Vehicle motion planning and control: other approaches

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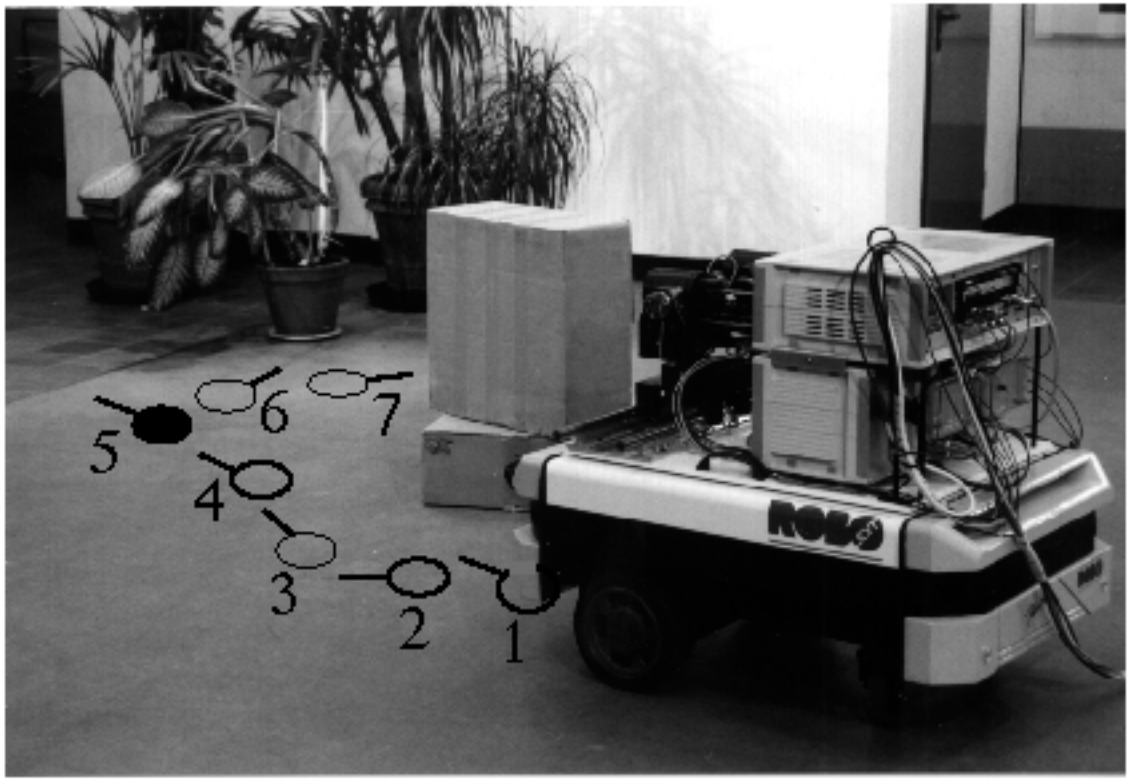
The problem

- move about in a 2D world, which is occupied by objects/stuff



The problem: components

- sense something about the environment
- know about the environment
- plan movement in the environment that is collision-free
- control vehicle to achieve planned movement
- estimate what vehicle actually did

Concepts

- local vs. global
  - information only about the local environment of the robot vs. global map information about the environment
- reactive vs. planning
  - motion planning "on the fly" in response to sensory inputs vs. motion planning for an entire action
- exact vs. heuristic
  - guaranty a path is found when one exists that fulfills the constraints. vs. generate a plan based on ad hoc principles, likely to fulfill constraints

Concepts

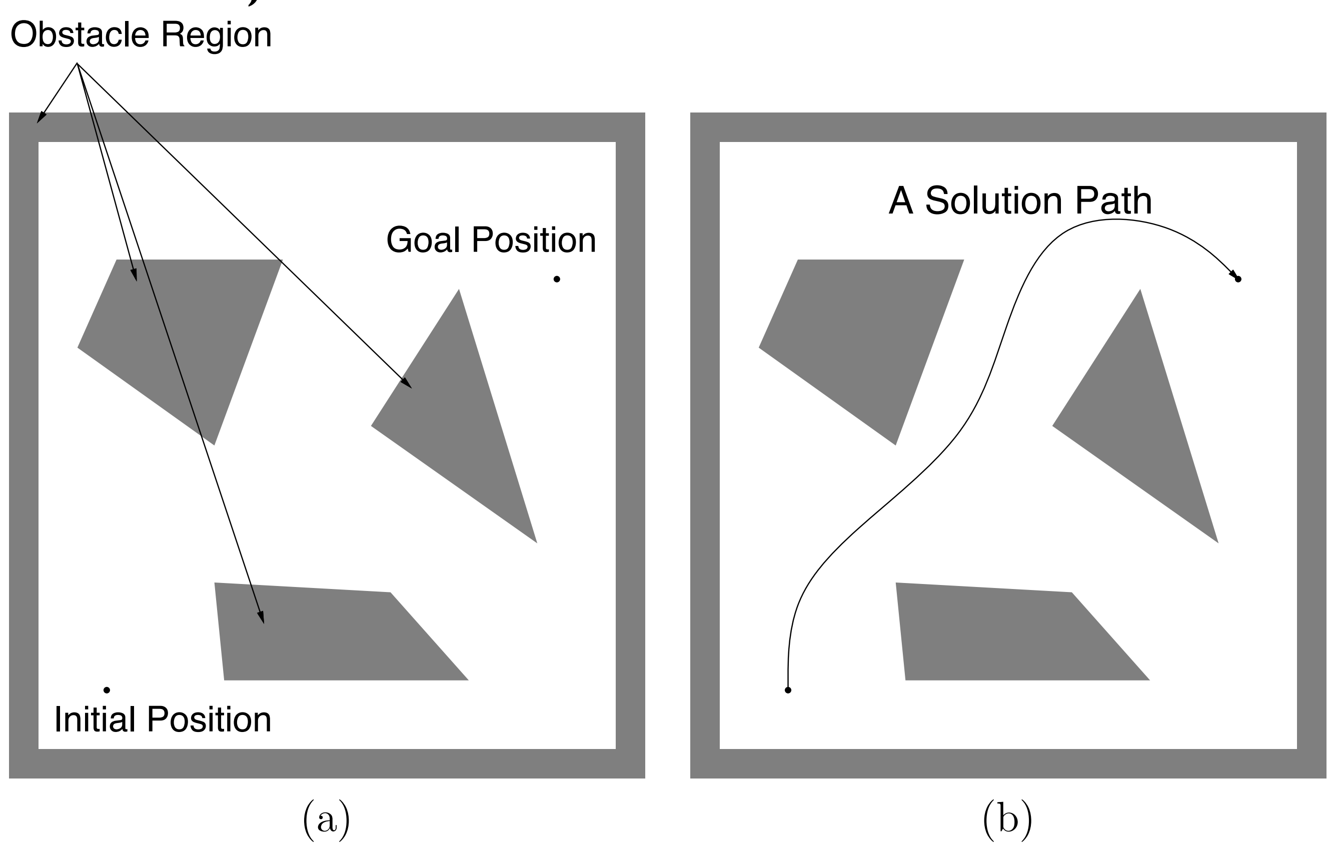
- continuous vs. discrete:
    - continuous state space variables vs. grid state spaces, graph state spaces
- behavior-based vs. classical
    - low-level sensory information vs. world representations

Approaches to vehicle path planning

- classical planning approaches
- potential field approach
- Borenstein & Koren
- (dynamic window approach)

Classical global path planning

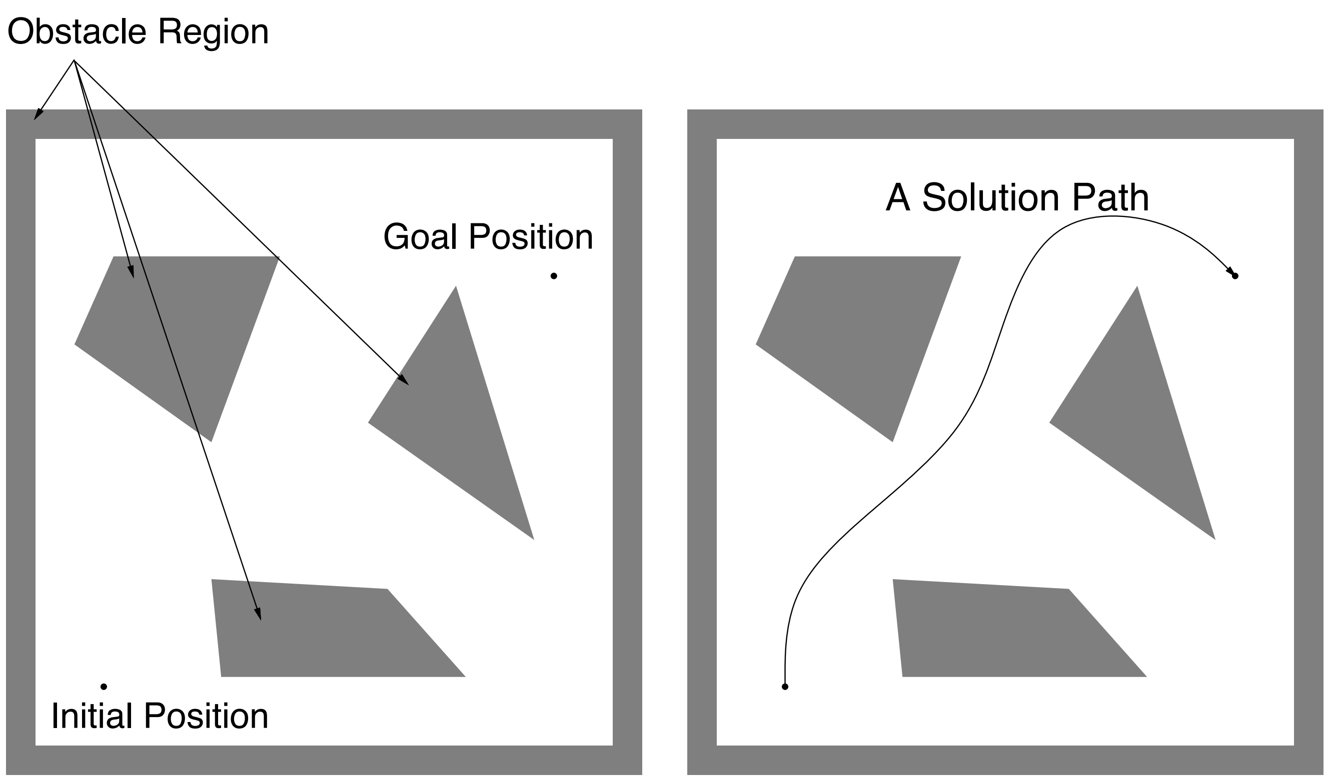
- Standard reference: Latombe: Robot motion planning, 1991
- very good general review: LaValle: Planning algorithms, 2006



[LaValle, 2006]

Classical global path planning

- mathematical theories of constraint satisfaction and decision theory
- searching spaces, sampling approaches



(a) (b)

[LaValle, 2006]

