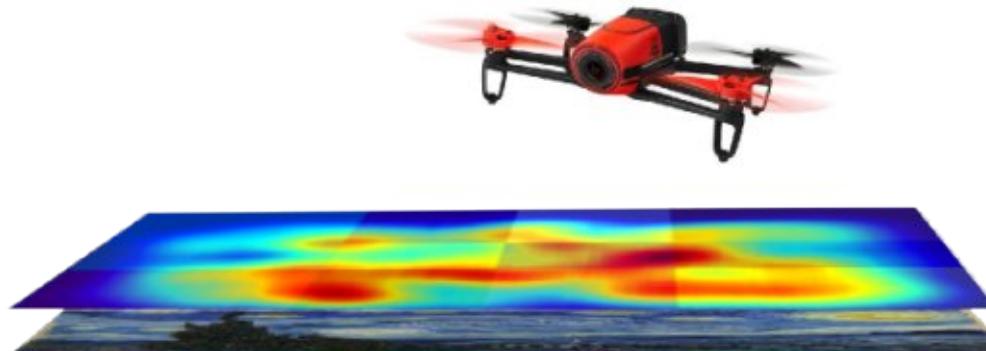


Machine Learning-based Indoor Localization for Micro Aerial Vehicles



Volker Strobel

Radboud Universiteit

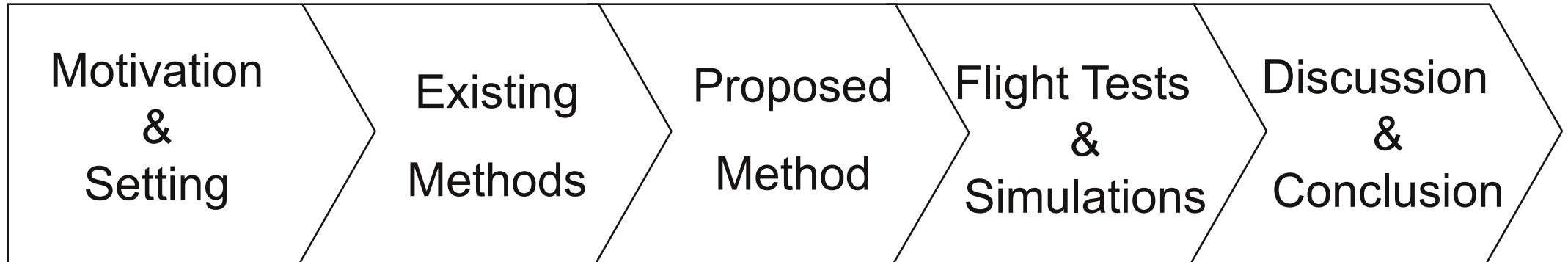


Louis Vuurpijl

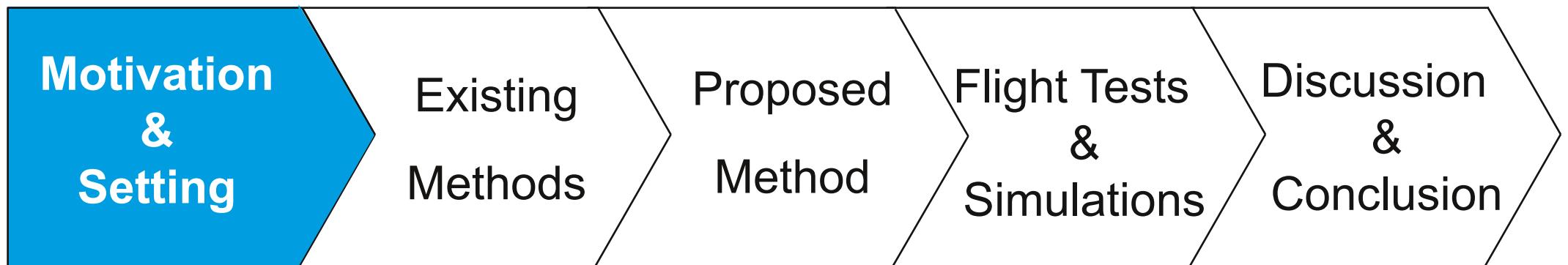
TUDelft
Delft
University of
Technology

Guido de Croon
Roland Meertens

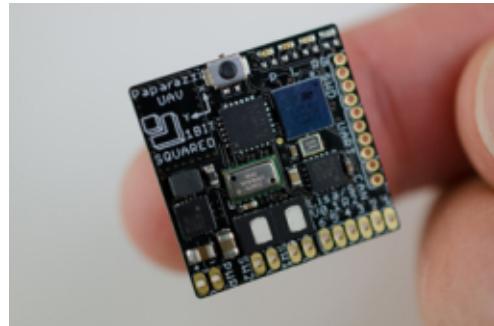
OUTLINE



OUTLINE



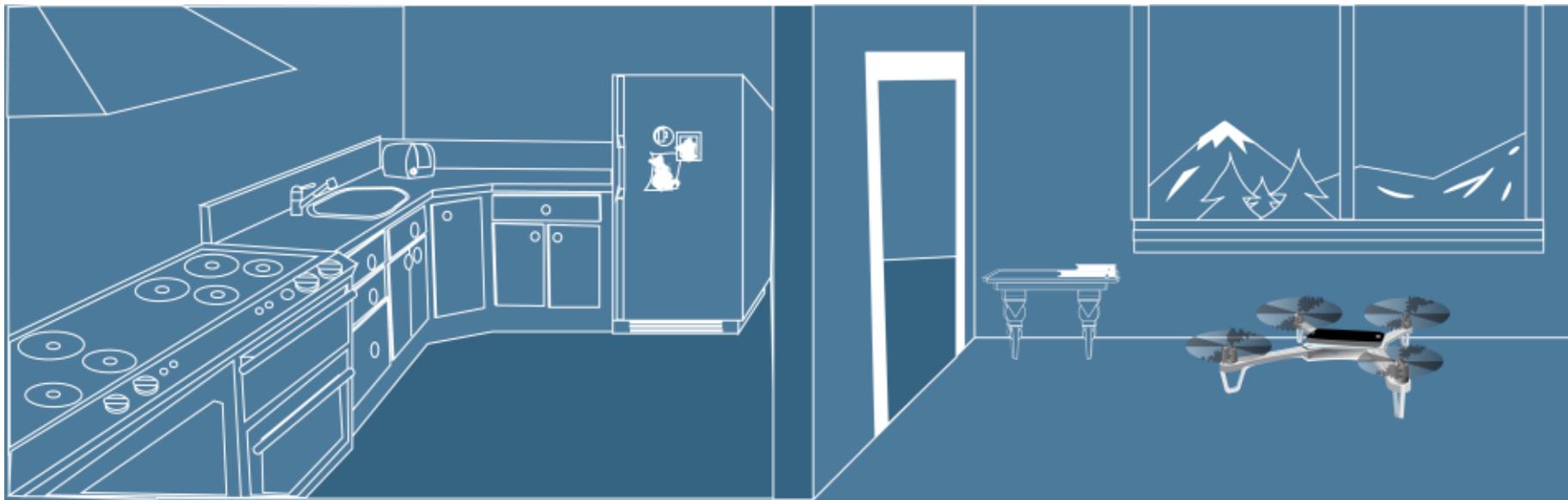
Micro Air Vehicle Lab



Miniaturization



MOTIVATION



MOTIVATION

Tools



Environment



known

modifiable

fixed

flat

MOTIVATION

Tools



Environment



known modifiable fixed flat

x,y-coordinates

real-time on-board fixed height

MOTIVATION

Research Question

Can vision-based indoor localization be done on a limited platform?

accurate

on-board

real-time

RESEARCH QUESTIONS

Research Question 1

Can vision-based indoor localization be done on a limited platform?

Research Question 2

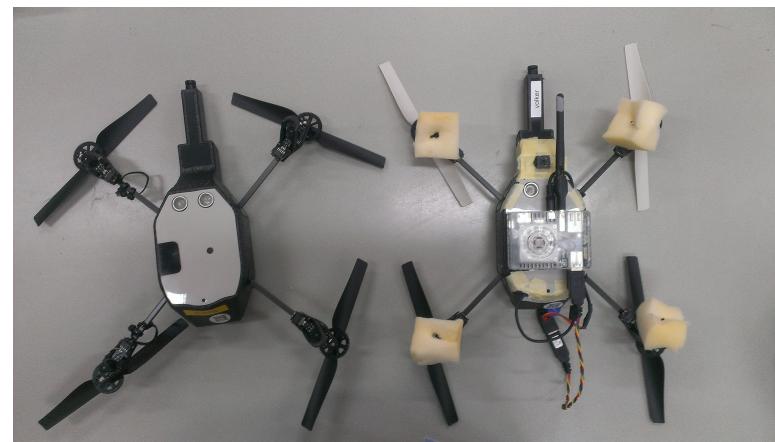
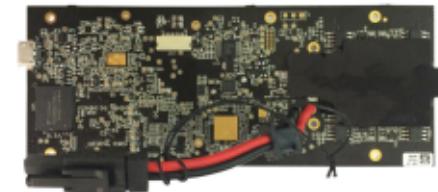
Can we predict the suitability of an environment for the proposed localization algorithm?

CHALLENGES

Limited platform

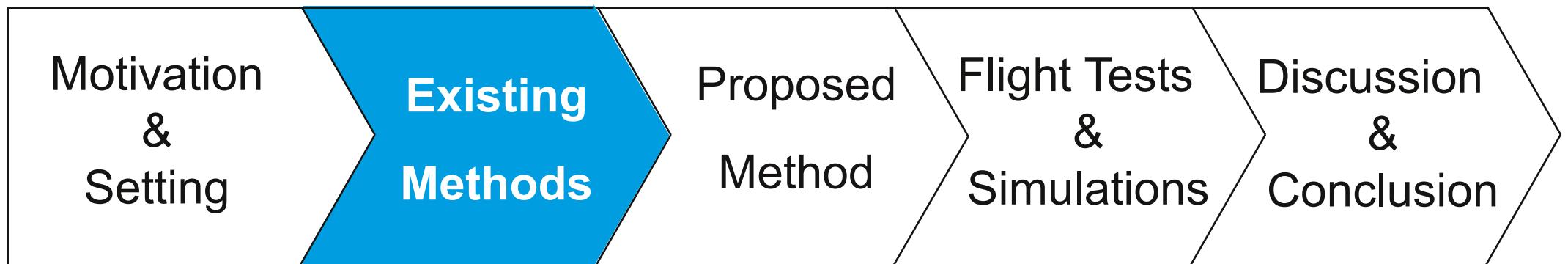


Low-level embedded
programming (C)



