# Ubiquitous Augmented Reality in AR-ready Environments

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Many of the videos shown in this talk can be found in our YouTube Channel **AugmentedRealityTUM**

# Augmented Reality (AR)

Provides users with computer information within their real environment

- Three-dimensional
- Immersive
- Interactive
- In real-time
- Mobile

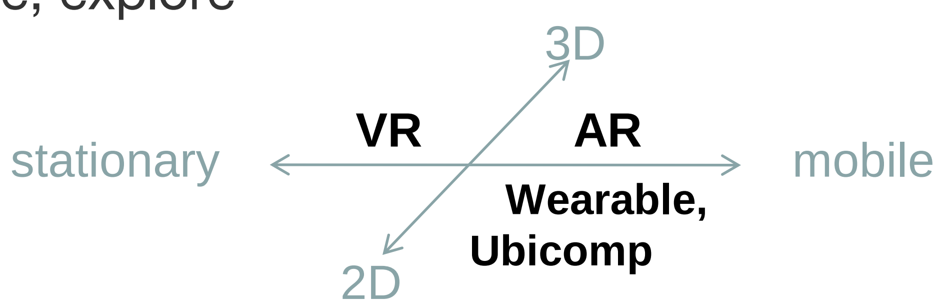
Technology-oriented Definition

[TU München, ForLog]

# Vision

- We are surrounded by information.
  - Information is real, but we cannot always memorize all of it and/or notice it with our limited senses.
  - Information has many dimensions.
  - Information can relate to many aspects of an object.
  - Information has many kinds of reference points.
  - Different people perceive information differently.
  - Information is not static – we need and want to interact with it.

- Computers can help us analyze, explore and understand information.
- Critical technologies:



# Ubiquitous Augmented Reality
## Our Approach (technology-driven)

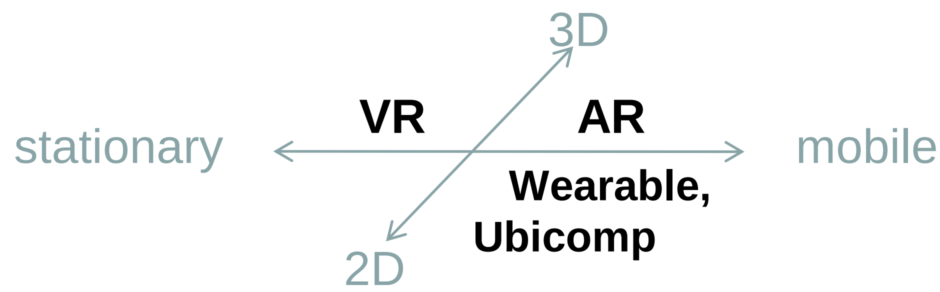
Mobile AR – integrated in stationary, wide-area, multi-media environments
*(ubiquitous / pervasive / ambient computing)*

- Ubiquitous Tracking
  - Mobile: head-mounted camera, gyroscope, …
  - Stationary: room-based cameras, RFIDs, GPS, …
- Ubiquitous Information Presentation
  - Mobile: head-mounted displays, portable displays, displays attached to mobile tools, head-mounted projectors…
  - Stationary: wall-sized displays, desktops, projectors, …
- Ubiquitous Interaction
  - Mobile: tracked persons/objects (tangibles), wearable devices (buttons), gestures
  - Stationary: context (spatial cells, time): “modes”, devices at fixed positions

Requires flexible, standardizing system architecture (middleware)

# Ubiquitous Augmented Reality

## VR versus AR: the human side




| | VR | AR |
|---|---|---|
| Properties | Engineered (safe) physical reality | Cluttered (dangerous) physical reality |
| Goal | Immerse in a secondary reality | Add secondary information to the primary (physical) reality |
| Problems | Lack of presence<br>- Degree of realism<br>- Simulator sickness | Lack of situation awareness<br>- Perceptual tunnelling, information overload, cognitive capture.<br>- Tracking, occlusion of physical objects |
| Approach | Exploit human sensing limitations<br>- e.g. Change blindness | Analyze potential distractions<br>- e.g. Eye tracking |
| Convergence | Use AR to enhance VR | Use VR to evaluate AR |

# Overview of this talk

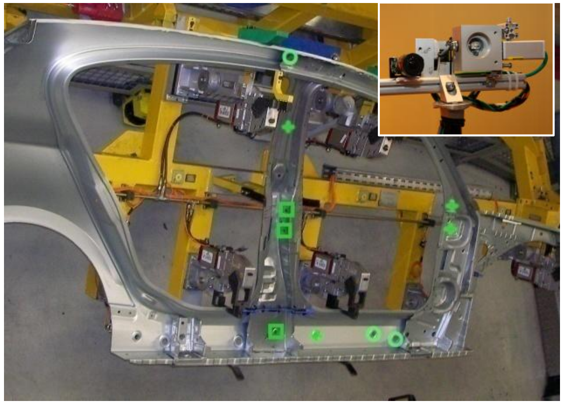
- Ubiquitous Information Presentation Schemes
- Usability in Real Life (Dangerous Situations)
- Ubiquitous Tracking

