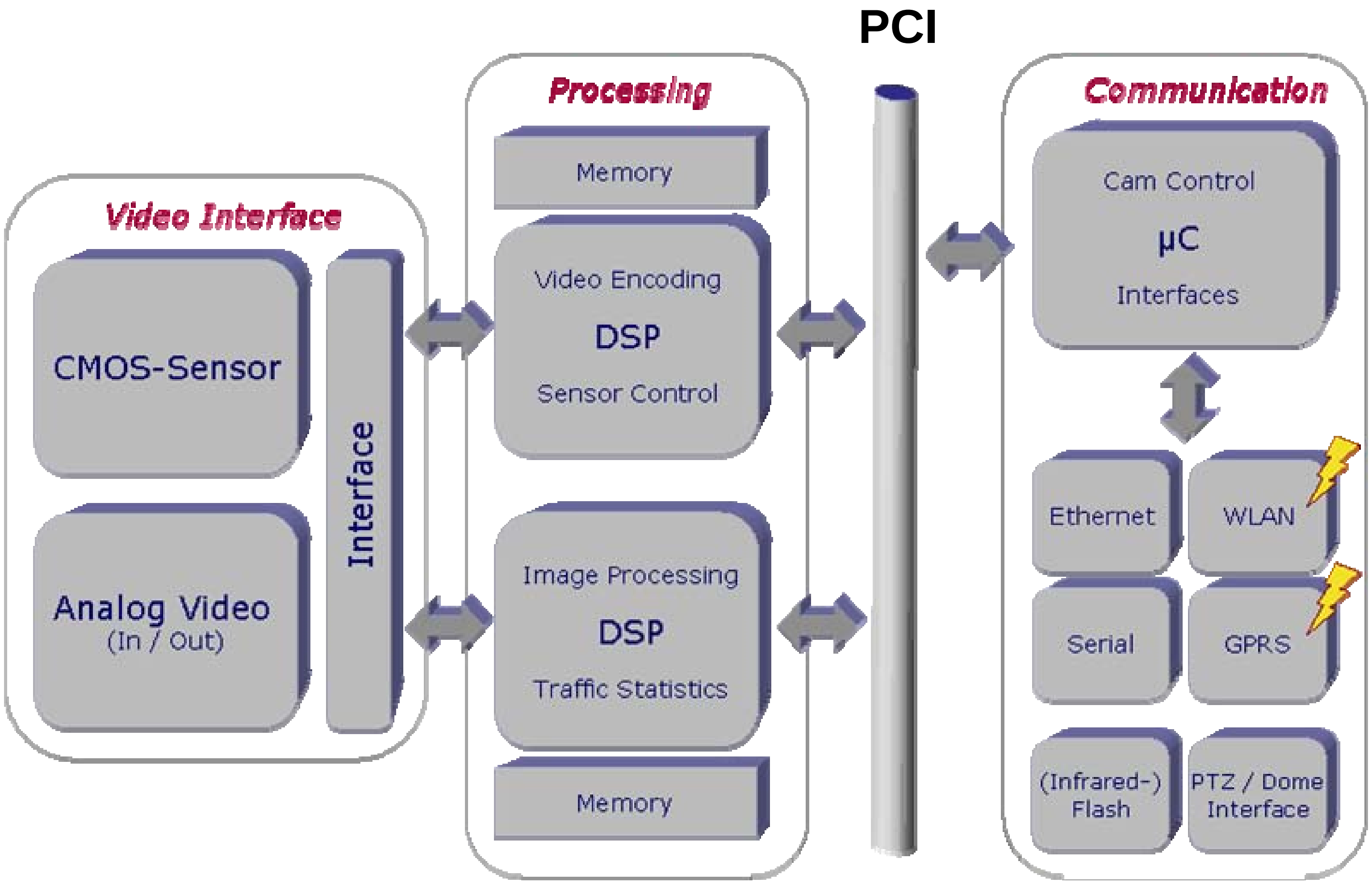
- Examples for abstracted image data
  - compressed images and videos
  - features
  - detected events





Scalable SmartCam Architecture

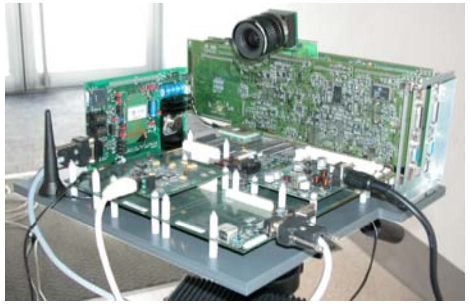
[IEEE Computer 2/2006]



SmartCam Prototypes

- 1. generation (single DSP)
  - COTS (NVDK, Ateme)

- 2. generation (multi-DSP & processor)
  - COTS (Intel baseboard, NVDKs)
  - 3 variations (different host processors) XScale PXA, XScale IXP, P4M



- 3. generation
  - PCB (10 x 25 cm), IXP+C6415+C6455
  - Spartan II for sensor interface&preprocessing
  - currently under development

Prototypes with different Performance

- Prototypes differ in various aspects
  - computing power, energy consumption
  - wired and wireless communication
  - optics and sensors

