Computer Vision for Mobile Robots in GPS Denied Areas

Michael Berli, 28th of April 2015
Supervisor: Tobias Nägeli

Robots can work in places
we as humans can't reach

and they can do jobs we are
unable or unwilling to do.

[1,2]

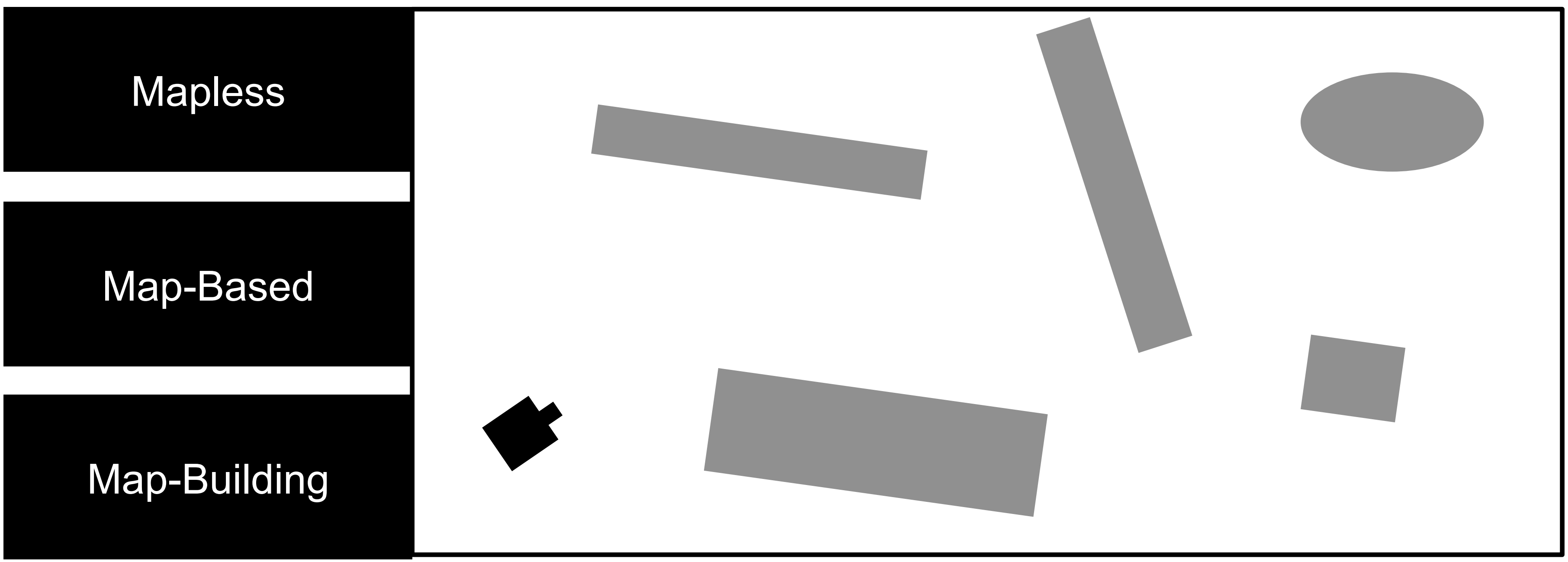
Autonomous mobile robots

- How do we make robots navigate autonomously?

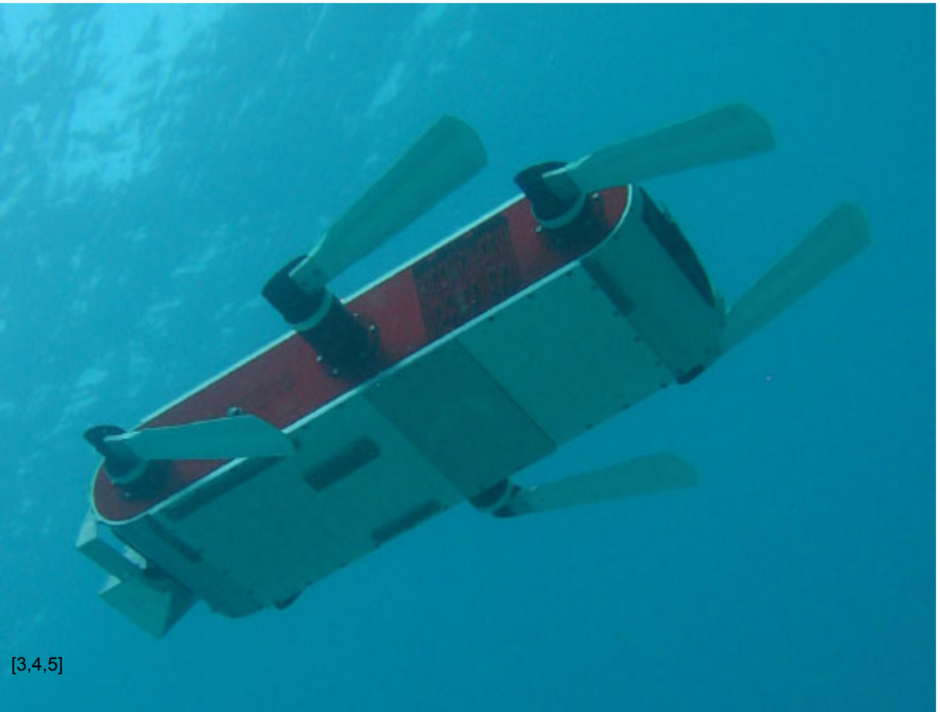
Robots should be able to explore an
unknown environment and navigate inside this
environment without active human control

Autonomous mobile robots

- Using computer vision for autonomous navigation



Robots



[3,4,5]

Focus in this talk

Type of robot

- Autonomous Ground Vehicles

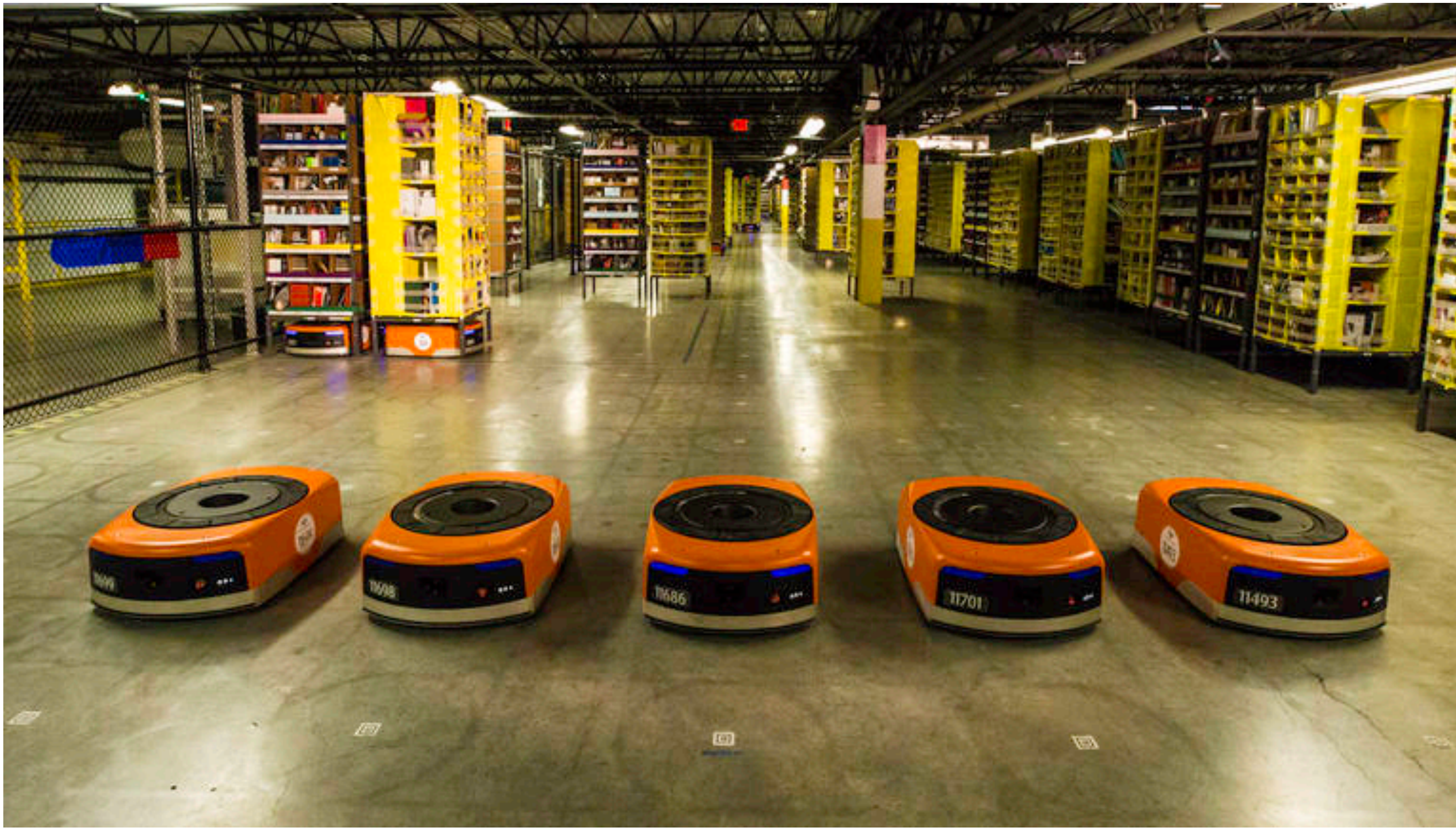
Environment

- Indoor environments (rooms, tunnels, warehouses)

Sensors

- Cameras, wheel sensors

Robot scenarios: Industrial-Automation

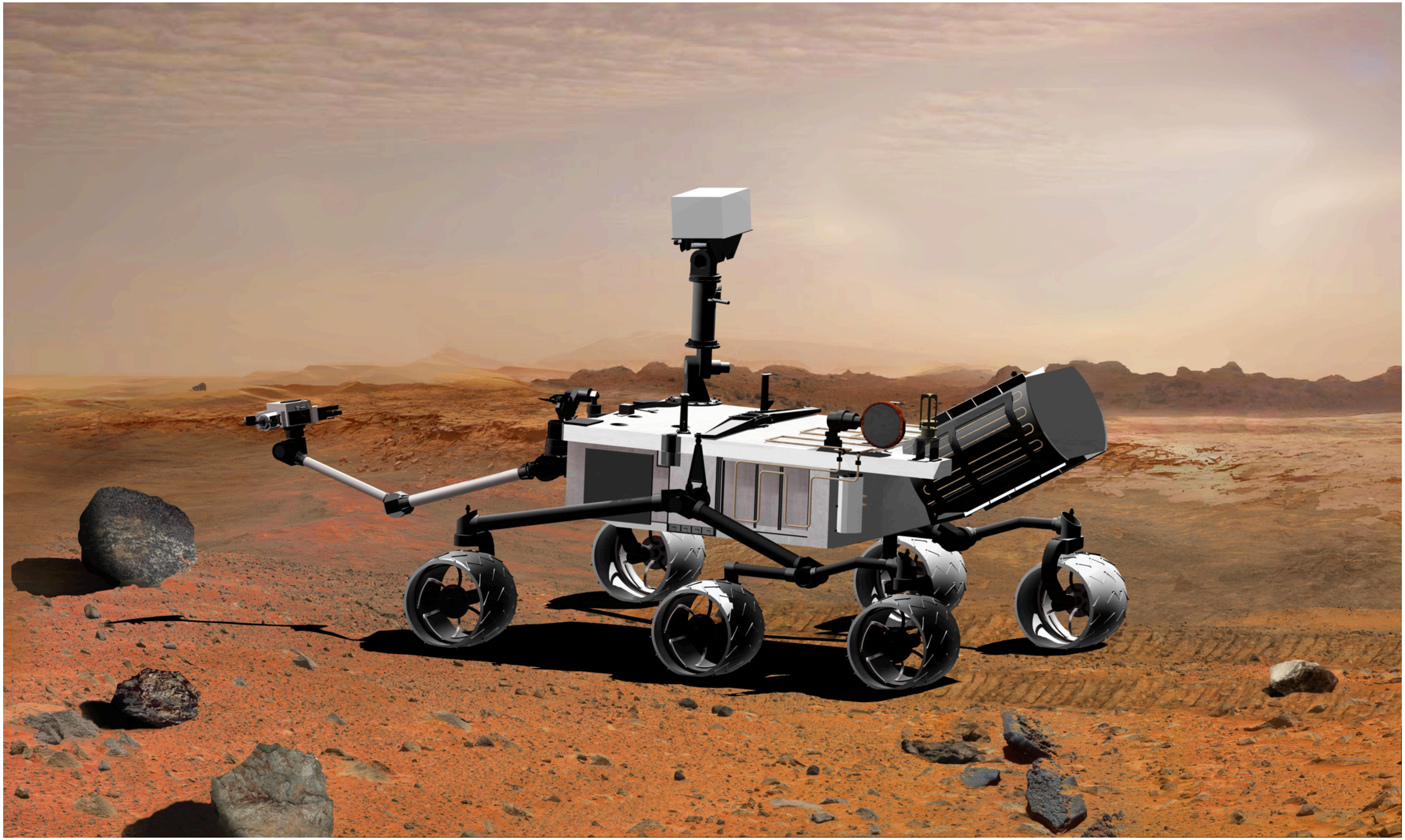


[6]

Robot scenarios: Inspection & Discovery

[7]

Robot scenarios: Space operations



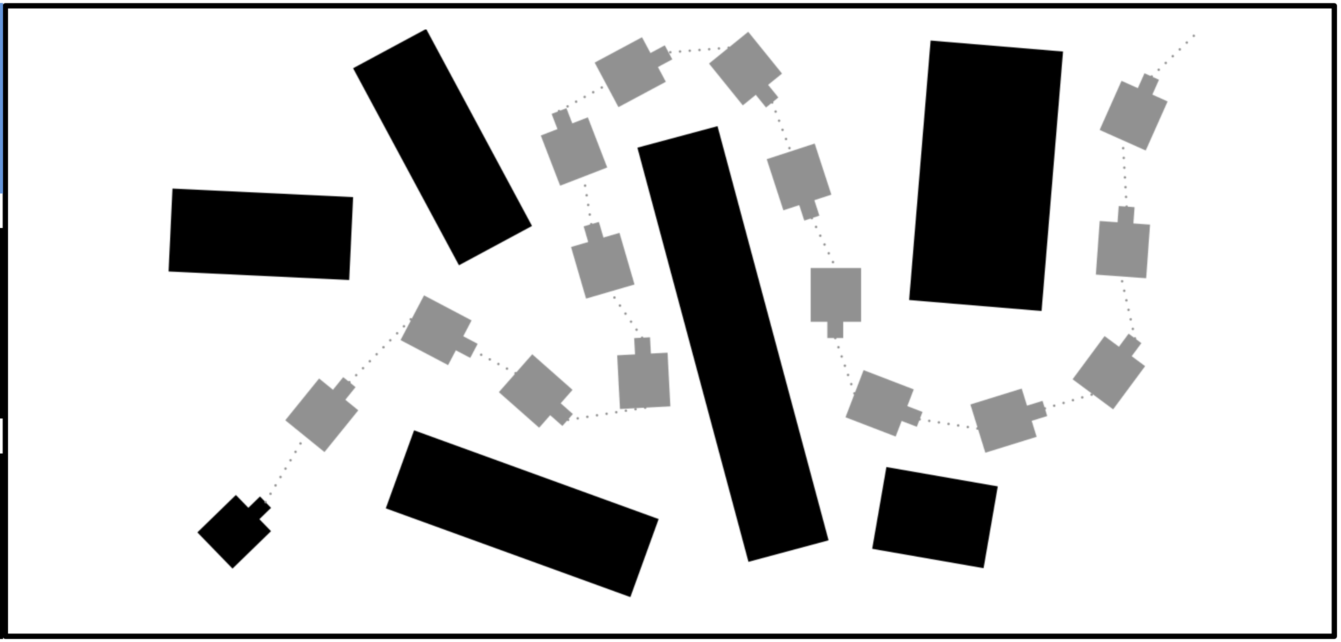
[8]

