GPU TECHNOLOGY CONFERENCE

TEGRA K1 AND THE AUTOMOTIVE INDUSTRY

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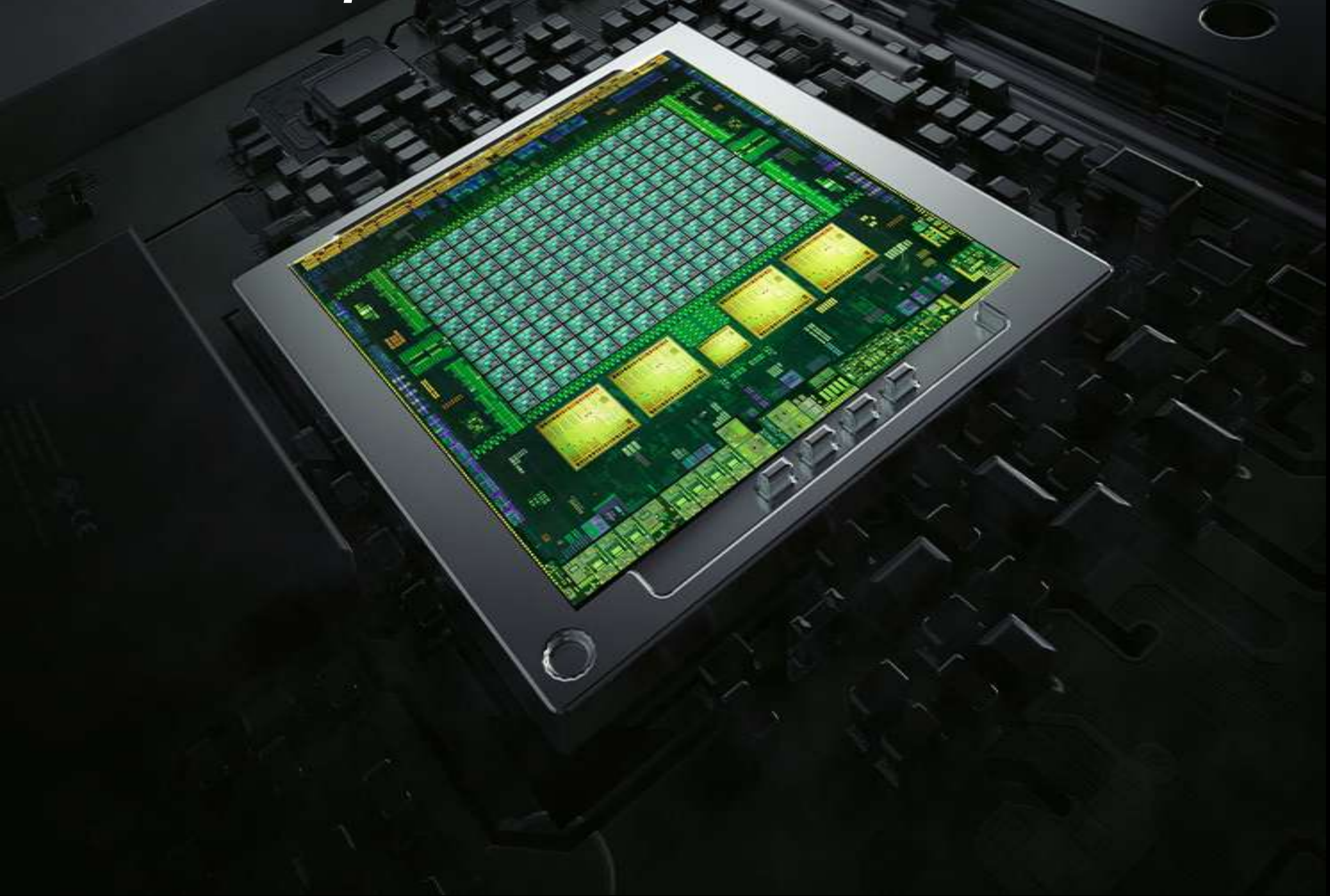
Previously:
Tegra in Automotive

Infotainment / Navigation

Digital Instrument Cluster

Passenger Entertainment

TEGRA K1
with Kepler GPU



GPU:
CUDA - Data-Parallel Processing
with Kepler architecture (sm_32)

