CS231M · Mobile Computer Vision

Spring 2015

Instructors: - Prof Silvio Savarese (Stanford, CVGLab)

- Dr Kari Pulli (Light)

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Agenda

- Administrative
  - Requirements
  - Grading policy
- Mobile Computer Vision
- Syllabus & Projects

Structure of the course

- First part:
  - Familiarize with android mobile platform
  - Work on two programming assignments on the mobile platform
- Second part:
  - Teams will work on a final project
  - Teams present in class 1-2 state-of-the-art papers on mobile computer vision

What you will learn

- How to program on the Android development platform
- State-of-the computer vision algorithms for mobile platforms
- Implement a working vision-based app on a mobile device

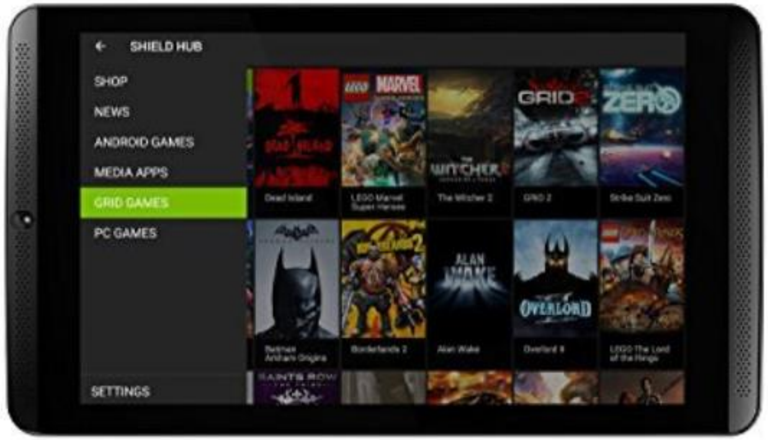
What you need to do

- Two programming assignments [40%]
- Course project [40%]
- Team presentations in class [15%]
- Class participation [5%]
- No midterms no finals!

Programming assignments [40%]

- Problem-0: warm up assignment (it won't be graded)
    - Self-calibration; it will guide you through installing the Android platform and help you run a simple toy application
- Two problem sets [20% each]
- Each graded problem set includes
    - a programming assignment [15%]
    - a write-up [5%]
- Two topics:
    - Feature detection, descriptors, image matching, panorama and HDR image construction
    - Object and landmark recognition; Image classification

Programming assignments [40%]



- Programming assignments will be implemented on **Nvidia Shield**: a Tegra-based (K1) Android tablet
  - Simulators can only be used for debugging
- NVIDIA tablets are available for each student who is taking the course for credit.
- Tablets kindly lent by Nvidia
- Supporting material/tutorials will be based upon the Android platform

Programming assignments [40%]

- Important dates:
  - Problem-0
    - Released: 4/6 (next Monday)
    - Due: 4/13
  - First problem assignment:
    - Released on 4/13
    - Due on 4/24
  - Second problem assignment:
    - Released on 4/24
    - Due on 5/6

Course Project [40%]

- Goal: implement a computer vision application on a mobile platform
- We encourage students to use the NVIDIA Tegra-based Android tablet
- Students can use iOS for final project (but please let us know if this is the case)
- NOTE: programming assignments must be completed on android

- Simulator can only be used for debugging

Course Project [40%]

- Teams: 1-3 people per team
  - The quality of your project will be judged regardless of the number of people on the team
  - Be nice to your partner: do you plan to drop the course?

Course Project [40%]

- Evaluation:
  - Proposal report 10%
  - Final report 20%
  - Final presentation 10%

Course Project [40%]

- Important dates:
  - Project proposal report due on 5/8
  - Project presentations on 5/27, 6/1, 6/3
  - Final project due: 6/7

Some examples of projects are:

- Recover the 3D layout of a room and augment it with new IKEA furniture
- Recognize your friend's face and link it to your friends on Facebook
- Localize yourself in a google map and visualize the closest restaurant on the smart phone's display
- Detect and face and turn it into a cartoon (and share it with friends)
- Create HDR panoramic images
- Recognize landmarks on the Stanford campus (e.g.: Memorial Church) and link it to relevant info from the web (Wikipedia, photos from other users, etc...)

Presentations in class [15%]

– Each student team will present 1-2 state-of-the-art papers on mobile computer vision
– Topics are pre-assigned but student teams can bid to present a paper of interest.
– Paper topics will be uploaded to the course syllabus soon.
– We are currently estimating a 15-30 minutes presentation per team

Evaluation:

- Clarity of the presentation
- Ability to master the topic
- Ability to answer questions

Class participation [5%]

- Participate in class by attending, asking questions and participate in class discussions
    - During lectures
    - During team presentations

- In-class and piazza participation both count.

- Quantity and quality of your questions will be used for evaluating class participation.

Late policy

- No late submission for problem sets and Project
- Two “24-hours one-time late submission bonus" are available;
  - that is, you can use this bonus to submit your PA late after at most 24 hours. After you use your bonuses, you must submit on your assignment on time
- NOTE: 24-hours bonuses are not available for projects; project reports must be submitted in time.

Prerequisites

- CS131A, CS231A, CS232 or equivalent
- Familiar with C++ and JAVA

Collaboration policy

– Read the student code book, understand what is 'collaboration' and what is 'academic infraction'.
– Discussing project assignment with each other is allowed, but coding must be done individually
– Using on line presentation material (slides, etc…) is not allowed in general. Exceptions can be made and individual cases will be discussed with the instructor.
– On line software/code can be used but students must consult instructor beforehand. Failing to communicate this to the instructor will result to a penalty

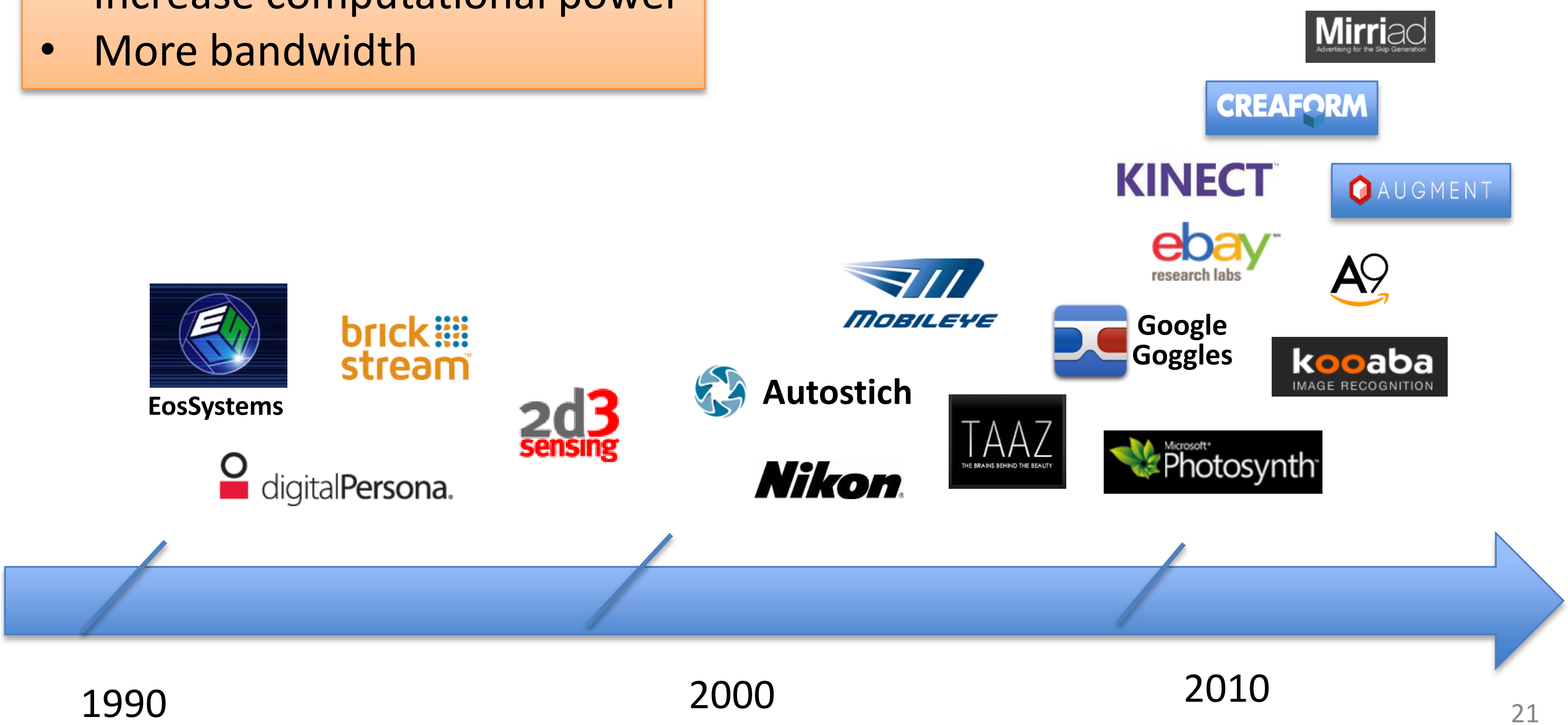
Agenda

- Administrative
  - Requirements
  - Grading policy
- Advanced topics in computer vision
- Syllabus & Projects

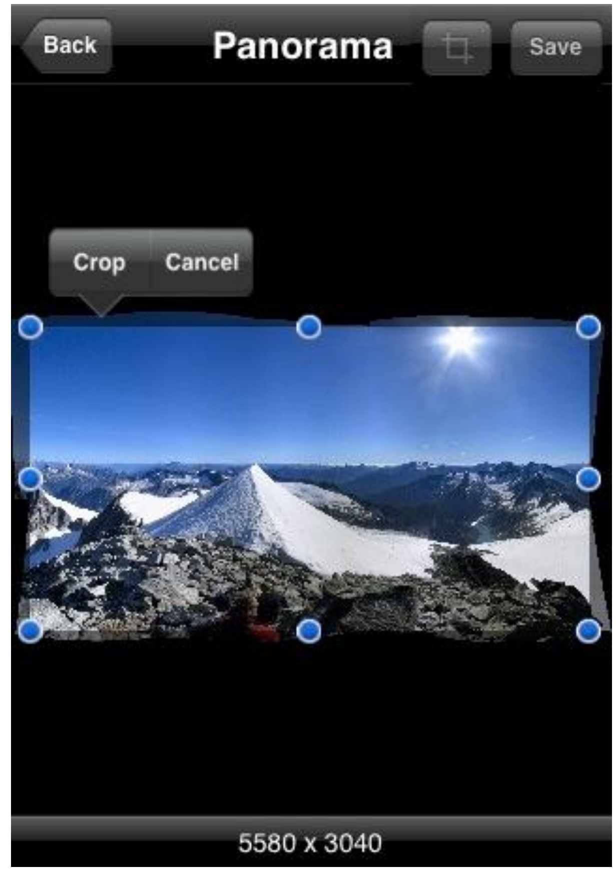
From the movie Minority Report, 2002

Computer vision and Mobile Applications

- More powerful machine vision
- Better clouds ☺
- Increase computational power
- More bandwidth



