Smartphone Imaging and Image Processing

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Mobile Devices Everywhere...

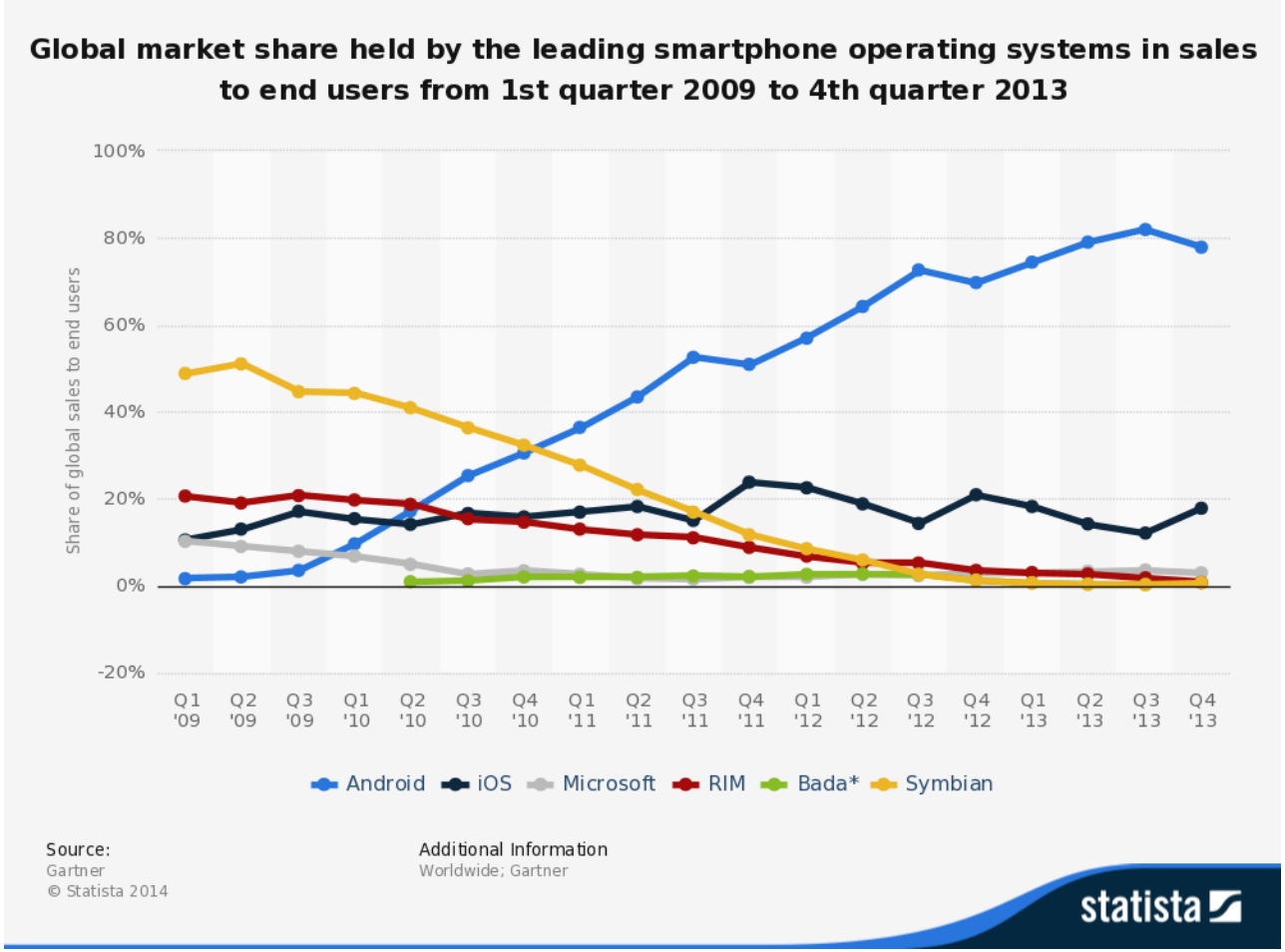
Mobile Devices

- **Penetration**
  - Billions of potentional users
  - More SIM cards than people
- **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
- **Modern smartphones** (2007-)
  - Convergence of mobile phones and PDAs
  - Nokia communicators (phone with data capabilities)
  - 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, RIM Blackberry
  - Fast accommodation to user's need is essential!
  - User's need should to 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, …
  - Earlier
    - Usually no transitions between ecosystems
  - Nowadays
    - Give service across the few platforms stayed alive
    - iOS, Android, Mac, PC, web

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

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**
- **…**

Some 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 smartphone**
  - Camera live view + location + orientation + location-based query + 2D/3D computer graphics

