SuperPoint: Self-Supervised Interest Point Detection and Description

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Research @ Magic Leap

CVPR 2018 Deep Learning for Visual SLAM Workshop

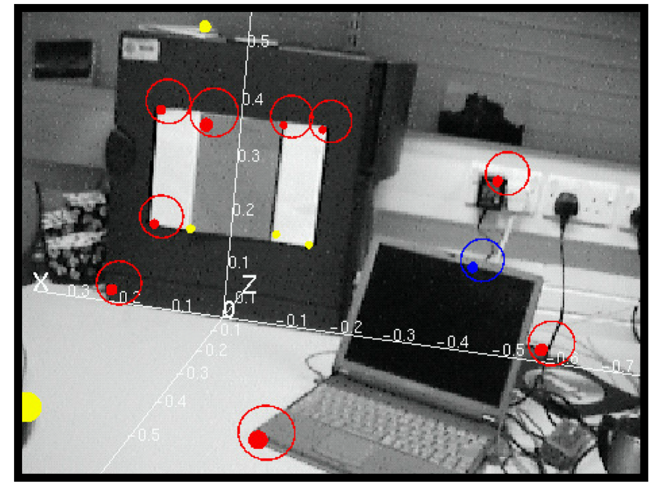
Main Ideas

- "SuperPoint"
    - A Deep SLAM Frontend
    - Multi-task fully convolutional network
    - Designed for Real-time
- "Homographic Adaptation"
    - Self-supervised recipe to train keypoints
    - Synthetic pre-training
    - Homography-inspired domain adaptation

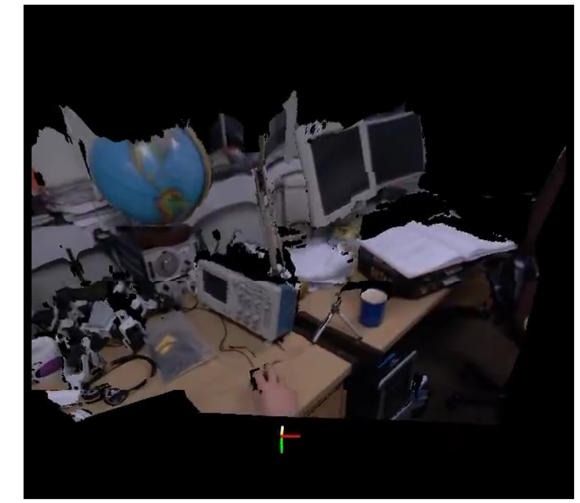
2000-2015 Visual SLAM

- Great Visual SLAM Research
- Real-time systems emerge
- Very few learned components

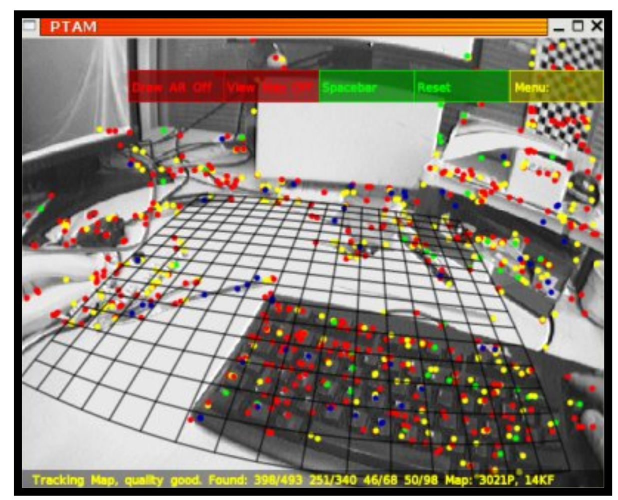
MonoSLAM



DTAM

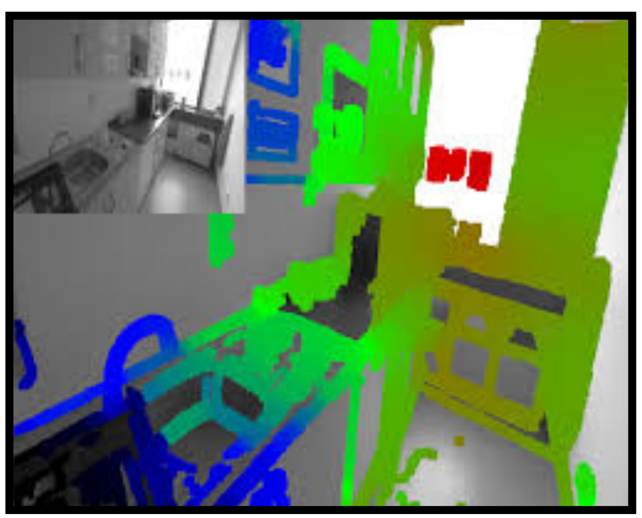


PTAM



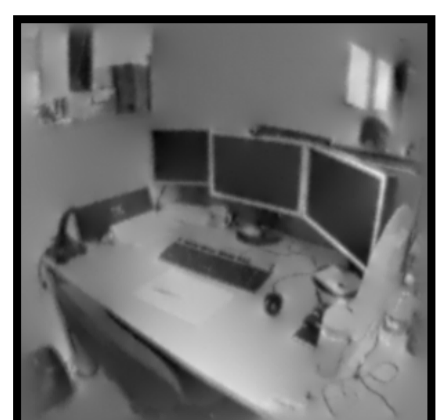
ElasticFusion

LSD-SLAM



KinectFusion

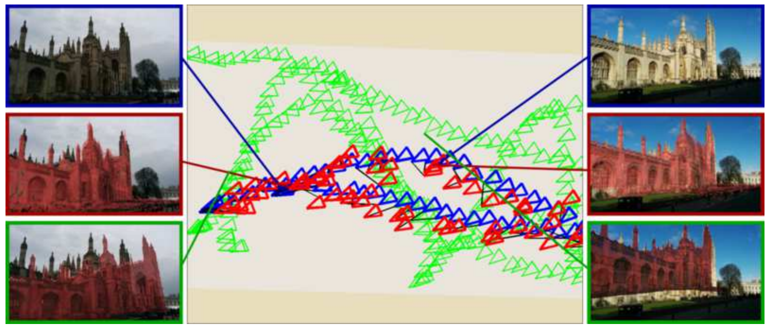
Event-camera SLAM



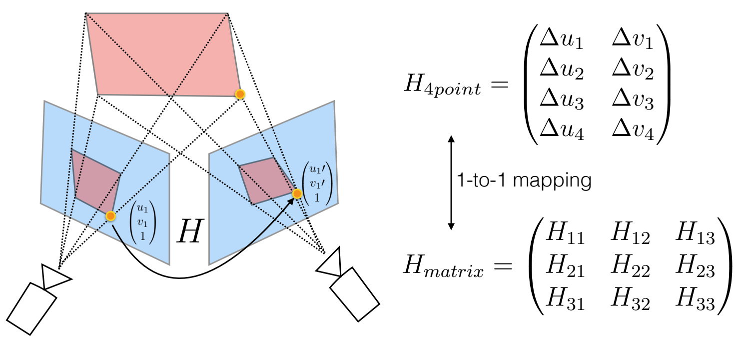
DynamicFusion

Collage courtesy: Andrew Davison's ICCV 2015 Future of Real-time SLAM workshop talk

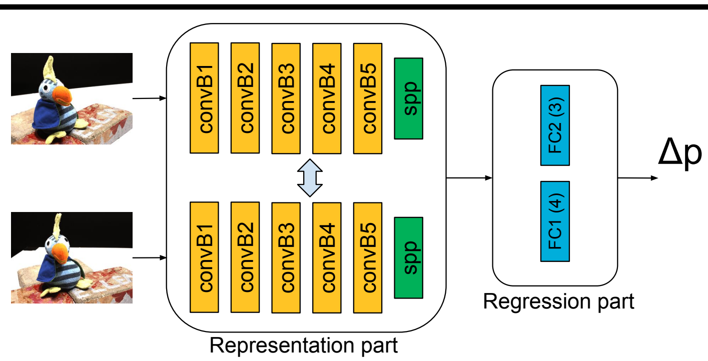
2015-2016: Simple End-to-End Deep SLAM?



PoseNet: A Convolutional Network for Real-time 6 DOF Localization



Deep Image Homography Estimation

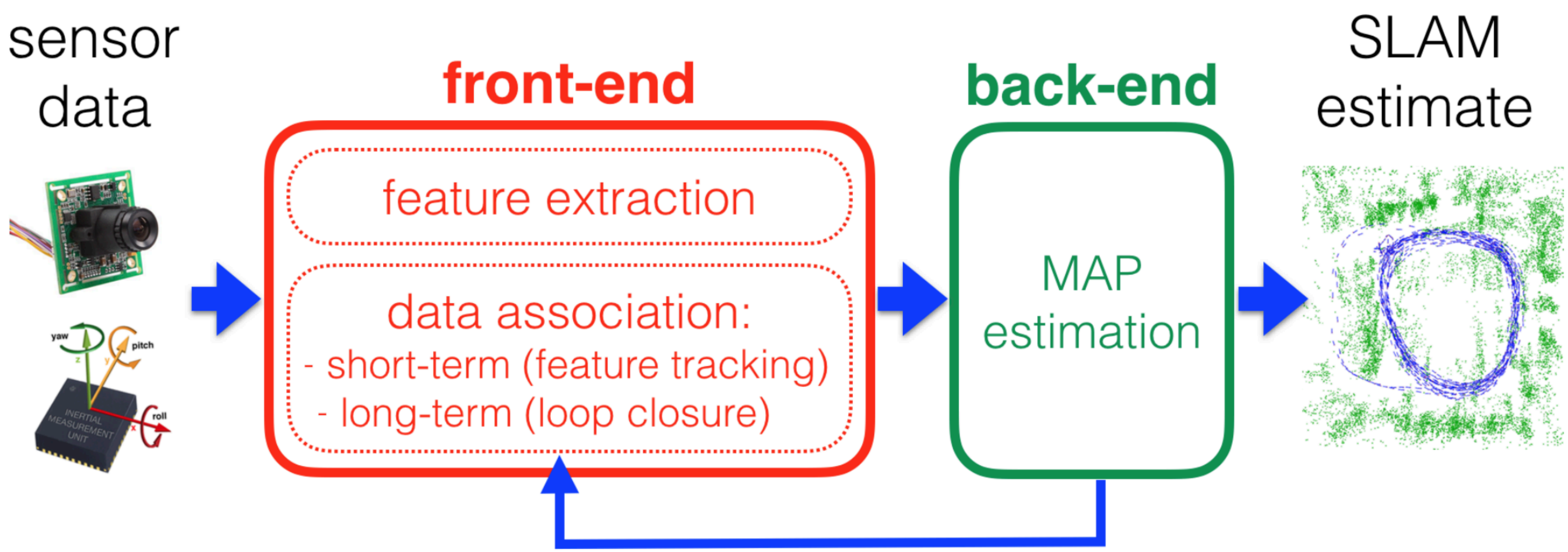


Relative Camera Pose Estimation Using Convolutional Neural Networks

Image(s) → Deep Network → Camera Pose / Map

- Deep Learning excitement is very high
- Simple end-to-end setups work across many computer vision tasks
  - Purely data-driven, powerful
  - Very few heuristics / little hand-tuning
- Accuracy not yet competitive
  - Maybe due to lack of large-scale data