Rinner et al. (multi-DSP)
10 GOPS @ 10Watt

WiCa/NXP (Xetal SIMD)
50 GOPS @ 600mWatt

CMUcam3 (ARM7)
60 MIPS @ 650mW

(Selected) Smart Camera Systems

System	Year	Platform	Distribution/Proc.	Autonomy
[Moorhead&Binni]	1999	ASIC	local	static
VISoc [Albani]	2002	SOC	local	static
[Wolf et al.]	2002	DPS (PC)	local	static
[Bramberger&Rinner]	2004	DSP	local	rem. conf.
[Dias&Berry]	2007	FPGA	local	active vis.
[Bauer]	2007	DSP	local	static
GestureCam [Shi]	2007	FPGA	local	static
[Bramberger et al.]	2006	multi-DSP	cooper. tracking	dyn. conf.
[Micheloni et al.]	2005	(PC)	MC-tracking	PTZ
[Fleck&Strasser]	2007	PowerPC	MC-tracking	static

(Selected) Smart Camera "Sensors"

System	Year	Platform	Distribution	Autonomy
Cyclops [Rahimi]	2005	ATmega128	coll. tracking	static
CMUcam 3 [Rowe]	2007	ARM7	local proc.	static
Meerkats [Margi]	2006	StrongARM	coll. tracking	static
MeshEye [Hengstler]	2006	ARM7	local	rem. conf.
WiCa [Kleihorst]	2006	Xetal (SIMD)	coll. gesture rec	static

Distributed Smart Cameras

Smart Cameras collaborate

- Autonomous cameras connected in a network
  - no central server
  - collaborative analysis among multiple cameras
  - dynamic configuration (structure and functionality)

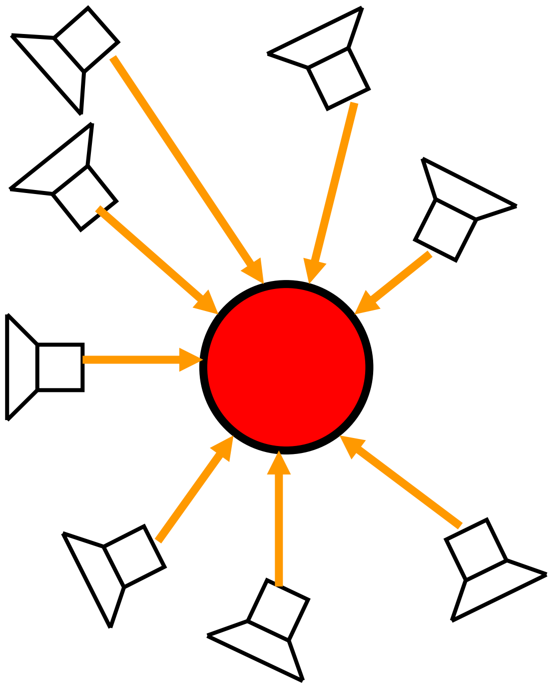
- Challenges for such collaborative DSC
  - camera selection and placement
  - calibration & synchronization
  - distributed processing
  - data distribution and control, protocols and middleware
  - distributed computer vision (distributed signal processing)
  - real-time, energy-awareness, …

(Potential) Advantages of DSC

- Scalability
  - no central server as bottleneck
- Real-time capabilities
  - Short round-trip times; “active vision”
- Reliability
  - High degree of redundancy
- Energy and Data distribution
  - Reduced requirements for infrastructure; easier deployment?
- Sensor coverage
  - Many (cheap) sensors closer at “target”; improved SNR
- …