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

Example from Layar: In London at Abbey Road

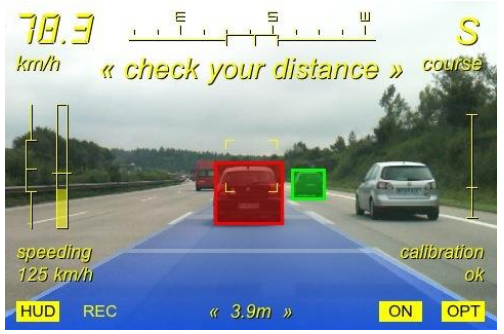
Image Search (Client-Server)

- Google Goggles (Android)
  - Buildings, paintings
  - Visual codes
  - Business card
  - Books, products
  - Solving Sudoku
- Google Cloud Vision API
  - Opened Spring 2016!
    - https://cloud.google.com/vision/
    - Accessible from smartphone apps also
    - Gives description of image contents
      - »It quickly **classifies images** into thousands of categories (e.g., "sailboat", "lion", "Eiffel Tower"),**detects individual objects and faces within images**, and finds and reads printed words contained within images.«
  - Try Google Photos!
    - Search for photos containing dogs, river, … in your own photo library

Source: Google System BlogSpot

Computer Vision

- Applications
  - OCR (optical character recognition)
    - Scanning and recognizing text on the go
  - Word Lens, CamTranslator, Google Translate
    - Translating words and phrases in camera live view
  - Augmented Driving (iPhone)
    - Lane detection, approaching vehicle warning
  - Doctor Mole
    - Analyzing skin pigments
  - Motion detection
    - Security
  - …



Mobile Image Processing

- **Native APIs available**
  - Camera handling (photo, live view), bitmap I/O and display
  - Accessing pixel data → mainly do it yourself processing!
    - Warning: Do not reinvent the wheel!

- **Dedicated image processing libraries**
  - OpenCV
    - http://www.opencv.org
    - Open source (BSD licence) and multiplatform
    - Computer vision, machine learning functionality
  - FastCV
    - https://developer.qualcomm.com/docs/fastcv/api/index.html
    - From Qualcomm (the chip maker), mobile specific

OpenCV

- >2500 optimized algorithms
  - Basic algorithms
    - Filtering, edge detection, histogram, Hough-transform, …
  - Complex functionality
    - 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

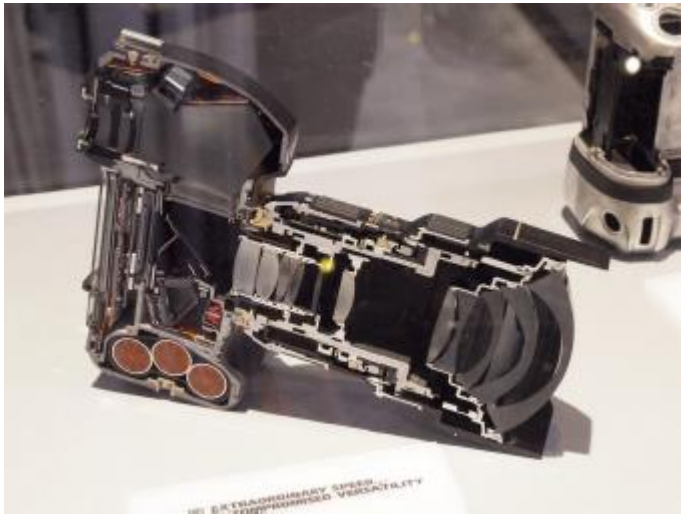
3D Mobile Computer Graphics

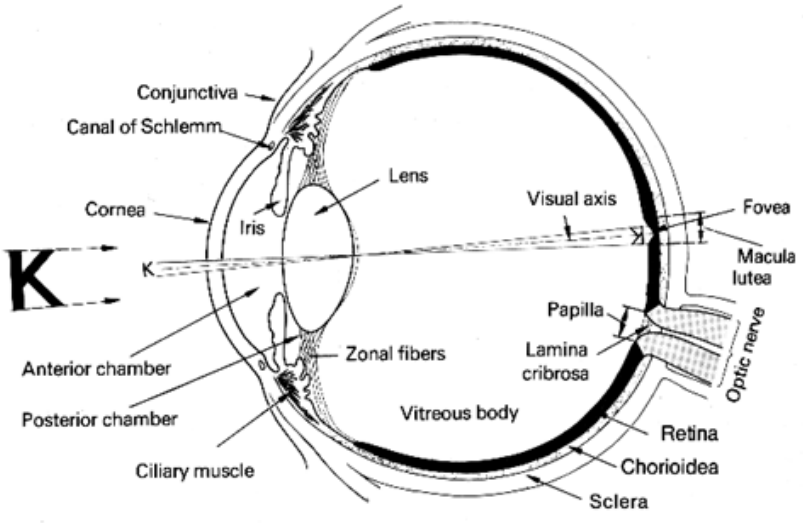
- Hardware
  - Dedicated GPUs
    - E.g., Nvidia Tegra platform, Qualcomm Adreno
  - Android-based Game Consoles
    - Nvidia Shield, Ouya, …

