Imaging Capabilities of Today's Smartphones

Attila Tanács

Department of Image Processing and Computer Graphics
University of Szeged

Mobile Devices Everywhere…

Mobile Devices

Penetration
- Billions of potentional users
- More SIM cards than inhabitants

Usage
- *Communication*
  - Basic: voice, SMS
  - Internet-based: Facebook, messengers, email, ...
- *Source of information*
  - Weather, stock indices, exchange rate, news, navigation, ...
- *Entertainment*
  - Games, e-books, music, multimedia

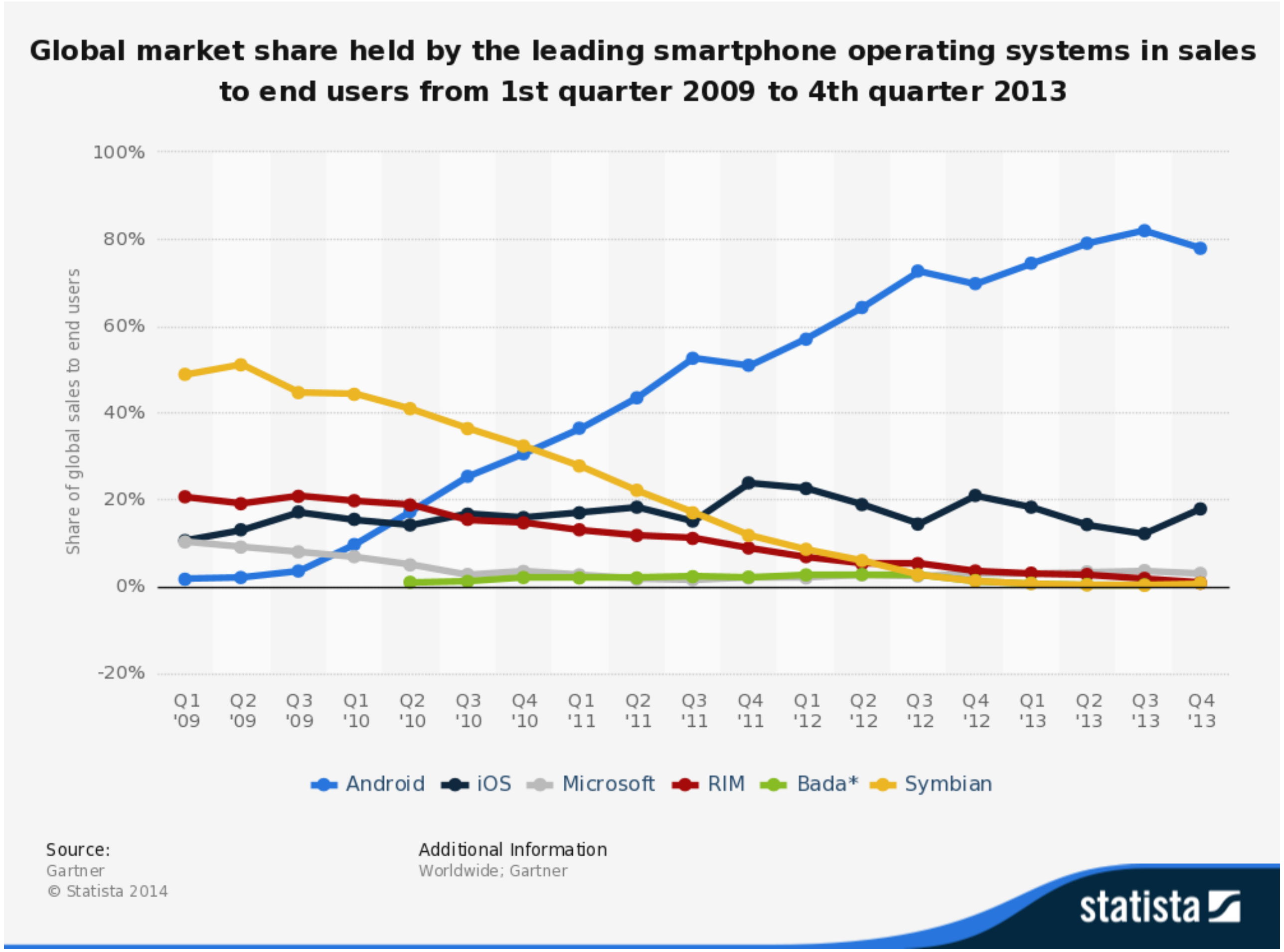
Feature phone
- Basic functions
  - Voice calls, SMS
- Closed system
- Limited developer possibilities

Smartphone
- Internet access
- Multitude of communication channels
- Expandable „knowledge"
- Open environment for developers
- App stores

History in a Nutshell

- **First mobile phone call** (1973)
  - Motorola (Martin Cooper → Joel S. Engel)
- **Manager calculators** (1980s, 1990s)
  - EPOC
  - Personal digital assistant, no phone!
- **Apple Newton platform** (1987-1998)
  - Handwriting recognition, digital assistant, no phone!
- **PDA era** (1996-2008)
  - Palm, Windows CE, Windows Mobile
  - Still no phone, multimedia push
- **Smartphones**
  - Convergence of mobile phones and PDAs
  - Nokia communicators
  - RIM Blackberry, Symbian
  - Apple iPhone, Android, Windows Phone, …
    - Radical market change from 2007!
- **Tablets**
  - Decline of PCs

Smartphone Platforms



Smartphone Platforms

- Stormy and fast progression in the last decade
  - Dominant platforms disappear abruptly
    - E.g., Palm, Windows Mobile, Symbian
  - **Fast accommodation to user's need is essential!**
  - **User's need should be figured out beforehand**
  - *It's Not a Battle of Devices, It's a War of Ecosystems* (S. Elop, Nokia)
    - Main business is content service
      - Software, e-book, music, movies, …
    - Usually no transitions between ecosystems

Hardware Progression

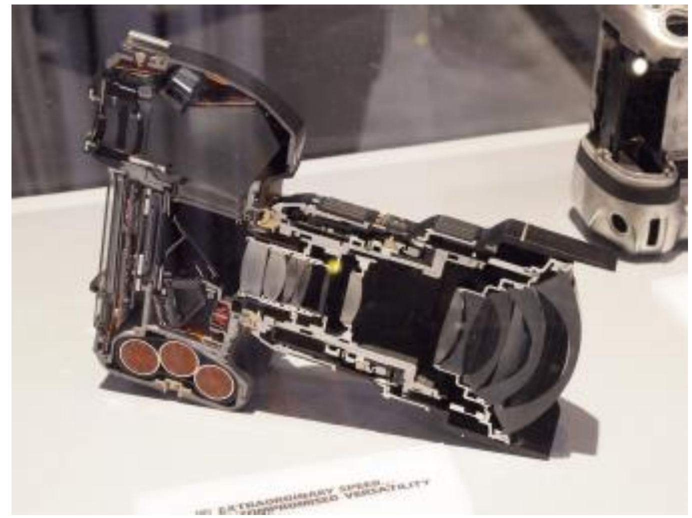
- CPU
  - Mainly ARM architecture (32 and 64-bits)
  - 16 MHz → 2.3 GHz (quad and octa core)
  - **Dedicated GPU**
- Memory
  - 1 MB → 1–3 GB
- Display
  - Resistive: stylus – old technology!
  - Capacitive: multi finger taps
  - Resolution: 160x160 black-white → 4K, 2.55''–7''
  - Autostereoscopic 3D displays
- New sensors
  - **Camera, GPS, accelerometer, magnetic compass, gyroscope,** microphone, magnetic field, light sensor, barometer,, ...