The three navigation classes

Mapless

Map-Based

Map-Building

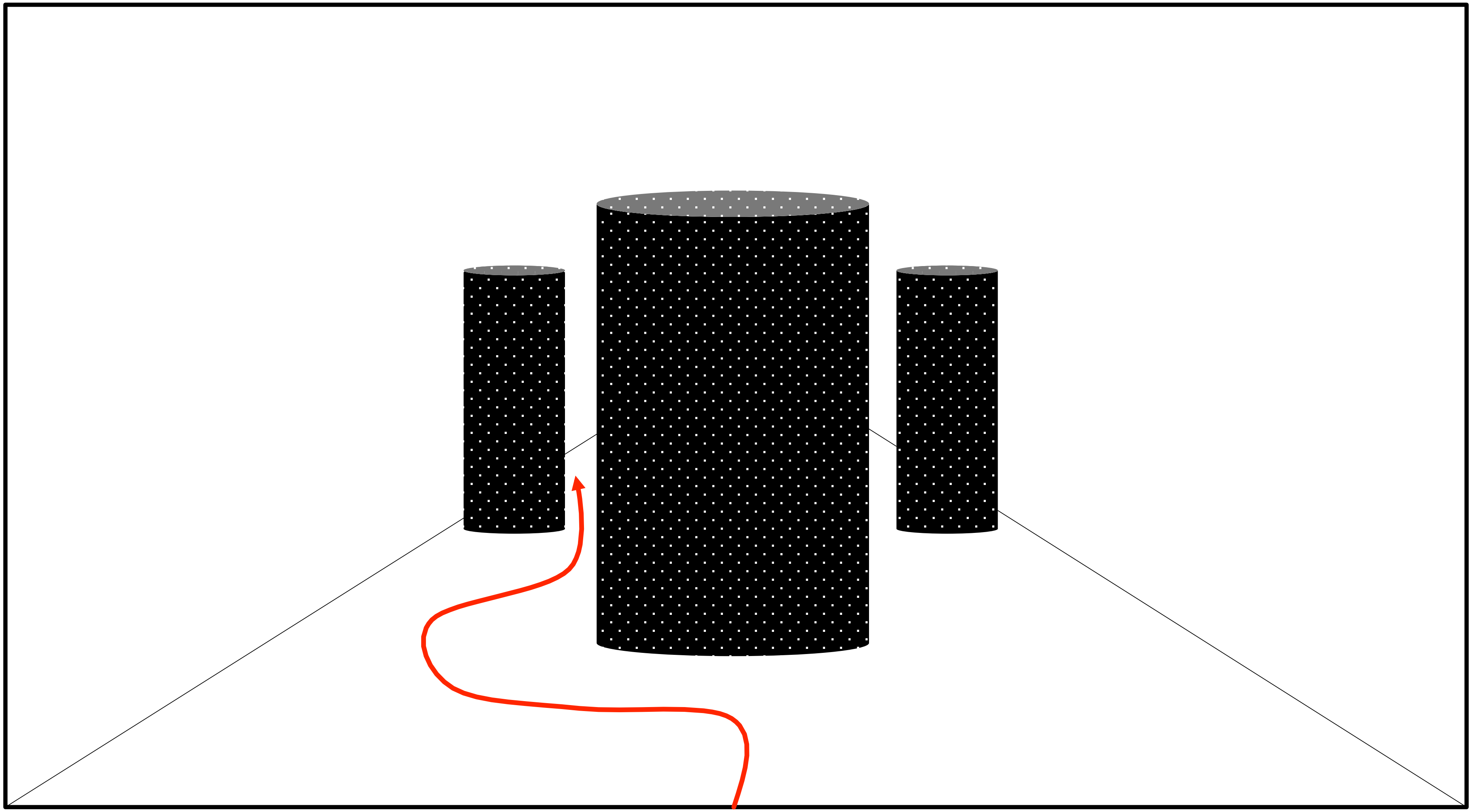


Mapless Navigation

Walk through Paris without colliding

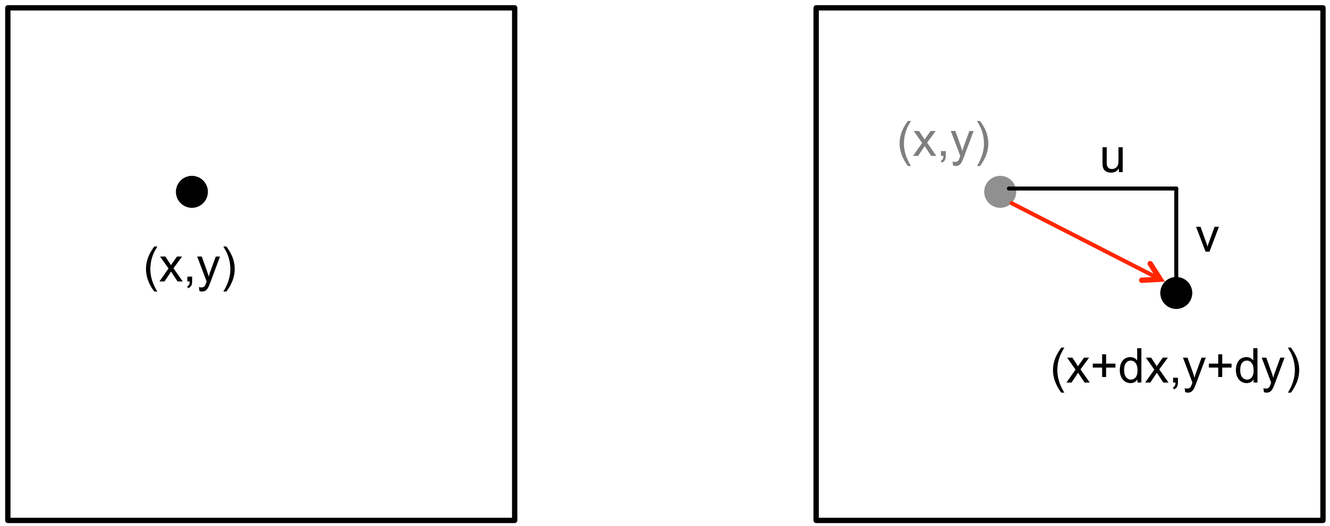
[10]

Collision Avoidance



Optical Flow

- Describe the **motion of patterns** in successive images



Frame @ t

Frame @ t+1

[11]

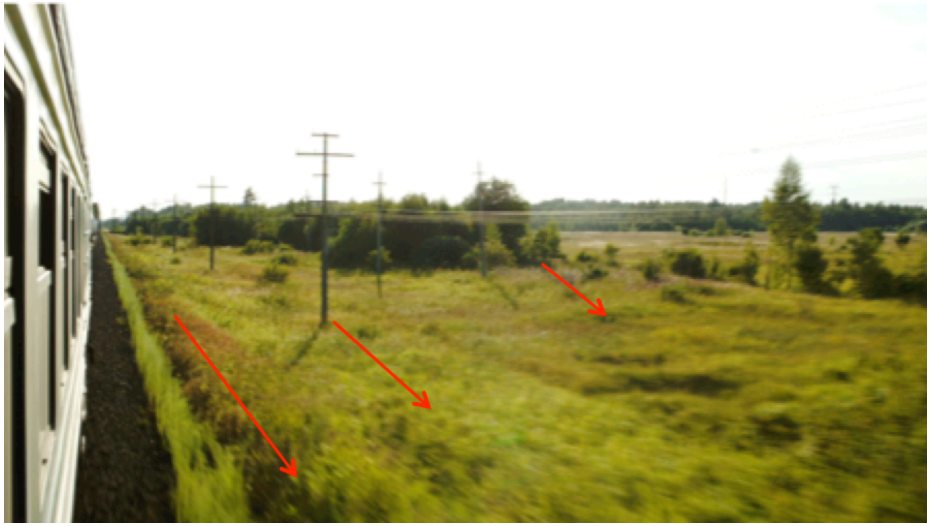
t_0

t_1

[11]

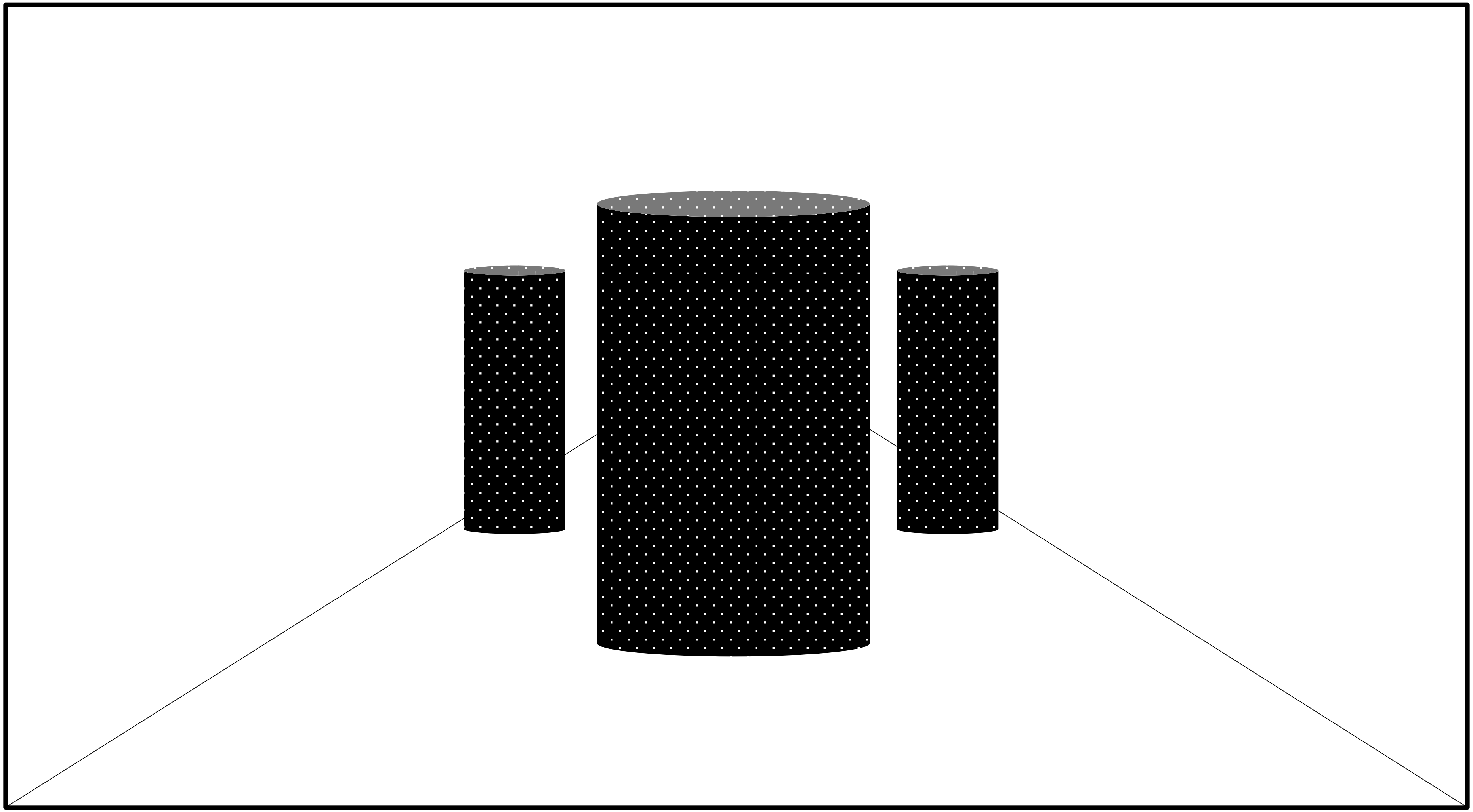
Optical Flow

- Get an understanding of **depth** in images
- **Time-To-Contact** between a camera and an object

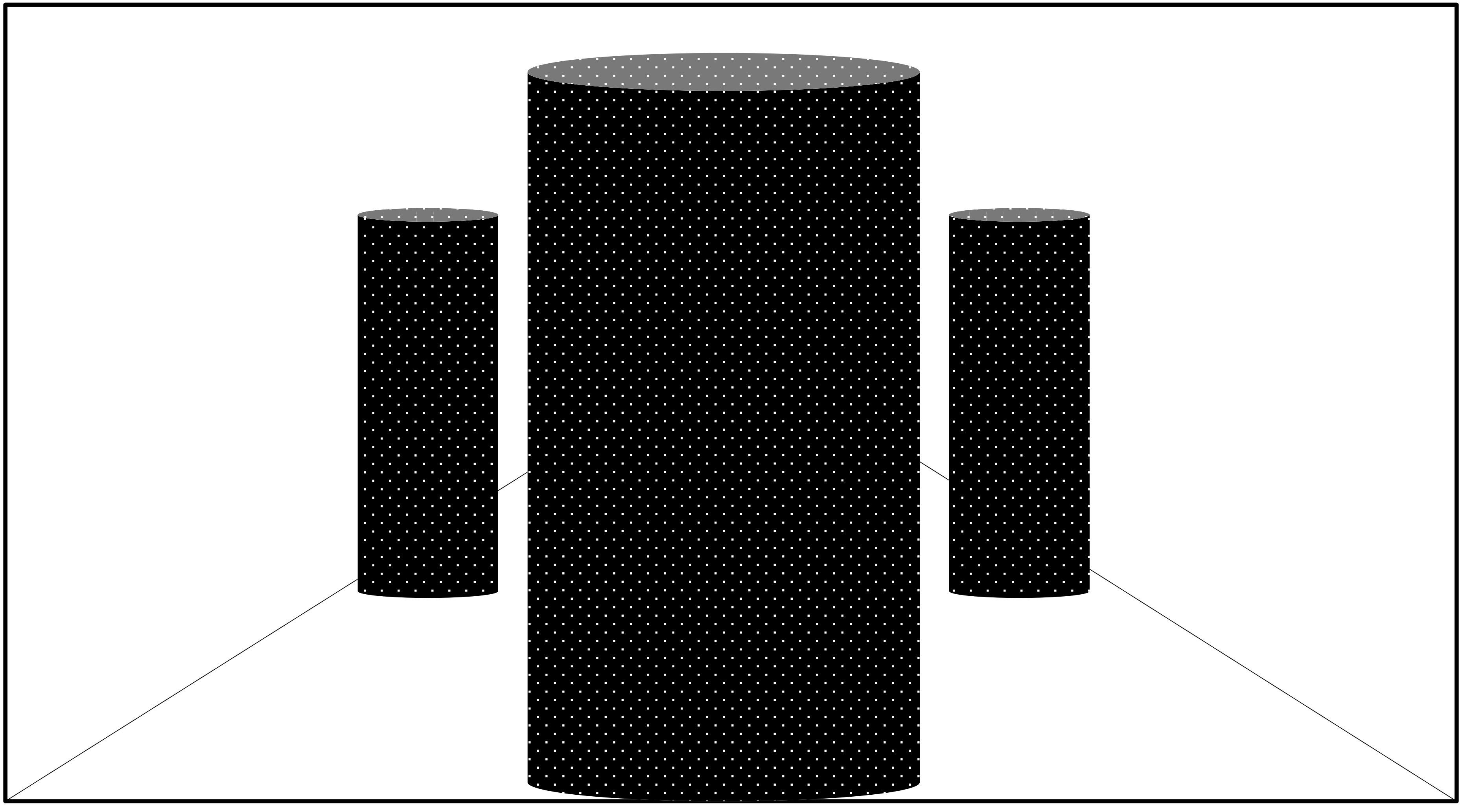


[11]