# Ubiquitous Information Presentation Schemes - Various Approaches -


Head-based

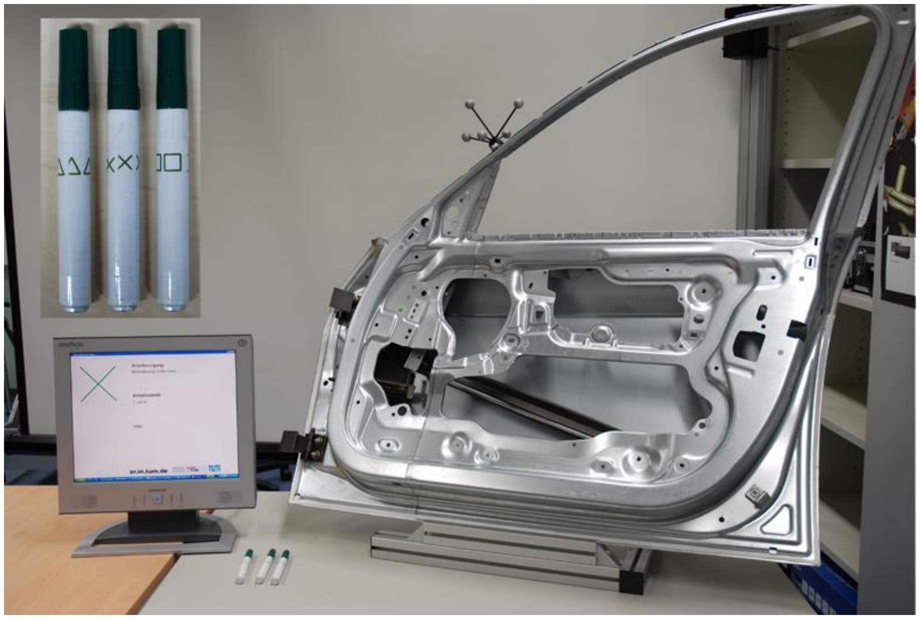

Hand-based

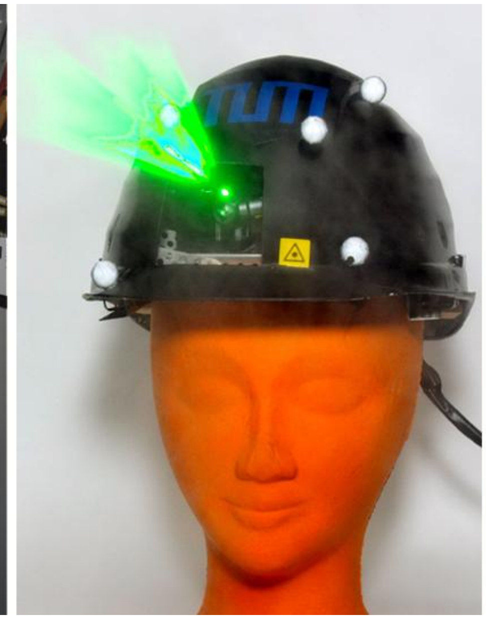

Desktop-based

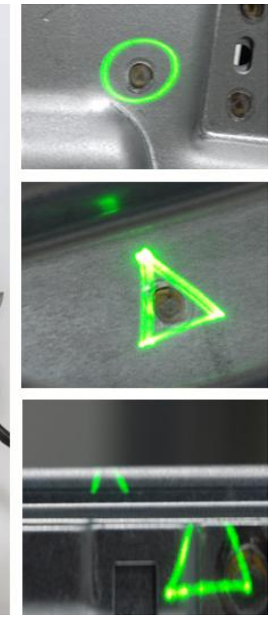

On real surfaces


Hybrid

# Split Presentation Schemes
# - Head-Mounted Laser Projector + Monitor -

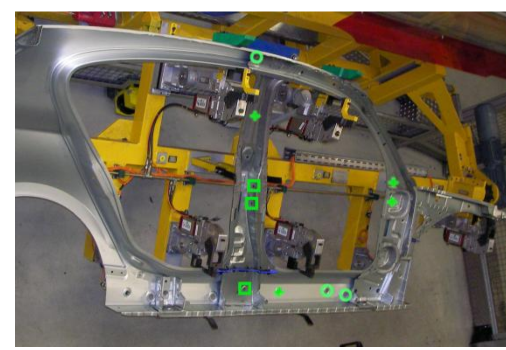






Industrial application: quality assurance

- Information “what to do”
- Information “where to do it”



Schwerdtfeger and Klinker: *Hybrid Information Presentation: Combining a Portable Augmented Reality Laser Projector with a Conventional Computer Display*, (short paper) IPT-EGVE Symposium, July 2007

# Ubiquitous Information Presentation Schemes
# Ego-centric vs. Exocentric Presentation

In ergonomics: compensation vs. pursuit

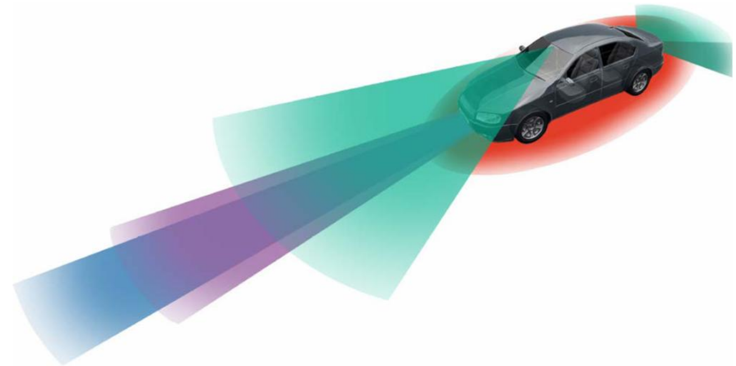
Six parameters, $2^6 = 64$ variations

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X | 0 | X | 0 | X | 0 | X | 0 | x | … | … | x |
| Y | 0 | 0 | X | X | 0 | 0 | x | x | … | … | x |
| Z | 0 | 0 | 0 | 0 | X | X | x | x | … | … | x |
| Rx | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | … | x |
| Ry | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | x |
| Rz | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | x |

# Overview of this talk

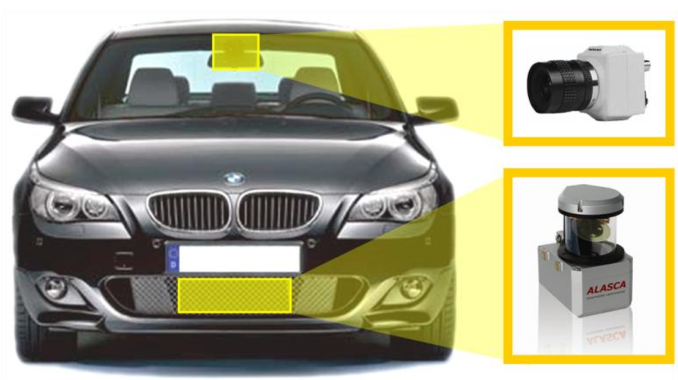
- Ubiquitous Information Presentation Schemes
- Usability in Real Life
- Ubiquitous Tracking

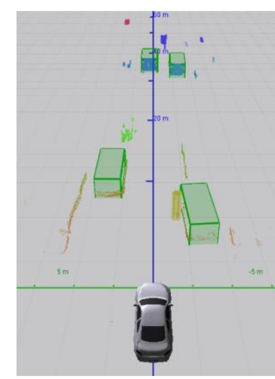
# Usability in Real Life (Dangerous Situations) - Car Driving (Sensor Visualization) -



Situation:

- Increasing number of sensors in the car
- What can be recognized? How reliably?
- How can drivers understand the automatic data interpretation process in a car – and the resulting autonomous actions?



Walchshäusl, Lindl, and Tatschke: *Detection of Road Users in Fused Sensor Data Streams for Collision Mitigation.* In Proceedings of 10th International Forum of Advanced Microsystems and Automobile Applications, Berlin, Apr. 25-27, 2006.

# Usability in Real Life (Dangerous Situations) - Car Driving (Sensor Visualization) -

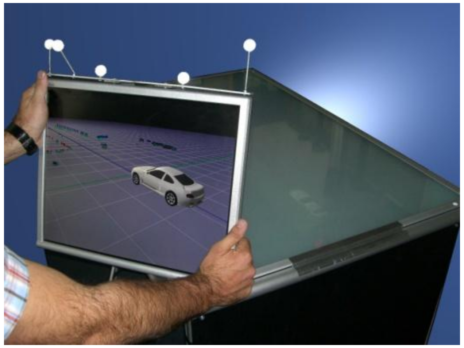
Goals

- Support for sensor research (debugging using live visualizations)
- Support of MMI research (appreciation of live sensor data)

Augmented Reality for Co-Drivers and Service Technicians

- Head-mounted Display
- Portable TFT Display
- Multi-touch Display in the lab





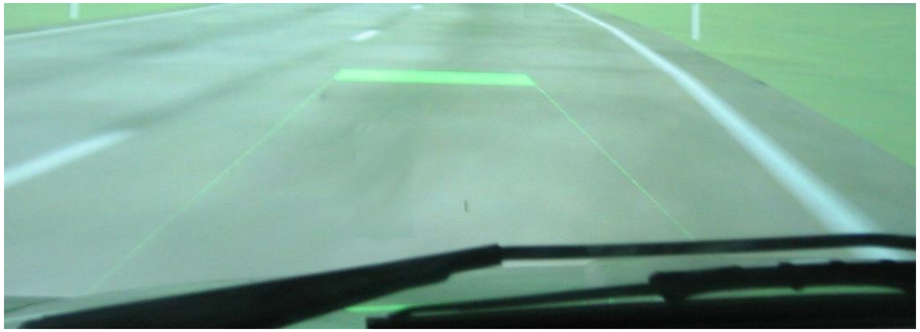
# Usability in Real Life (Dangerous Situations)
# - Car Driving (Danger Ahead) -

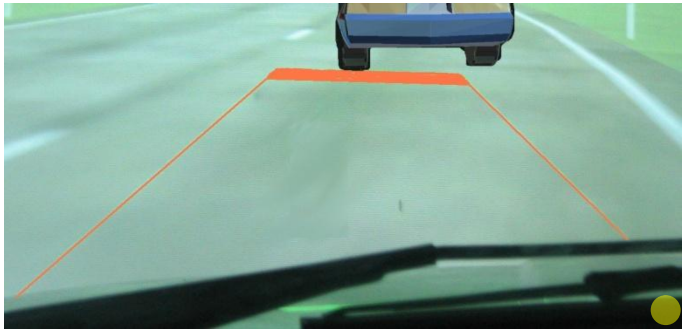
Goal:

- Avoidance of rear-end accidents (e.g.: using ACC)

Approach:

- Visualization of the breaking path in the HUD as
  - Bar [Bubb 76]
  - Drive path





Tönnis, Lange and Klinker: *Visual Longitudinal and Lateral Driving Assistance in the Head-Up Display of Cars*, ISMAR 07, Nov 2007.