Real-world

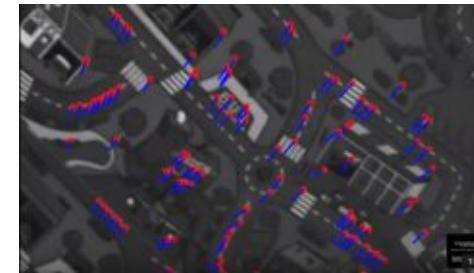
OUTLINE



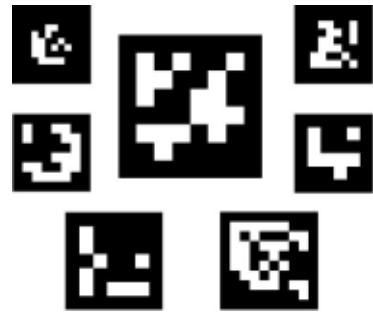
METHODS FOR ONBOARD LOCALIZATION



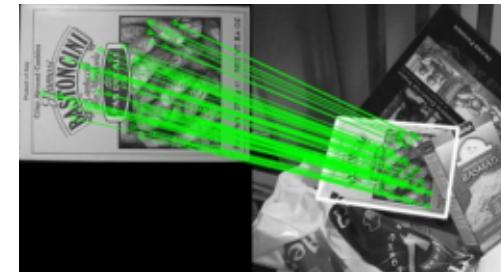
Laser range finder



Optical flow

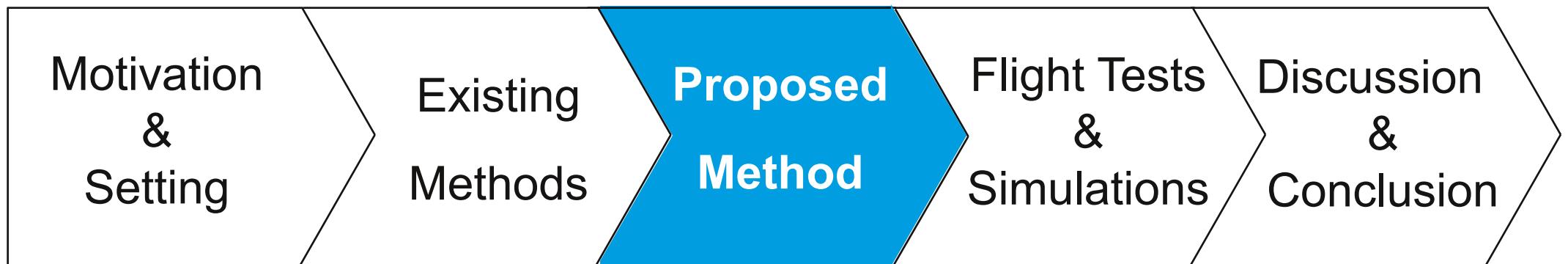


Markers

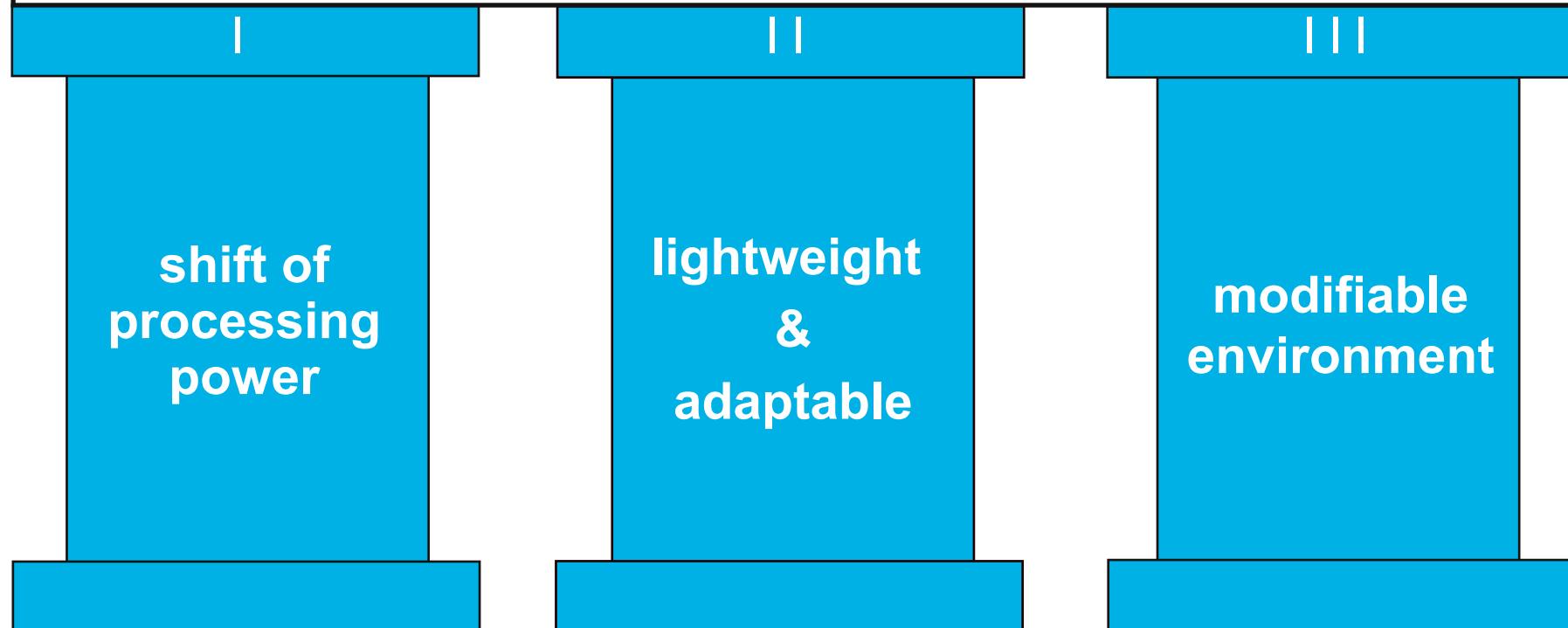


Homography finding

OUTLINE



EFFICIENT INDOOR LOCALIZATION



APPROACH

Flight phase



DUMMY: INSERT SIFT VIDEO

APPROACH

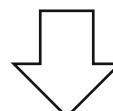
Flight phase



1 sec / Image



APPROACH

 ~~Flight phase~~
Pre-flight phase



create
Dataset



x y
200 300



210 320

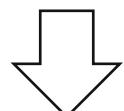
⋮

⋮



111 210

APPROACH

 ~~Flight phase~~
Pre-flight phase



Flight phase



create

compare

Dataset

x y

200 300



210 320

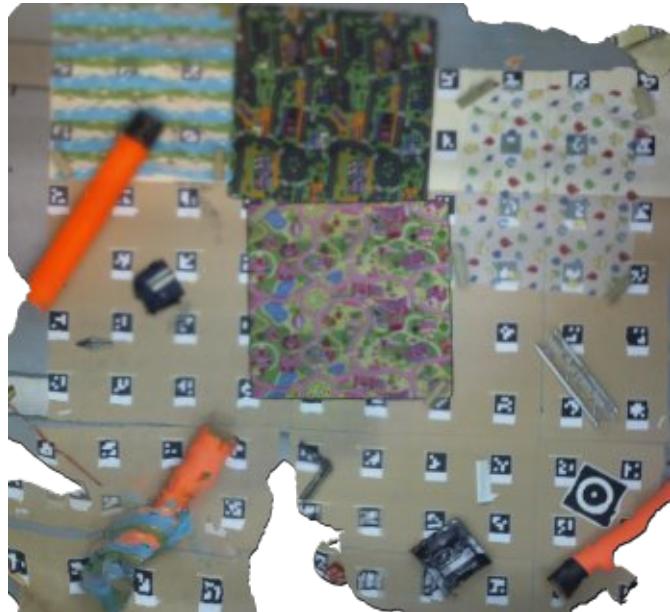


111 210



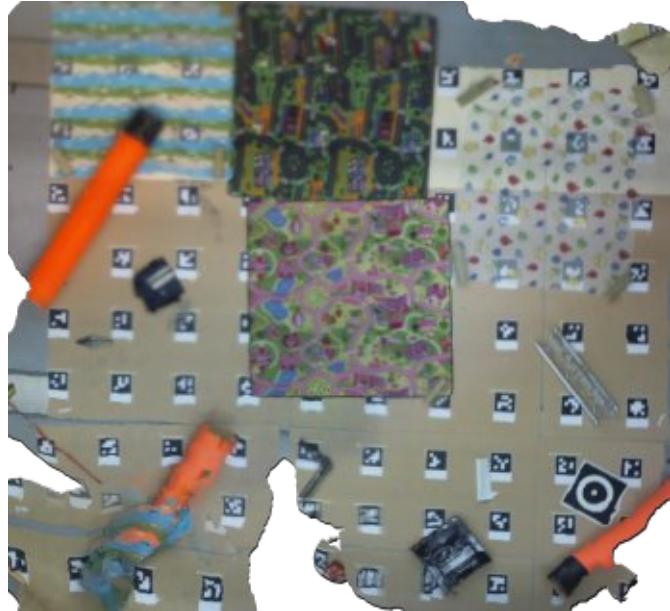
GROUND TRUTH ESTIMATION

Orthomap



GROUND TRUTH ESTIMATION

Orthomap

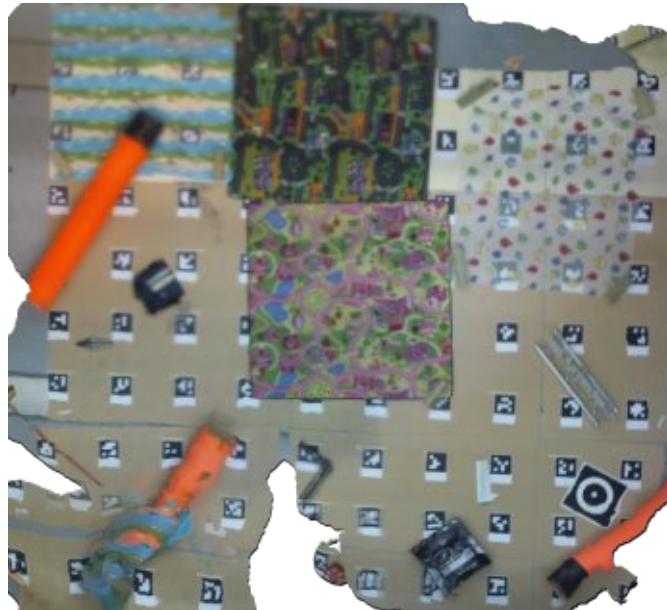


Poster



GROUND TRUTH ESTIMATION

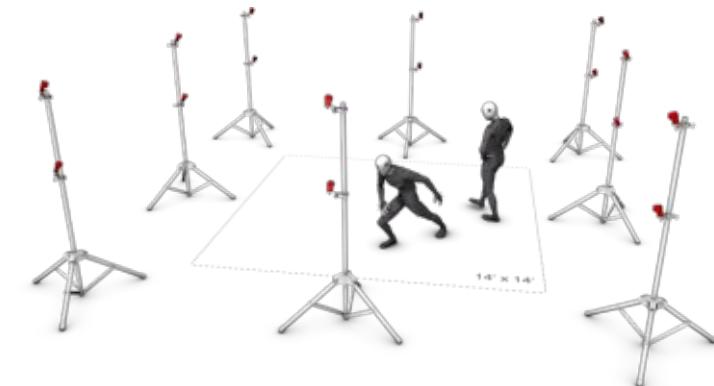
Orthomap



Poster

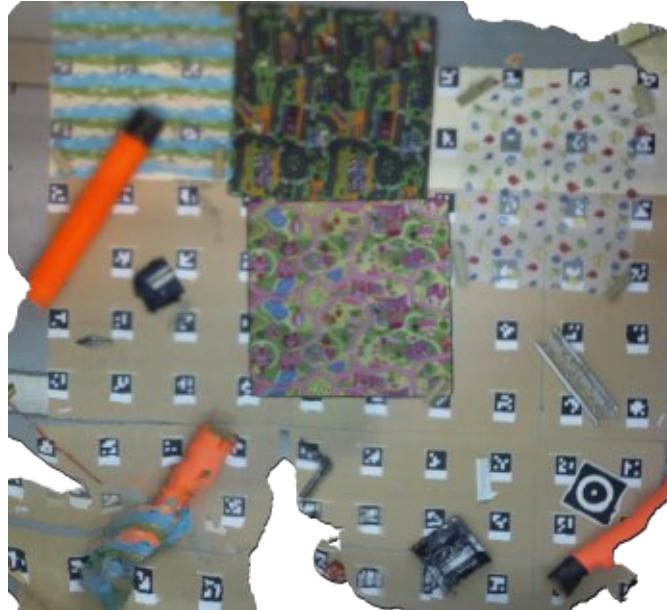


Motion tracking



GROUND TRUTH ESTIMATION

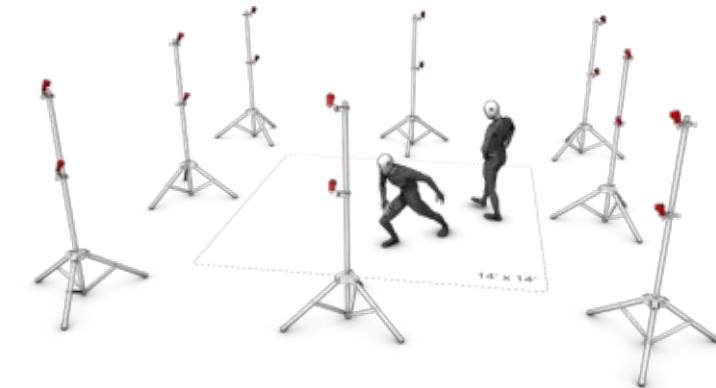
Orthomap



Poster



Motion tracking



Dataset

x	y
---	---

200	300
-----	-----

210	320
-----	-----



⋮

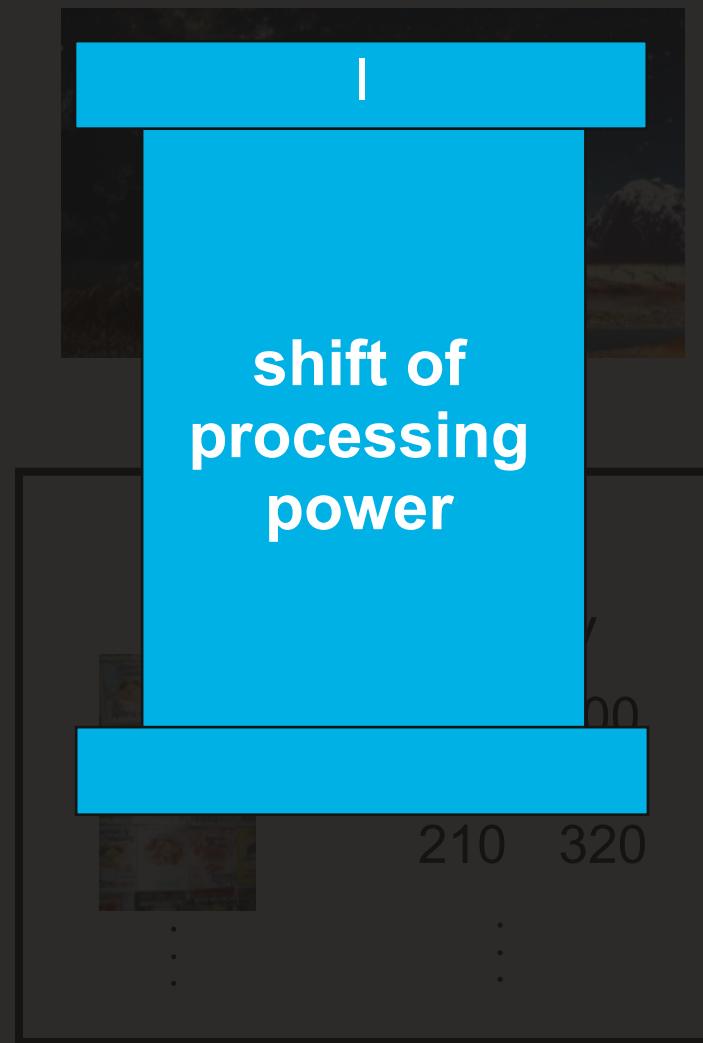
⋮

GROUND TRUTH ESTIMATION

Orthomap



Poster

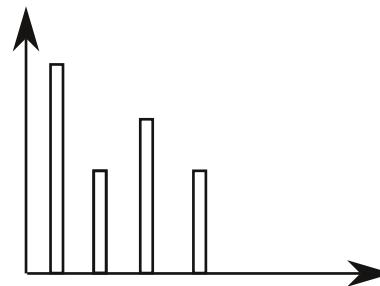


Motion tracking

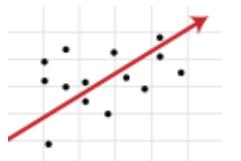


CHALLENGES

Image features?



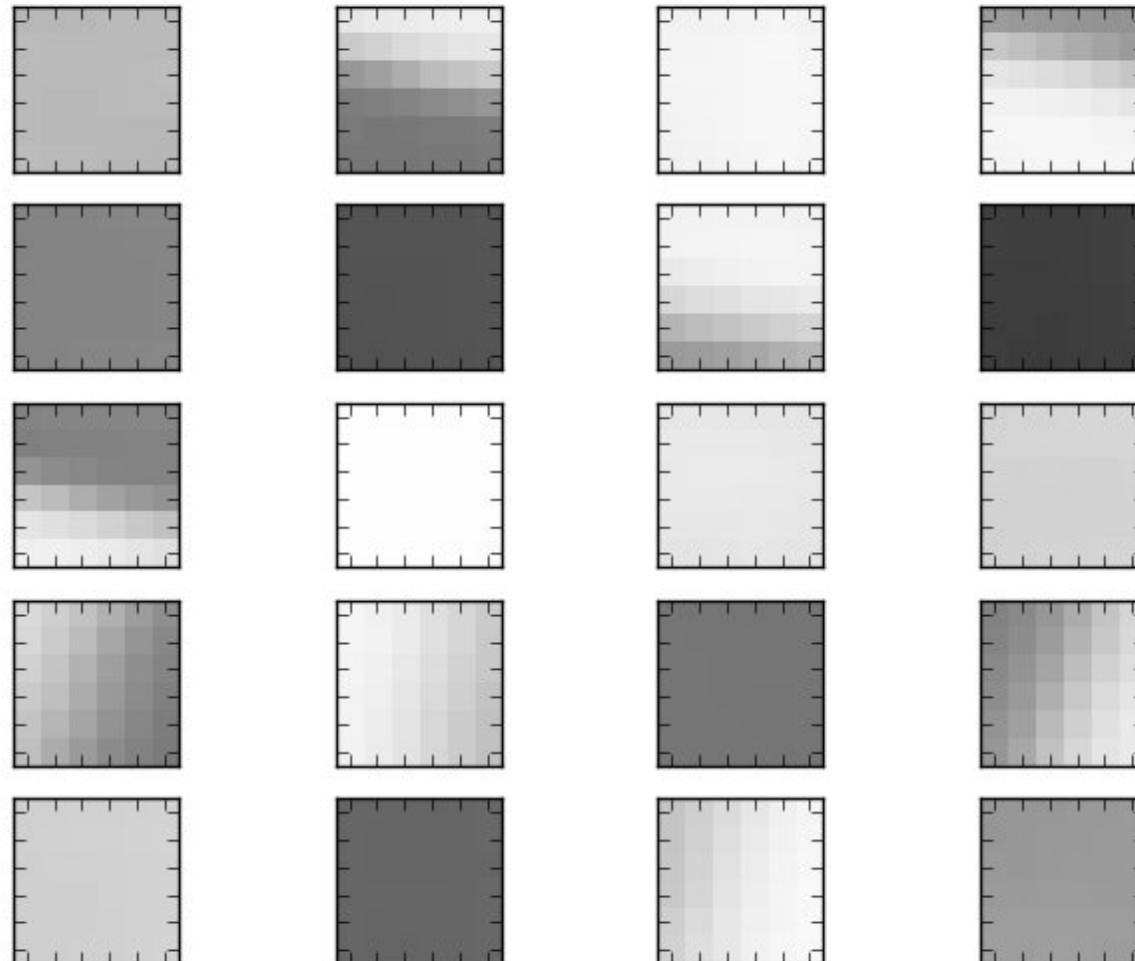
2-dimensional
regression



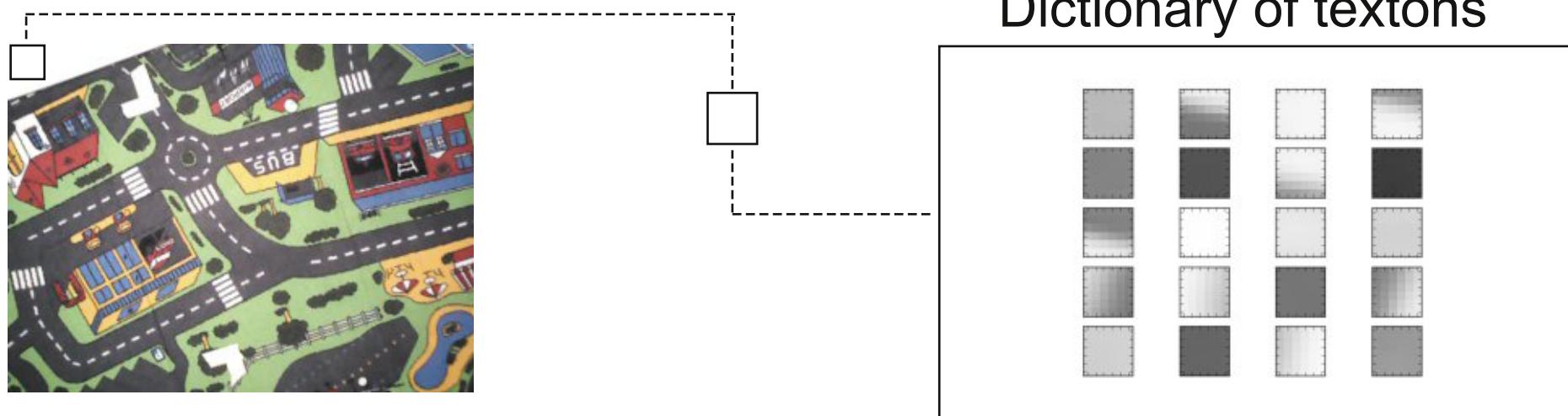
Which map is good?