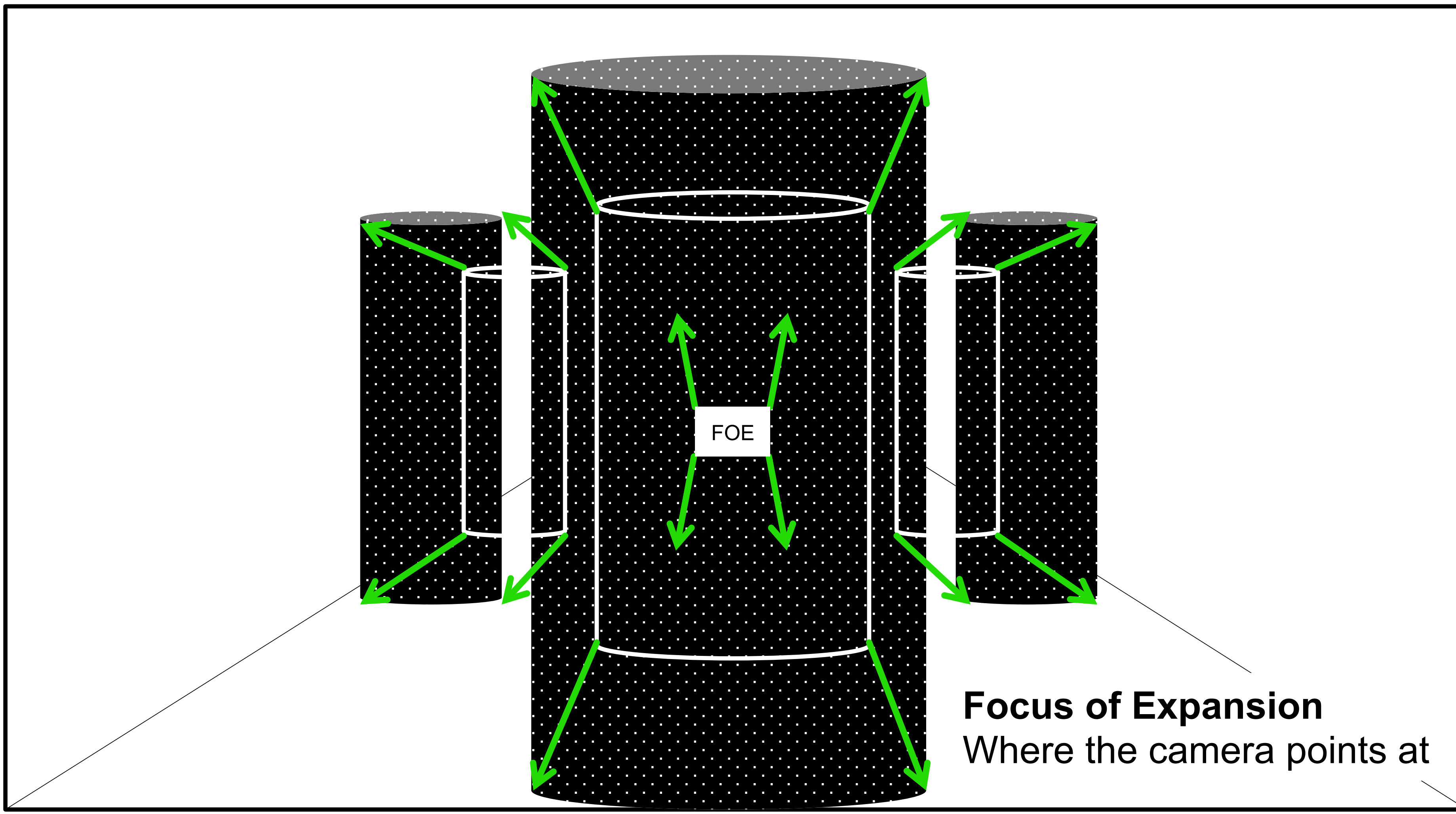
Optical Flow: Time-To-Contact



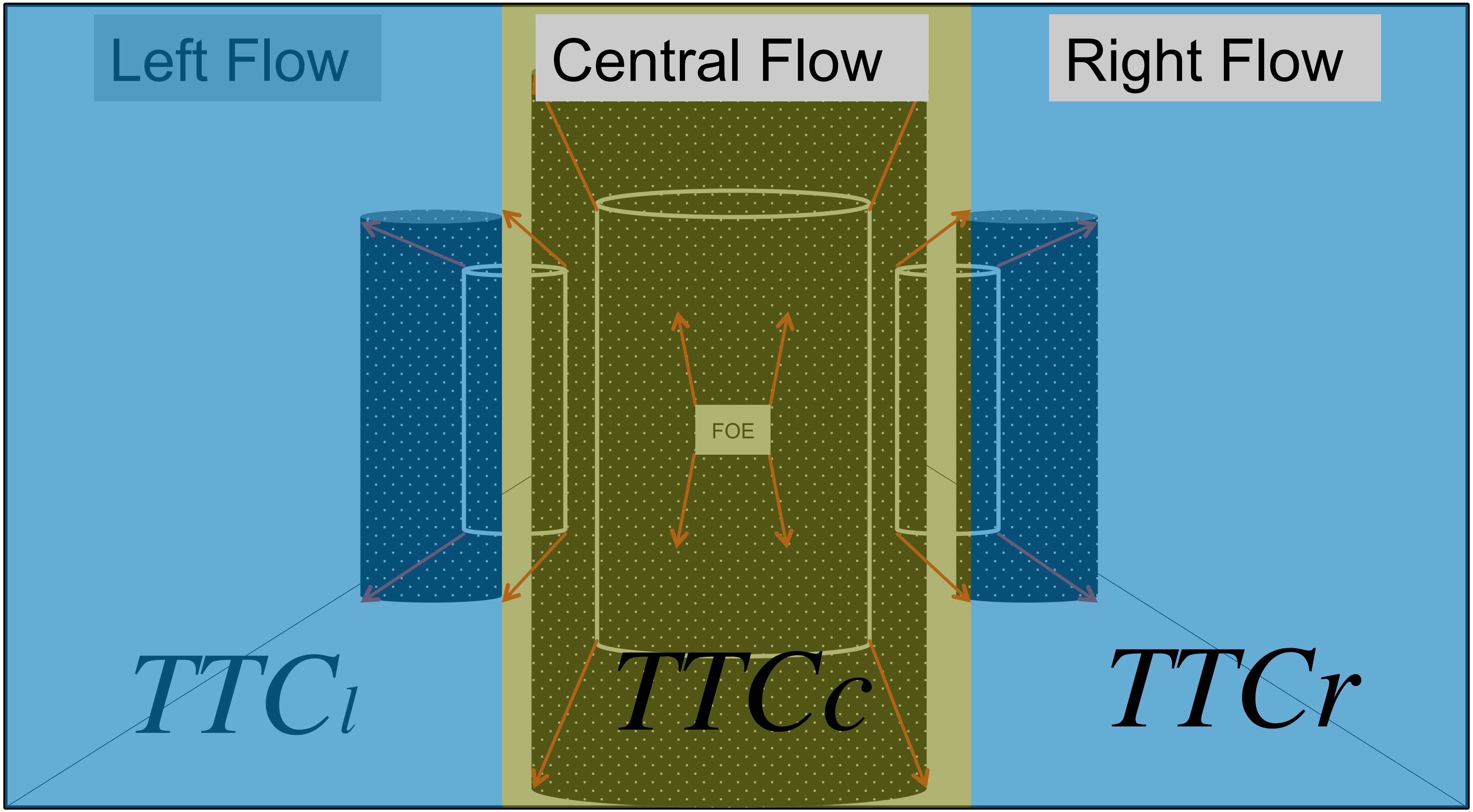
Optical Flow: Time-To-Contact



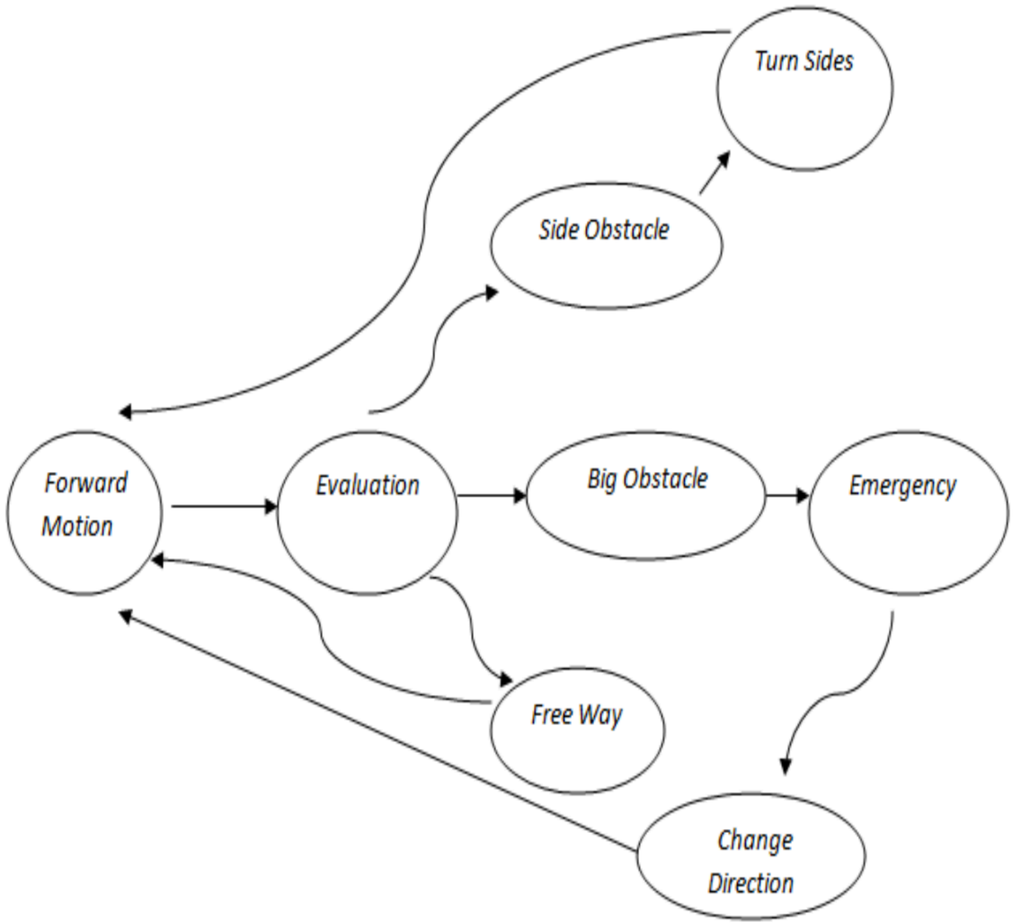
Optical Flow: Time-To-Contact



Optical Flow: Time-To-Contact

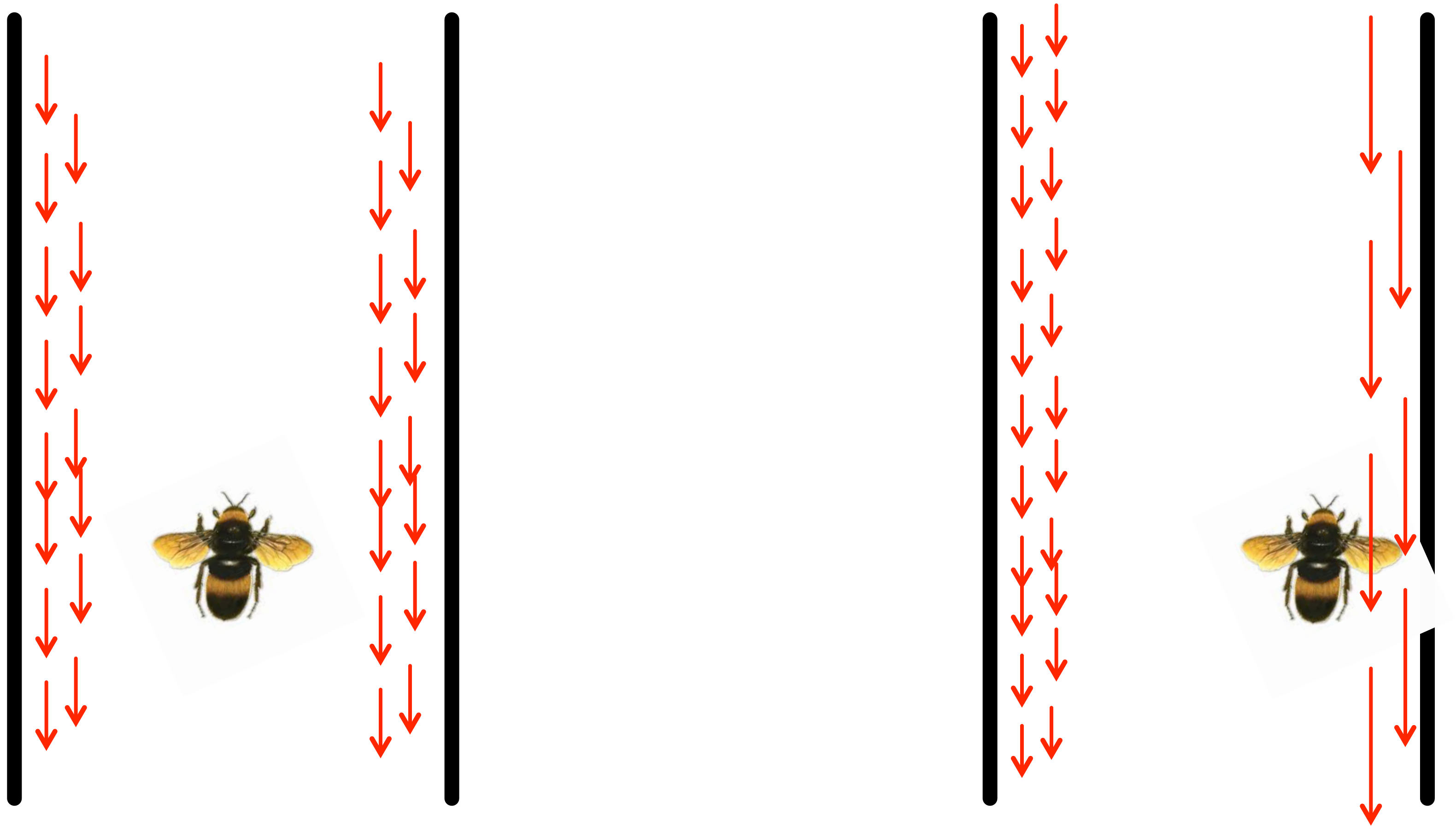


Obstacle Avoidance FSM

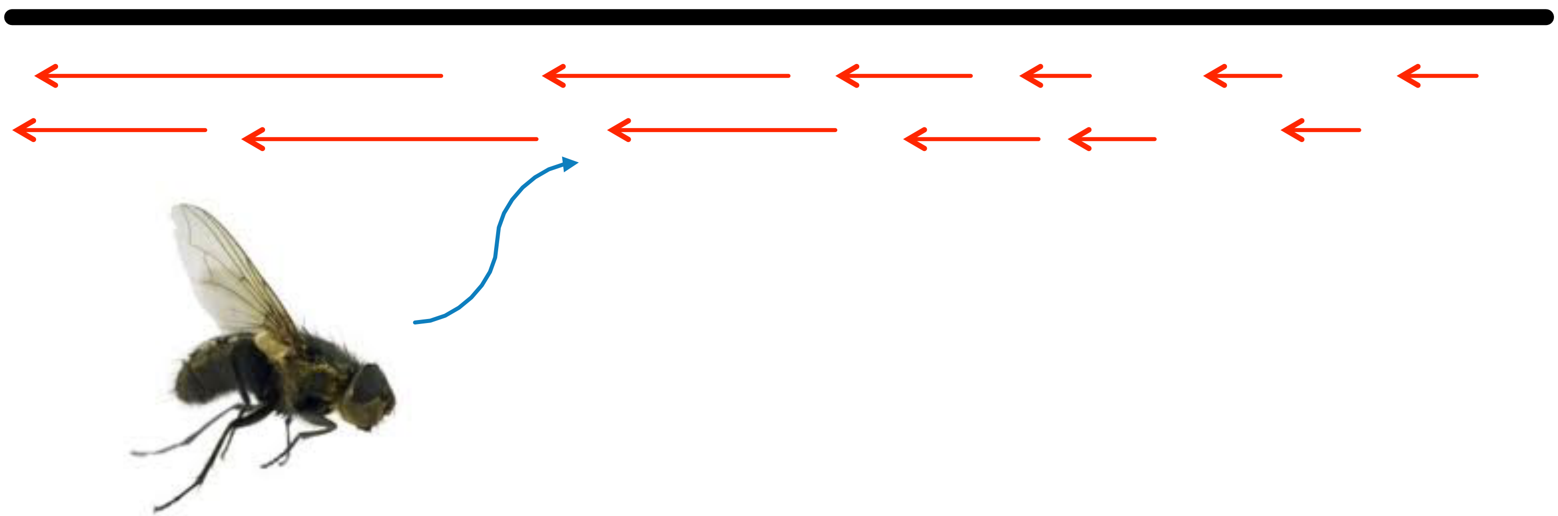


[23]

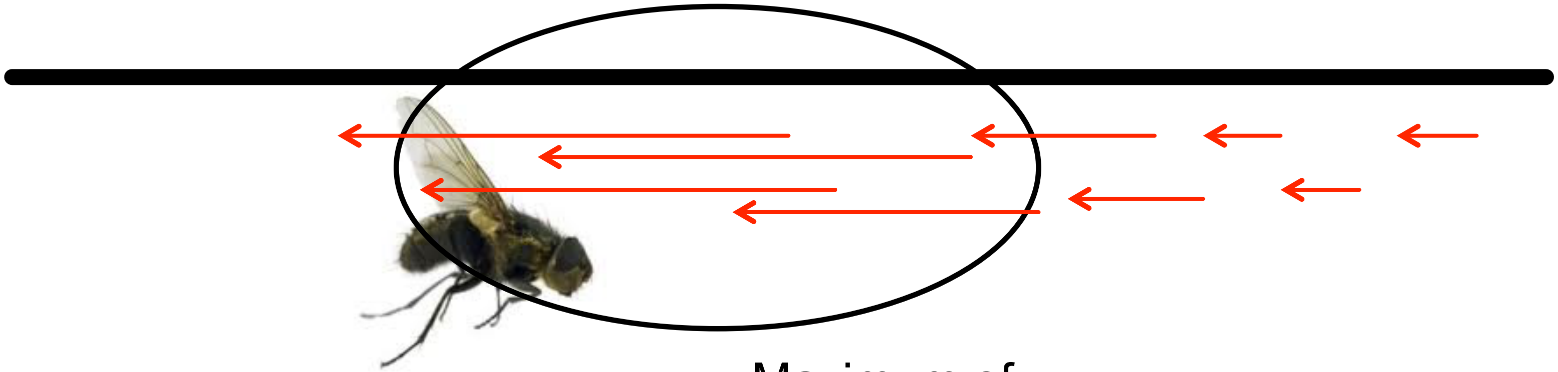
Inspired by biology



Inspired by biology



Inspired by biology



Optical Flow: Further applications

- Applications for visually impaired
- Image Stabilization
- Video Compression (MPEG)

Drawbacks

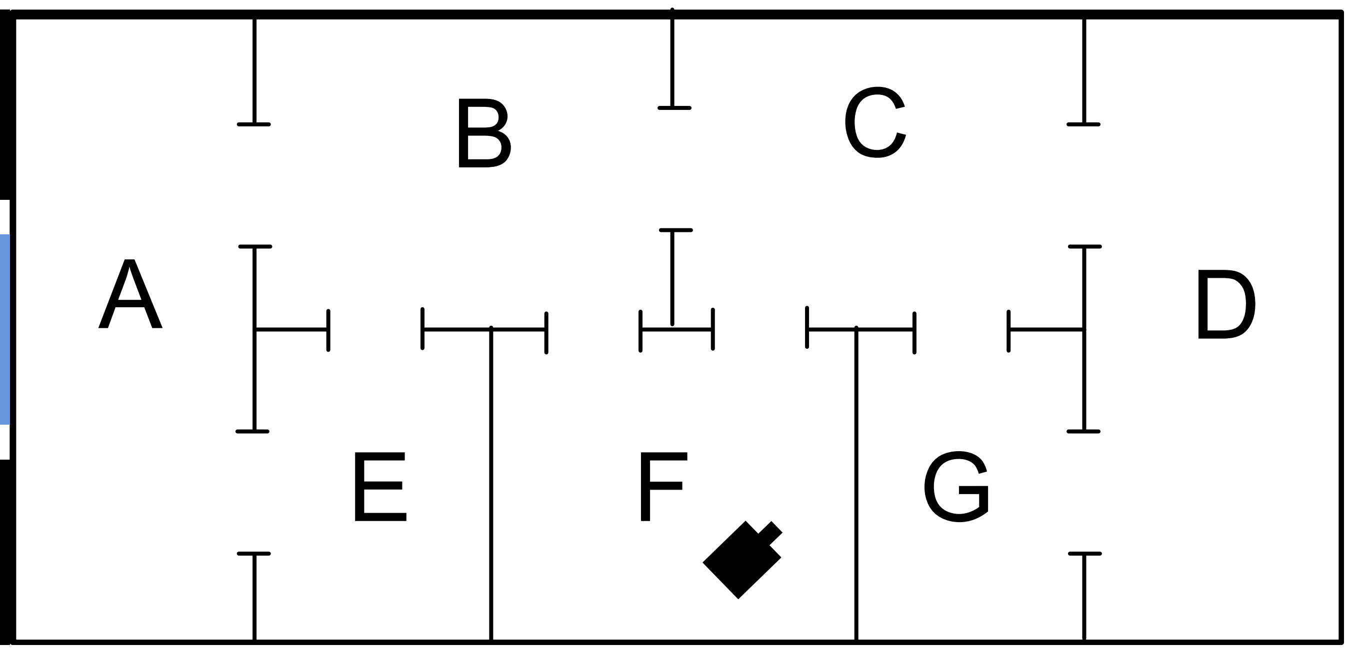
- Hard if no textures
- Dynamic scenes?

The three navigation classes

Mapless

Map-Based

Map-Building



Map-Based Navigation

Use a map of Paris to navigate to champs elysée

[12]

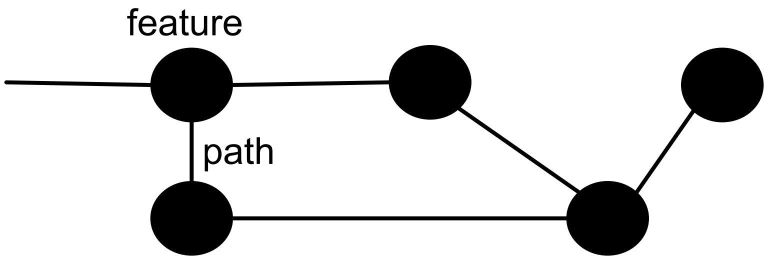
Map-Based Navigation: Robot Scenario

[13]

Map-Based Navigation: Map Representation

Topological Map

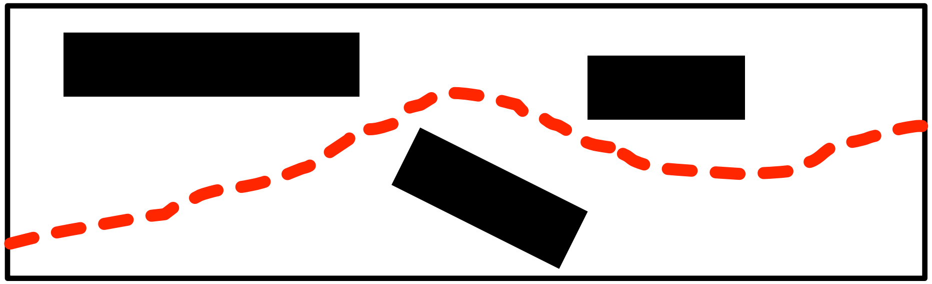
Graph-based representation of features and their relations, often associated with actions.