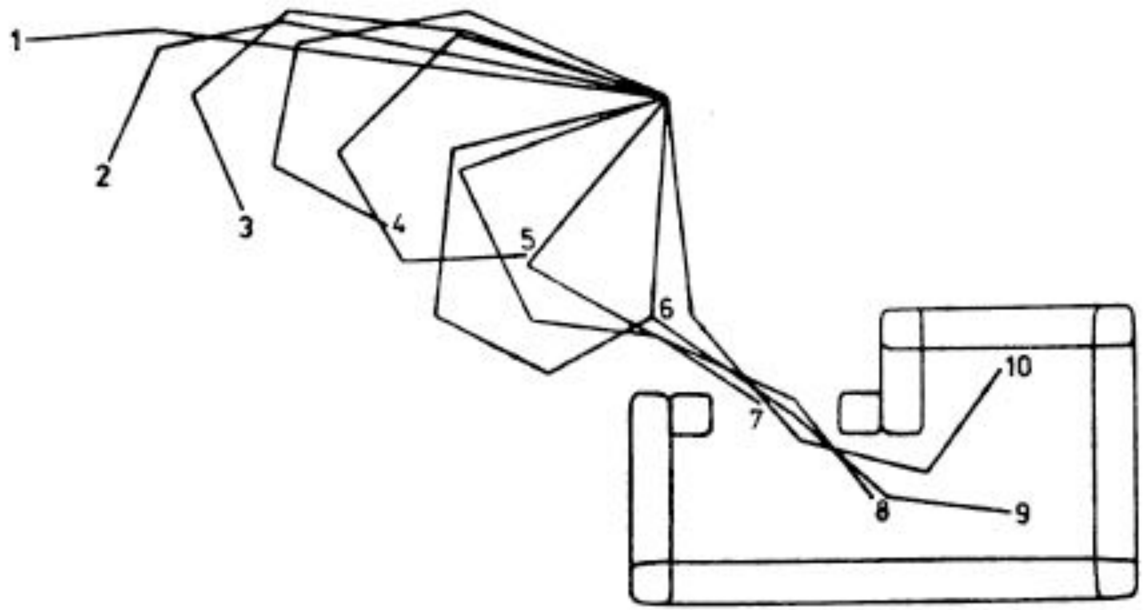
Classical local path planning

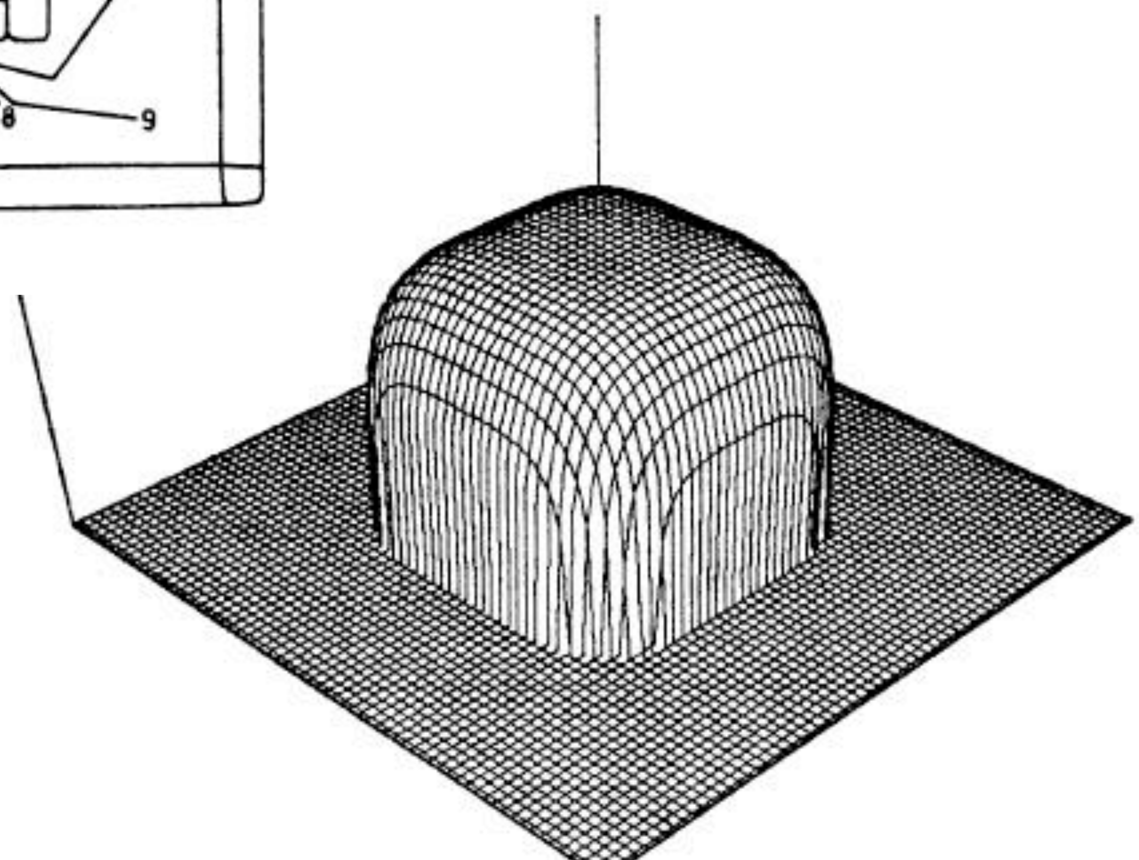
- reference: Cox, Wilfong: Autonomous Robot Vehicles, 1990
- based on known world (e.g., as polygonial representation of surfaces)
- taking into account vehicle model
- smoothness constraints

Potential field approach

- invented by Khatib, 1986 (similar earlier formulation: Neville Hogan's impedance control)
- the trajectory of a manipulator or robot vehicle is generated by relaxing a point in a potential field to an equilibrium point
- the manipulator 3D end-position or vehicle 2D position is updated by descending within that potential field
- obstacle surfaces are potential hills; target states are potential minima

Potential field approach



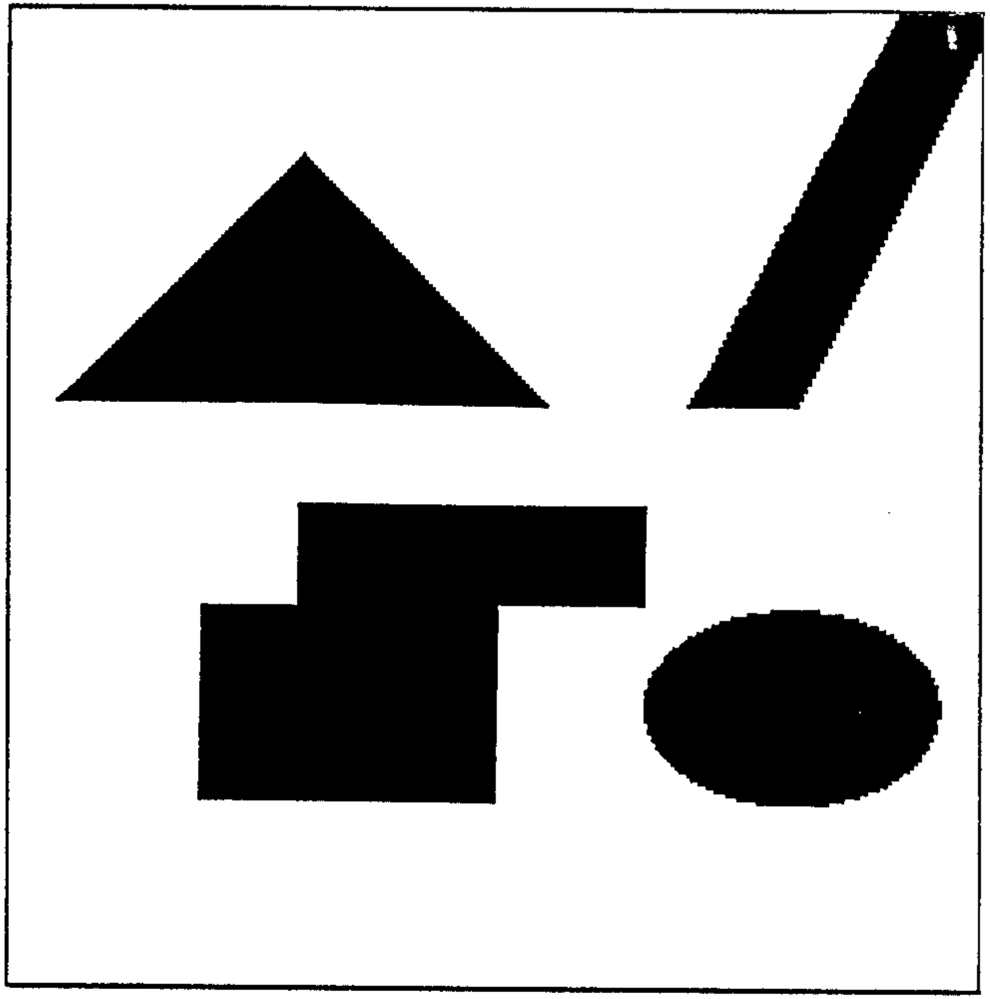


potential field approach

- as a heuristic planning approach
- idea: have target and obstacle representation
- make potential minimum at target
- make potential maximum at obstacles
- compute downhill gradient descent for path generation

potential field approach

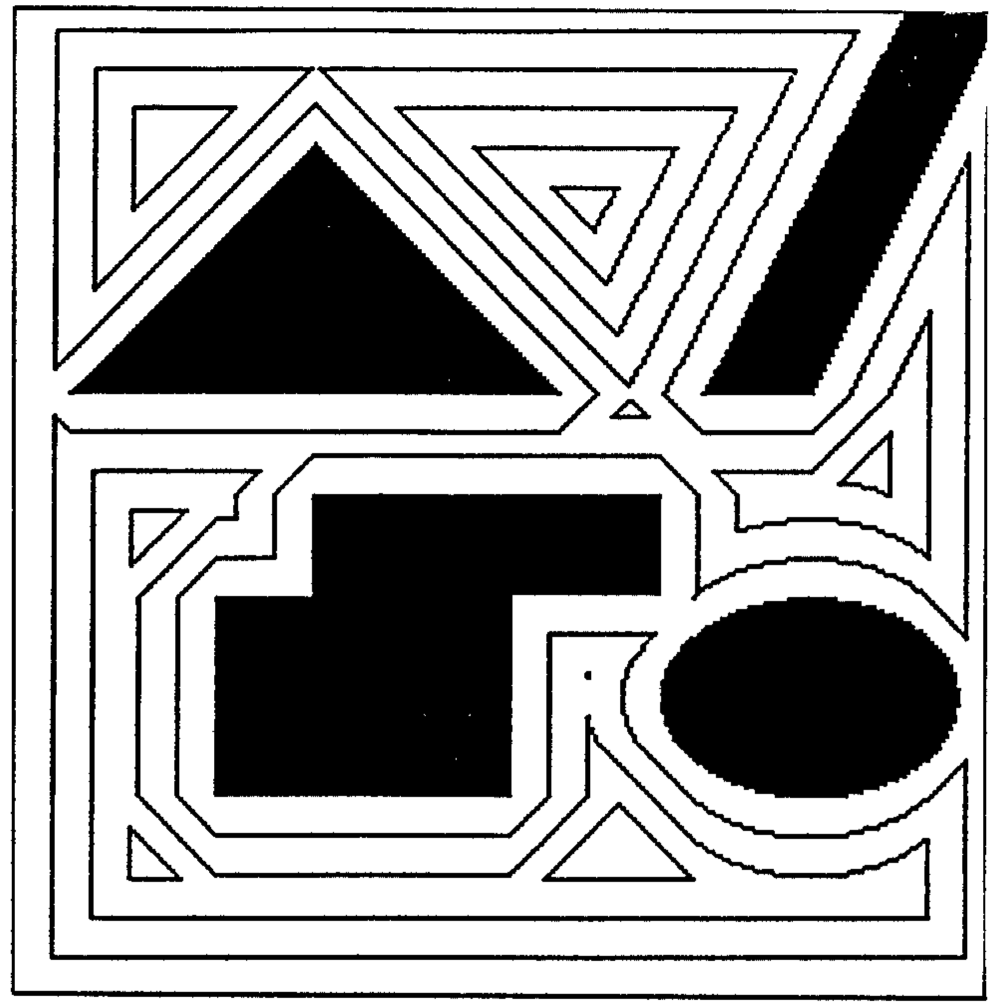
- obstacle configuration



[Barranquand, Langlois, Latombe, 1989]