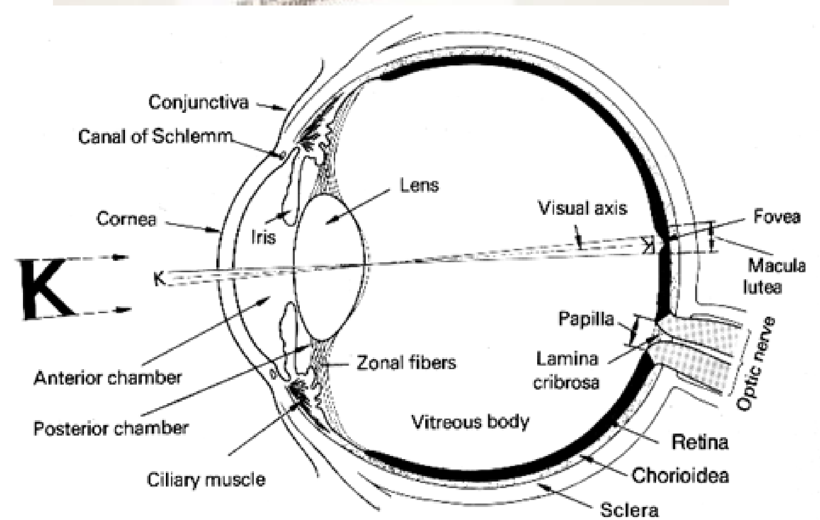
Mobile Phone Cameras

- **1997: Sharp, Kyocera: initial experiments (in Japan)**
- **2000: First phone camera**
  - Sharp J-SH04, 0.1 MP resolution
- 2000: Eyemodule Digital Camera Springboard Module for Handspring Visor
  - 320x240 resolution
- 2002: Sony Ericsson T68i
  - First MMS-capable phone (with externally attachable camera)
- 2002: Sanyo SCP-5300
  - First camera phone in USA, VGA (0.3 MP) resolution
- **2003: more camera phones than digital cameras**
- **2004: Nokia sells the most digital cameras**
- 2006: half of the mobile phones have a camera
- **2008: Nokia is the biggest camera manufacturer (analogue and digital all together!)**
- 2010: almost all phones have cameras

Image Acquisition

- **Imaging sensor**
  - Sensitivity (ISO)
  - Resolution (MP)
  - Size, type
- **Lens**
  - Shutter speed
  - Focal length
    - Zoom
  - Aperture
- **Illuminance**
  - Amount, evenness
    - → HDR (High Dynamic Range)
  - Color temperature



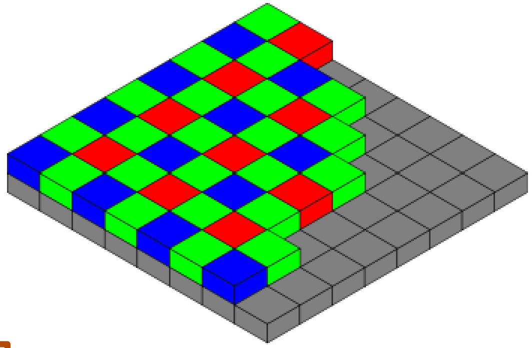


Source: [Stanford University]()

Imaging Sensors

- CCD
  - Charge-Coupled Device
  - Since 1969
  - Good quality images with low noise
  - Expensive manufacturing
  - Significant power need

Source: *WikiMedia Commons*

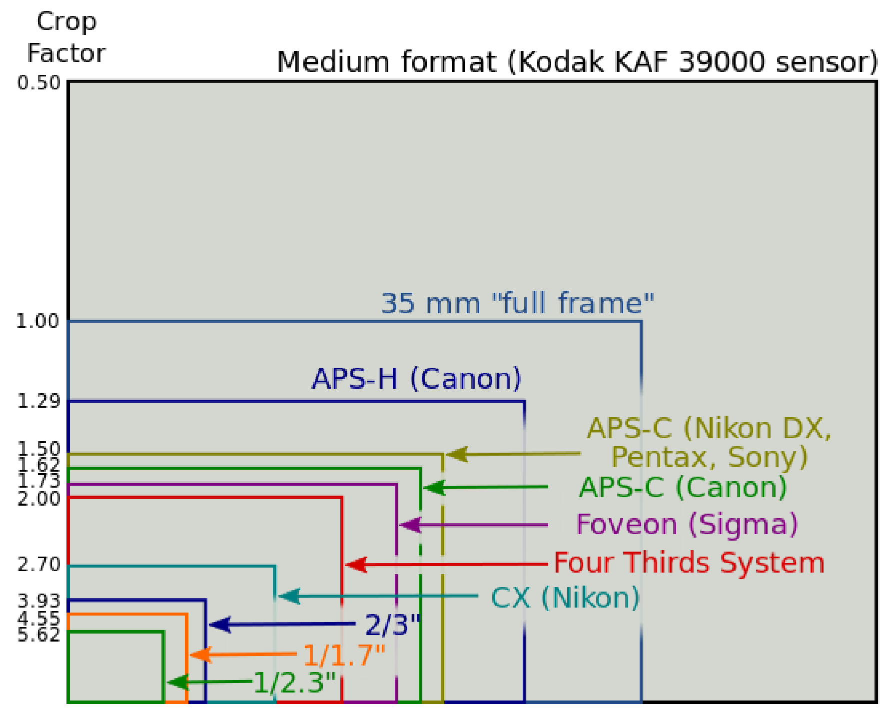


- CMOS
  - Complementary Metal Oxide Semiconductor
  - Mediocre image quality, noise sensitivity
  - Cheap technology
  - Low power need

Imaging Sensor Size

- Larger sensor size →
  - Less noise
  - Better depth of field
  - Better photos

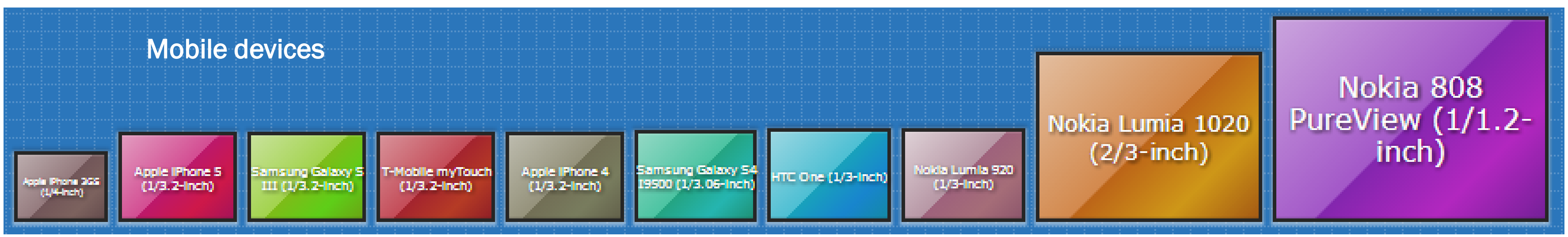
- Few examples
  - 35 mm: DSLR
  - APS-C: DSLR, MILC
  - 4/3’’: MILC
  - 1/1.8’’: top compact
  - 1/2.5’’: compact, better mobile
  - 1/3.2’’: ordinary mobile