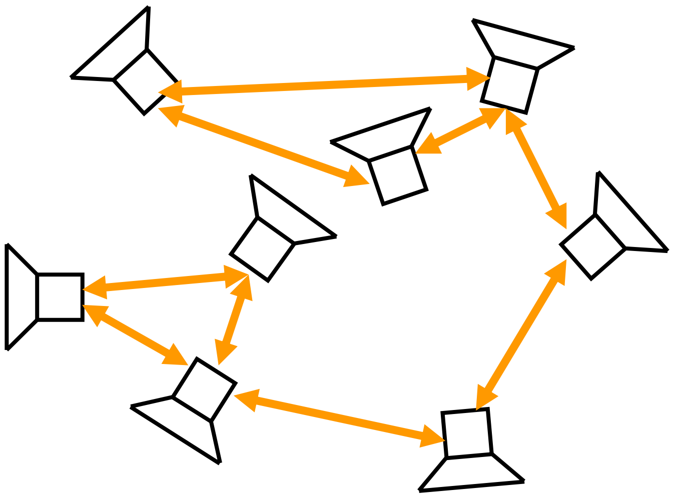
Networking

Traditional Camera Networks



Cameras stream images/ videos to „server“

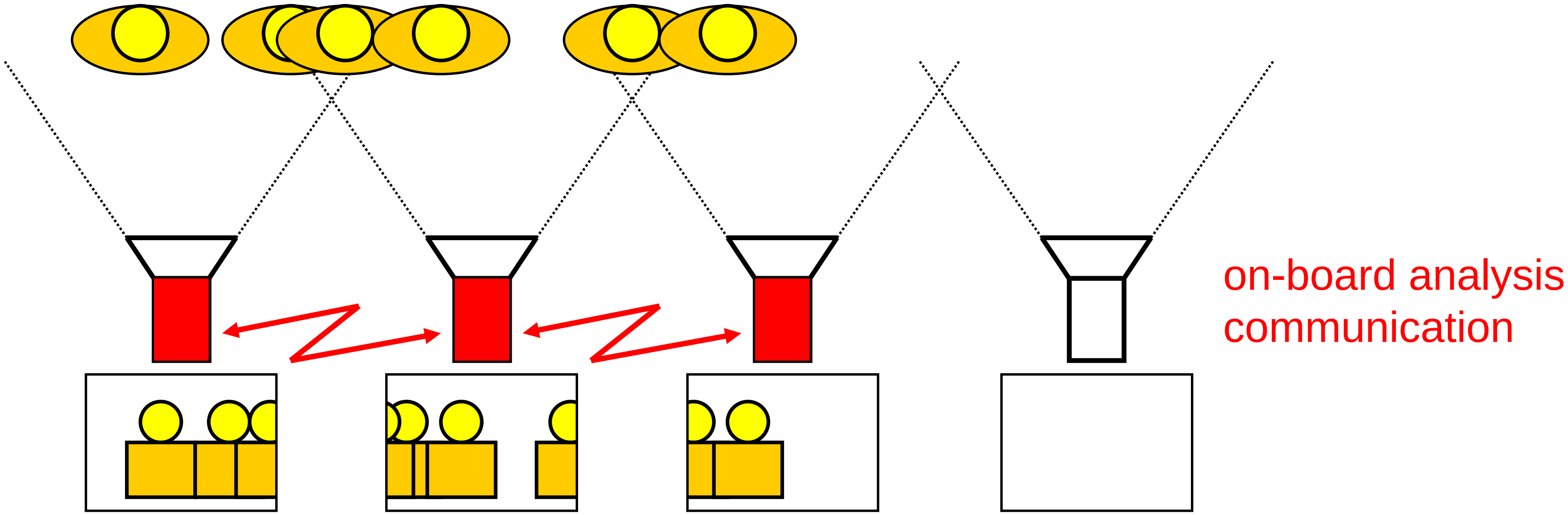
Smart Camera Networks



Cameras collaborate directly (spontaneous, p2p, ad-hoc)

Distributed Processing in Network

- Example: autonomous tracking of mobile objects among multiple cameras



- Computation follows (physical) object
  - requires spontaneous communication; distributed control & data