potential field approach

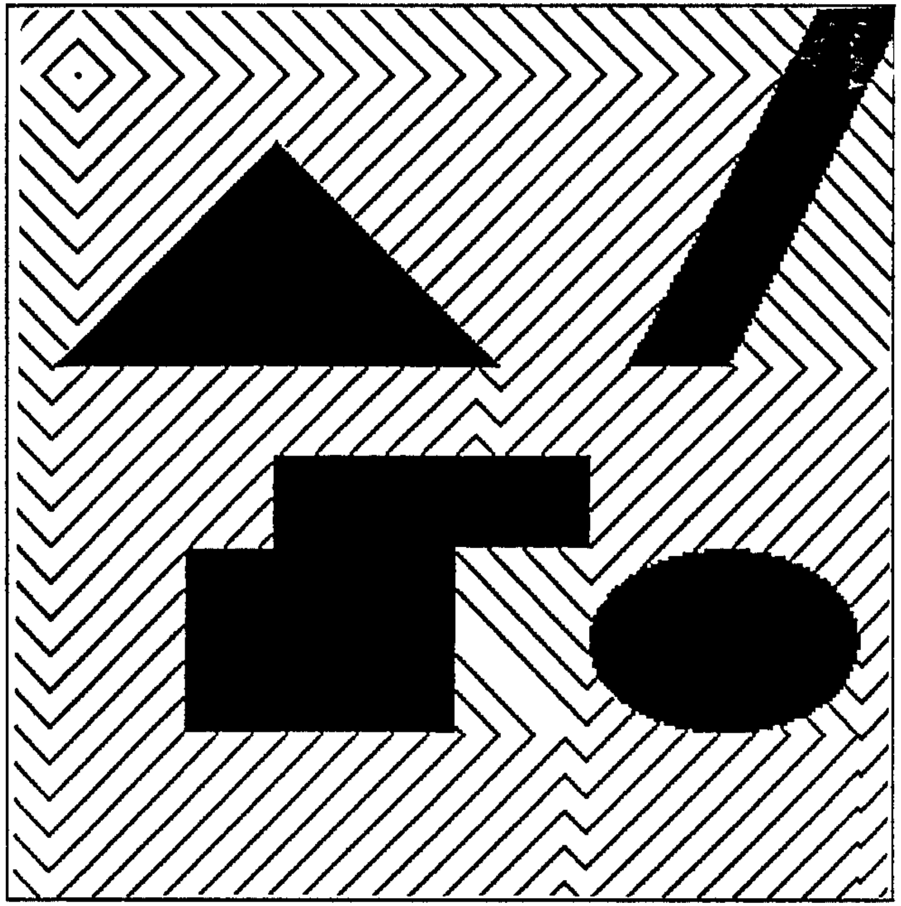
- contours of associated obstacle potential field



[Barranquand, Langlois, Latombe, 1989]

potential field approach

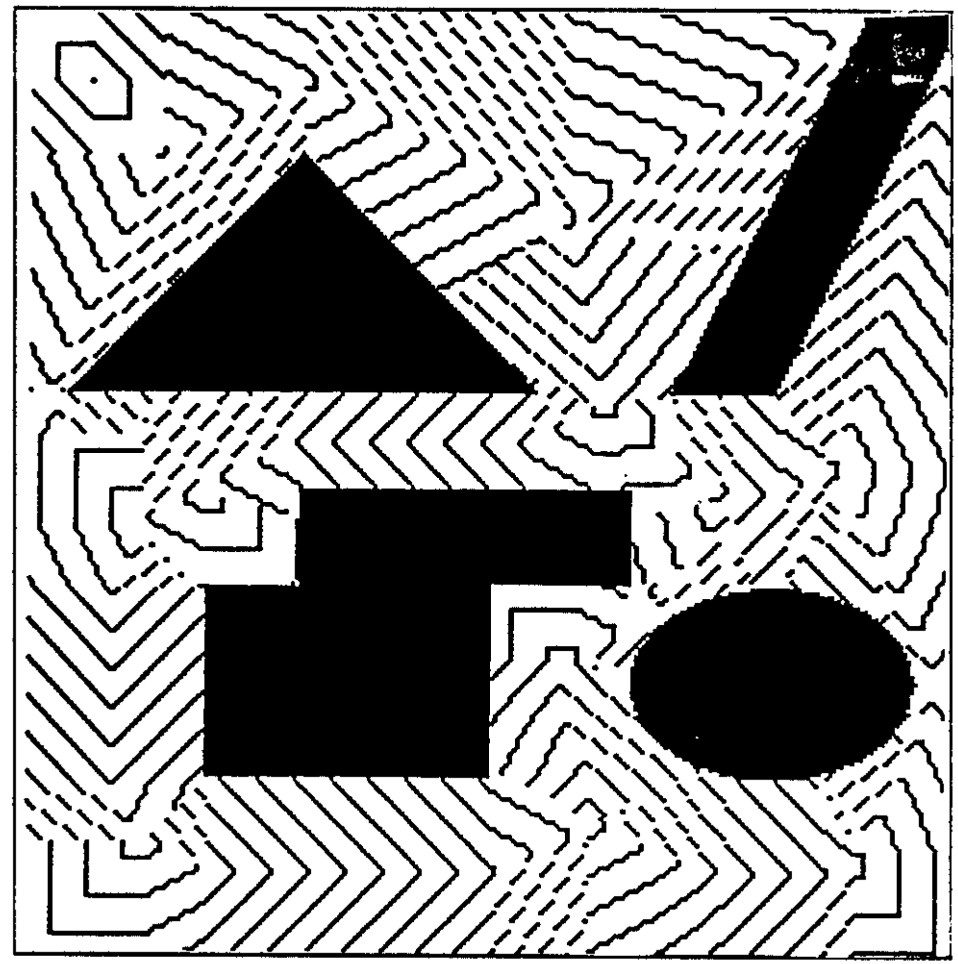
- contours of target potential field



[Barranquand, Langlois, Latombe, 1989]

potential field approach

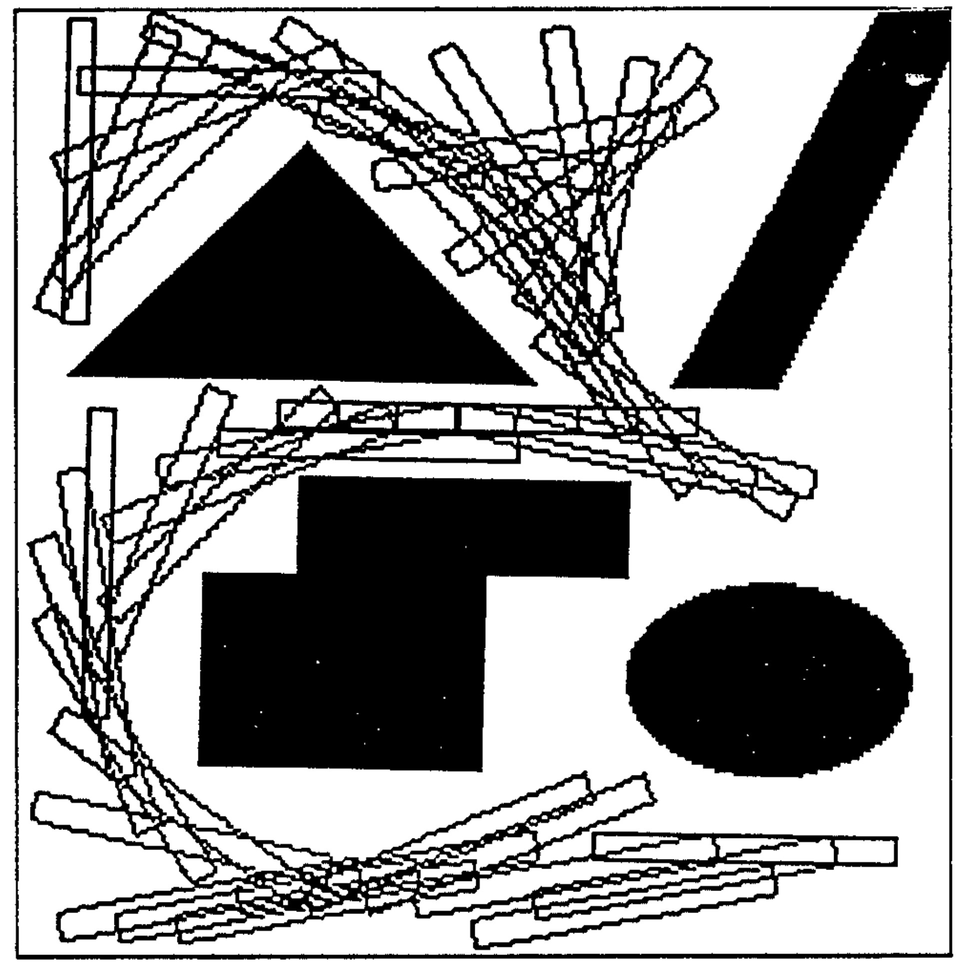
- contours of improved target potential field (by adding bubbles around obstacles)