Tönnis, Lange, Klinker , Bubb: *Transfer von Flugschlauchanzeigen in das Head-Up Display von Kraftfahrzeugen.* VDI/VW Tagung "Integri.Sicherheit und Fahrerassistenzsysteme, Wolfsburg, Okt.'06.

# Usability in Real Life (Dangerous Situations)
# - Car Driving (Danger Ahead) -

Evaluations in a Fixed-Base Driving Simulator:

- Test participants drive faster with a drive-path assistant.
- The drive-path assistant generates higher speed oscillations.
- Steering is improved.
- Test participants preferred the bar.
- Drive path reduced concentration on the driving task.

Tönnis, Lange and Klinker: *Visual Longitudinal and Lateral Driving Assistance in the Head-Up Display of Cars*, ISMAR 07, Nov 2007.

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# Usability in Real Life (Dangerous Situations) - Car Driving (Danger Ahead) -

Important issues

- Information overload
    - Too much information, too rapid changes
- Perceptual tunneling
    - Focusing on a single stimulus
- Cognitive capture
    - Absentmindedness, reduced situational awareness
- Occlusion of real objects

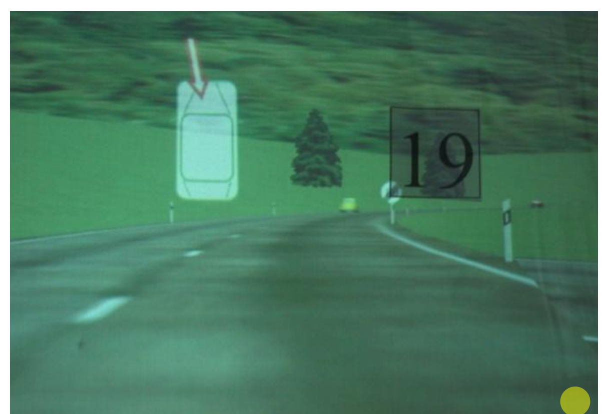
# Usability in Real Life (Dangerous Situations) - Car Driving (Danger from Behind) -

Goal:

- Guide a user's attention to danger from behind

Approach:

- Visualization by sound and in the HUD as
  - 2D overview (bird's eye view)
  - 3D arrow


Tönnis and Klinker: *Effective Control of a Car Driver's Attention for Viaual and Acoustic Guidance towards the Direction of Imminent Danger*, ISMAR 06, Oct. 2006.

# Usability in Real Life (Dangerous Situations) - Car Driving (Danger from the Side) -

Evaluations in a Fixed-Base Driving Simulator:

- 3D arrow (with or without sound) better than 2D overview.
  - Faster recognition of danger (shorter reaction times).
  - Smaller lane deviations.
- Multi-modal warnings (picture and sound) better than graphical warning alone.
- Important:
  - Use of a real HUD in the driving simulator.
  - Model of the 3D arrow.

# Usability in Real Life (Dangerous Situations) - Car Driving (Simulation Environments) -

Goal:

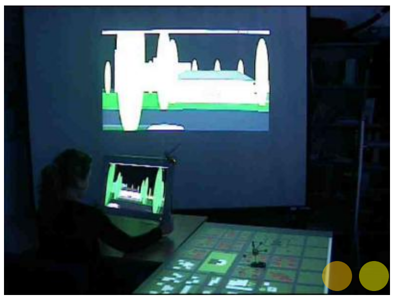
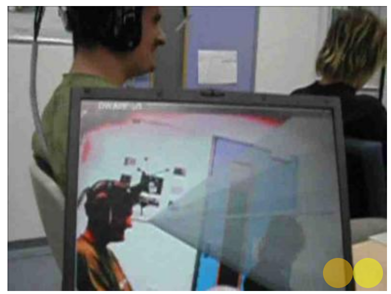
- Analysis and evaluation of new MMIs in realistic, dynamic scenes

Alternatives:

- Experiments using real cars in real traffic
  - Dangerous
  - Situations cannot be selected systematically
- Driving simulators
  - Significant modeling effort
  - Partially insufficient realism (esp. w.r.t. dynamic traffic behavior)

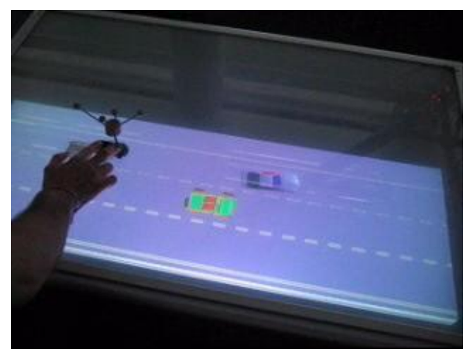
# Usability in Real Life (Dangerous Situations)
# - Car Driving (Simulation Environments) -

- CAR Simulation Environment


- Parent Simulation Environment

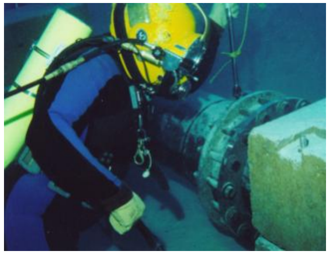





Sandor and Klinker*: Lessons Learned in Designing Ubiquitous Augmented Reality User Interfaces.* In: Emerging Technologies of Augmented Reality. Interfaces & Design, Idea Group Inc, 2006.

Tönnis: *The Tangible Car: Rapid Intuitive Traffic Scenario Generation in a Hybrid Table-Top and Virtual Environment.* 4th Int. Workshop on the Tangible Space Initiative, in Conjunction with ISMAR 07,

# Usability in Real Life (Dangerous Situations)
# - Professional Diving Operations -



Stress due to environmental and working conditions

- Pressure
- Visibility
- Weightlessness
- Current

Restrictions on divers‘ sensory input cause

- Diminished spatial position and orientation awareness
- Reduced cognition and memory
- Reduced confidence and safety, increased fear (even panic)

Improve conditions by adding elements in divers‘ views to increase

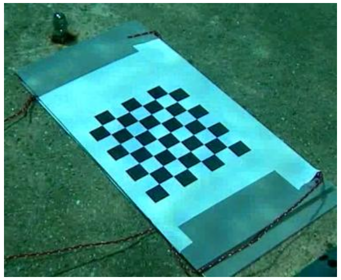
- Awareness
- Safety

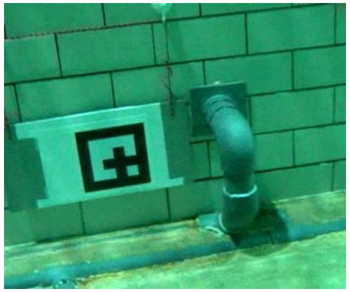
Morales, Keitler, Maier and Klinker*: An Underwater Augmented Reality System for Professional Diving Operations.* OCEANS 2009, MTS/IEEE, Biloxi, Mississippi, Nov. 2009.

