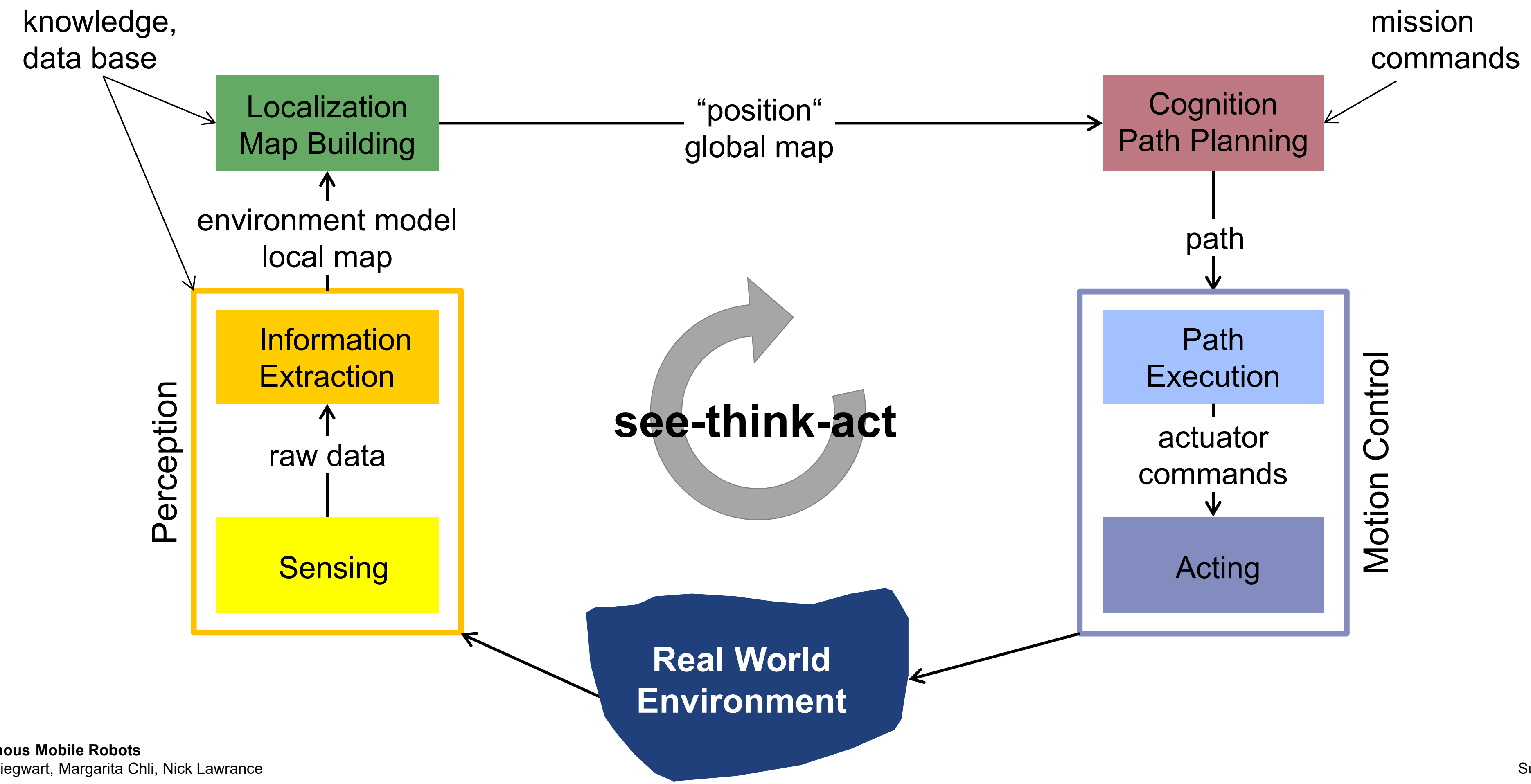
Mobile Robots | **Summery**

Autonomous Mobile Robots

Roland Siegwart, Margarita Chli**,** Nick Lawrance

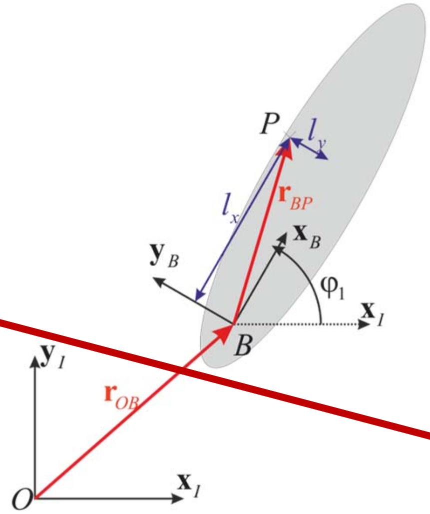
Introduction | probabilistic map-based localization