Panoramic Photography



Cloudburst RESEARCH

HumanEyes
Print Out of the Box

kolor

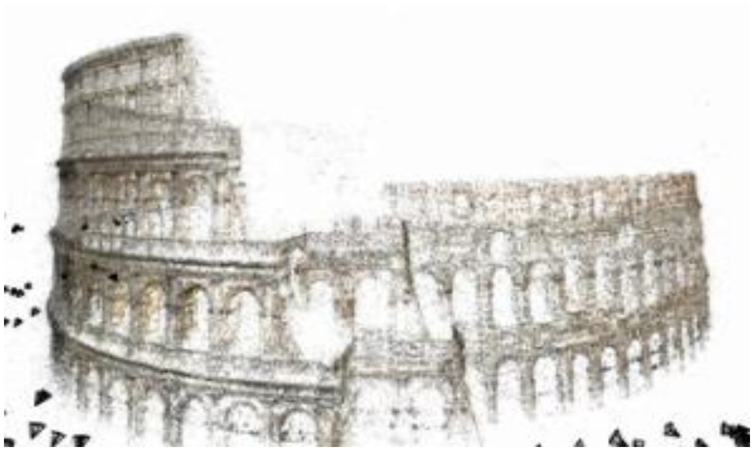
HDR

Intellsys

Digital photography

Adobe Photoshop

3D modeling of landmarks

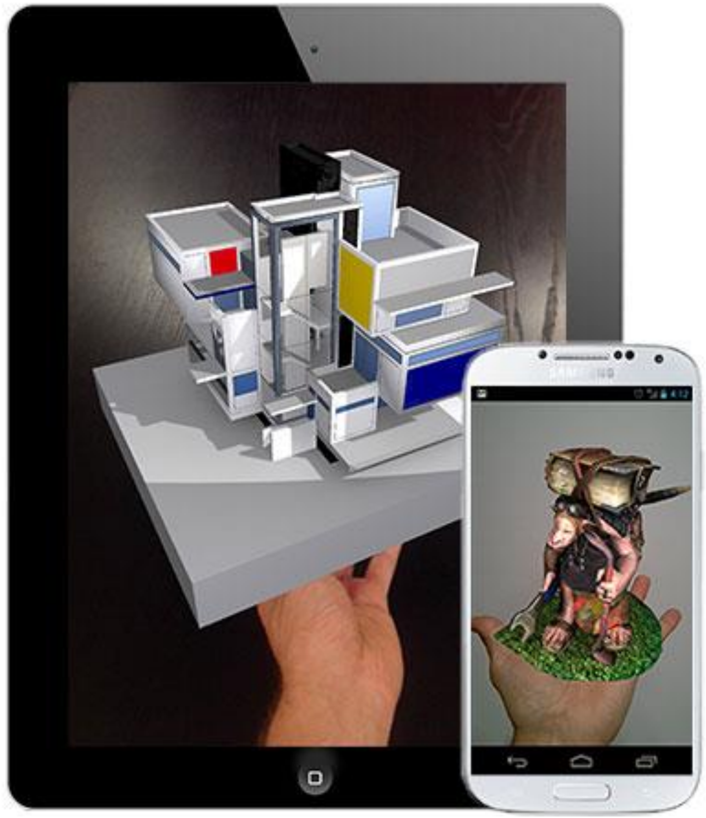


Microsoft Photosynth

VLSAM

By Johnny Lee

Augmented reality



AUGMENT

Fingerprint biometrics

digitalPersona

Visual search and landmarks recognition

RICOH

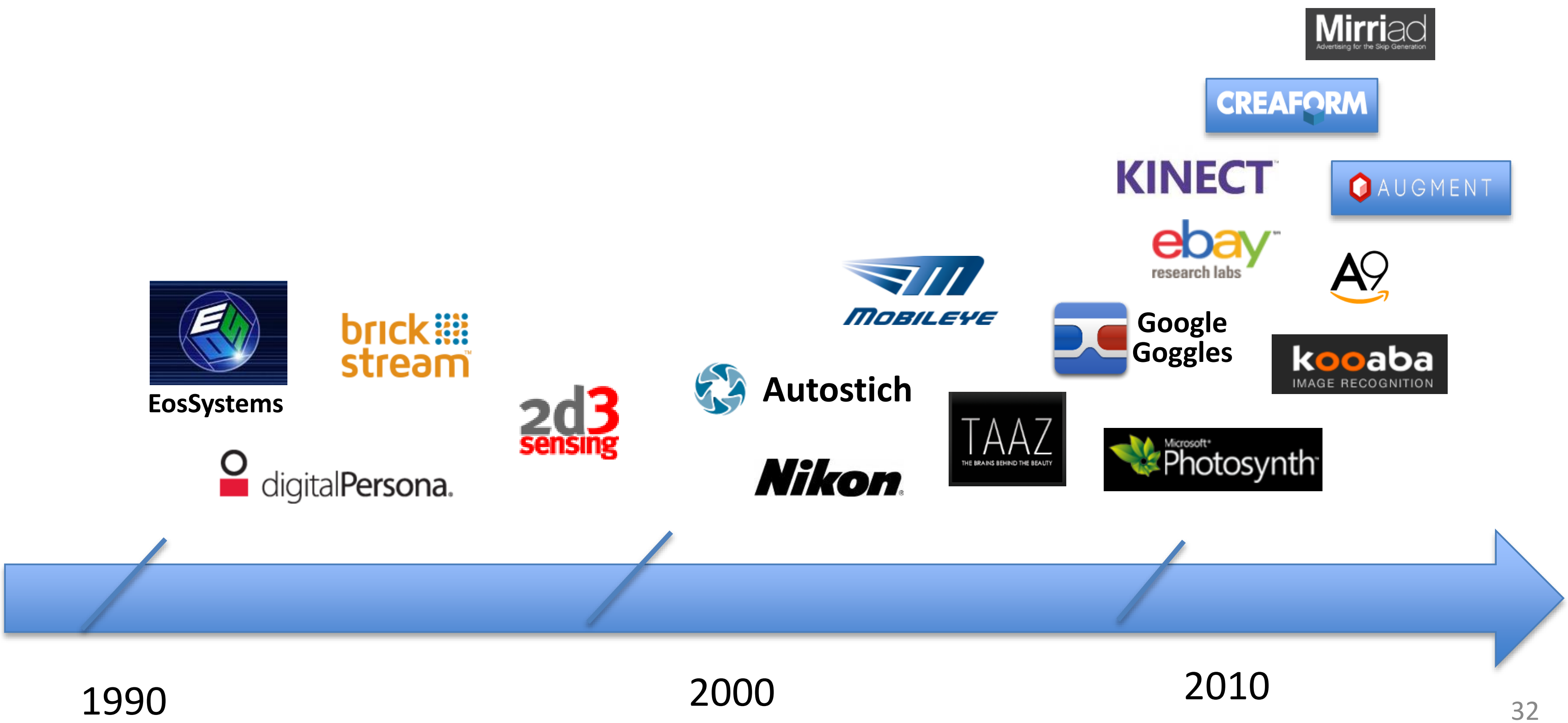
A9

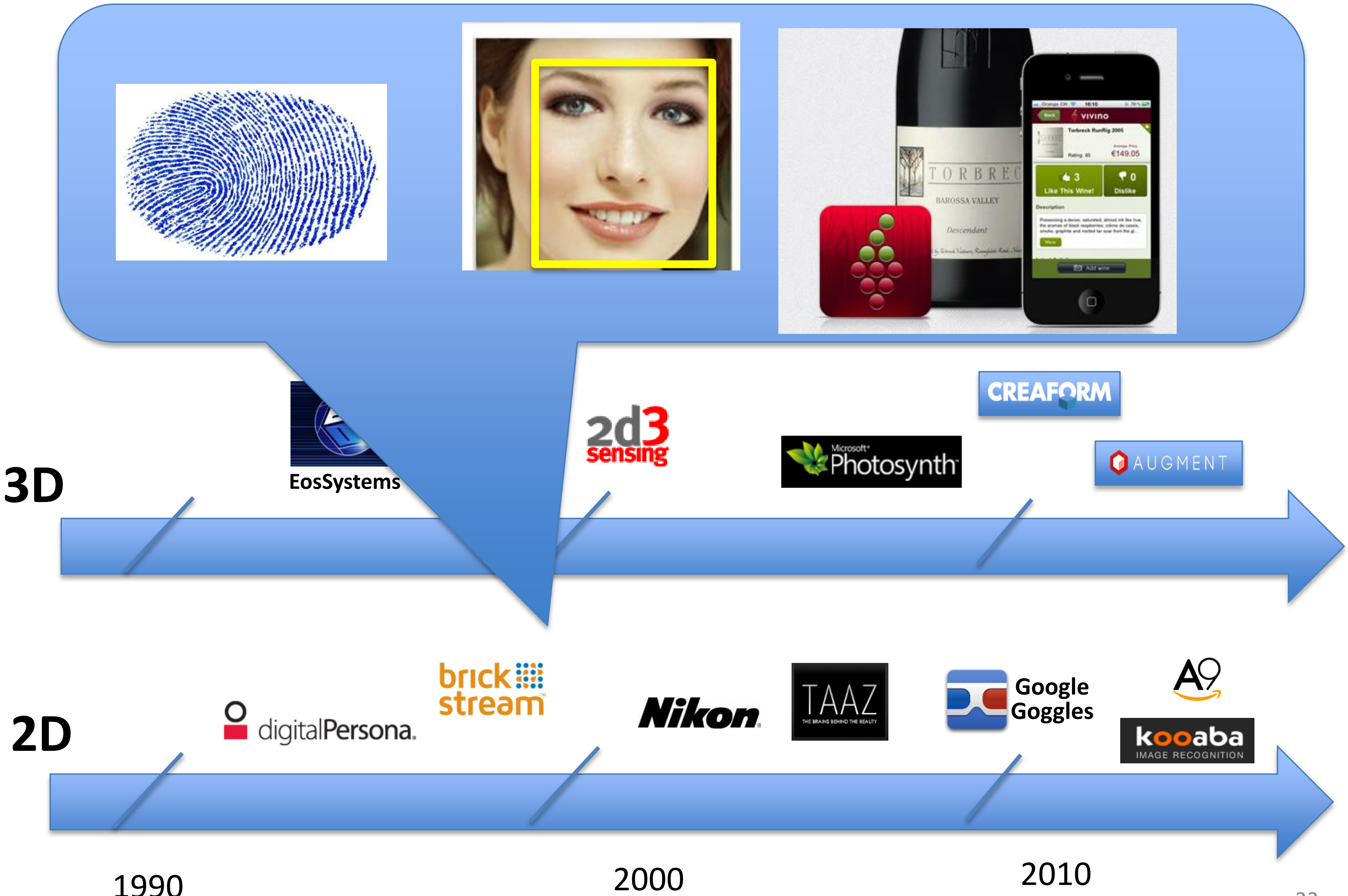
Image search engines

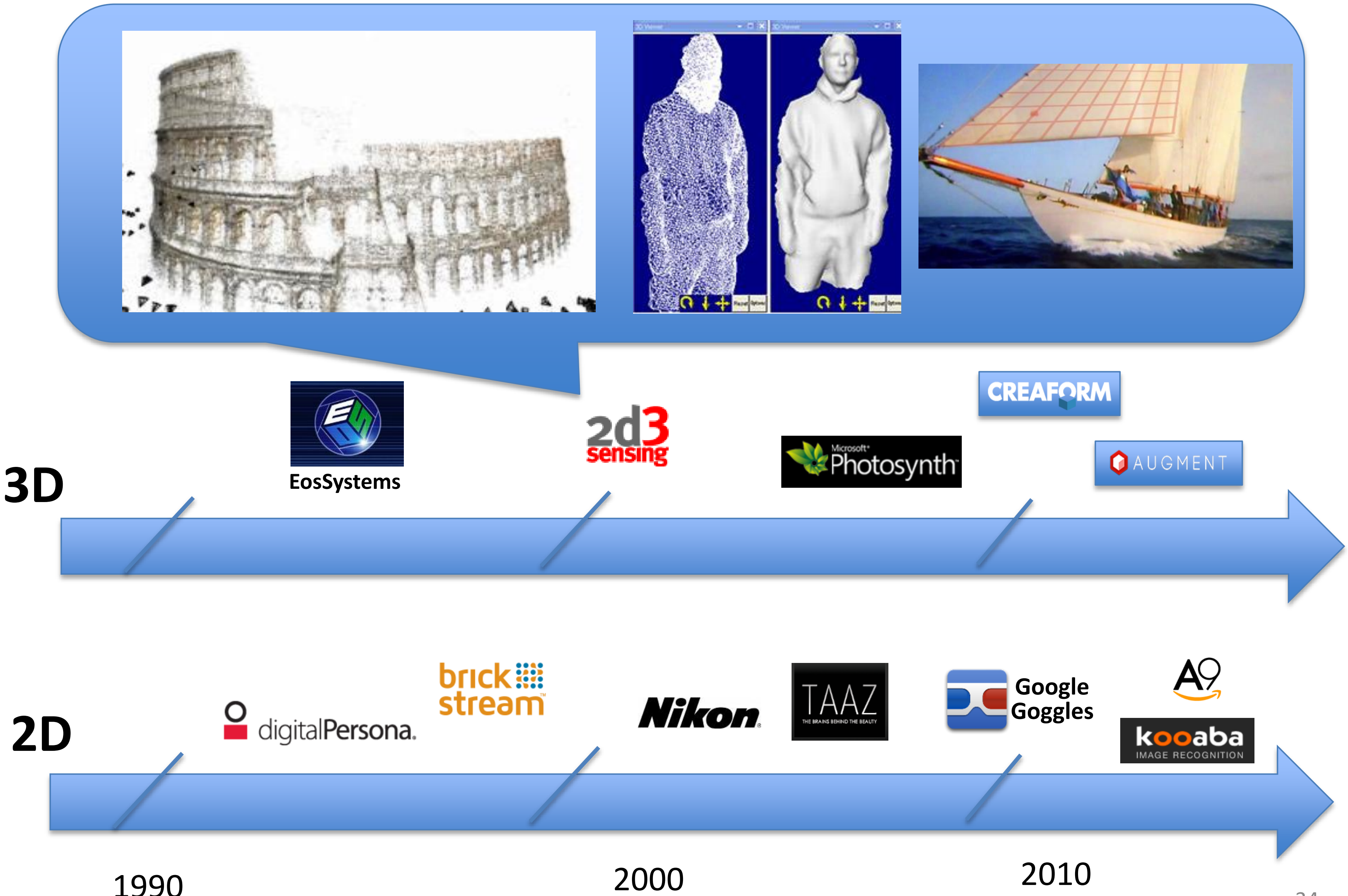
Google Image Search
Picasa
flickr
webshots
bing
YouTube Broadcast Yourself
Incogna
LTU technologies
picsearch
YAHOO!

Face detection

Computer vision and Mobile Applications




3D
EosSystems
2d3 sensing
Microsoft Photosynth
CREAFORM
AUGMENT
2D
digitalPersona.
brick stream
Nikon
TAAZ
Google Goggles
A9
kooaba IMAGE RECOGNITION
1990
2000
2010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2D
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Current state of computer vision

3D Reconstruction

- 3D shape recovery
- 3D scene reconstruction
- Camera localization
- Pose estimation

2D Recognition

- Image matching
- Object detection
- Texture classification
- Activity recognition

Mobile computer vision

Embedded systems

A special purpose computer system enclosed or encapsulated within a physical system

Courtesy of Prof Tim Cheng

They are everywhere today!

- Consumer electronics
- Communication
- Entertainment
- Transportation
- Health
- Home appliances

Examples of embedded systems

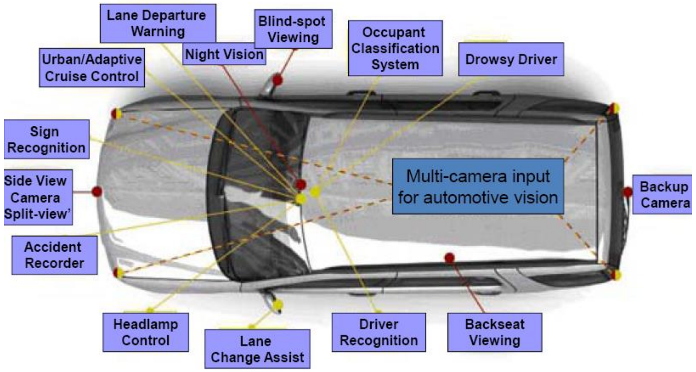
- Video-assisted robots
- Medical imaging devices

Courtesy of Prof Tim Cheng

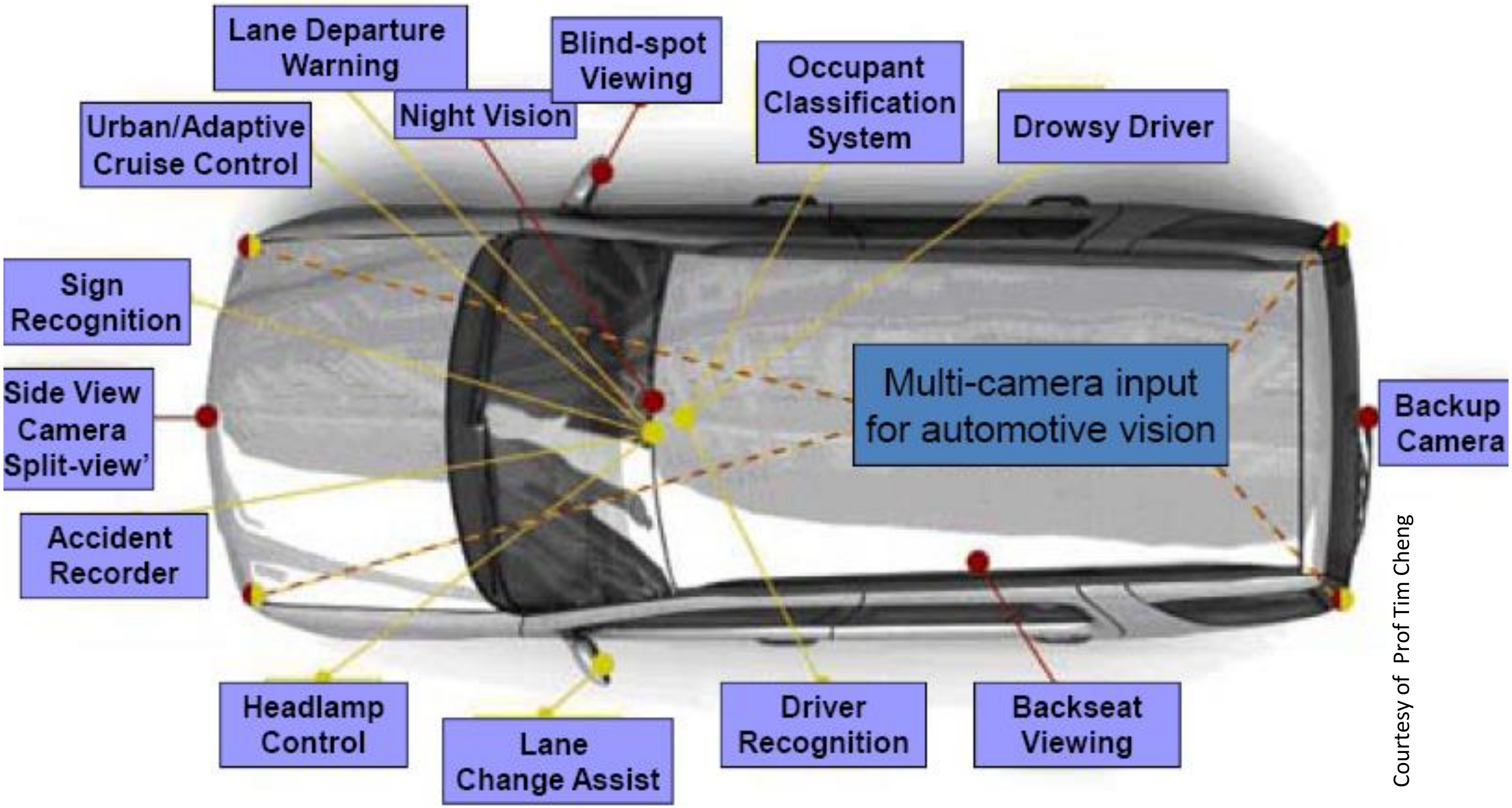
Examples of embedded systems

- Video-assisted robots
- Medical imaging devices
- Autonomous cars

Automotive Vision



Automotive Vision



Courtesy of Prof Tim Cheng

Examples of embedded systems

- Video-assisted robots
- Medical imaging devices
- Autonomous cars
- Smart phones
- Tablets
- Glasses