Source: Engadget

Imaging Sensor Size

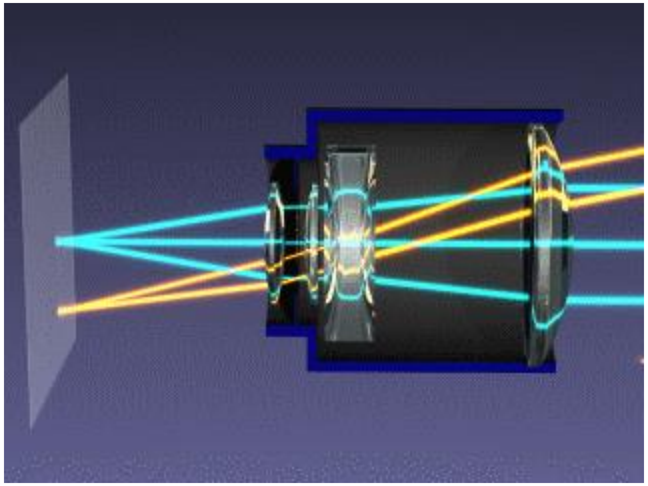
- In mobile devices
  - Usually small sized sensors
  - Two exceptionally large mobile sensors from Nokia



Sources: *Camera Image Sensor Comparison*

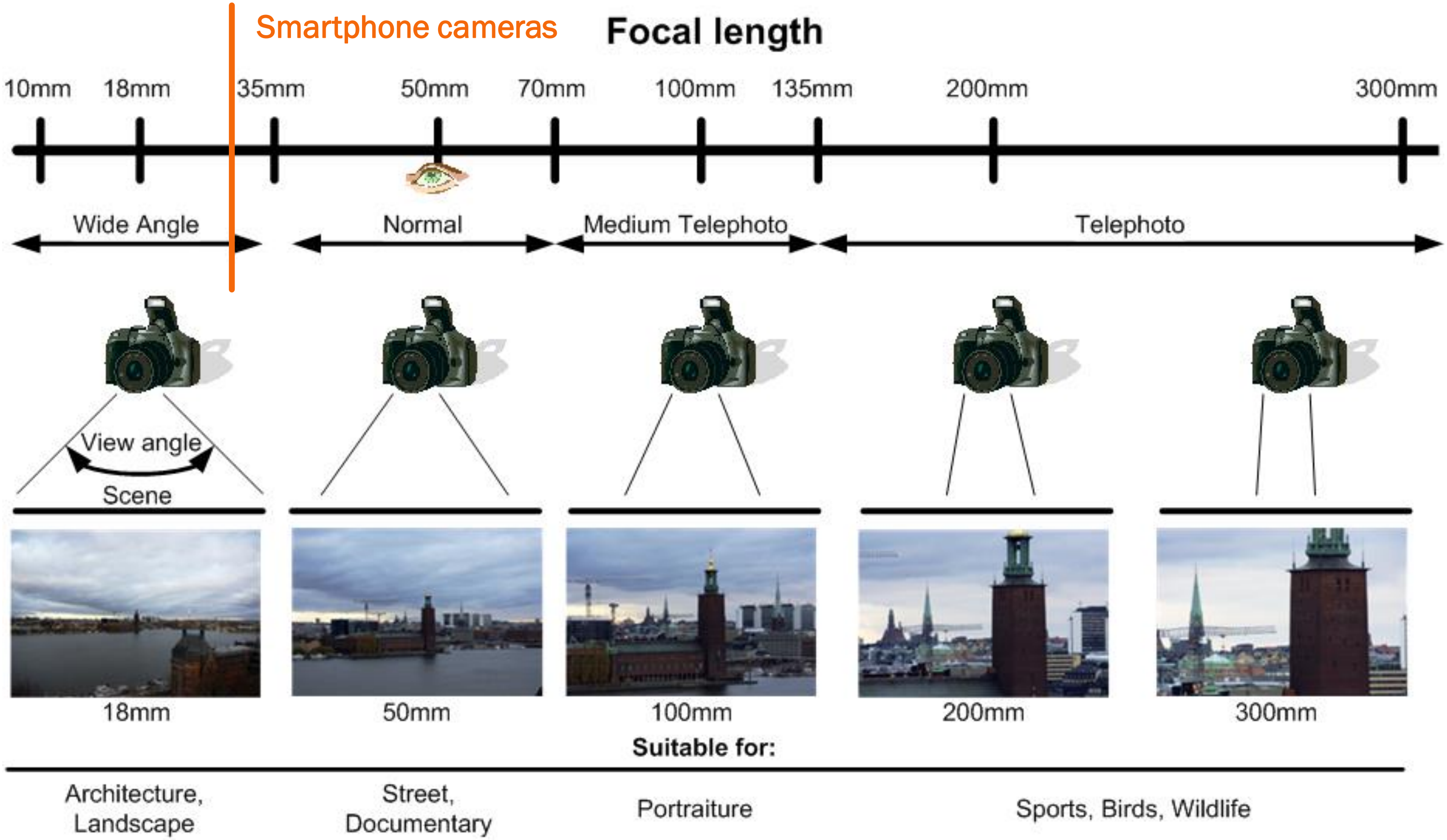
Lens

- **Brightness**
  - Amount of light getting through the lens
  - Aperture (F-stop) and shutter speed
- **Focal length**
  - Angle of view
  - Fixed
    - Mobile or „pancake” lens (MILC, DSLR)
    - Simpler buildup ⟶ smaller lens
  - Zoom
    - 3x-5x: compact, MILC, DSLR
    - 5x-40x: ultrazoom (compact) cameras



Source: [Camera Lenses Research Project]

Lens Angle of View



Source: http://www.digital-photography-student.com/lens-focal-length-explained/

Photo and Video Formats

- Still photo formats
  - RAW (lossless compression, professional devices)
    - „Undeveloped", raw data, Bayer-filtered measurements
    - Without geomeric corrections (lens correction visible)
    - Exposition parameters can be changed (temperature, brightness, ...)
    - Usually not available on mobile devices
      - Android API for RAW photos starting from Lollipop (>5.0)
        - Optional API, needy manufacturer support
  - JPEG (lossy compression)
    - Hardware implementation
- Movie formats
  - 3GP, MOV, AVI, ...

Image: Yu-Lin Chan (http://oldlenses.blogspot.hu/)

Mobile Phone Camera Overview

High enough megapixel count, but

- Cheap and small sized sensors
  - Low power consumption and price is dominant
- Weak lens
  - Longer shutter speeds
    - Blurry photos, especially in low light situations
  - Weak flash or lack thereof
    - Works acceptably only in good illuminance
  - Miniaturized size
    - Geometric distortions
- Limited parameter settings
  - Automatism, slow!

Megapixel count alone is not a good indicator of imaging quality!

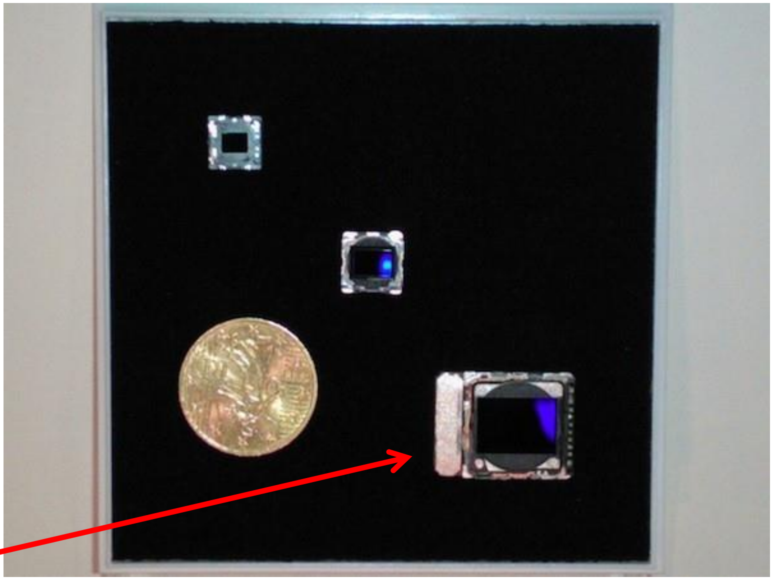
Mobile Phone Camera Overview

- Advantages
  - Small, always at hand, easily available
    - *„The best camera is the one that's with you"* (*Chase Jarvis*)
  - Might replace low-end compact cameras
  - Photos can be edited and shared instantly
  - Good quality video