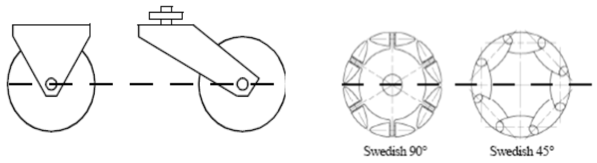
Legged Robots and Kinematics

- Types and application of **legged systems**
  - Number of legs
  - Analogy to nature
- Static and dynamic stability
- Locomotion control

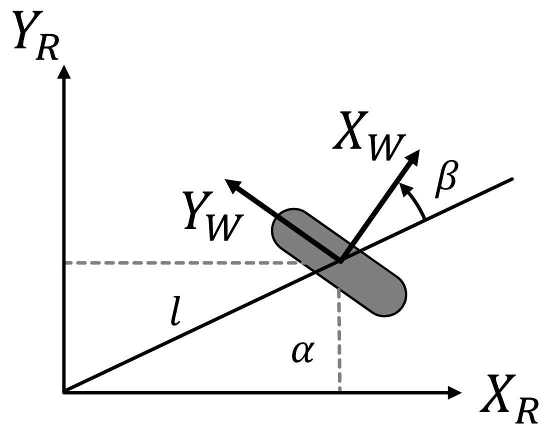
- Basics of **rigid body kinematics**
  - Translation, rotations, and homogeneous transformation
  - Translational and angular velocities
  - Rigid body kinematics formulation
  - Vector differentiation in moving coordinate systems



Wheeled Locomotion



- Wheeled types and arrangements
- Kinematics
  - Constraints imposed by wheels
  - Forward or inverse differential kinematics
- Analysis of the differential kinematics equations
  - **the degree of maneuverability**
    = degree of mobility + degree of steerability



Commputer Vision | Projective Geometry

- Perspective projection 
  - Intrinsic and extrinsic parameters

Perspective Projection Matrix

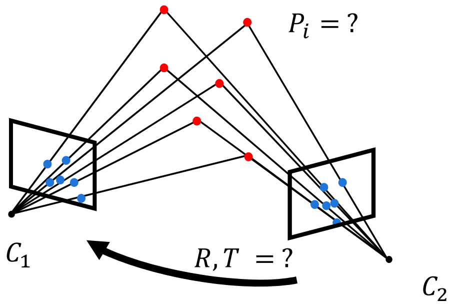
$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \boxed{K[R|T]} \cdot \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix}$$

- Stereo vision 
  - Correspondence search
  - Rectification
  - Disparity map

$$Z_P = \frac{bf}{\boxed{u_l - u_r}}$$

Disparity

- Structure from motion
  - Epipolar geometry
  - Epipolar constraint
  - Essential matrix
  - 8-point algorithm



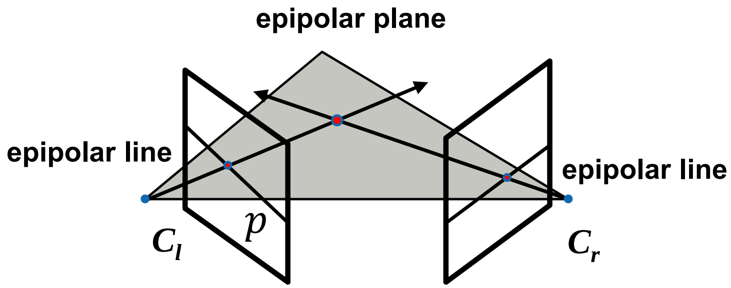
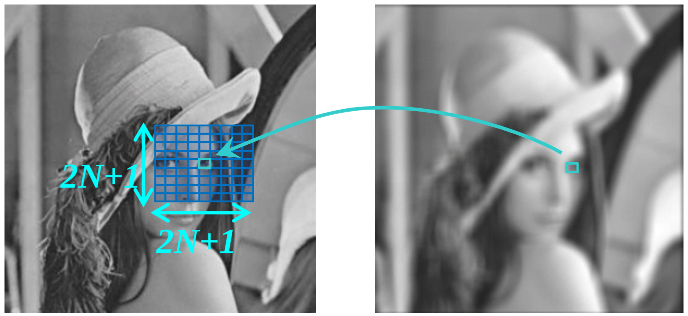