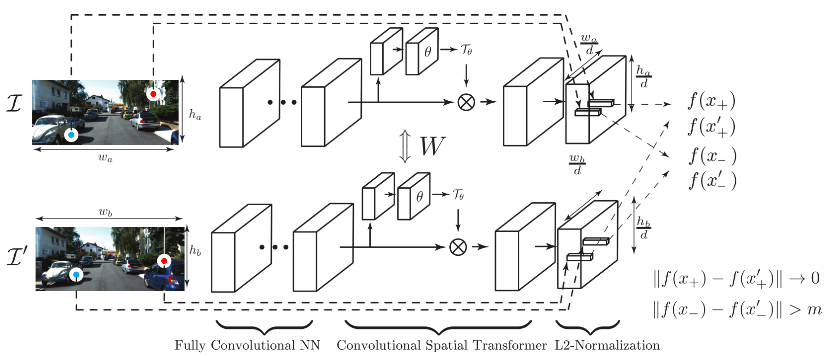
2017-2018: Splitting Up the Problem



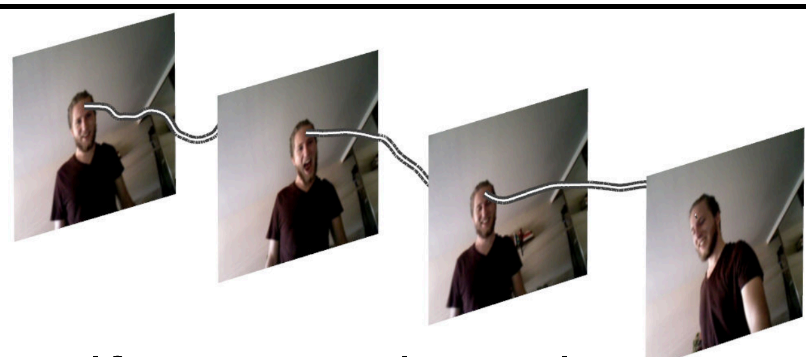
- **Frontend**: Image inputs
  - Deep Learning success: Images + ConvNets
  - Most of current work "deep-ifys" the Frontend -> Focus of this talk
- **Backend**: Optimization over pose and map quantities
  - 2018: Early deep learning work -> Focus of other oral at 12:05pm

Photo Credit: Cadena et al 2016

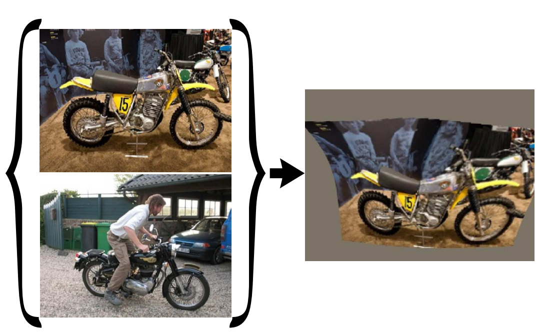
2017-2018 Deep Frontends: Dense



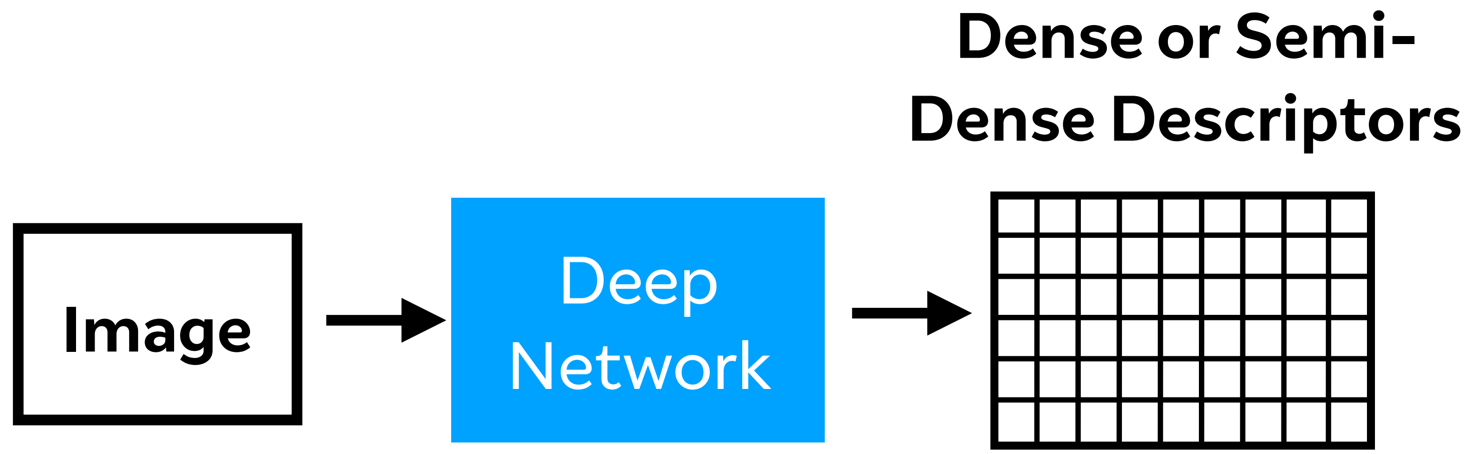
Universal Correspondence Network



Self-supervised Visual Descriptor Learning for Dense Correspondence

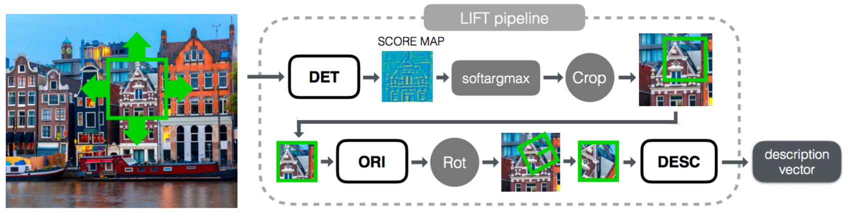


Convolutional neural network architecture for geometric matching

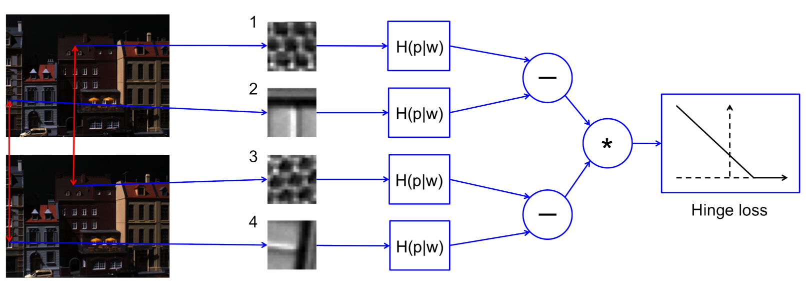


- Dense output approaches
- <u>Powerful</u> Matchability
- Not practical in low-compute SLAM systems
  - Too expensive for realtime BA