- 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
- Coming: Vulkan API

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



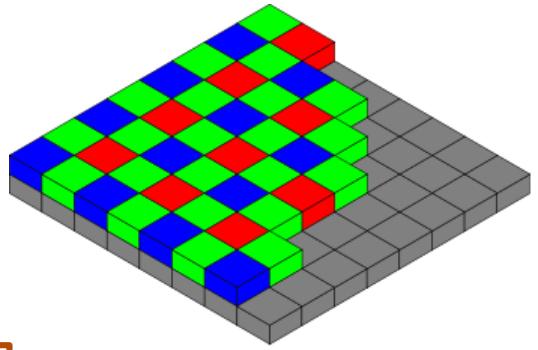


Source: Stanford University

Imaging Sensors

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

Source: WikiMedia Commons

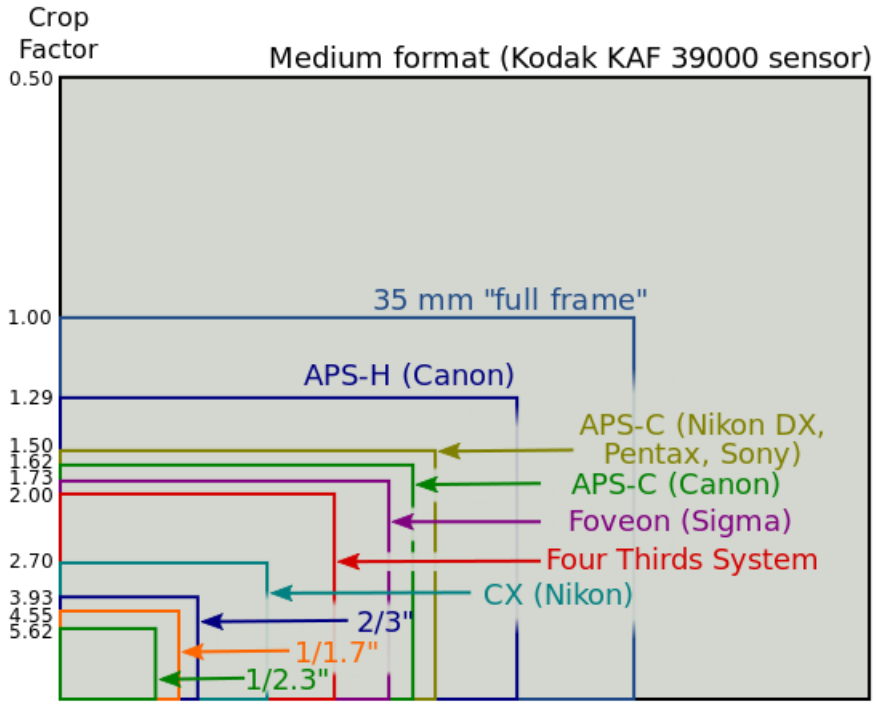


- CMOS
  - Complementary Metal Oxide Semiconductor
  - Mediocre image quality, noise sensitivity
  - **Cheaper technology**
  - **Low power consumption**

Imaging Sensor Size

- Larger sensor size →
  - Less noise
  - Better depth of field
  - Better photos
  - But larger lens needed!