- Distinguishing factor for manufacturers
  - OS and other phone features are mainly similar
  - Manufacturers pay attention to camera capabilities
    - Especially in high-end devices

Mobile Camera Progress

- Progress in the past few years
  - Sony Exmor R sensors
    - Better for low light situations
  - Apple iPhone 4S
    - Fast camera (f/2.4)
  - HTC devices
    - Dedicated chip, f/2.0 camera
  - Samsung
    - Back side illumination (BSI)
    - IsoCell sensor
  - Nokia 808 PureView
    - 41 MP, big sensor size
  - HTC One
    - Ultrapixel camera (5 MP, bigger sensors)



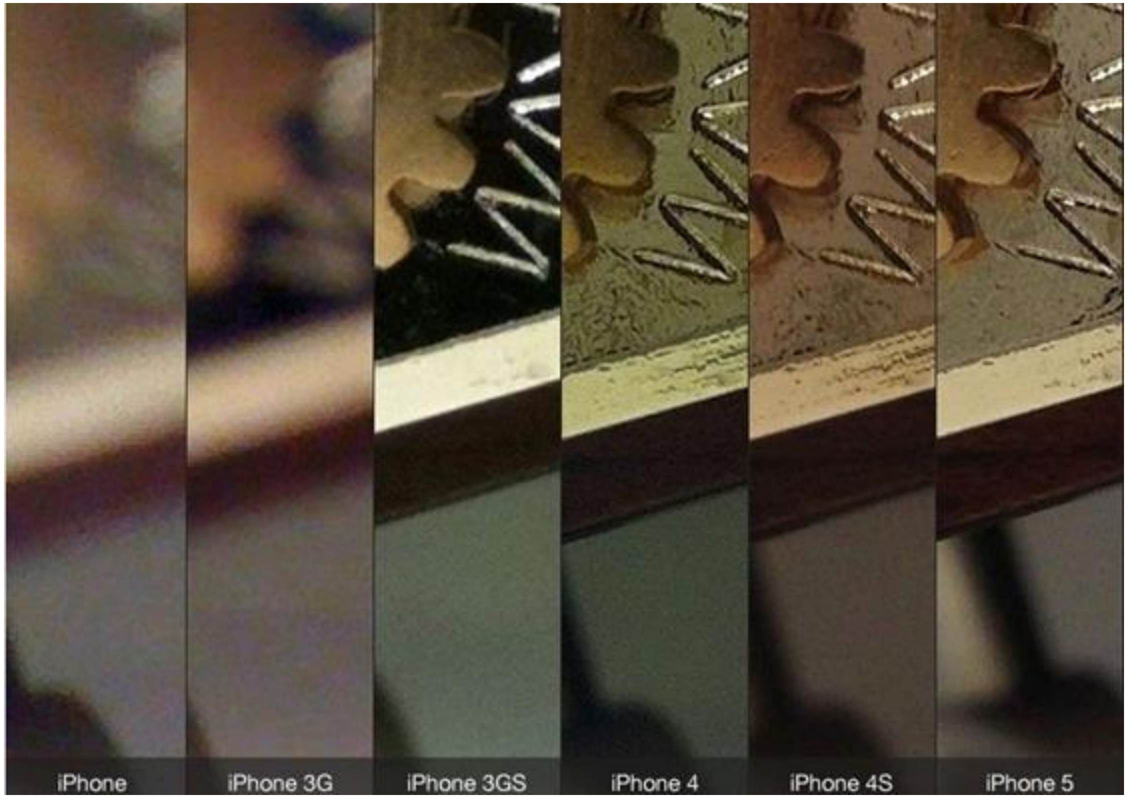
Source: *Engadget*

iPhone 4 camera module, source: arstechnica.com

iPhone Camera Progress

Source: [CameraTechnica]

iPhone Camera Progress



Source: *iPhone Informer*

Digital Cameras with Android OS

- Nikon Coolpix S800c
- Samsung Galaxy Camera
- Samsung Galaxy NX (interchangeable lens!)
- Panasonic Lumix CM1 (1'' sensor, Leica lens)

Lens-only Cameras

- Sony QX10 and QX100
  - Lens only
  - Wifi connection to smarphone
    - Viewfinder
  - Can be attached to mobile device

Source: Sony

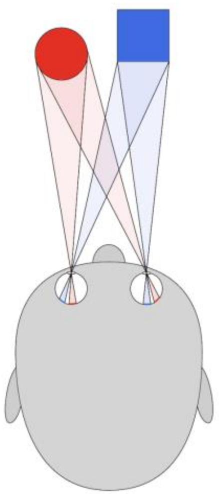
Lens Clips

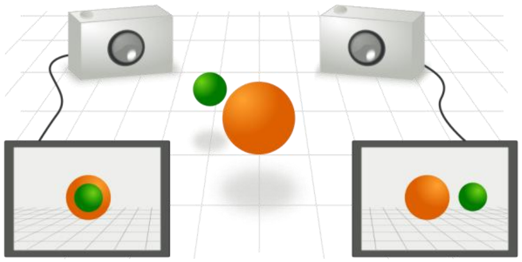
Olloclip 4-in-1 lens clip
Source: [Engadget]

Vktech 60x microscope clip for Samsung Galaxy S4
Source: [Android Central]

Stereo Imaging and Display

- Depth sensing
  - Two eyes from different viewpoints
  - The image of an object in the two retinas depends on the distance
- Stereo (machine) vision
  - Mimic human vision
  - Two cameras at the same time
  - Used for robot vision, 3D reconstruction, ...

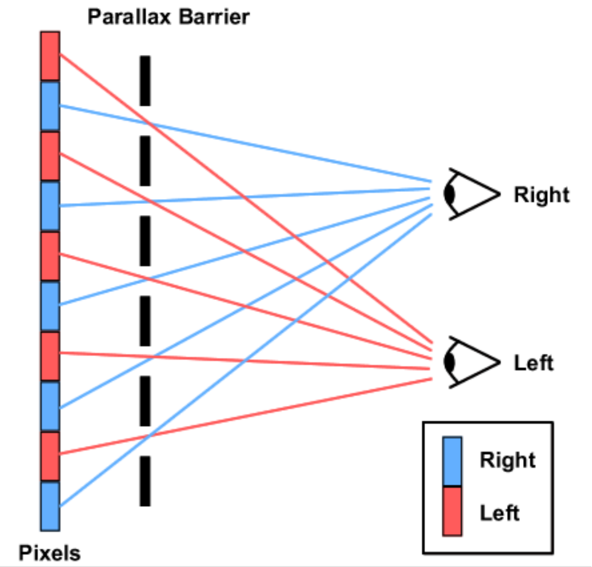




Kép: Arne Nordmann

Autostereoscopic 3D Displays

- **Features**
  - Glass-free 3D
  - Visible from fixed position
- **Principle**
  - Stereo imaging
  - Parallax barrier display
- **Application**
  - Consoles, mobile phones, tablets
  - Taking 3D photos and videos
  - 3D games
  - Distance estimation
    - Works for few metres



Virtual Reality (3D)