[Barranquand, Langlois, Latombe, 1989]

potential field approach

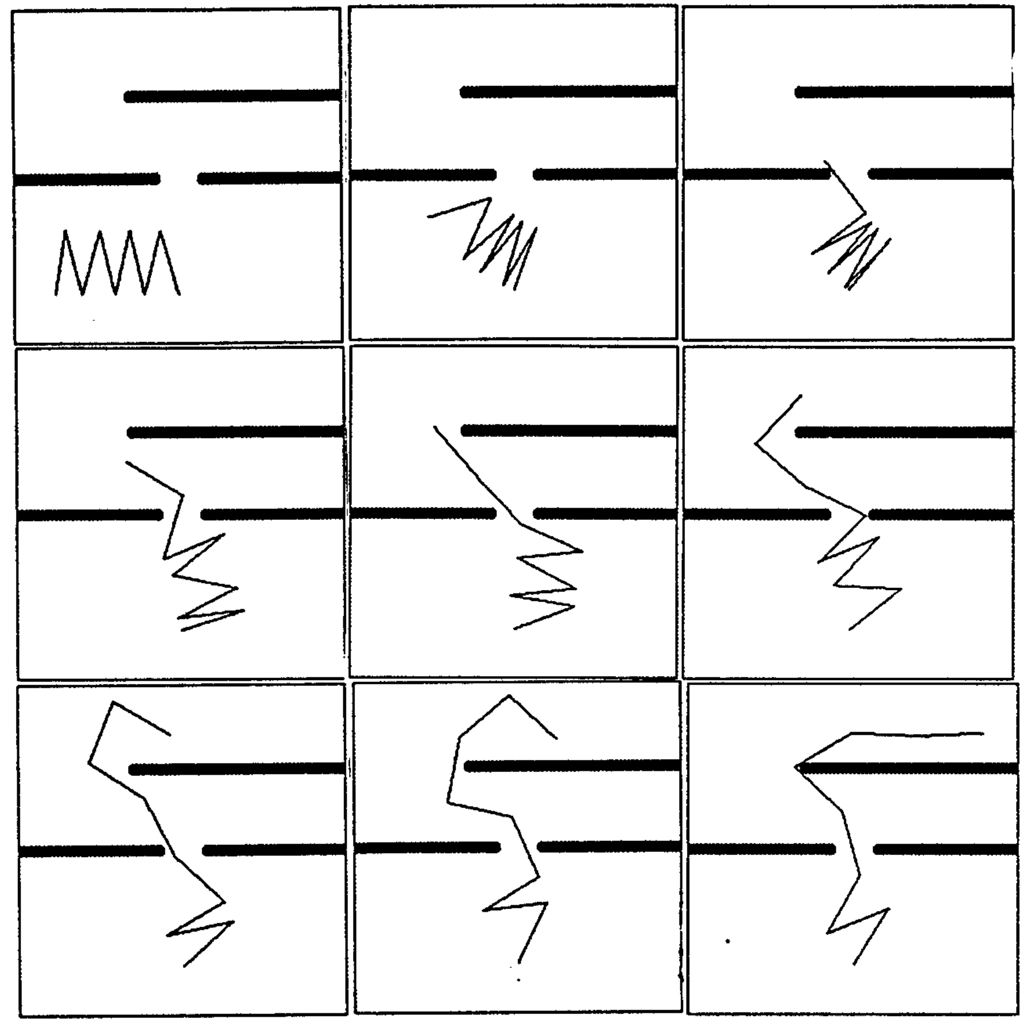
- adding all contributions leads to solution: gradient descent for vehicle



[Barranquand, Langlois, Latombe, 1989]

potential field approach

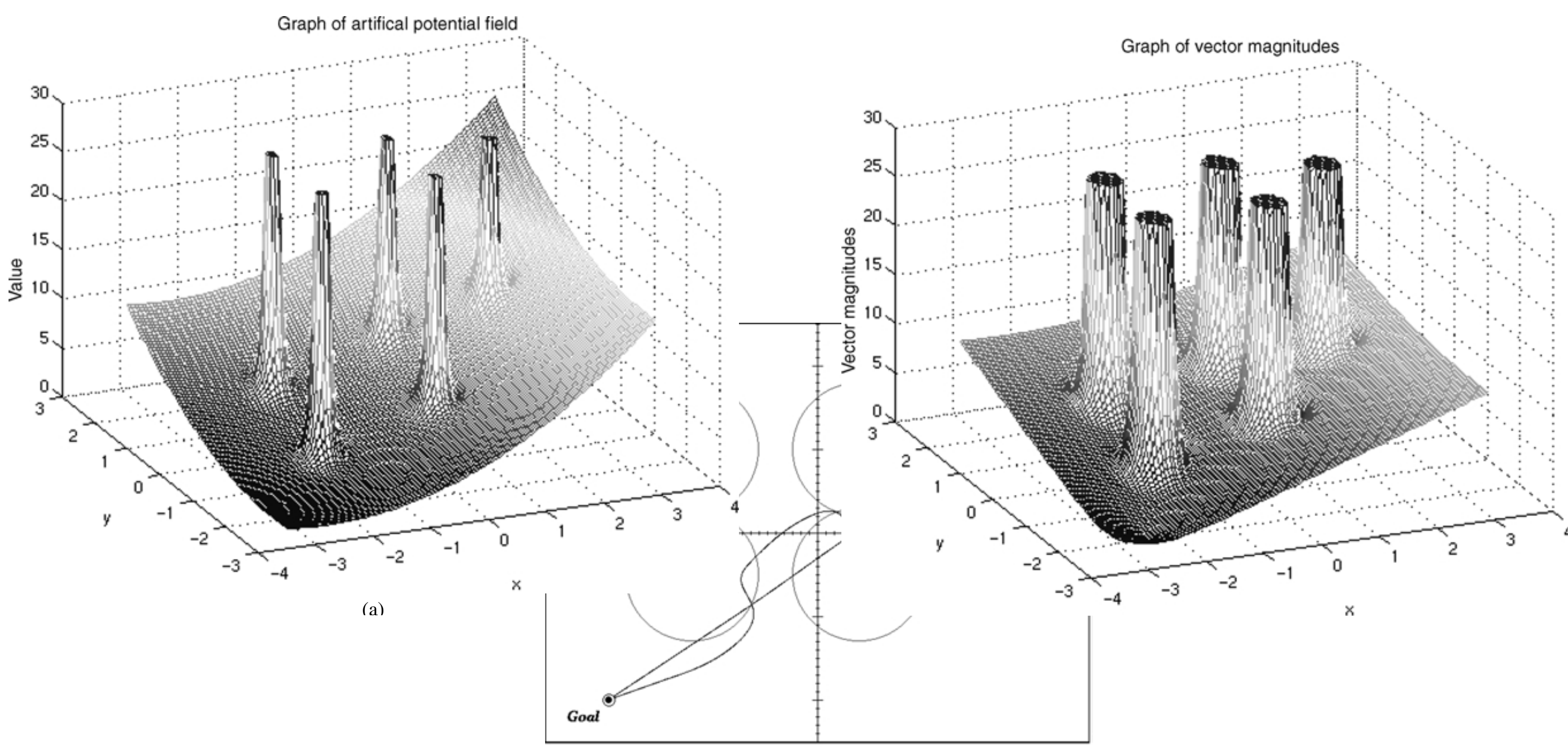
- generalization to higher-dimensional configuration spaces



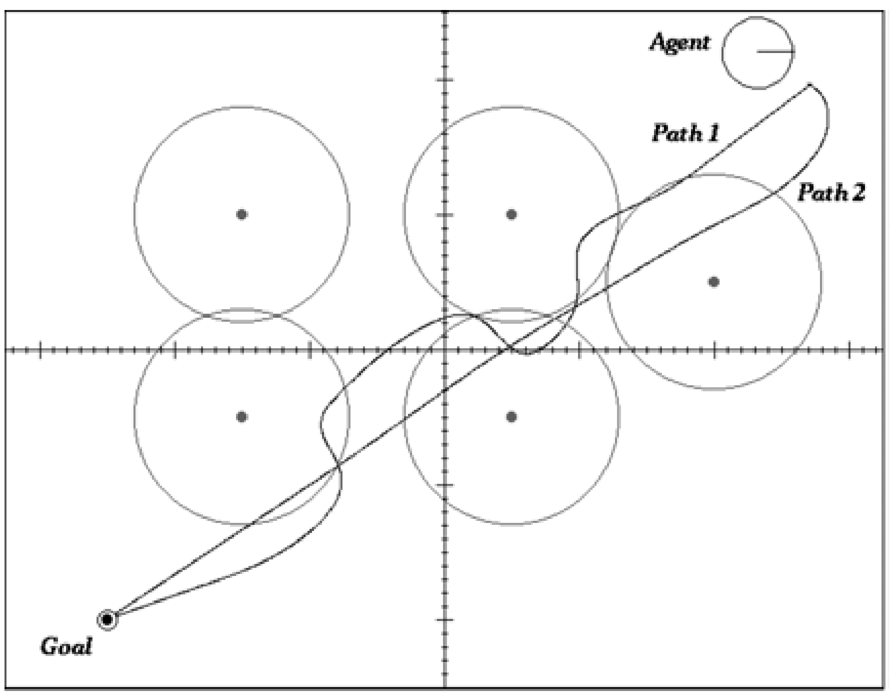
[Barranquand, Langlois, Latombe, 1989]

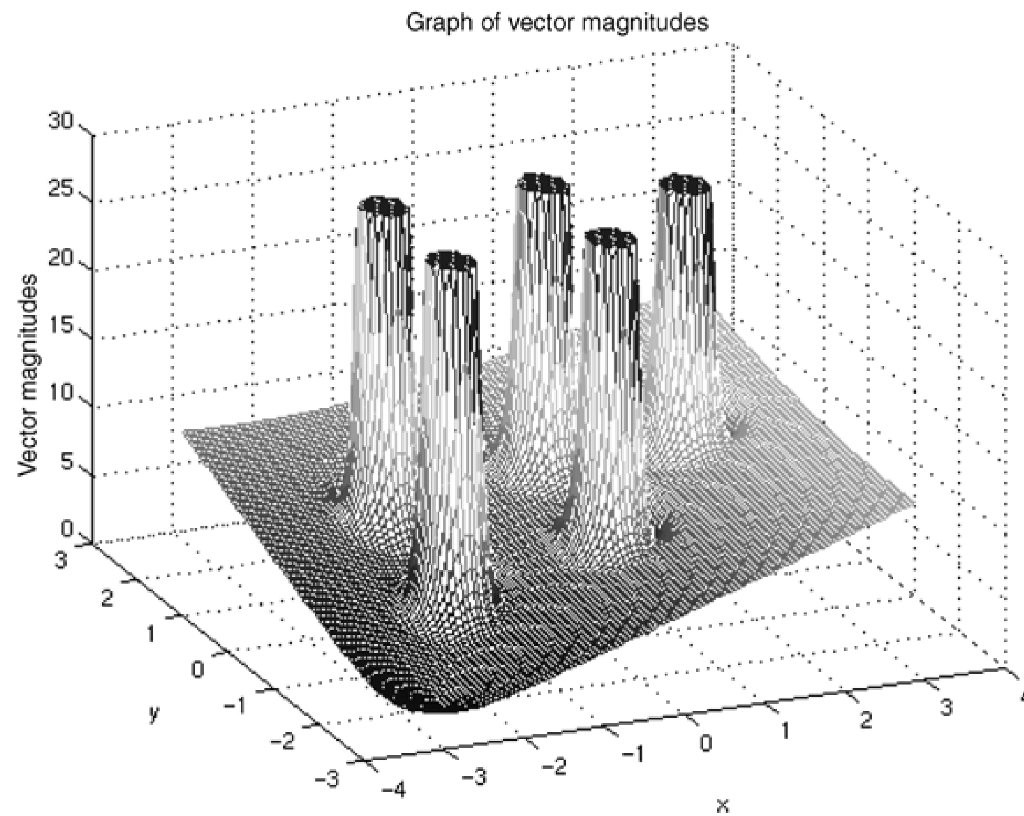
comparison to human behavior

- Fajen/Warren compared fit of potential field approach to fit of attractor dynamics approach for human locomotion data