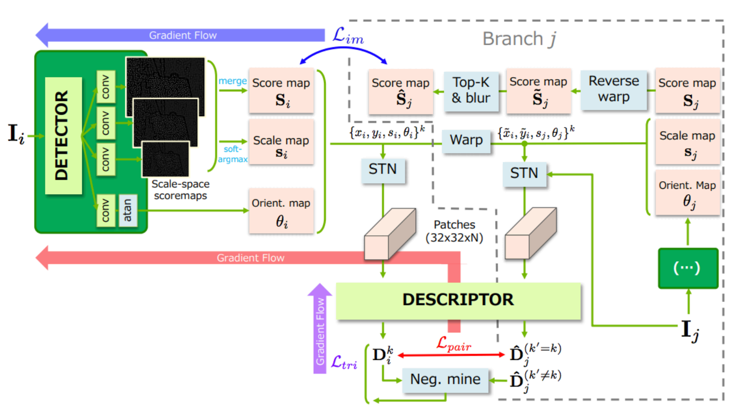
2017-2018 Deep Frontends: Sparse



LIFT: Learned Invariant Feature Transform

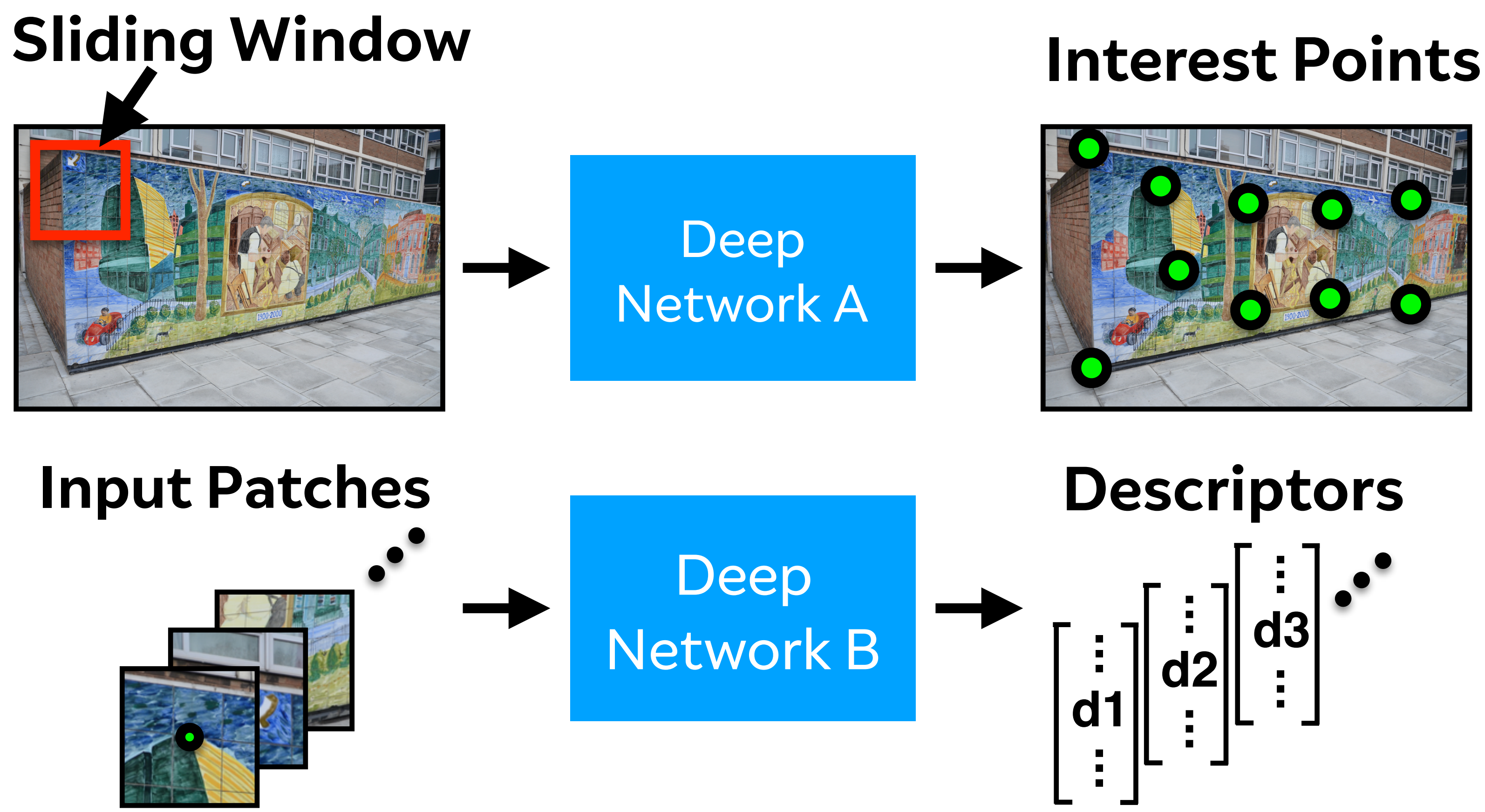


QuadNetworks: Unsupervised Learning to Rank for Interest Point Detection



LF-Net: Learning Local Features from Images

Existing Patch-based Systems

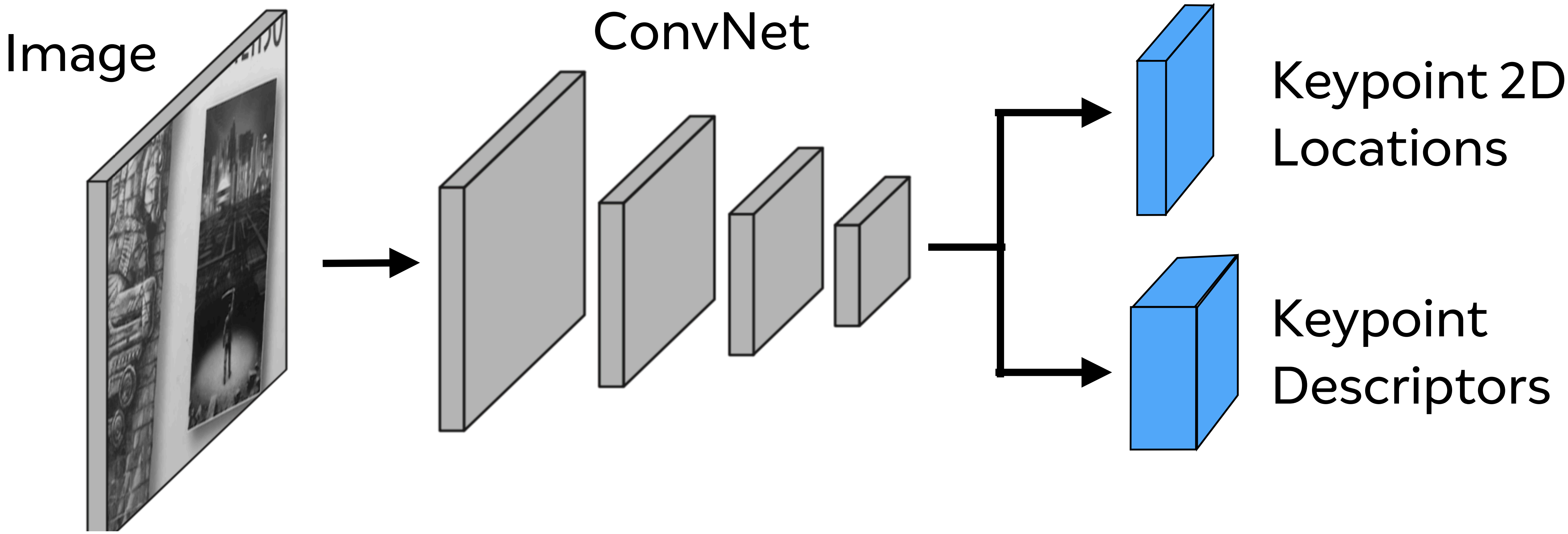


- Most low-compute Visual SLAM built on sparse frontends
- Extract points -> “Backend Ready”
- Most learned systems patch-based
  - Two separate networks
  - Lack powerful matchability of dense methods

Question

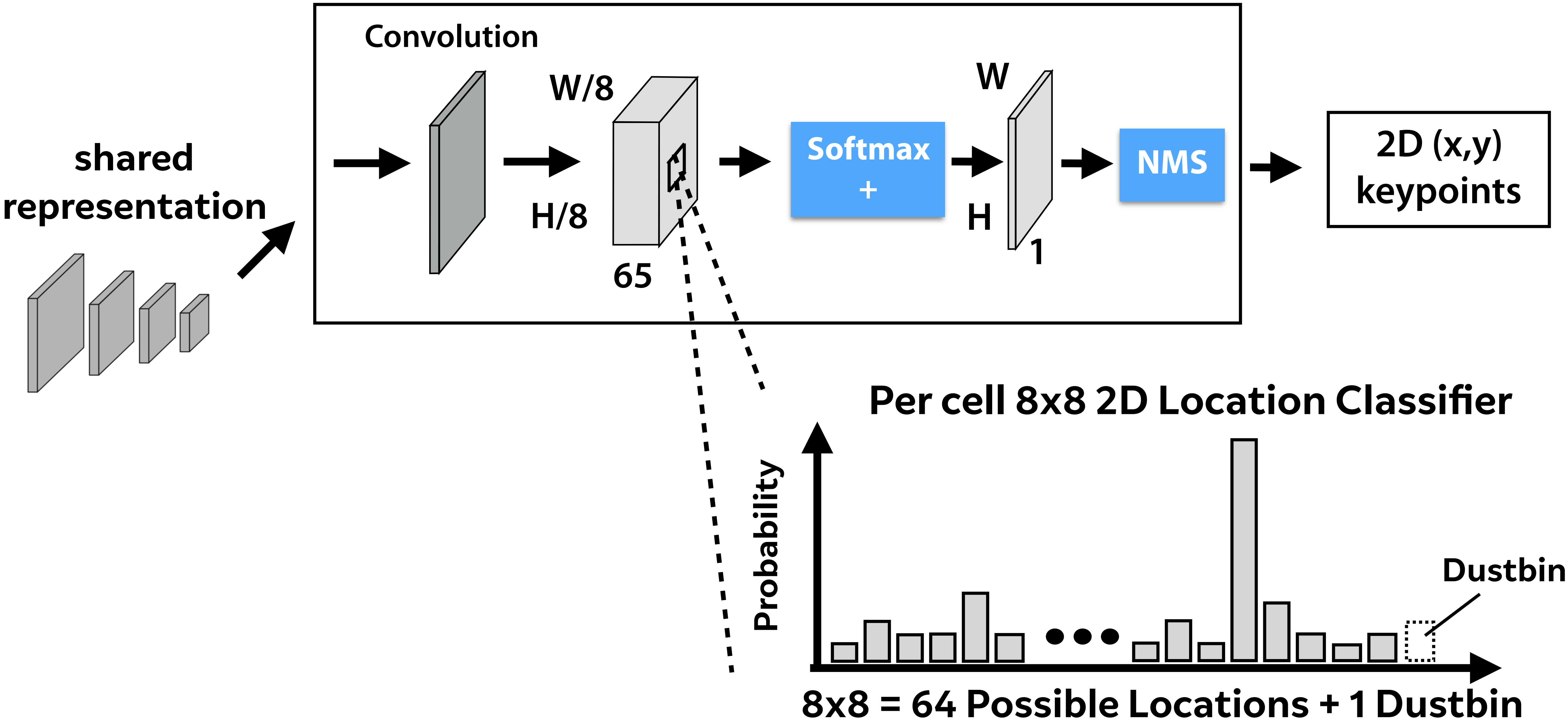
- How can we get the **power of dense matchability** and the **practicality of sparse output** in a **learnable framework**?

SuperPoint: A Deep SLAM Front-end



- Powerful fully convolutional design
  - Points + descriptors computed jointly
  - Share VGG-like backbone
- Designed for real-time
  - Tasks share ~90% of compute
  - Two learning-free decoders: no deconvolution layers