- Fully immersive 3D
  - Sensor-based 3D world generation
- Active ongoing research
  - Standalone devices
    - Oculus Rift, Sony Morphesus, Samsung Galaxy VR
- Mobile solution: Google Cardboard
  - (Very) cheap alternative
  - Can be built from paper box
  - Screen is divided into two parts
  - Renders the different views
  - Uses two cheap lenses

Source: [SlashGear]

Uneven Illumination

- HDR (High Dynamic Range)
  - Difficult illumination situations (dark and bright regions in the image)
  - Software solution
    - Series of photos with different exposure values (e.g., ±2 EV, 3-5 photos)
    - Fixed position, stand still scene
    - Photo fusion
      - Divide the photos to little squares
      - Select the one with highest information content
        - Entropy
      - Blending to get smooth boundaries

Images: A.A. Ghostasby, András Osztroluczki and Erik Zajác

Software Photo Processing

- Artificial deph of field simulation („lens blur”)
  - Software post processing algorithms
  - Camera movement during exposition (small video)
    - Estimating distance of object points
    - E.g., Google Camera application (Android)
  - Related articles
    - Blurring the background: Understanding focus, defocus, refocus and Ufocus
    - Battle of the Blur: Defocus camera showdown
    - Google's new camera app brings Photo Sphere and Lens Blur to Android devices
    - Google Camera: What's new, and a guide to the latest features
    - New SDK lets developers take advantage of HTC One M8's dual cameras

Lens Blur Example

Photo by Colby Brown

One of several input photos | Depth map (black close, white far) | Photo with Lens Blur

Source: *[Google Research BlogSpot]*

Lens Blur Example

Photo by Rachel Been

Lens Blur selfie, background focus | Lens Blur selfie, foreground focus

Source: *Google Research BlogSpot*

Using Two Different Lenses

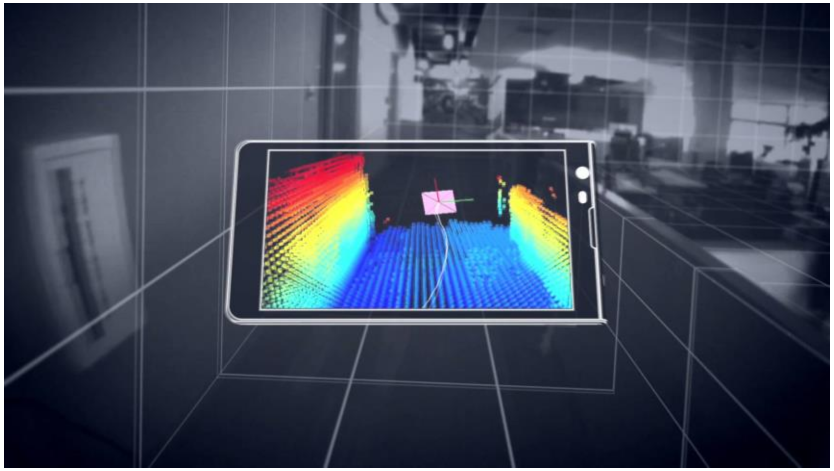
- Not stereo!
- Dual-lens smartphone cameras are coming, and this is why we want one
  - „The big trick here is Corephotonics' use of **two lenses with two different focal lengths.** One lens is wide-angle, while the other is at 3x zoom. This means you can **switch lenses to magnify more distant subjects** without resorting to digital zoom."
  - „In the test set-up shown in the video above, which compared the dual-lens system side-by-side with a traditional smartphone camera (with both modules pointed at a test card around a foot away), the Corephotonics system **outputted a clear 13-megapixel image regardless of whether it was at 1x or 3x zoom.**"
  - **„By contrast, Nokia's PureView cameras rely solely on digital zoom such that outputting a 3x magnified image entails a drop in resolution down to five megapixels.**"
  - „Corephotonics' system can also **deliver smooth zooms**, for example during video recording, by employing a mix of digital zoom and lens-switching."

Using Two Different Lenses

- [Huawei's Honor 6 Plus packs glass on both sides, uses two cameras for neat tricks]()
  - „The pair of cameras give you access to a great shooting mode that **lets you adjust the focal point *and* aperture after you've already taken a photo**, as well as a choice of **apertures — from f/0.95 to f/16.**"
  - „The way it works is **it uses both cameras at the same time to capture several photos at different apertures** — think of it as taking several "layers" of a photo in quick succession. It creates a noticeable but small bit of shutter lag, but the results are worth it."
  - „Hop into the gallery and you can see the picture you took at the aperture you set before capture, but **you can also switch to an editing mode** that really takes advantage of the cameras. You can tap to focus on any area in the frame, and at the same time adjust the aperture to get the right effect. You can crank it up to f/16 and bring everything in focus, or drop all the way down to f/0.95 and get very specific about the focal point to blur everything else out."

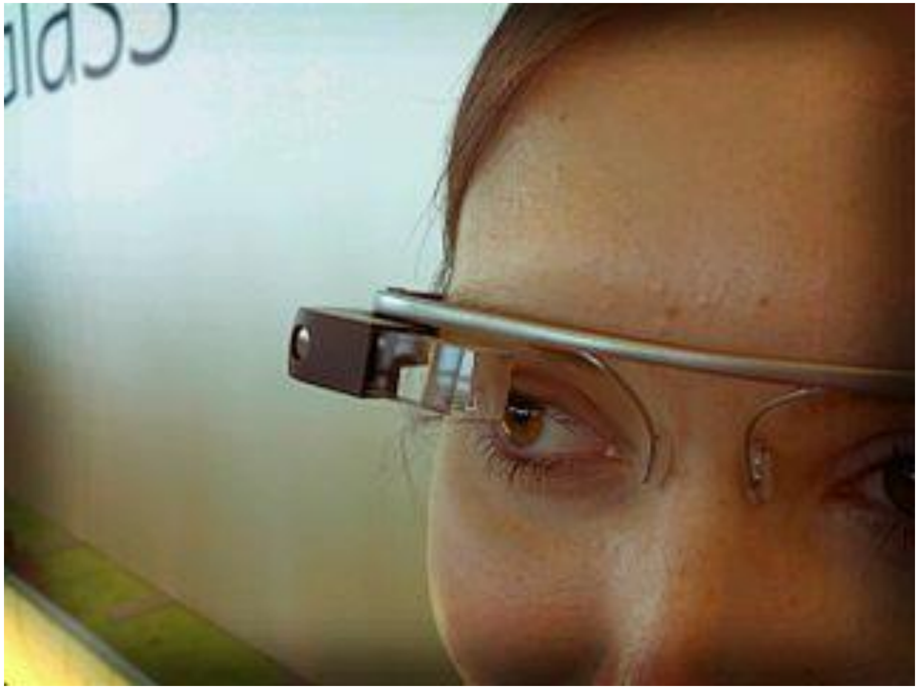
(Near) Future

- RGB-D sensor
  - Color + distance
    - Kinect-like sensor
  - Google Project Tango
    - Mapping 3D interior of rooms
    - Small distances
    - No direct (sun)light
    - Development kit is available (in the USA)
  - Official YouTube Video
  - The next mobile imaging war won't be waged over megapixels
    - „Though Mountain View is focused on 3D mapping, so-called **depth camera tech could dramatically improve all the pictures** you take with your smartphone."



(Near) Future

- Smart Glasses
  - E.g., Google Glass
  - Experimental phase
  - Features
    - Glass with miniature display
    - Voice control + touchpad
  - Possibilities
    - Hands-free guidance
    - Location-based services
  - Problems
    - Privacy concerns
    - Face recognition apps are forbidden from the official app store!