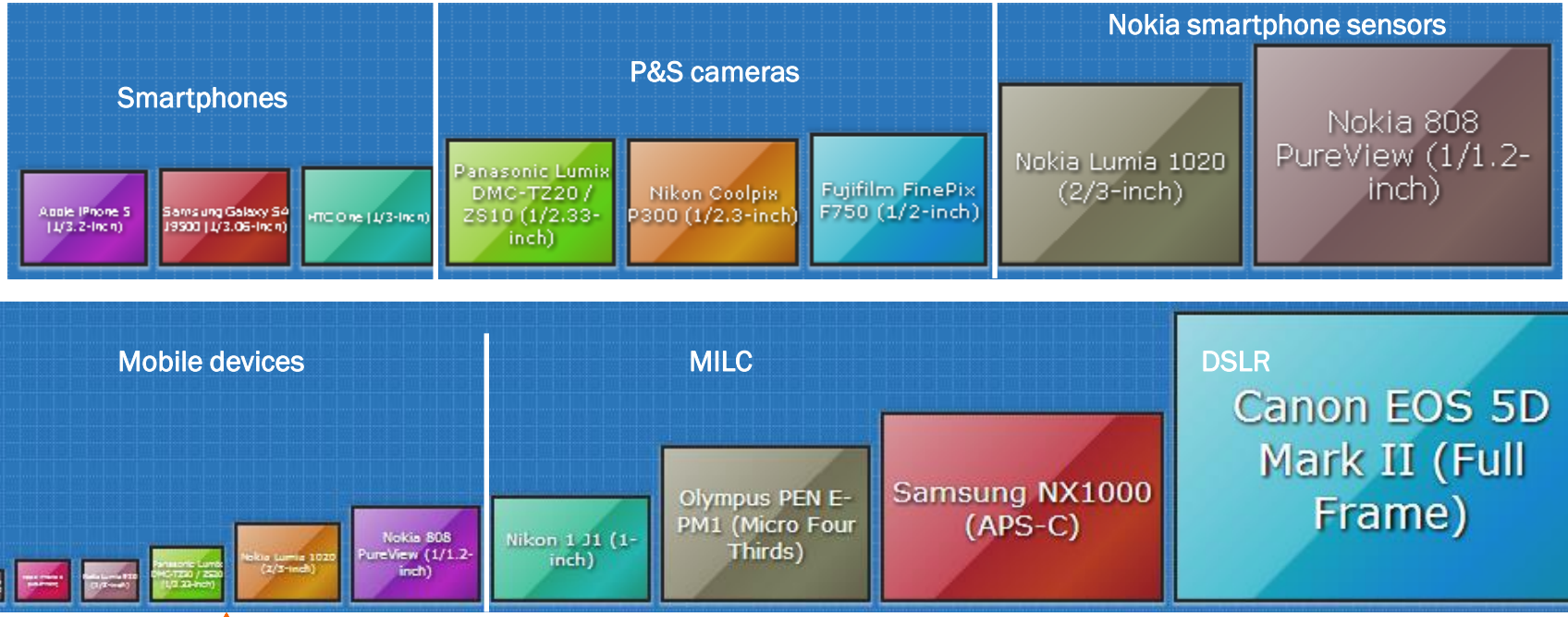
- Few examples
  - 35 mm: DSLR
  - APS-C: DSLR, MILC
  - 4/3'': MILC
  - 1/1.8'': top compact
  - 1/2.3'': compact, better mobile
  - 1/3.2'': ordinary mobile



Source: Engadget

Imaging Sensor Size

- In mobile devices
  - Usually small sized sensors
  - Comparable to average P&S cameras



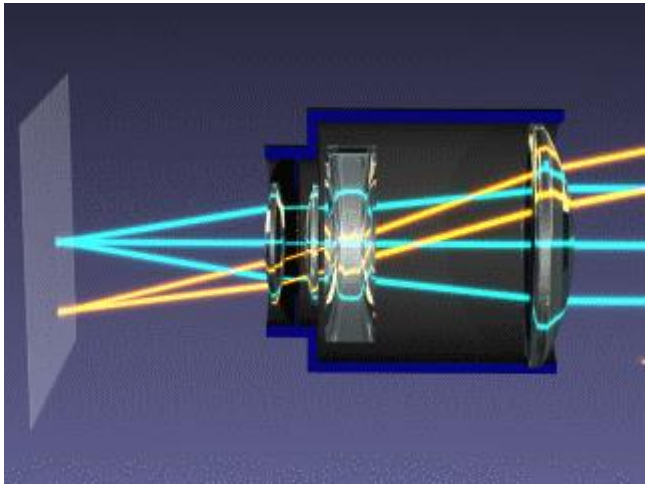
Average Point&Shoot cameras

Sources: [Camera Image Sensor Comparison]