# Usability in Real Life (Dangerous Situations) - Professional Diving Operations -

- Hardware
  - Watertight housing for web-camera and HMD (eMagin Z800 3D Visor)
  - Watertight housing for HMD driver and umbilical connections to surface

- Tracking setup (Ubitrack)
  - Underwater camera calibration
  - Underwater HMD calibration (SPAAM)
  - Laminated marker

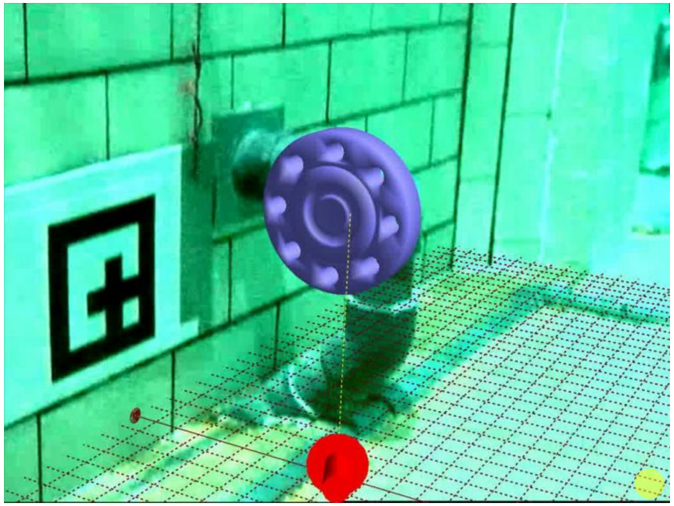


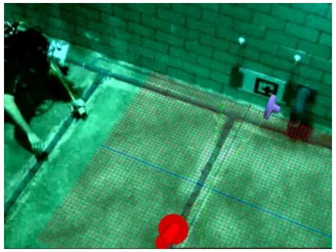


# Usability in Real Life (Dangerous Situations) - Professional Diving Operations -

Underwater maintenance

- Provide information relevant to
  - Orientation and position awareness
    - Artificial horizon (red grid)
  - Navigation aids
    - Red arrow + rubber band
  - Context-dependent memory
    - 3D model (e.g. of an assembling task)



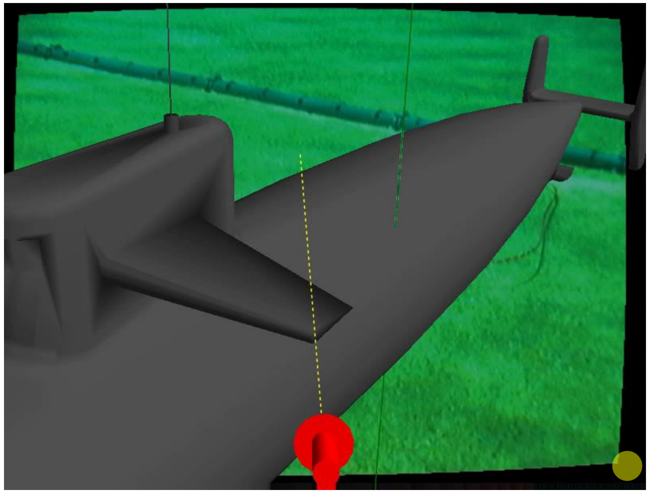


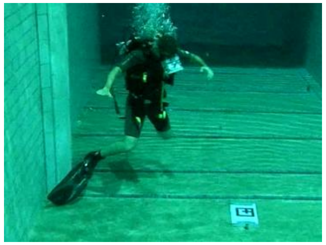
Morales, Keitler, Maier and Klinker: *An Underwater Augmented Reality System for Professional Diving Operations.* OCEANS 2009, MTS/IEEE, Biloxi, Mississippi, Nov. 2009.

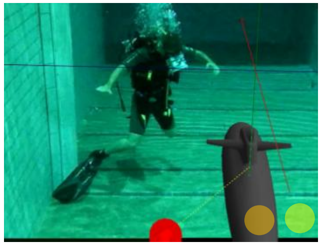
# Usability in Real Life (Dangerous Situations) - Professional Diving Operations -

Underwater vessel inspection

- Provide information relevant to
  - Navigation aids
    - Red arrow + rubber band
  - Context-dependent memory
    - 3D model of vessel



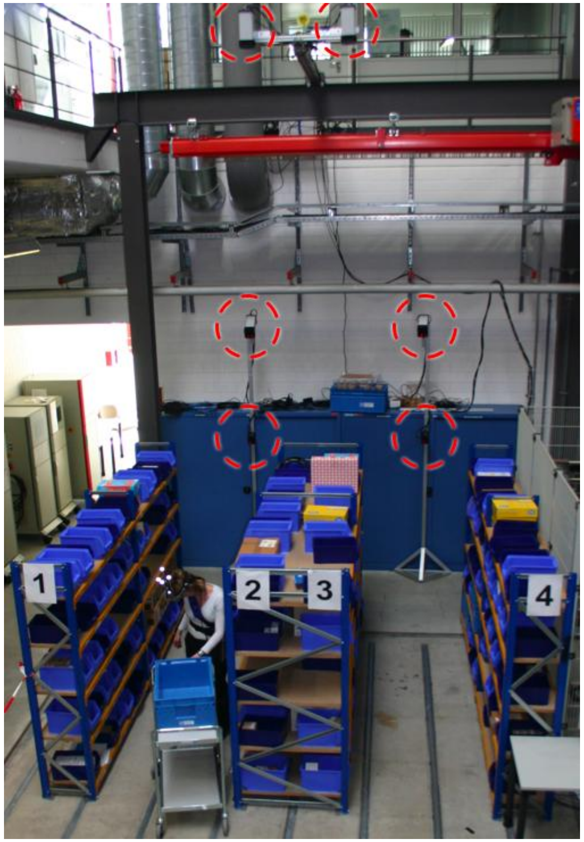




Morales, Keitler, Maier and Klinker: *An Underwater Augmented Reality System for Professional Diving Operations.* OCEANS 2009, MTS/IEEE, Biloxi, Mississippi, Nov. 2009.

# Usability in Real Applications
# - Navigation Support in Picking Tasks -

- Collection of large assortments in series production
  - Large storage area, many objects, varying size
  - Flexible arrangement in the storage area
  - Changing staff
- Several phases
  - Course navigation
  - Fine navigation
- Existing systems
  - Mobile data terminal with scanner
  - Pick-by-light
  - Pick-by-voice

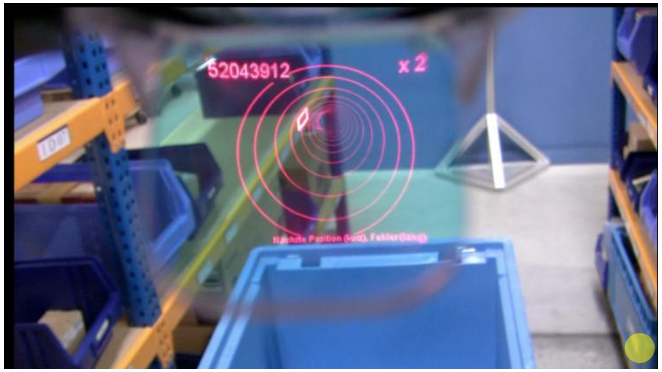



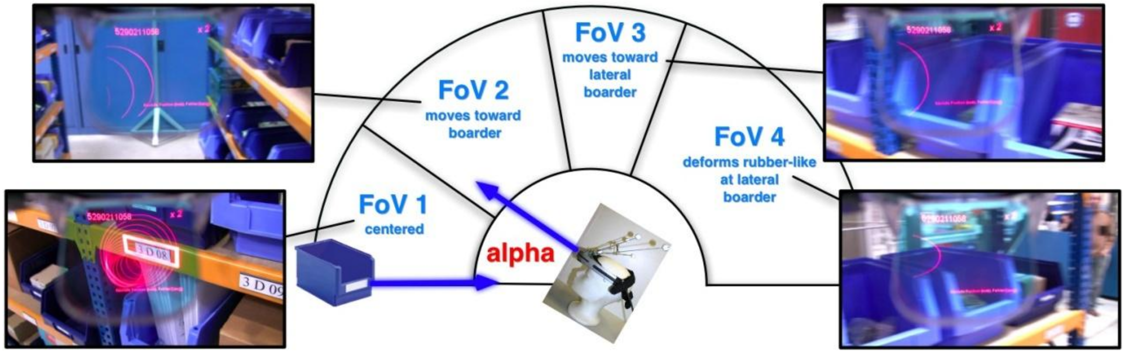

Schwerdtfeger, Reif, Günthner, Klinker: *Pick-by-Vision – There is Something to Pick at the End of the Augmented Tunnel.* Submitted to: Special Issue on "Autmented Reality" of the Springer Journal on Virtual Reality (M. Billinghurst and D. Schmalstieg, eds.), Springer Verlag, 2010.