+ simple and compact
- no absolute distances
- obstacle avoidance needed

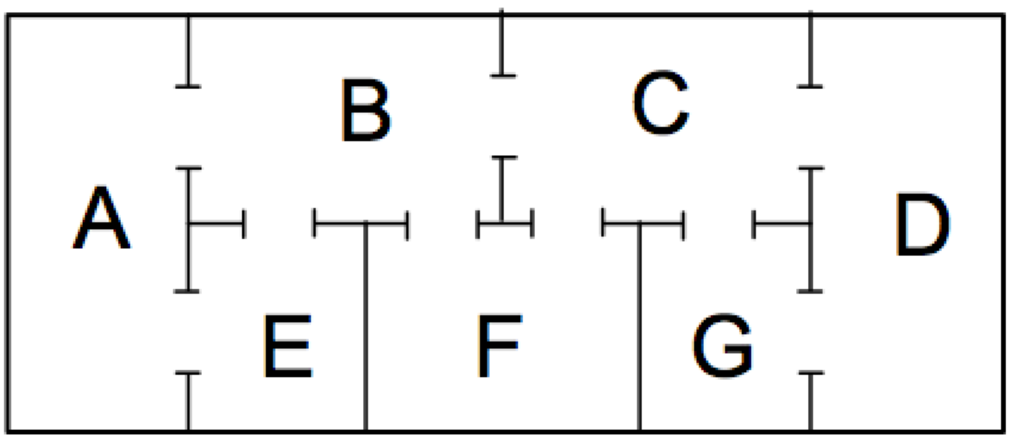
Metric Map

Two-Dimensional space in which objects and paths are placed.

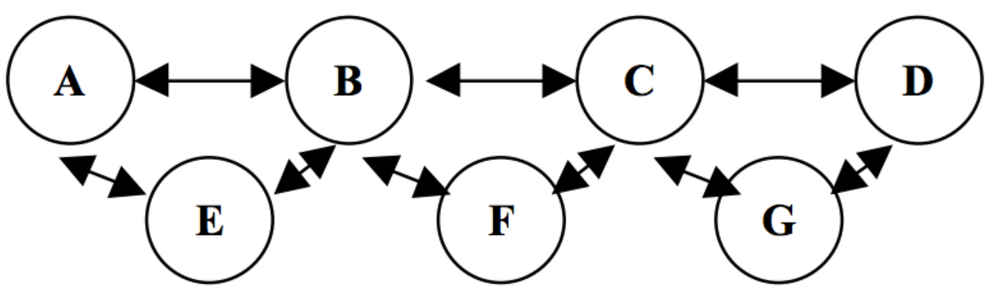


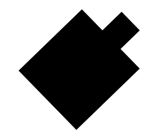
+ very precise
- hard to obtain and to maintain

Map-Based Navigation Example



Build a topological map of the floor





Use the topological map to navigate

Feature Extraction

Feature

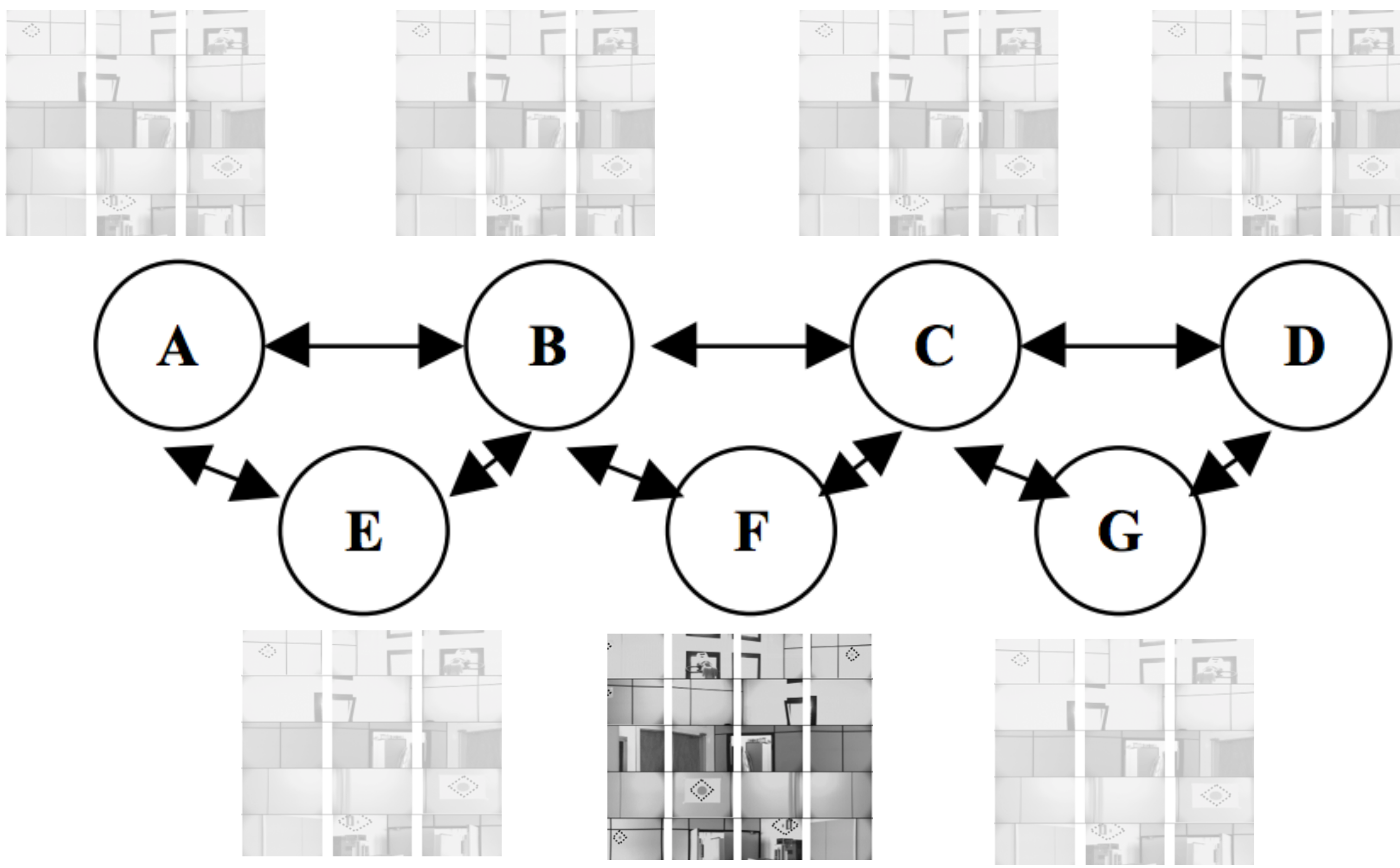
> Elements which can easily be re-observed and distinguished from the environment

- Features should be
  - Easily re-observable and distinguishable
  - Plentiful in the environment
  - Stationary

Room Identification

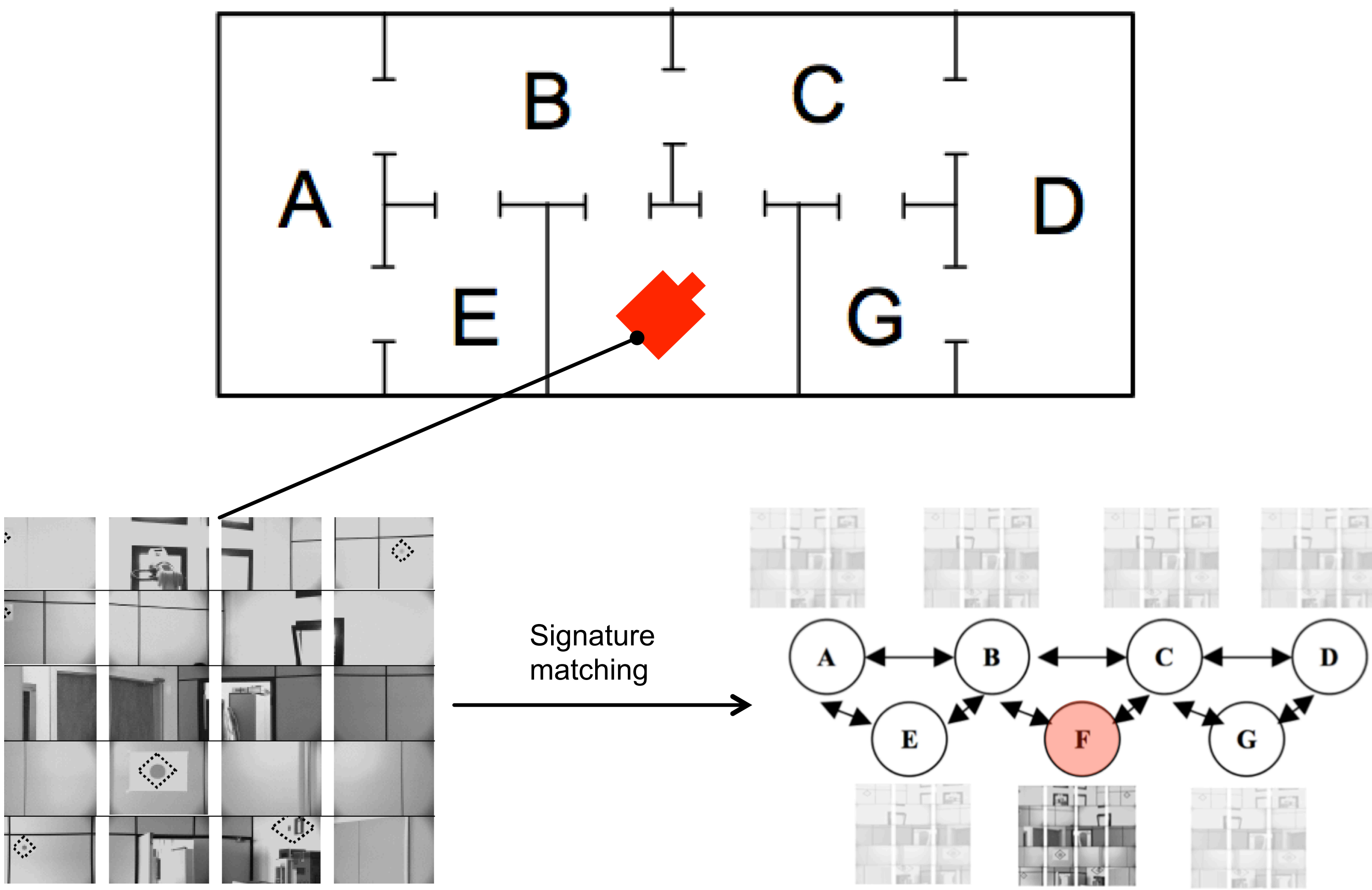
[14]

Topological Map



[14]

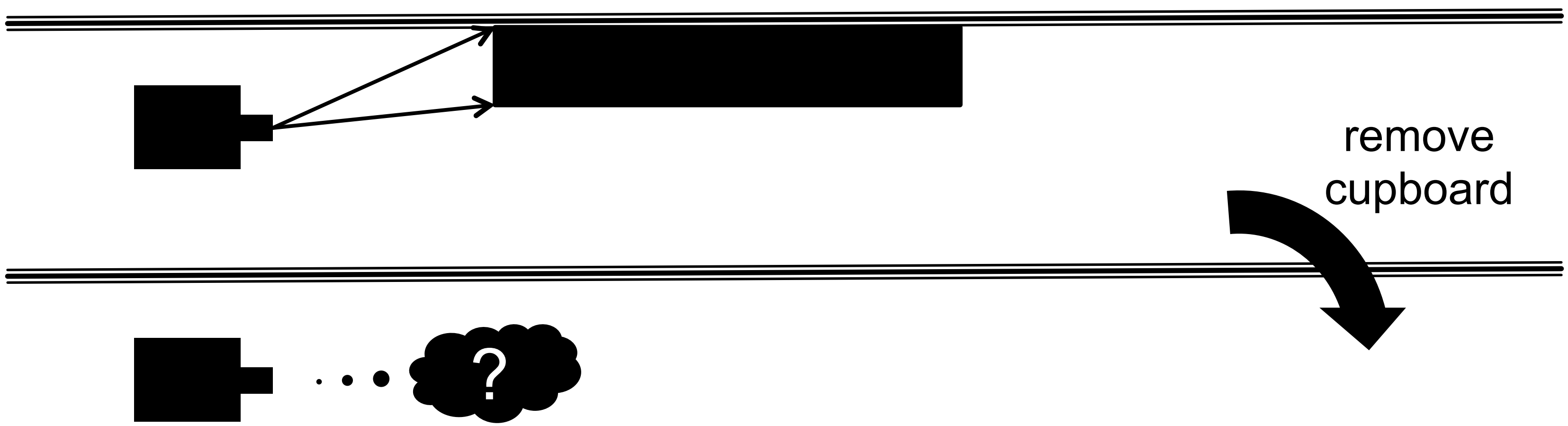
Room Searching



[P]

Drawbacks and Extensions

- Learning and maintenance is expensive



- Use scanner tags or artificial beacons?

The three navigation classes

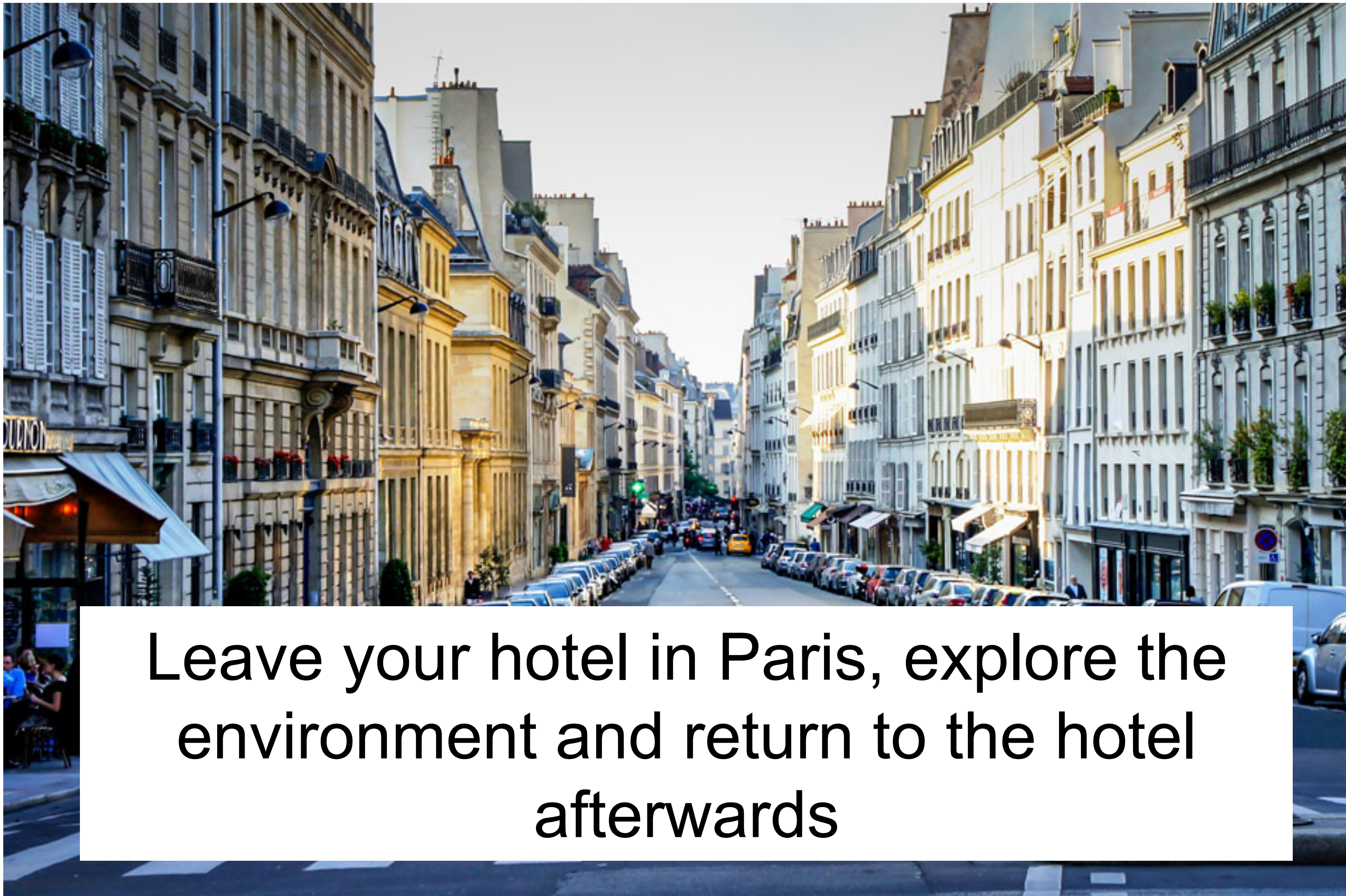
Mapless

Map-Based

Map-Building

[15]

Map-Building Navigation



Leave your hotel in Paris, explore the environment and return to the hotel afterwards

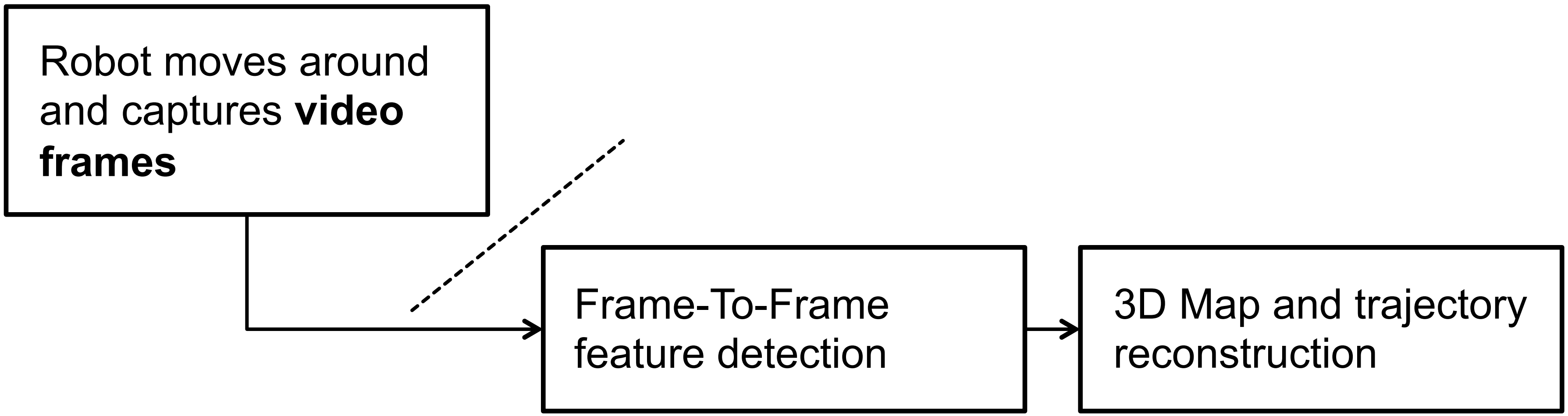
[16]

