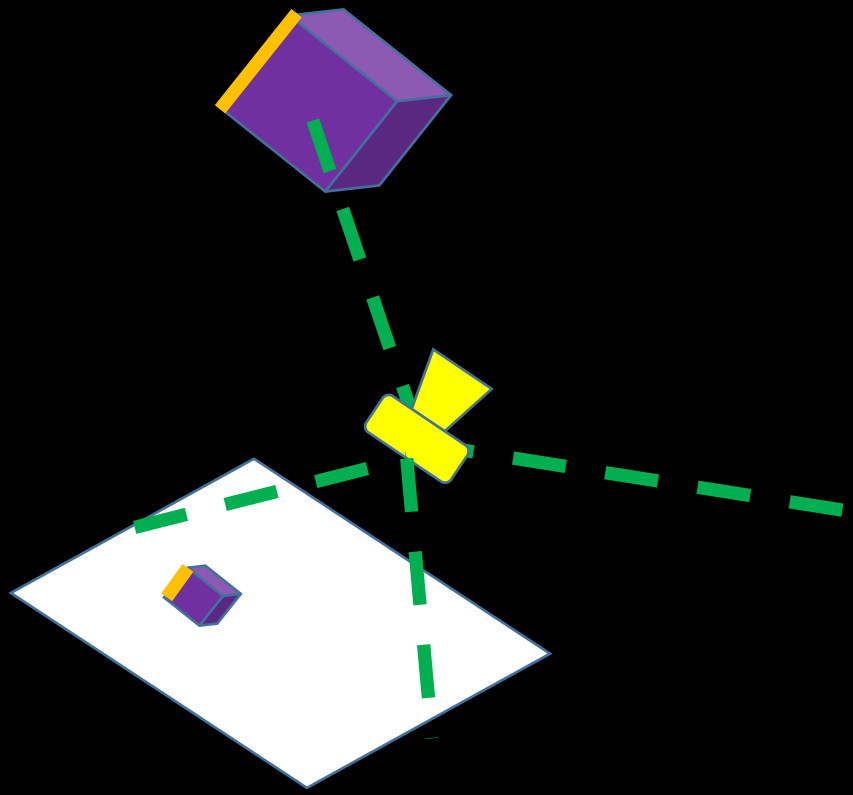
Part 2: Tracking, Registration and SLAM

Microsoft HoloLens

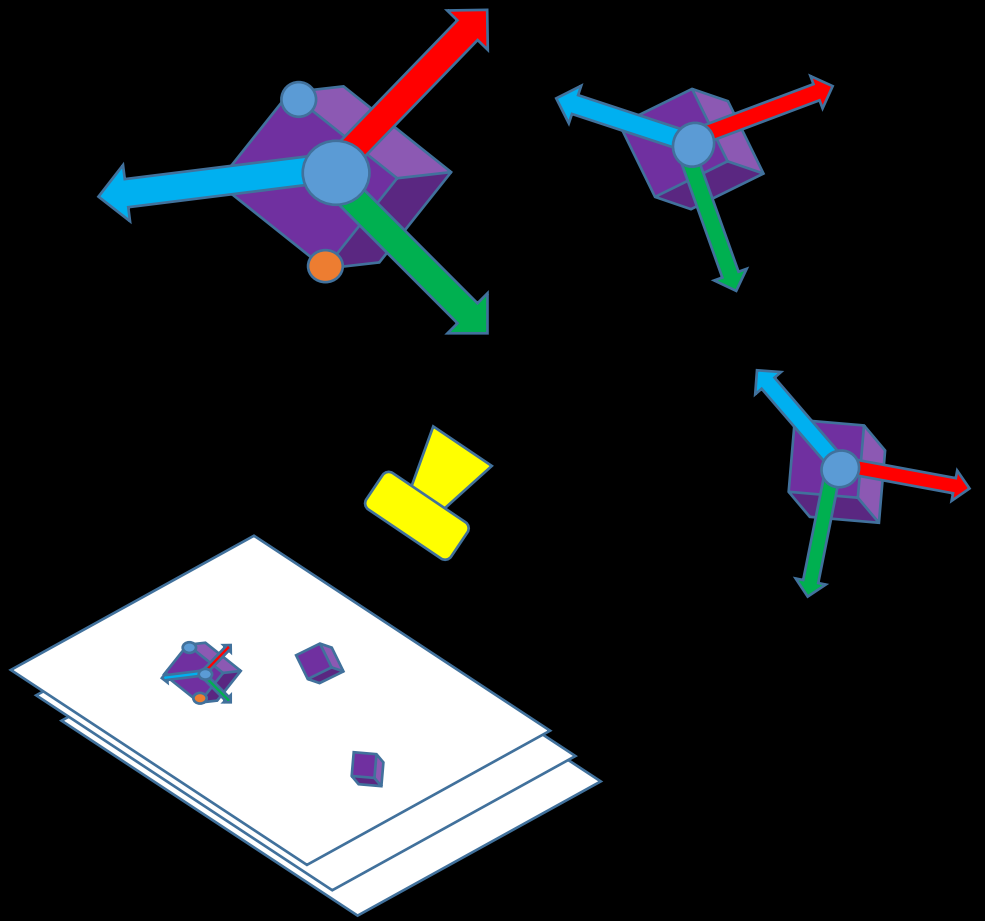
Tracking, Calibration and Registration

- Calibration
  - Associate virtual units to real units
  - Spatial, Angular



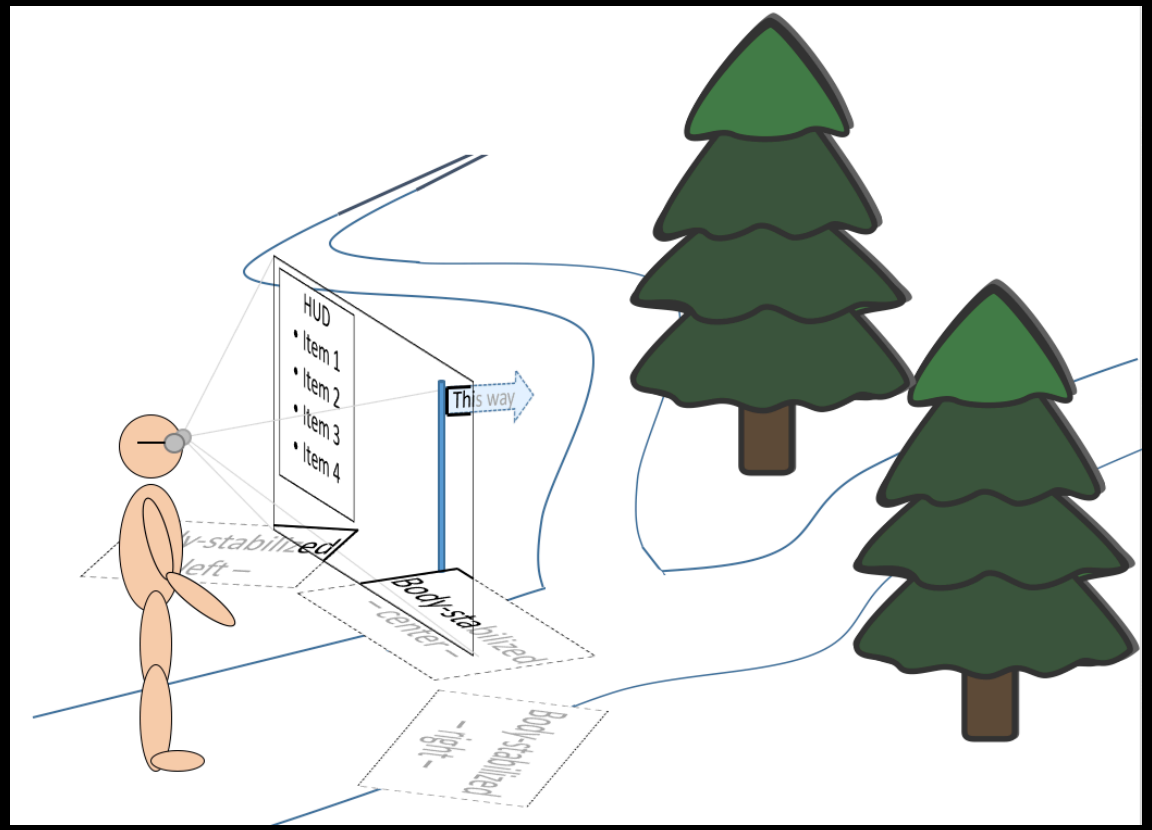
Tracking, Calibration and Registration

- Calibration
  - Associate virtual units to real units
  - Spatial, Angular
- Registration
  - Figure out correspondences
  - Align coordinate systems
- Tracking