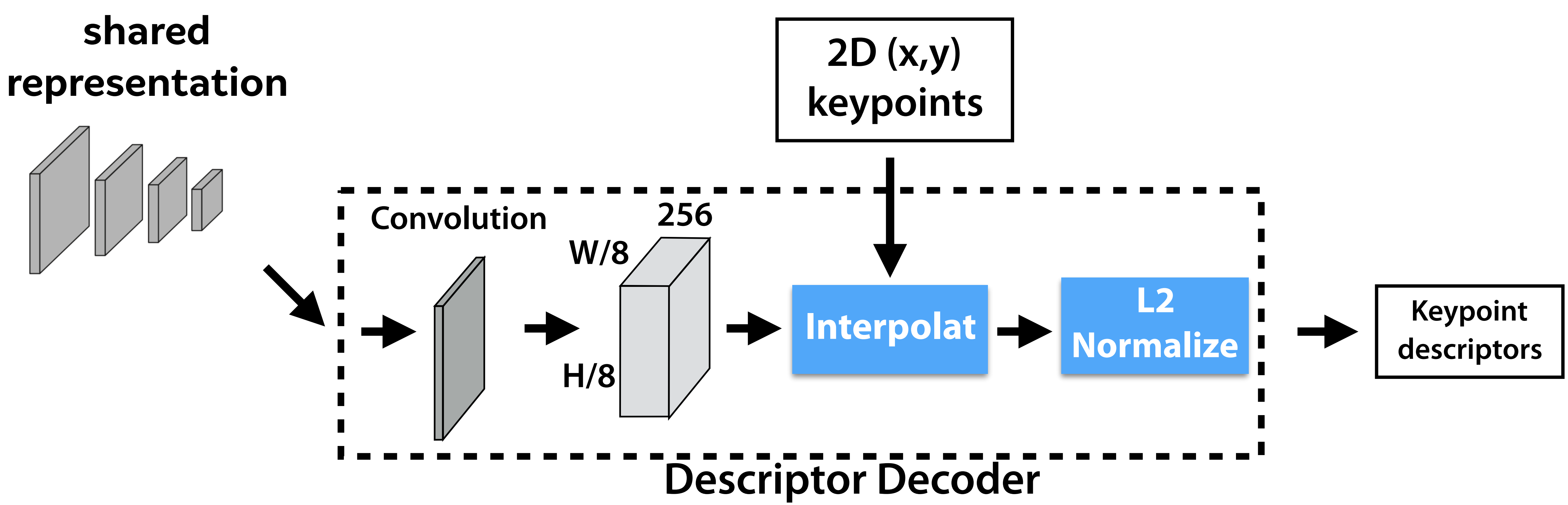
Keypoint / Interest Point Decoder



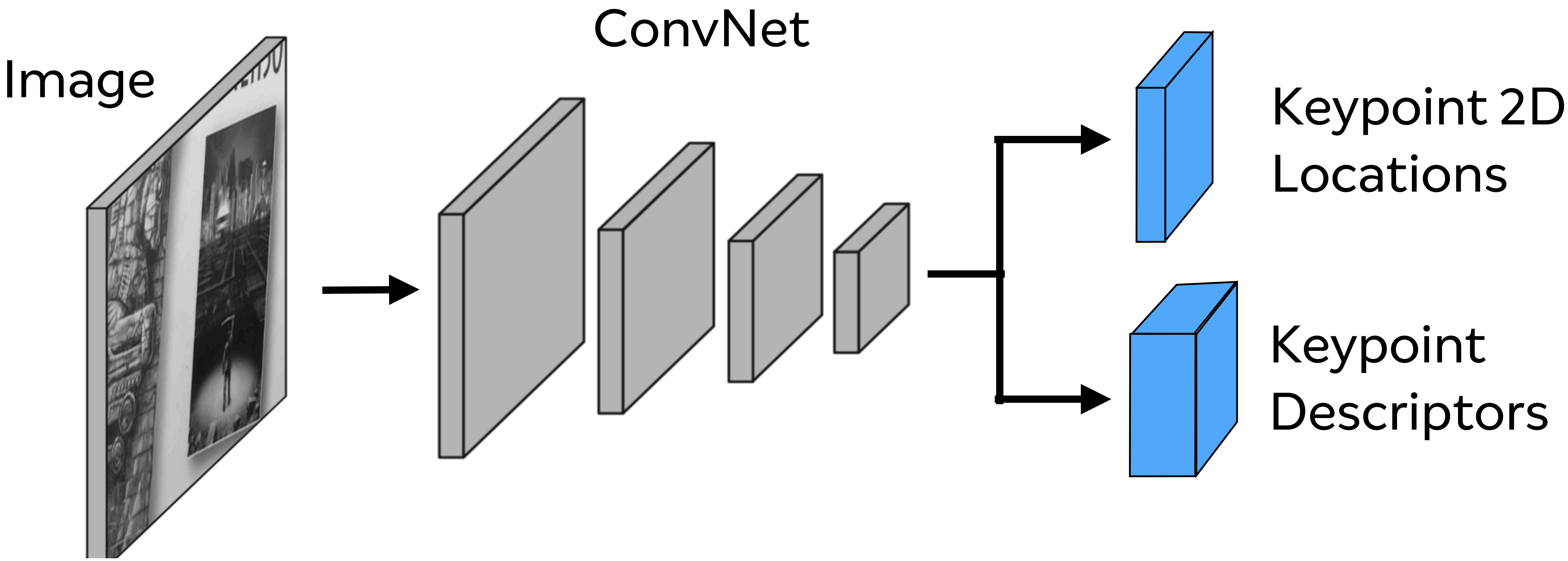
- No deconvolution layers
- Each output cell responsible for local 8x8 region

Descriptor Decoder

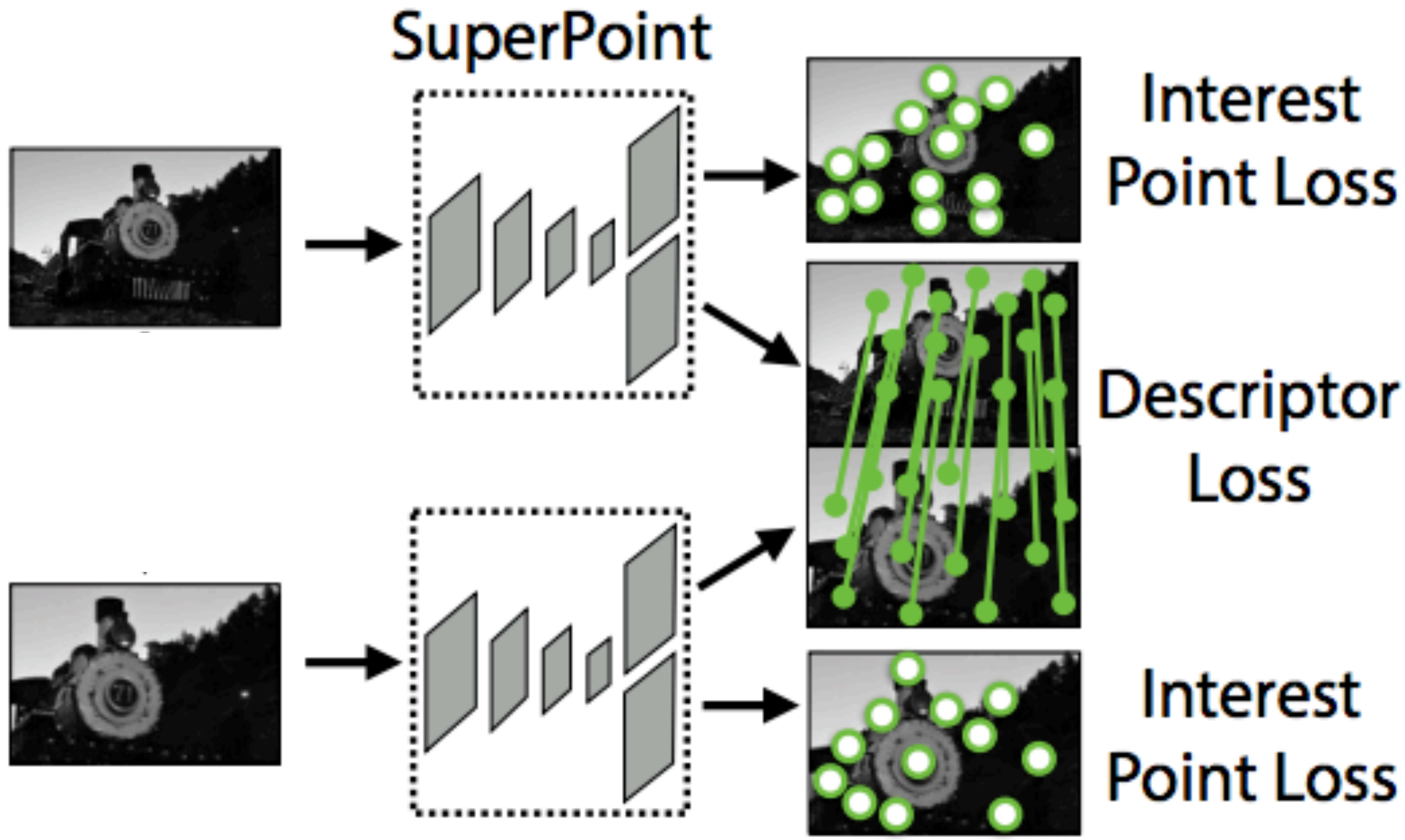
- Also no deconvolution layers
- Interpolate using 2D keypoint into coarse descriptor map



How To Train SuperPoint?



Setting up the Training



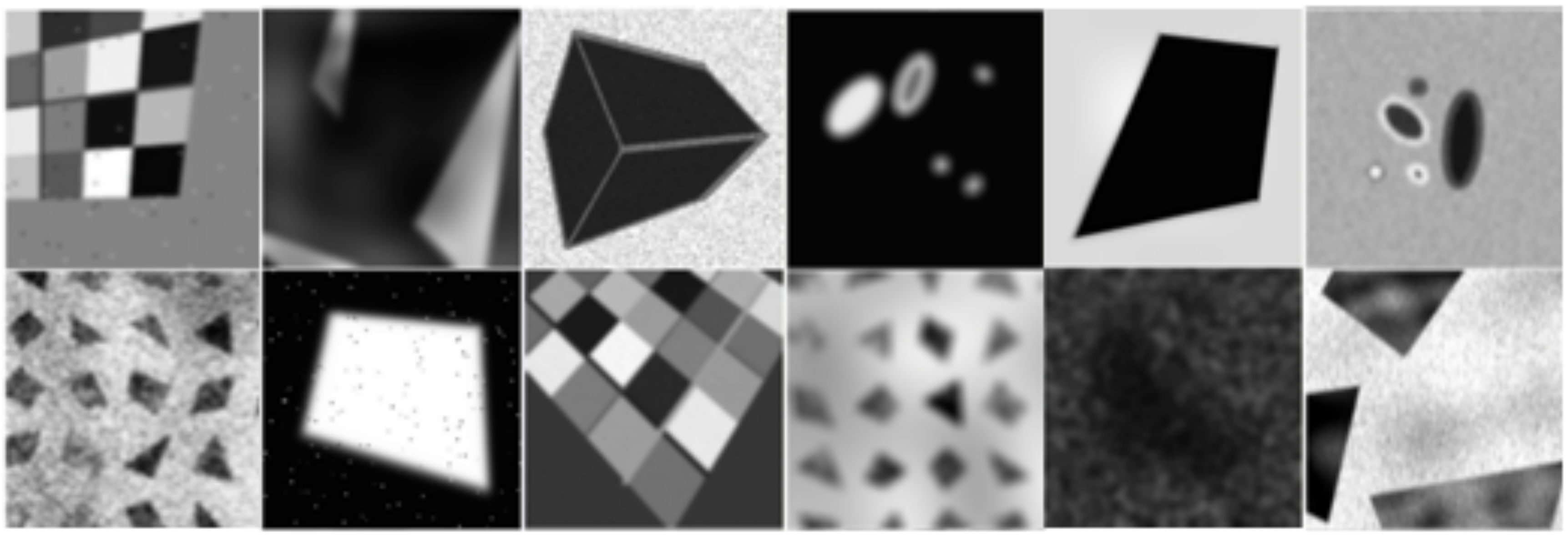
- Siamese training -> pairs of images
- Descriptor trained via metric learning
- Keypoints trained via supervised keypoint labels

How to get Keypoint Labels for Natural Images?