Smart phones & tablets:
common characteristics

- Low cost
- Small package
- Resource constraints
- Real-time constraints (for some systems/applications)

Hardware Components

- Powerful mobile processors
- Dedicated chips for display driver, touchscreen control, GPS, bluetooth, WiFi more…
- Storage/Memory
- Display/touchscreen
- Communications/Connectivity
- Graphics
- Camera
- Accelerometer
- Compass/gyroscope

Powerful Mobile Processors

- Microcontrollers/Microprocessors– run OS, applications
- GPU – architected for fast rendering operations
- DSP – architected for fast, parallel vector operations

- Nvidia Tegra-K1 based Android tablet

Operating systems

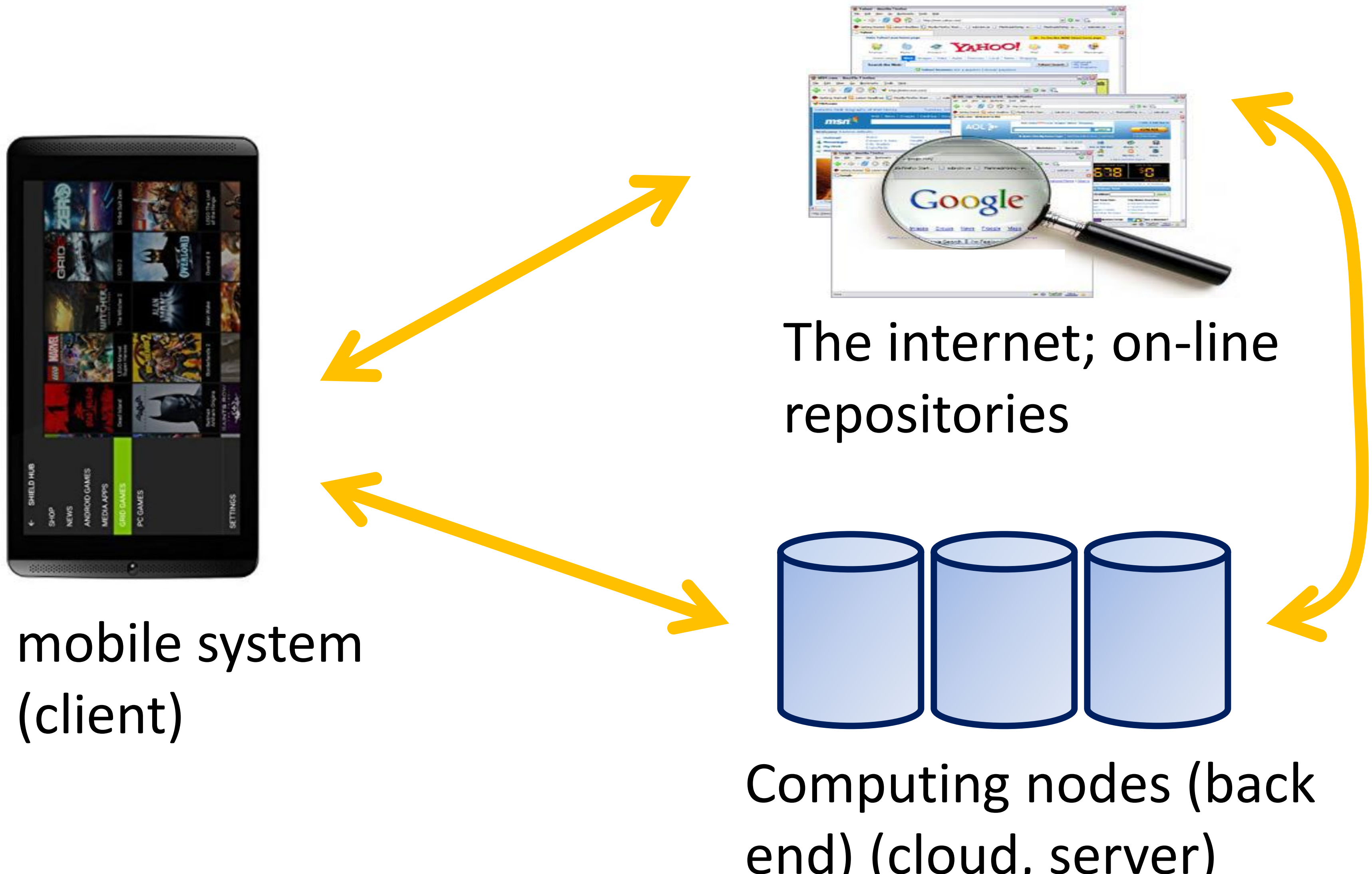
Android OS

- Released in 2008
- Software platform based on Linux 2.6
- Developed by Google and the Open Handset Alliance
- Emulators on Mac, Windows, and Linux
- Version 5 (lollipop)

Challenges

- The mobile system has limited: computational power - bandwidth - memory
  - What to compute on the client (features, tracks)
  - How much data must be transferred to the back end
  - What to compute on the back end
  - How much data must be transferred back to the client to visualize results
- Computer vision algorithms with
  - Guaranteed (high)accuracy
  - Efficient (use little computational power/memory)
  - Fast (possibly real time)
- Many of these CV problems are still open

Client and Server paradigm



In this class

- We will explore computer vision algorithms
  - Meet challenges above
  - Can be implemented on a mobile system

Class organization

Part 1:
- Review the Android architecture
- Introduce Android development platform

Part 2:
- Feature detection and descriptors
- Image matching
- Panorama and HDR images

Part 3:
- Object detection, landmark recognition and image classification
- Deep Learning and random forest

Part 4:
- Tracking, VSLAM, and virtual augmentation

Part 5:
- Special topics in mobile computer vision
- Project discussion and presentations

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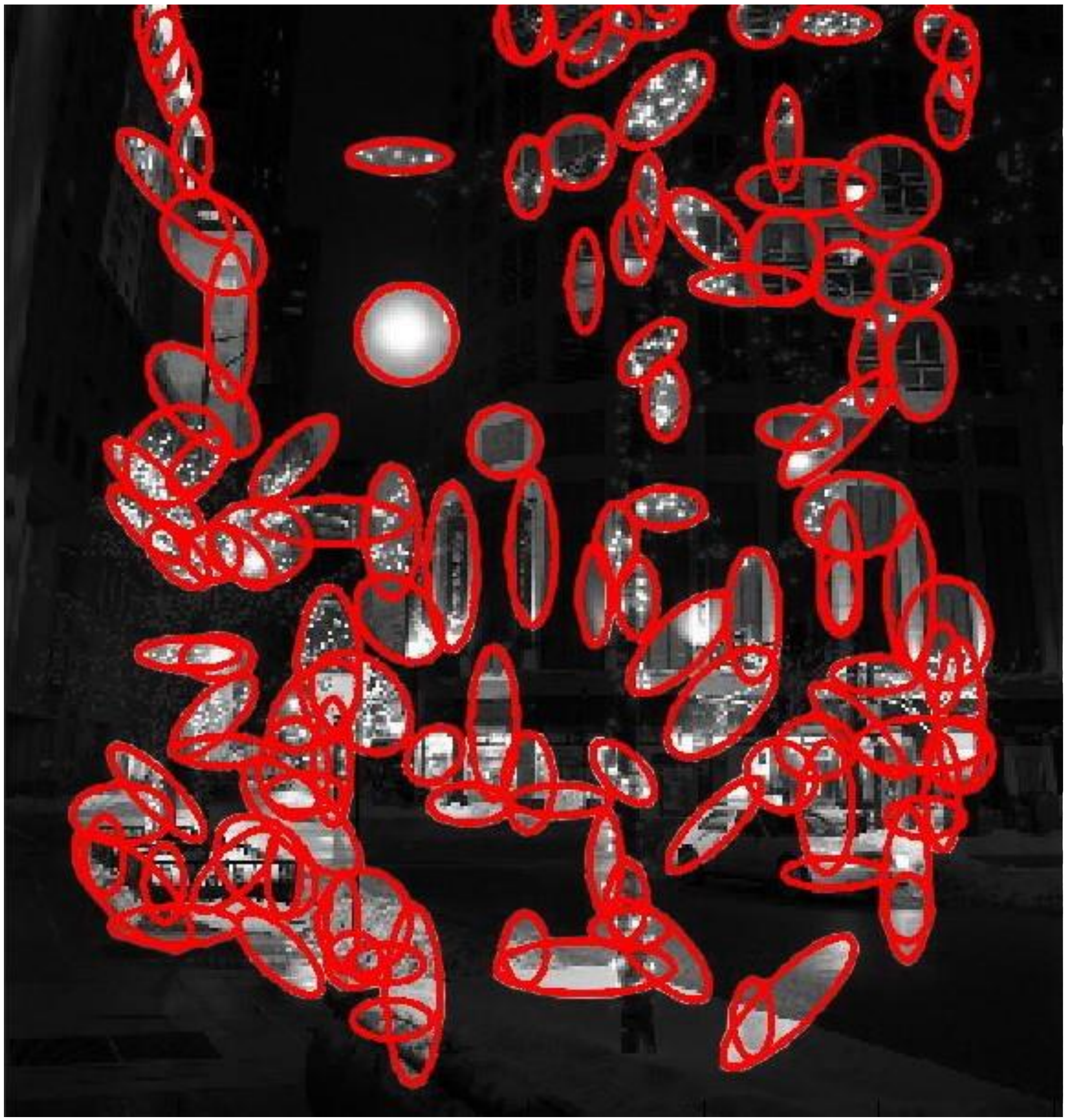
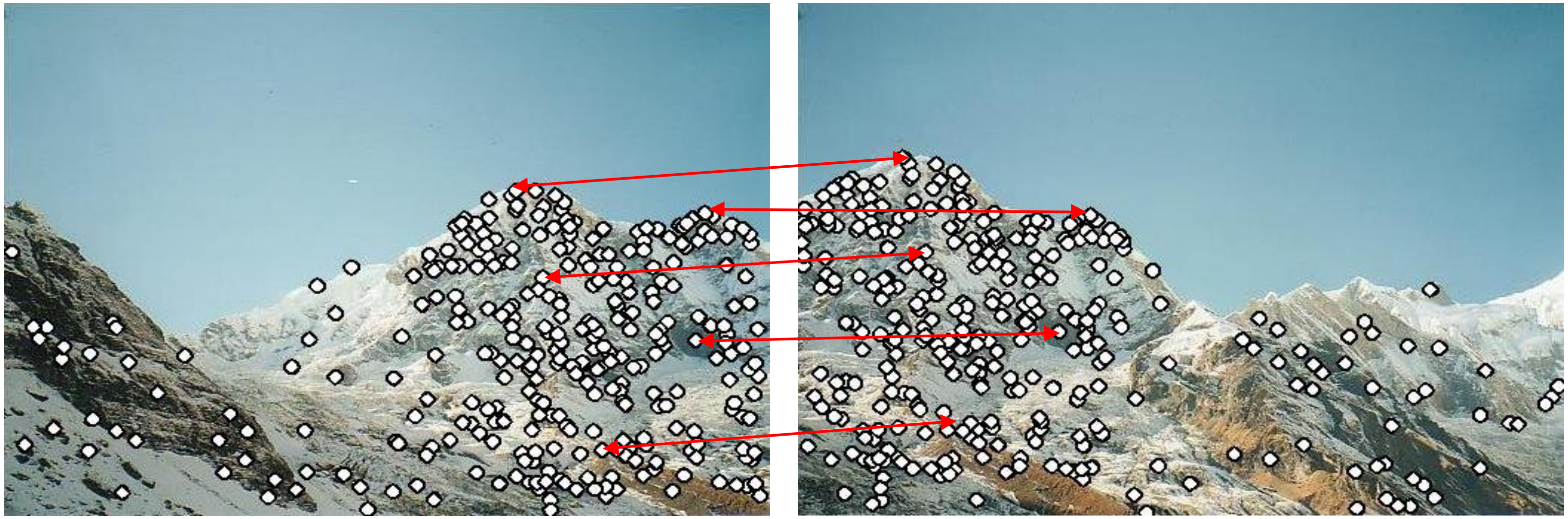
Features and descriptors



- Detectors:
  - DoG
  - Harris
- Descriptors:
  - SURF: Speeded Up Robust Features
  - Implementation on mobile platforms

[Bay et al 06]
[Chen et al 07]

Image matching



- M. Brown and D. Lowe, “recognizing panoramas”, 03
- Yingen Xiong and Kari Pulli, "Fast Panorama Stitching for High-Quality Panoramic Images on Mobile Phones", IEEE Transactions on consumer electronics, 2010