Image Saliency | image filtering & place recognition

Image Filtering:

Correlation vs. Convolution

- Use in template matching, smoothing & taking the derivate of an image



- Image filtering for **Edge Detection**

- Point Features:
  Harris, **SIFT**, FAST, BRIEF, BRISK
  & their characteristics
  e.g. scale/rotation invariance,
  computational time

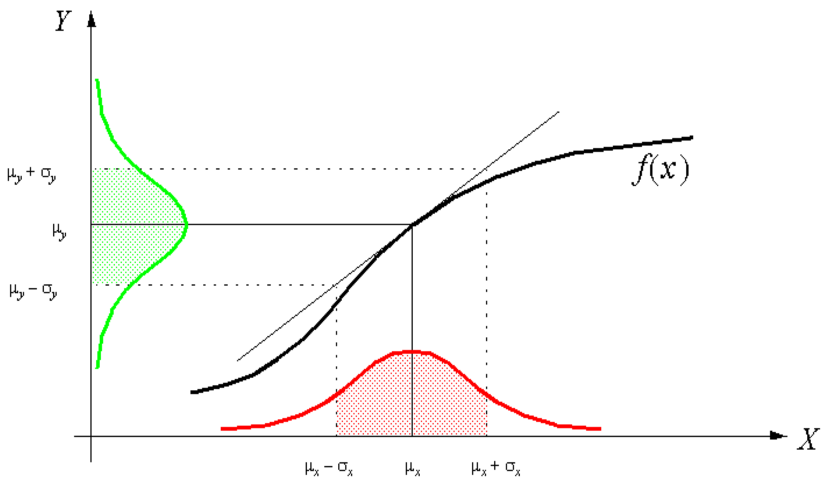
Building and using the visual vocabulary for **Place Recognition**

Examples of Visual Words

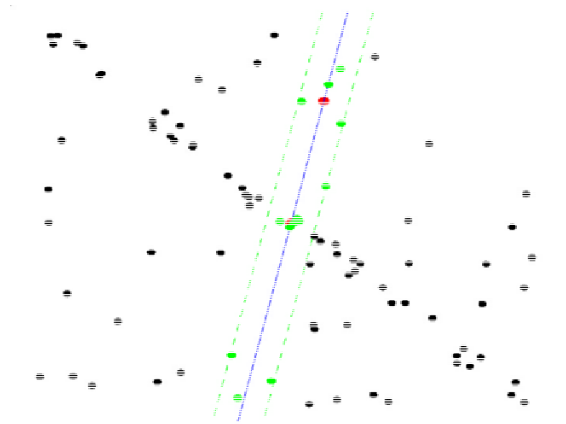
Line Fitting | algorithms & error propagation

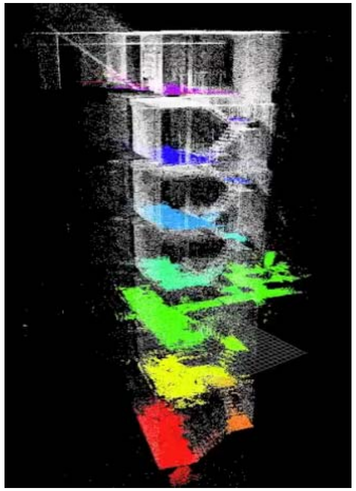
The **Error Propagation Law**

- How uncertainties propagate through a function.