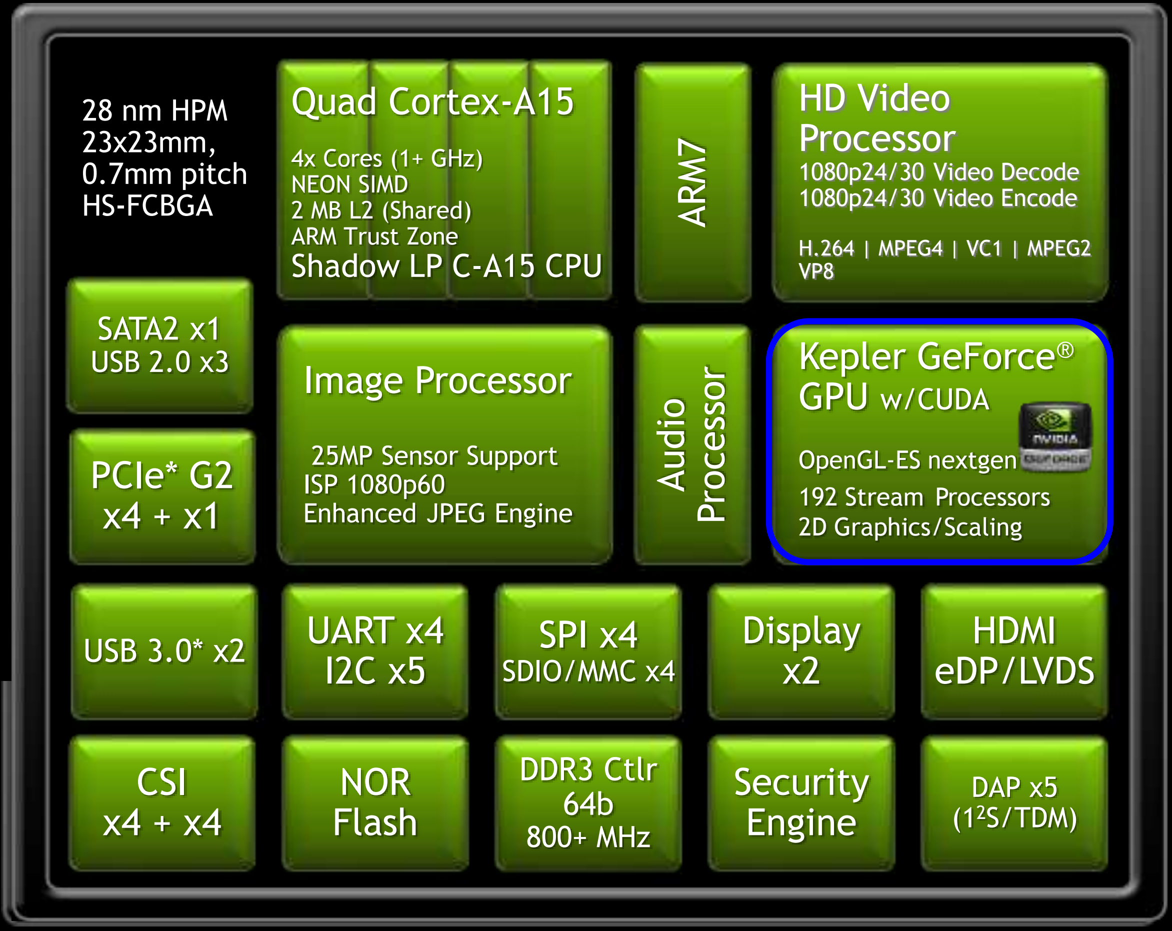
192 CORES (1 SM): > 200 GFLOPS

CPU:
- 4 x A15 ARM cores w/ NEON

Memory:
- Shared CPU/GPU:
- 12GB/S BANDWIDTH

GPU USE for COMPUTER VISION

TEGRA K1



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Misc:
- Video Codec Engine (incl. Motion Estimation Engine)

- several other hardware units (e.g. Video preprocessing)

MAJOR PERFORMANCE IMPROVEMENTS FOR MOBILE APPLICATIONS

Hence,
Tegra K1's added goal:

and, ultimately:
autonomous driving!