Automatic Panorama Stitching

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Sources: M. Brown

High Dynamic Range (HDR) images

Mertens, Kautz, van Reeth PG 2007

LDR images

Weight maps

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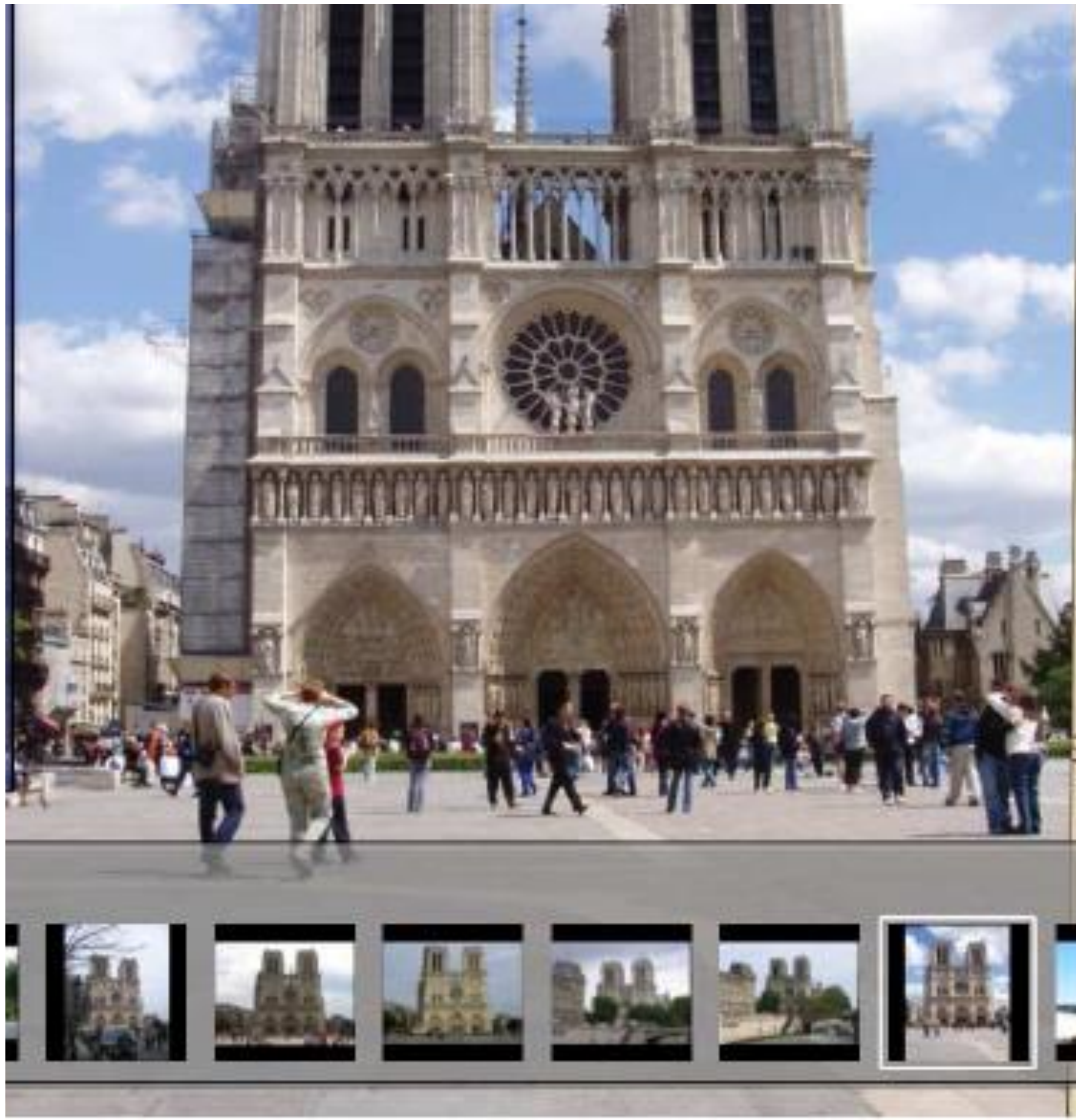
Visual search and landmarks recognition

Location/landmark recognition



Quack et al 08
Hays & Efros 08
Li et al 08

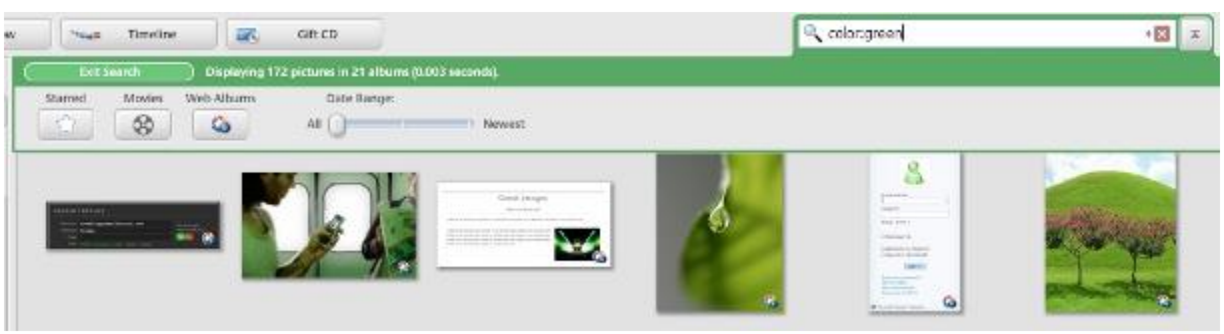
Courtesy of R. Szelisky and S. Seitz

Web repositories

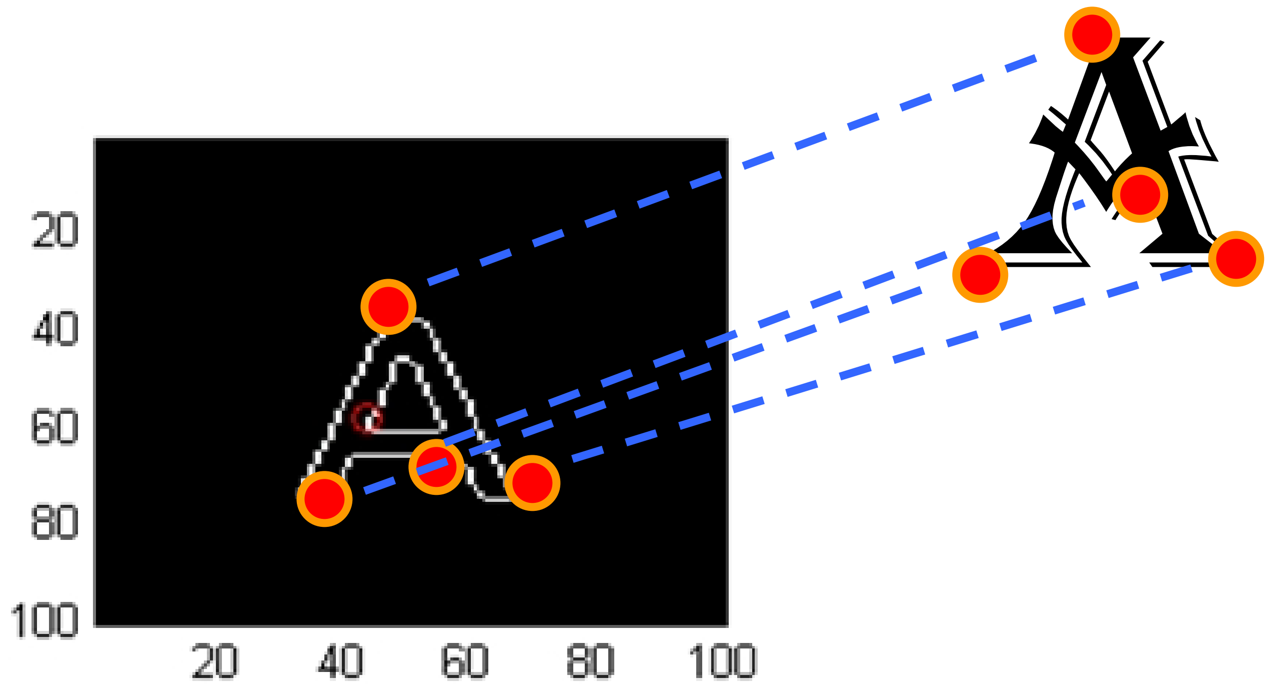
Yeh et al 04
Zheng et al 09

Facebook

(on the cloud; eg picasa)



Shape and object matching

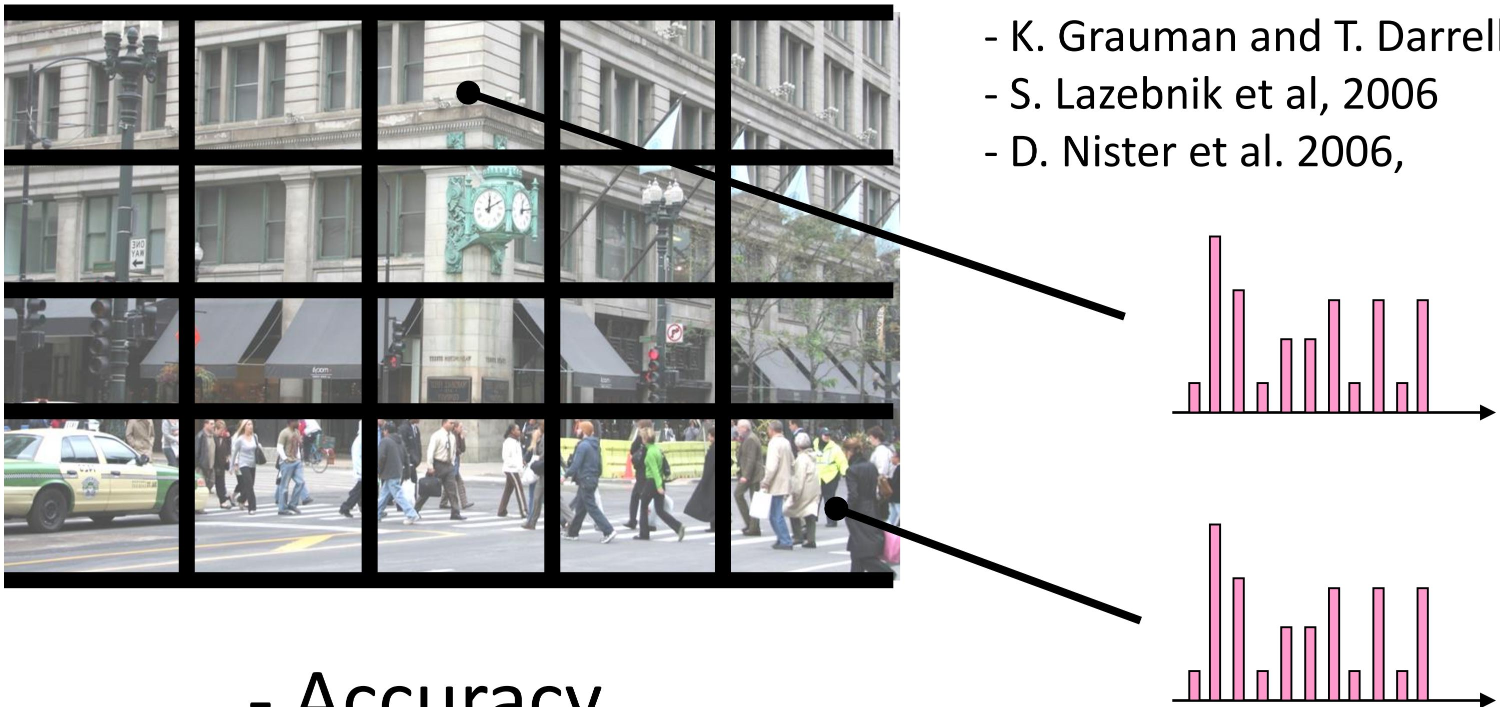


- Shape Classification Using the Inner-Distance [Ling and Jacobs 07]

Bag of words representations

- Pyramid matching
- Recognition with a Vocabulary Tree

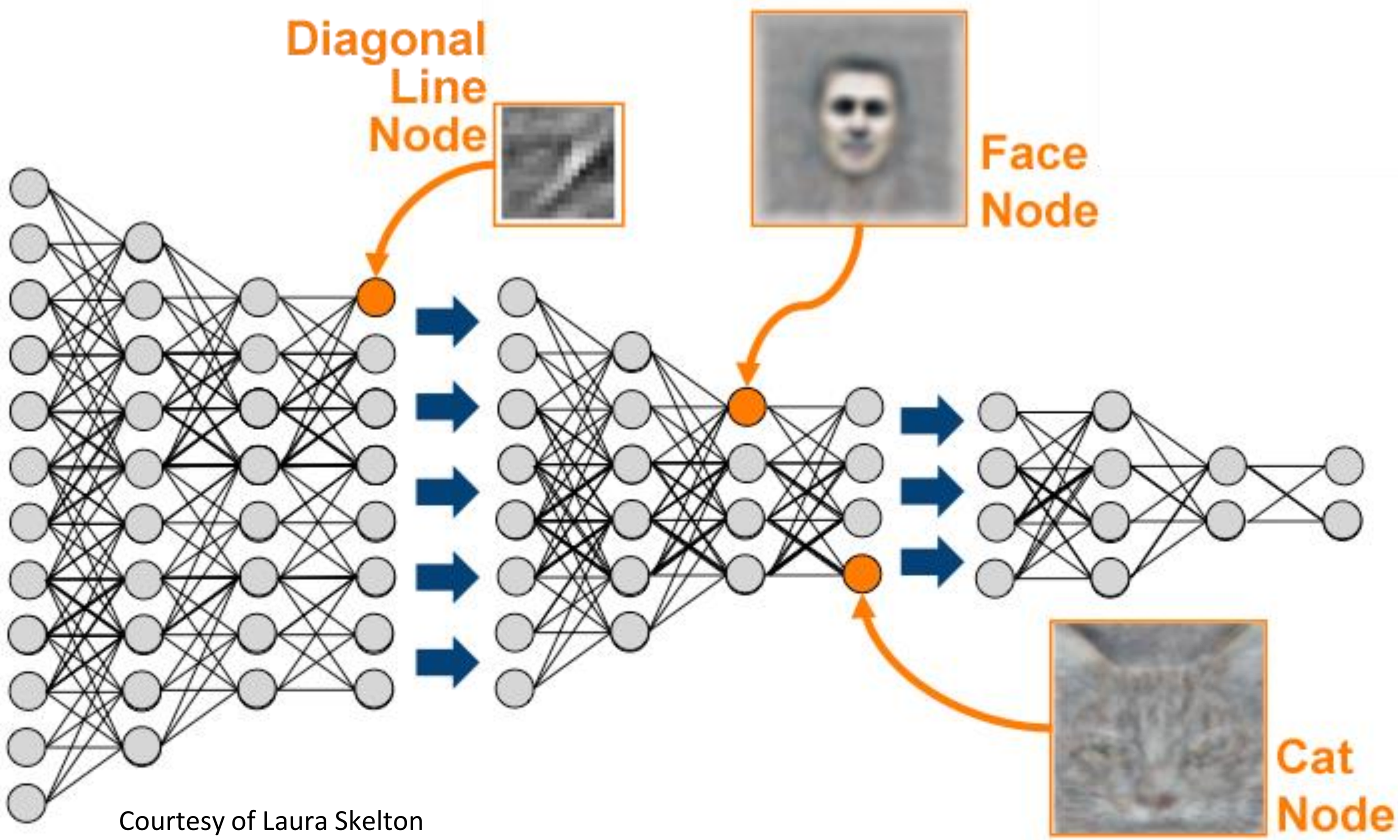
- K. Grauman and T. Darrell 2005
- S. Lazebnik et al, 2006
- D. Nister et al. 2006,



- Accuracy
- Efficiency
- Scalability to large database

Deep learning and random forests

Hinton, Bengio, Lecun, Ng, Breiman, Amit, Geman, etc….