# Usability in Real Applications
# - Navigation Support in Picking Tasks -

Pick-by-Vision

- Omni-directional support of object selection
- HMD-based
- Visualisations
  - Direct: rectangle
  - Meta: tunnel
- Ubiquitous tracking

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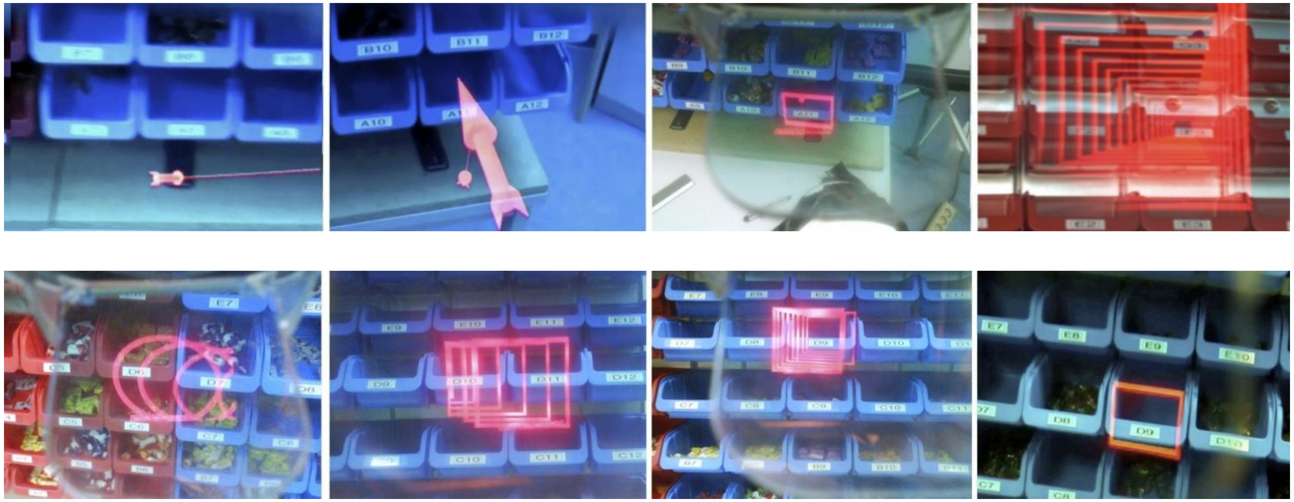
# Usability in Real Applications
# - Navigation Support in Picking Tasks -

Important issues

- Quality and understandability of the 3D display: uniqueness (Arrow vs. frame)
- Support for estimating appropriate speed of motion (rotation) (Arrow/rubber band vs. tunnel)
- Occlusions



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# Usability in Real Applications
# - Navigation Support in Picking Tasks -

Long series of user tests

- Several evaluations (objective and subjective data, plus informal comments)
- Informal comments from exhibits, fairs, open houses.
- Collaboration with occupational scientists (analysis of heart rate variablilty)

Experiences

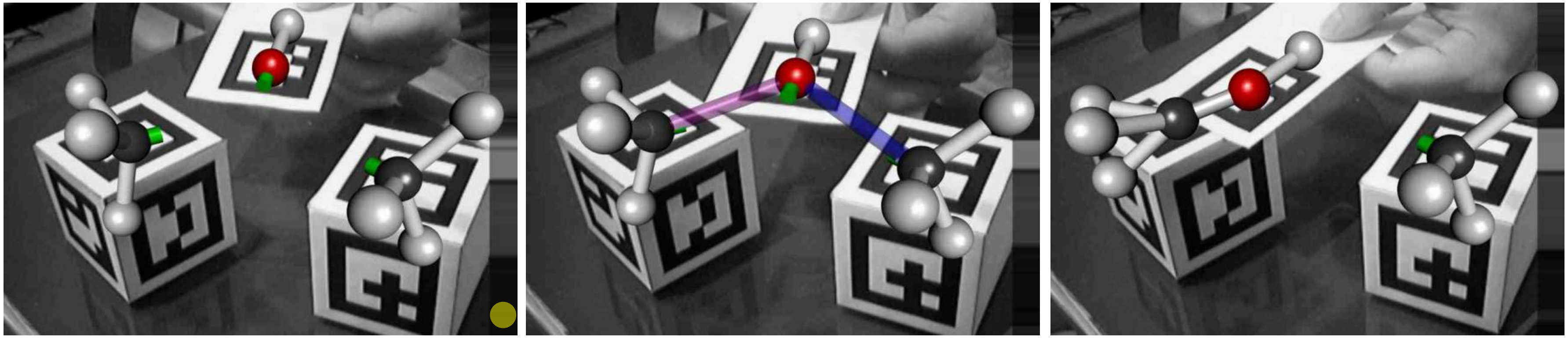
- Special (non-standard) initial learning phase („try-and-ask“)
- Optional interruptions by the supervisor
- Initially many „formative“ tests, expert interrogations with few people

Schwerdtfeger, Reif, Günthner, Klinker: *Pick-by-Vision – There is Something to Pick at the End of the Augmented Tunnel.* Submitted to: Special Issue on “Autmented Reality” of the Springer Journal on Virtual Reality (M. Billinghurst and D. Schmalstieg, eds.), Springer Verlag, 2010.

# Usability in Real Applications
# Intelligence Amplification

Augmented chemical reactions

- Dynamic 3D visualization of potential molecular bonds
  - Investigation of spatial impact (is there enough space?)
  - AR-based interactive exploration of options
- Teaching tool for students:
  - Interactively controlled simulation and visualization of atomic forces