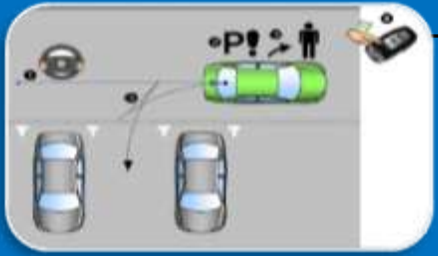
PATH TO AUTONOMOUS DRIVING CAR

Routine Driver Assistance

• • •

1 camera CV
4 camera visual

Piloted Drive & Autonomous Parking



4-6 camera CV
4 camera visual

Autonomous Drive

6-8 camera CV
4 camera visual

Today — 2016 — 2020

PATH TO AUTONOMOUS DRIVING CAR

Driver Assistance

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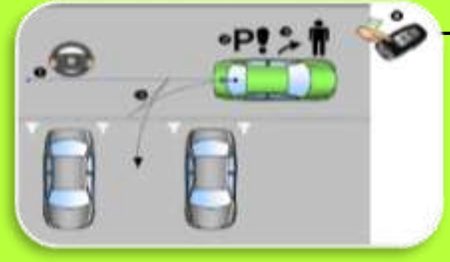
Piloted Drive & Autonomous Parking



4-6 camera CV

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Autonomous Drive

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Today → 2016 → 2020

Previous Use: Driver Assistance

Pedestrian Detection
Blind Spot Monitoring
Lane Departure Warning

Collision Avoidance (*)
Traffic Sign Recognition
Adaptive Cruise Control

Limitation due to one camera processed:
Car had little notion of 3D surroundings
(exception: CollAvoidance *).

A map of 3D surroundings is
only in *driver's head*...

Autonomous Parking & Piloted Drive: Goals

- Car must navigate itself (albeit at low speeds)
- Needs notion of
  - **Own 3D motion and position** (beyond GPS & wheels)
  - **Obstacles** (Curbs, other cars, pedestrians,...)
  - **Free space** (for Parking)

Computer Vision: 3D Mapping!

"STRUCTURE FROM MOTION"

- On-the-fly 3D scene from camera @ 30 fps
- Reconstructs the "Structure" (3D point cloud) from "Motion" (moving features in video)
- Provides input for high-level processing (e.g. lane and curb detectors, parking cars)
- Note: Assumes mostly <u>static</u> scene outside!

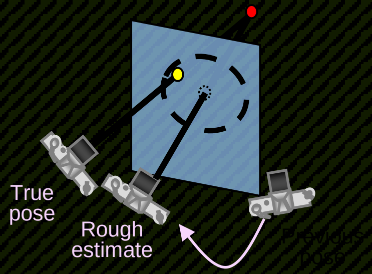
STRUCTURE FROM MOTION

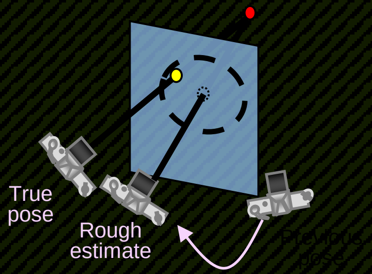
Feature Detection

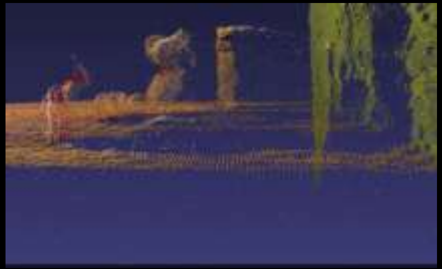
Feature Tracking

Camera Position & Motion

Triangulation (3D Scene)



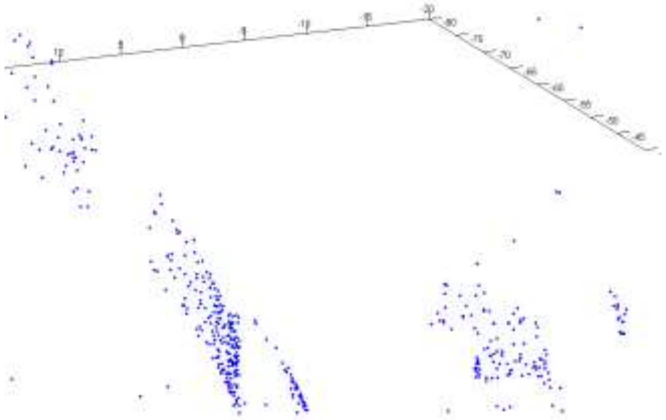




EXAMPLE ADAS APPLICATION

- Structure From Motion

Static Scene, Moving Camera



3D Point Cloud &
Camera Motion (R,t)