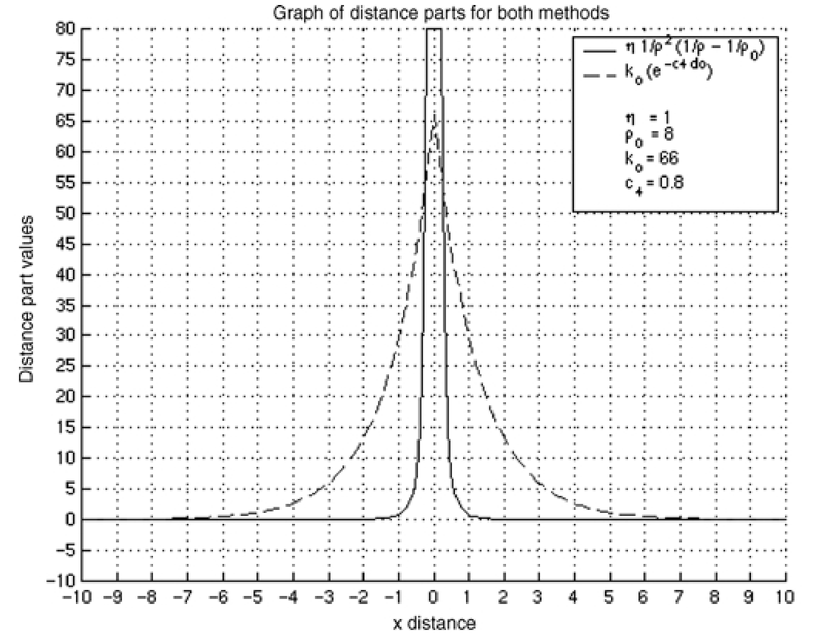
comparison to human behavior



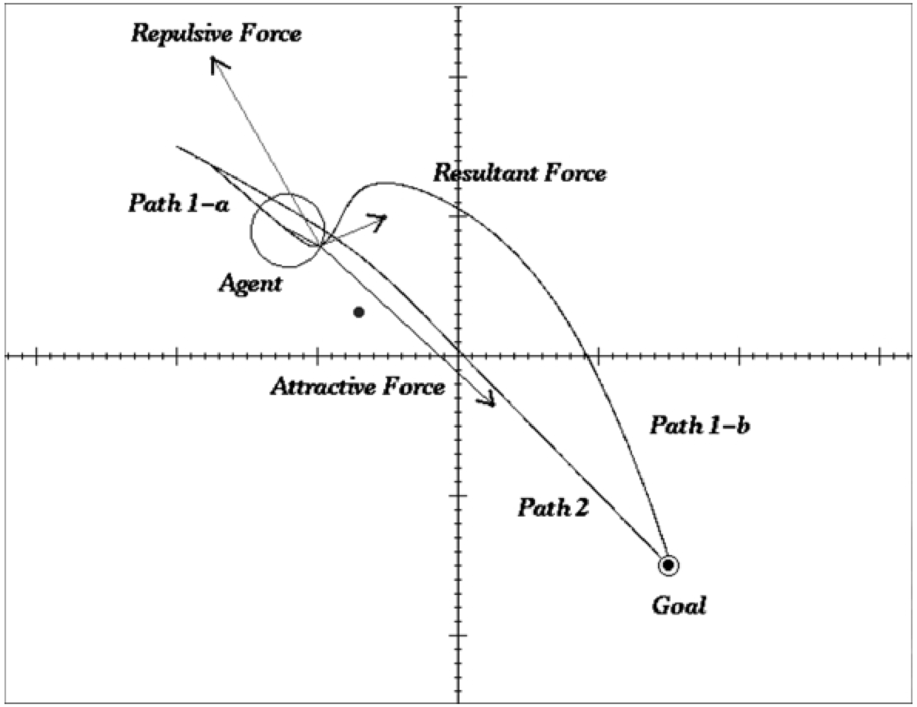


comparison potential field vs. attractor dynamics

- potential sharper than distance dependence of repellor

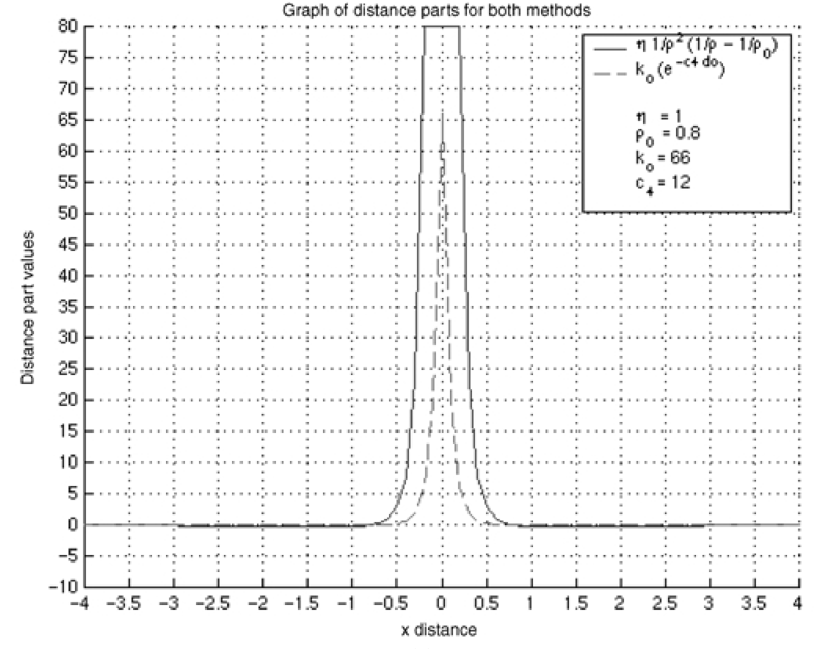


(a)

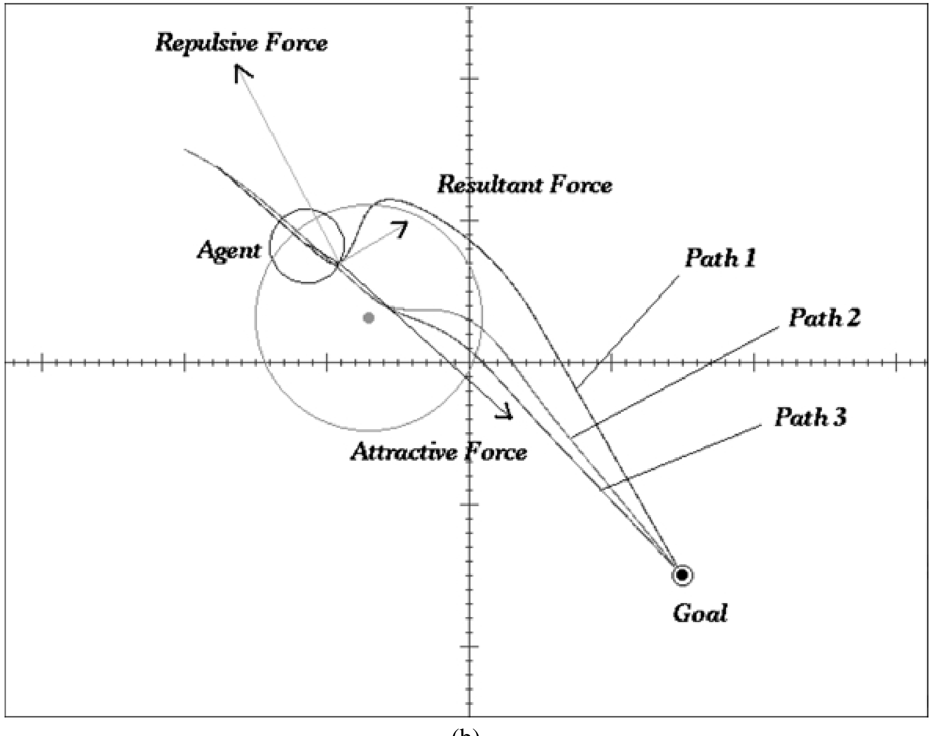


(b)

comparison potential field vs. attractor dynamics



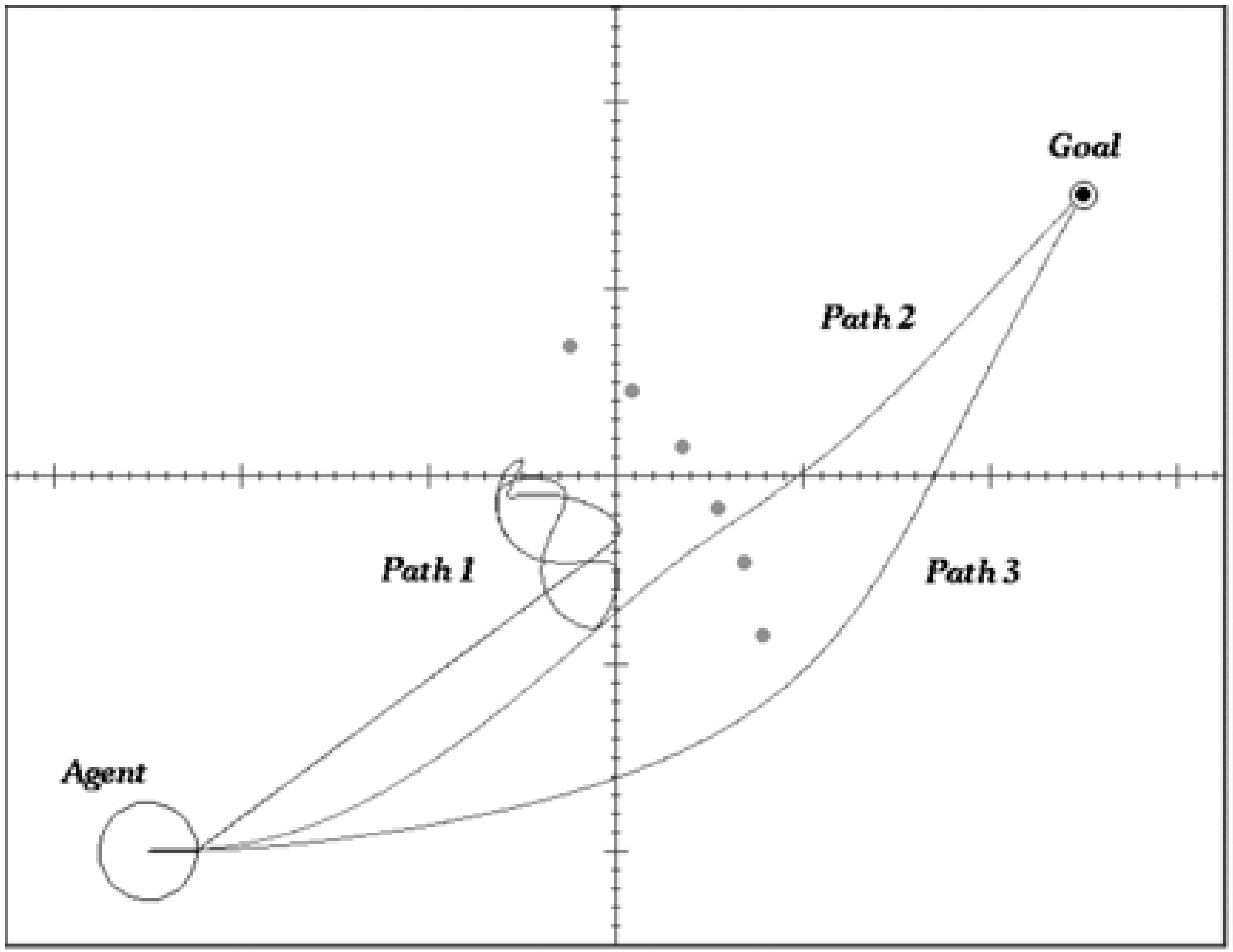
(a)