- Need large-scale dataset of annotated images
  - Too hard for humans to label

Self-Supervised Approach

Synthetic Shapes (has interest point labels)



First train on this

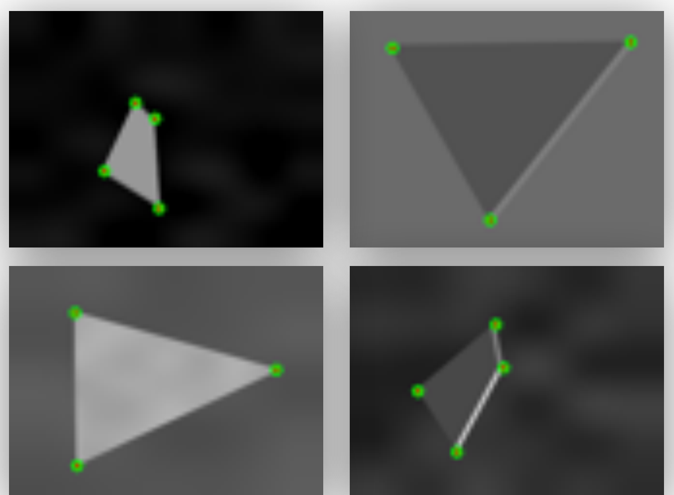
“Homographic Adaptation”

MS-COCO (no interest point labels)

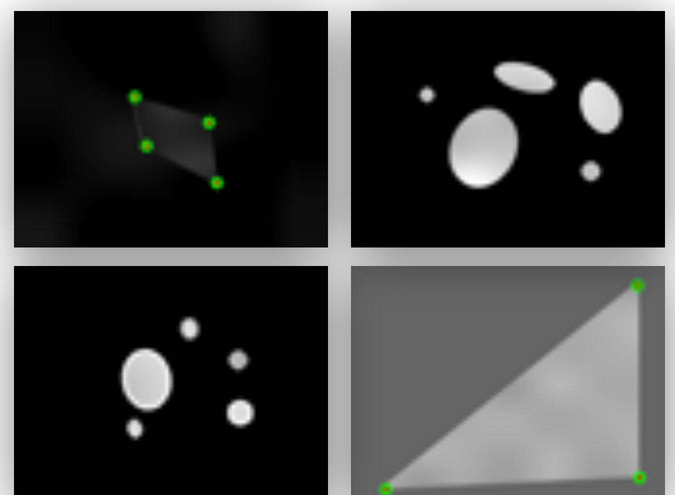
Use resulting detector to label this

Synthetic Training

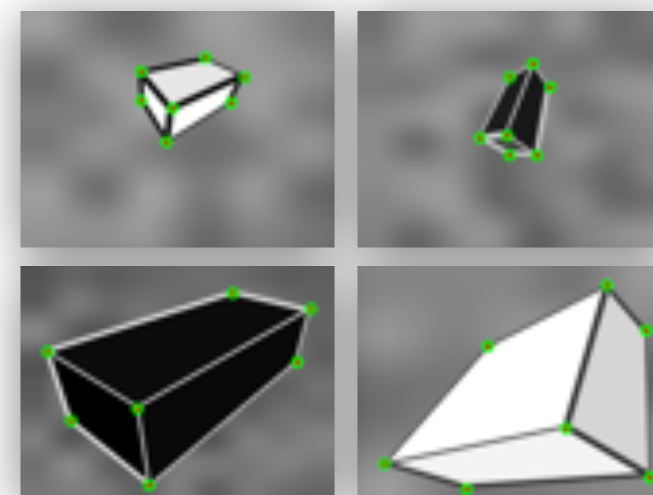
- Non-photorealistic shapes
- Heavy noise
- Effective and easy



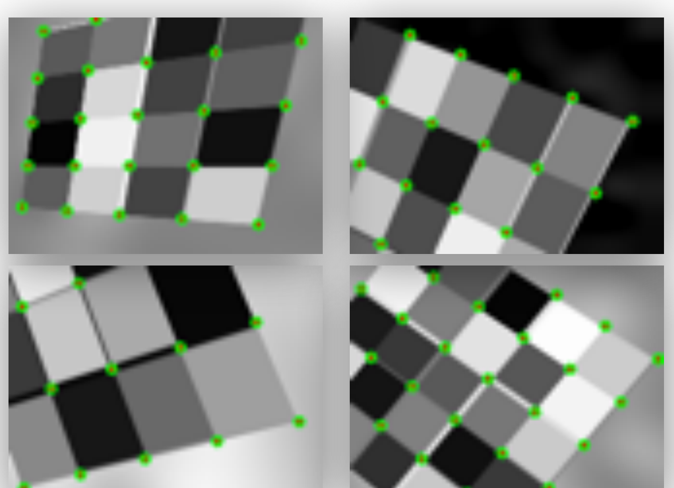
Quads/Tris



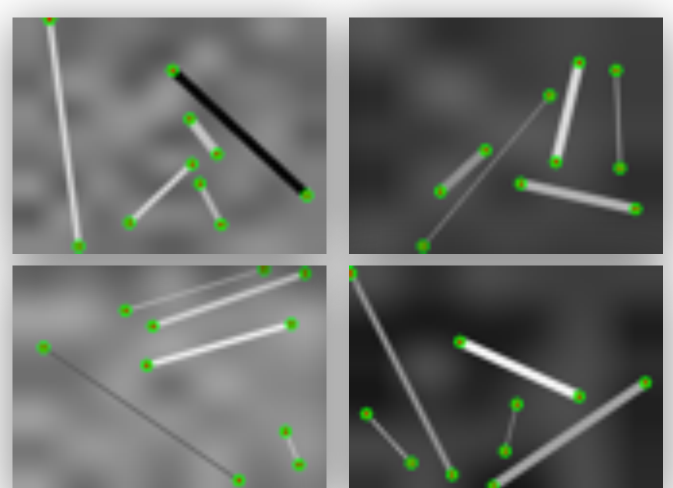
Quads/Tris/Ellipses



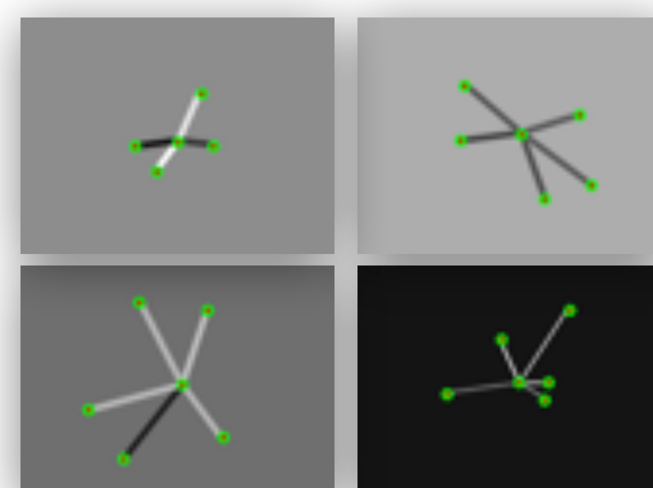
Cubes



Checkerboards



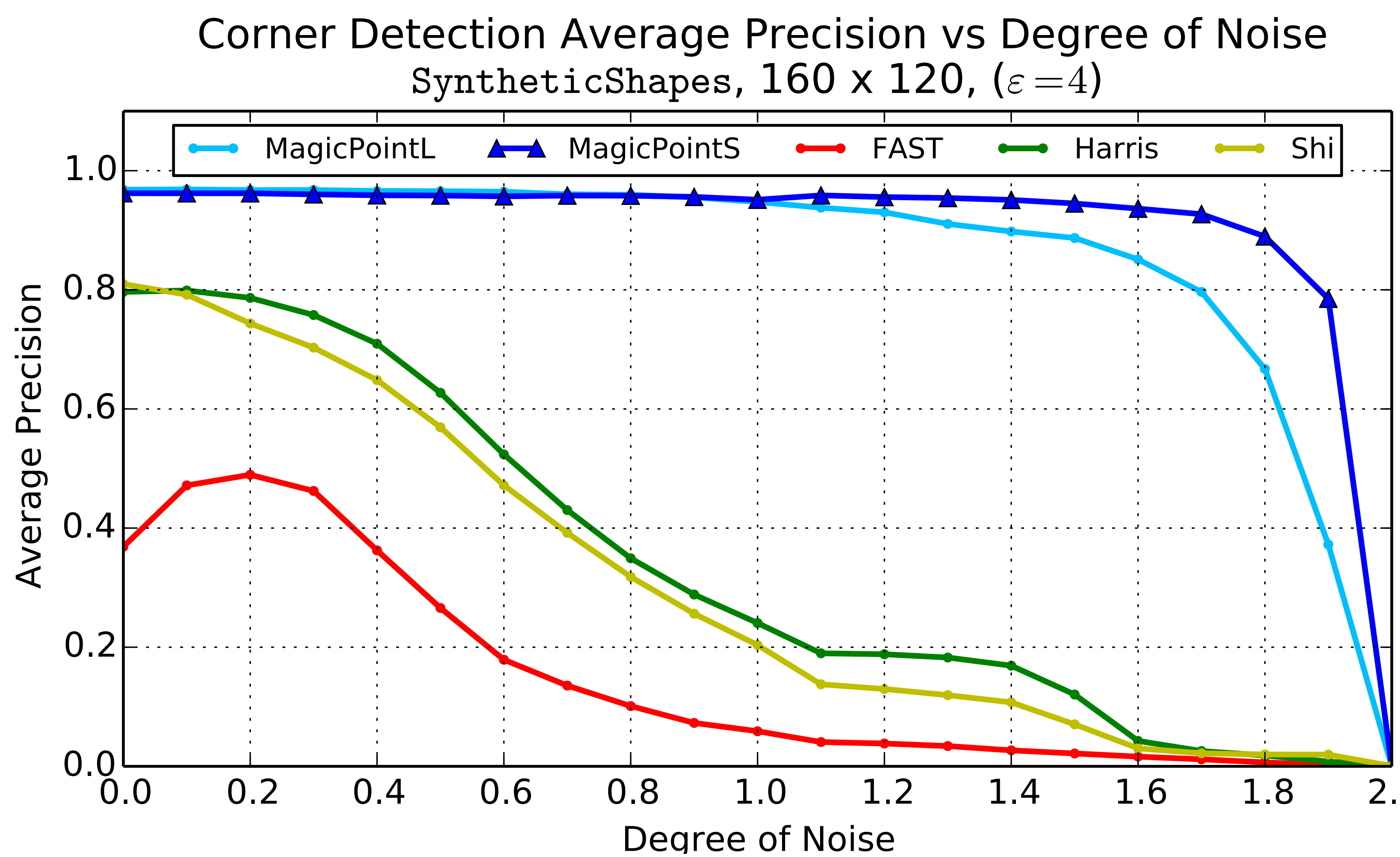
Lines



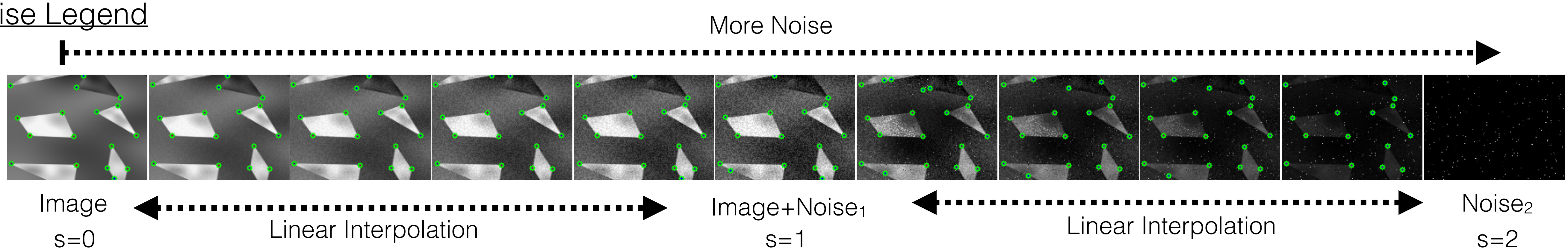
Stars

Early Version of SuperPoint (MagicPoint)