Map-Building Navigation

- Goal: in an unknown environment the robot can build a map and localize itself in the map

- **Two application categories**
  - Structure from Motion (Offline)
  - Simultaneous Localization and Mapping (SLAM) ← **Real-Time!**

Structure from Motion (Offline)



Pros

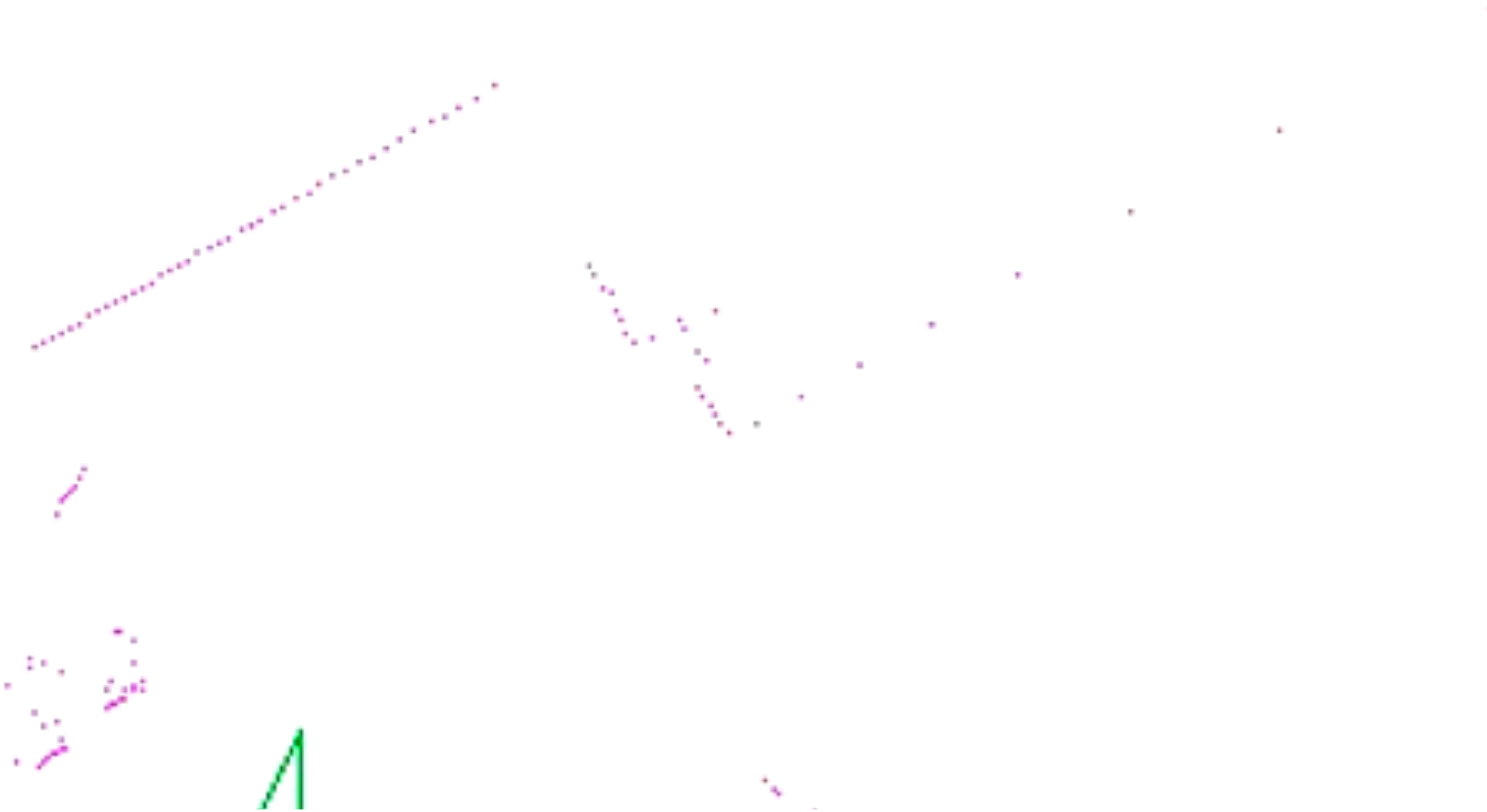
- Well studied
- Very accurate and robust solution

Cons

- Offline approach
- Changing environment requires new learning phase

Simultaneous Localisation and Mapping (SLAM)

- Build a map using **dead reckoning** and **camera readings**
- We focus on EKF-SLAM (Extended Kalman Filter)



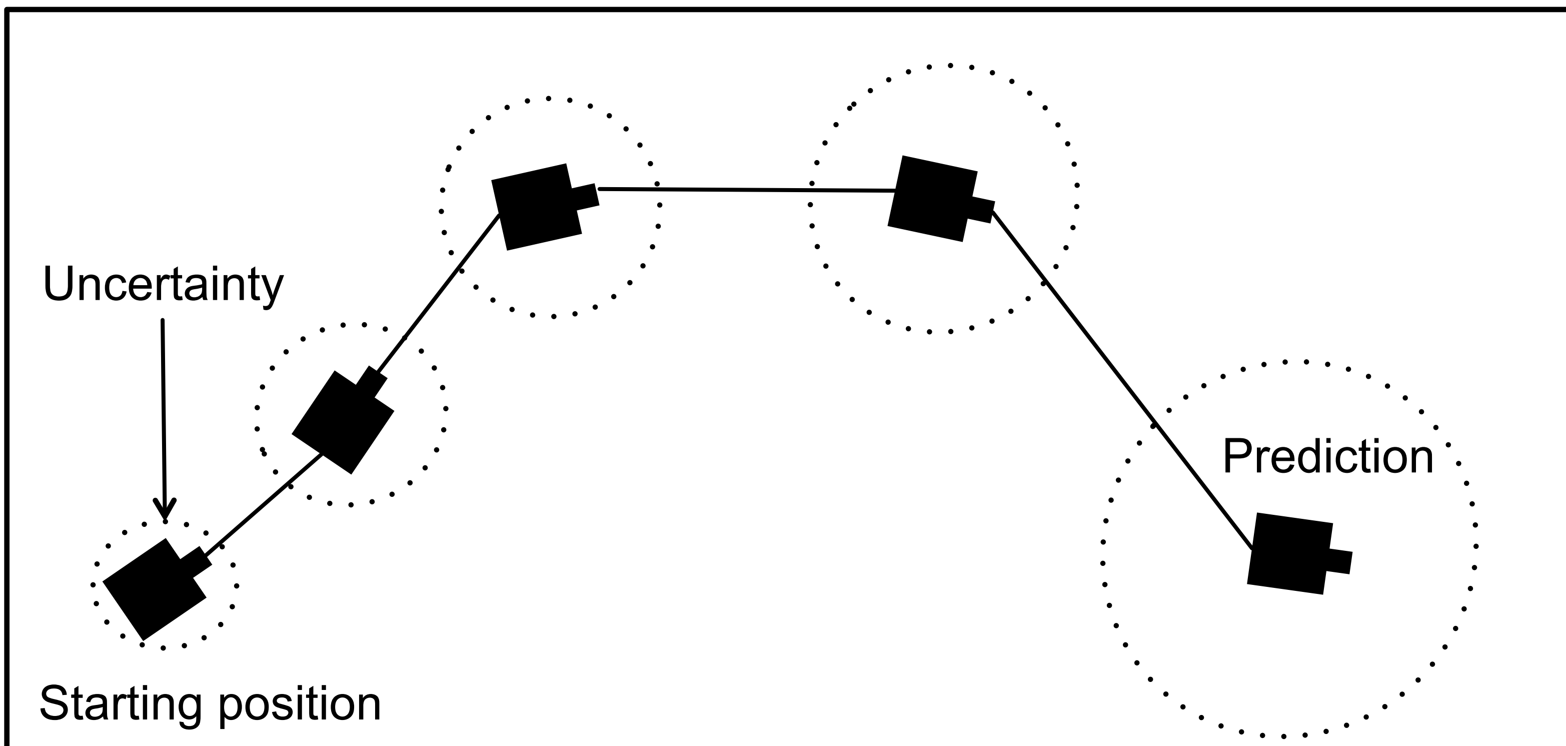
[15]

A map built with SLAM

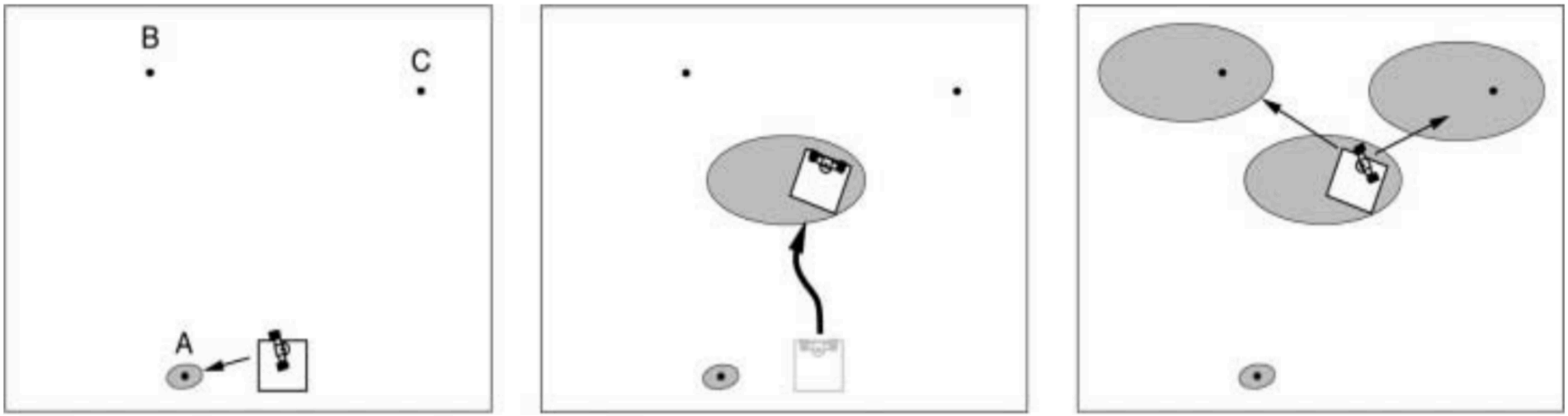
[15]

Dead Reckoning

- **Motion estimation** with data from odometry and heading sensors



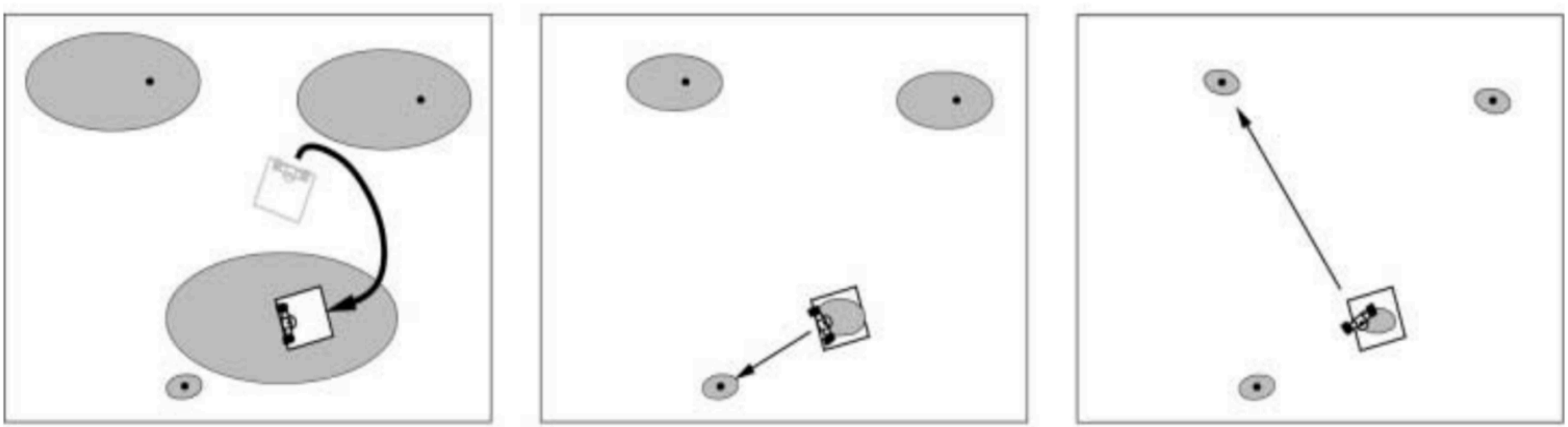
Six steps of map-building (1/2)



(1) Initialise feature A. (2) Drive forward (3) Initialise B. and C.

[17]

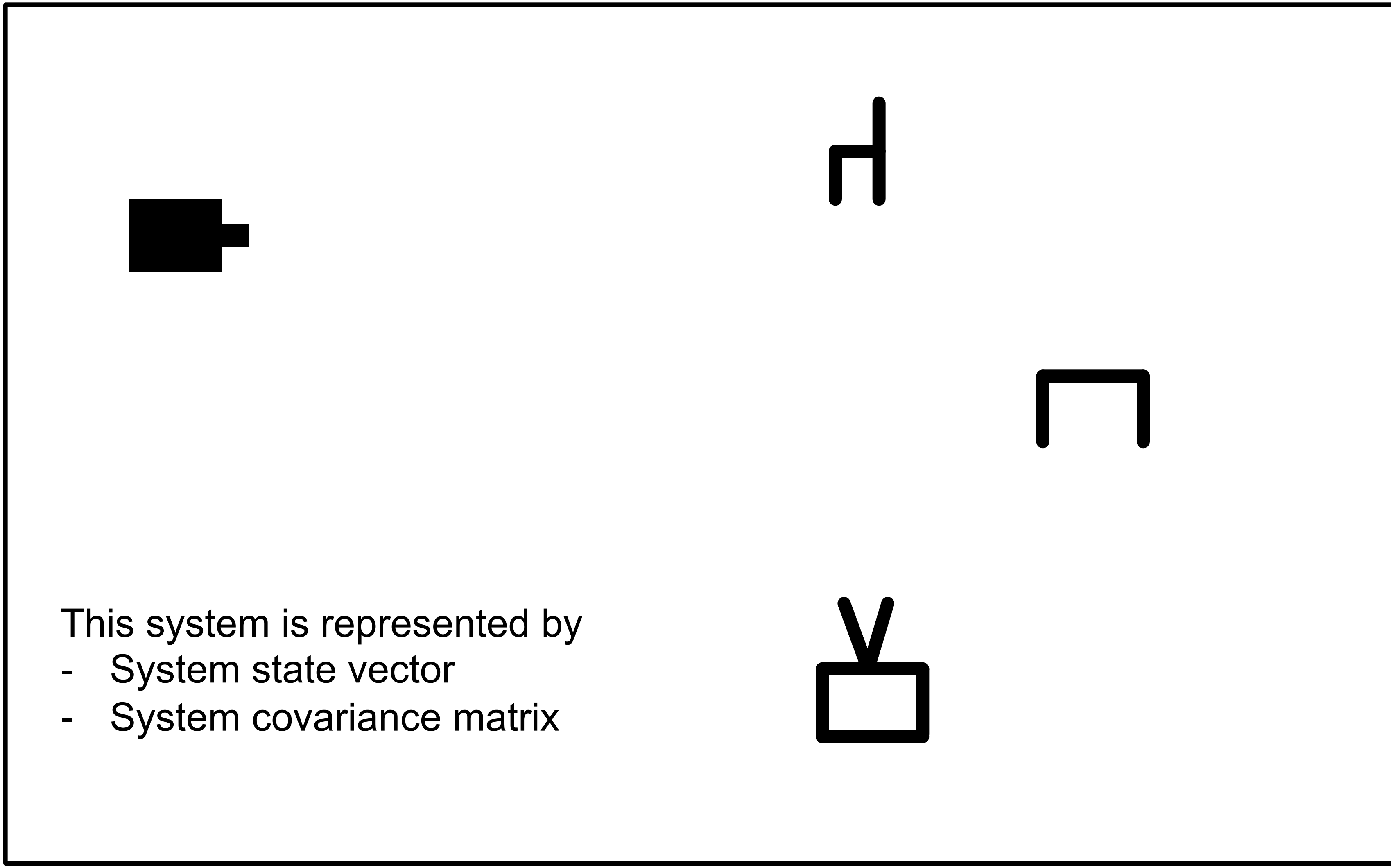
Six steps of map-building (2/2)



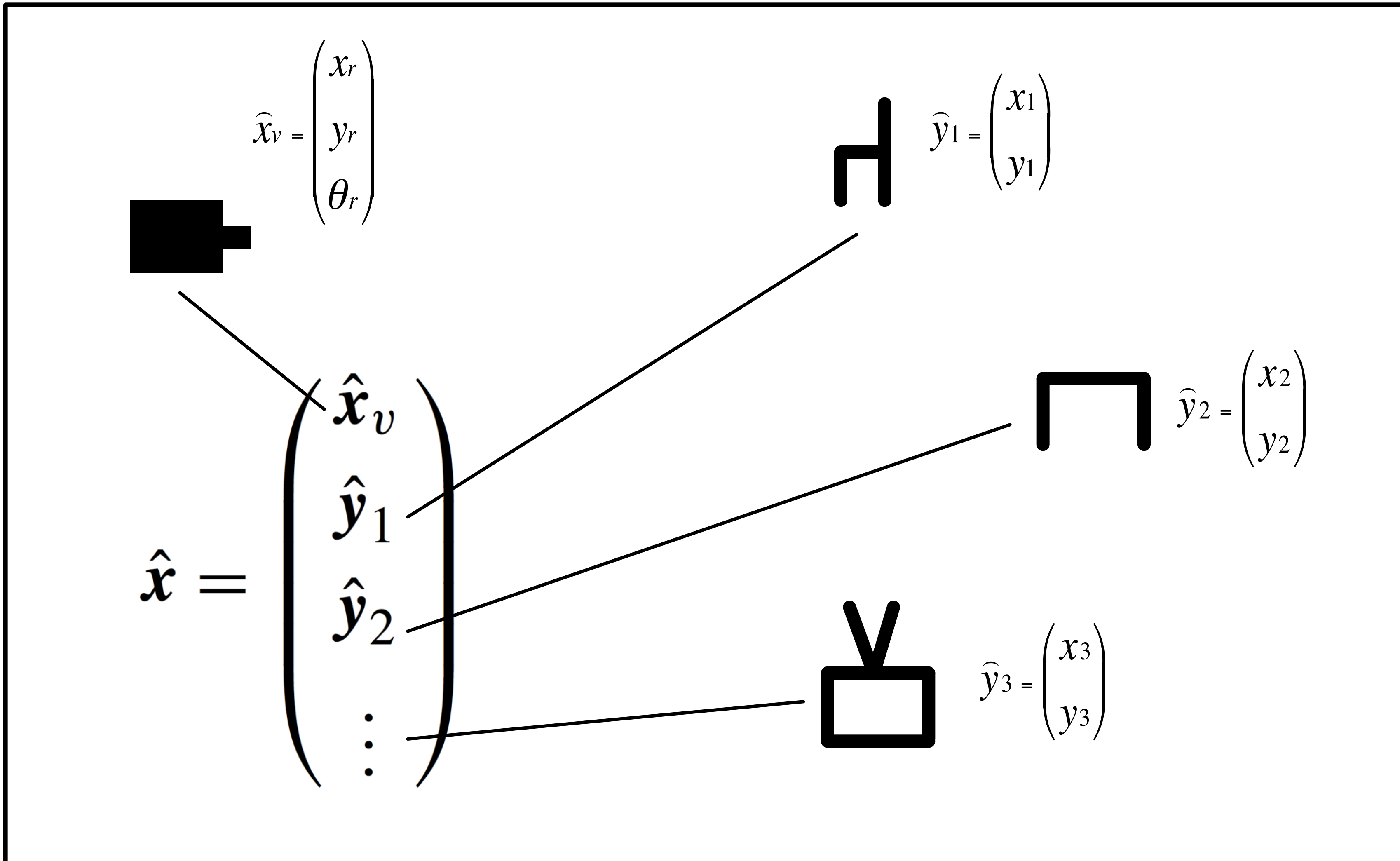
(4) Drive back (5) Re- measure A. (6) Re-measure B.