Courtesy of Laura Skelton

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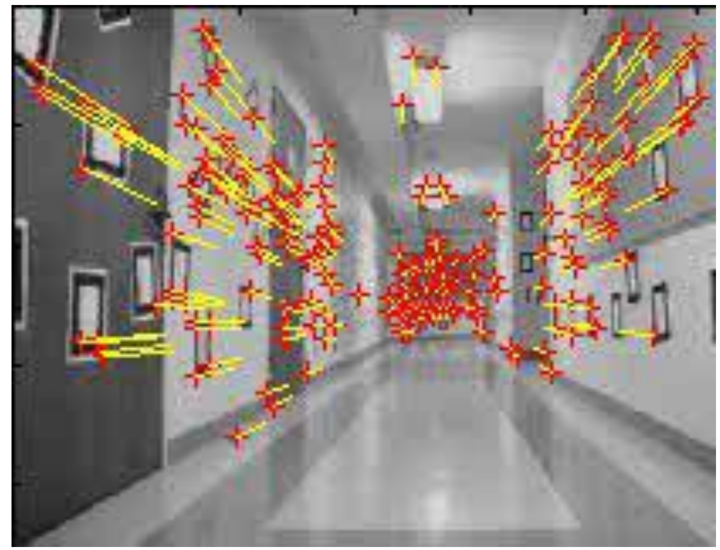
Features from videos

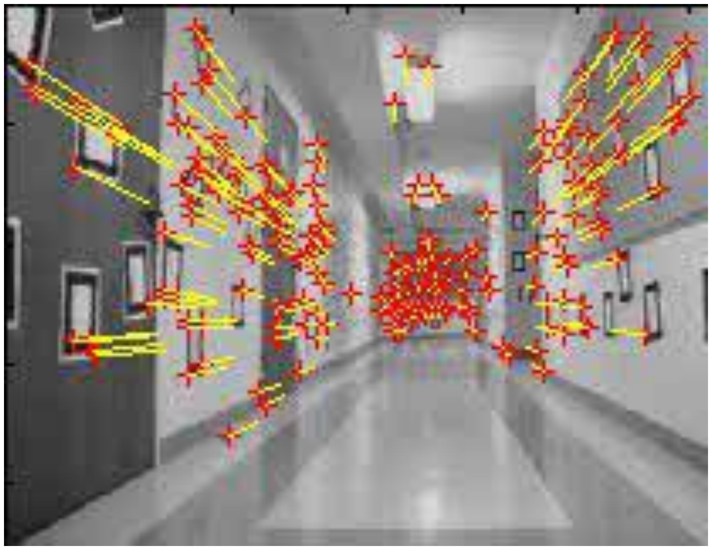


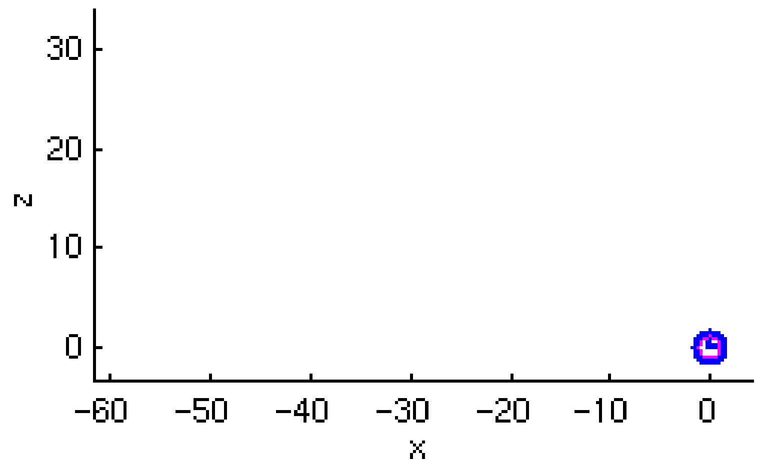
Courtesy of Jean-Yves Bouguet

- Features from videos
- Descriptors from videos
- On-line feature tracking

•Ferrari et al 01
•Skrypnyk & Lowe 04
•Takacs et al 07
•Ta et al 09
•Klein & Murray 09

3D reconstruction and camera localization





Courtesy of Jean-Yves Bouguet

- SFM
- VSLAM

- Ferrari et al 01
- Skrypnyk & Lowe 04
- Takacs et al 07
- Ta et al 09
- Klein & Murray 09

Tracking and Virtual Reality insertions

"Server-side object recognition and client-side object tracking for mobile augmented reality", Stephan Gammeter , Alexander Gassmann, Lukas Bossard, Till Quack, and Luc Van Gool

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Agenda

- Administrative
  - Requirements
  - Grading policy

- Mobile Computer Vision

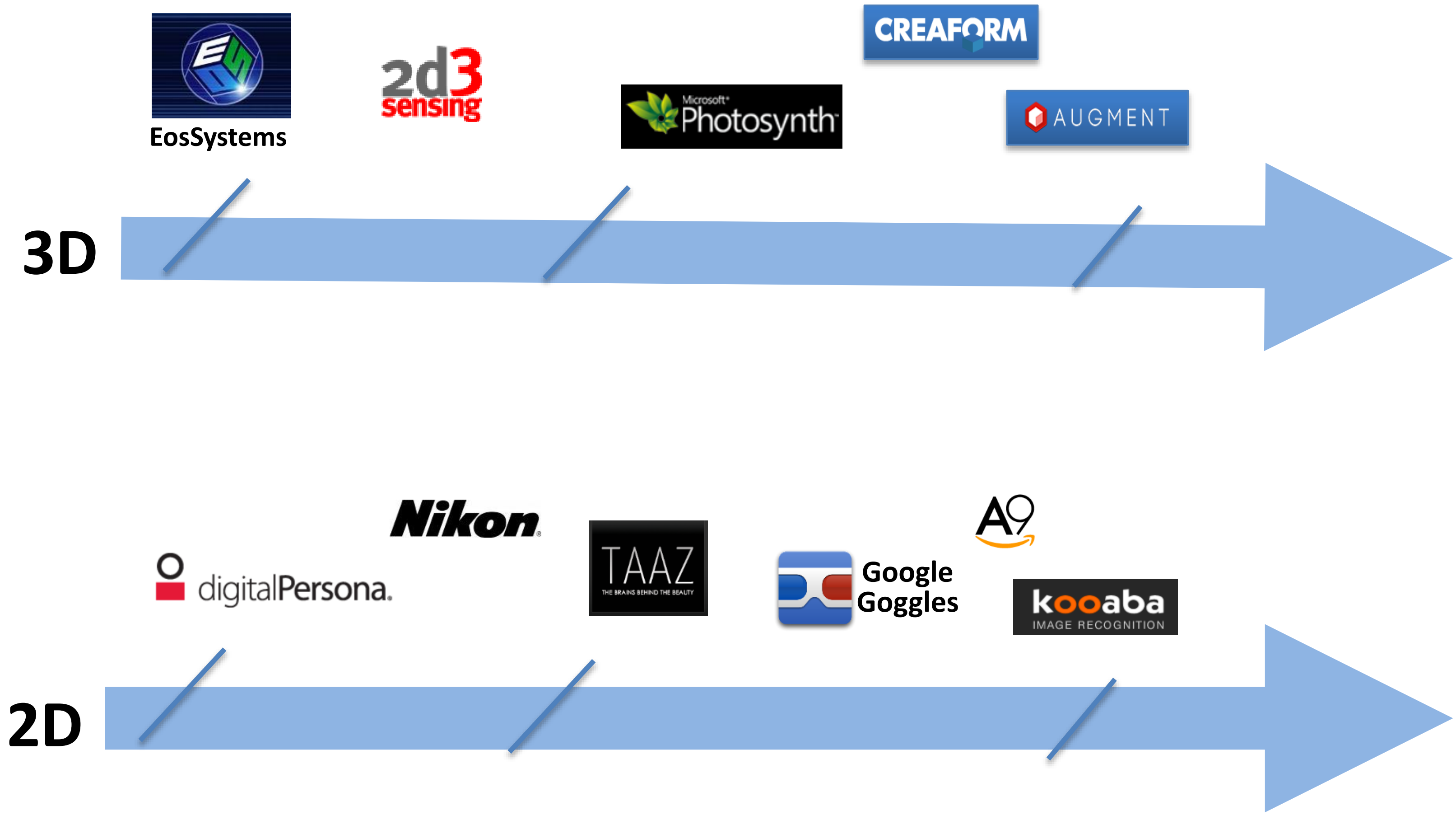
- Syllabus

Next Lecture

- Overview of the Android platform & guiding examples by Dr Alejandro Troccoli (Nvidia)

- Please come and pick up your tablet!
  – Today until 6pm, 126 Gates
  – Tomorrow from 2-3pm, 126 Gates

Computer vision and Applications



Computer vision and Applications

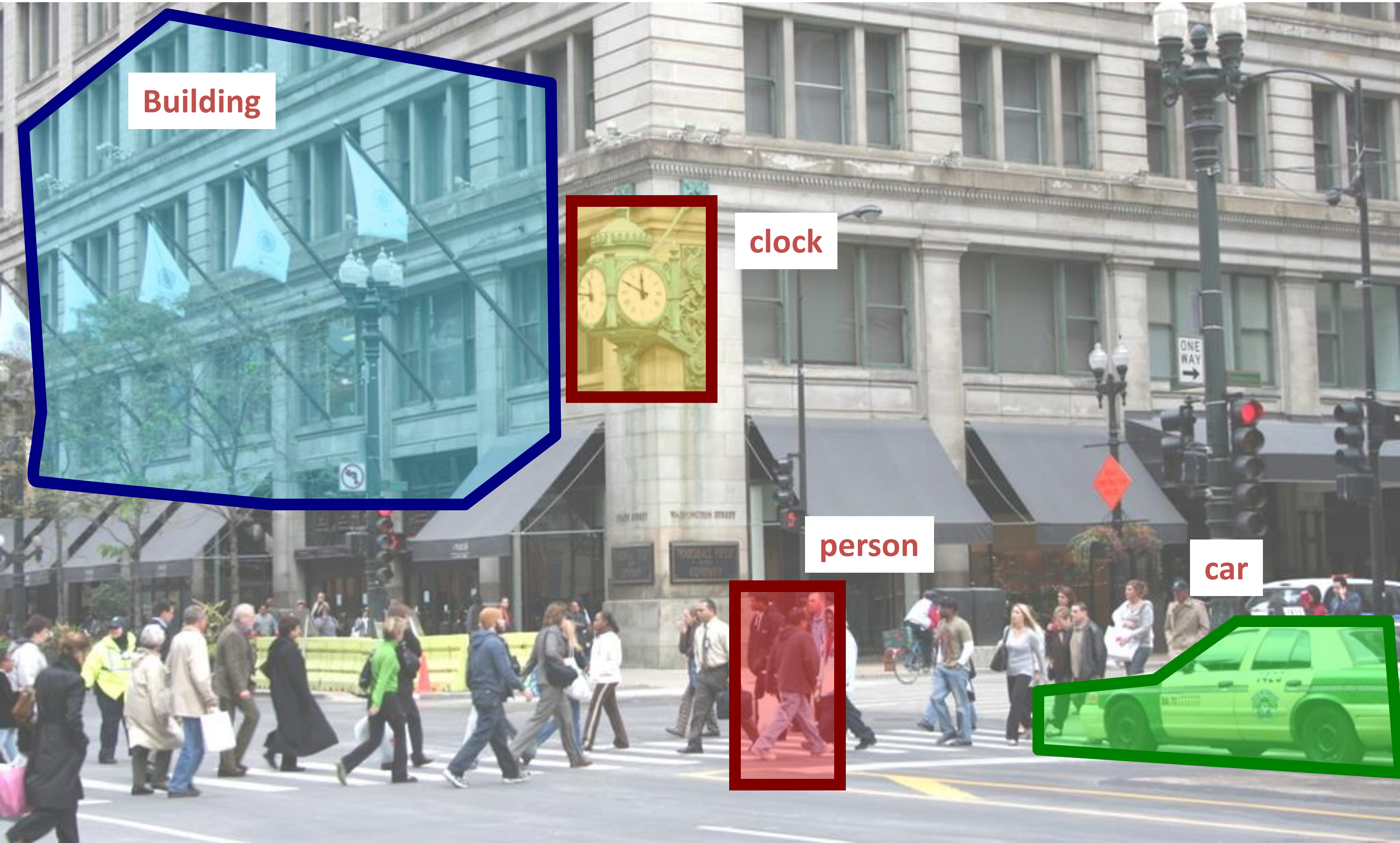
How to make this to work?

Solve a number of challenging computer vision problems and implement them on a mobile system

- Image classification
- Object detection
- Tracking
- Matching
- 3D reconstruction

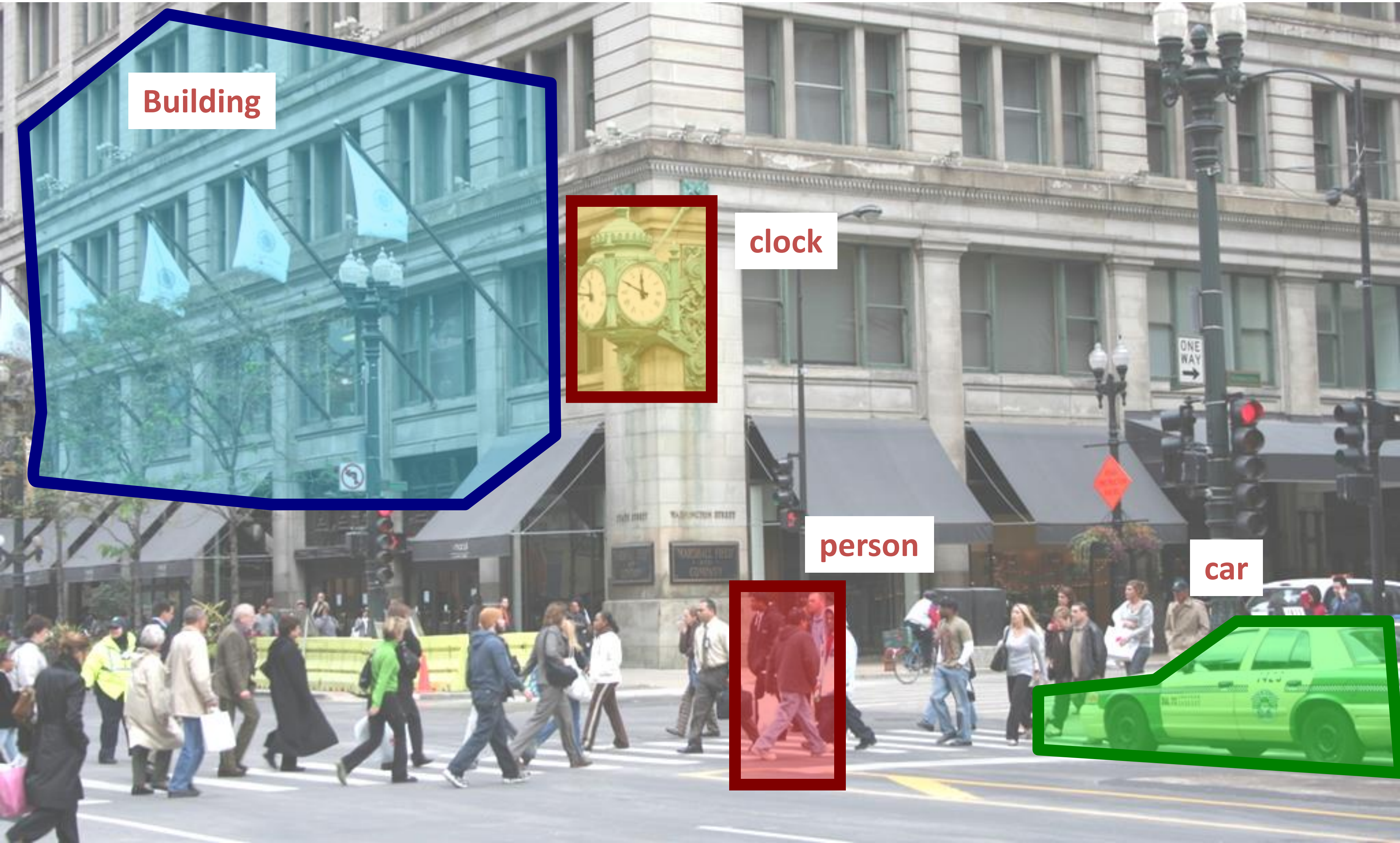
Detection & object recognition

Does this image contain a car? [where?]