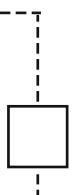
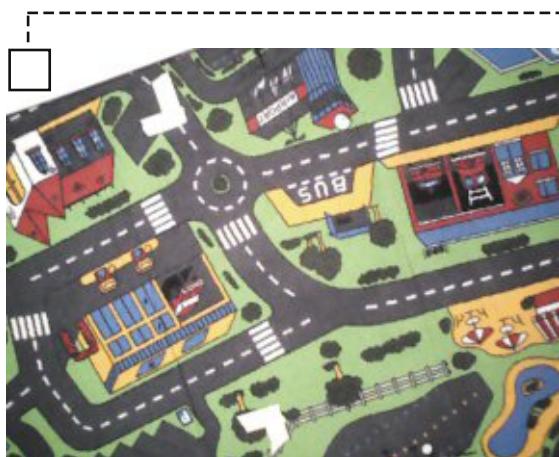
TEXTONS AS IMAGE FEATURES



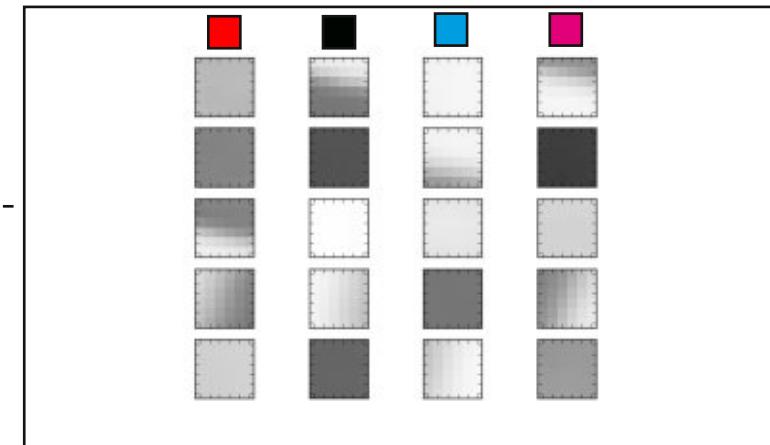
MACHINE-LEARNING APPROACH



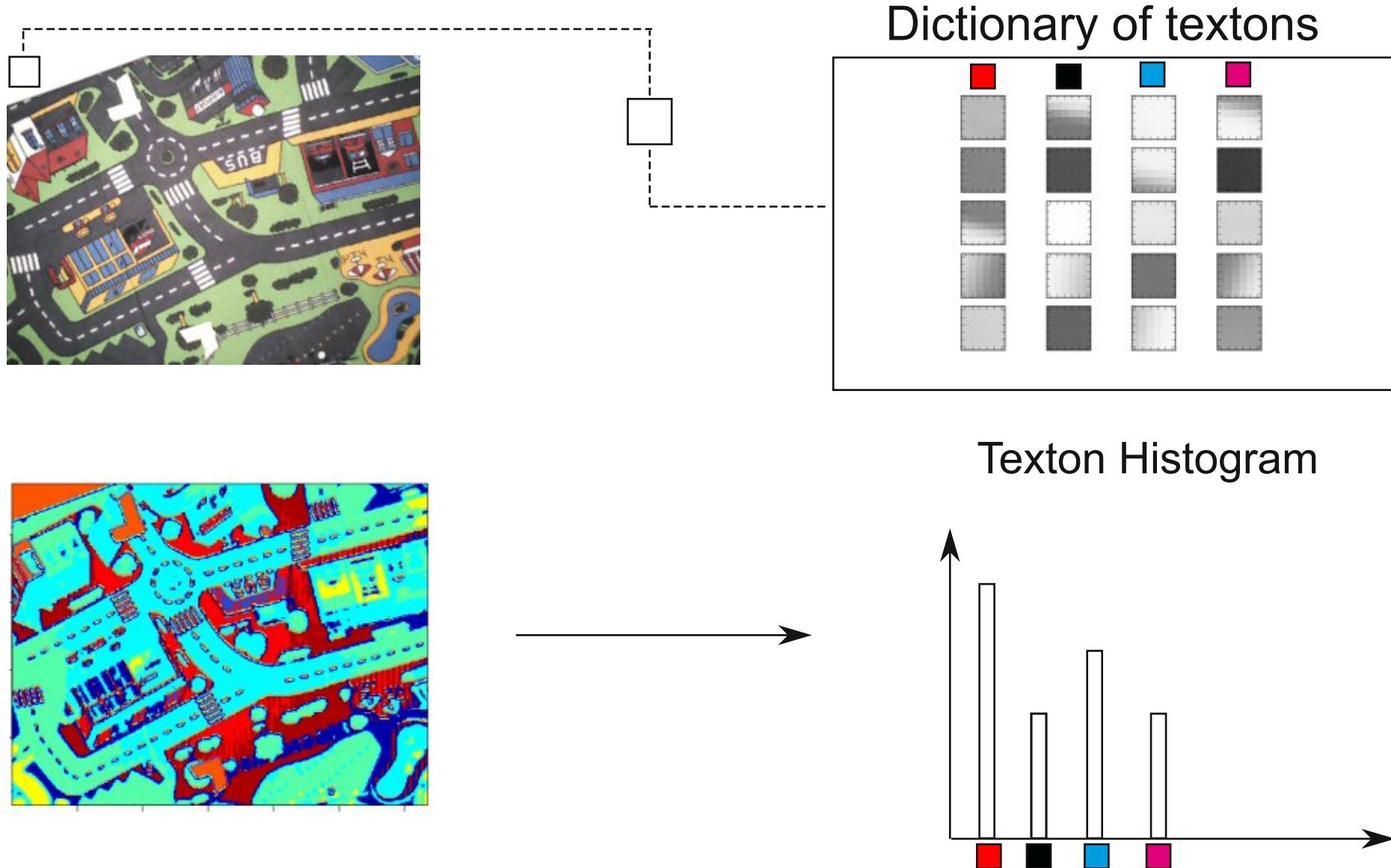
MACHINE-LEARNING APPROACH



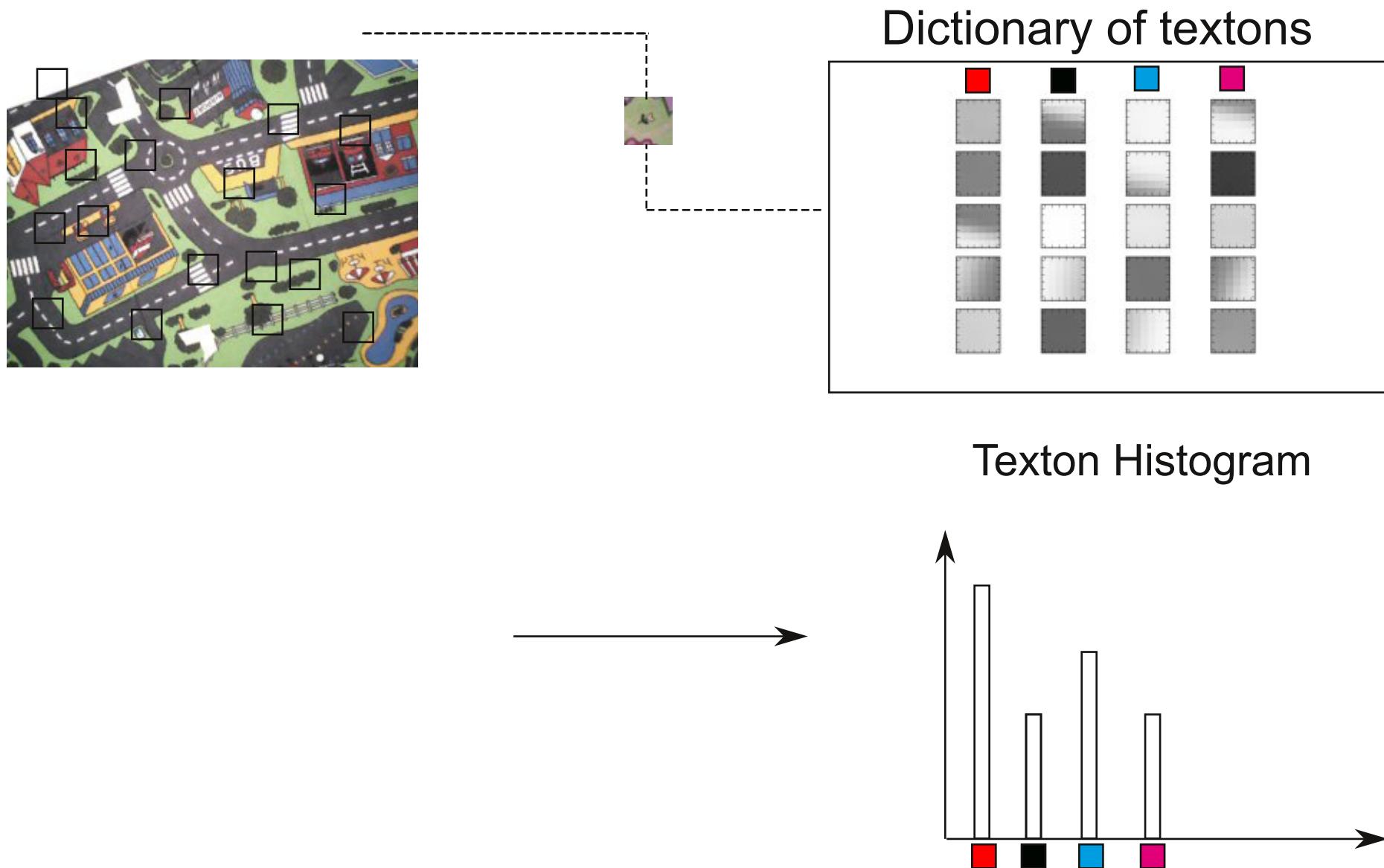
Dictionary of textons



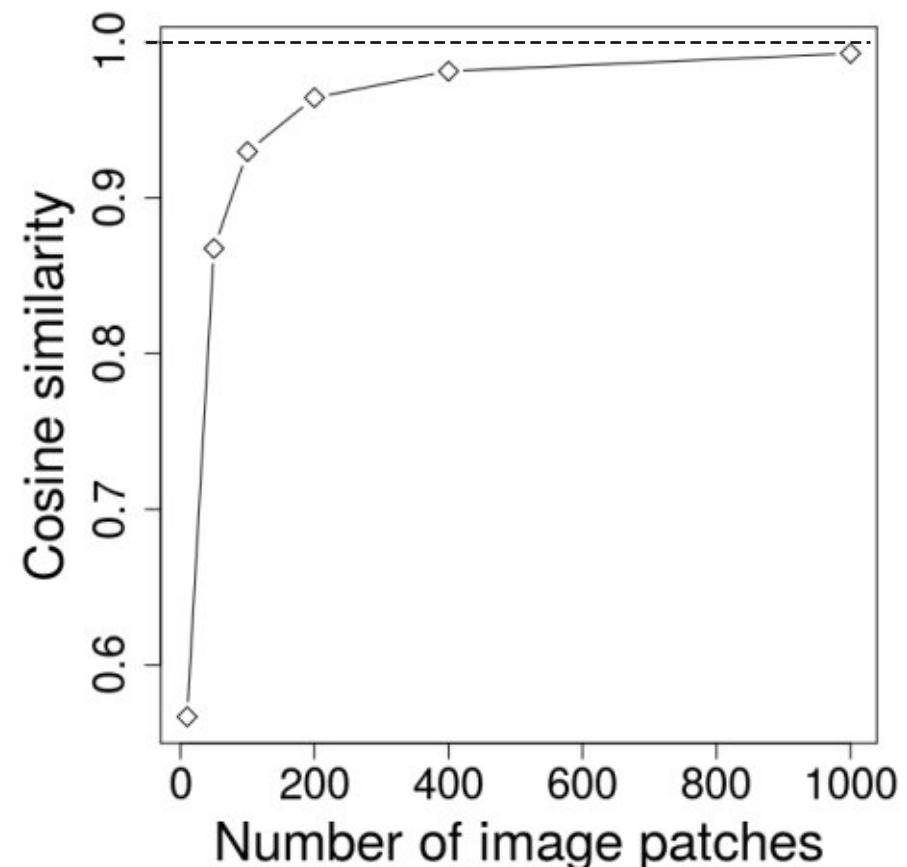
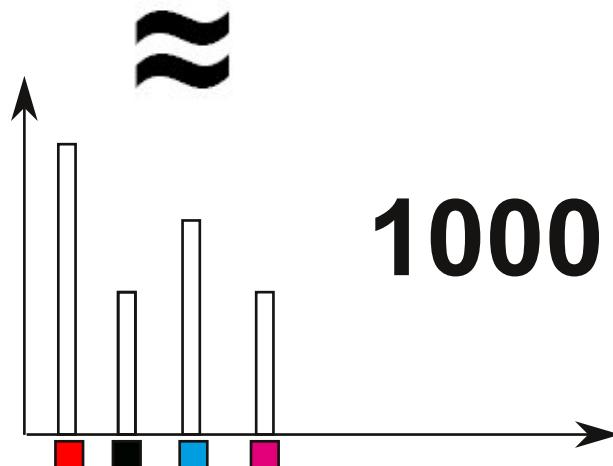
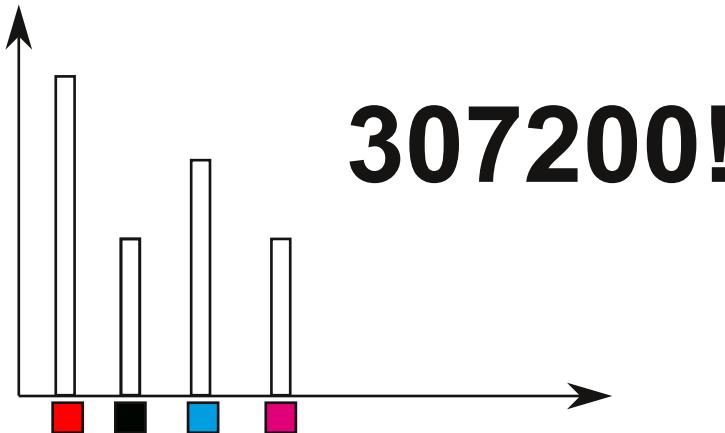
MACHINE-LEARNING APPROACH