[17]

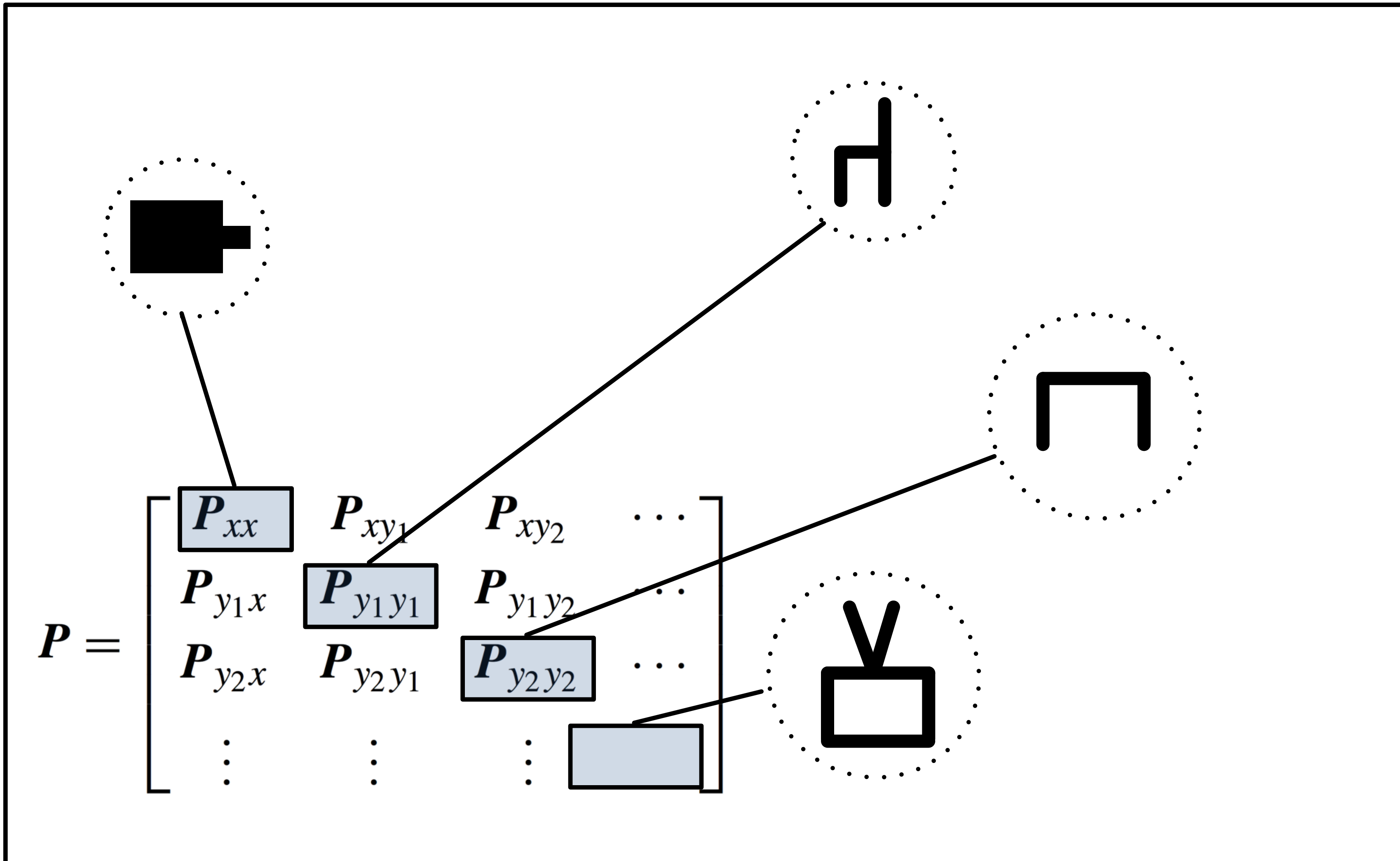
EKF-SLAM: The system



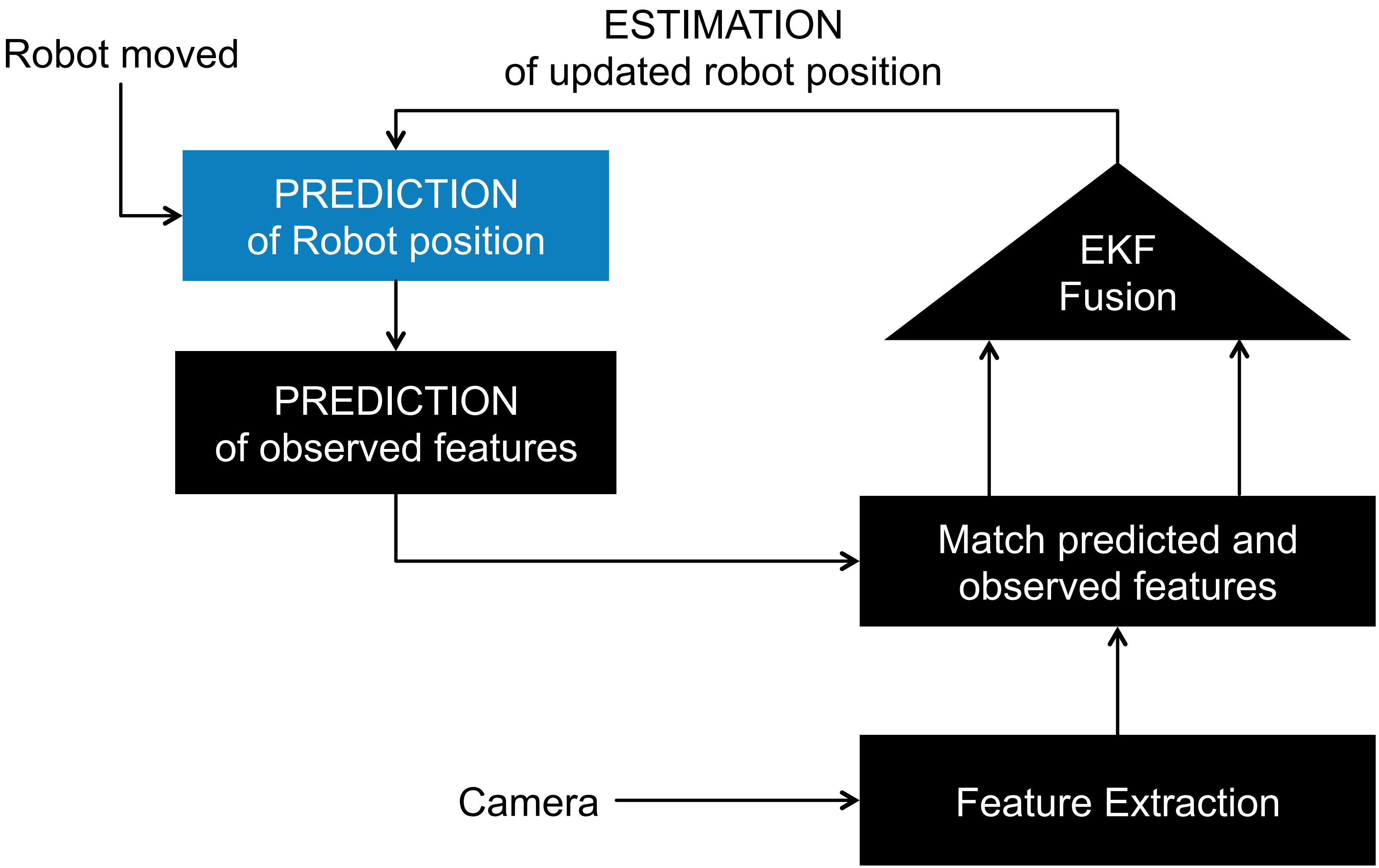
EKF-SLAM: The state vector



EKF-SLAM: The covariance matrix



SLAM Process



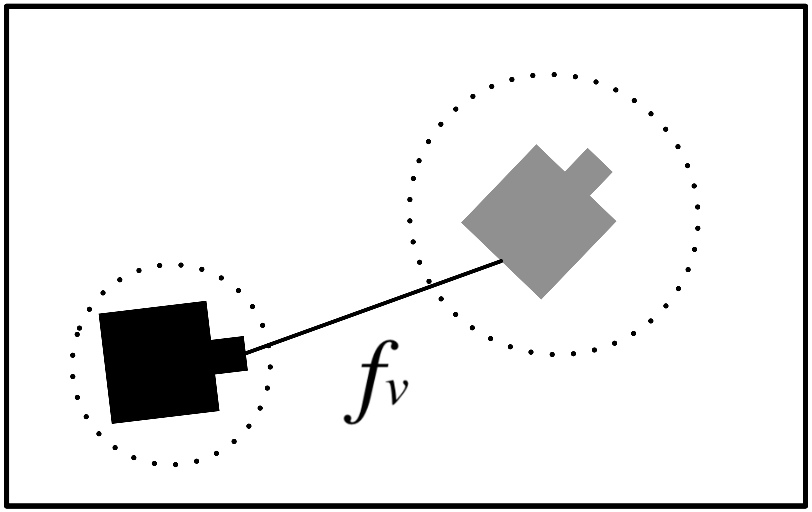
Motion model

- Estimate robot's new position after a movement

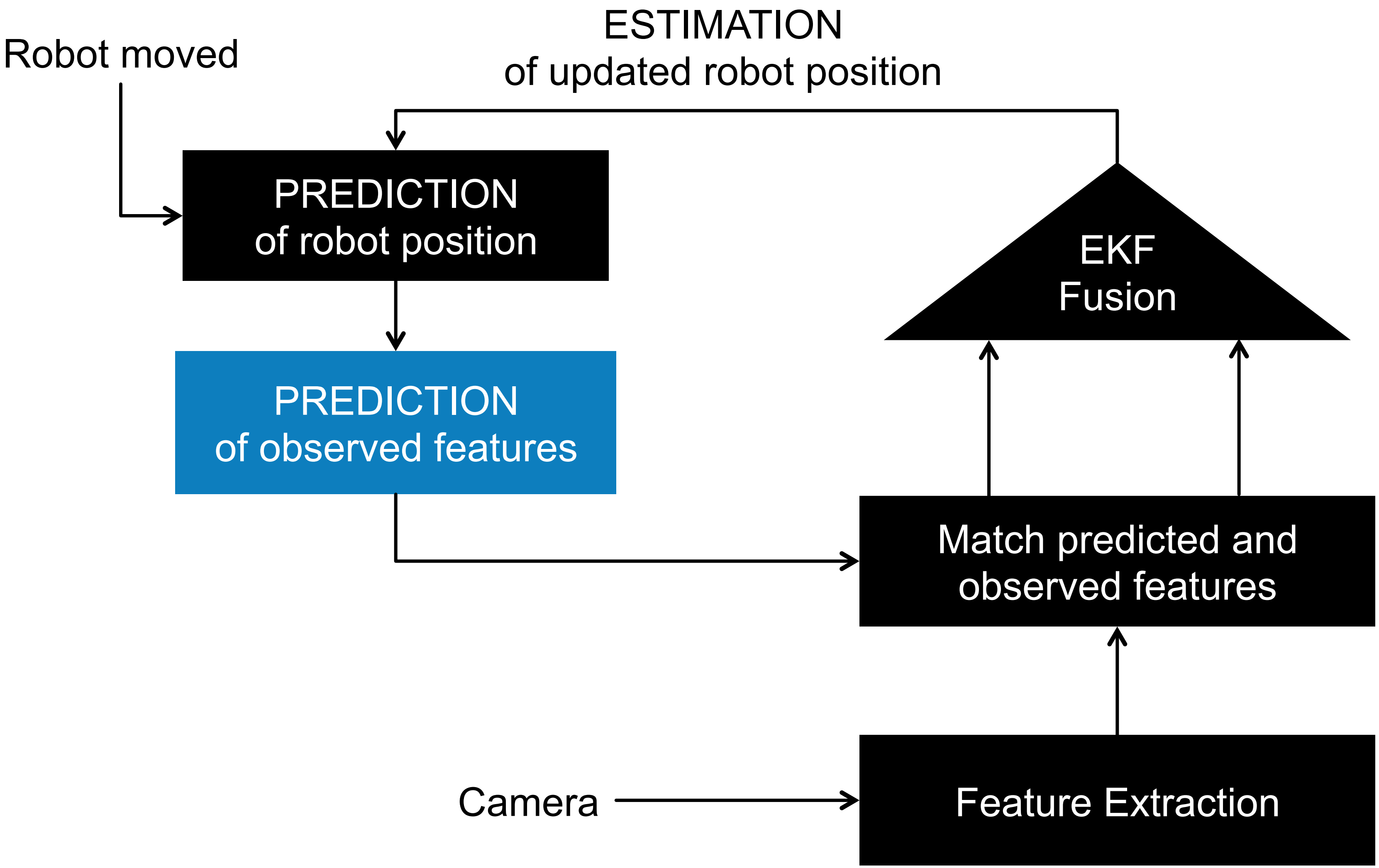
Motion model

$$x_v = f_v(\hat{x}_v, u)$$

- x_v → Estimated robot position
- $\hat{x}_v$ → old position
- u → odometry

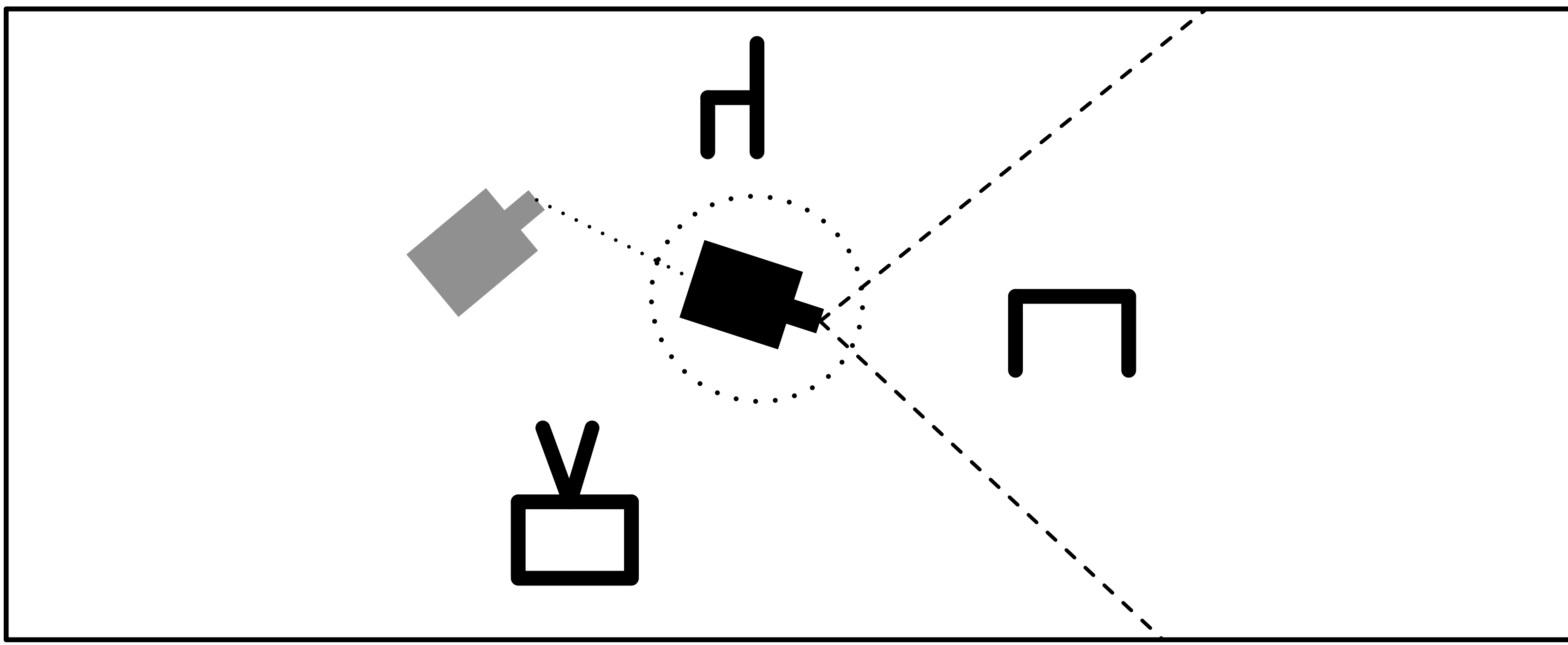


SLAM Process

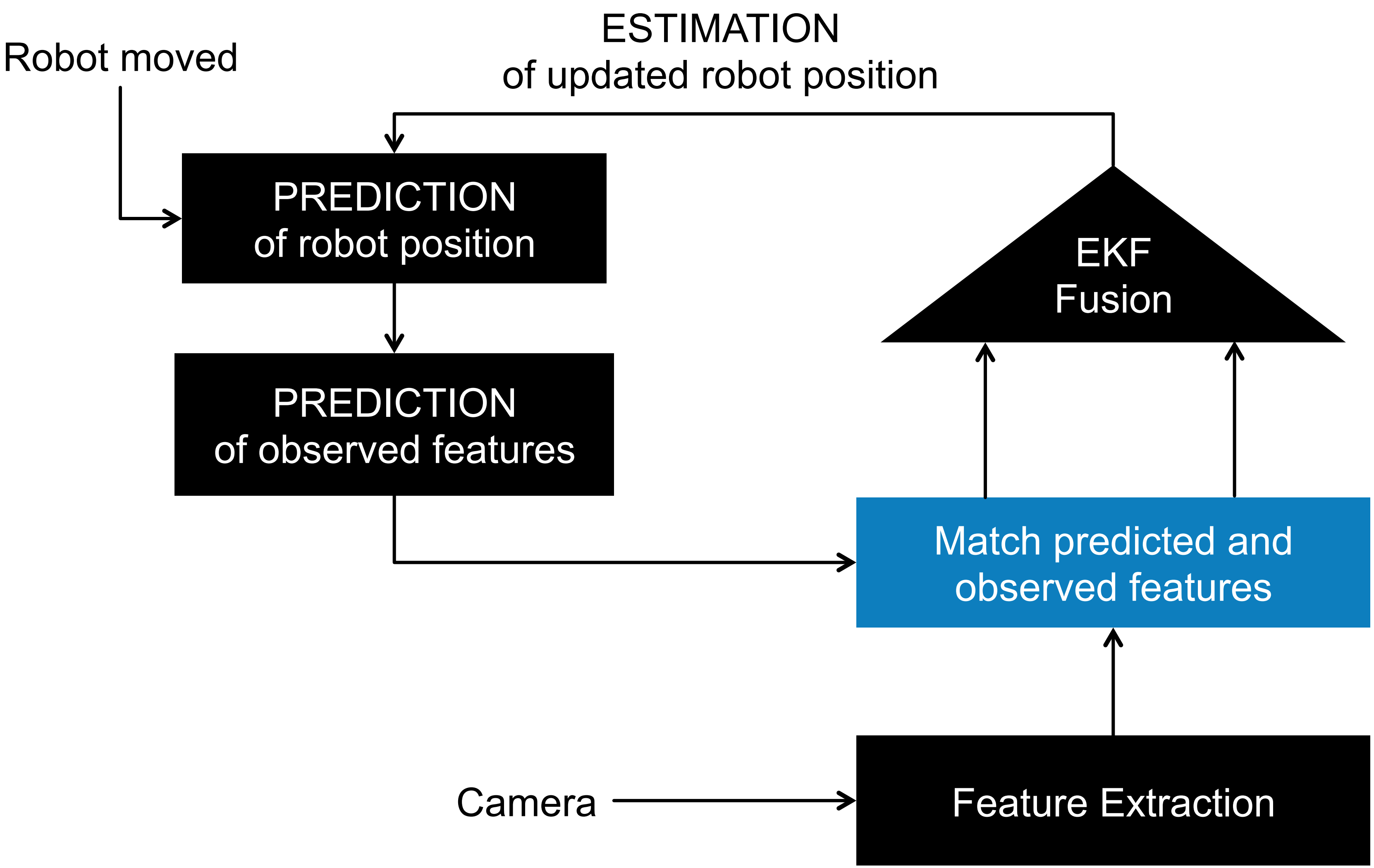


Measurement model

- Based on the predicted robot position and the map, use a **measurement model** to predict which features should be in view now

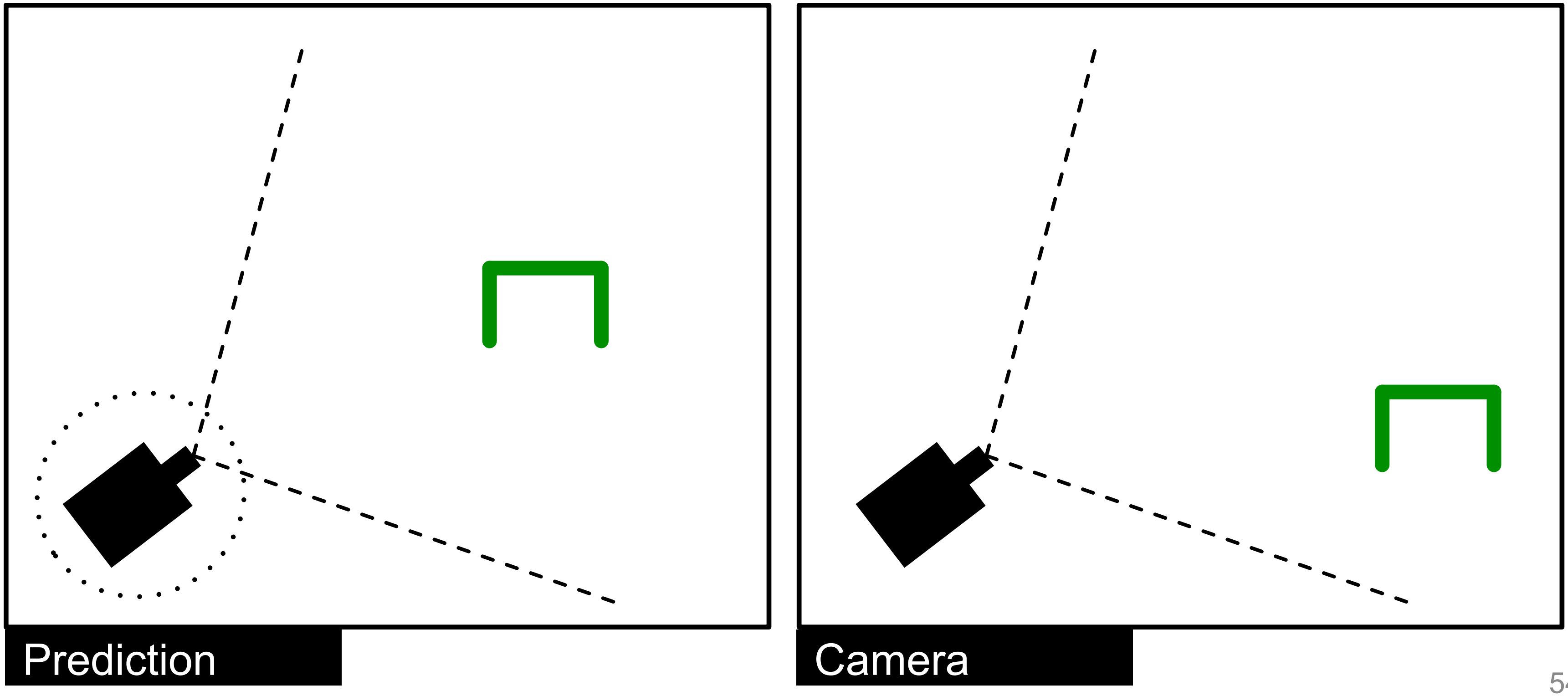


SLAM Process