STRUCTURE FROM MOTION

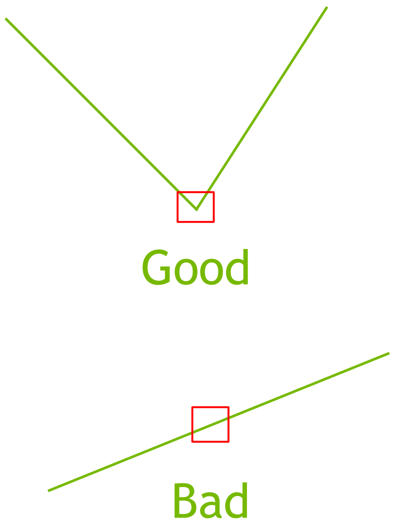
- Input
  - Frames from Calibrated Camera
- Pipeline Overview
  - Harris Corner Detection
  - Image Pyramid Creation
  - Multi-Scale Lucas-Kanade Sparse Optical Flow
  - RANSAC
  - Triangulation
- GPU Implementation
  - CUDA Kernels
  - Are now available as part of Vision Works!

FEATURE DETECTION

- TASK
  - Find a sparse set of points that can be tracked reliably
  - The points should cover the images somewhat evenly
- IMPLEMENTATION
  - Harris Filter to find corners in the image
  - 3x3 Filter Size, Scharr Derivates

$$A = \sum_u \sum_v w(u,v) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} = \begin{bmatrix} \langle I_x^2 \rangle & \langle I_x I_y \rangle \\ \langle I_x I_y \rangle & \langle I_y^2 \rangle \end{bmatrix}$$

  - Image is split into 16x16 Blocks
  - At most one corner returned per Block



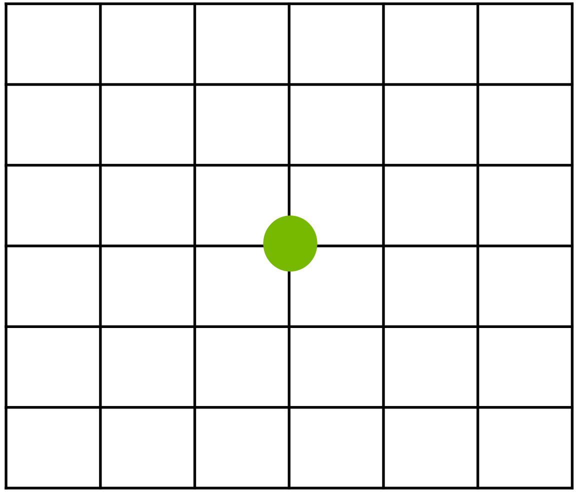
HARRIS CORNER

- Result
  - Frame Size: 1280x800
  - 646 Corners Found
  - ROI via Mask Image
- Performance
  - 715 us