Detection:

Which object does this image contain? [where?]



Detection & object recognition

Does this image contain a clock? [where?]


~10,000 to 30,000

Challenges: illumination

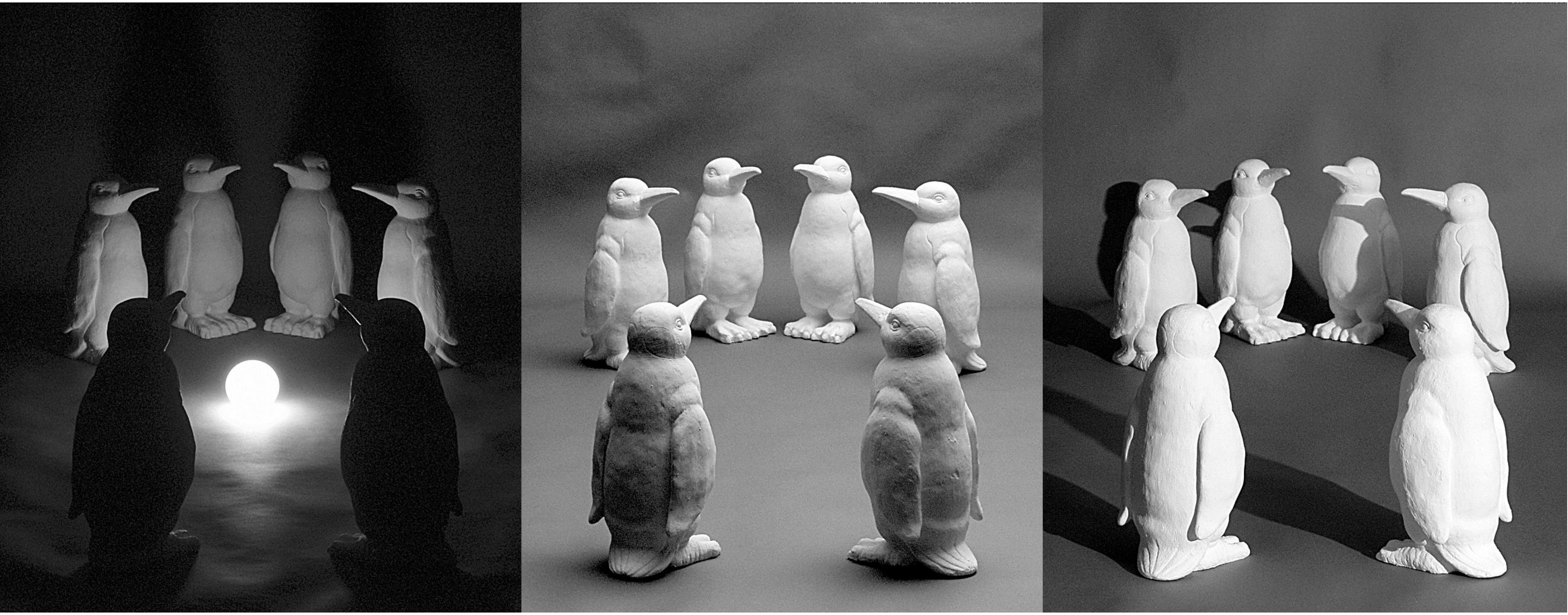


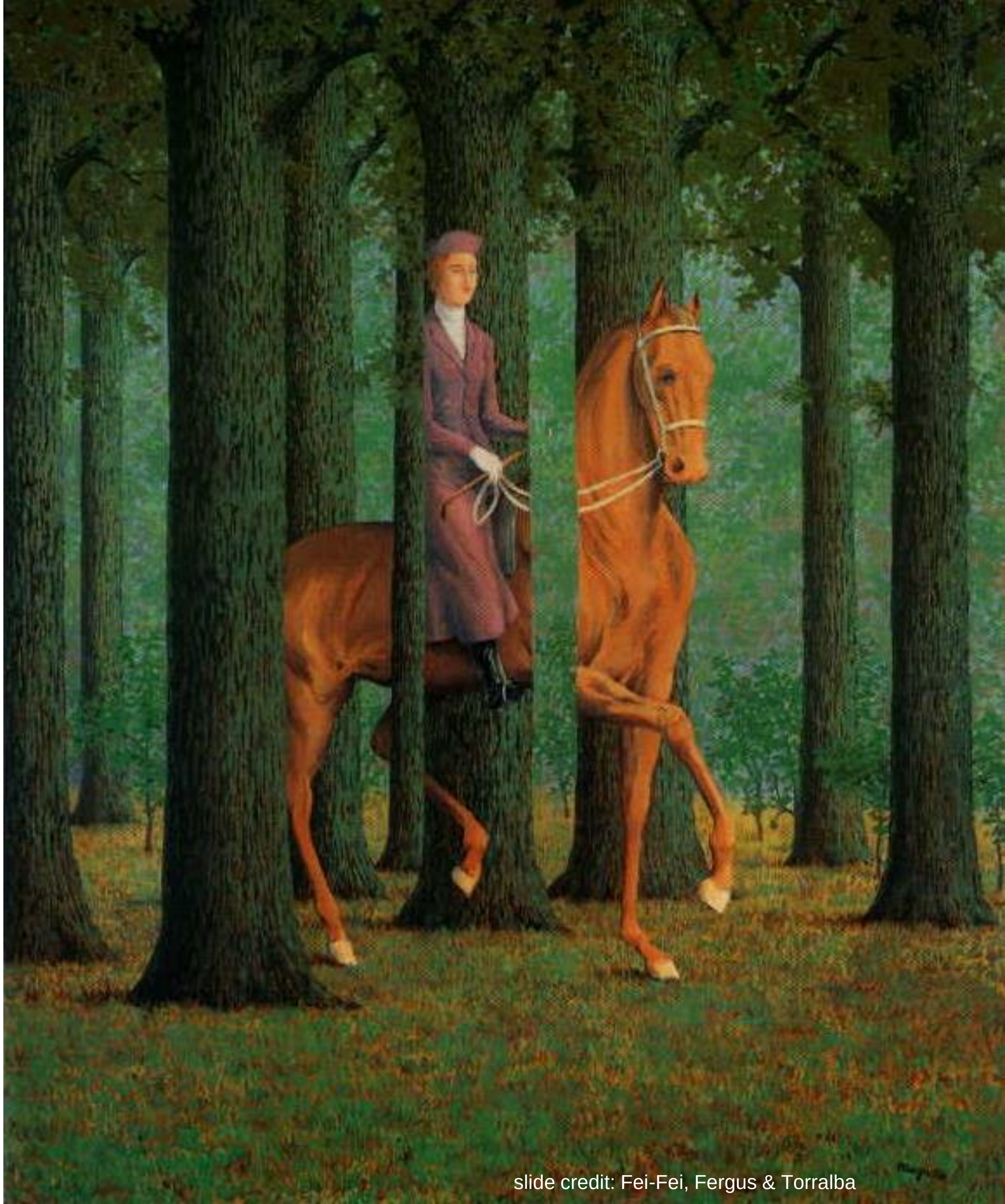
image credit: J. Koenderink

Challenges: scale

slide credit: Fei-Fei, Fergus & Torralba

Challenges: deformation

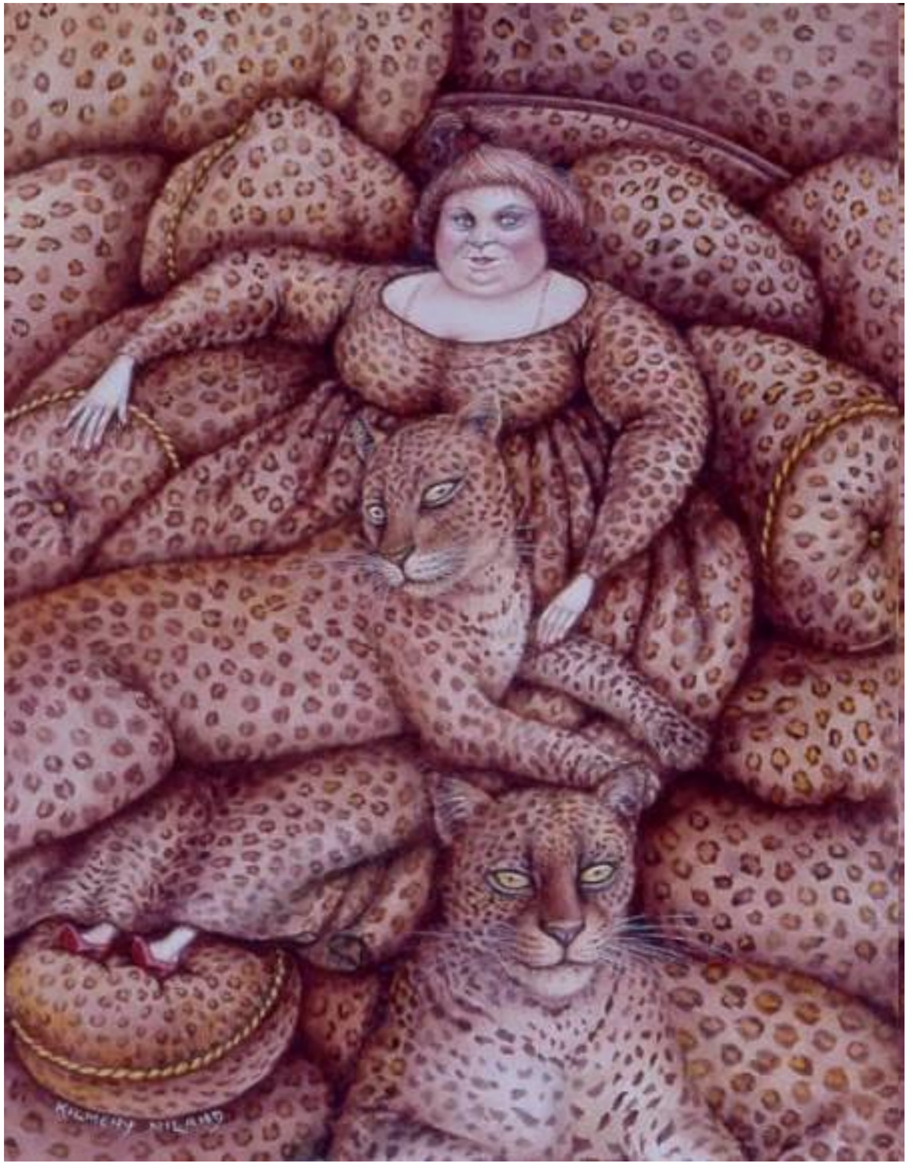
Challenges: occlusion



Magritte, 1957

slide credit: Fei-Fei, Fergus & Torralba

Challenges: background clutter



Kilmeny Niland. 1995

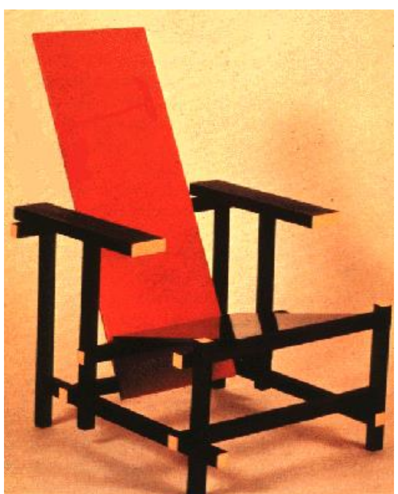
Challenges: viewpoint variation

Michelangelo 1475-1564

slide credit: Fei-Fei, Fergus & Torralba

Challenges: intra-class variation



Recognition

– Search strategy: Sliding Windows — Viola, Jones 2001,
  - Simple
  - Computational complexity (x,y, S, θ, N of classes)

    - BSW by Lampert et al 08

    - Also, Alexe, et al 10

Recognition

– Recognition task

– Search strategy: Sliding Windows   Viola, Jones 2001,

- Simple
- Computational complexity (x,y, S, θ, N of classes)

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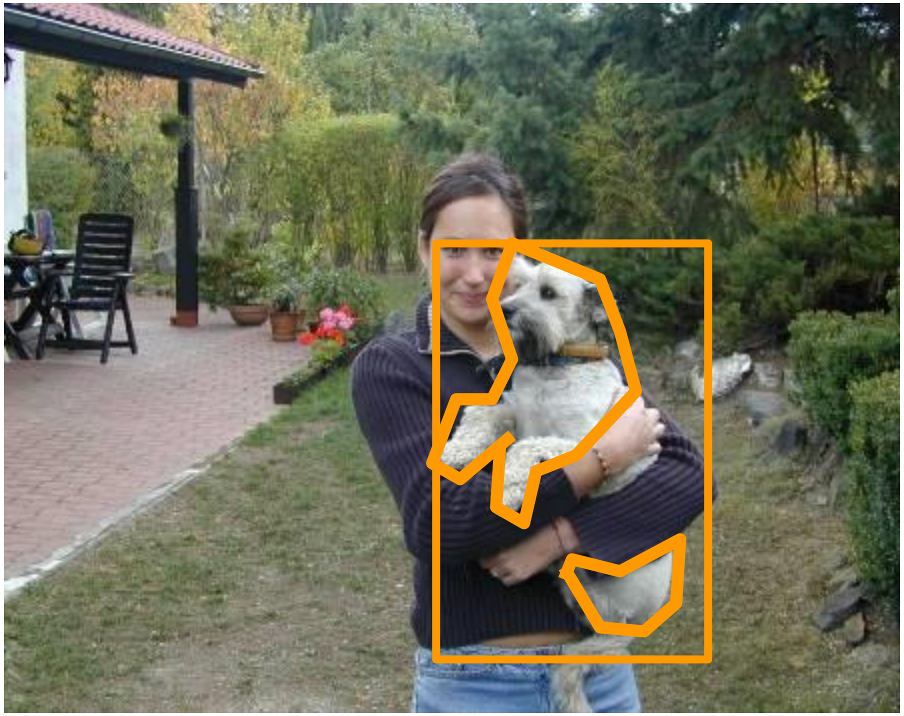
- Localization
  - Objects are not boxes