Source: WikiMedia Commons

Future

- HTC talks cameras, optical zooming on the not-so-distant horizon
  - „Back to the future -- quite literally. HTC's future plans include taking on the large DSLR cameras used by enthusiasts and professional photographers. Whitehorn explains that **it's likely smartphone camera capabilities will match (if not surpass) high-end camera equipment as the lens barrier begins to fall apart.** This would make it more difficult to justify taking a large camera (unless it's a shoot requiring specialist hardware, of course) when the smartphone can produce quality shots. It's interesting as Whitehorn closes by stating that "the camera industry needs to feel totally threatened." We're certainly excited to see what HTC and other manufacturers will achieve in a year regarding smartphone optics."
- The next mobile imaging war won't be waged over megapixels
  - „By using two lenses with different focal lengths, for example, you could zoom in on subjects with quality that rivals bulky optical zooms. It could also eliminate a number of other shortcomings without adding an awkward hump like the one seen on the Lumia 1020. **You could soon have much better light sensitivity, less noise and depth of field control that rivals a DSLR.** The benefits are clear, but Google is not alone in its pursuit. The battle for a better smartphone camera is on, and you could be the one to reap the rewards."

?

Mobile Camera Applicability Today

- Huge social impact!
  - Family
    - Sending photos and videos to any distances
    - Instantly
  - Politics
    - Broadcast events
    - News channels
  - Science
    - Meteorology
    - Tsunami
    - …
- Taking notes
  - Opening hours, advertisements
- Visual codes
  - Bar codes, QR codes
- Photo processing and filtering
  - Montage, HDR, time lapse, removing moving objects, …
- Photo sharing and upload
  - Instagram, Twitter
- Content-based image search, augmented reality
  - Client-server applications
- Image analysis
  - Face detection, OCR, …
- Video calls
- …

Applications

- Visual codes
  - Product identification
  - Business card scanning
  - URL
  - General text
- Complex imaging functions
  - Smile/blink detection
  - Post processing
  - HDR imaging
  - Panorama creation (even using sensor information)
  - Taking 3D photos

Augmented Reality

- **Combining the most capabilities of the mobiles**
  - Camera live view + location + orientation + location-based query + 2D/3D computer graphics

- **Apps**
  - Layar (Android, iPhone)
  - Wikitude World Browser
  - Games

Example from Layar: In London at Abbey Road

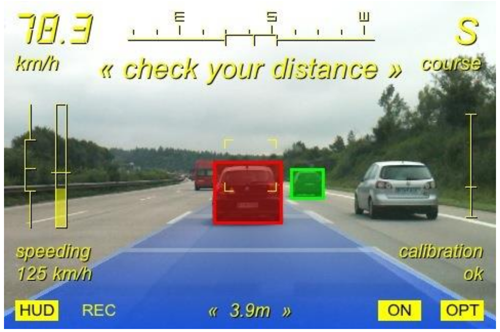
Image Search (Client-Server)

- Google Goggles (Android)
  - Buildings, paintings
  - Visual codes
  - Business card
  - Books, products
  - Solving Sudoku

Source: Google System BlogSpot

Computer Vision

- Applications
  - OCR (optical character recognition)
    - Google Docs: lefotózott szöveg felismerése (angol)
  - Word Lens (iOS), CamTranslator (Android)
    - Translating words and phrases on camera live view
  - Augmented Driving (iPhone)
    - Lane detection, approaching vehicle warning
  - Doctor Mole
    - Analyzing skin pigments
  - Motion detection
    - Security
  - ...



OpenCV

- **Open source (BSD licence)**
  - Computer vision
  - Machine learning
- **>2500 optimized algorithms**
  - Filtering, edge detection, histogram, Hough-transform, …
  - Face detection and recognition, movement classification, object tracking, image stitching, content-based image search, …
- **Multiple platforms and programming languages**
  - >10 years of development, numerous contributors
  - C++ template interface
  - Python, Matlab, Java bindings
  - Windows, Linux, Mac OS, Android, iOS versions
    - Architecture-specific pre-built libraries

3D Mobile Computer Graphics

- Hardware
  - Dedicated GPUs
    - E.g., Nvidia Tegra platform, Qualcomm Adreno
  - Android-based Game Consoles
    - Nvidia Shield, Ouya, …

- Software API: OpenGL ES
  - ES = Embedded System
    - Redundant functions are eliminated
  - Open standard for 3D graphics
  - Almost all mobile platforms support it (iOS, Android, Java ME)
    - Except Microsoft…
  - OpenGL ES 1.1: Fixed rendering pipeline
  - OpenGL ES 2.0: Vertex and fragment shaders, programmable pipeline
  - OpenGL ES 3.0: above Android 4.4 KitKat

Research Projects

- **Related projects**
  - *Car Recognition from Frontal Images in Mobile Environment*
    - Viktor Varjas, Attila Tanács
  - *Evaluation of Point Matching Methods for Wide-baseline Stereo Correspondence on Mobile Platforms*
    - Endre Juhász, Attila Tanács, Zoltan Kato
  - *Collaborative Mobile 3D Reconstruction of Urban Scenes*
    - András Majdik, József Molnár, Attila Tanács, Levente Hajder, Rui Huang, Zsolt Sánta, Zoltan Kato

Acknowledgments

- This work was partially supported by the European Union and the European Social Fund through project FuturICT.hu (grant no.: TAMOP-4.2.2.C-11/1/KONV-2012-0013).

Research Projects

- **Car make and model recognition**
  - From frontal images of cars taken by mobile devices

- **Refining a previous gradient-based approach**
  - Previous papers from literature
  - Ground truth test + practical application with an *outlier class*
  - *Robustness test + semi- and fully automatic versions*
  - *Image database having more samples per classes*

Model and make recognition $\longrightarrow$ Peugeot 307

Car Model and Make Recognition

- **Basic idea**
  - Number plates are ususally in fixed position
  - The size of the number plate is in most of the cases fixed (in a given country)
  - The image content in a fixed (relative to the number plate size) neighborhood of the number plate describes well the car model and make

Number plate detection, rotation compensation, ROI extraction

- **Evaluation scenarios**
  - Using ground thruth data
    - Manually provided number plate corner points: good for classification evaluation
  - Semi- and fully automatic approaches
    - Practical applicability

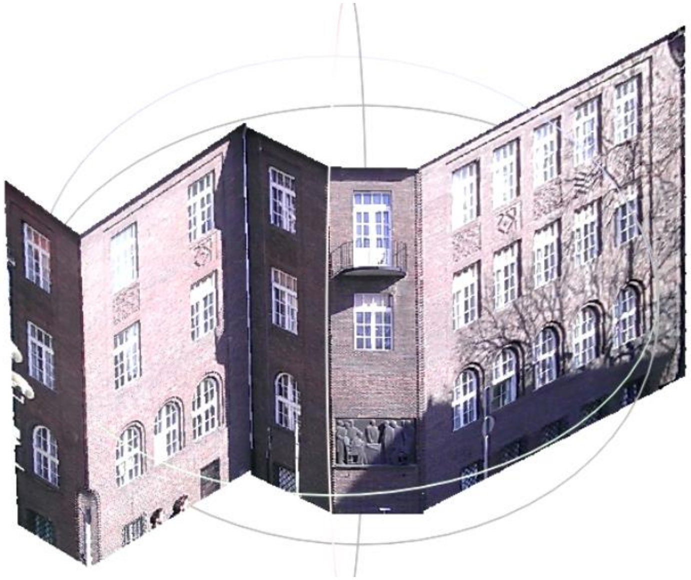
Collaborative Mobile Visual Computing

- **Mobile**
  - **Smartphone explosion!**
  - **Sensors** on-board
    - Camera module + position, orientation, acceleration, …
  - **Network connection**
    - Wifi and/or mobile internet communication
  - Capable and still increasing **computing power**
  - **Billions of potential users!**