MACHINE-LEARNING APPROACH

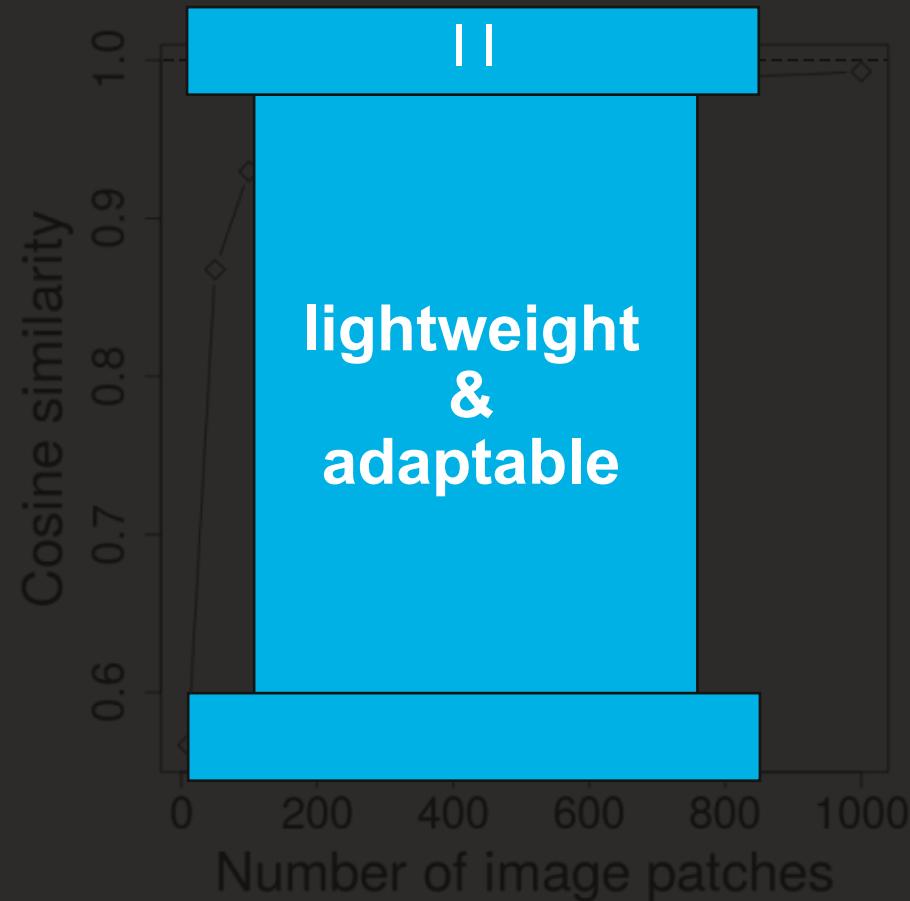


MACHINE-LEARNING APPROACH



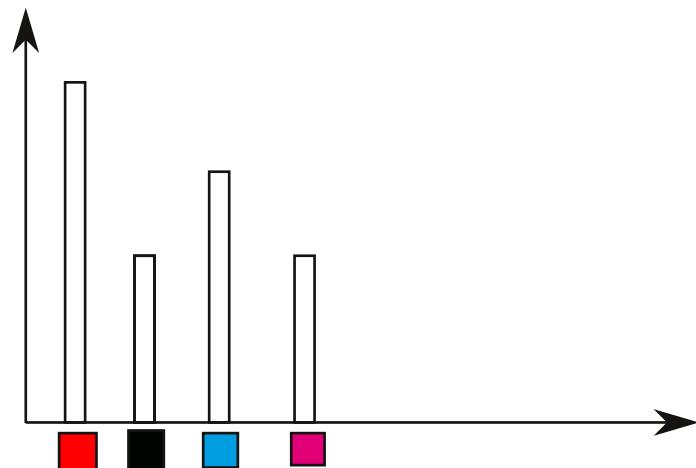
MACHINE-LEARNING APPROACH

307200!

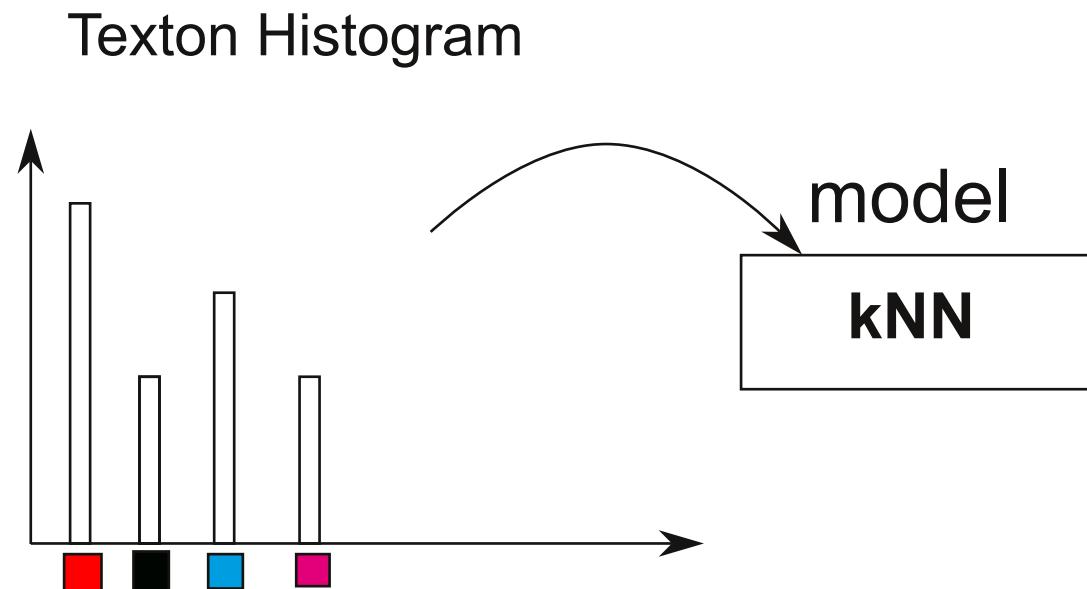


MACHINE-LEARNING APPROACH

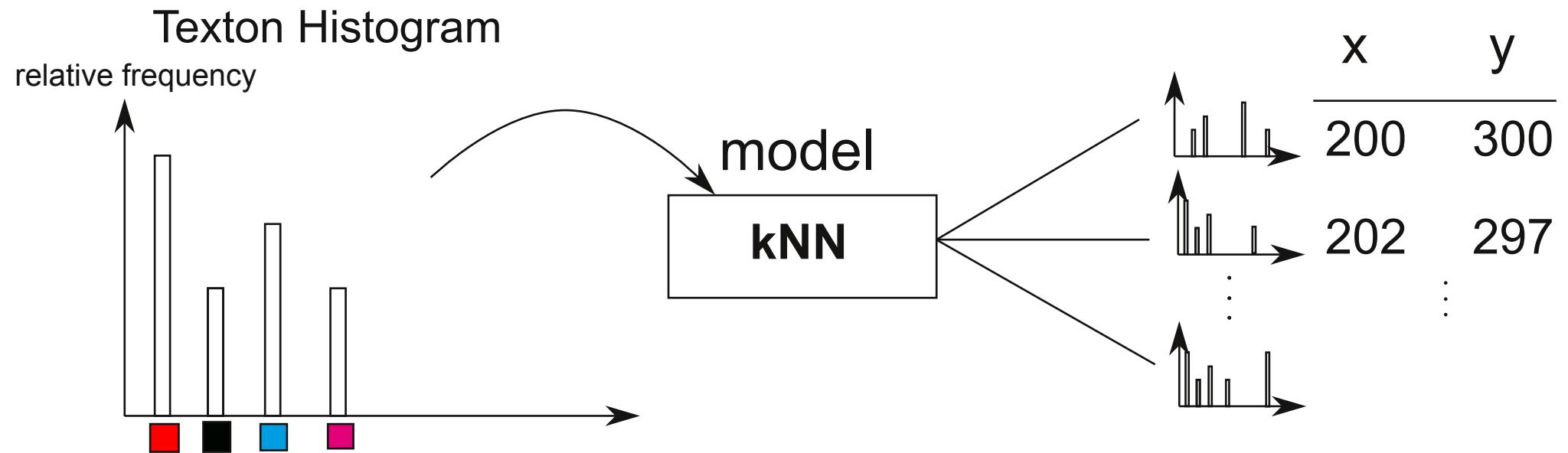
Texton Histogram



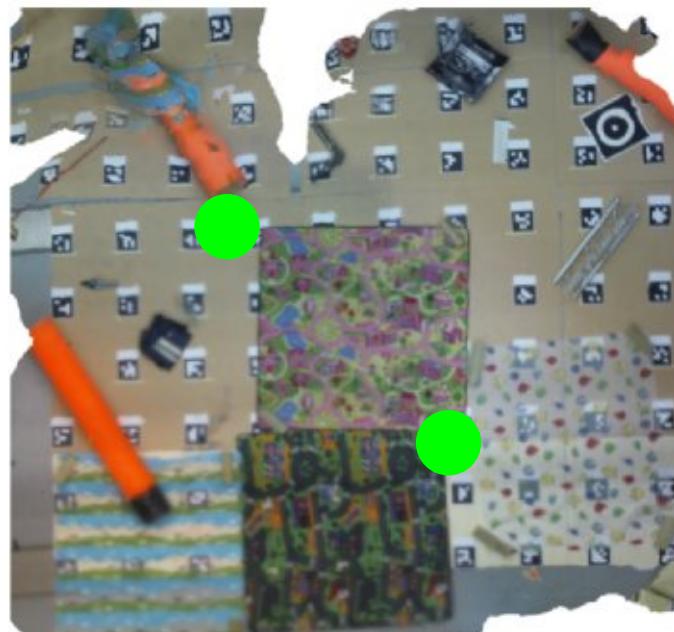
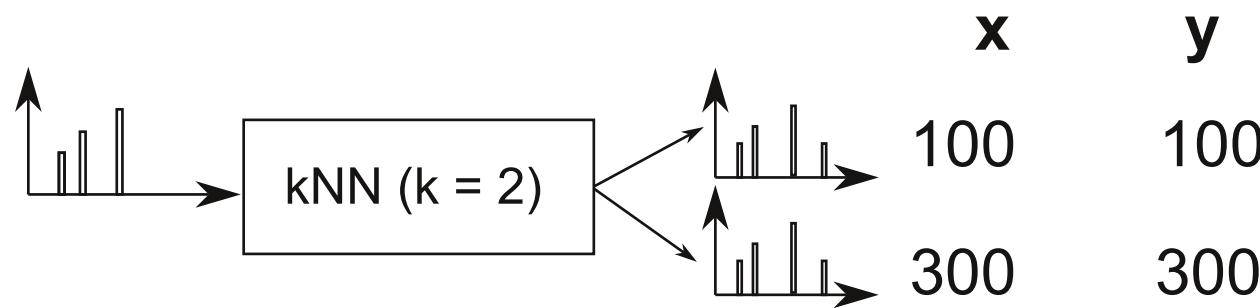
MACHINE-LEARNING APPROACH



MACHINE-LEARNING APPROACH

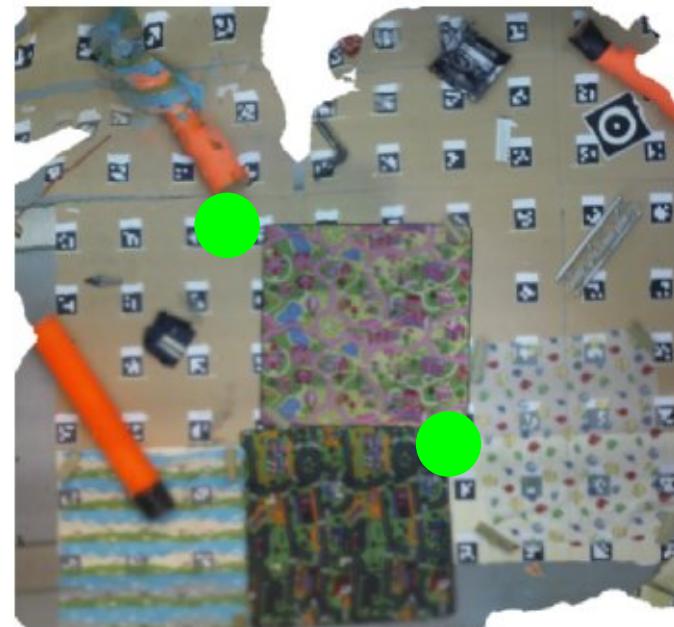


FILTERING



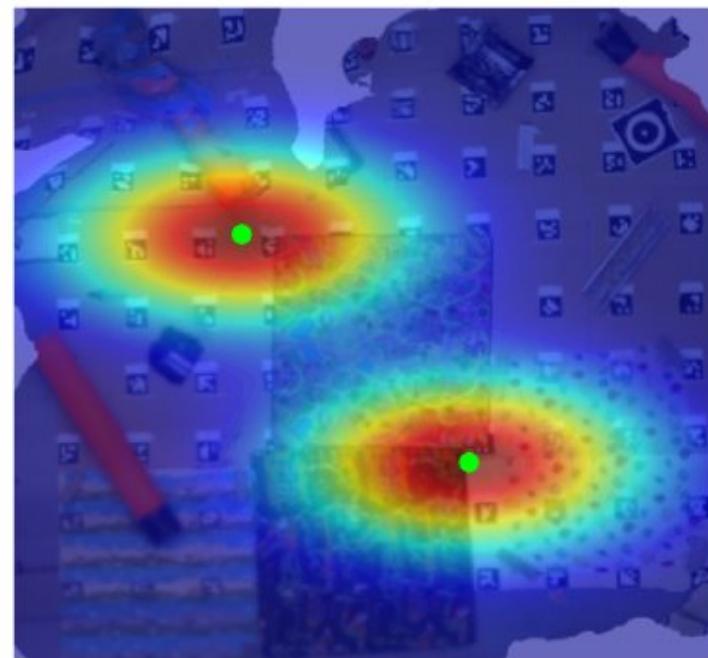
FILTERING

Sensor model (Likelihood)



FILTERING

Sensor model (Likelihood)



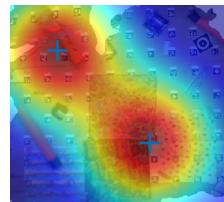
2-D Gaussian mixture model

FILTERING

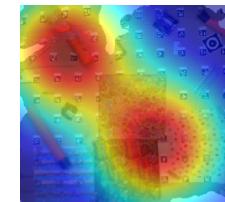
Prior (t = 1)