Recognition

– Recognition task

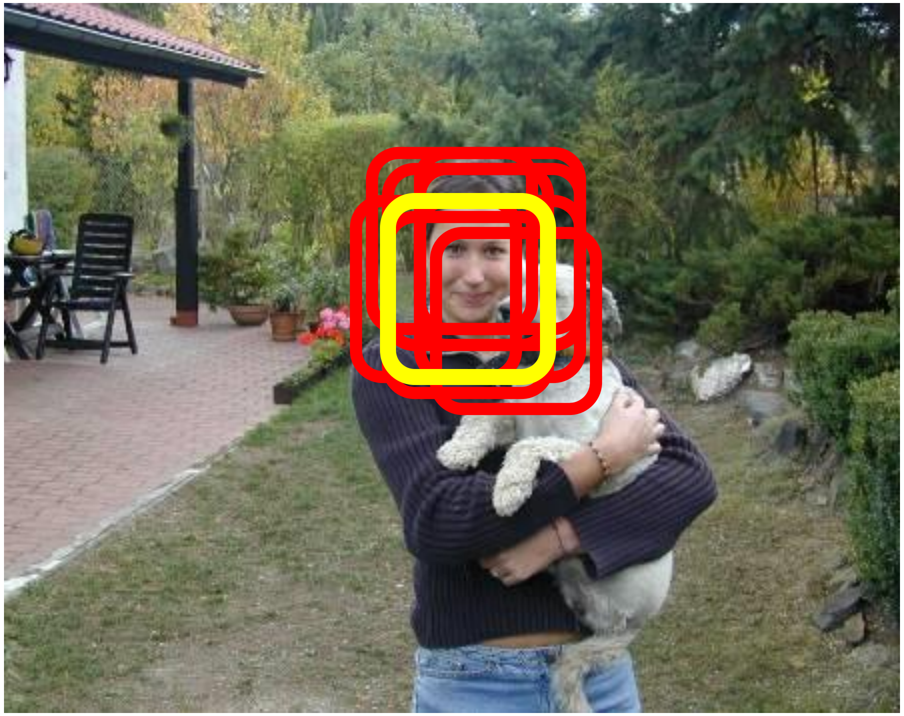
– Search strategy: Sliding Windows   Viola, Jones 2001,

- Simple
- Computational complexity (x,y, S, θ, N of classes)

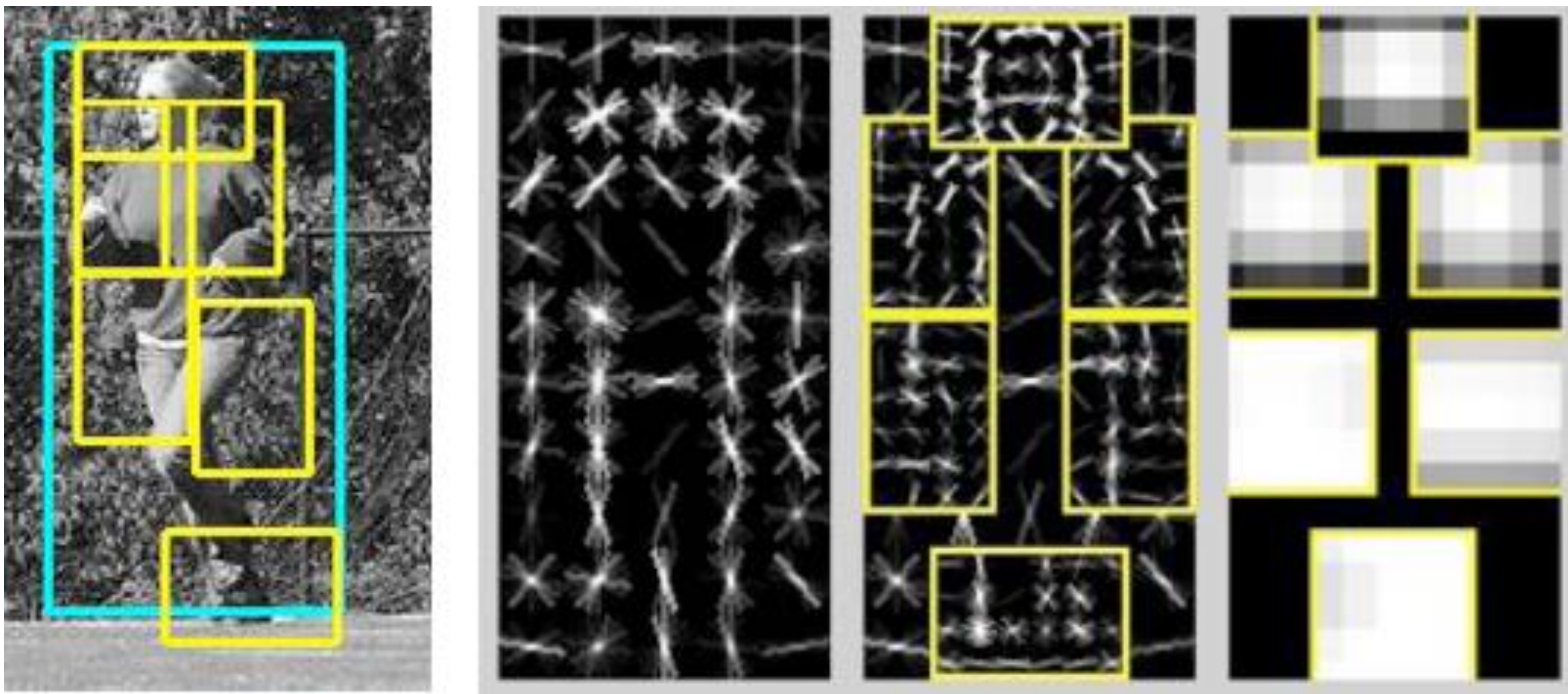
  - BSW by Lampert et al 08
  - Also, Alexe, et al 10

- Localization
  - Objects are not boxes
  - Prone to false positive

    Non max suppression:
    Canny '86
    ….
    Desai et al , 2009



Star models by Latent SVM

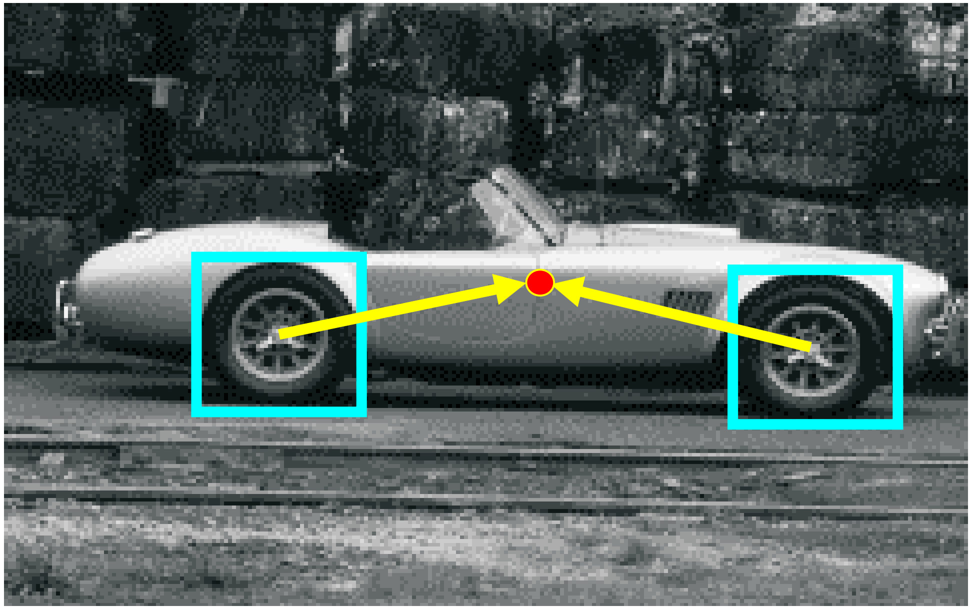


Felzenszwalb, McAllester, Ramanan, 08

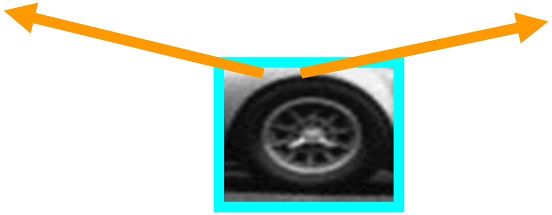
• Source code:

Implicit shape models

- Visual codebook is used to index votes for object position



training image



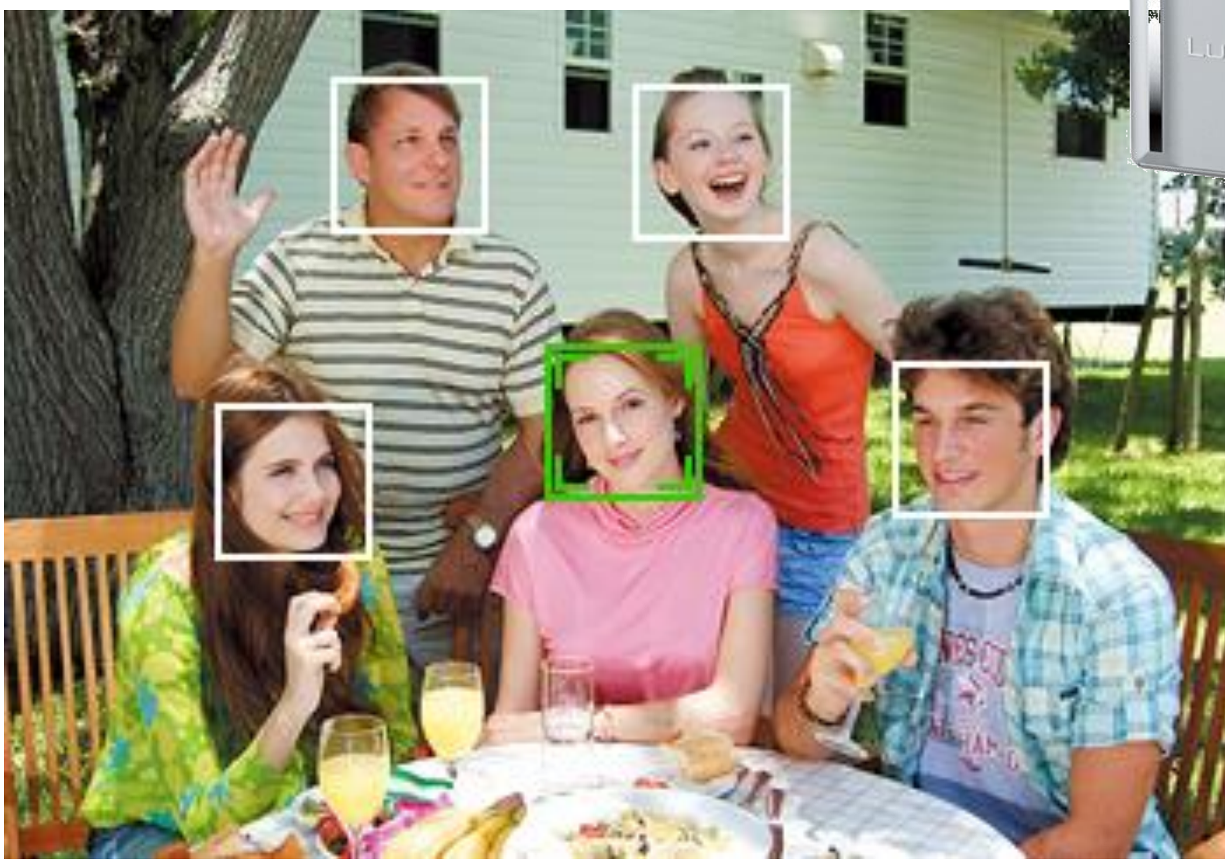
visual codeword with displacement vectors

B. Leibe, A. Leonardis, and B. Schiele, [Combined Object Categorization and Segmentation with an Implicit Shape Model](), ECCV Workshop on Statistical Learning in Computer Vision 2004

Credit slide: S. Lazebnik

Face Recognition

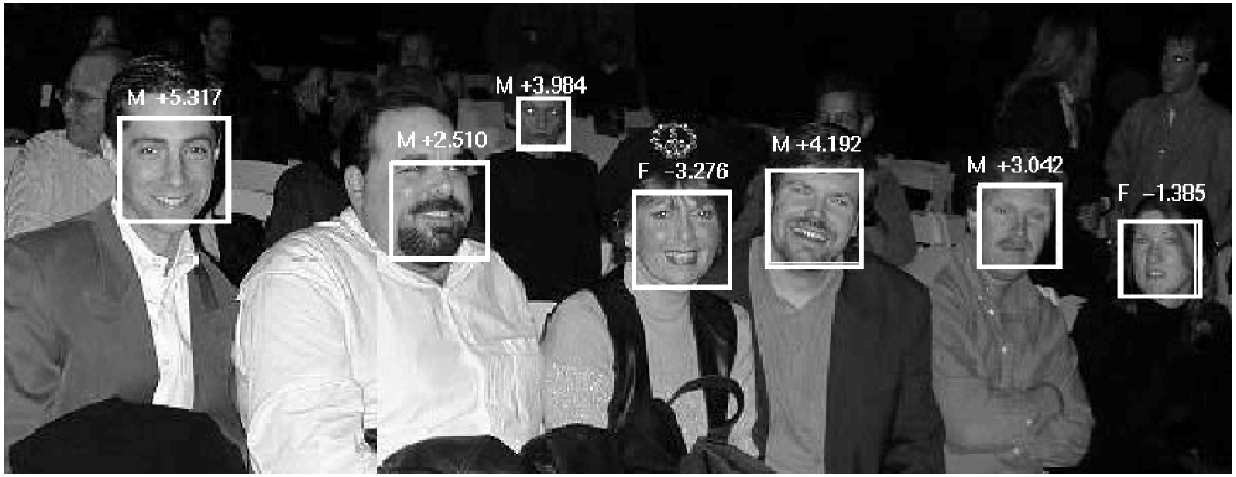
- Digital photography
- Automatic face tagging



The Viola/Jones Face Detector

P. Viola and M. Jones. *Rapid object detection using a boosted cascade of simple features*. CVPR 2001.

- A “paradigmatic” method for real-time object detection
- Training is slow, but detection is very fast
- Extensions to mobile applications