Lens

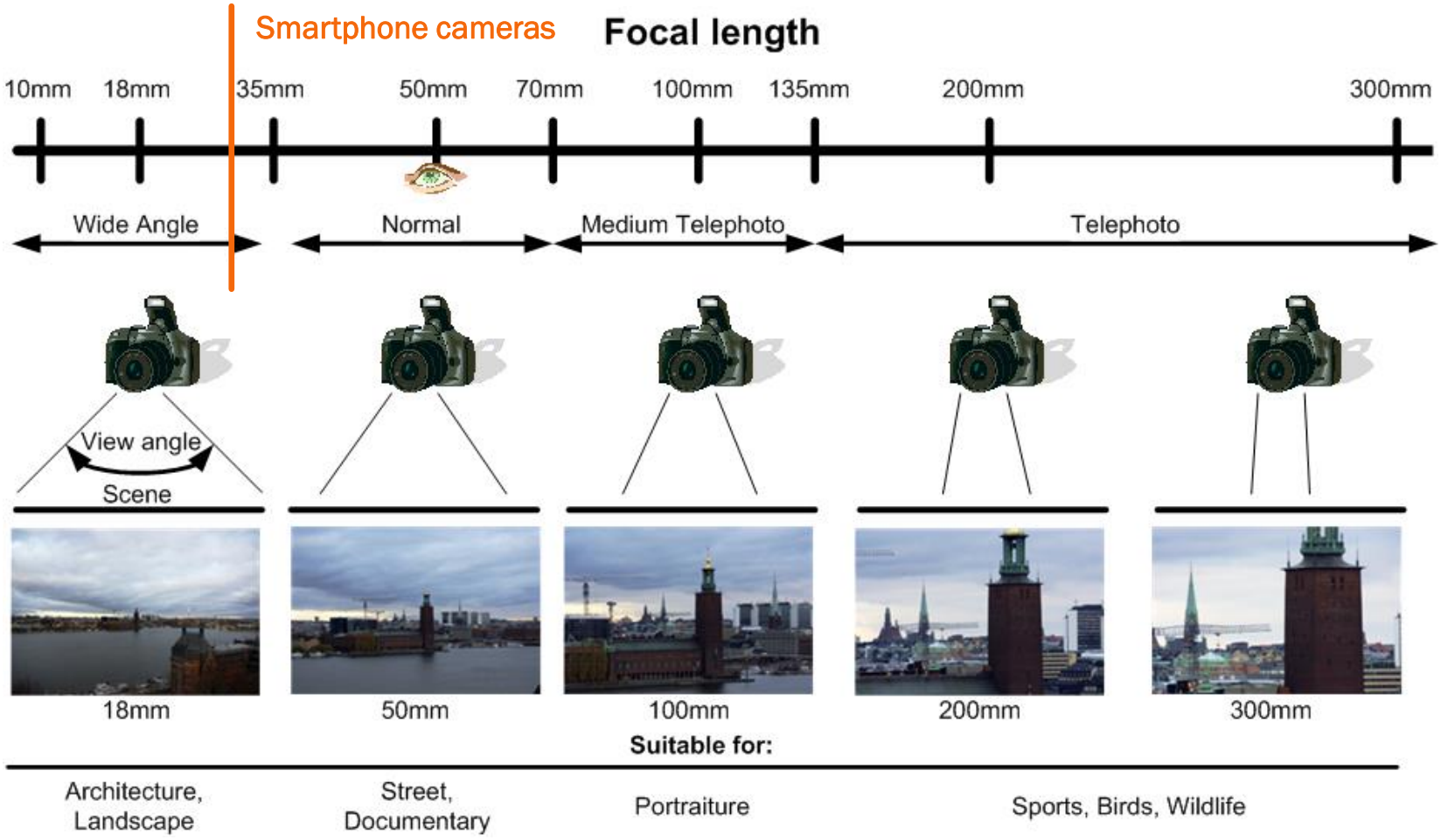
- **Brightness**
  - Amount of light getting through the lens
  - Aperture (F-stop) and shutter speed play role

- **Focal length**
  - Determines the 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
    - Only very few smartphones have zoom!



Source: Camera Lenses Research Project

Lens Angle of View



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

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

Progress in Mobile Imaging

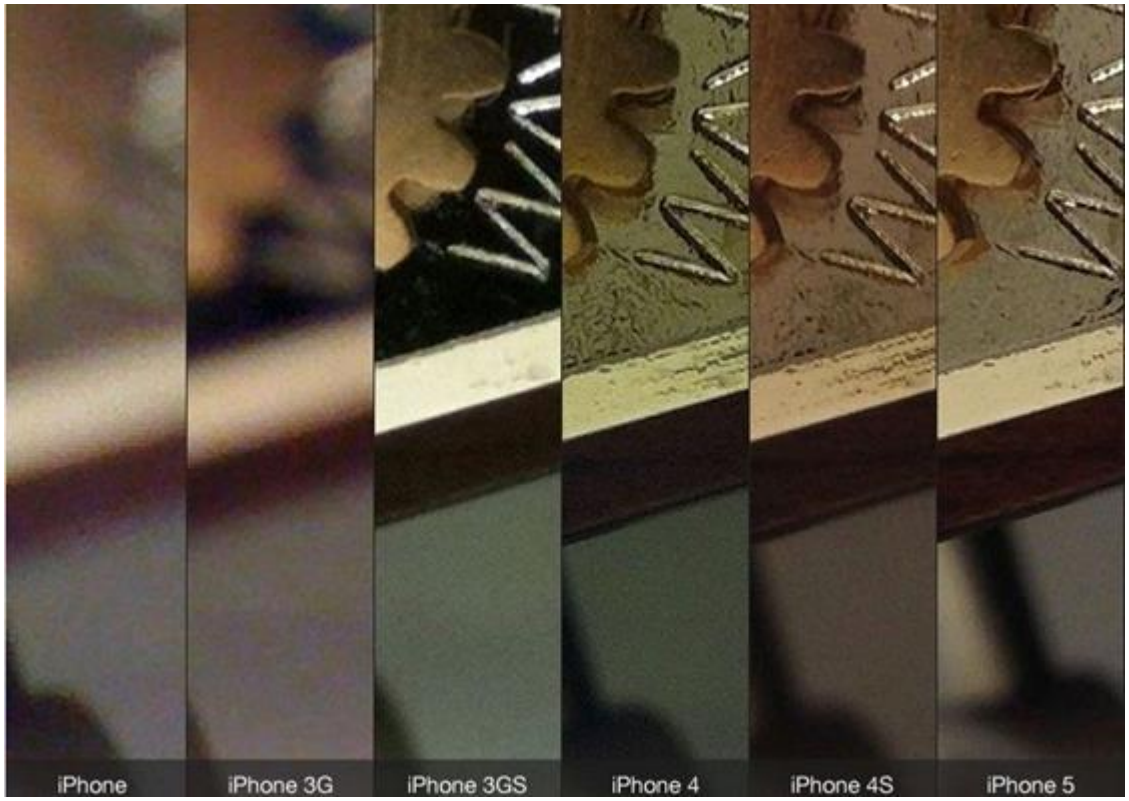
- **Better sensors**
  - BSI, Exmor, IsoCell, Ultrapixel, …
  - Megapixel war is (mainly) over!
  - Dedicated processing chip
  - OIS (optical image stabilization)
- **Camera function**
  - Zoom lens (thicker device)
  - Faster and more precise focusing using laser light
  - Dual-lens systems (with different parameters)
  - Better front side camera module („selfie” camera)
- **Software photo processing**
  - HDR
  - Simulate depth-of-field
  - Sensor-based panorama