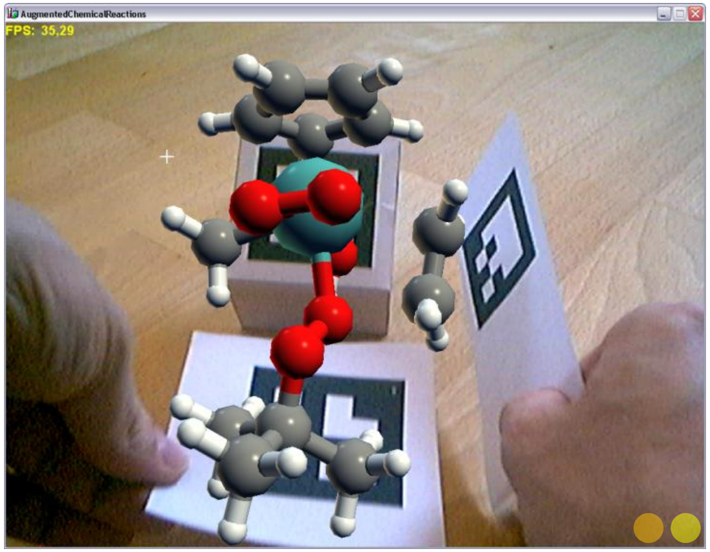


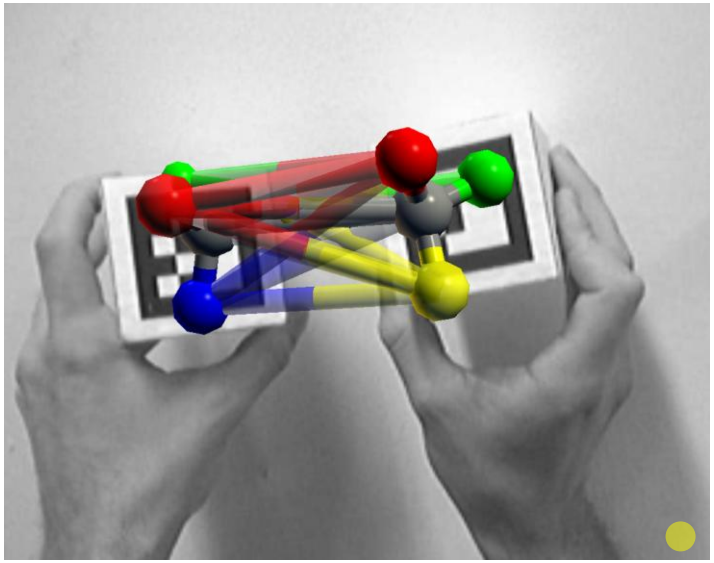
Maier, Tönnis, Klinker, Raith, Drees, Kühn: *What Do you Do When Two Hands Are not Enough? Interactive Selection of Bonds Between Pairs of Tangible Molecules*
International Symposium On 3D User Interfaces (3DUI), Waltham, MA, March 2010.

# Usability in Real Applications
# Intelligence Amplification

Augmented chemical reactions

- Example:
  catalyst design for metal organic reactions
  - Catalyst: organomolybdenum complex
  - Educt 1: peroxide molecule (front), bond with central metal of the catalyst
  - Educt 2: ethen molecule (right)
- Problem:
  generally more than two hands required
  - Bond selection
    - Distance-based selection
    - Selection by shaking (toggling through a list)
  - Confirmation



Maier, Tönnis, Klinker, Raith, Drees, Kühn: *What Do you Do When Two Hands Are not Enough? Interactive Selection of Bonds Between Pairs of Tangible Molecules*
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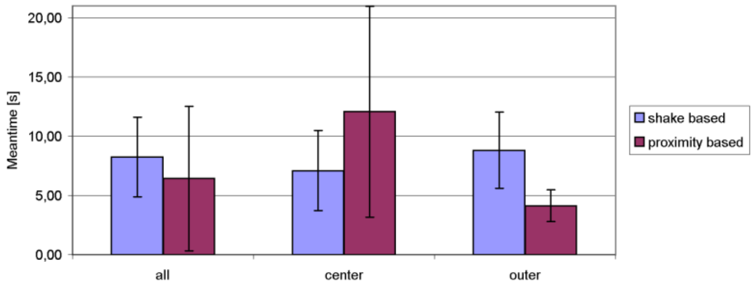
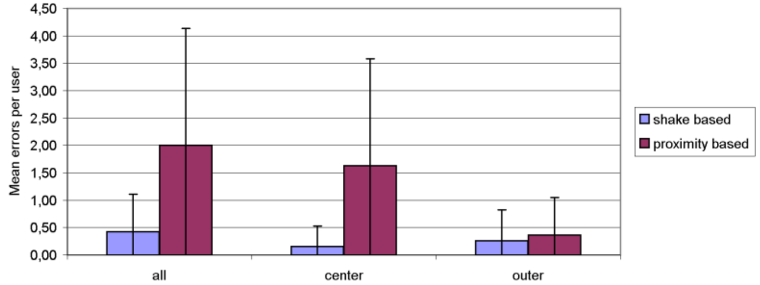
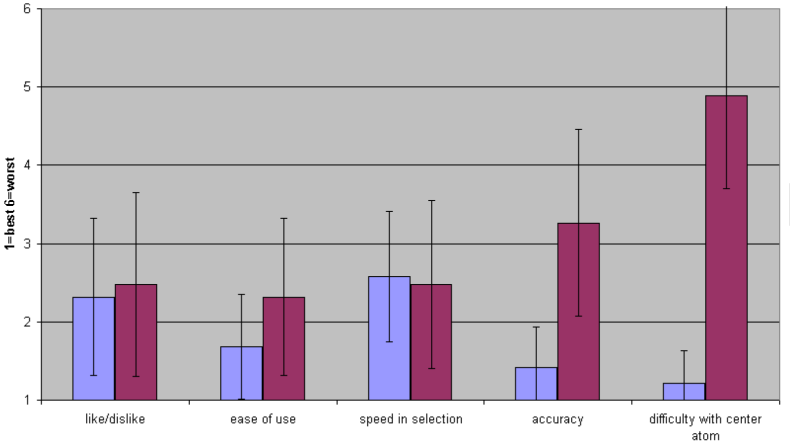
# Usability in Real Applications Intelligence Amplification

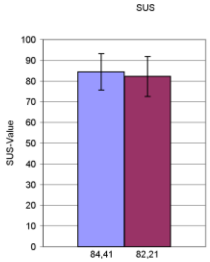
## First evaluation

- 19 persons (7f, 12m, 20-51 y)
- Most of the without prior exposure to AR
- Within-subject design
- 2 test phases (24 bonds each, permuted)

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# Overview of this talk

- Ubiquitous Information Presentation Schemes
- Usability in Real Life (Dangerous Situations)
- Ubiquitous Tracking

# Ubiquitous Tracking
# - Goals -

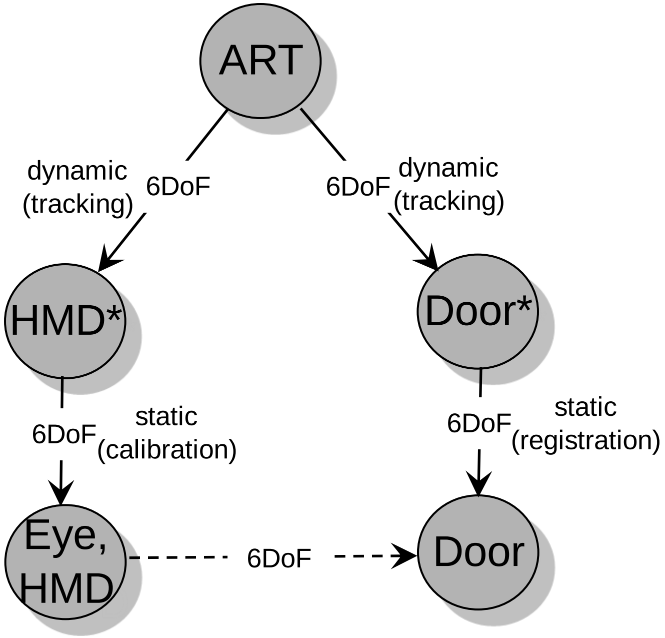
Creation and implementation of a framework independently of specific applications and devices that is capable of providing context-dependent tracking services in heterogeneous, wide areas.