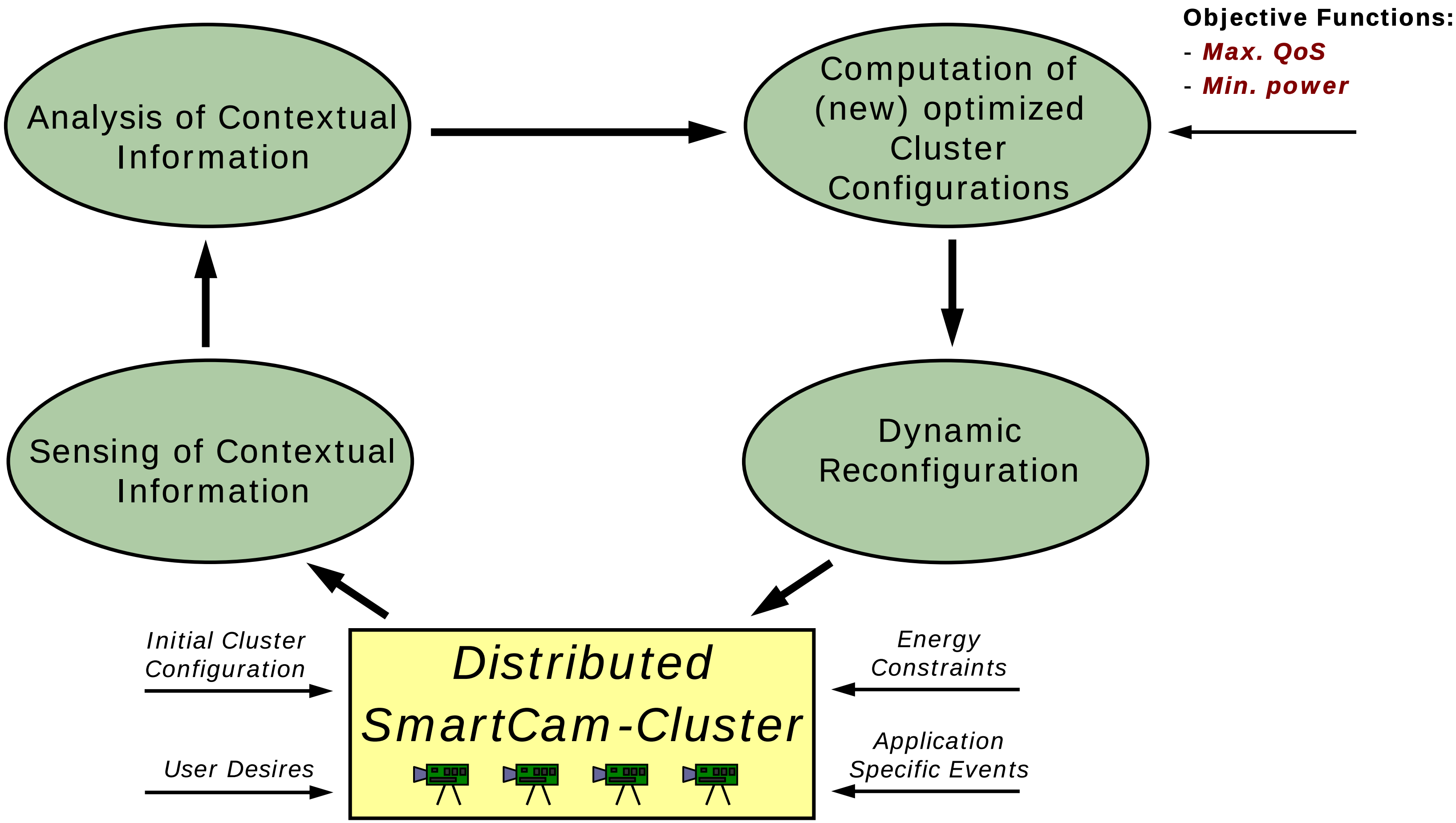
Need for Dynamic Reconfiguration

- Dynamic communication among cameras
  - cameras may be included to or removed from network
  - communication pattern depends on observed scene
- Modification of functionality
  - adaptation/configuration of on-board image processing
  - „load" new algorithms
- Changes in available resources
  - hardware failures
  - different QoS requirements

Dynamic Reconfiguration

- What is a “configuration” ?
  - Executing services s at various QoS-levels q_s on different resources r
  - Configuration of single camera $C_i = (s \times q_s \times r)$
  - Configuration of network: $C = (C_1 \times \ldots \times C_i \times \ldots \times C_N)$
- Find optimal configuration of the network at runtime
- Various optimization parameters
  - QoS, power consumption, reliability,…
  - multi-criterion optimization
  - requires a “system model”

Dynamic Reconfiguration Loop



Dynamic Reconfiguration Applications

- Combined power and QoS optimization   [IEEE AINA 2006]
  - exploiting dynamic power management
  - switching hardware components to different power levels
  - implemented on single- and multi-processor SmartCam
- Improving fault tolerance and service availability
  - requires onboard monitoring&diagnosis
  - in case of a detected fault, start a reconfiguration
- Application-specific reconfiguration
  - “download” services to cameras on demand
  - may overcome resource limitations on camera