"Toward Geometric Deep SLAM"
DeTone et. al. 2017



Noise Legend



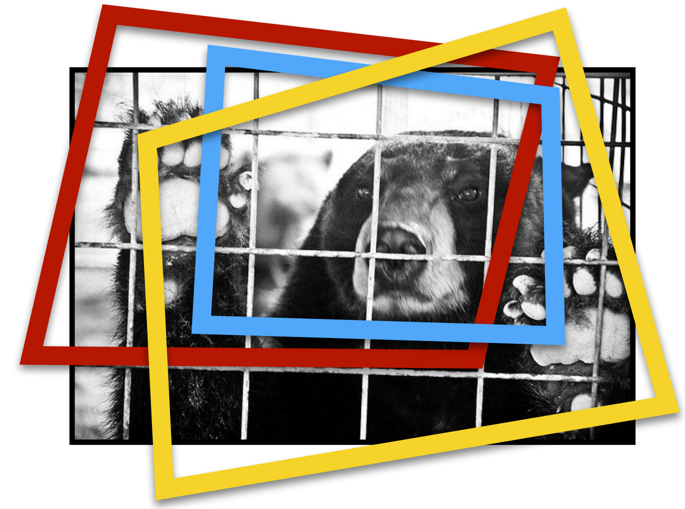
Generalizing to Real Data

- Synthetically trained detector
  - Works! Despite large domain gap
  - Worked well on geometric structures
  - Under performed on certain textures unseen during training

Homographic Adaptation

Unlabeled Input Image

Synthetic Warp + Run Detector



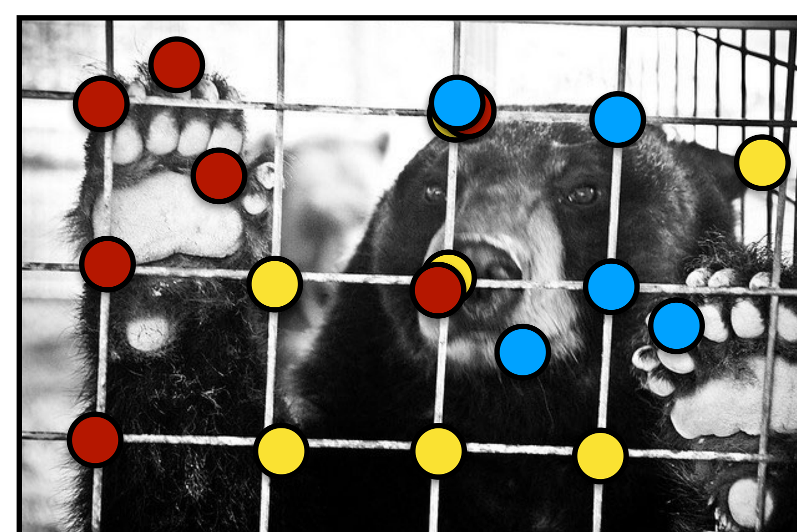
Point Set #1

Point Set #2

Point Set #3

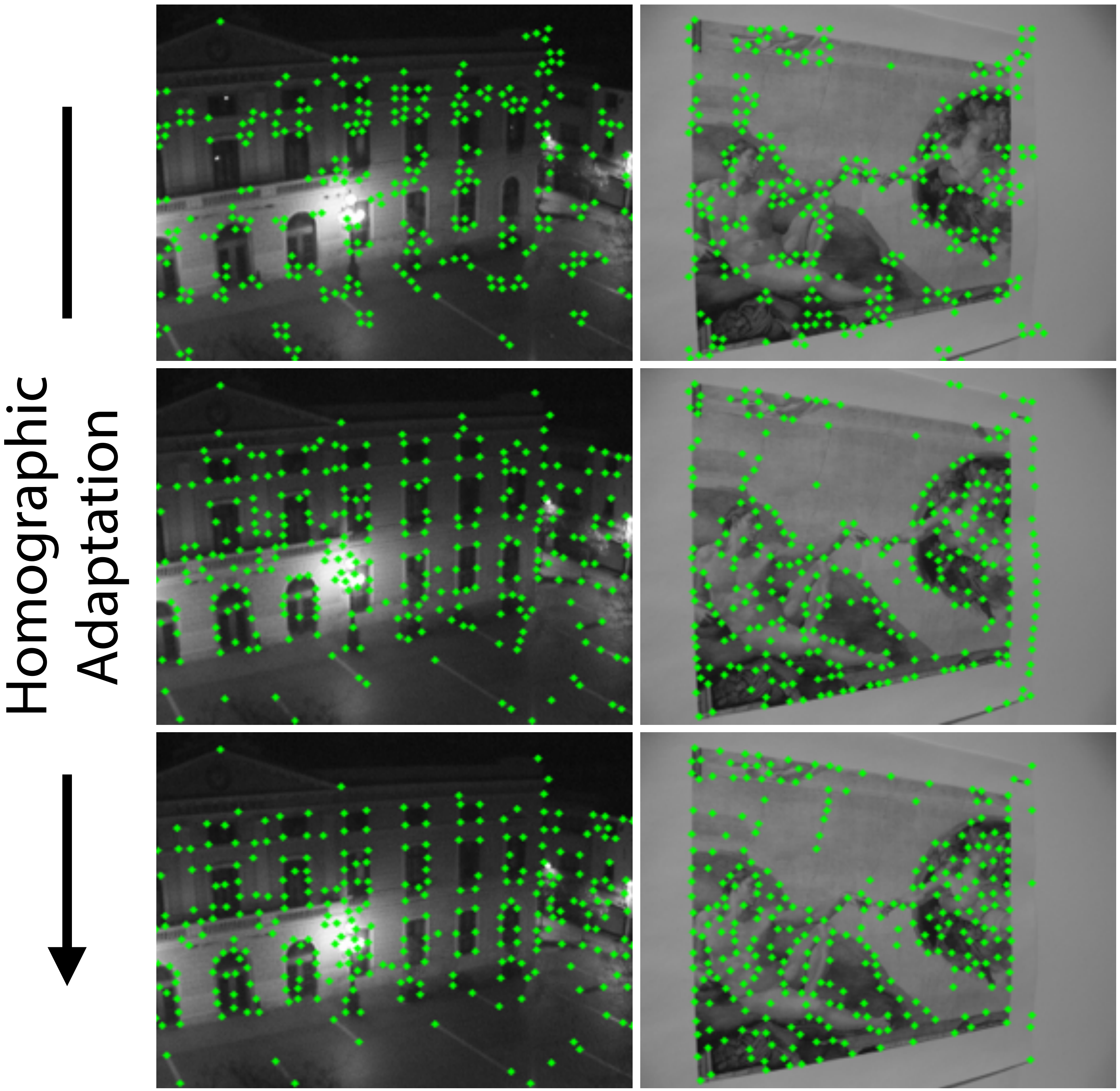
Point Aggregation

Detected Point Superset



- Simulate planar camera motion with homographies
- Self-labelling technique
  - Suppress spurious detections
  - Enhance repeatable points

Iterative Homographic Adaptation



- Label, train, repeat, …
- Resulting points:
  - Higher coverage
  - More repeatable

HPatches Evaluation

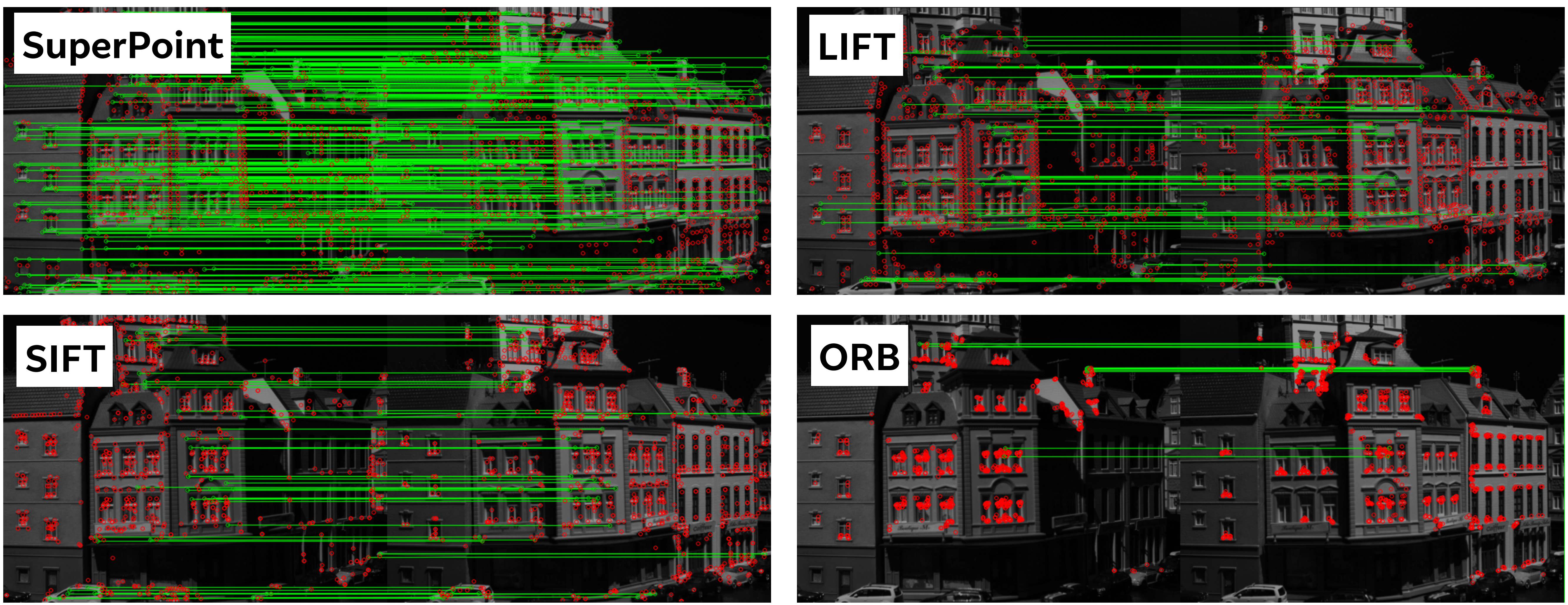
- Homography estimation task
- Dataset of 116 scenes each with 6 images = 696 images
- Indoor and outdoor planar scenes
- Compared against LIFT, SIFT and ORB

