A Taxonomy of Spatial Knowledge for Navigation and its Application to the Bremen Autonomous Wheelchair

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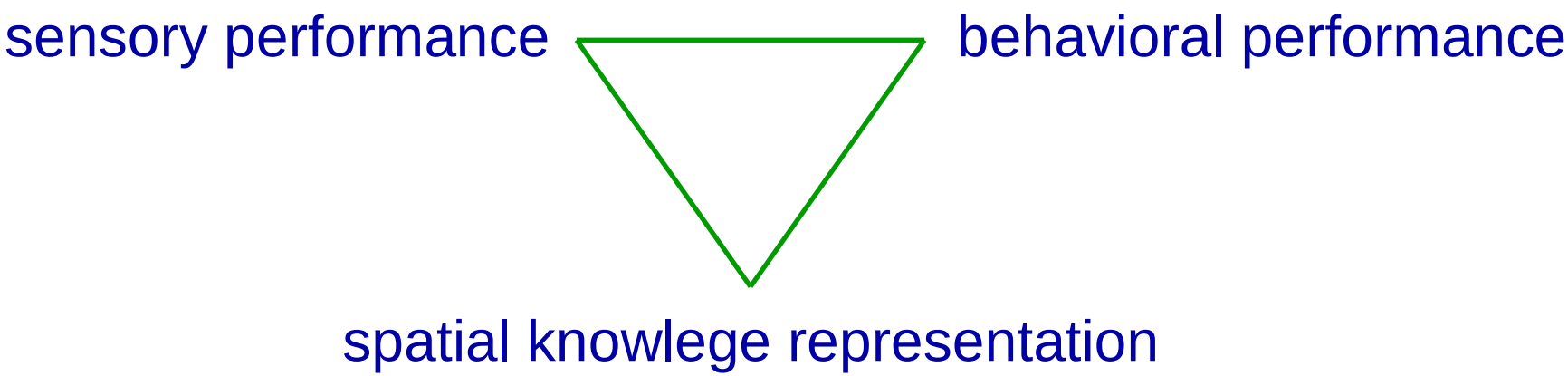
Spatial Knowledge and Navigation



The Spatial Cognition Triangle

- ternary relation
- different items are given – desired,
  are to be analyzed – to be synthesized

A Taxonomy of Navigation

Objectives

- unification of terminology, concepts, and theories in psychology, biology *understanding mechanisms of navigation*
  artificial intelligence and robotics *developing navigational skills*
- coordinated approach to theoretical and empirical investigations

Results of Coordination Workshops

- same essential issues; complementary

analytical approaches:

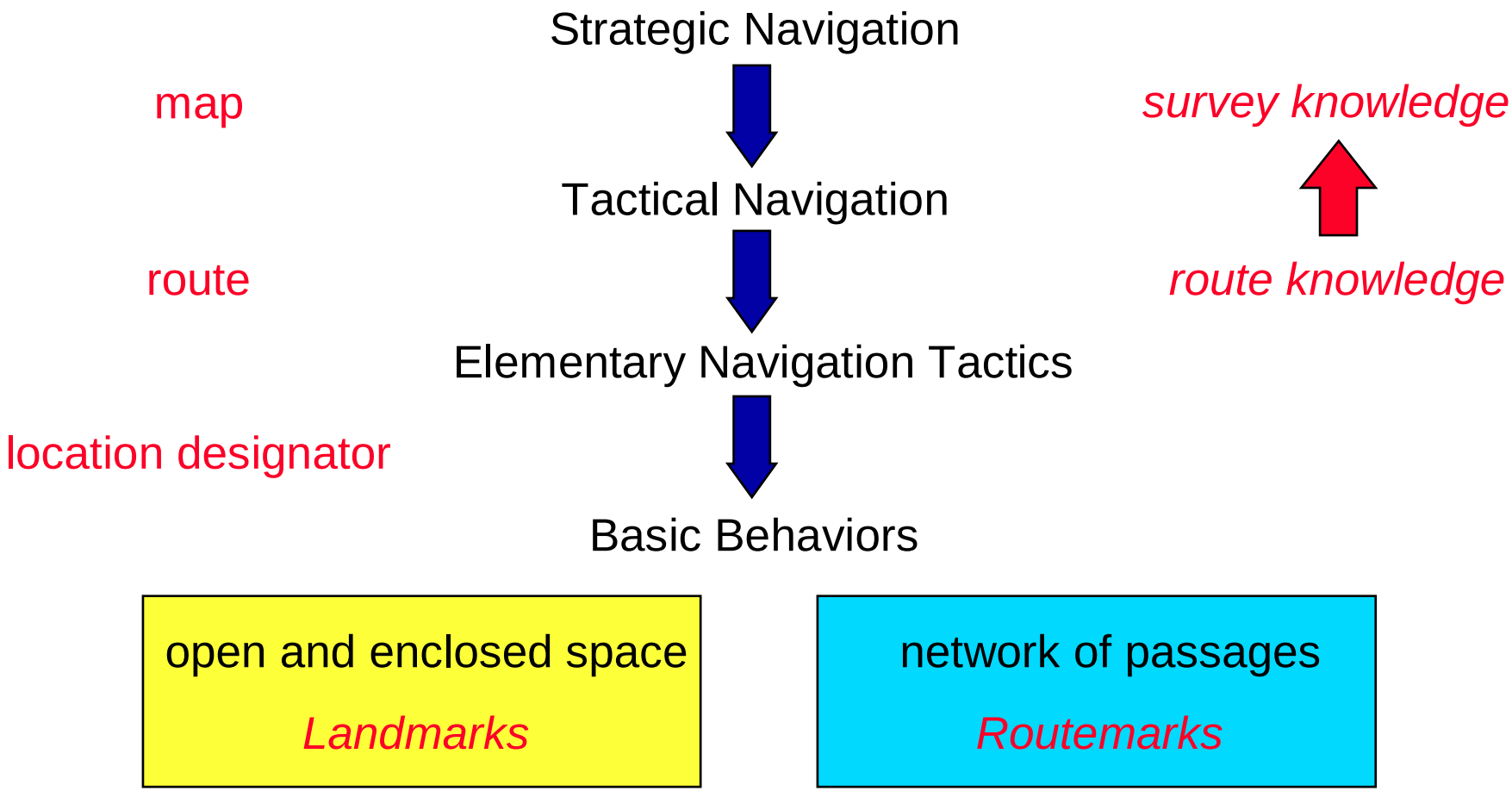
- guide for developing robotic skills

synthetic approaches :

- modeling — isolation of specific aspects — testing of hypotheses
- generation of questions for empirical investigations e.g. about navigational performance and conjectured mental representations
- restriction of theory to algorithmically + biologically plausible model

A Taxonomy

Hierarchy of Elementary and Higher-Order Behaviors



Navigation in Network of Passages

Passage

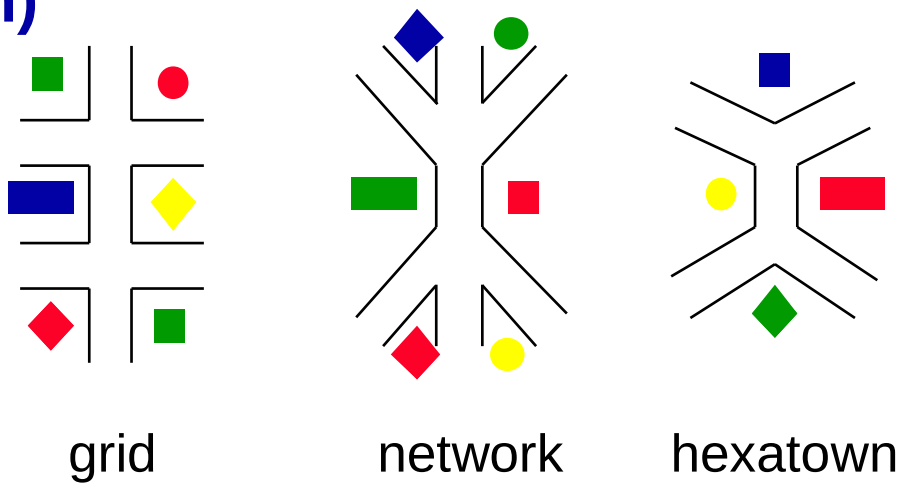
- tunnel, corridor, path, trail, track, road

Basic Behaviors

- (centered) passage following (e.g. on road)
- wall following left / right
- turning into designated passage

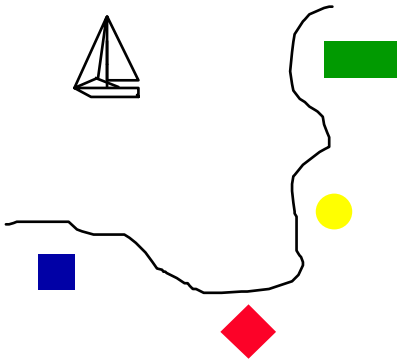
Branching (Tactical Decision)