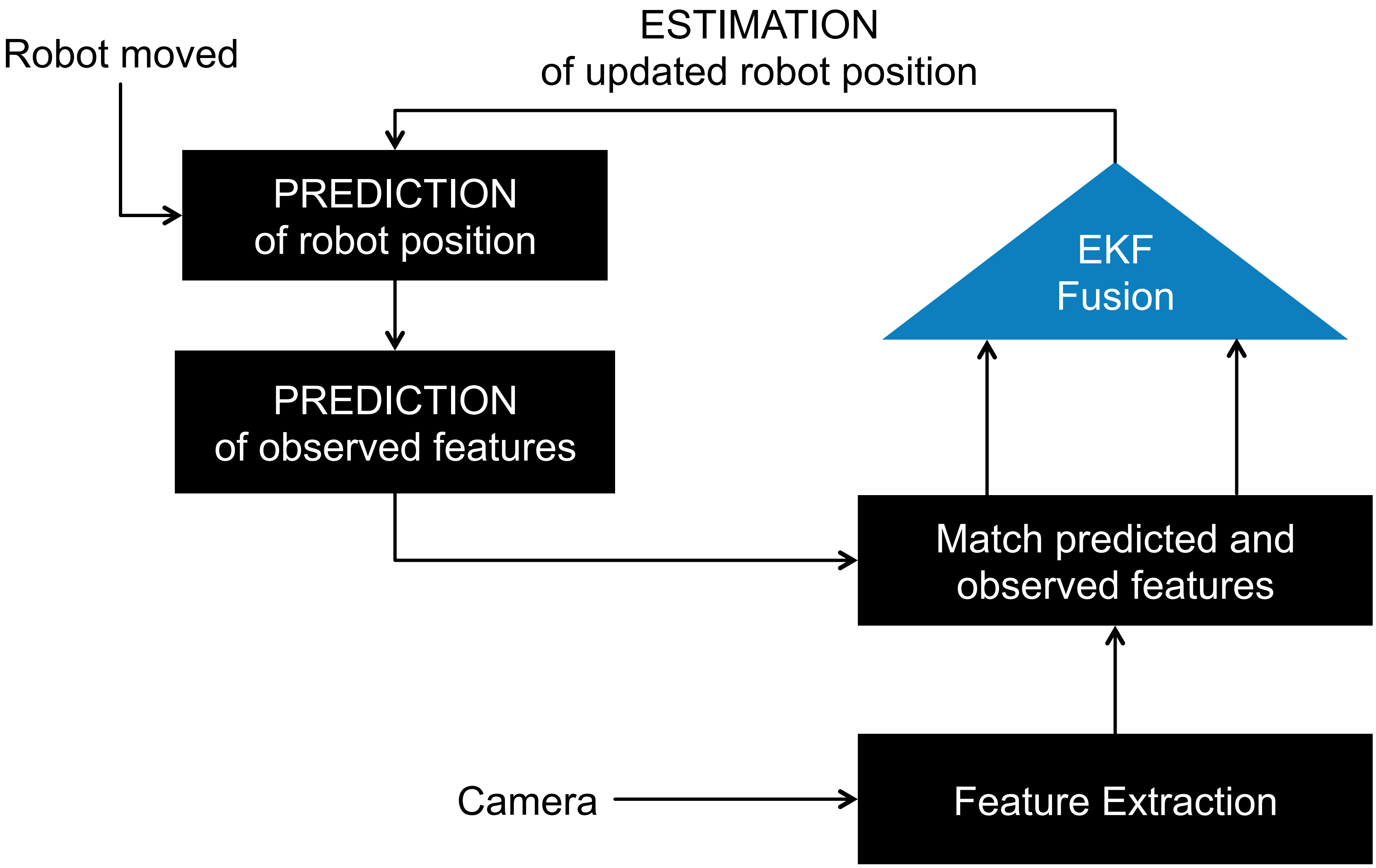


Data matching

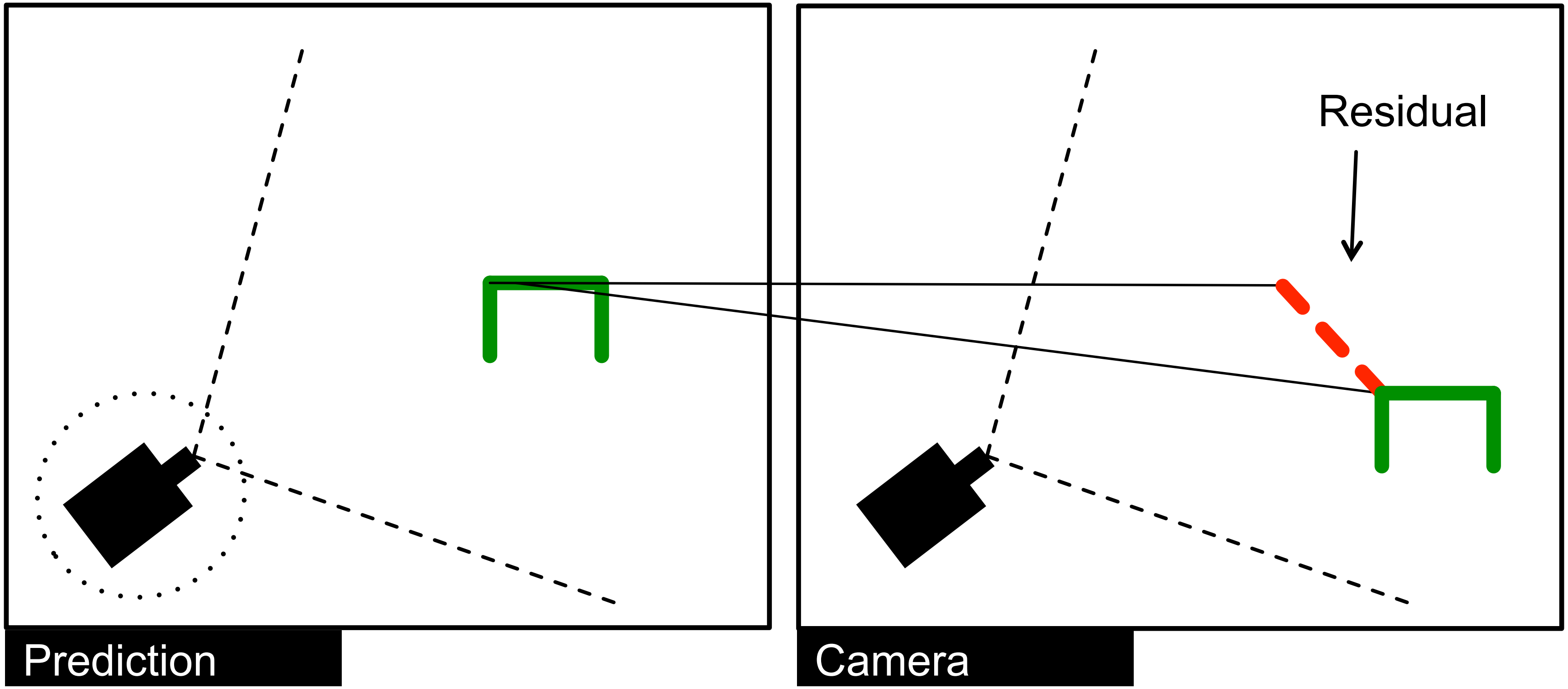
- Match predicted and observed features



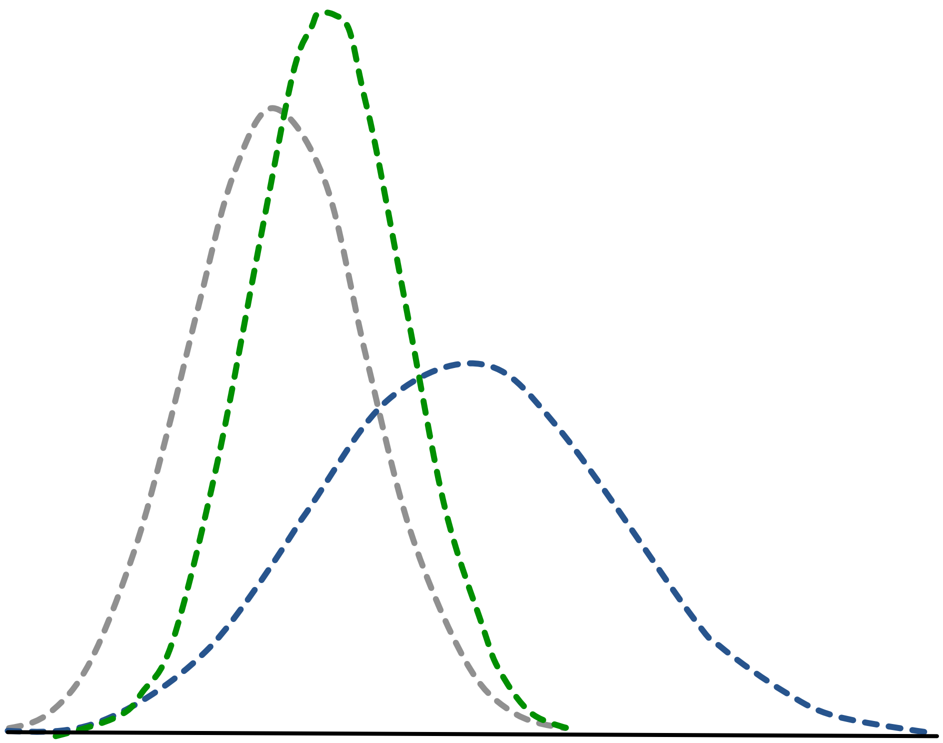
SLAM Process

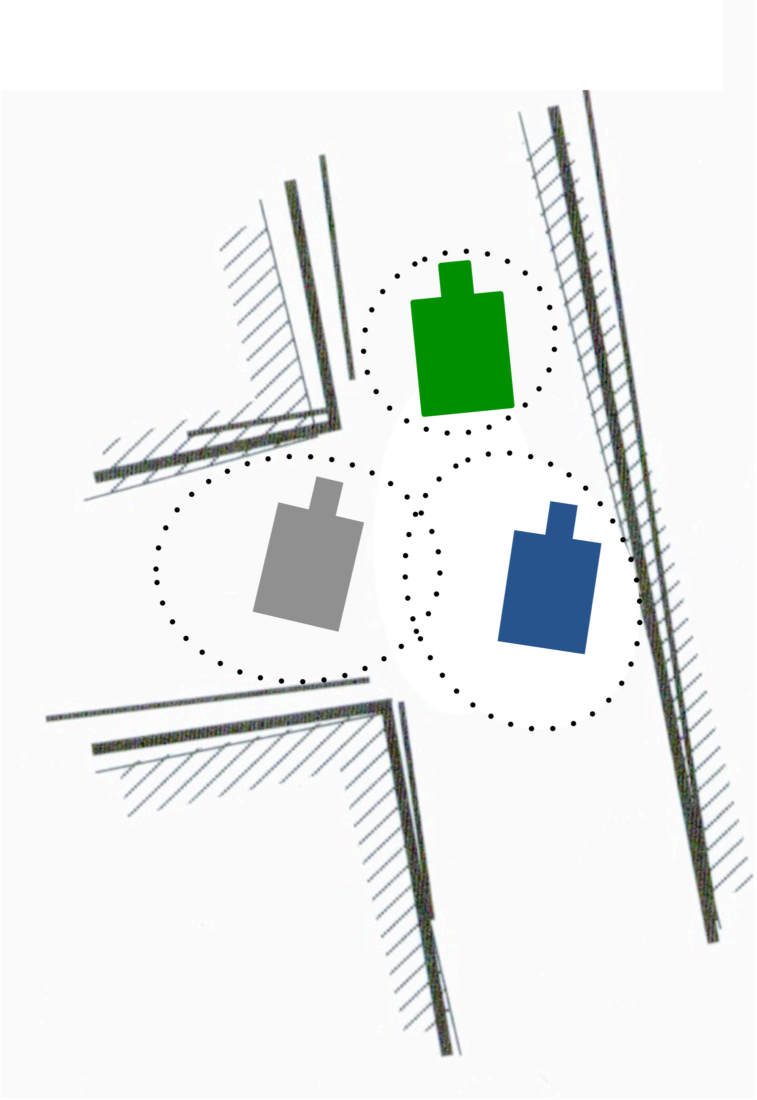


EKF Fusion



EKF Fusion





EKF Update

$$\hat{\boldsymbol{x}} = \begin{pmatrix} \hat{\boldsymbol{x}}_v \\ \hat{\boldsymbol{y}}_1 \\ \hat{\boldsymbol{y}}_2 \\ \vdots \end{pmatrix}$$

$$\boldsymbol{P} = \begin{bmatrix} \boldsymbol{P}_{xx} & \boldsymbol{P}_{xy_1} & \boldsymbol{P}_{xy_2} & \cdots \\ \boldsymbol{P}_{y_1 x} & \boldsymbol{P}_{y_1 y_1} & \boldsymbol{P}_{y_1 y_2} & \cdots \\ \boldsymbol{P}_{y_2 x} & \boldsymbol{P}_{y_2 y_1} & \boldsymbol{P}_{y_2 y_2} & \cdots \\ \vdots & \vdots & \vdots & \end{bmatrix}$$