(b)

- potential softer than distance dependence of repellor

spurious attractors in potential field approach



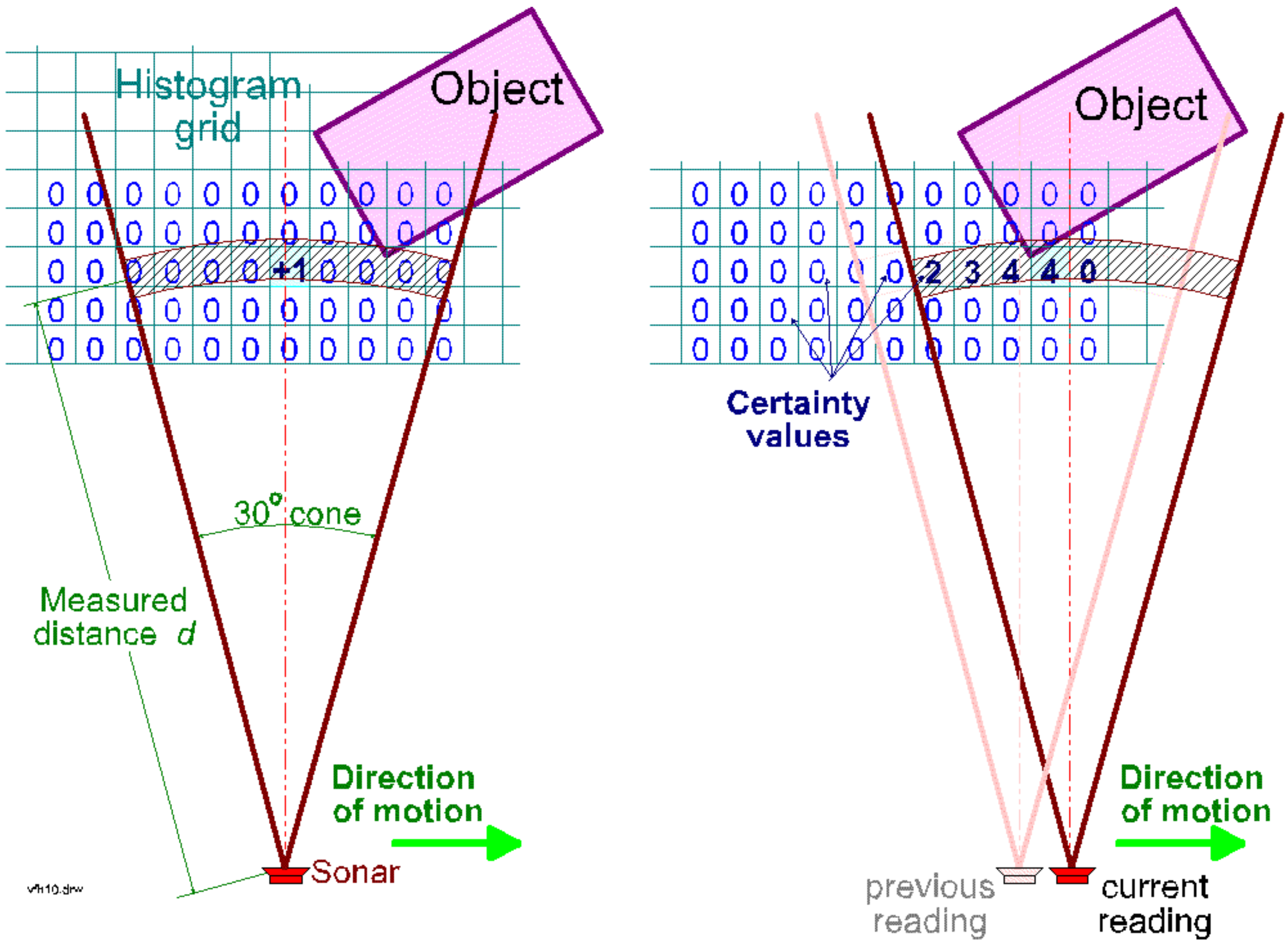
potential fields: limitations

- spurious attractors and constraint violations
- solution: making potential field approach exact and global: navigation functions
- potential computed such that it only has the right maxima and minimal
- but: computational cost
- but: requires global information

Virtual force field: Borenstein & Koren

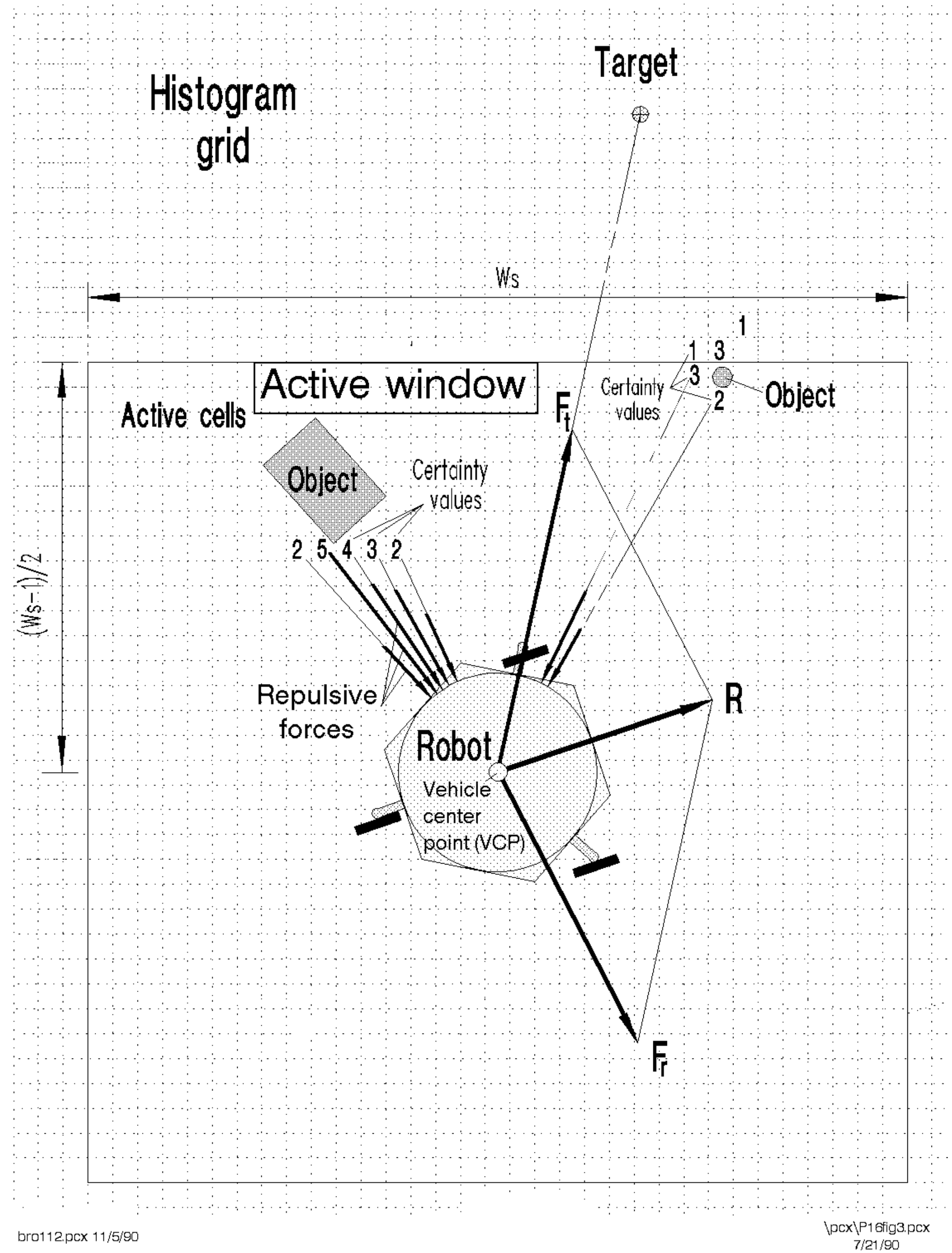
- ultra-sound histograms: the virtual force field concept
- vector-field histogram concept: polar histogram (heading direction!); height (strength) depends on both certainty and distance
- threshold: determine free sectors
- select free direction closest to target