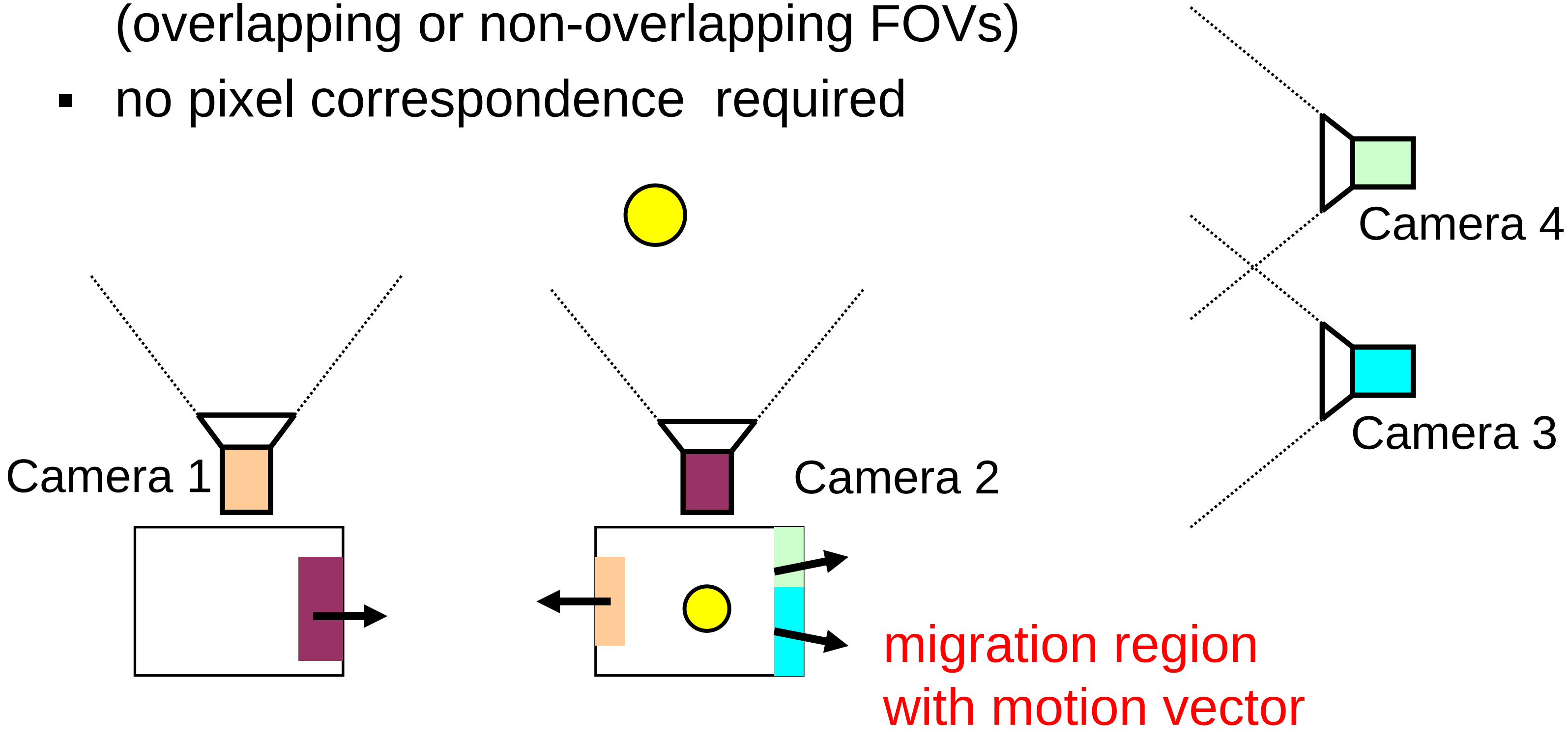
Autonomous Multi-Camera Tracking

[EURASIP JES 1/2007]

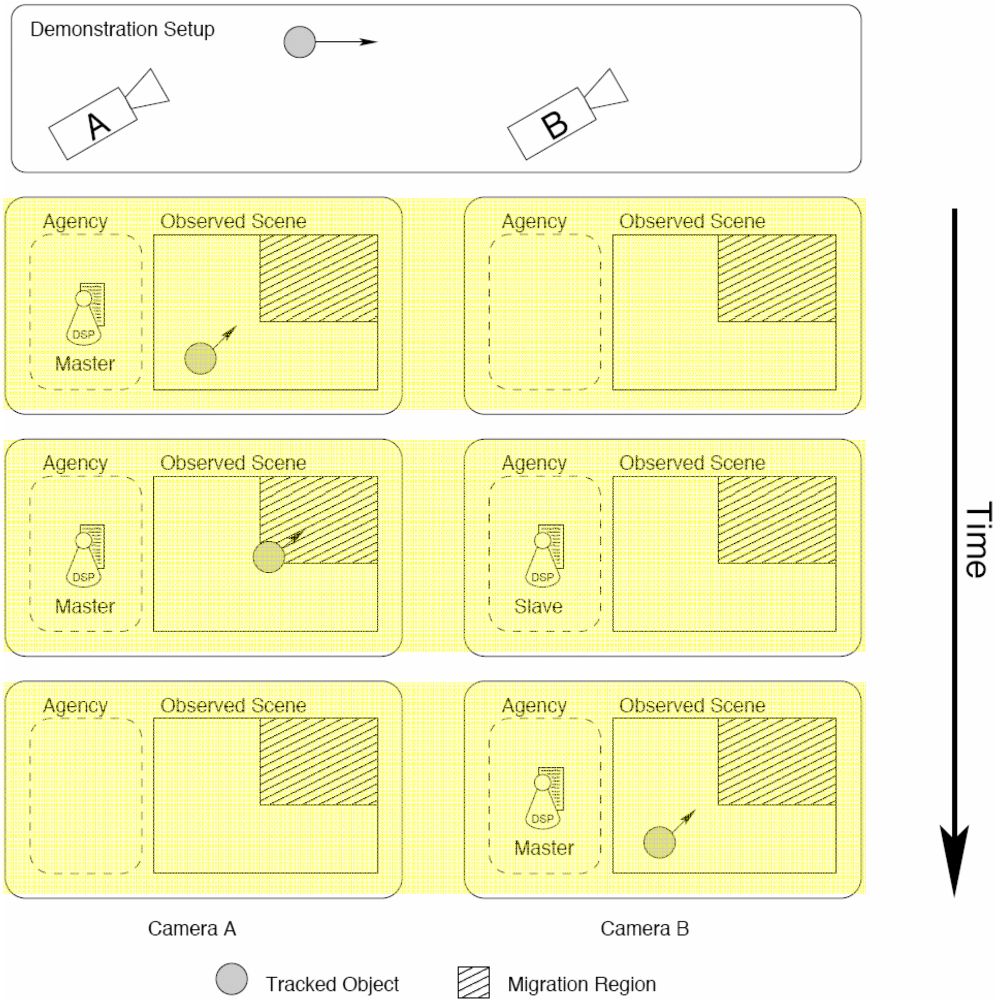
- Assumptions for multi-camera tracking
  - implement on distributed embedded smart cameras
  - avoid accurate camera calibration
  - do not rely on central coordination
- Important design questions
  - What (single-camera) tracking algorithm to use?
  - How to coordinate the cameras?
    i.e., distributed control, exploit locality
  - How to hand over tracking from one camera to next?
- Treat questions independently
  - standard ("color-based") CamShift tracker
  - focus on hand over strategy