SLAM – Research topics

- Robustness in changing environments
- Multiple robot mapping

Motion estimation of agile cameras

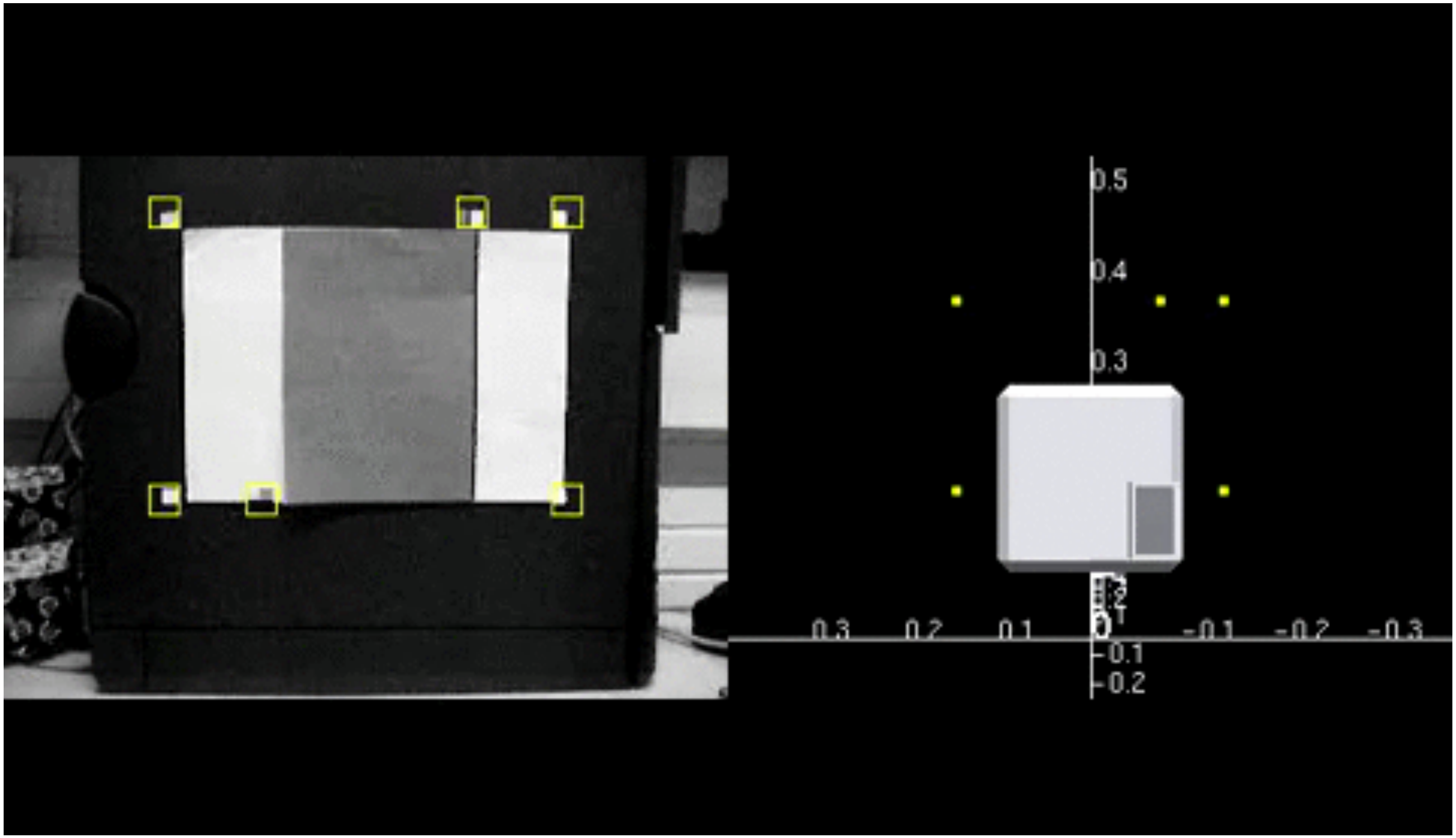
- **Real-Time SLAM with a Single Camera**
  - *Andrew J. Davison, University of Oxford, 2003*
- **Parallel Tracking and Mapping for Small AR Workspaces**
  - *Georg Klein, David Murray, University of Oxford, 2007*

[18]

Motion estimation of agile cameras

- No odometry data, **fast and unpredictable** movements
- Use a constant velocity model instead of odometry

$$x_v = \big(\underbrace{x \quad y \quad z}_{\text{Position}} \quad \underbrace{\alpha \quad \beta \quad \delta}_{\text{Orientation}} \quad \underbrace{v_x \quad v_y \quad v_z \quad v_\alpha \quad v_\beta \quad v_\delta}_{\text{Velocity}} \big)$$



[19]

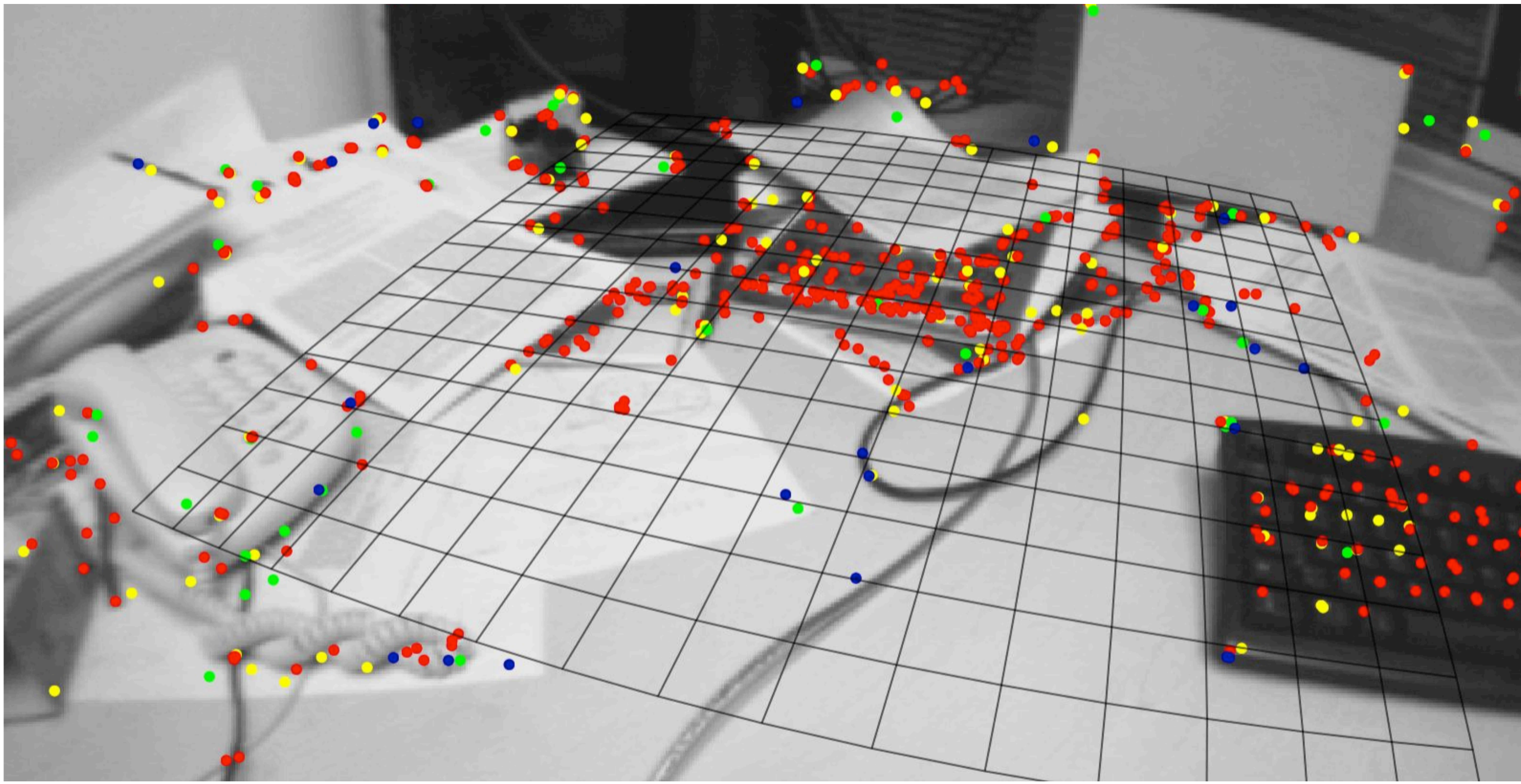
Motion estimation of agile cameras

- **Real-Time SLAM with a Single Camera**
  - *Andrew J. Davison, University of Oxford, 2003*

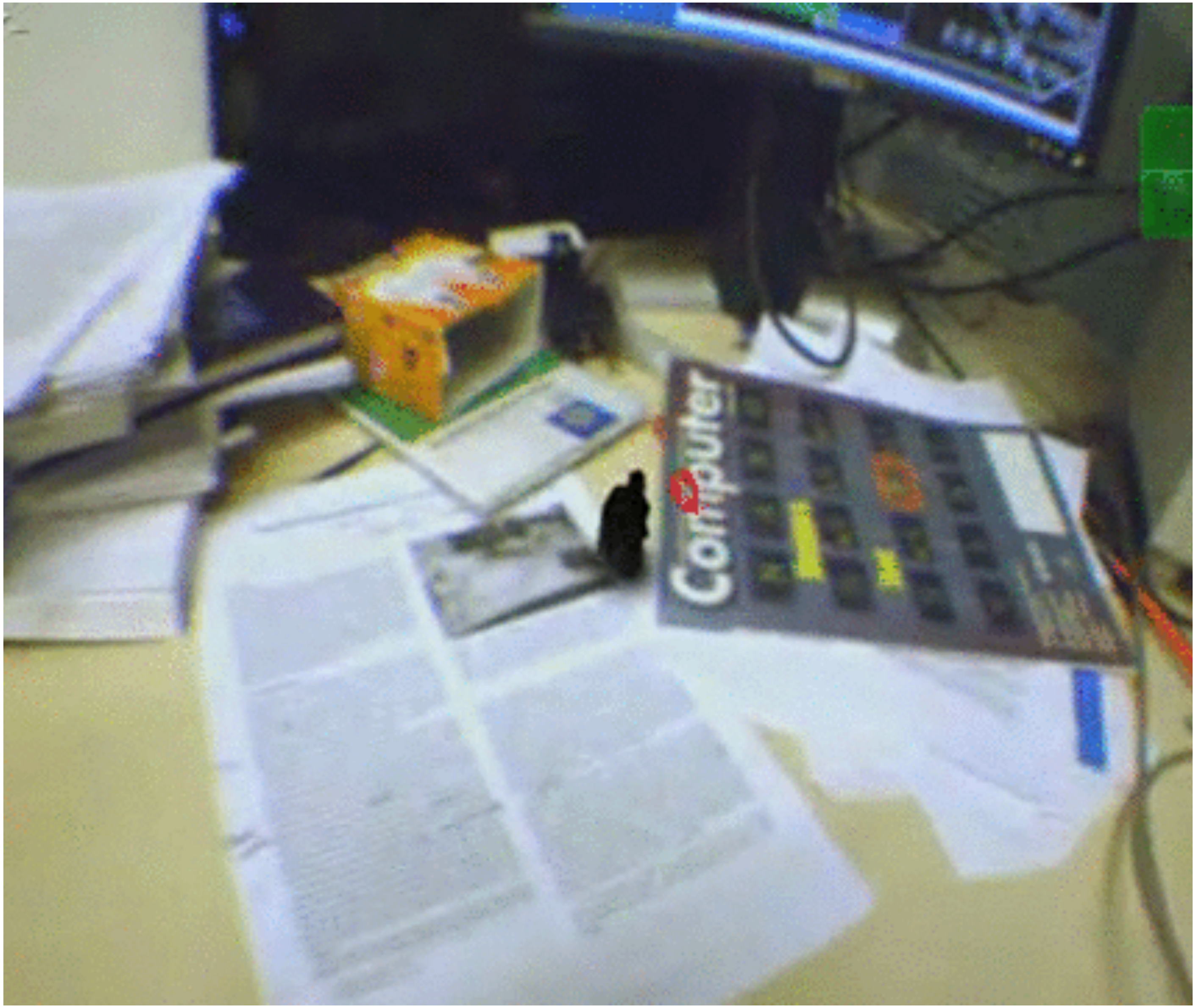
- **Parallel Tracking and Mapping for Small AR Workspaces**
  - *Georg Klein, David Murray, University of Oxford, 2007*

[19]

Tracking and Mapping for AR Workspaces



[20]



[21]

What we have seen

- What autonomous mobile robots are used for
- How todays mobile robots navigate autonomously
  - mapless, map-based, map-building
- The potential and the challenges of SLAM

References

Papers

1. Bonin-Font, Francisco, Alberto Ortiz, and Gabriel Oliver. "**Visual navigation for mobile robots: A survey.**" Journal of intelligent and robotic systems 53.3 (2008): 263-296.
2. Davison, Andrew J. "**Real-time simultaneous localisation and mapping with a single camera**." Proceedings of 9th IEEE International Conference onComputer Vision, 2003.
3. Klein, Georg, and David Murray. "**Parallel tracking and mapping for small AR workspaces**." Proceedings of 6th IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR), 2007
4. Davison, Andrew J. "**Sequential localisation and map-building for real-time computer vision and robotics**“, Robotics and Autonomous Systems 36 (2001) 171-183. 2001
5. Mehmed Serdar Guzel, Robert Bicker. “**Optical Flow Based System Design for Mobile Robots**”, Robotics Automation and Mechatronics, 2010
6. M. Mata, J-M.Armingol, A. de la Escalera, M.A. Salichs. “**Using learned visual landmarks for intelligent topological navigation of mobile robots**”, Mata, 2003

References

Images & Videos

1. https://www.youtube.com/watch?v=ISznqY3kESI
2. http://si.wsj.net/public/resources/images/BN-EJ674_DYSON3_G_20140904010817.jpg
3. http://cdn.phys.org/newman/gfx/news/hires/2013/therhextakes.jpg
4. http://www.designboom.com/cms/images/andrea08/aqua201.jpg
5. http://www.flyability.com/wp-content/uploads/2013/08/Flyabiliy-Gimball-2.png
6. http://cnet4.cbsistatic.com/hub/i/r/2014/12/01/b1baf339-67d6-4004-bc66-7dd34c11a870/resize/770x578/3d17e8de0dbd6d26cbf13e53a6c0b655/amazon-kiva-robots-donna-7611.jpg
7. http://cryptome.org/eyeball/daiichi-npp10/pict29.jpg
8. http://i.space.com/images/i/000/007/679/original/curiosity-mars-rover.jpg?1295367909
9. http://si.wsj.net/public/resources/images/BN-EJ674_DYSON3_G_20140904010817.jpg
10. http://www.paris-tours-guides.com/image/avenue-champs_elysees/walking-champs-elysees-paris.jpg
11. http://videohive.net/item/moving-train-and-passing-landscape/8960245?ref=Grey_Coast_Media&ref=Grey_Coast_Media&clickthrough_id=415192702&redirect_back=true
12. http://www.effectiveui.com/blog/wp-content/uploads/2012/06/Paris-Interactive-Map.jpg
13. https://timedotcom.files.wordpress.com/2015/03/463383156.jpg?quality=65&strip=color&w=1100
14. http://portal.uc3m.es/portal/page/portal/dpto_ing_sistemas_automatica/investigacion/lab_sist_inteligentes/publications/icra03a.pdf
15. http://www.soue.org.uk/souenews/issue4/mobilerobots.html
16. http://www.foreignpixel.com/wp-content/uploads/galleries/post-1227/full/street.jpg
17. https://www.doc.ic.ac.uk/~ajd/Publications/davison_kita_ras2001.pdf
18. http://ecx.images-amazon.com/images/I/41cveXjTHdL._SY300_.jpg
19. http://www.robots.ox.ac.uk/˜ajd/Movies/realtime 30fps slam.mpg
20. http://www.robots.ox.ac.uk/~gk/publications/KleinMurray2007ISMAR.pdf
21. http://www.robots. ox.ac.uk/~gk/videos/klein 07 ptam ismar.avi
22. https://www.bcgperspectives.com/content/articles/business_unit_strategy_innovation_rise_of_robotics/
23. Mehmed Serdar Guzel, Robert Bicker. “Optical Flow Based System Design for Mobile Robots”, 2010