Kép forrása: PixInfo

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)

Bulkier, but better lens, in place photo processing and sharing.

Lens-only Cameras

- Sony QX10 and QX100
  - Lens only, no display and buttons
  - Wifi connection to smartphone
    - Viewfinder, control
  - Can be attached to mobile device

Better lens, but cumbersome usage!

Source: Sony

Lens Clips

Easy usage but questionable quality!

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

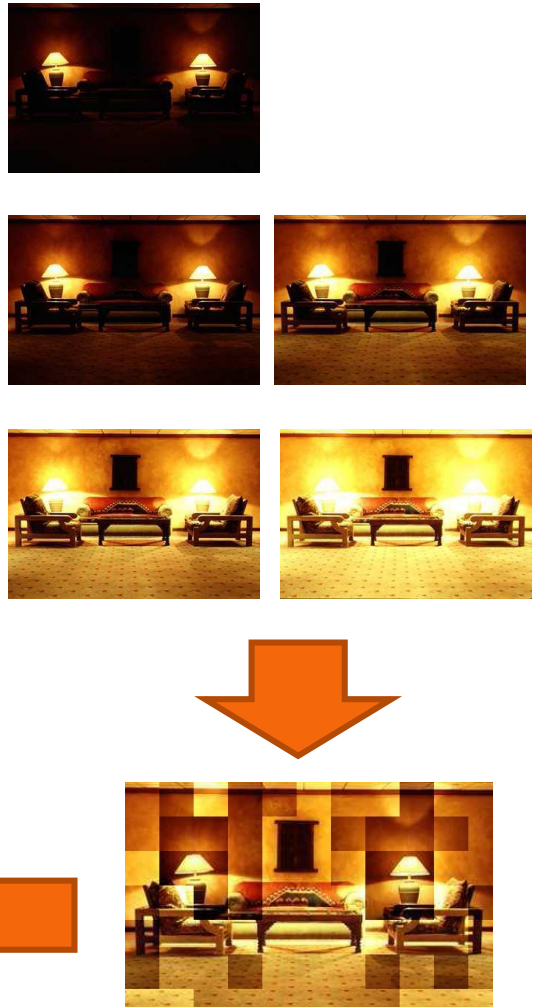
Vktech 60x microscope clip for Samsung Galaxy S4
Source: [Android Central]

Software Photo Processing

- Panorama creation
  - Horizontal and sphere (StreetView-like) panoramas
- High Dynamic Range images
  - Handling uneven lighting conditions
- Artificial depth-of-field simulation (”lens blur”)
  - Highlight what is important in the scene
  - Refocus: interactively select area after image capture

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

Artificial depth-of-field simulation

- ”Lens blur”
  - Wide DoF: (almost) everything is sharp in the scene
    - „Documentary”
  - Shallow DoF: only objects at a certain distance interval are sharp, others are blurred
    - Photographer can show what he/she thinks is important in the scene
    - **Hard to obtain using mobile camera modules due to physical constraints**

Photo by Sascha Haeberling

Photo without Lens Blur Photo with Lens Blur

Source: Google Research BlogSpot

Artificial depth-of-field simulation

- Usage (Google Camera)
  - Camera movement during exposition (small video)
    - See YouTube video
  - Estimating distance of object points
  - Follow-up interactive refocus using the depth map and blur strength