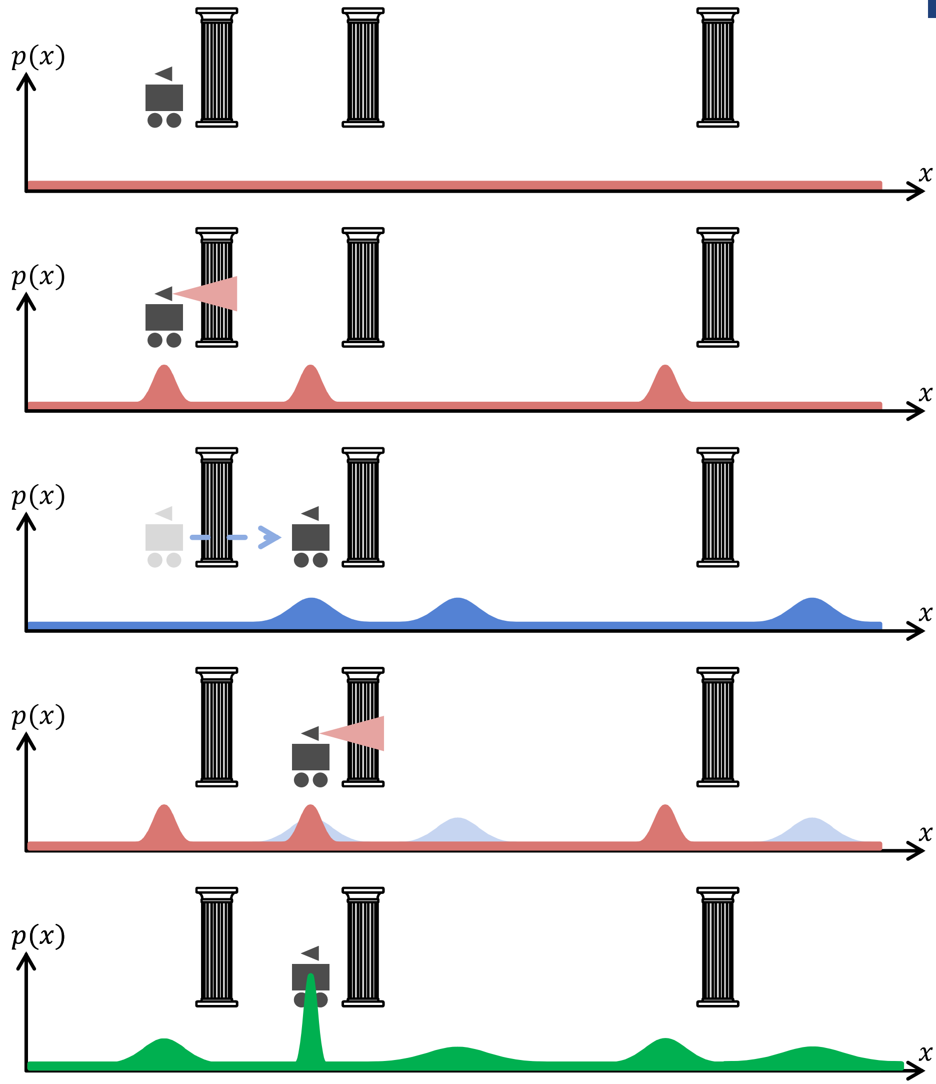
- **Line Fitting algorithms** for image/laser point clouds
  - Split-and-merge, RANSAC, Hough Transform,..
  - How they work & their relative characteristics and applications





Courtesy of ETH - ASL

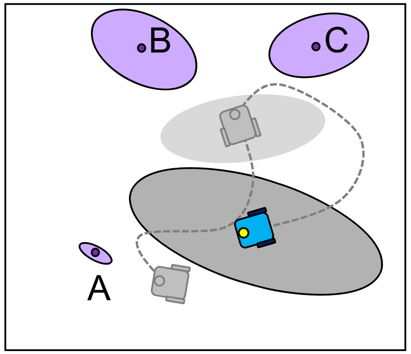
Localization | where am I?