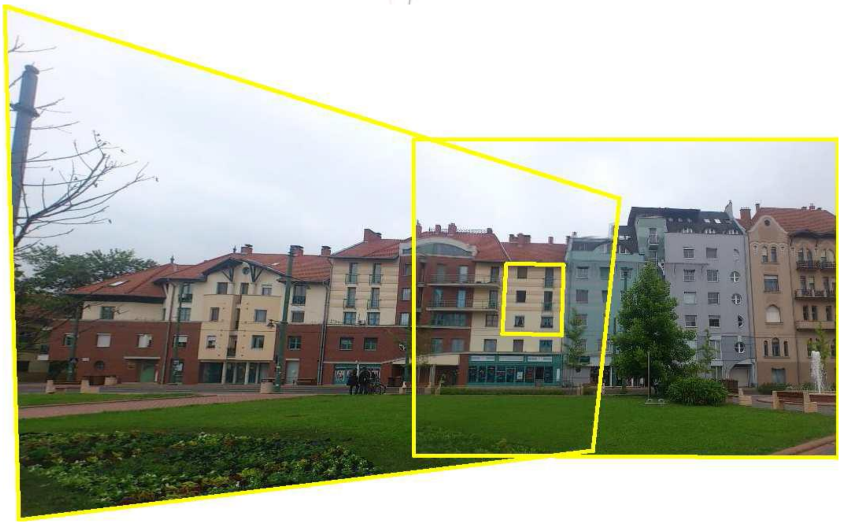
- **Collaborative**
  - Near **synchronous** imaging
  - **Decentralized**, ad-hoc camera network
  - Computation is done by the peers
  - **Data is shared** among them by request

Collaborative Mobile Visual Computing

- High-level collaborative tasks
  - 3D reconstruction of urban scenes
  - Synthetic view generation
  - Panorama generation



- Fundamental algorithmic problems
  - Wide-baseline stereo matching
  - Correspondence (2 images)
    - Detect corresponding objects in the images
    - Erroneous correspondence detection
  - Camera calibration
    - How the 3D scene is projected to a plane?
  - Ad-hoc camera network calibration
    - Which cameras are close to each other?
    - Which cameras have a common view?
  - Communication
    - Infrastructure for peer-to-peer data exchange



Stereo Reconstruction Pipeline

Preliminary steps

- Image acquisition
  - Using calibrated cameras
- External calibration
  - Overlapping view detection
  - Pose estimation
- Planar patch segmentation

Pairwise reconstruction

- Planar patch correspondence
  - Rectification
  - Constrained affine registration
  - Un-rectification
- Homography-based reconstruction
  - Plane normal and distance computation
- Uncertainty verification
  - Reject patches of possible misregistration