FEATURE TRACKING / SPARSE OPTICAL FLOW

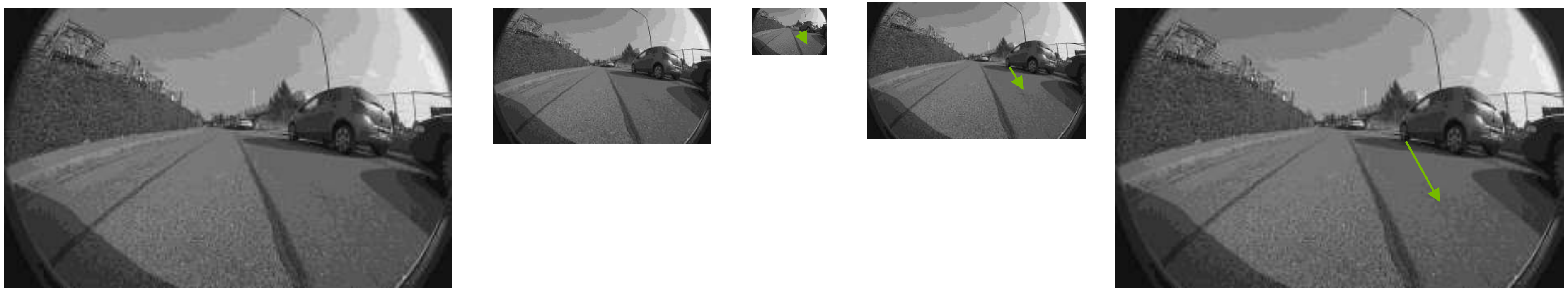
- TASK
  - Find the locations of corresponding corners between two frames
- Implementation
  - Multi-Scale Lucas-Kanade Optical Flow
  - 6x6 Window Size, Scharr Derivatives (Symmetric Window!)
  - 6 Pyramid Levels

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i) I_y(q_i) \\ \sum_i I_y(q_i) I_x(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i) I_t(q_i) \\ -\sum_i I_y(q_i) I_t(q_i) \end{bmatrix}$$



MULTI-SCALE

LK Upscale & LK Upscale & LK



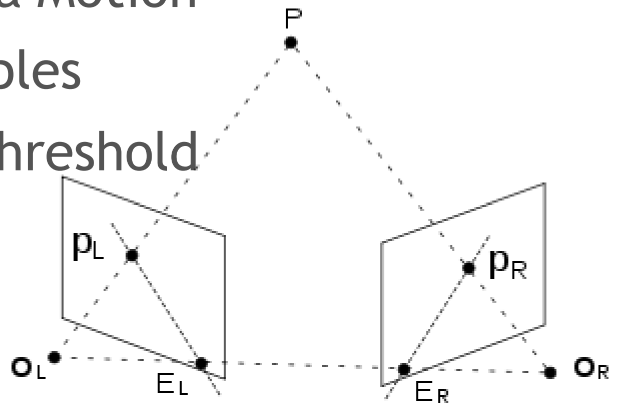
ORIGINAL ½ ¼

MULTI-SCALE LUCAS-KANADE FLOW

- Result
  - 609 Tracks
- Pyramid
  - 445 us
  - 5+1 Levels
- LK
  - 1080 us
  - 6x10 Iterations

OUTLIER FILTERING

- TASK
  - Filter Feature Tracks that are not in correspondence with a Camera moving in a static 3D World
- IMPLEMEMENTATION
  - RANSAC: Random Sample Consensus
  - 7 Tracks are sufficient to compute the Camera Motion
  - Generate many Hypothesis from random samples
  - Inlier if Angular Reprojection Error is below Threshold (Oliensis, PAMI, 2002)
  - Sample with highest # of Inlier is Winner

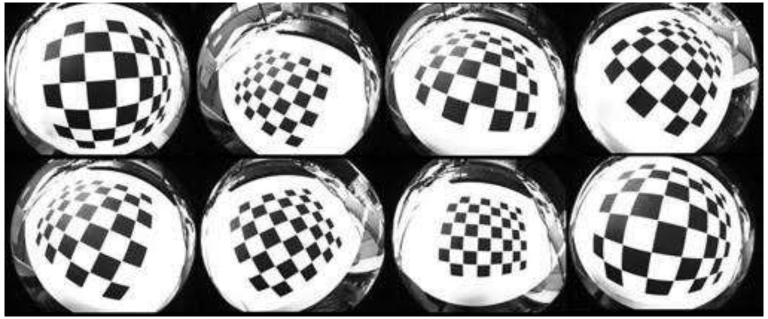


RANSAC + CAMERA MOTION?