  - Dynamic update of registration



Frames of Reference

- Word-stabilized
  - E.g., billboard or signpost
- Body-stabilized
  - E.g., virtual tool-belt
- Screen-stabilized
  - Heads-up display



Aspects of Tracking

- Electromagnetic radiation
  - Visible light
  - Infrared light
  - Laser light
  - Radio signals
  - Magnetic flux
- Sound
- Physical linkage
- Gravity
- Inertia

- Signal strength
- Signal direction
- Time of flight
  - Absolute time
  - Signal phase
  - Synchronized clocks

- DOF = independent dimension of measurement
- Full tracking requires 6DOF
  - 3DOF position (x, y, z)
  - 3DOF orientation (roll, pitch, yaw)
- Some sensor deliver only a subset
  - E.g., gyroscope → 3DOF orientation only
  - E.g., tracked LED → 3DOF position only
  - E.g., mouse → 2DOF position only

Stationary Tracking: Mechanical

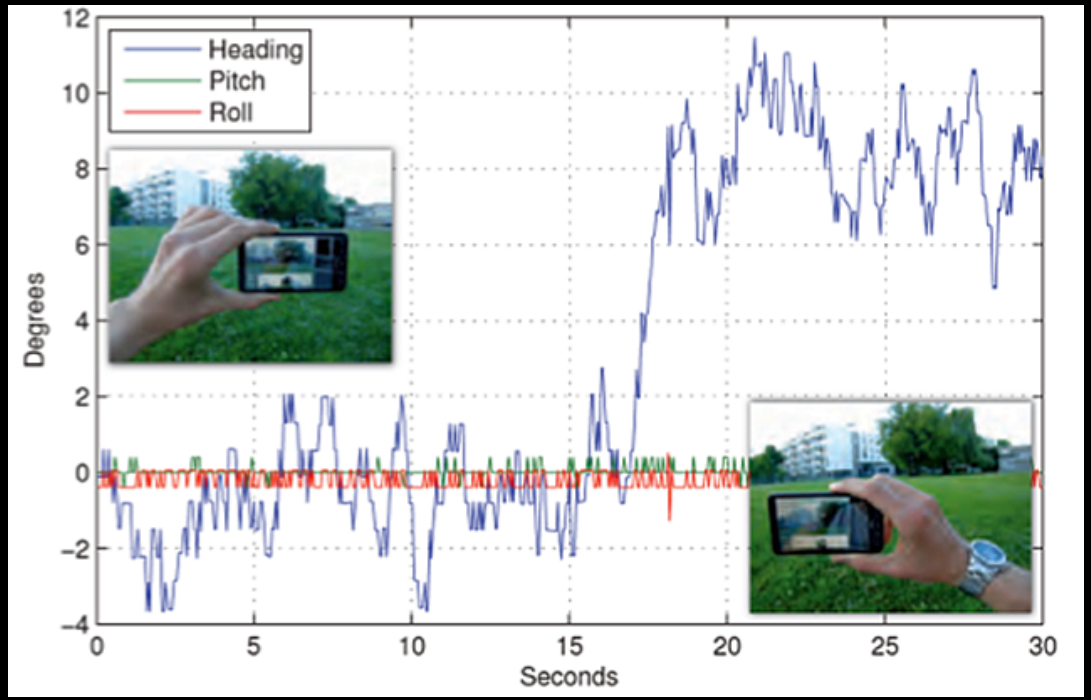
- Track end-effector of articulated arm
- Joints with 2 or 3 DOF
- Rotary encoders or potentiometers
- High precision
- Fast
- Freedom of operation limited