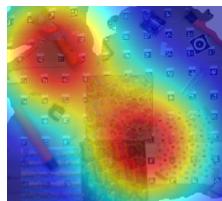
Likelihood (t = 1)



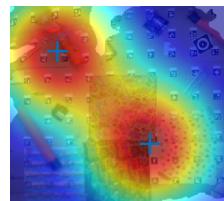
Posterior (t = 1)



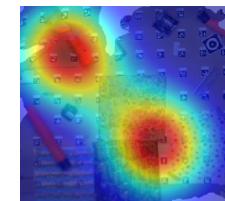
Prior (t = 2)



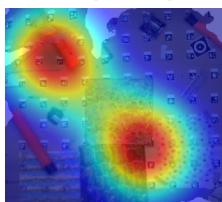
Likelihood (t = 2)



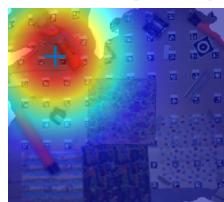
Posterior (t = 2)



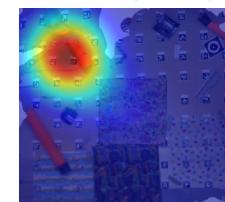
Prior (t = 3)



Likelihood (t = 3)



Posterior (t = 3)

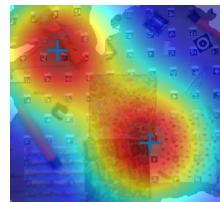


FILTERING

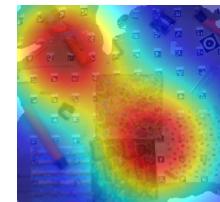
Prior (t = 1)



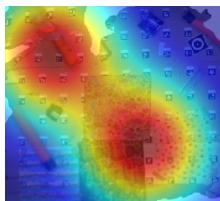
Likelihood (t = 1)



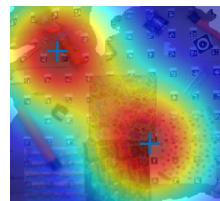
Posterior (t = 1)



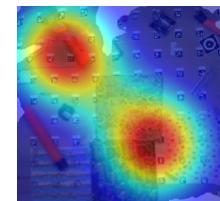
Prior (t = 2)



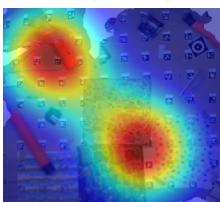
Likelihood (t = 2)



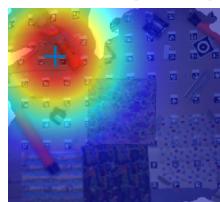
Posterior (t = 2)



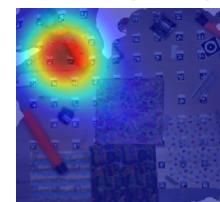
Prior (t = 3)



Likelihood (t = 3)

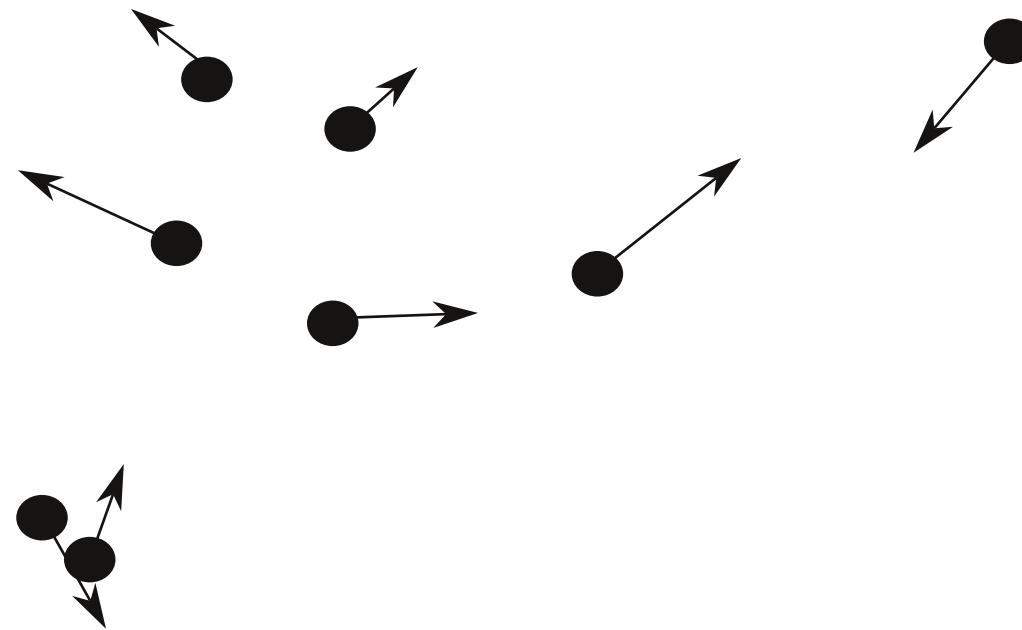


Posterior (t = 3)



+ proximity-based motion model

PARTICLE FILTER



DUMMY: VIDEO FAST FLIGHT

DUMMY: PARTICLE FILTER

**lightweight
&
adaptable**

MAP EVALUATION

FLOOR



MAP EVALUATION



IDEAL SIMILARITY
of histograms for fixed position

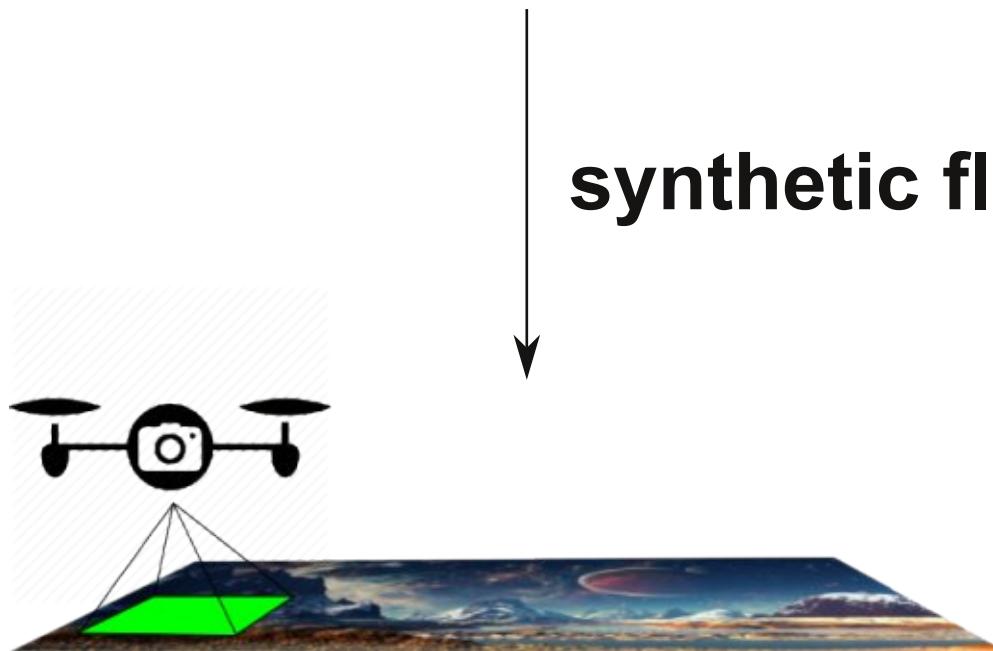
MAP EVALUATION - SYNTHETIC FLIGHT



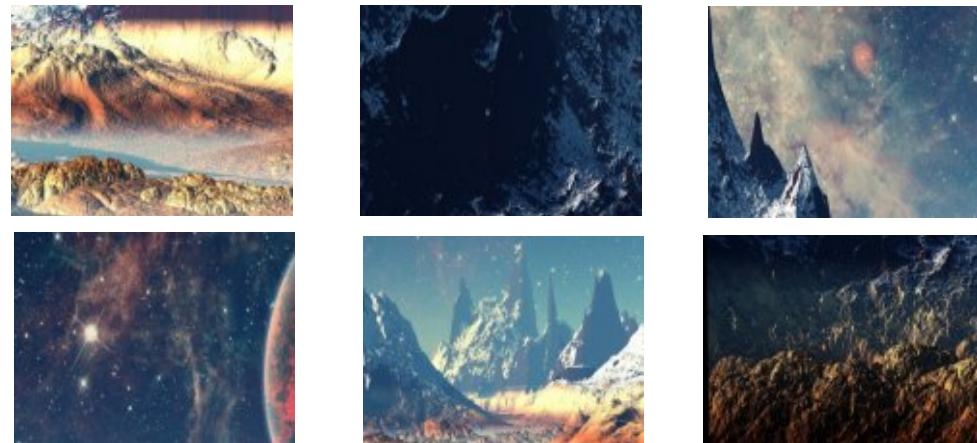
MAP EVALUATION - SYNTHETIC FLIGHT



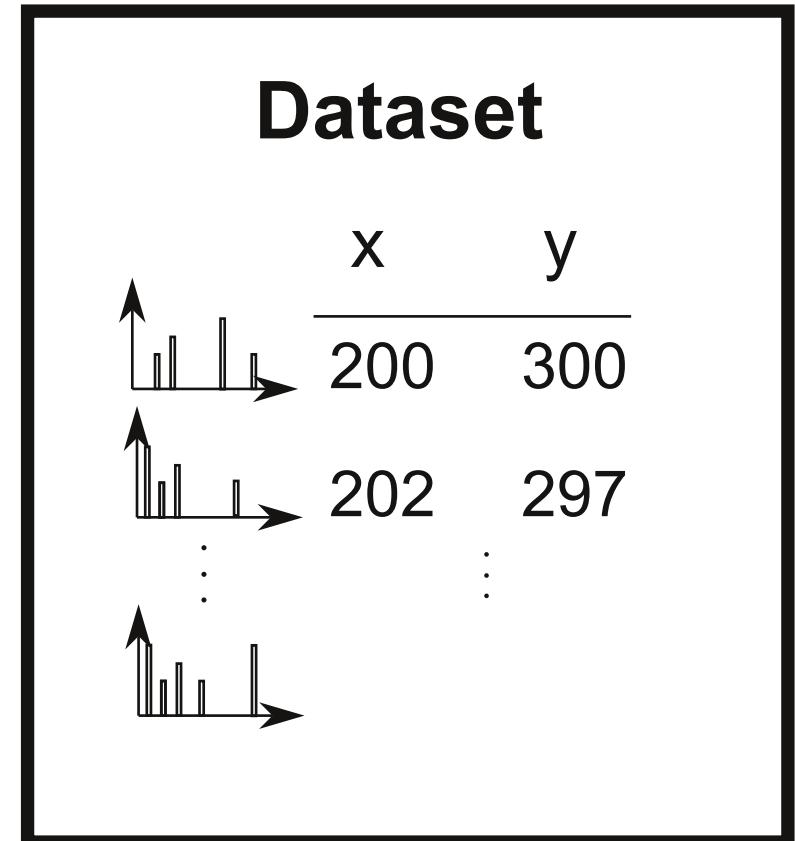
synthetic flight



MAP EVALUATION - SYNTHETIC FLIGHT



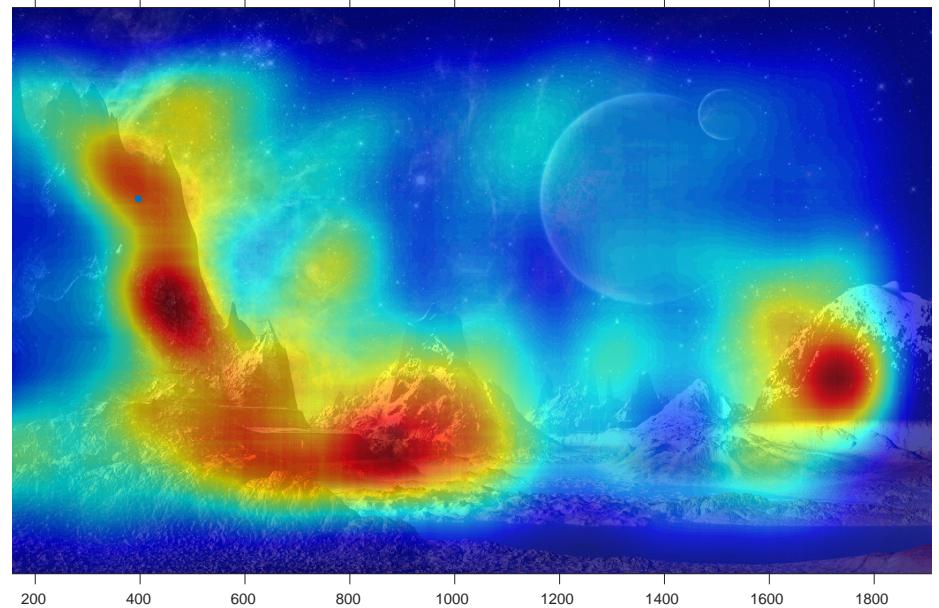
1000 patches



MAP EVALUATION



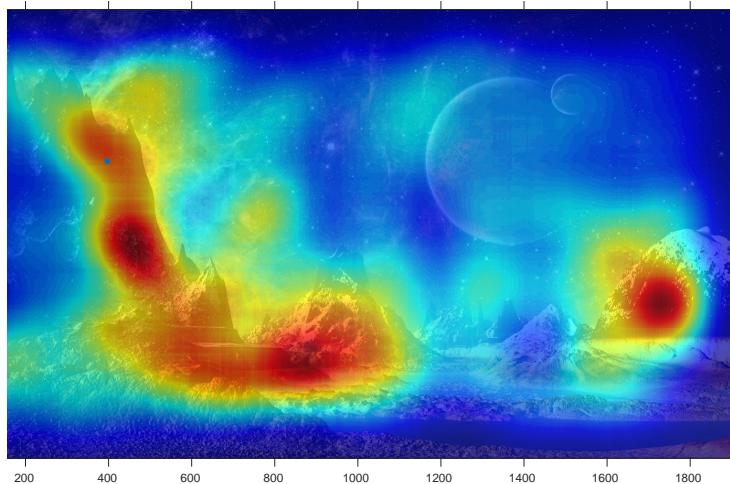
IDEAL SIMILARITY
of histograms for fixed position



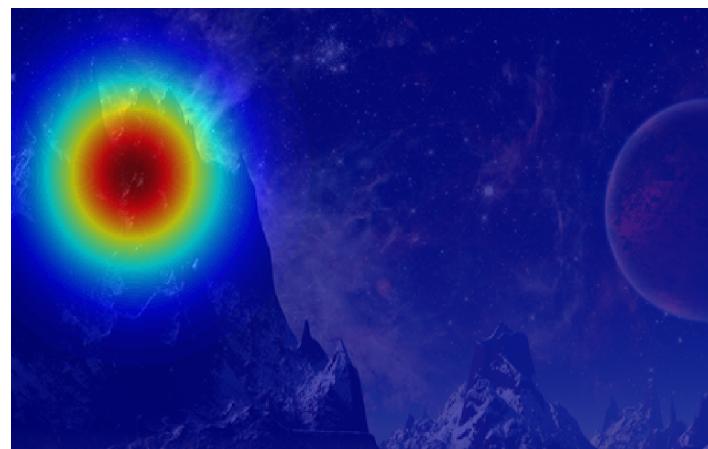
ACTUAL SIMILARITY
(Gaussian smoothing)