- SEE: The robot queries its sensors → finds itself next to a pillar
- ACT: Robot moves one meter forward
  - motion estimated by wheel encoders
  - accumulation of uncertainty
- SEE: The robot queries its sensors again → finds itself next to a pillar
- Belief update (information fusion)

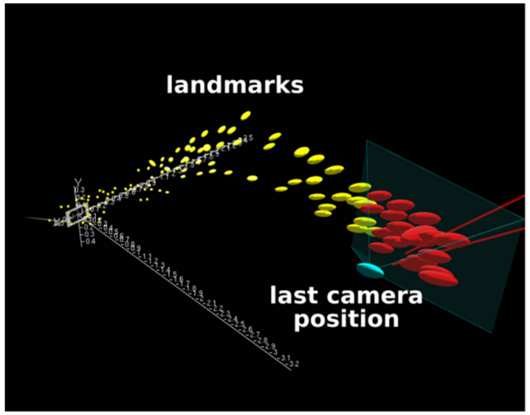
SLAM | approaches & current challenges

- What is SLAM and how does it work?
- The graphical representation SLAM & the approaches to solve it:
  - **Full graph optimization**
  - **Filtering**
  - **Keyframe-based**



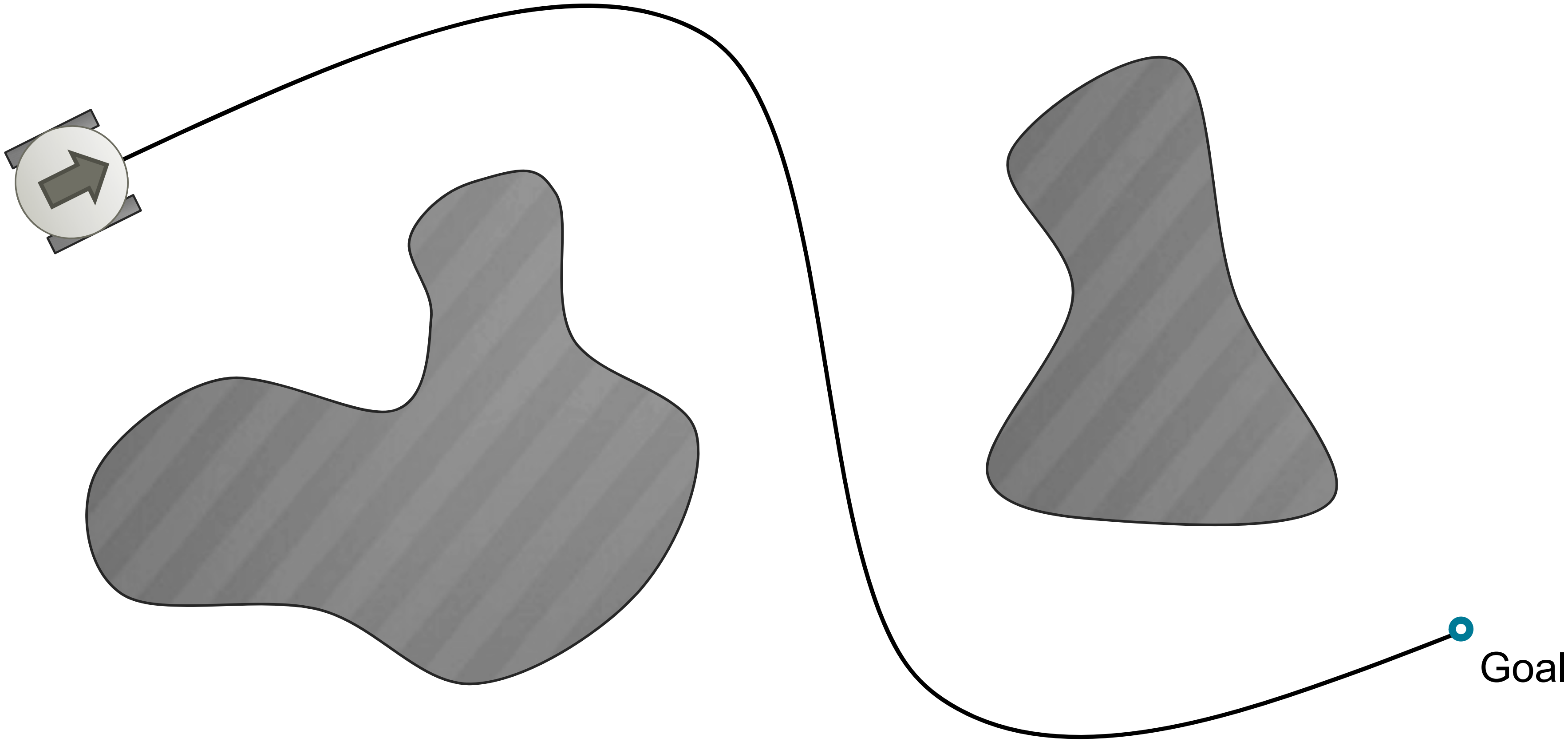
Popular techniques & how they work:

- **EKF SLAM via MonoSLAM** [Davison et al. 2007]



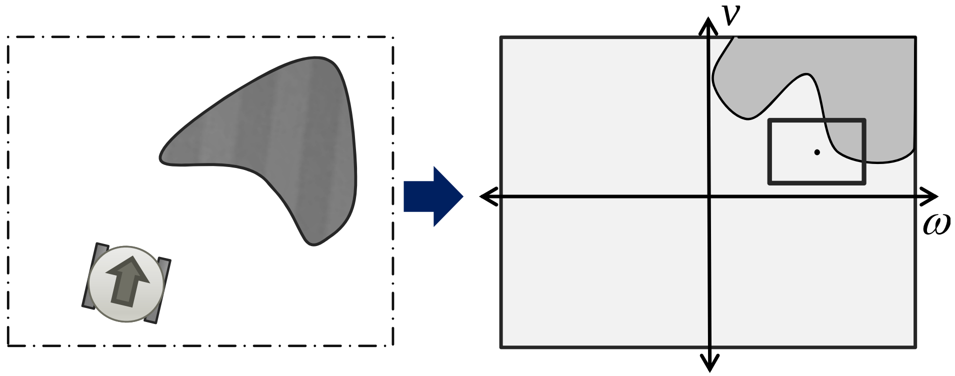
- **SLAM today & Challenges**

Motion Planning | the planning problem

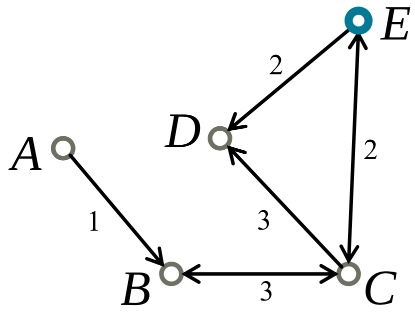


Motion Planning| hierarchical decomposition & approaches

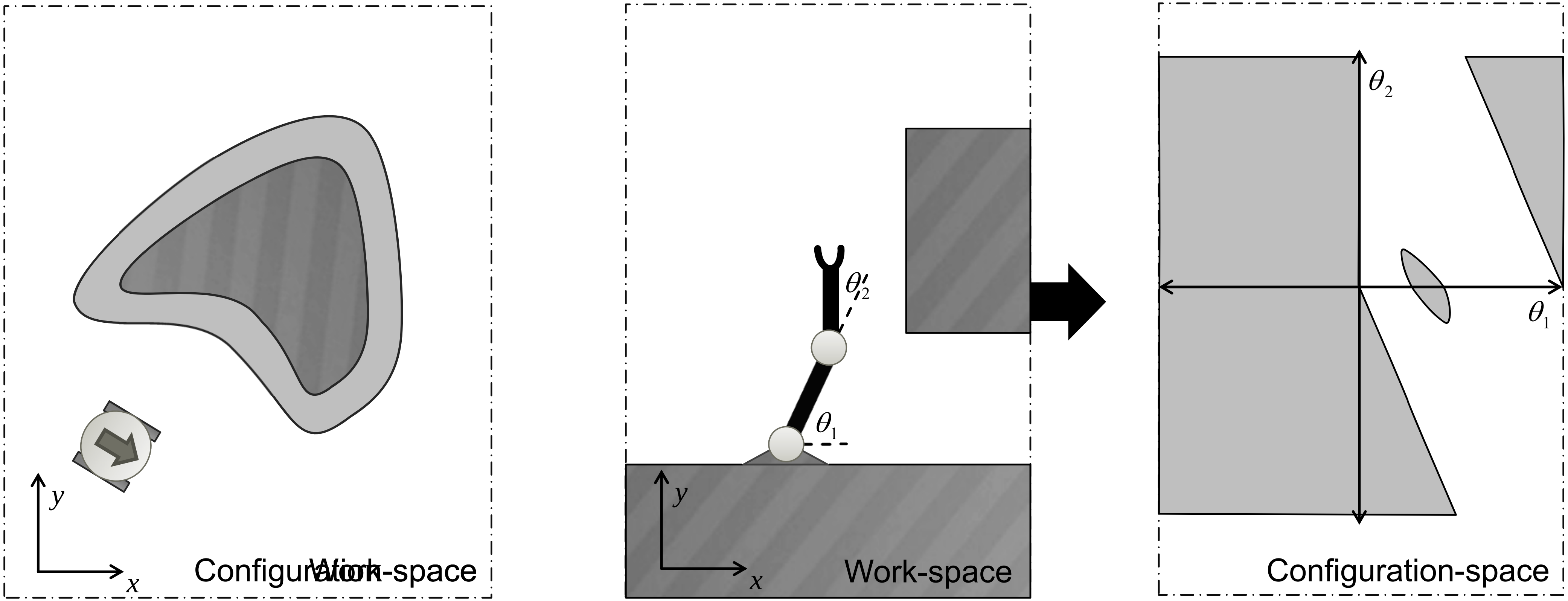
1. Local collision avoidance
   - Dynamic Window Approach
   - (Reciprocal) Velocitiy Obstaces
   - Local potential fields