Fakespace BOOM

CyberGrasp

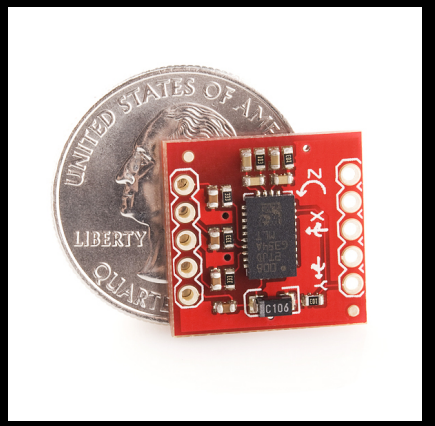
Mobile Tracking: Magnetometers

- Electronic compass
- Measure direction of Earth magnetic field in 3D
- Principle: magnetoresistance (Hall effect)
- Often very distorted measurements



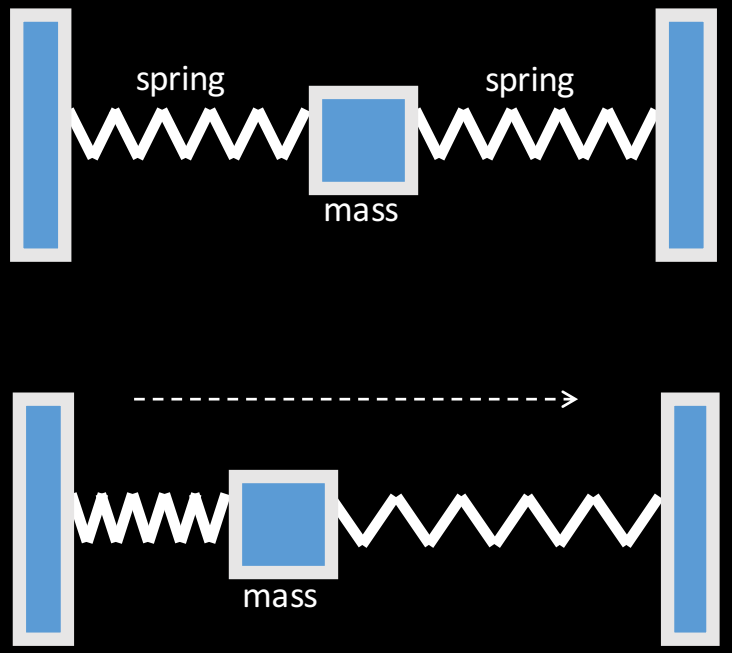
Mobile Tracking: Gyroscopes

- Determines rotational velocity
- Electronic gyro
  - Measures Coriolis force of small vibrating object
  - Micro-electromechanical system (MEMS)
  - High update rate (1KHz)
  - Only relative measurements
  - Must integrate once to determine orientation → drift



Mobile Tracking: Accelerometer

- MEMS device
- Displacement of small mass
- Measures
  - Change of electric capacity, or
  - Piezoresistive effect of bending
- Subtract gravity (the difficult part!)
- Integrate twice numerically to get position
- Drift problems
- Linear accelerometer+ Gyroscope + Compass = *inertial measurement unit* (IMU)