- Trackers partially wearable and partially stationary
- Trackers available across several applications
- Applications independent of tracker installations
- Tracking arrangements configured dynamically, establishing real-time connections between trackers and applications

- Critical aspects:
  - Explicit description of spatial relationships (Spatial Relationship Graph)
  - Automatic compilation of spatial relationships into data flows between sensors, fusion components, and applications (Data Flow Network)
  - Efficient, robust and precise use in real applications

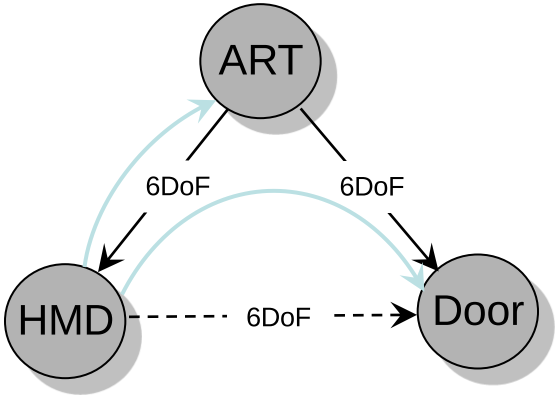
# Ubiquitous Tracking
# - Spatial Relationship Graph (SRG) -

| 3D World | SRG |
|---|---|

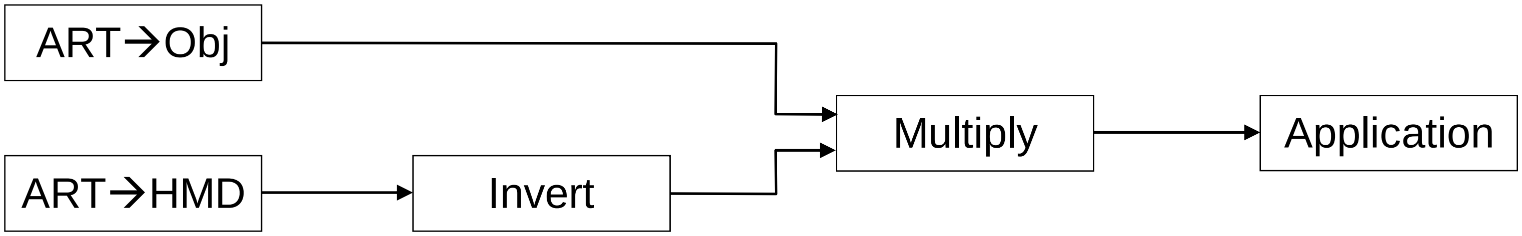


# Ubiquitous Tracking
# - Automatic Compilation into Data Flow Networks -

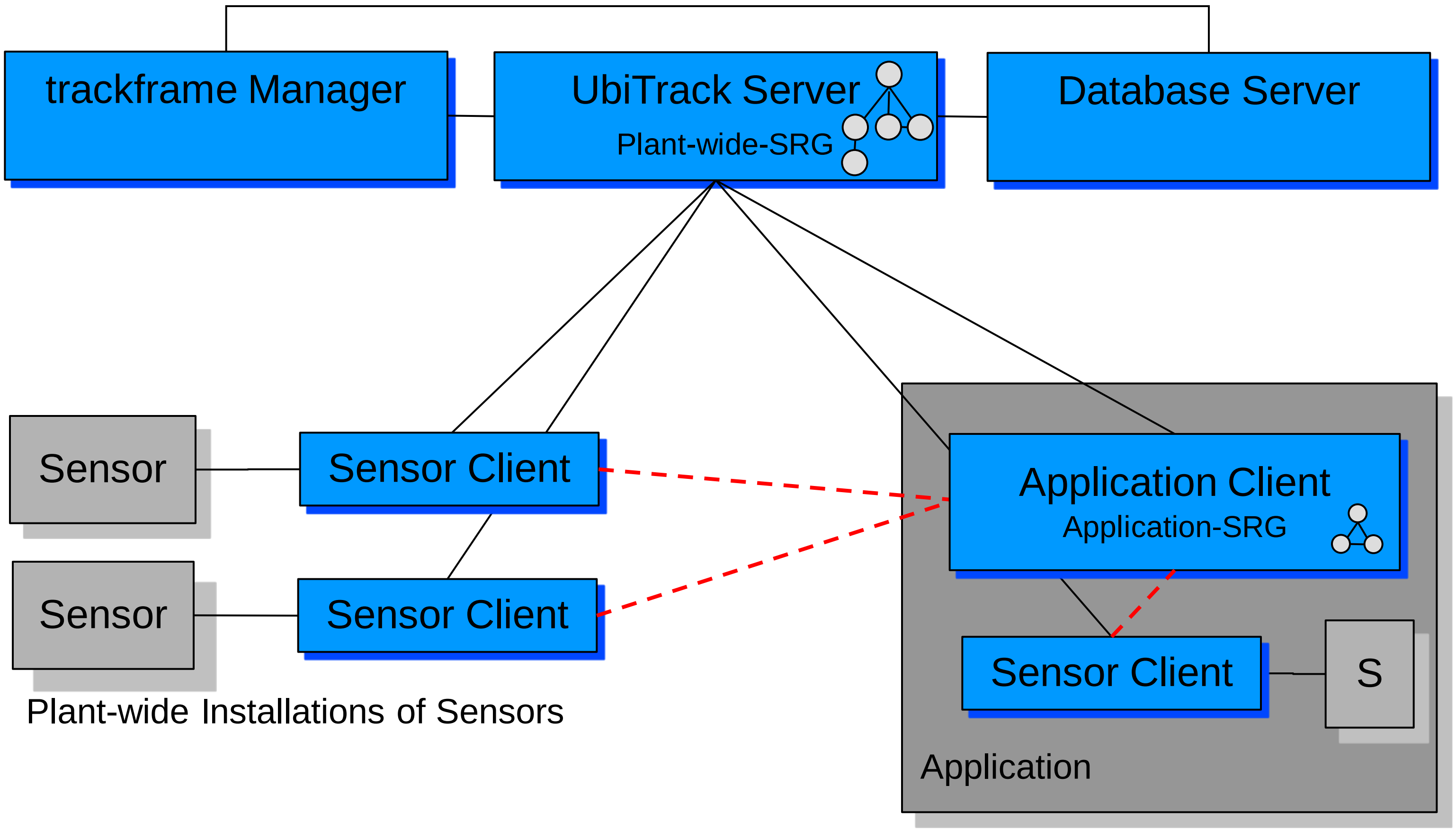
- Spatial Relationship Graph (SRG)




- Data Flow Network (DFN): SRG edges = DFN nodes



# Integration Concept for Applications

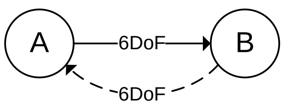



Huber, Pustka, Keitler, Echtler and Klinker: *A System Architecture for Ubiquitous Tracking Environments*, ISMAR 07, Nov. 2007.

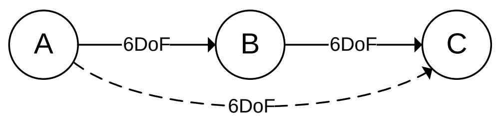
Becker, Huber and Klinker: *Utilizing RFIDs for Location-Aware Computing*, UIC, June 08.

# Spatial Relationship Patterns

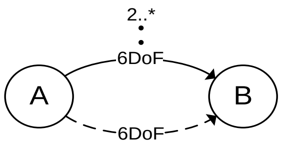
- Inversion



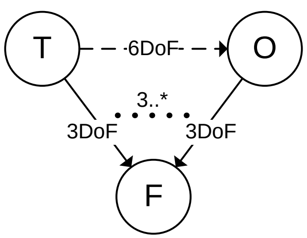

Concatenation



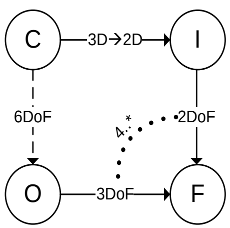

Sensor Fusion



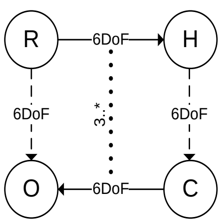

- 3D-3D Pose Estimation




2D-3D Pose Estimation




Hand-Eye Calibration



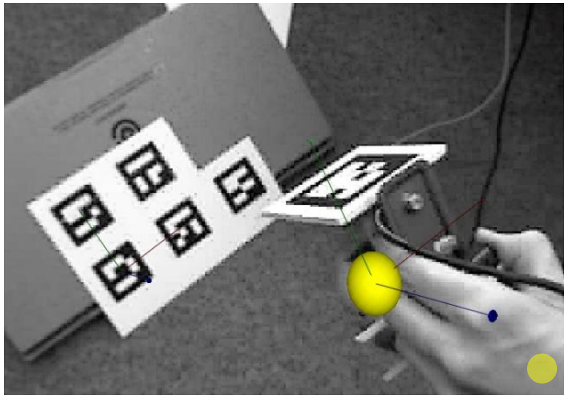

Pustka, Huber, Bauer and Klinker: *Spatial Relationship Patterns: Elements of Reusable Tracking and Calibration Systems*, ISMAR 06, Oct. 2006. AWARD.