Source: Google Research BlogSpot

Photo by Colby Brown

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

Lens Blur Example

Photo by Rachel Been

Lens Blur selfie, background focus

Lens Blur selfie, foreground focus

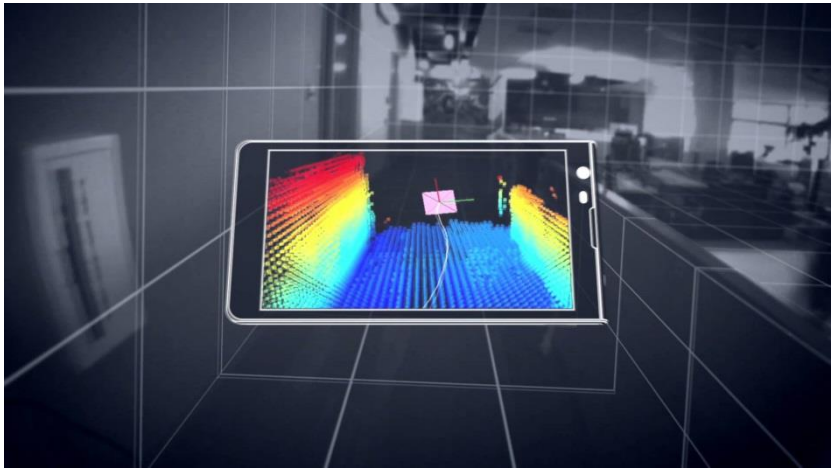
Source: Google Research BlogSpot

Recent Hardware Improvements

- Dual lens cameras
  - Lenses with two different focal lengths
    - Dual-lens smartphone cameras are coming, and this is why we want one
    - Can switch lenses to magnify more distant subjects without resorting to digital zoom
  - Lenses with different aperture
    - Honor 6 Plus: F/2 and F/2.4 apertures
      - It uses both cameras at the same time to capture several photos at different apertures
      - Lets 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

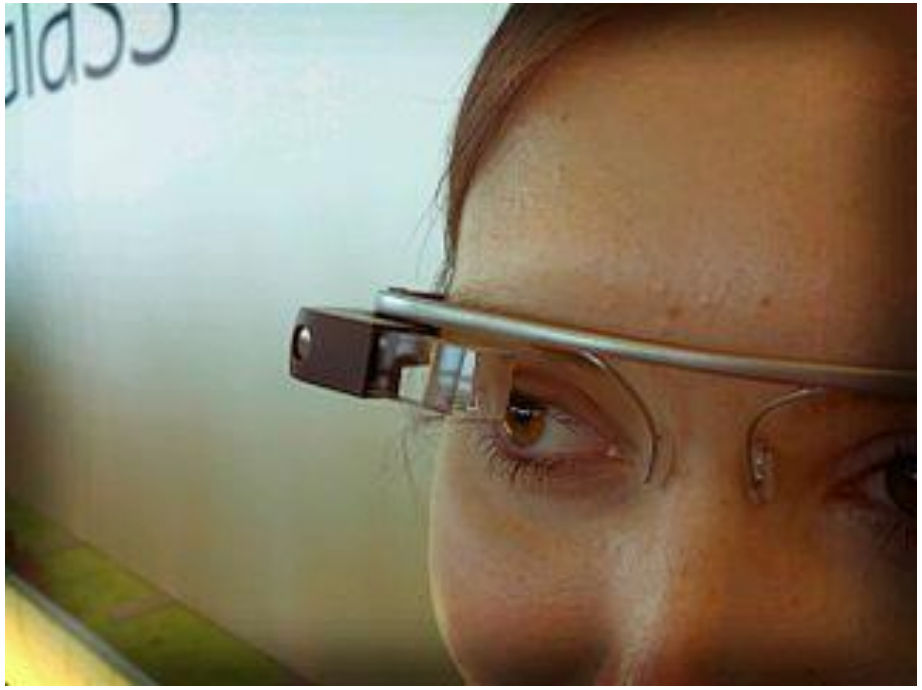
(Near) Future

- RGB-D sensor
  - Color + distance
    - Kinect-like sensor
  - Google Project Tango
    - Mapping 3D interior of rooms
    - Small distances (few meters)
    - No direct (sun)light
    - Development kit is available (in the USA)
    - Lenovo Phab 2 Pro phablet is coming (first commercial Tango device)
  - 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
    - Camera
  - Problems
    - Privacy concerns
    - Face recognition apps were forbidden from the official Glass app store!



Source: WikiMedia Commons

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

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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 → 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