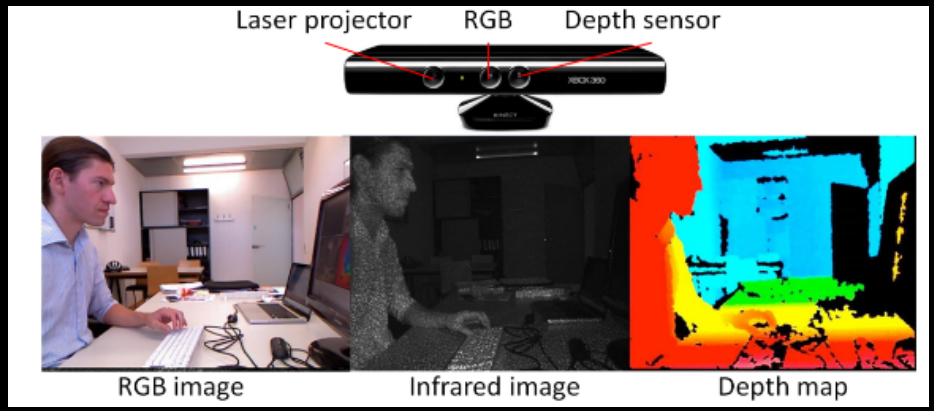


Optical Tracking

- Track features
  - Markers
    - Active and Passive
    - Fiducial and Natural
  - Illumination
    - Natural, Infrared and Structured
  - Cameras
    - RGB and Depth
  - Algorithms
    - Model-based and Model free

Optical Tracking: Illumination

- Passive illumination
  - Natural (or existing) light sources
  - Visible spectrum 380-780nm
  - Cannot track when it is too dark (mostly indoors)
- Active illumination
  - Often infrared spectrum
  - LED beacons
  - Camera with infrared filter delivers high contrast
  - Not suitable with sunlight
- Structured light
  - Project a known pattern into the scene
  - Projector with regular light or laser
  - Laser ranging



HTC Vive "Lighthouse" Tracking System

Leap Motion

- 2 cameras, 3 infrared LEDs
- Short-distance reflection of the hands

Optical Tracking: Markers

- Fiducial Markers
  - Known pattern
  - Square, Circular, Pulsed LEDs
- Retro-reflective markers
  - Motion capture