50% of dataset:
<u>Illumination</u>
Change

50% of dataset:
<u>Viewpoint</u>
Change

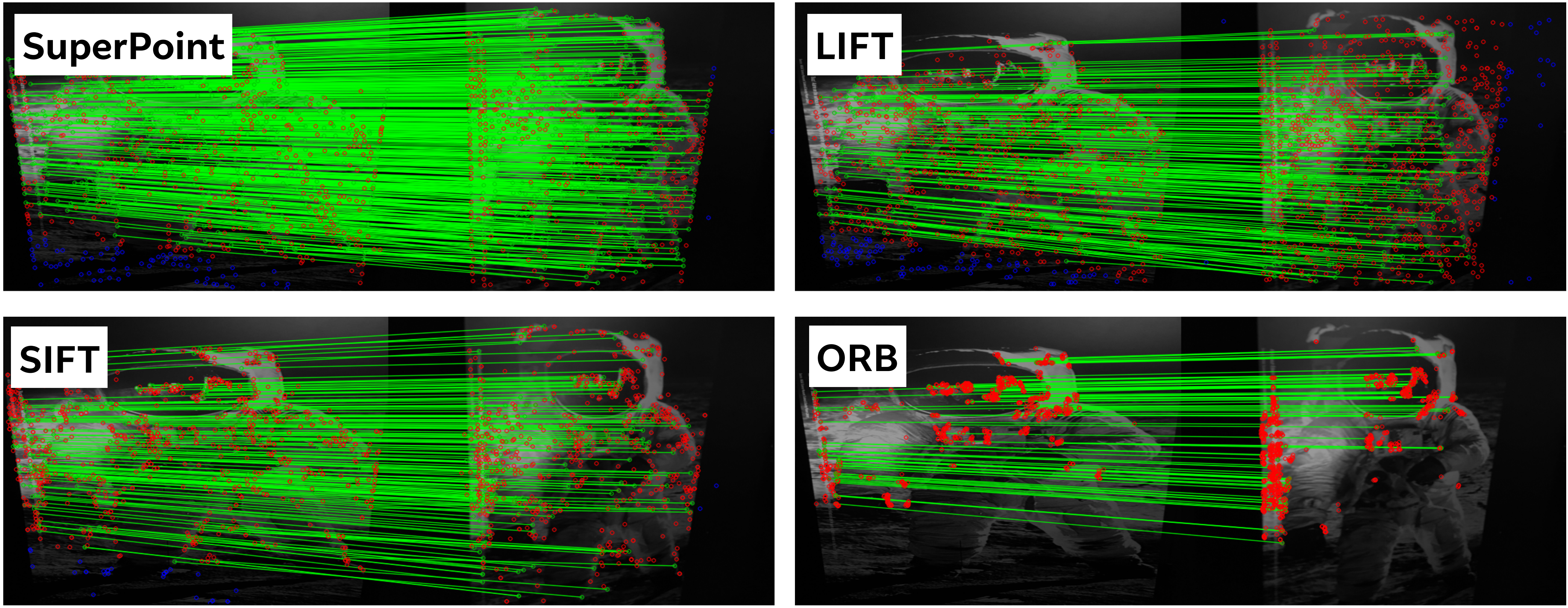
Qualitative Illumination Example

- SuperPoint -> denser set of correct matches
- ORB -> highly clustered matches



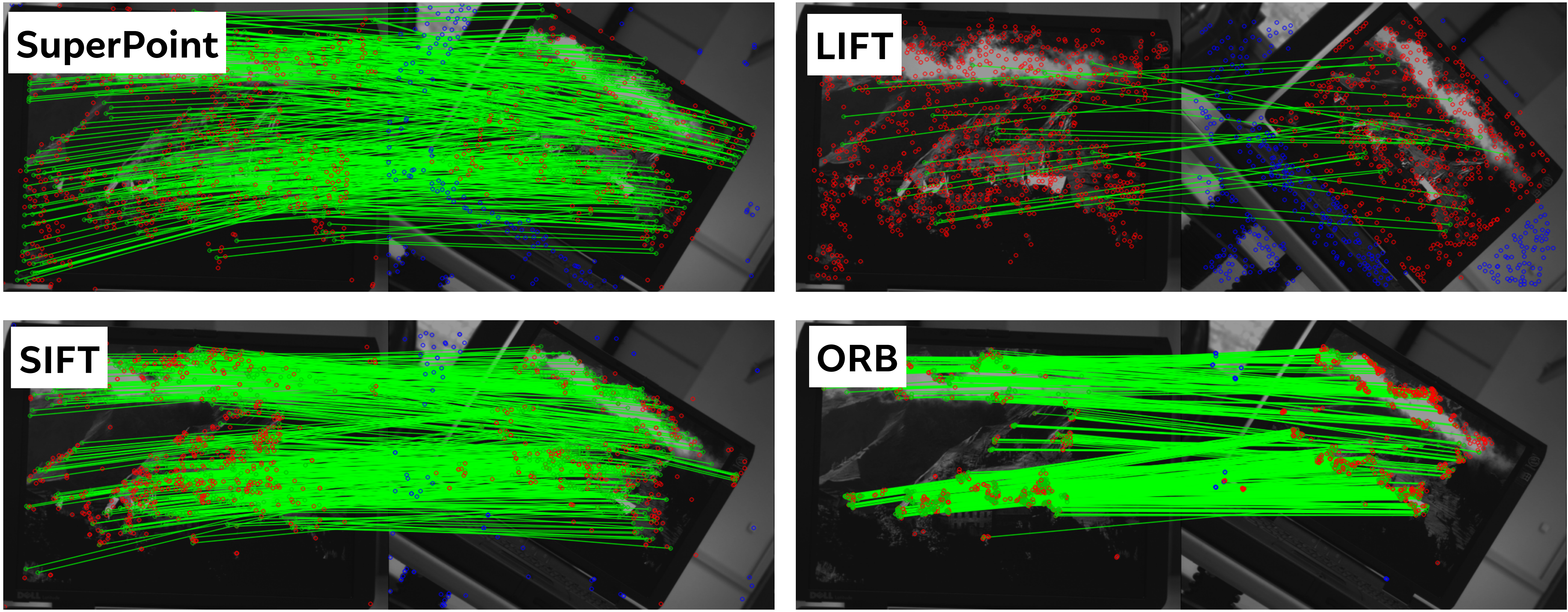
Qualitative Viewpoint Example #1

- Similar story



Qualitative Viewpoint Example #2

- In-plane rotation of ~35 degrees



HPatches Evaluation

	Core Task	Sub-metrics			
		Descriptor Metrics		Detector Metrics	
	Homography Estimation ↑	NN mAP ↑	M. Score ↑	Rep. ↑	MLE ↓
SuperPoint	**0.684**	**0.821**	**0.470**	0.581	1.158
LIFT	0.598	0.664	0.315	0.449	1.102
SIFT	0.676	0.694	0.313	0.495	**0.833**
ORB	0.395	0.735	0.266	**0.641**	1.157

Timing SuperPoint vs LIFT

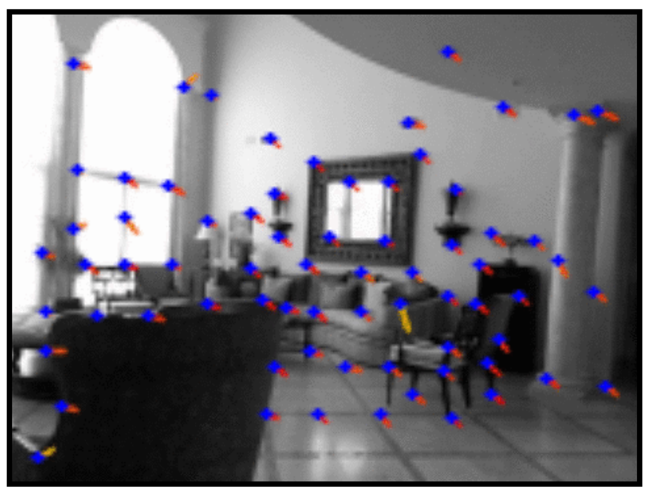
- Speed important for low-compute Visual SLAM
  - SuperPoint total 640x480 time: ~ 33 ms
  - LIFT total 640x480 time: ~2 minutes

3D Generalizability of SuperPoint

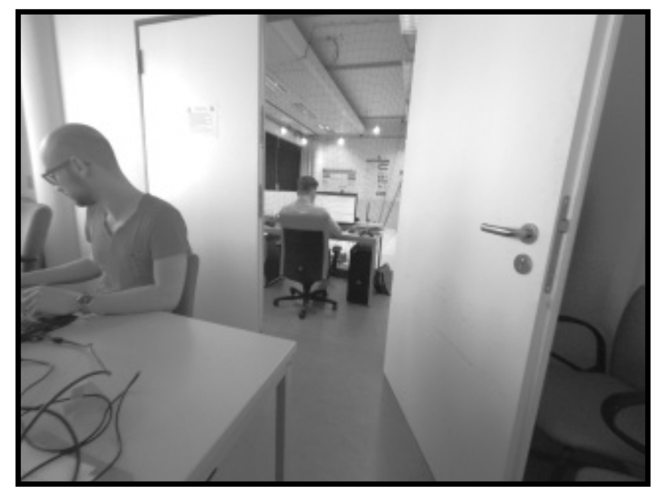
- Trained+evaluated on planar, does it generalize to 3D?
- "Connect-the-dots" using nearest neighbor matches
- Works across many datasets / input modalities / resolutions!

Freiburg (Kinect)

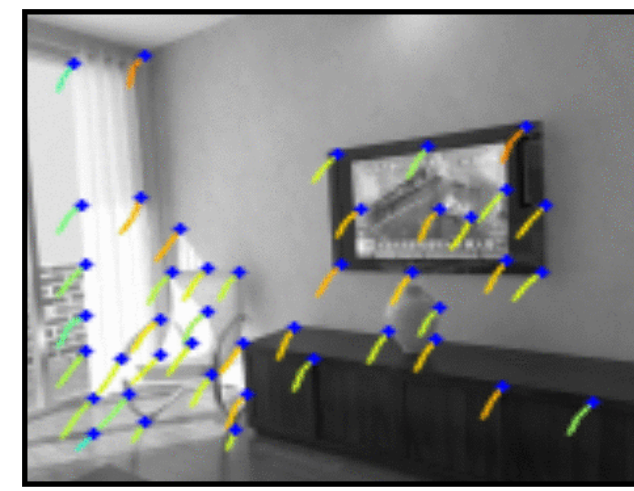
NYU (Kinect)



MonoVO (fisheye)



ICL-NUIM (synth)



MS7 (Kinect)

KITTI (stereo)

New Announcement, Research @ MagicLeap

Public Release of Pre-trained Net:

github.com/MagicLeapResearch/SuperPointPretrainedNetwork

- Sparse Optical Flow Tracker Demo
- Implemented in Python + PyTorch
- Two files, minimal dependencies
- Easy to get up and running

magic leap

Research @ Magic Leap

SuperPoint Weights File and Demo Script

Introduction

This repo contains the pretrained SuperPoint network, as implemented by the originating authors. SuperPoint is a research project at Magic Leap. The SuperPoint network is a fully convolutional deep neural network trained to detect interest points and compute their accompanying descriptors. The detected points and descriptors can thus be used for various image-to-image matching tasks. For more details please see

- Full paper PDF: SuperPoint: Self-Supervised Interest Point Detection and Description
- Authors: *Daniel DeTone, Tomasz Malisiewicz, Andrew Rabinovich*