Spatial Relation among Cameras

- Camera neighborhood relation
  - important for determining "next camera(s)"
  - based on pre-defined "migration region" in camera's FOV (overlapping or non-overlapping FOVs)
  - no pixel correspondence required



Multi-Camera Handover Protocol



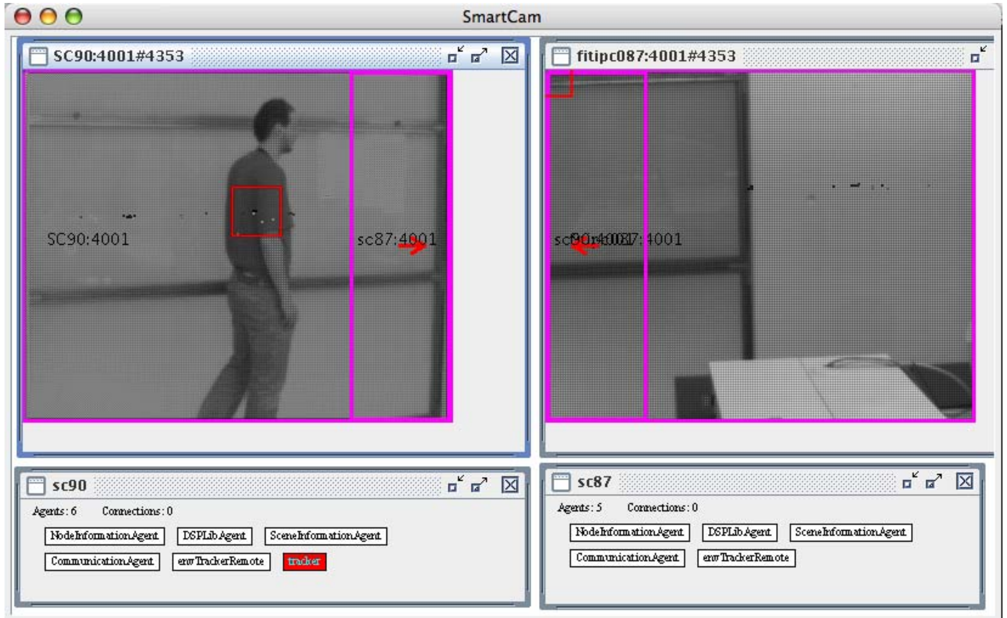
Master/Slave handover

1. camera A tracks object
2. whenever object enters migration region tracking agent is cloned on “next” camera (slave)
3. slave starts tracking when slave identifies object master gets terminated

Tracker initialization

- color histogram a initialization data

Implementation & Results



Visualization

- migration region (magenta)
- tracked object (red rectangle)

- tracking agent (red box)

Code size	15 kB
Memory requirement	300 kB
Internal state	256 B
Init color histogram	< 10 ms
Identify object	< 1ms

CamShift (single camera)

Loading dynamic executable	8 ms
Initializing tracking algorithm	250 ms
Creating slave on next camera	18 ms
Reinitializing tracker on slave	2 ms
Total	**278 ms**

Multi-camera performance

Application: Traffic Monitoring

- Online traffic data
  - classification/counting
  - lane utilization
  - fusion of audio & video

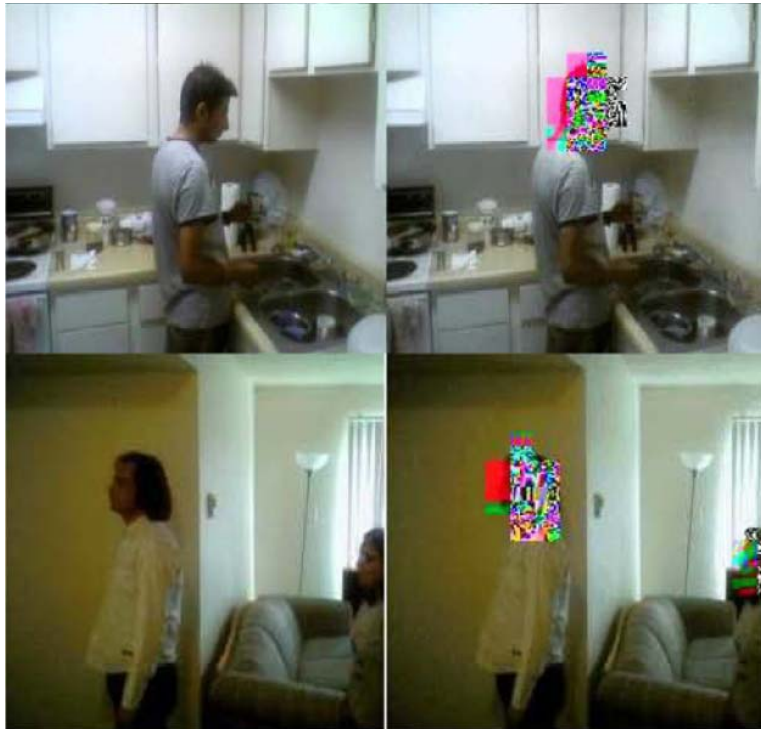
[IEEE ICDSC-07]