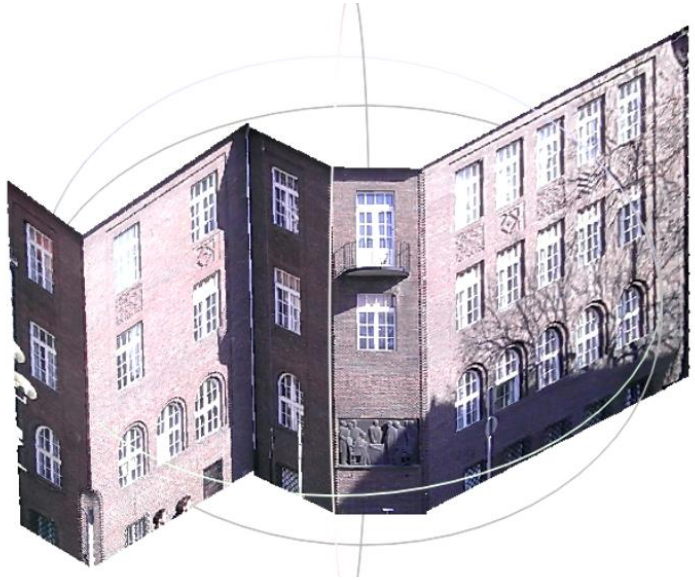
Collaborative Mobile Visual Computing

- **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

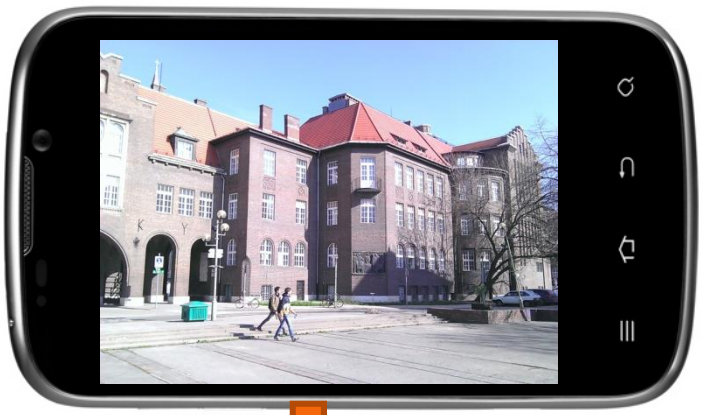


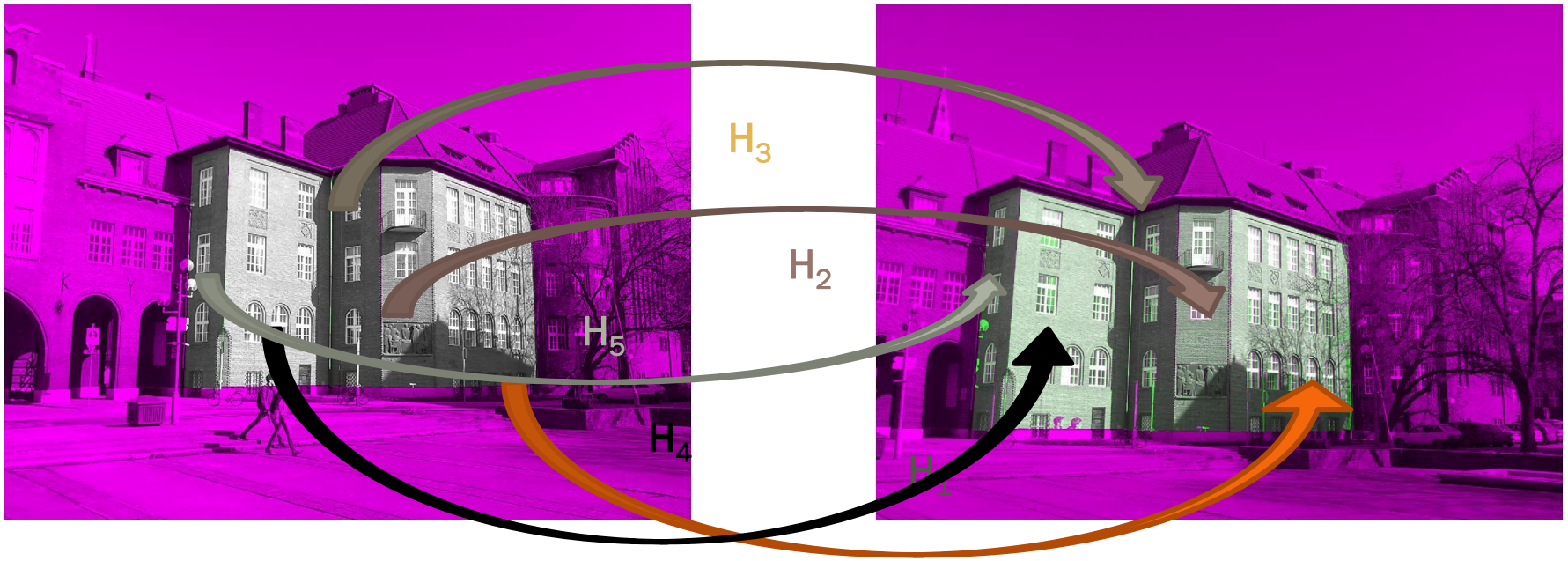
Stereo Reconstruction Pipeline

- **Large, near planar regions**
  - Two images from different viewpoints
  - Regions identified manually in one of the images

- **Correspondence**
  - Find the pair of the regions in the other image
    - Planar homography

- **Reconstruction**
  - 3D orientation and distance can be computed

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