This demo showcases a simple sparse optical flow point tracker that uses SuperPoint to detect points and match them across video sequences. The repo contains two core files (1) a PyTorch weights file and (2) a python deployment script that defines the network, loads images and runs the pytorch weights file on them, creating a sparse optical flow visualization. Here are videos of the demo running on various publically available datsets:

Freiburg RGBD:

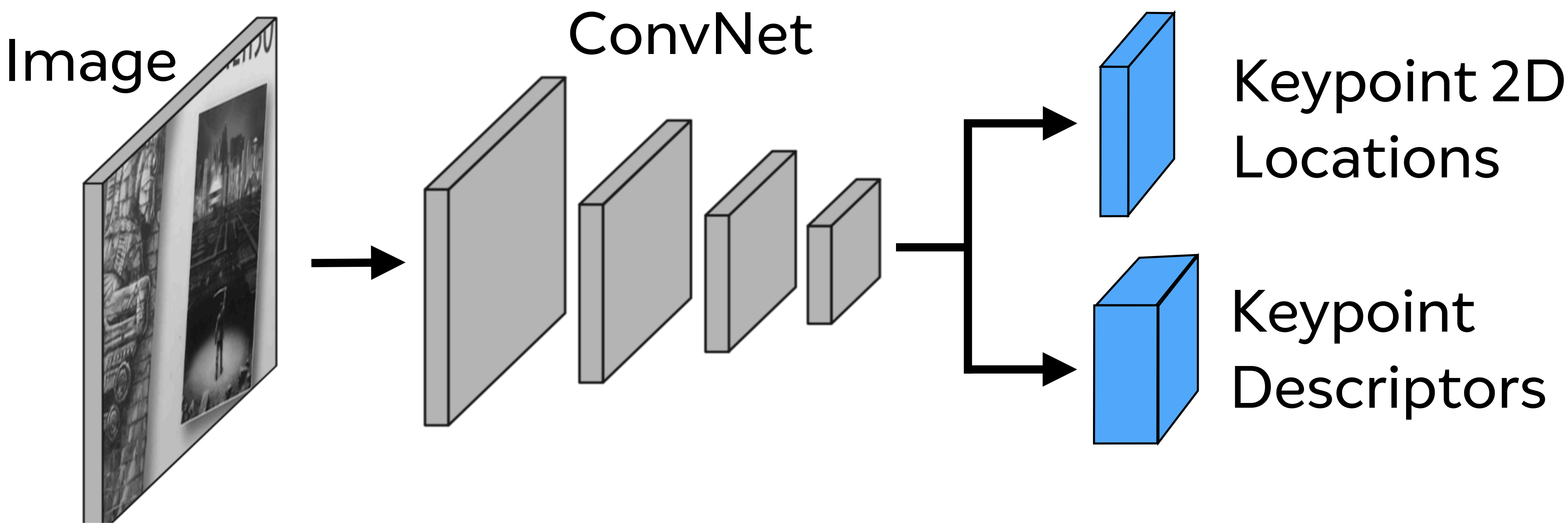
Take-Aways

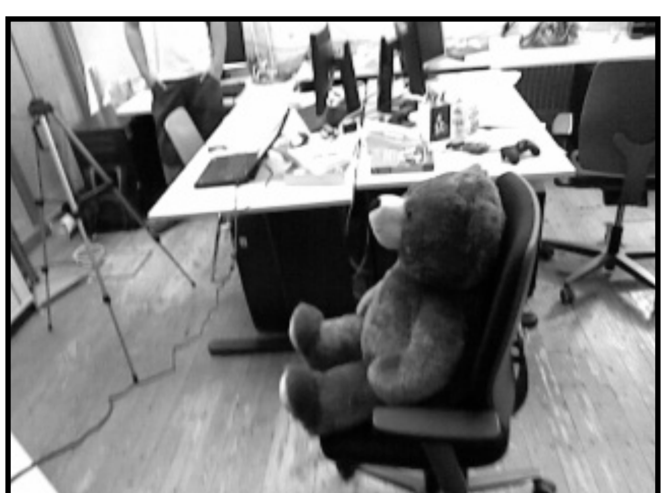
- “SuperPoint”: A Modern Deep SLAM Frontend
  - Non-patch based fully convolutional network
  - Real-time deployability
- Self-supervised recipe to train keypoints
  - Synthetic pre-training
  - Homography-inspired domain adaptation
- Public code available to run SuperPoint

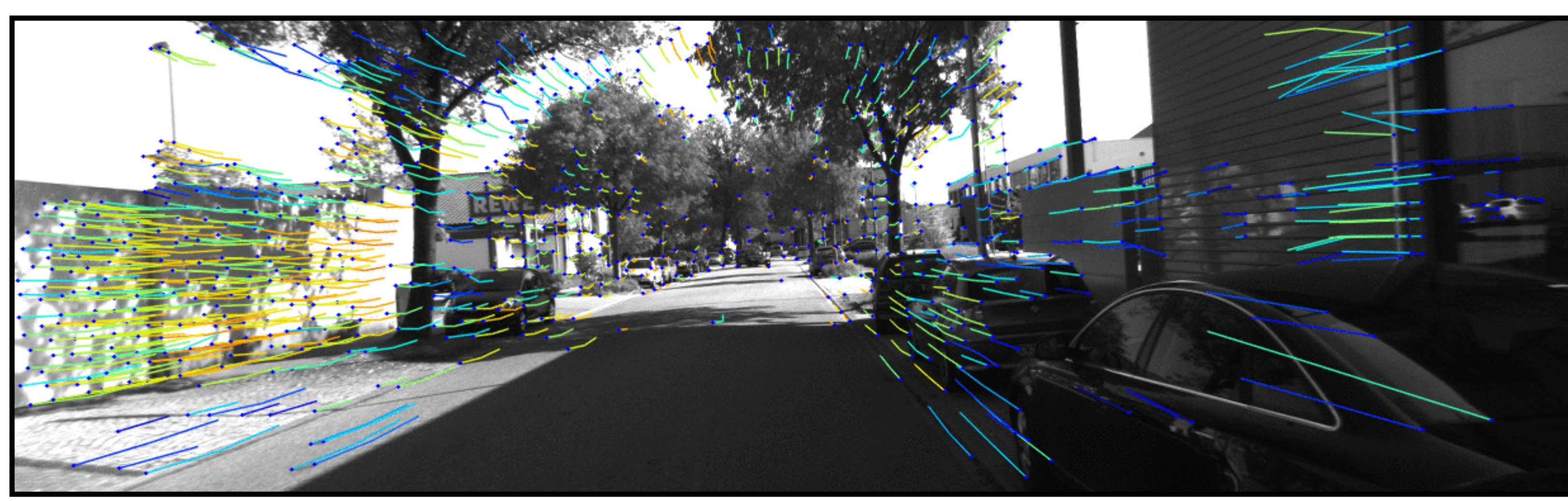
Thank You

Questions?

SuperPoint: A Modern Deep SLAM Front-end



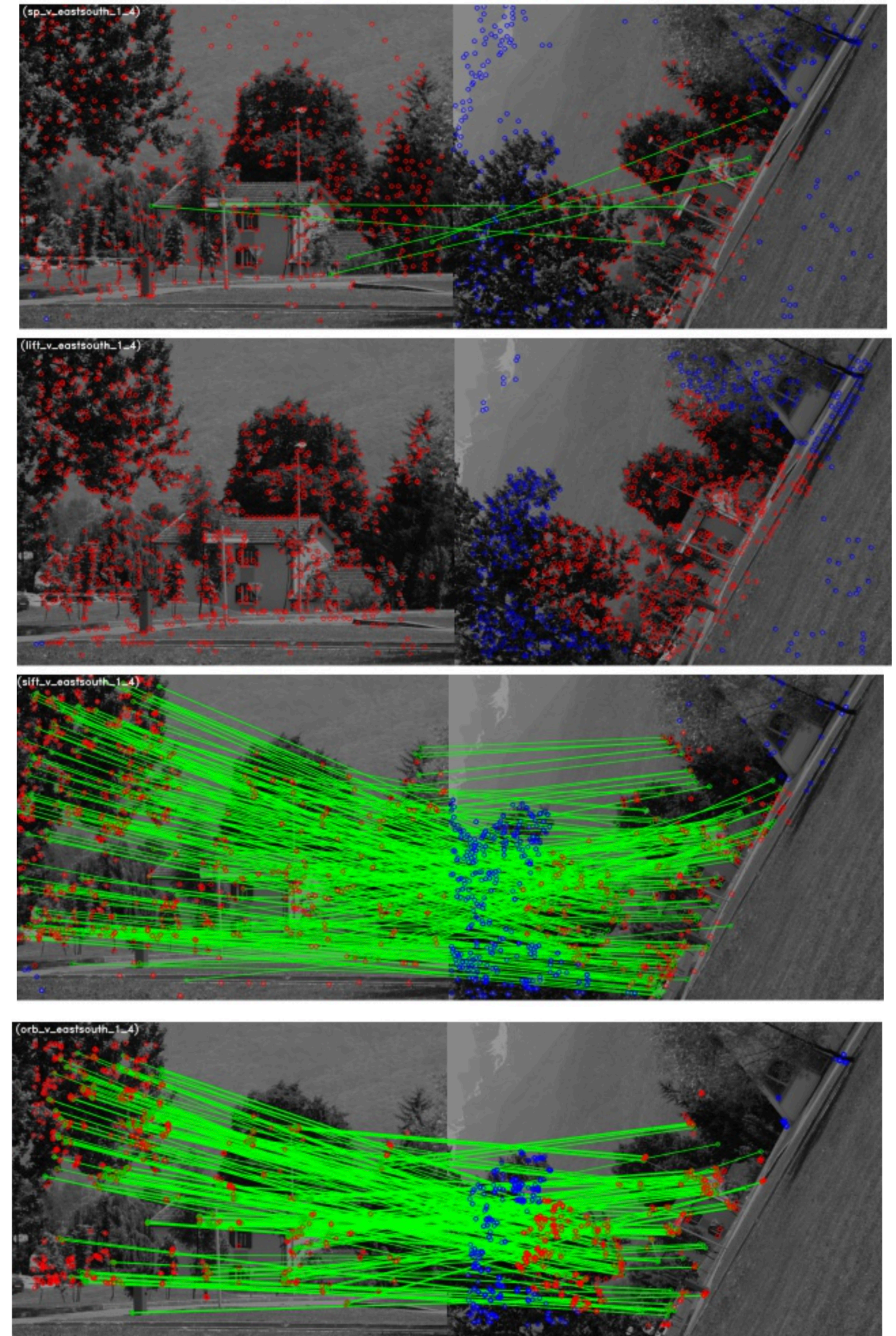




Extra Slides

Failure Mode: Extreme Rotation

- Extreme in-plane rotations
- Trained for ~30 deg rotations
- Optimized tracking scenarios
- LIFT also struggles, despite learned orientation estimation



Super-Point

LIFT

SIFT

ORB

Iterative Homographic Adaptation