- Result
  - 545 Tracks
  - Rotation Matrix
  - Translation Vector
- Performance
  - 54 Iterations
    (max 30% Outlier)
  - 975 us

CAMERA CALIBRATION

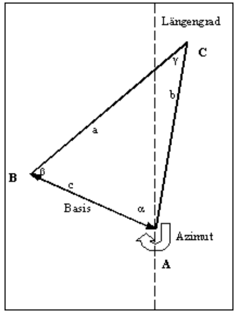
- TASK
  - Find the relation between Pixel location and Optical ray
- IMPLEMENTATION
  - Lens with large viewing angle best for ADAS
  - Need Camera Model that can handle those
  - We use the model proposed by Scaramuzza and his MATLAB toolbox to calibrate our Camera (https://sites.google.com/site/scarabotix/ocamcalib-toolbox)



TRIANGULATION

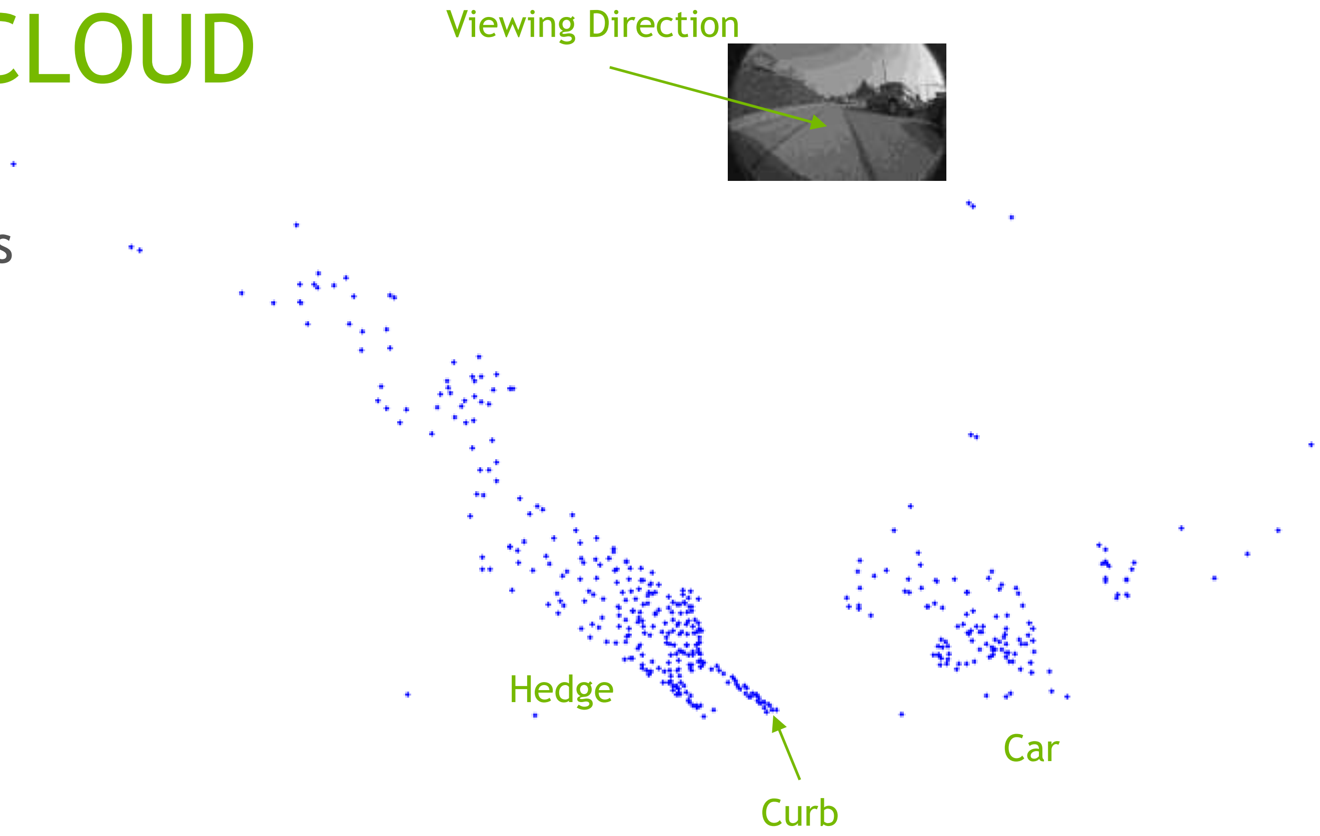
- TASK
  - Find 3D Points for Tracks given Camera Calibration and Motion
- IMPLEMENTATION
  - Compute Rays for Feature Locations from Camera Calibration
  - Least-Squares Solution (Rays will not intersect in practice)