MAP EVALUATION

ACTUAL

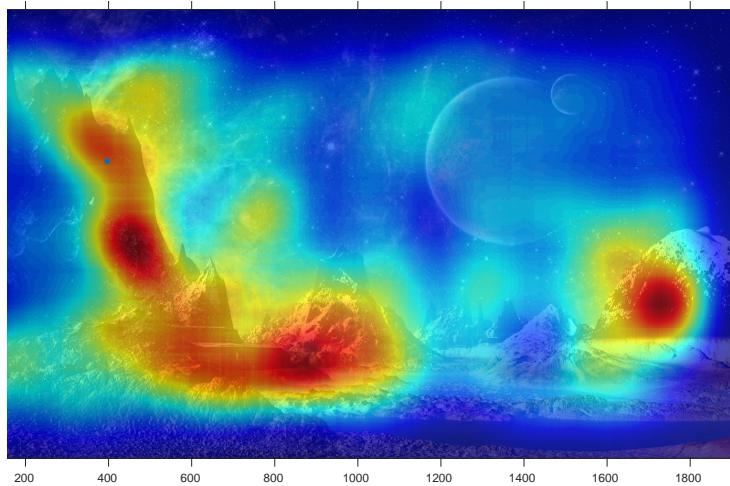


IDEAL

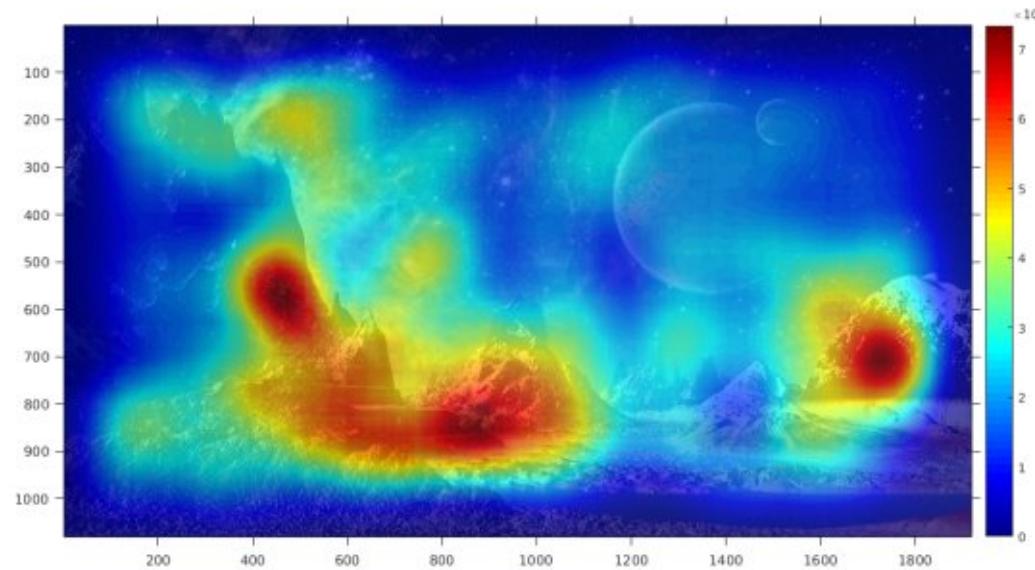
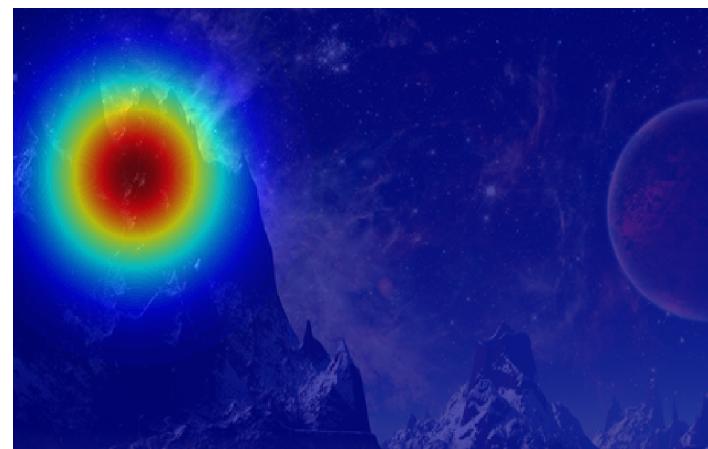


MAP EVALUATION

ACTUAL

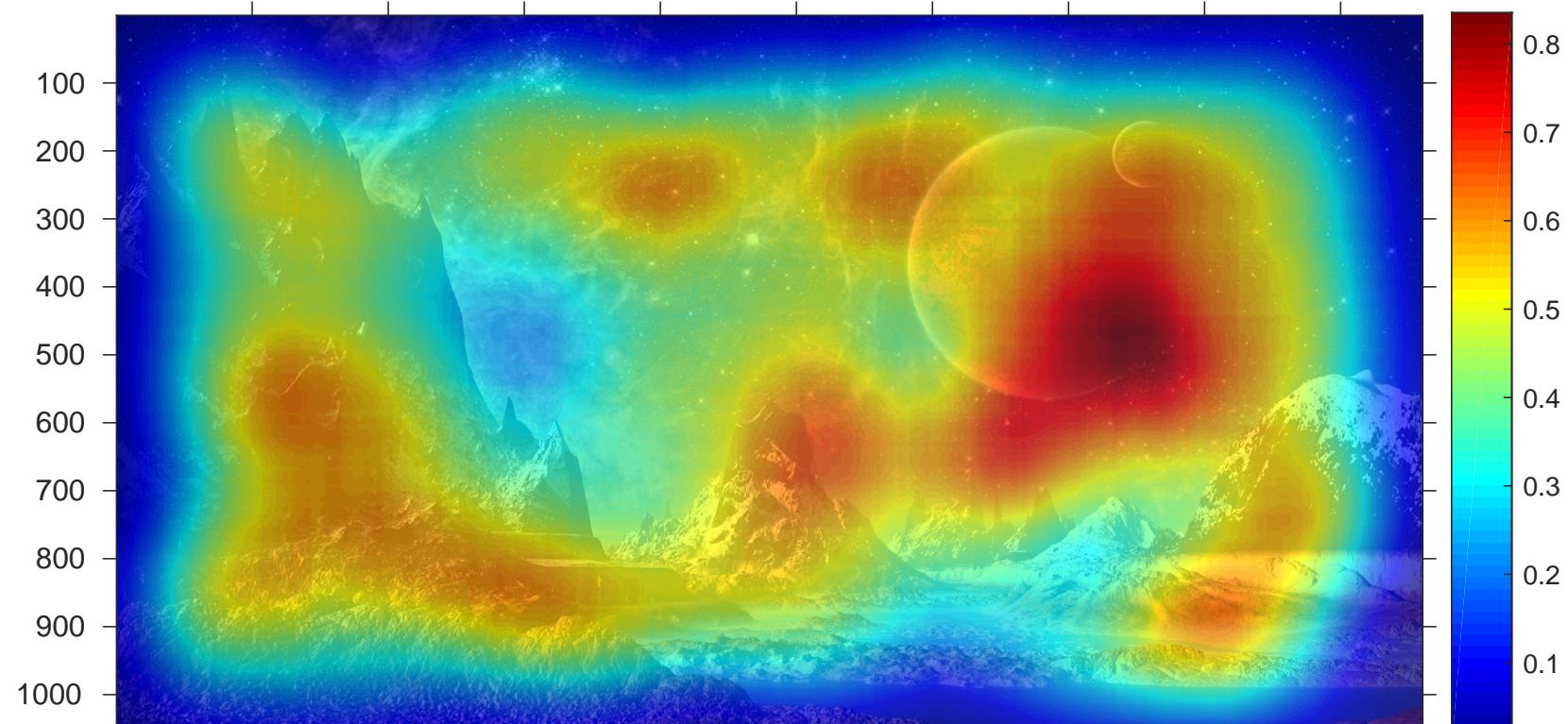


IDEAL



LOSS

MAP EVALUATION



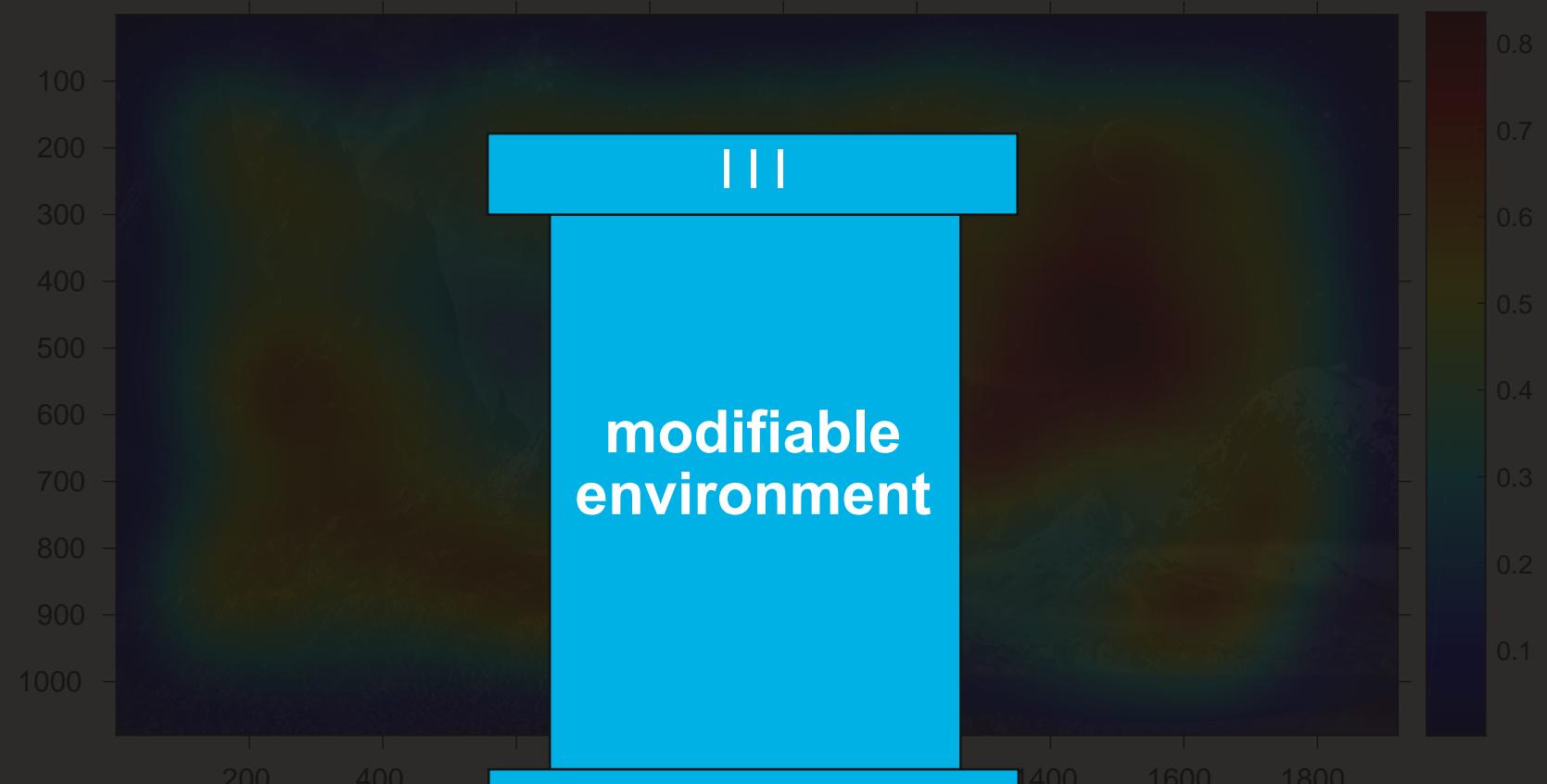
GLOBAL LOSS
(1000 patches)