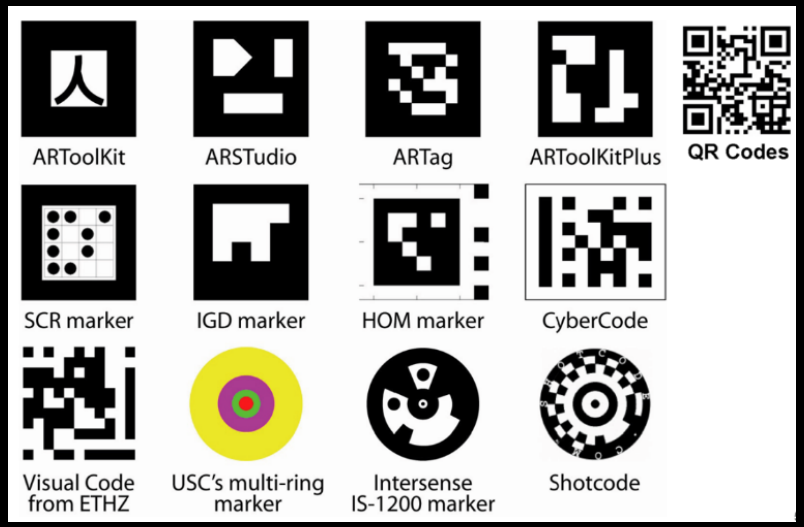


Image: Daniel Wagner

www.augmentedrealitybook.org

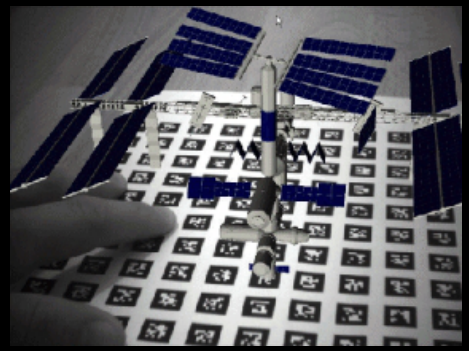


Image: Mark Fiala

Image: Andrei State, UNC Chapel Hill

Optical Tracking: Markers

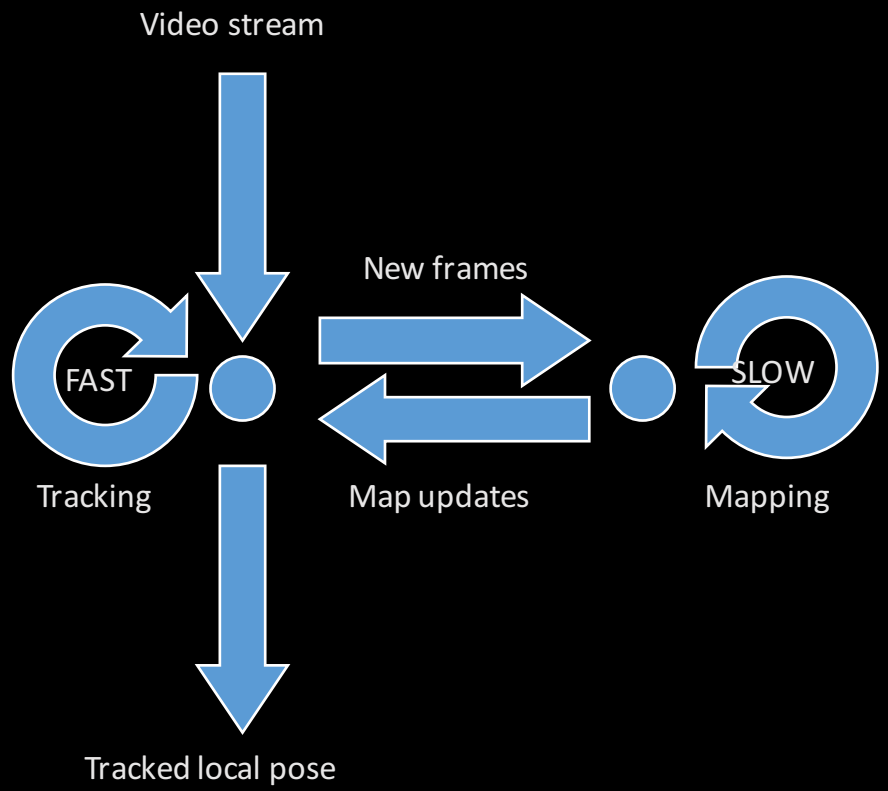
- Natural Markers
  - Corner or Edge Features
  - Stable
  - Textured surfaces
  - Compiled into descriptors and stored
  - Correspondence
    - Multi-camera constraints
    - RANSAC
  - Structure from Motion
    - Bundle Adjustment

Building Rome in a Day,
Agarwal et al., ICCV 2009

SLAM

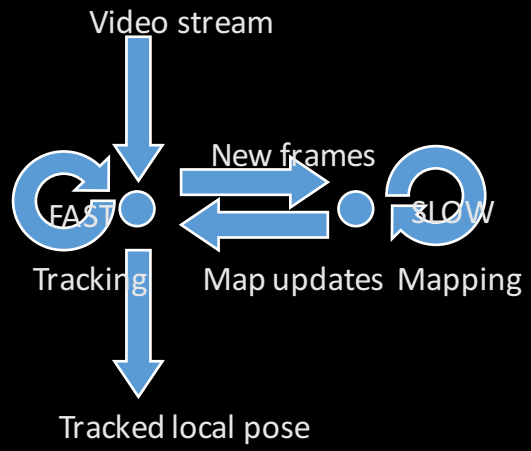
- **S**imultaneous **L**ocalization **a**nd **M**apping
- Standard SLAM: Repeat until tracking is lost
  - Extract features from live image (or track features in image)
  - Match features to existing map
  - Determine camera pose from matched 3D points
  - Try to triangulate new features to get new 3D points
  - Insert any new 3D points into map (or update existing map points)
- Keyframe SLAM
  - Build map only from selected keyframes
  - Split tracking and mapping into two threads
  - Tracking at framerate, mapping at slower rate

Parallel Tracking and Mapping (PTAM)



Parallel Tracking and Mapping for Small AR Workspaces,Klein and Drummond, ISMAR 2007