# Automated Sensor Fusion

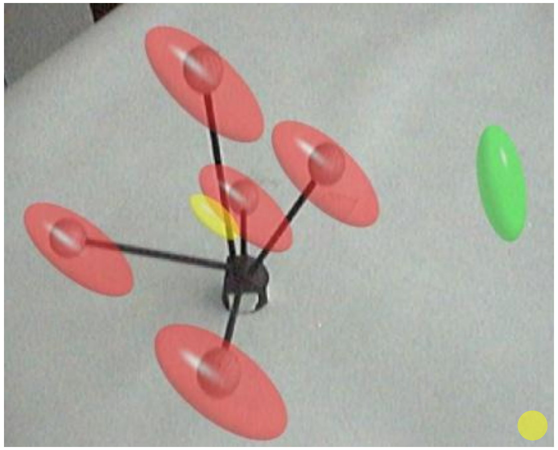
Patterns/algorithms for

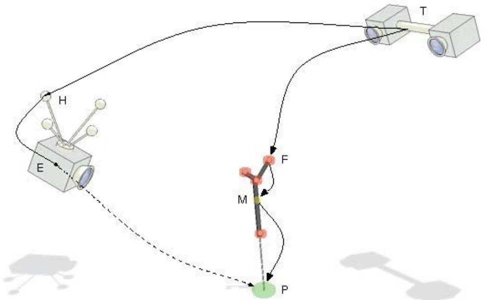
- Calibration
  - Camera estimation
  - Hand-eye calibration
  - Display calibration (SPAAM)
- Registration
  - 3D-3D pose estimation
- Sensor fusion
  - Complementary
    - Functionally complementary
    - Temporally/spatially complementary
  - Competitive
    - Binary competitive („winner take all“)
    - Mixed competitive (error reducing: Kalman)
  - Co-operative
    - Independent co-operation (concatenation, correction)
    - Dependent co-operation (initialization)

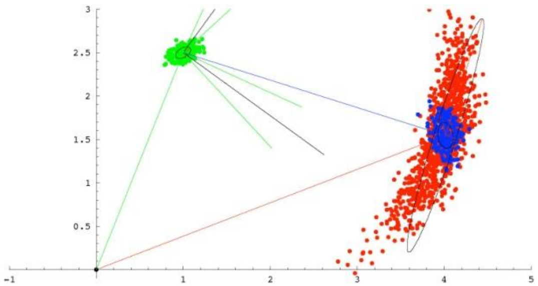
# Error Estimation and Propagation in SRGs



- Computation of sensor error
  - Gaussian errors
  - High-precision ART tracking
  - Simple marker tracking
- Fusion algorithm
  - Kalman filter
  - Fully integrated into framework

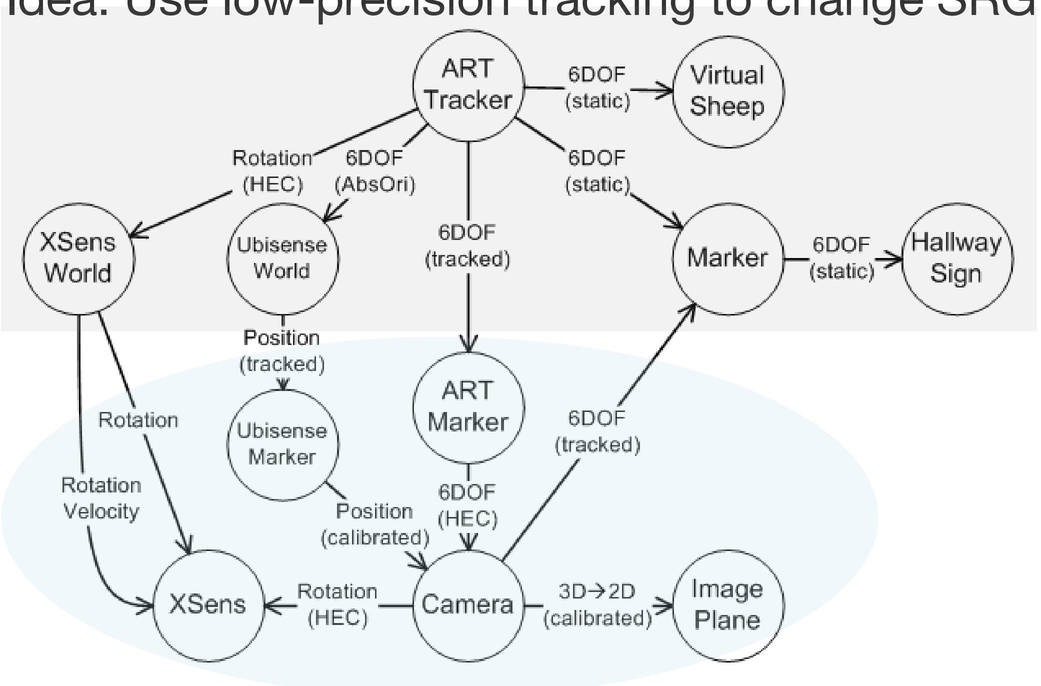




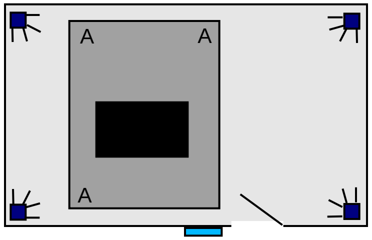



# Dynamic Reconfiguration

- Scenario: AR-equipped person enters room with high-precision tracking
- Client and application should automatically connect
- Idea: Use low-precision tracking to change SRG








# Summary / Conclusions

- Augmented/Mixed Reality has the potential to significantly help computer users integrate and understand a wealth of digital information in their real surroundings
- AR won't be used in isolation
- Our approach: AR → Ubiquitous AR
- Research issues under investigation
  - Concepts/middleware for integrating AR into a wider, ubiquitous information presentation scheme
  - Usability
- Particular emphasis: User interfaces for critical or complex situations
  Recently:
  • AR-Tunnel for picking
  •.Visualization concepts for traffic anticipation
  • Augmented Chemistry
  • AR for divers

Thank you

# Recent / new/ other things we do

- Ubiquitous interaction in real environments
  - AR-Tunnel for picking
  - Visualization concepts for traffic anticipation („just beyond the horizon“)
  - Augmented Chemistry
  - AR for divers
  - Navigation metaphors in large nD-environments („virtual Arabia“)
  - 2D/3D UIs for use in catastrophic events
  - AR on mobile devices
- Multi-touch environments: TischLib (OpenSource)
- Tracking cart for wide area tracking (ISMAR tracking contest)
  - People tracking
  - Sensor synchronization
  - Less precise tracking (wide area)
  - ToF based tracking
  - Trackman
- Outreach / Teaching:
  - Itüpferl
  - Mädchen machen Technik
  - Rappelkiste
  - Bachelor program „Informatik: Games Engineering“