Virtual force field: Borenstein & Koren



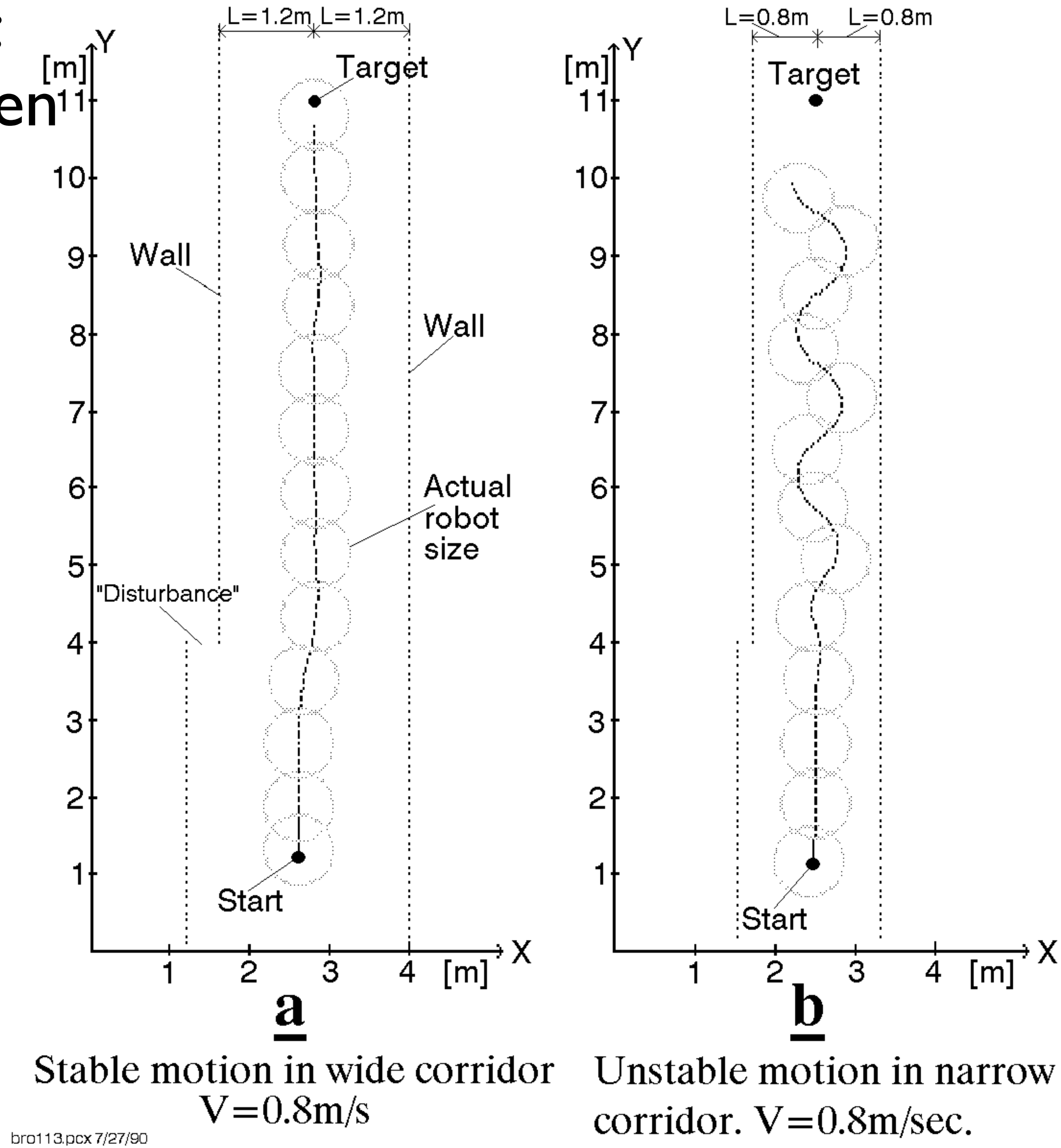
Virtual force field: Borenstein & Koren

- vector toward target
- active window around robot
- use histogram within active window to compute vectors pointing away from obstacle
- vector summing
- ~dynamic approach!



Virtual force field: Borenstein & Koren

- Problem: oscillations in narrow passages

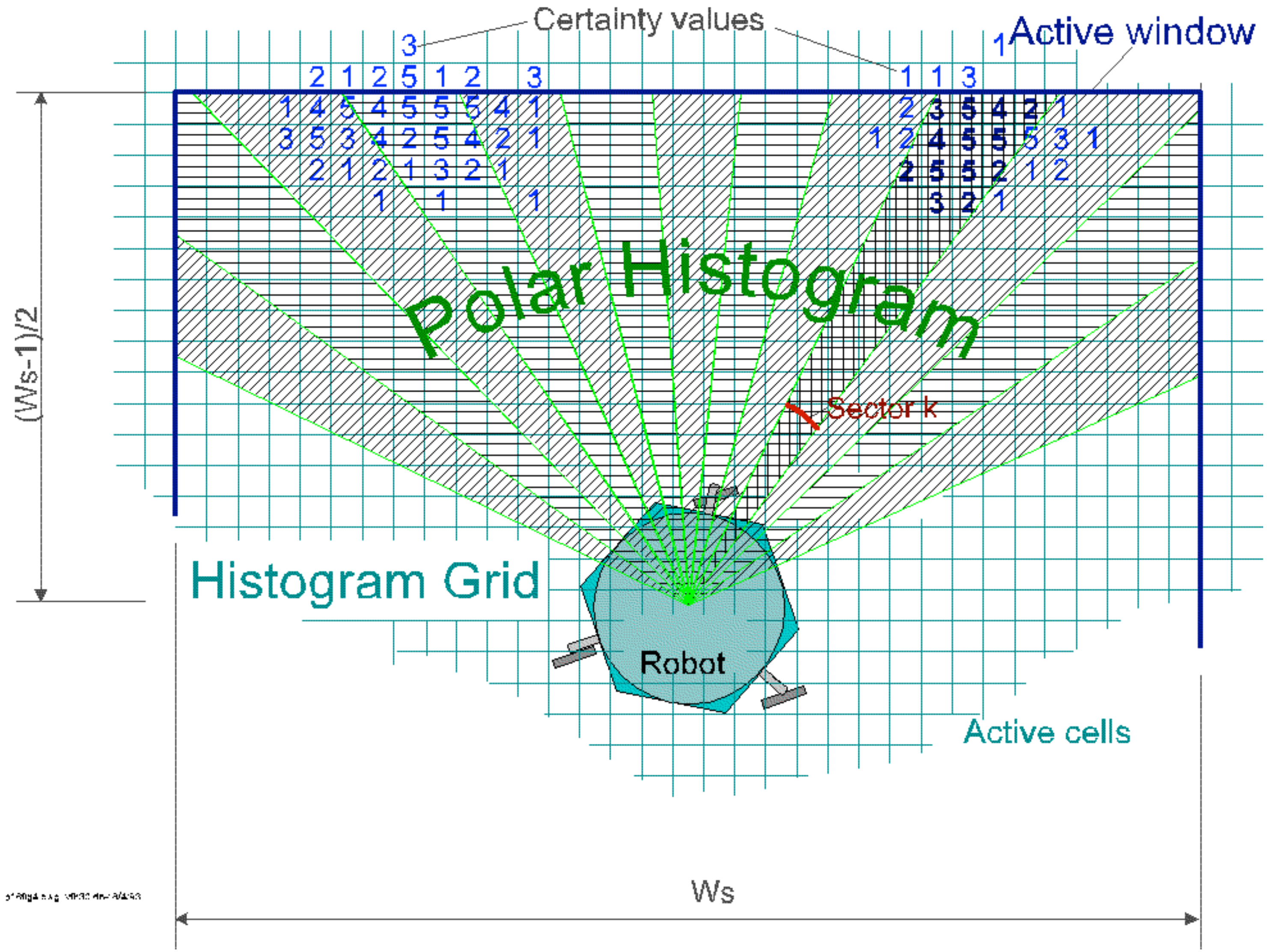


Stable motion in wide corridor V=0.8m/s

Unstable motion in narrow corridor. V=0.8m/sec.

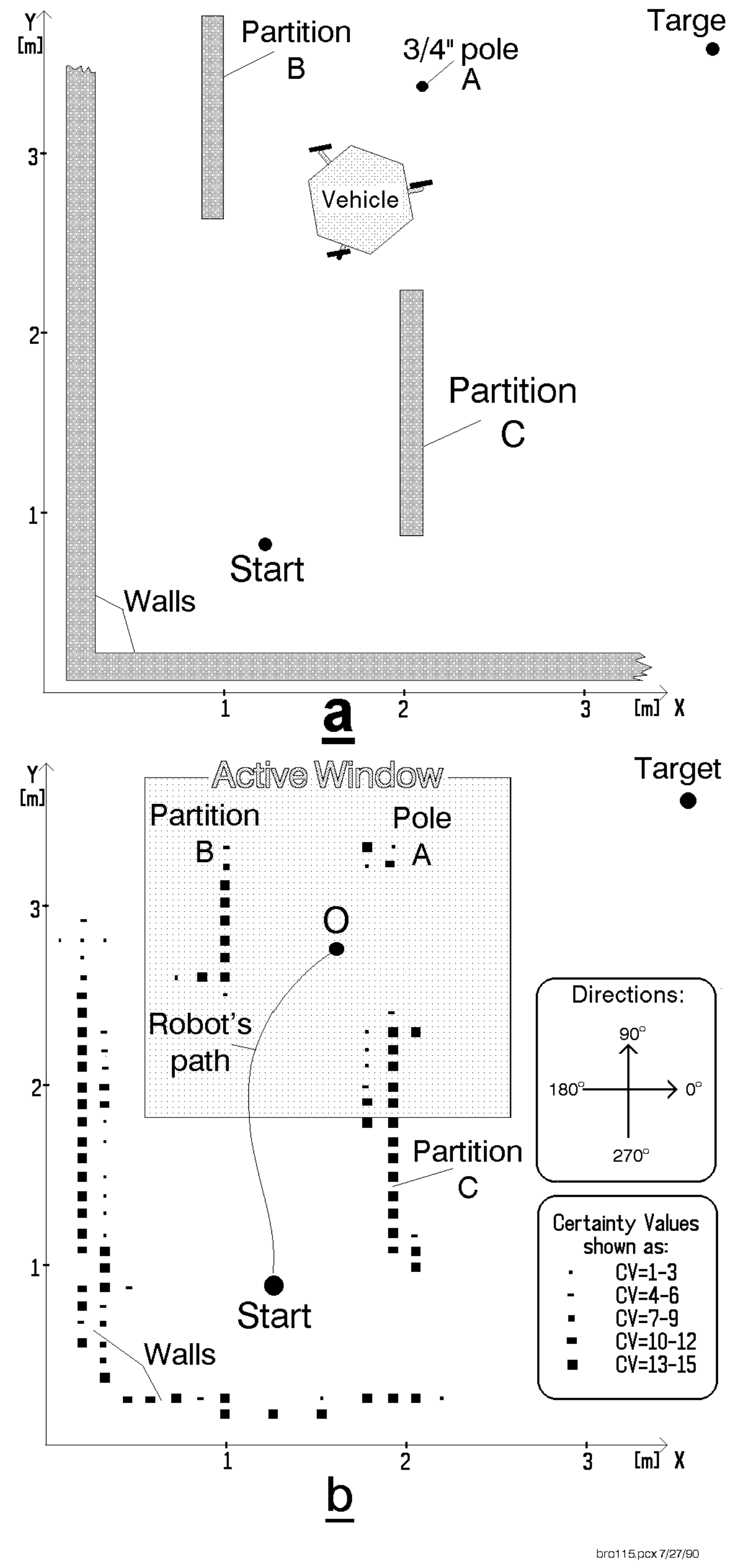
Vector field histogram: Borenstein & Koren