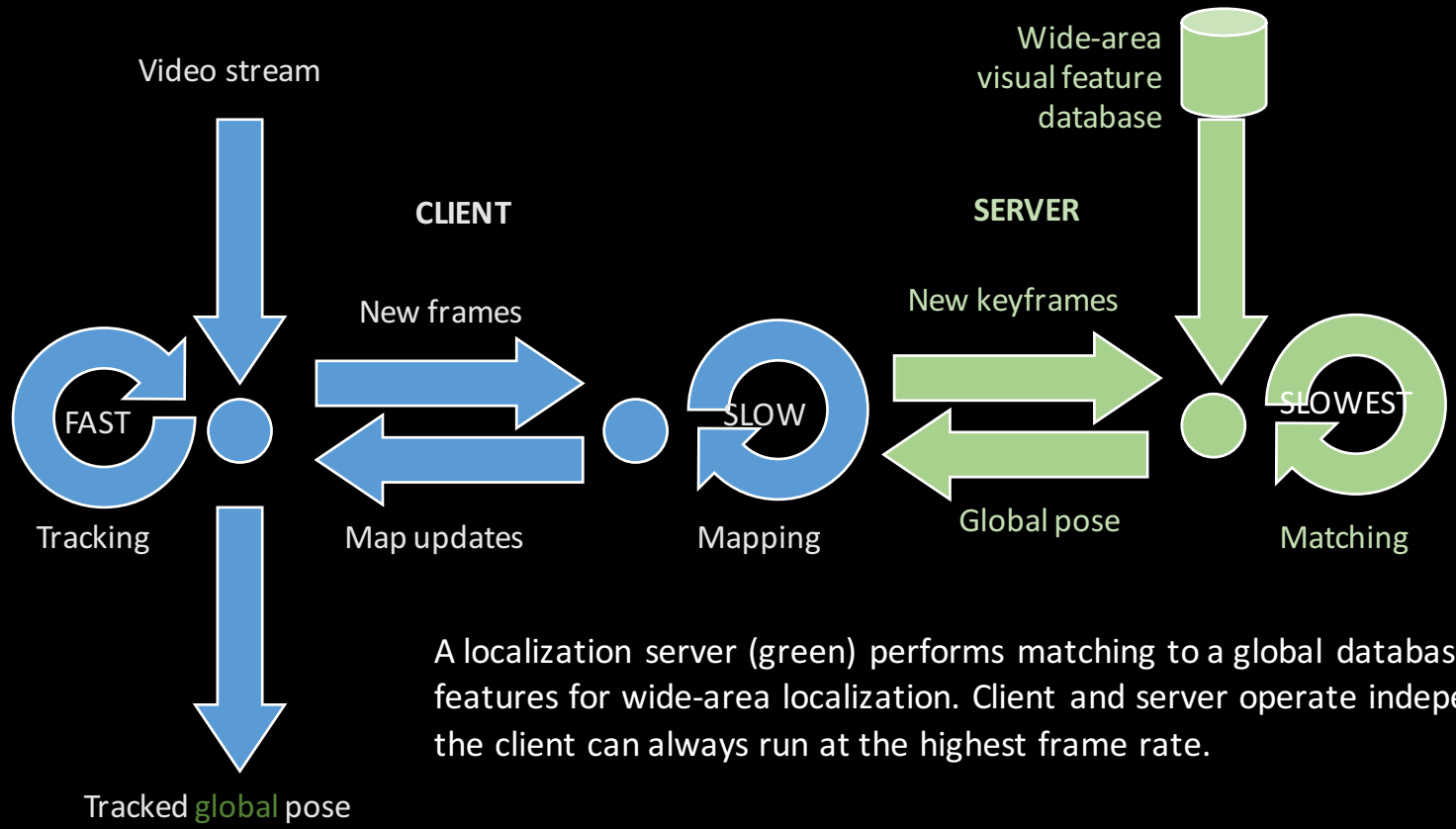
Parallel Tracking and Mapping (PTAM)



On the train to Kyoto

Parallel Tracking and Mapping for Small AR Workspaces, Klein and Drummond, ISMAR 2007

PTAM + Wide area localization



A localization server (green) performs matching to a global database of visual features for wide-area localization. Client and server operate independently, so the client can always run at the highest frame rate.