$0 < \text{average global loss} < 1$

MAP EVALUATION

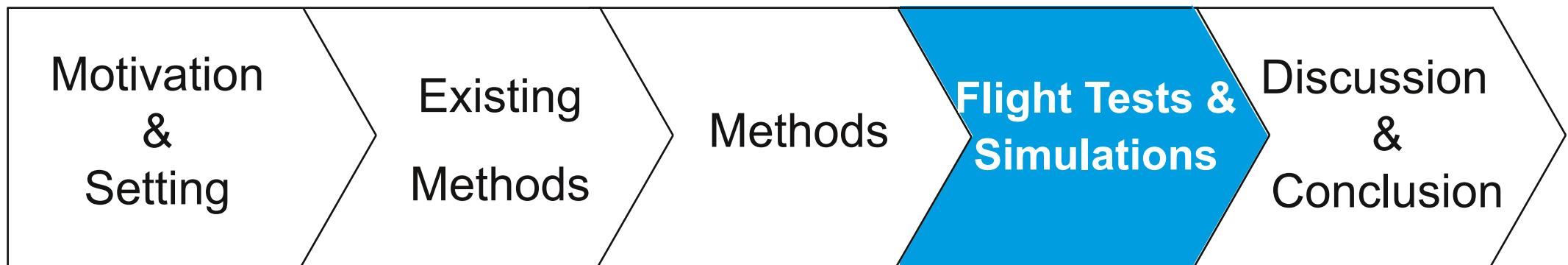


MAP EVALUATION

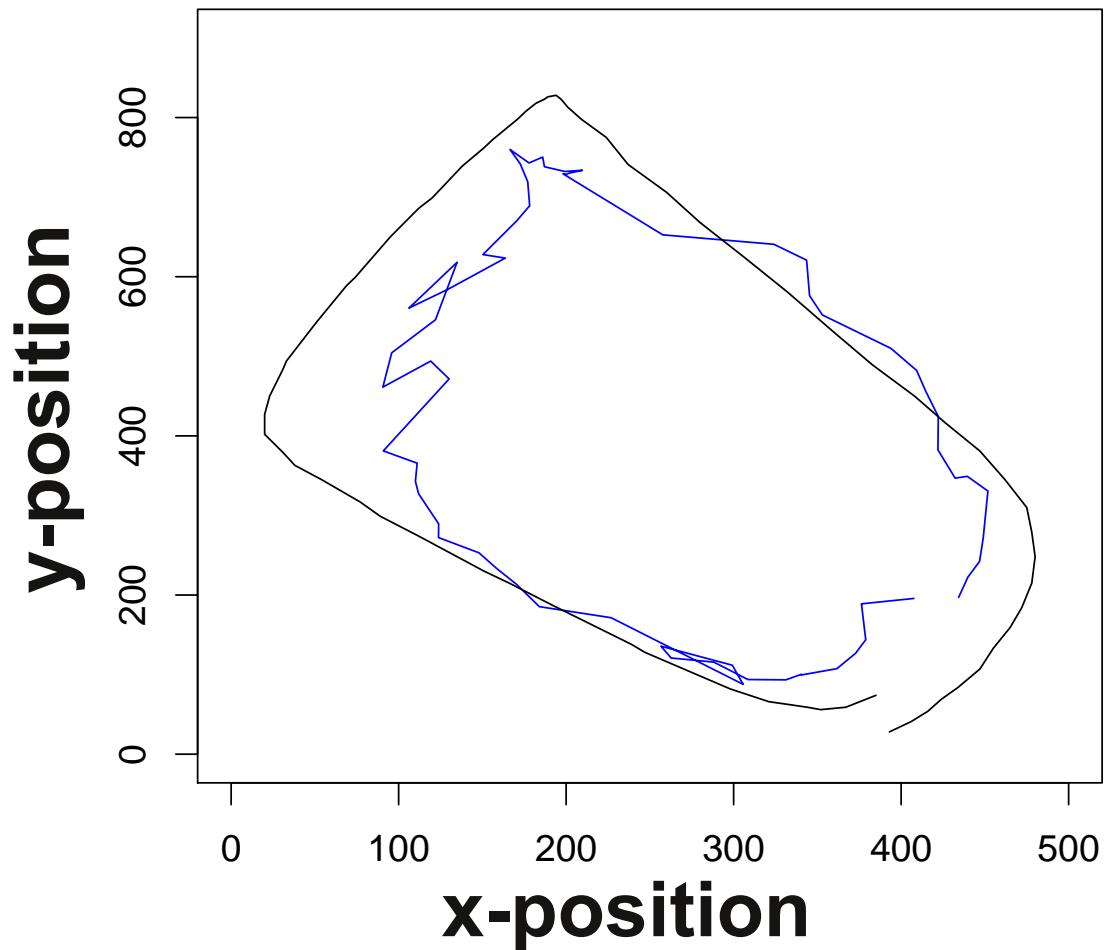


$0 < \text{global loss} < 1$

OUTLINE



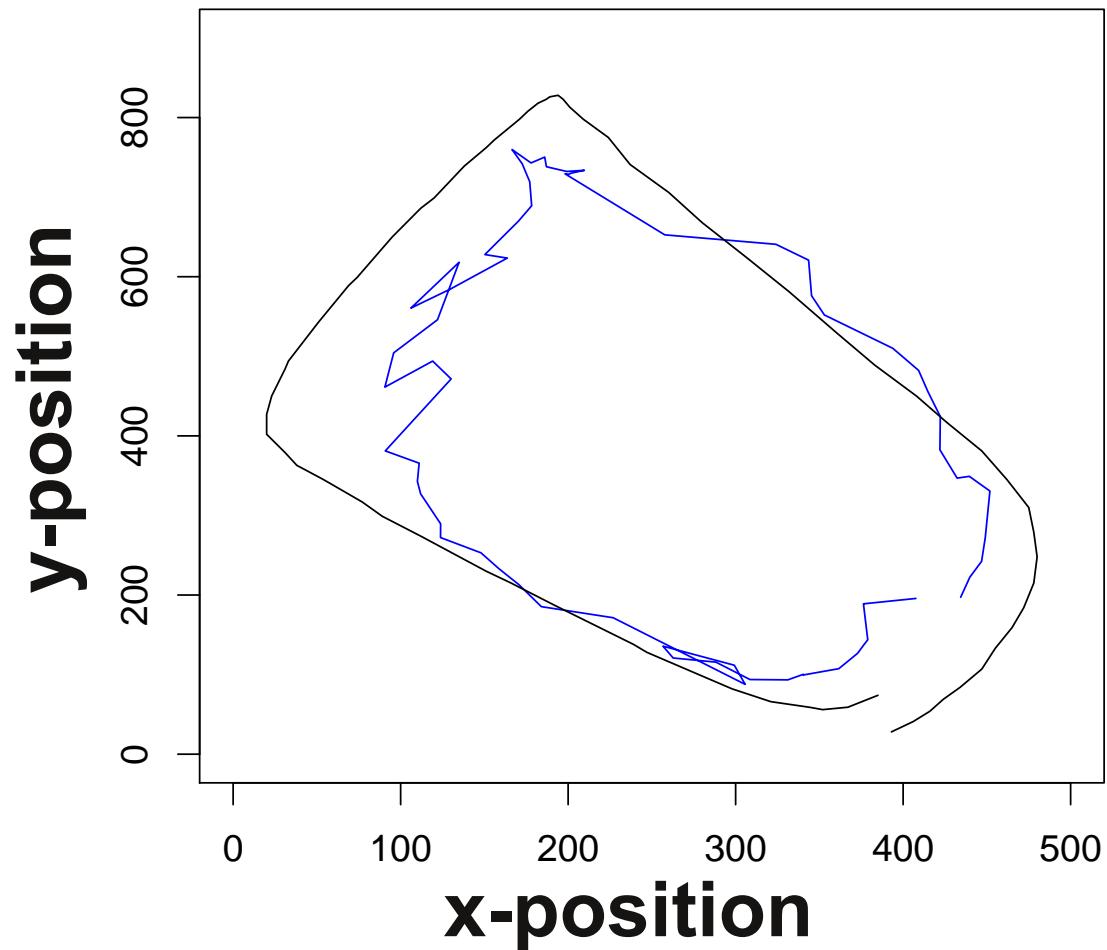
FLIGHT ACCURACY



Mean difference

x: 46 cm
y: 54 cm

FLIGHT ACCURACY



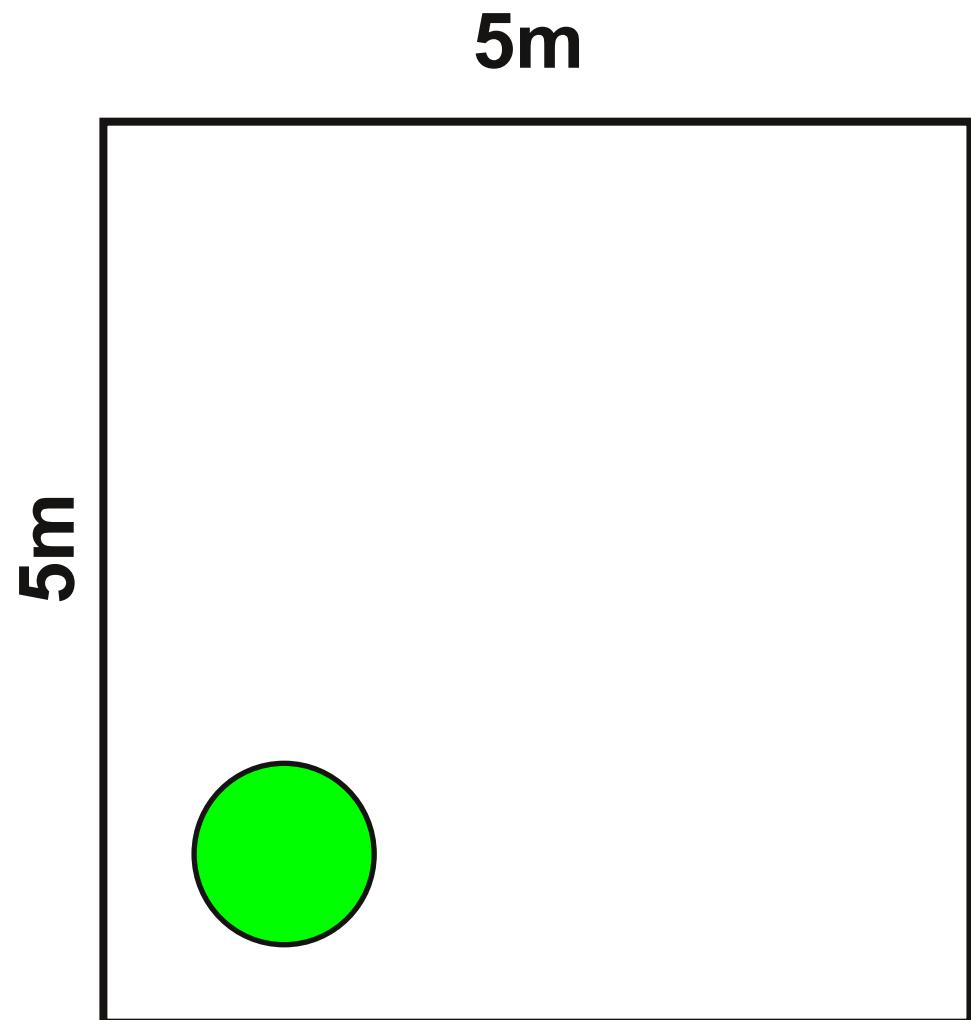
Mean difference

x: 46 cm
y: 54 cm

Standard Deviation

x: 56 cm
y: 71 cm

TRIGGERED LANDING



criterion:
in circle (radius: 60 cm)

safety criterion:
low variance of particles

4 / 6 in landing area

Mean distance outliers: 16 cm

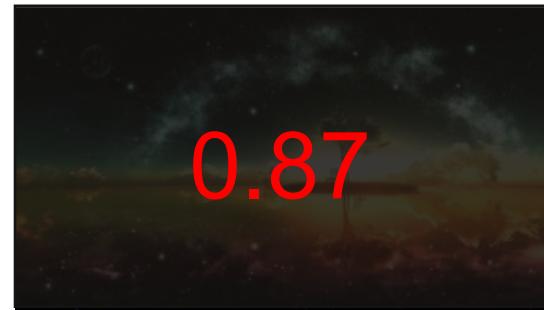
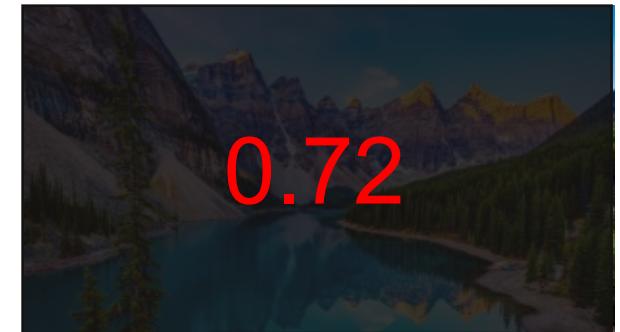
DUMMY: VIDEO TRIGGERED LANDING

MAP EVALUATION

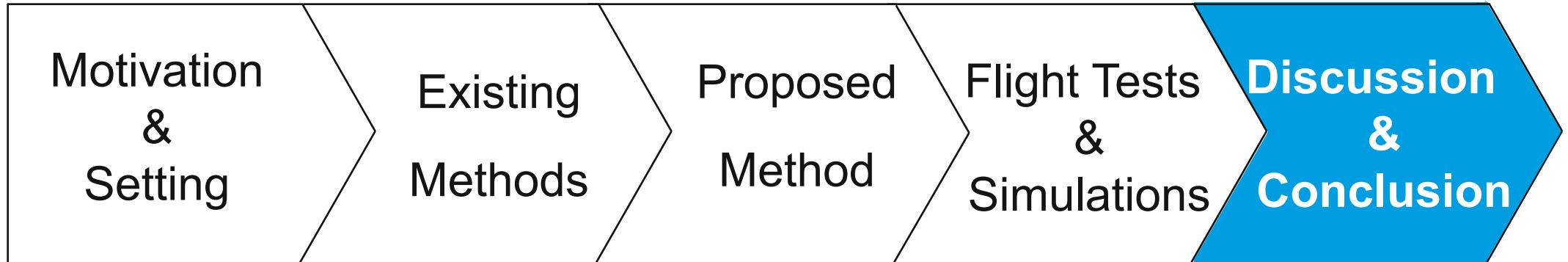


46 images

MAP EVALUATION - LOSSES



OUTLINE



RESEARCH QUESTIONS

Research Question 1

Can vision-based indoor localization be done on a limited platform?

Research Question 2

Can we predict the suitability of an environment for the proposed localization algorithm?

DISCUSSION

Implications:

- paves the way to indoor flight



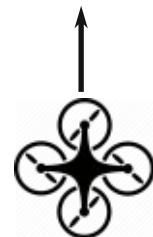
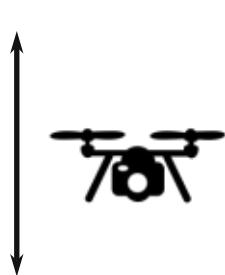
- adaptable to different platforms



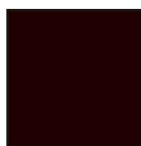
DISCUSSION

Possible improvements:

- flexible height and rotations



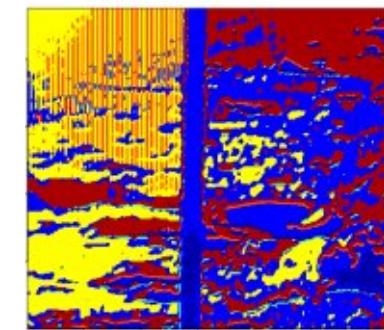
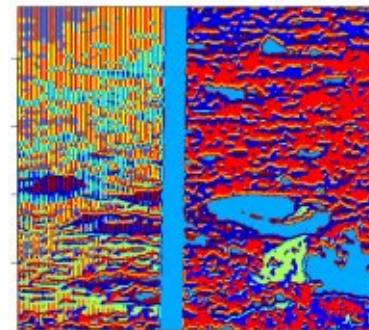
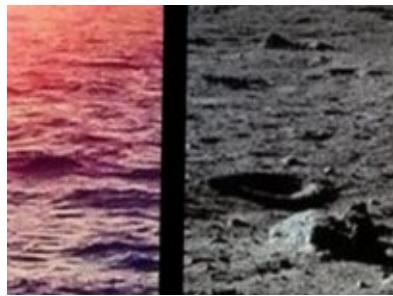
- robustness to different lighting conditions



DISCUSSION

Future research:

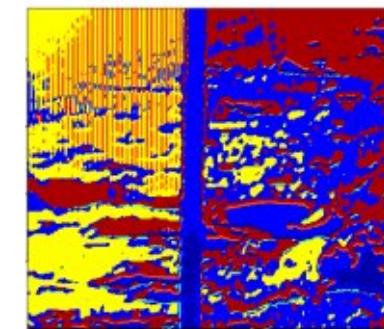
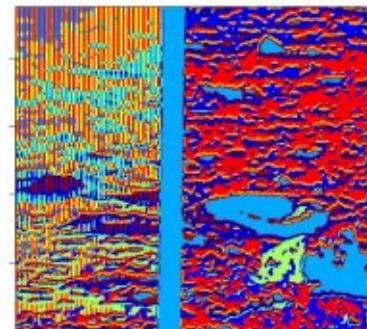
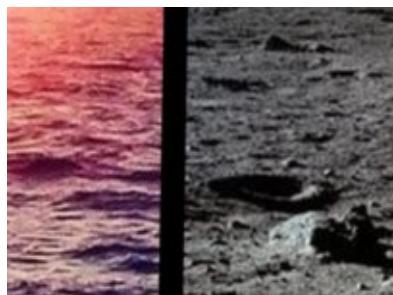
- bridge reality gap



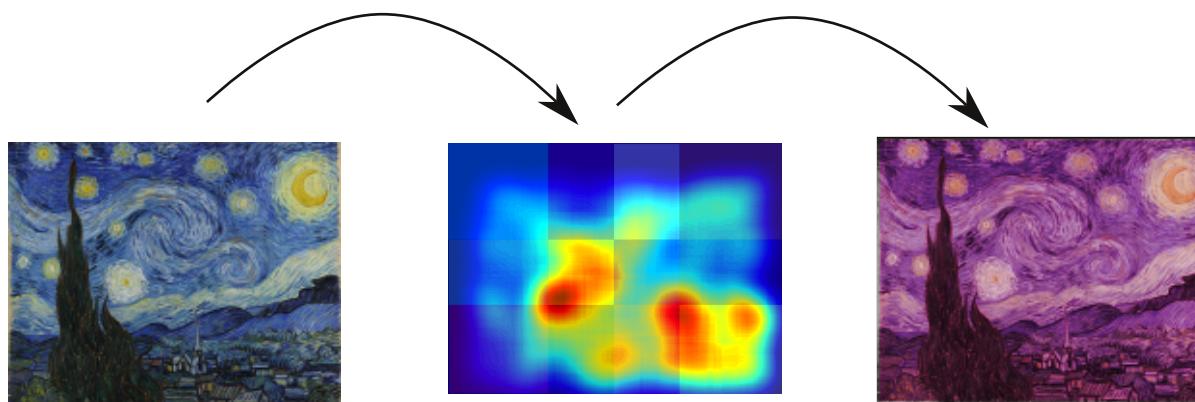
DISCUSSION

Future research:

- bridge reality gap



- automatic map generation (evolutionary algorithm)

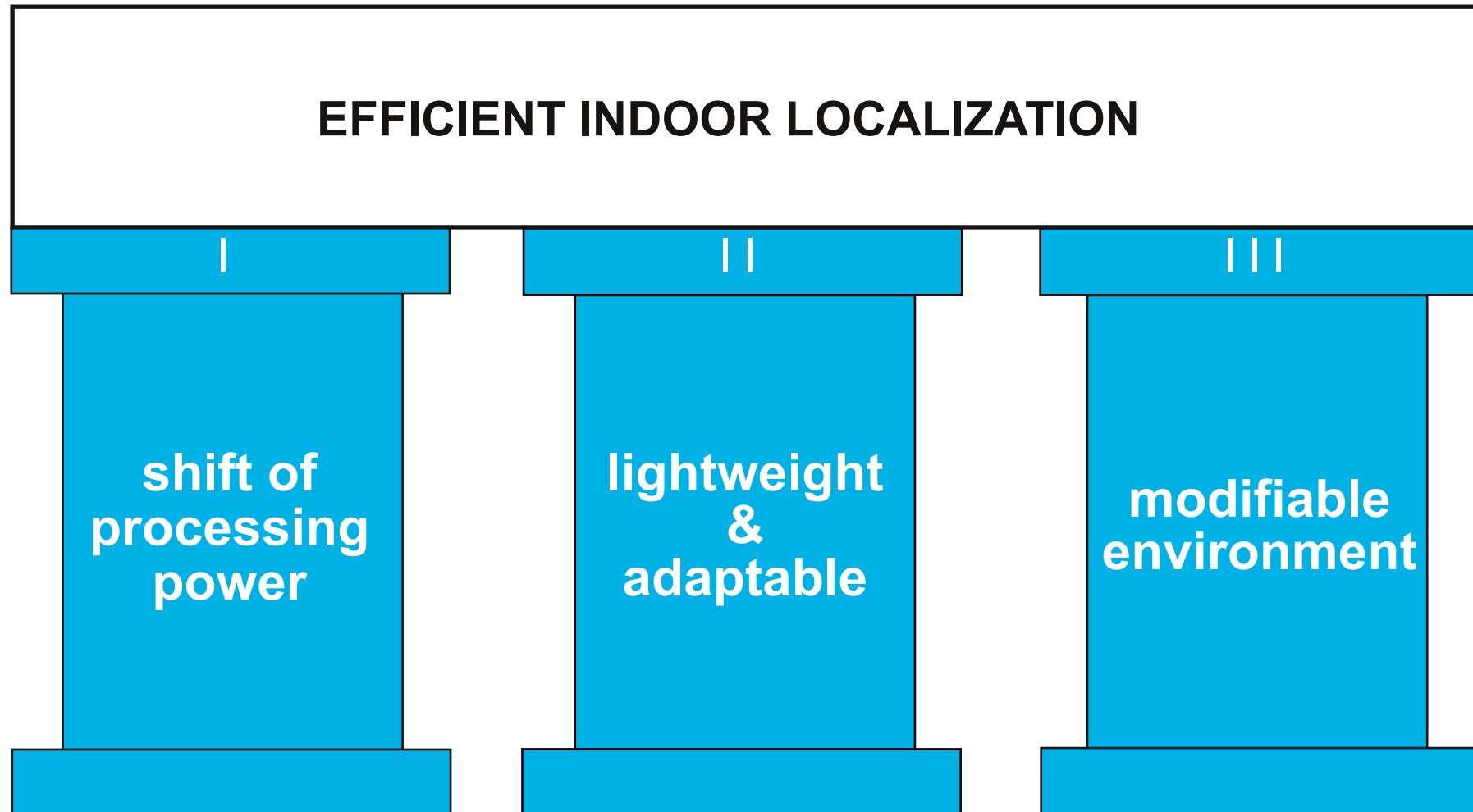


CODE CONTRIBUTIONS

- draug: Image augmentation with synthetic views (C++)
<https://github.com/Pold87/draug>
- Map evaluation (MATLAB)
<https://github.com/Pold87/evaluation-thesis>
- Localization: homography finding (C++),
particle filter (C), texton-based approach (C)
<https://github.com/paparazzi/paparazzi>



CONCLUSION

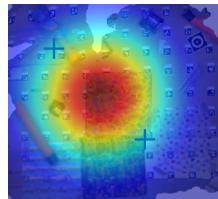


KALMAN FILTER

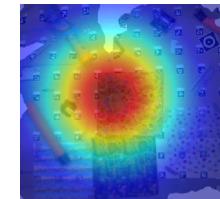
Prior (t = 1)



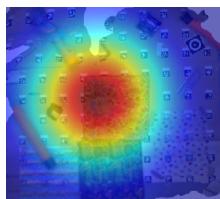
Likelihood (t = 1)



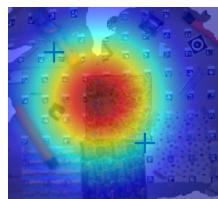
Posterior (t = 1)



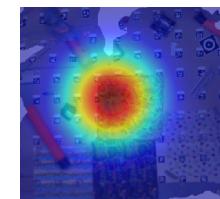
Prior (t = 2)



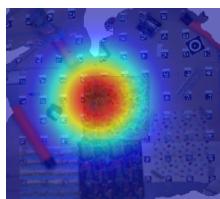
Likelihood (t = 2)



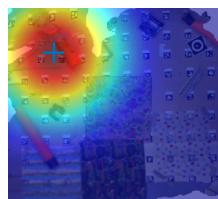
Posterior (t = 2)



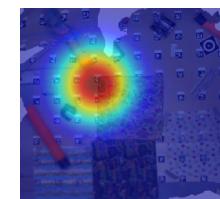
Prior (t = 3)



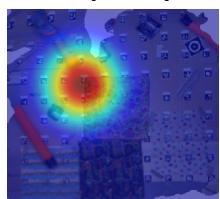
Likelihood (t = 3)



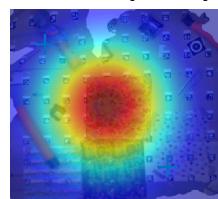
Posterior (t = 3)



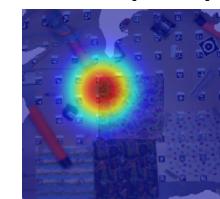
Prior (t = 4)



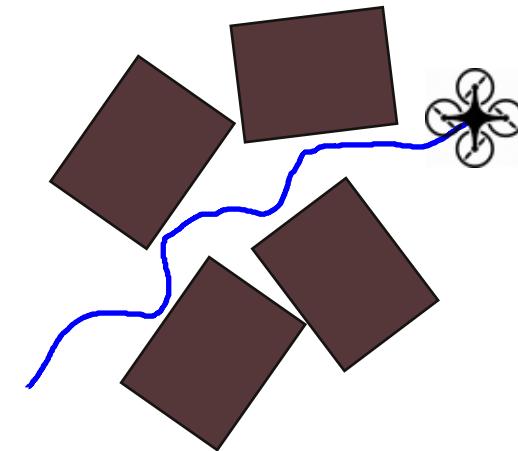
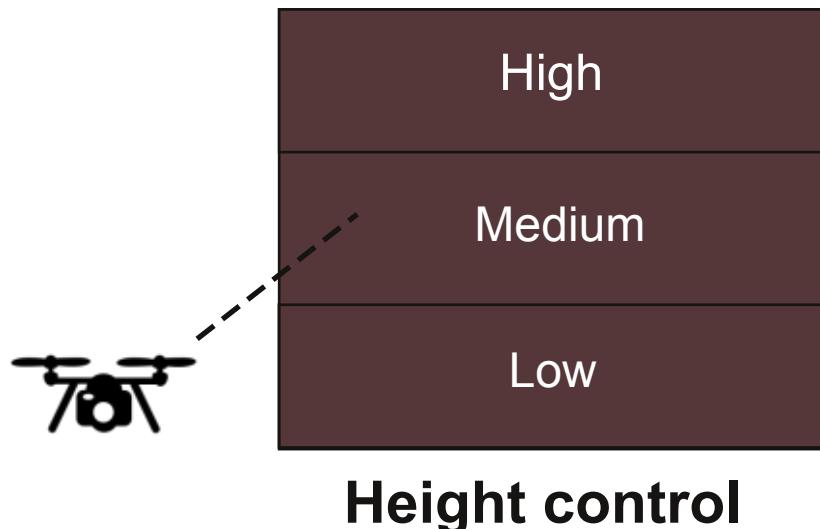
Likelihood (t = 4)



Posterior (t = 4)



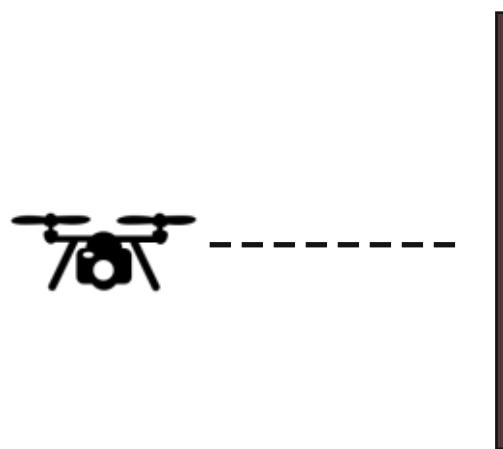
FOUNDATION



Obstacle Avoidance



Safe Landing Spot Detection



Distance Measurement

METHODS FOR ONBOARD LOCALIZATION

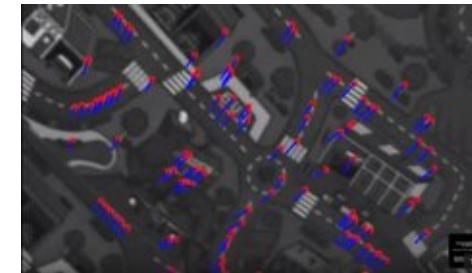


Laser range finder

METHODS FOR ONBOARD LOCALIZATION



Laser range finder

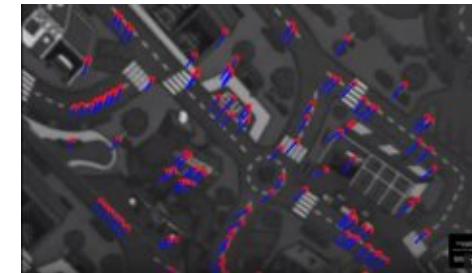


Optical flow

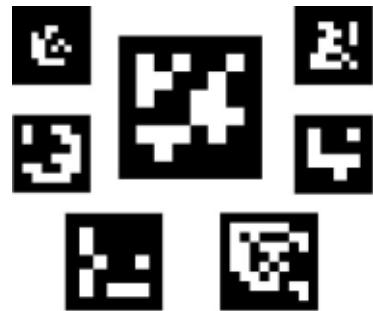
METHODS FOR ONBOARD LOCALIZATION



Laser range finder



Optical flow

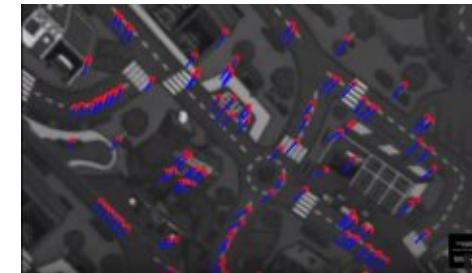


Markers

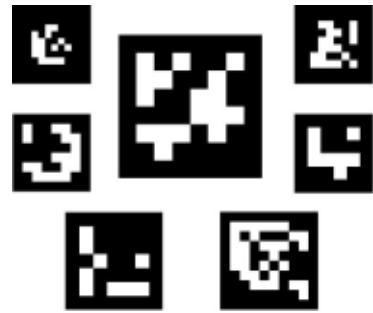
METHODS FOR ONBOARD LOCALIZATION



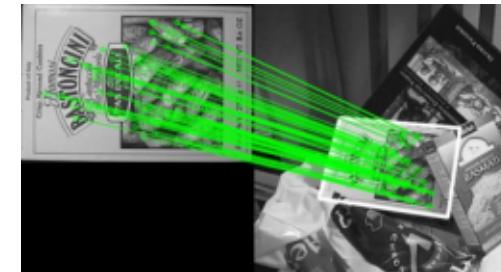
Laser range finder



Optical flow



Markers



Homography finding

MAP EVALUATION

GOOD



0.57

BAD



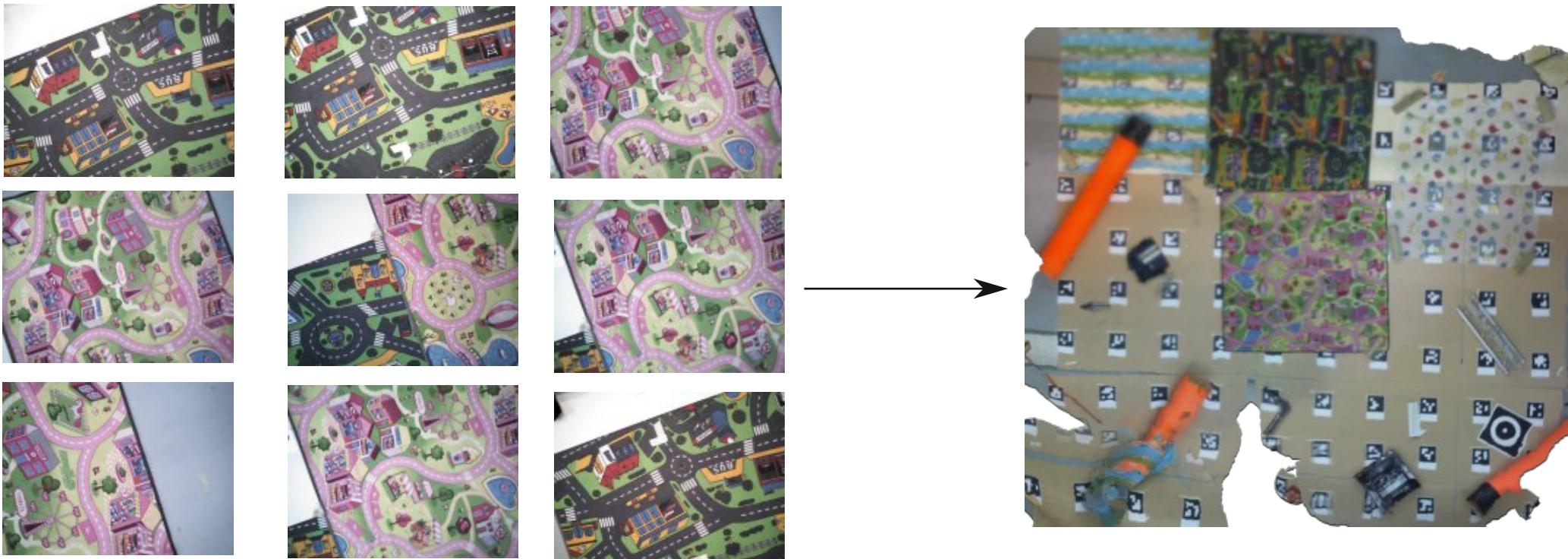
0.98

SCALABILITY



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SCALABILITY



Orthomap

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