- Vehicle tracking
  - speed estimation
  - traffic jam detection

[Leistner et.al CVPRW 2007]

Application: Privacy Protection

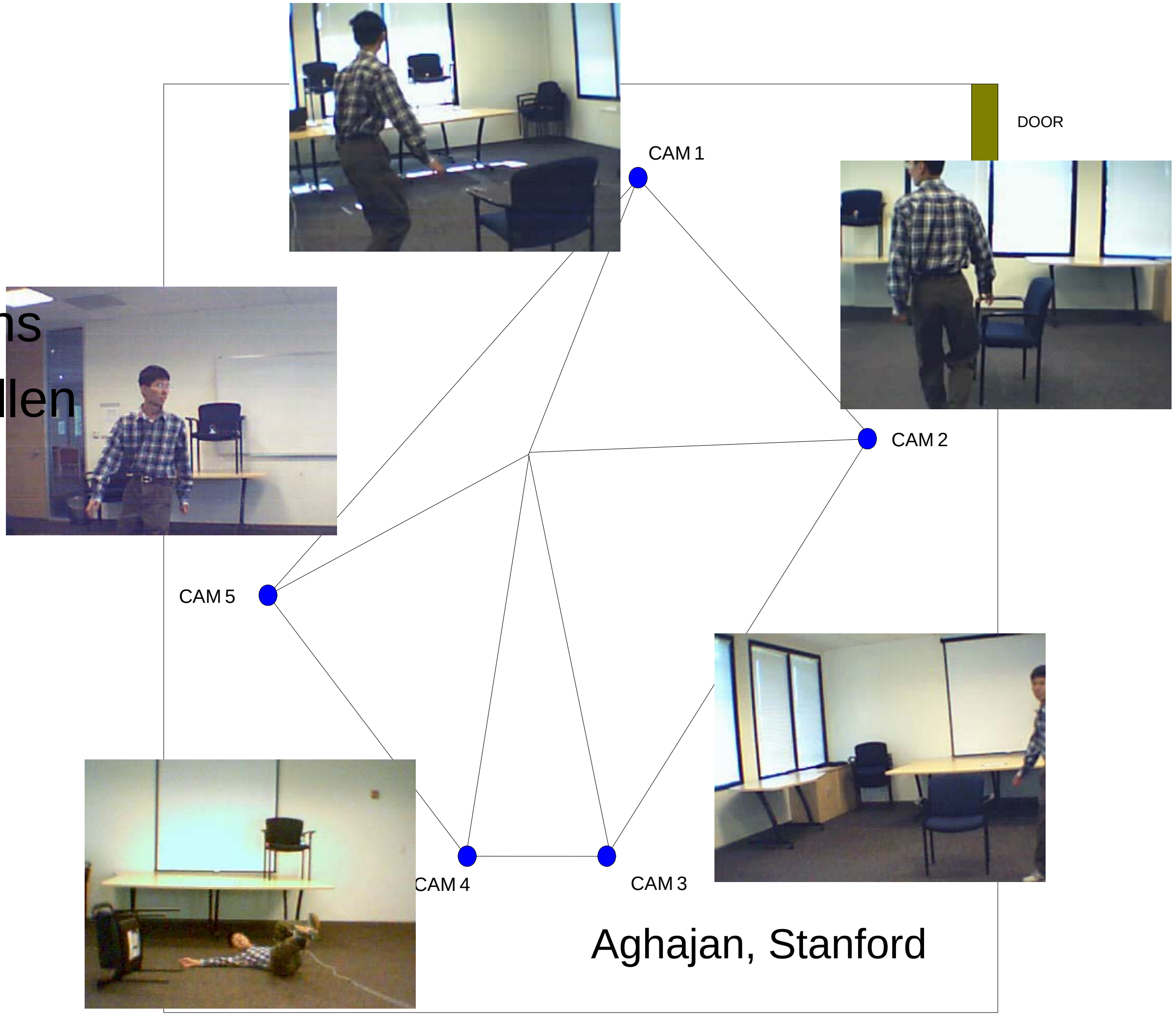
- Security with privacy protection
  - automatic head detection and tracking
  - encryption of head area



Boult, Univ. Colorado

Application: Assisted Living

- Assist Living for elderly people
  - detect and report dangerous situations
  - example: Detect fallen person
  - challenge: Privacy



(Potential) further Applications

- Entertainment (computer games)
  - in 3D environments
- „Smart Rooms / Smart Environments
  - detection gestures, sign language, room occupancy …
- Environmental monitoring
  - sensor fusion, habitat monitoring
- Security
  - Safety enhancement (trains, cars), access control, surveillance
- „Virtual Reality“
  - augment real world with digital information
- …