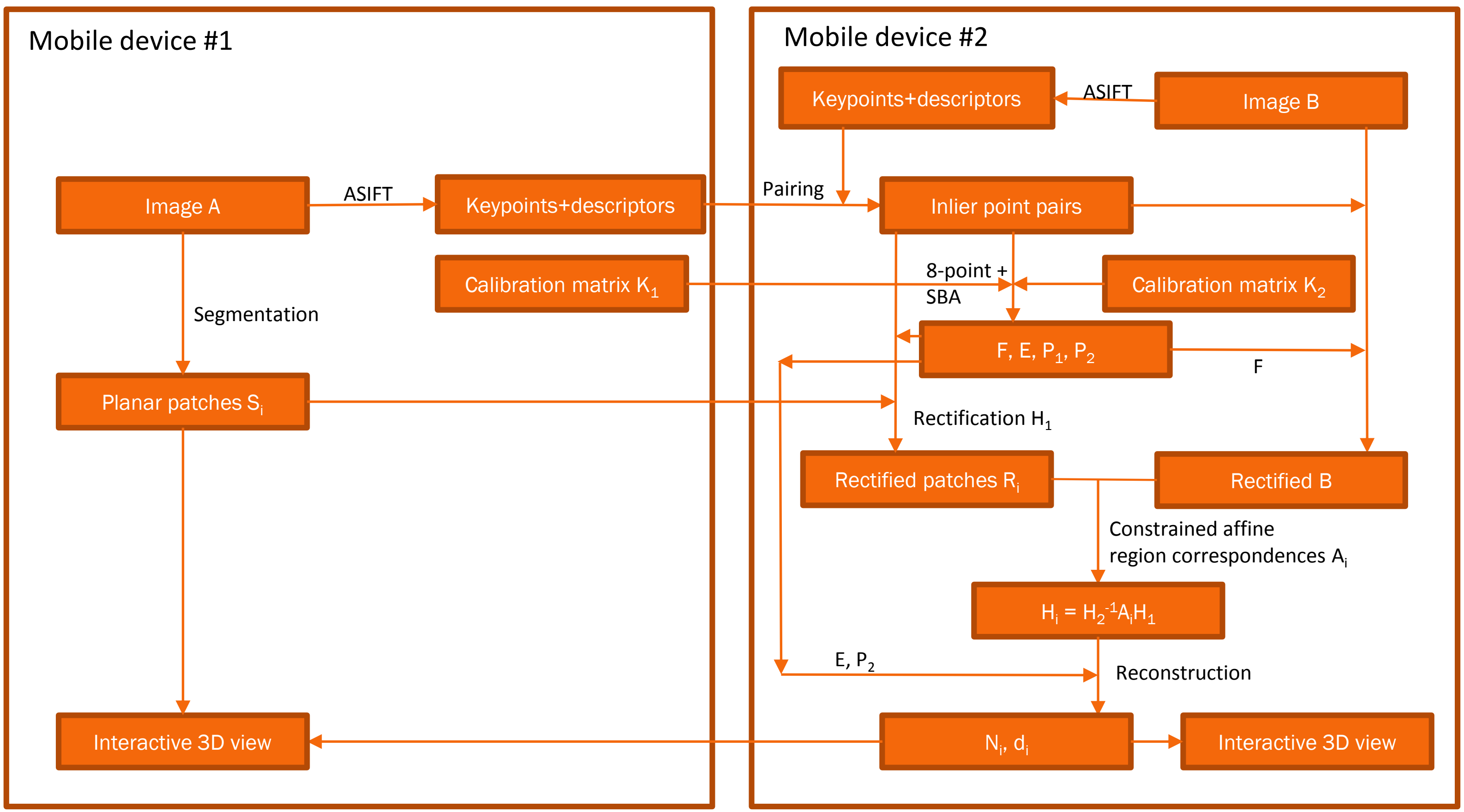
Visualization

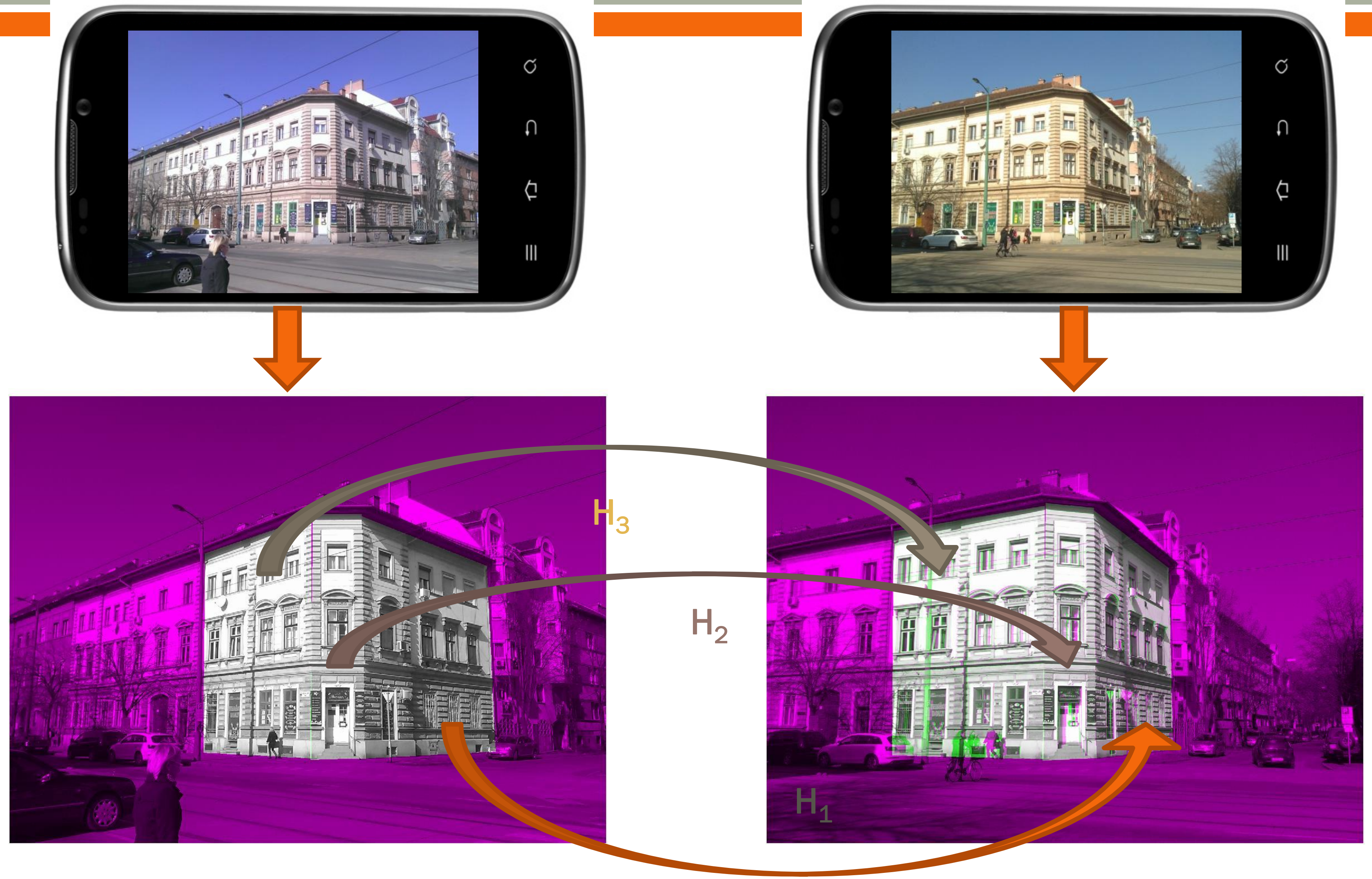
- 3D display and interaction
- Optimal texture selection
  - Camera view direction
  - Color equalization

Stereo Reconstruction

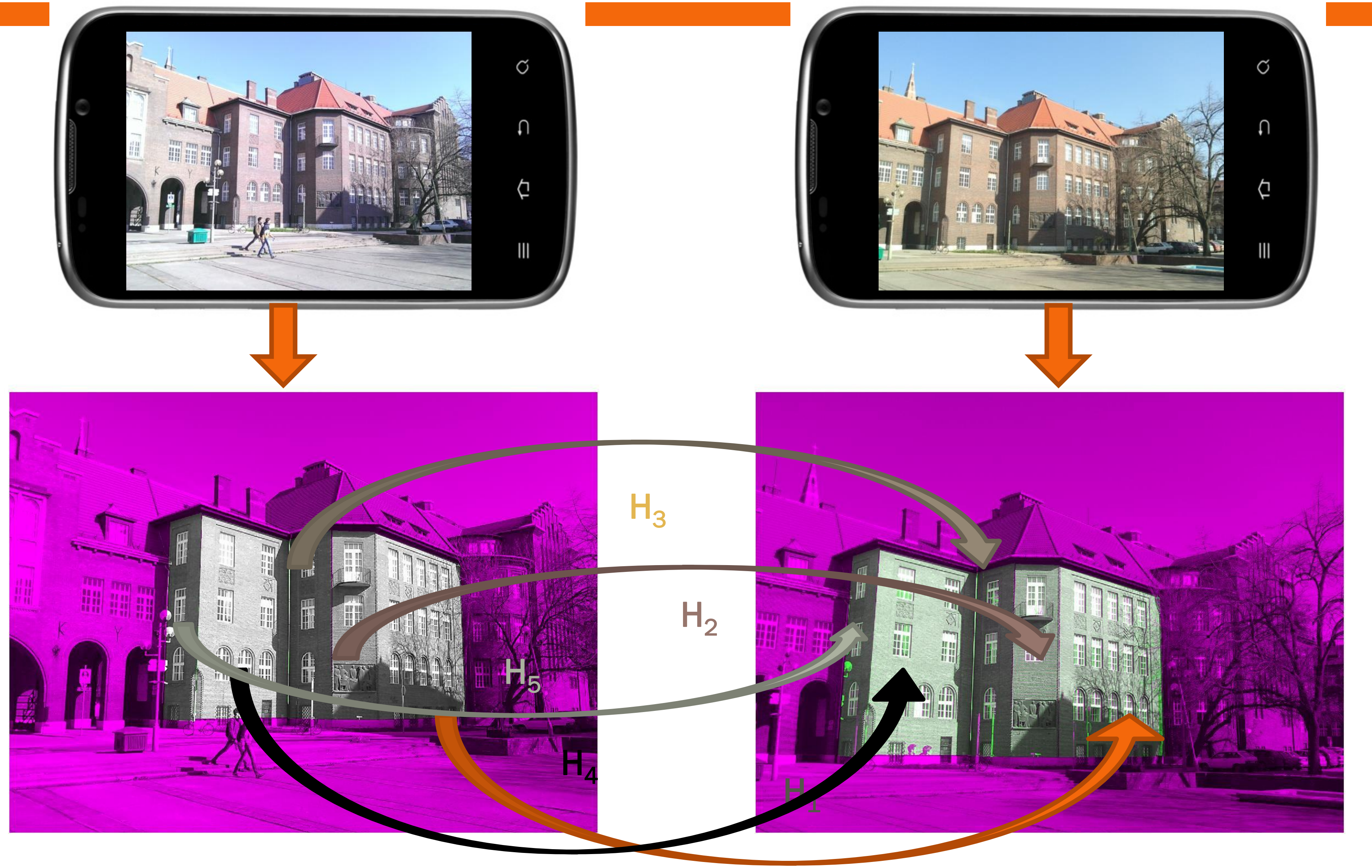
- Experimental results
  - Dataset of 52 image pairs taken by different cameras
  - Faster version: 24 good, 10 acceptable, 18 failed
  - More elaborative search: 27 good, 12 acceptable, 13 failed
- **Computing time** (Offline – Samsung Galaxy Note 3)
  - Network traffic (~2-3 MB) – not addressed here
  - ASIFT ~7 sec on each image, ~30 sec pairing
    - Can be conducted in collaborative manner
  - Patch matching ~12 sec each
    - Four threads can be run in parallel; can be conducted in collaborative manner
  - Pose estimation, rectification, reconstruction
    - ~1-2 sec
  - Can be made faster
    - SIMD implementation using GPU, multi-threaded ASIFT
    - Constantly evolving, significant growth of mobile computing power

Fully Collaborative Solution





H_3
H_2
H_1


H_3
H_2
H_5
H_4
H_1