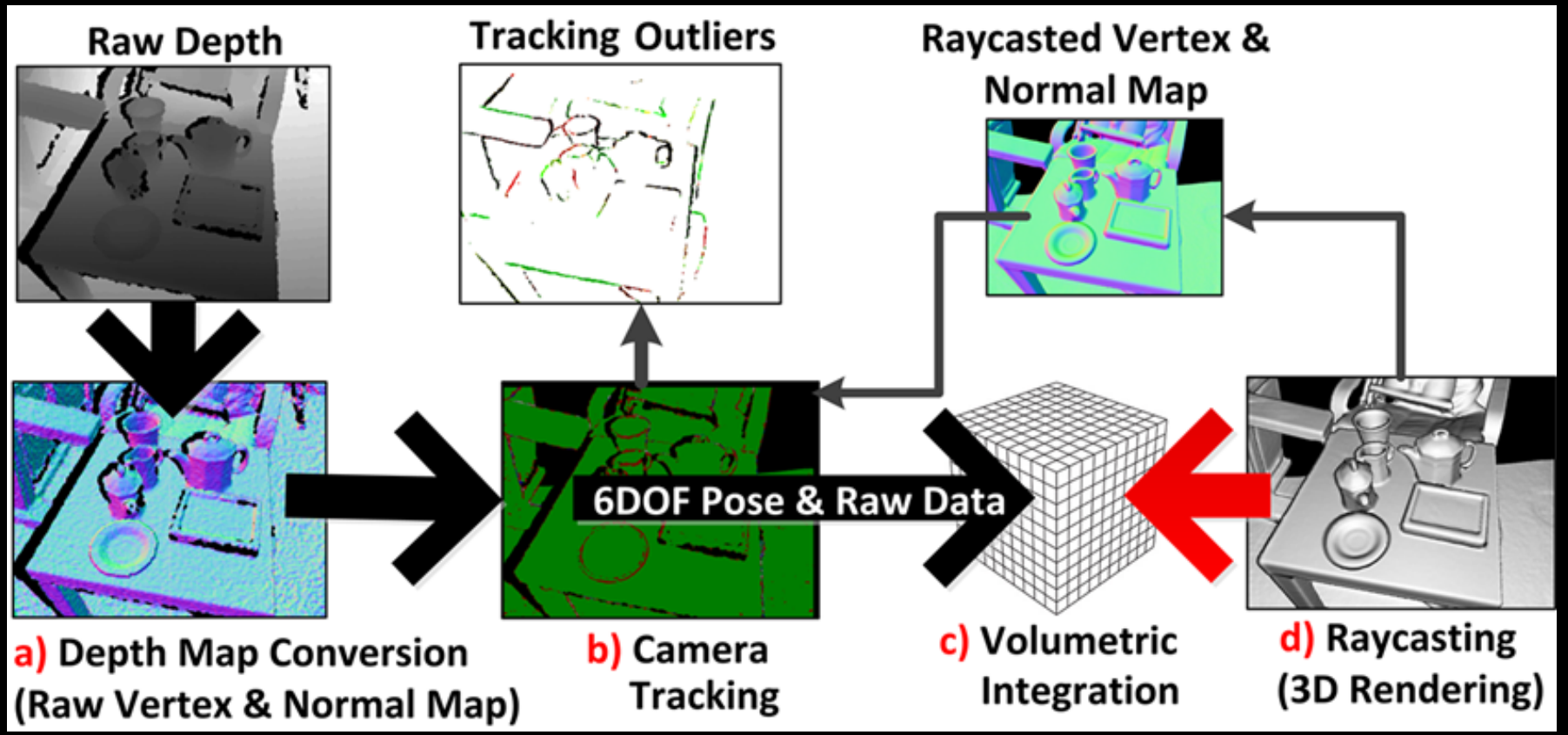
Instant Outdoor Localization and SLAM Initialization from 2.5D Maps

Clemens Arth, Christian Pirchheim, Jonathan Ventura, Dieter Schmalstieg and Vincent Lepetit

Graz University of Technology

ISMAR 2015

Dense SLAM: Kinect Fusion



KinectFusion: Real-Time Dense Surface Mapping and Tracking, Newcombe et al., ISMAR 2011

Scalable Real-time Volumetric Surface Reconstruction

Jiawen Chen Dennis Bautembach Shahram Izadi

Microsoft Research, Cambridge, UK

ACM SIGGRAPH 2013
Technical Papers

(contains audio)