2. Global planning
   - Harmonic potential fields
   - Graph search (BF, Dijkstra, A*)
   - Randomized tree search (RRT)



Motion Planning | work-space versus configuration-space



Exam

- Type
  - Written session examination
- Language of examination
  - English
- Course attendance confirmation required
  - No
- Repetition
  - The performance assessment is only offered in the session after the course unit. Repetition only possible after re-enrolling.
- Mode of examination
  - written 120 minutes
- Aids
  - 4 A4-pages summary (2 sheets written on both sides or 4 sheets written on one side);
  - Calculator

Exam | Wednesday 14.08.2019, 14:00-16:00

- Content of the exam:
  - MOOC (video segment, exercises, quizzes)
  - Book "Autonomous Mobile Robots" and add on slides
- Mode: The exam will be a combination of
  - Multiple Choice (comprehensive) 20-30%
  - Comprehension questions
  - Calculations, similar to exercises, but simpler and solvable without computer
- Two preparation sessions:
  - First: around 2 weeks before the exam
  - Second: 2-3 day before the exam
- More information about the preparation session and an example exam will be sent to you before the end of June.

Exam (example exercise exam)

Autonomous Mobile Robots - Exercise Exam

Roland Siegwart, Margarita Chli, Martin Rufli

Date of Exam: Exercise summer 2016

Question	Points	Score
A. Multiple Choice	20	
B. Mobile Robot Kinematics	3	
C. Forward Kinematics	6	
D. Kinematic Constraints	8+2	
E. Stereo Vision	7+1+2+5	
F. Markov Localization	4+4	
G. Kalman Filter Based Localization	7	
H. SLAM	6+3+2+4	
I. Graph Search: Dijkstra's Algorithm	6+5+2	
J. Collision Avoidance: Velocity Obstacle Approach	2+2+3	

Exam (example exercise exam)

Autonomous Mobile Robots — Exercise Exam 2016, ETH Zurich

A. Multiple Choice Questions

Decide whether the following statements are true or false. Cross the checkbox on the corresponding answer.
You will be credited 1 point for a correct answer, while 1 point will be subtracted from the total, if your answer is wrong.

1	In a holonomic system, the measure of the traveled distance of each wheel is sufficient to calculate the final position of the robot.	TRUE	☐	FALSE	☐
2	For a robot with 2 degrees of maneuverability, position of instantaneous center of rotation is constrained to a line.	TRUE	☐	FALSE	☐
3	Open-loop control can be used to move the robot in the unknown environment.	TRUE	☐	FALSE	☐
4	Non-holonomic robot is able to move instantaneously in any direction in the space of its degrees of freedom.	TRUE	☐	FALSE	☐

Exam (example exercise exam)

B. Mobile Robot Kinematics

Please specify degrees of maneuverability, mobility and steerability for the following three-wheel configurations and explain why.