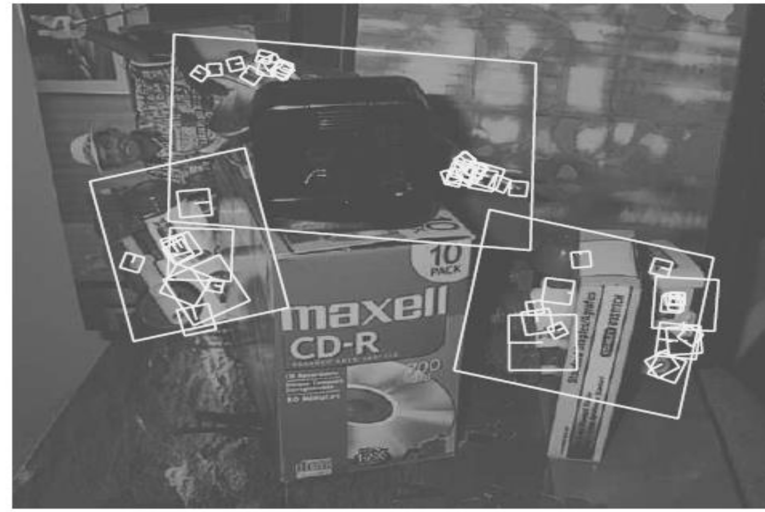
Single 3D Object Recognition

- No intra-class variation
- High view point changes

Single 3D Object Recognition

Lowe. ’99, ’04

Hsiao et al CVPR 10

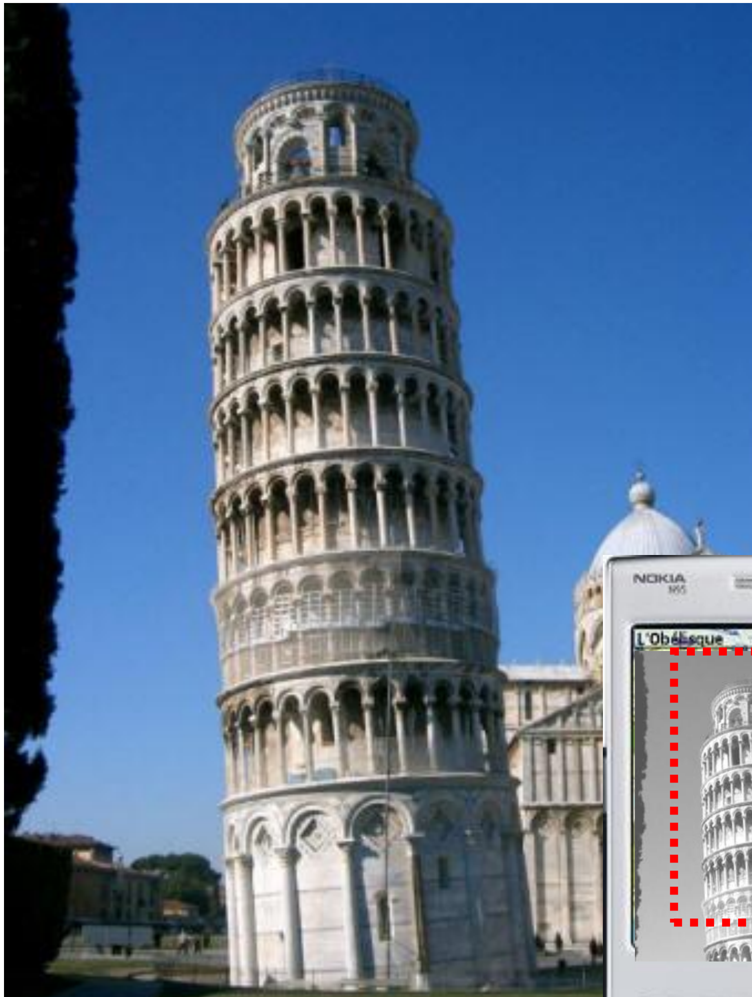


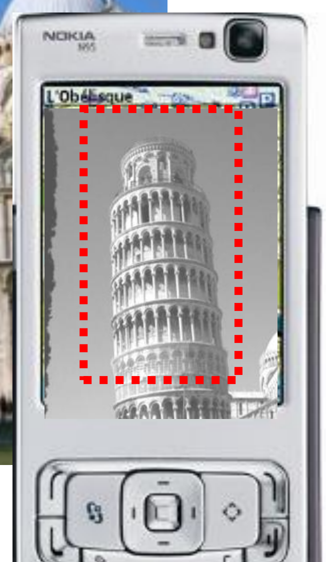
Courtesy of D. Lowe

- Handle severe occlusions
- Fast!

Single 3D Object Recognition

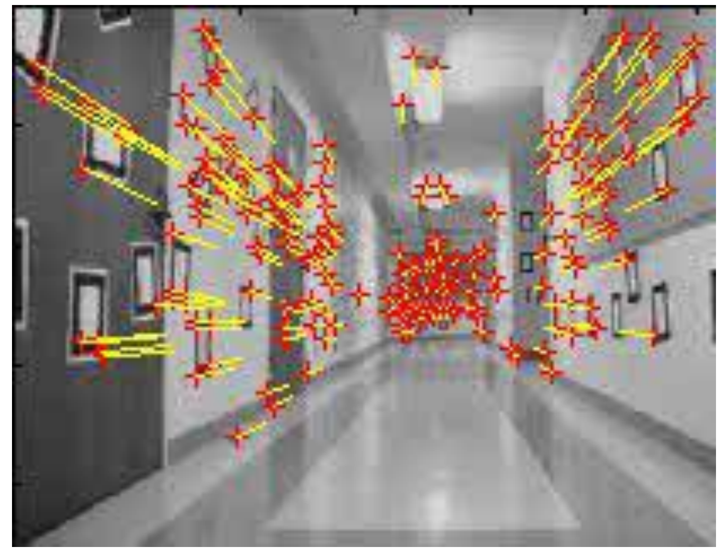
- Recognizing landmarks

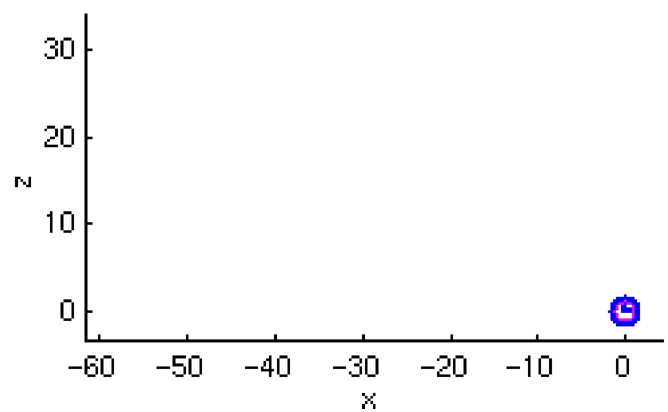




+ GPS

Tracking and 3D modeling





G. Klein and D. Murray. Improving the agility of keyframebased SLAM. In ECCV08, 2008.

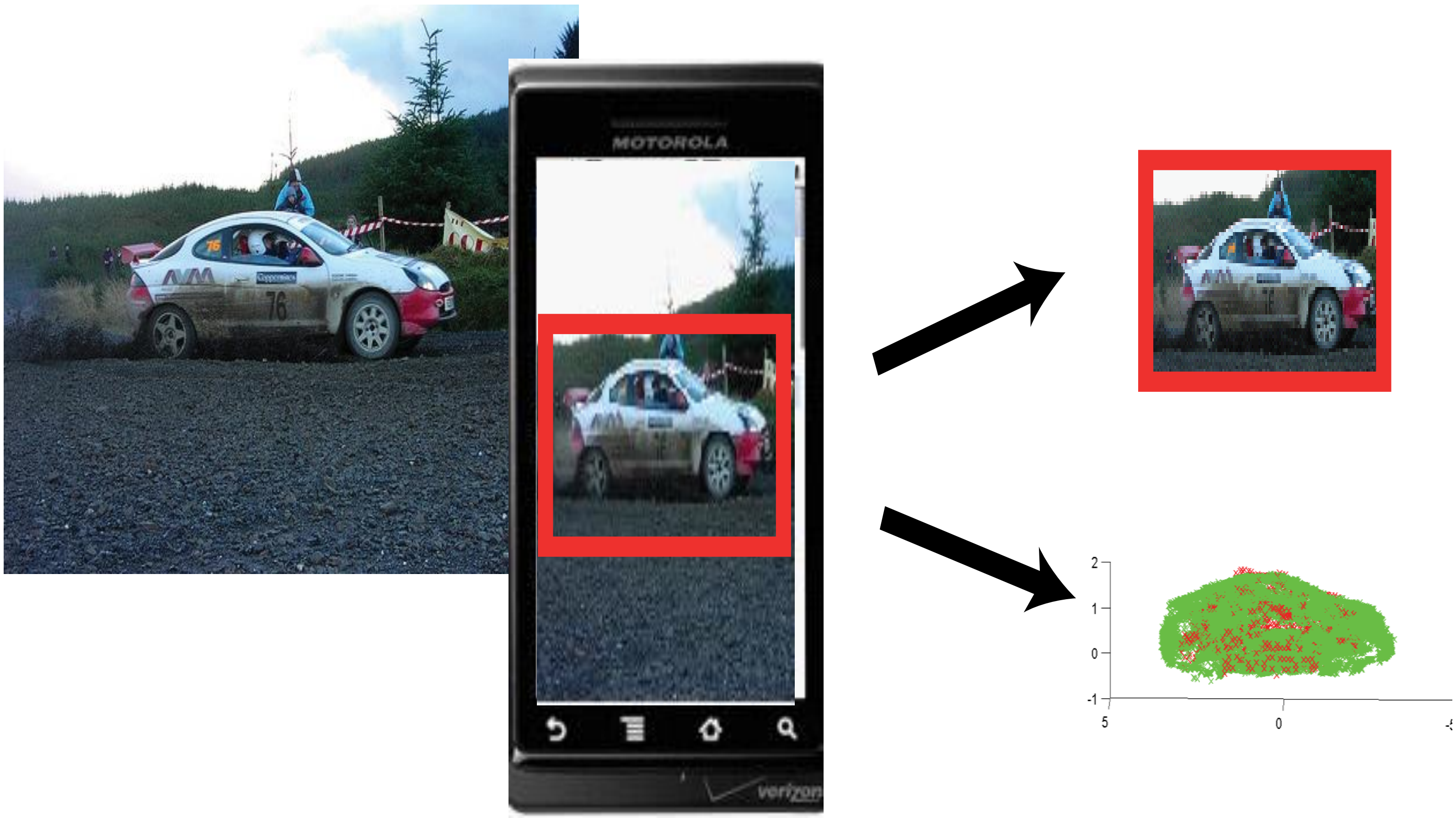
G. Klein and D. Murray. Parallel tracking and mapping on a camera phone. In ISMAR'09, 2009

Courtesy of Jean-Yves Bouguet – Vision Lab, California Institute of Technology

Tracking and Virtual Reality insertions

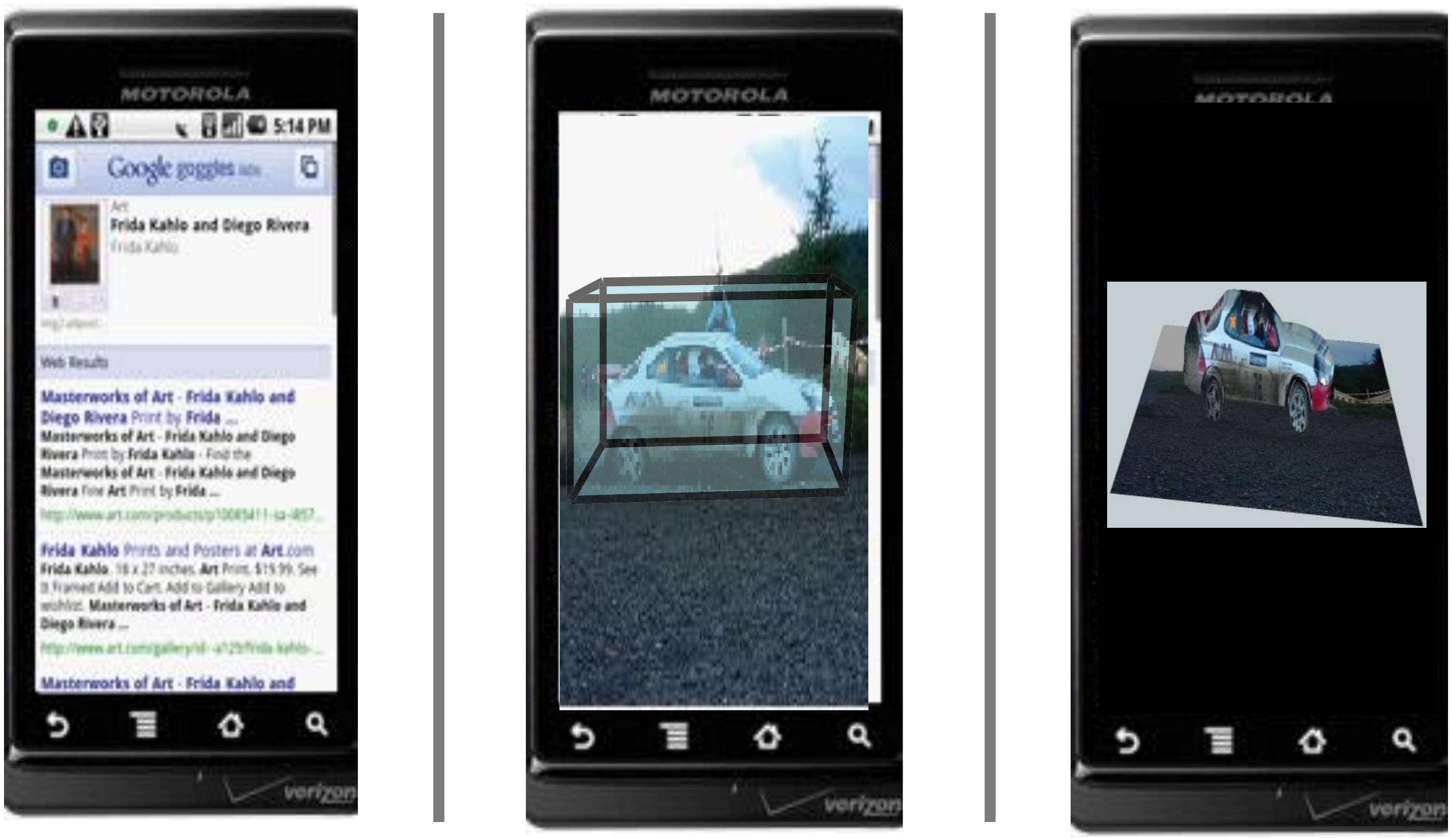
"Server-side object recognition and client-side object tracking for mobile augmented reality", Stephan Gammeter , Alexander Gassmann, Lukas Bossard, Till Quack, and Luc Van Gool

Detection and 3d Modeling



Min Sun, Gary Bradski, Bing-xin Xu, Silvio Savarese, Depth-Encoded Hough Voting for Joint Object Detection and Shape Recovery, ECCV 2009

Detection and 3d Modeling



Min Sun, Gary Bradski, Bing-xin Xu, Silvio Savarese, Depth-Encoded Hough Voting for Joint Object Detection and Shape Recovery, ECCV 2009

Automatic Panorama Stitching

Sources: M. Brown

Automatic Panorama Stitching

•M. Brown and D. Lowe, “recognizing panoramas”, 03
•Yingen Xiong and Kari Pulli, "Fast Panorama Stitching for High-Quality Panoramic Images on Mobile Phones", IEEE Transactions on consumer electronics, 2010

Sources: M. Brown

Agenda

- Administrative
  - Requirements
  - Grading policy

- Advanced Topics in Mobile Computer Vision

- Syllabus & Projects