Trends and Challenges

- From static to dynamic and adaptive
  - Adaptation & learning (networking, functionality, scene,…)
- From small to large camera sets
  - E.g., more interest in statistics on behavior (instead of individuals)
- From vision-only to multi-sensor systems
  - Fusion of data from multiple (heterogeneous) sensors
- Development process of DSC
  - How to model, develop, deploy, operate, maintain applications
- Privacy & Security
  - Important cross-layer topic for user acceptance
- …

Conclusion

Smart Cameras

- combine
  - sensing,
  - processing and
  - communication

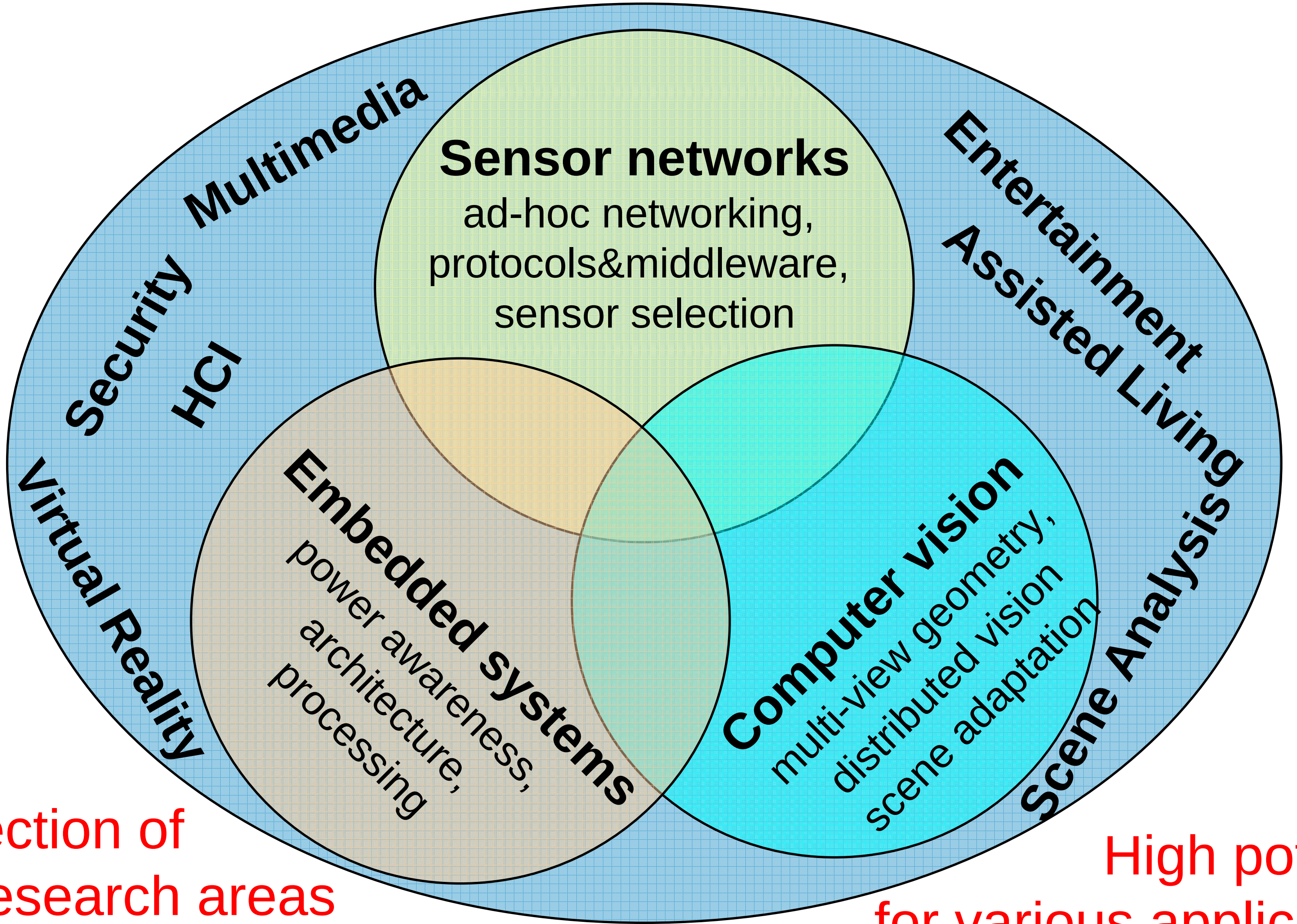
  in a single embedded device

- 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 (multi-camera system)

Smart Cameras as Key Technology

- For many applications including
  - Life Sciences
  - Security & Monitoring
  - Traffic
  - Entertainment
- Distributed cameras migrate to smart networks, which helps to overcome „hard problems“
  - occlusion
  - communication bandwidth
  - energy supply
  - reliability

DSC is Interdisciplinary Research



Intersection of
“hot” research areas

High potential
for various applications

DSC-related Activities

- **ACM/IEEE Int. Conf. on Distributed Smart Cameras**

Stanford (Sep. 7-11) www.icdsc.org

  - **Workshops, Tutorials, PhD-Forum, …**

- **Special Issue on Distributed Smart Cameras (Oct 2008)** Proceedings of the IEEE

Further Information

- Mail

  Pervasive Computing

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