$$\hat{\beta} = (X^T X)^{-1} X^T y \, .$$



3D POINT CLOUD

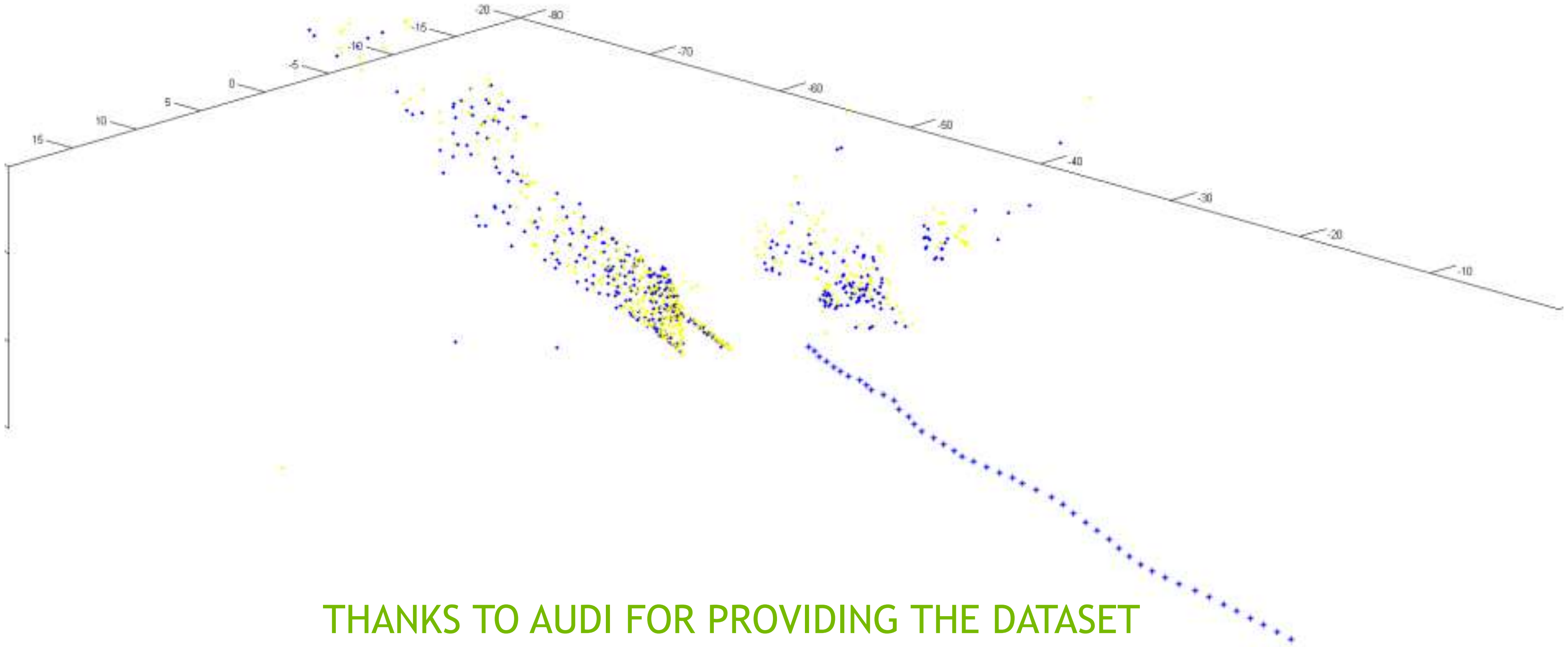
- Result
  - 446 3D Points
- Performance
  - 70 us



TIMING SUMMARY

Function	Total GPU Time in Microseconds (10^{-6} sec)	Comment
Harris Corner	715 us	Feature Detection
Down Sampling	445 us	Pyramid Creation
Lucas-Kanade Optical Flow	1080 us	Feature Tracking
RANSAC	975 us	Outlier Filtering + Relative Camera Motion
Triangulation	70 us	3D Point Cloud
TOTAL	3285 us (3.3 ms)	SfM Time per Frame and Camera

SFM DEMO



THANKS TO AUDI FOR PROVIDING THE DATASET