- transform active window in world grid into polar histogram



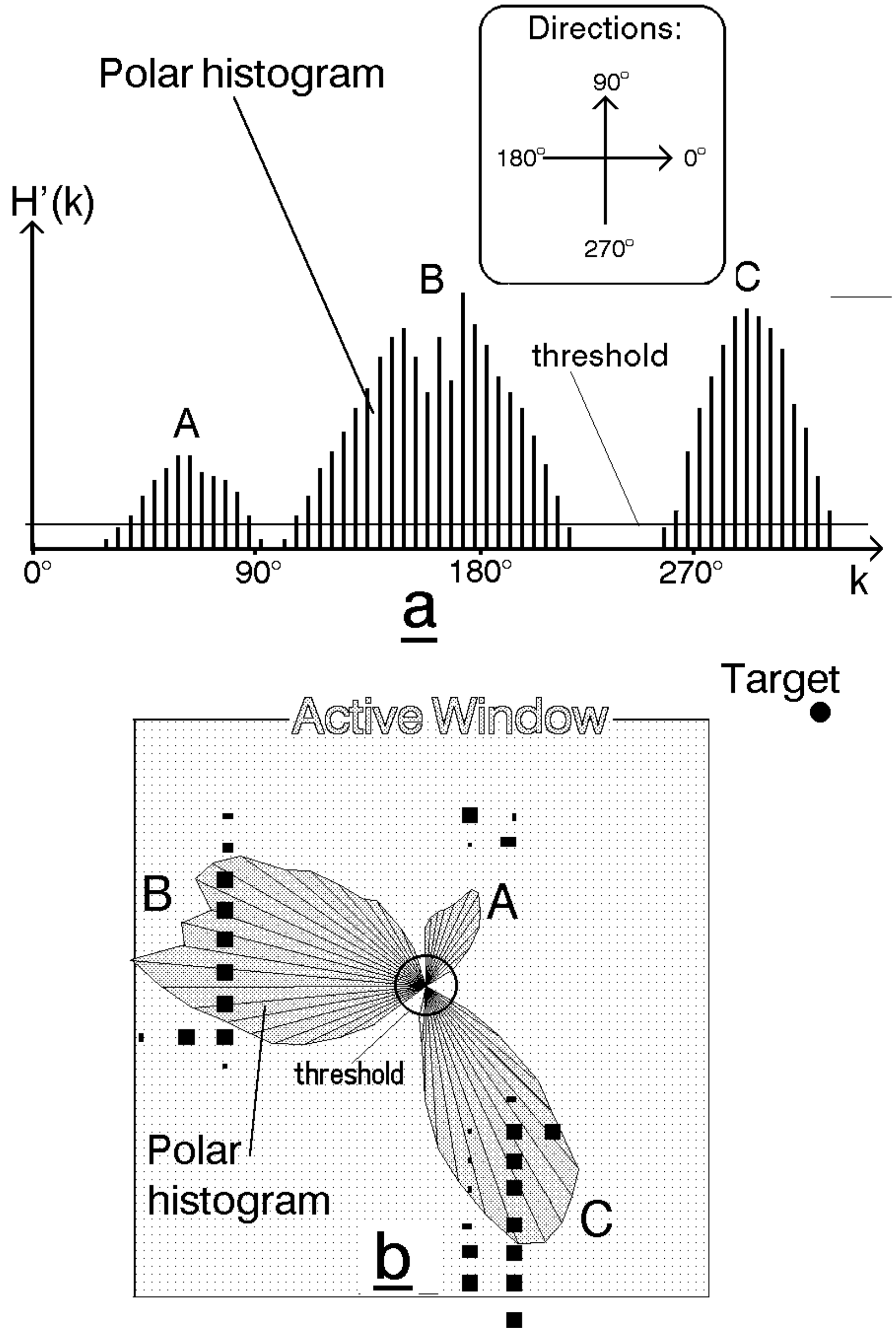
Vector field histogram: Borenstein & Koren

- lab set-up



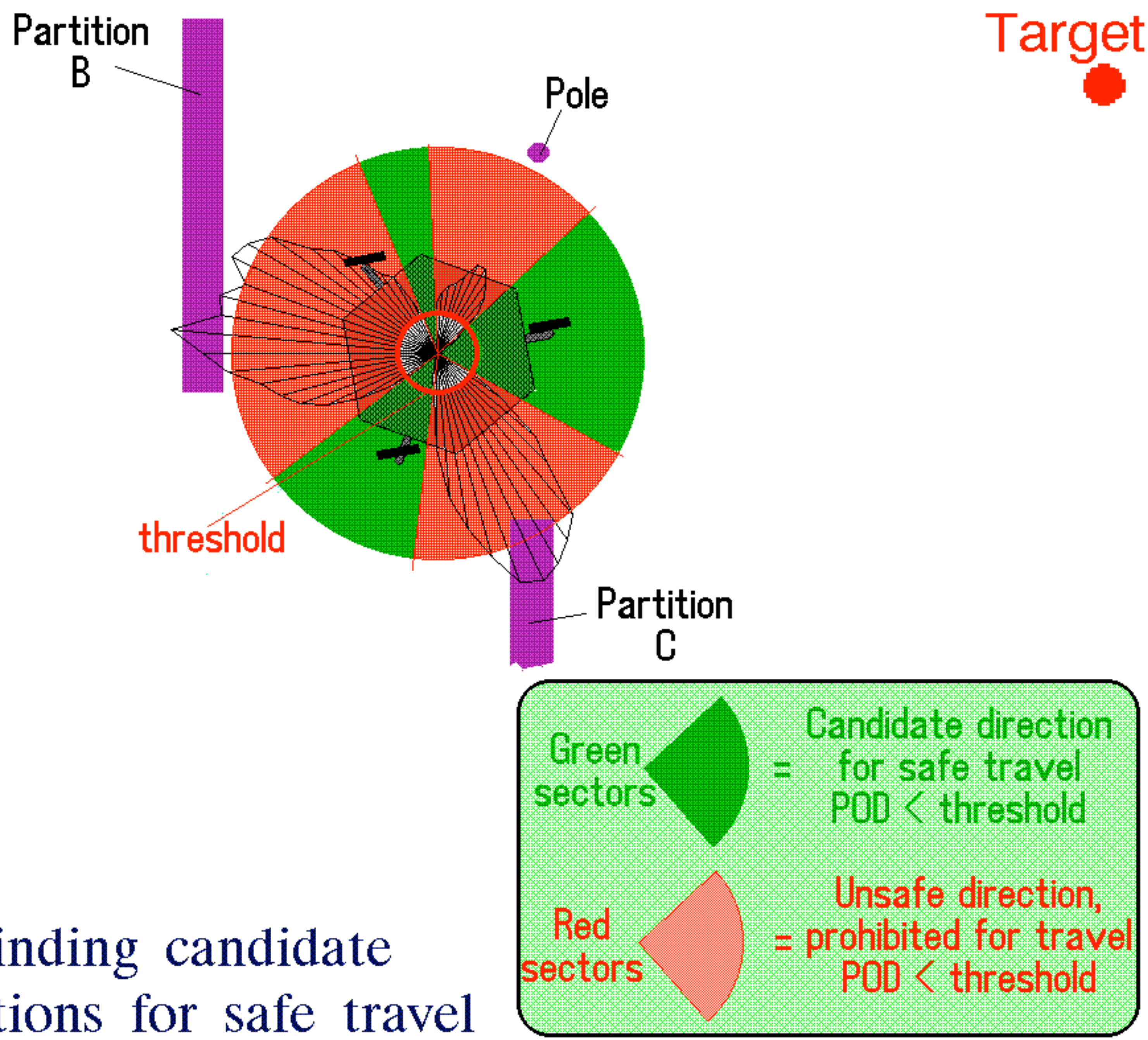
Vector field histogram: Borenstein & Koren

- local polar histogram provides “free” directions



Vector field histogram: Borenstein & Koren

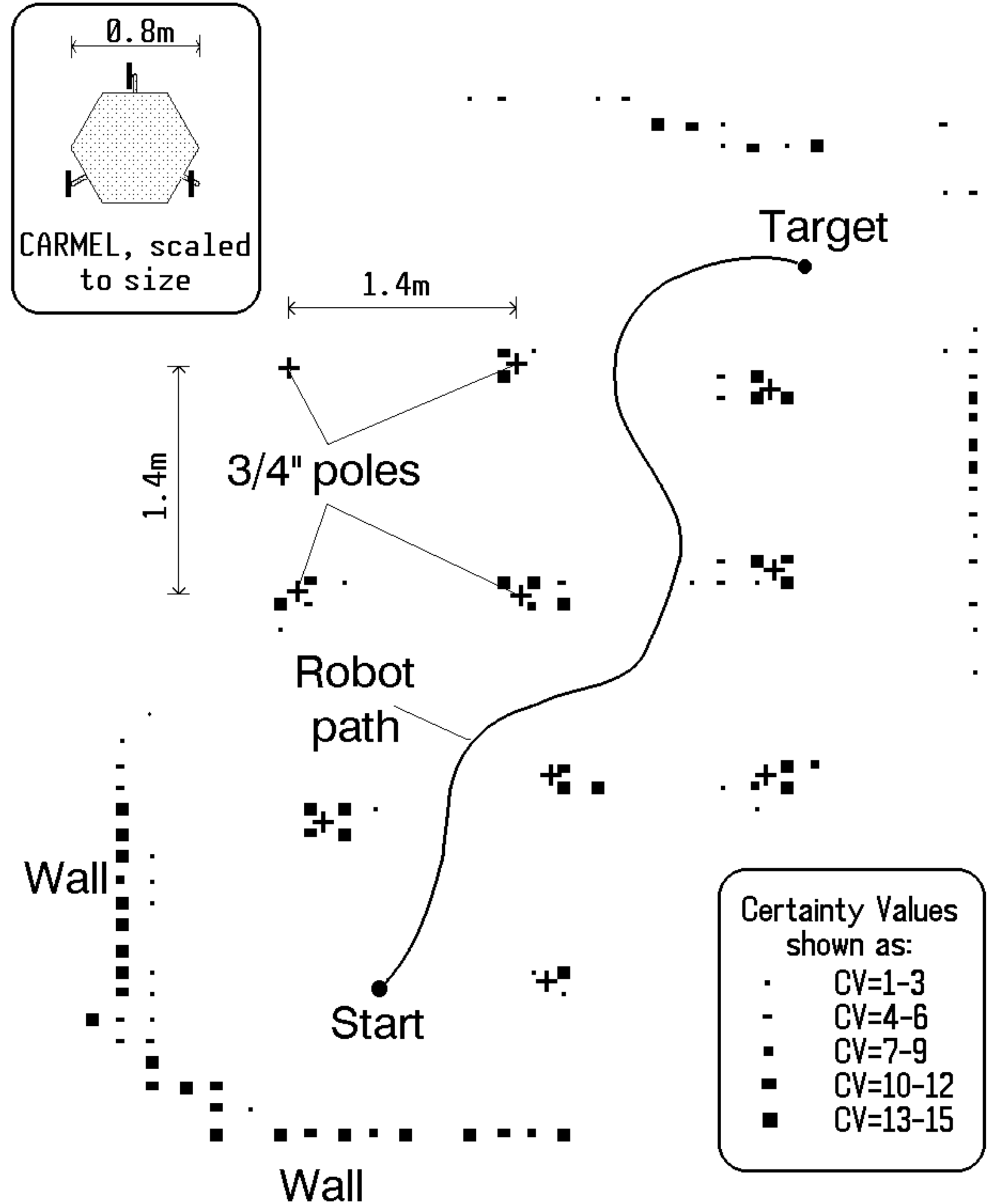
- Select safe direction algorithmical



Finding candidate directions for safe travel

Vector field histogram: Borenstein & Koren

- works



Conclusions

- powerful approaches exist for motion planning
- the best/exact approaches make strong demands on world representations and computation
- the fast/heuristic approaches have limitations
- in practice, the attractor dynamics approach is competitive