- left, right, straight,
  designated ("n-th") branch
- branch characterized by
  view = routemark constellation
- triggering of next behavior

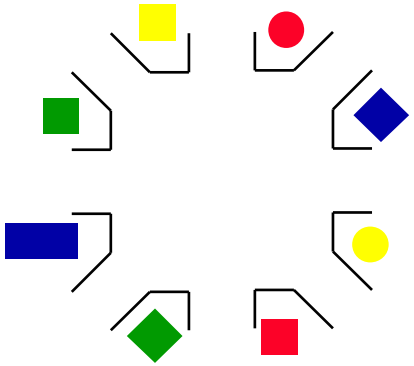


grid network hexatown

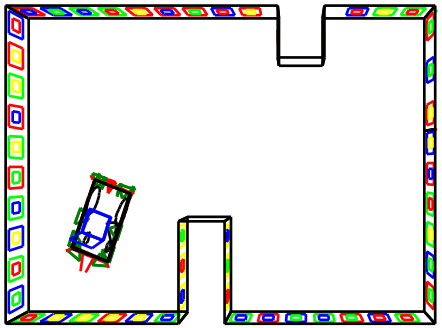
Navigation in Space



ocean



town square

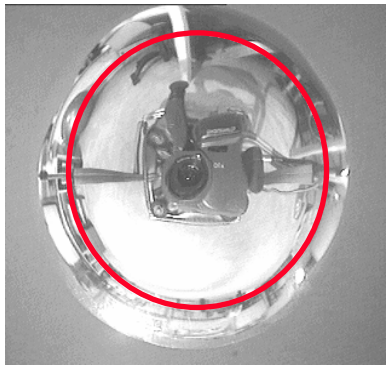


office

Open and Enclosed Space: Analogous

Vectorial Navigation

- target vector vs. direction of compass
- target vector vs. self-movement (dead reckoning)
- path integration → *homing vector*



Positional Navigation (Triangulation)

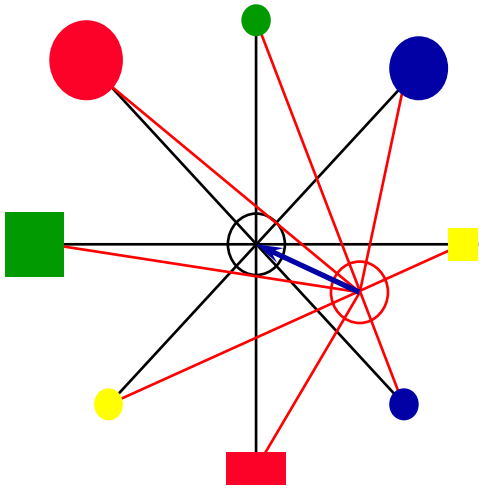
- view = constellation of (fixed) landmarks
- view = constellation of (moving) celestial bodies

Navigation Tactics

Task-Oriented Tactics

example: honey bee

- directional navigation with learned target vector to find foraging region
- learning, following route to forage (routemarks)
- return to nest region using homing vector
- (spiral) search for nest
- "home in" to nest (recognize view of landmarks)

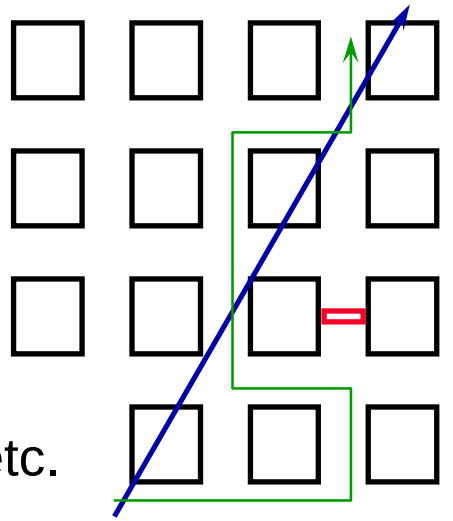


Concatenate Specialized Tactics

- at target: trigger next behavior

Overlay Tactics to Increase Robustness

- distinguish for analysis and modeling
- sun compass, polarization of light, magnetic field etc.
- tactic in space || tactic in passages



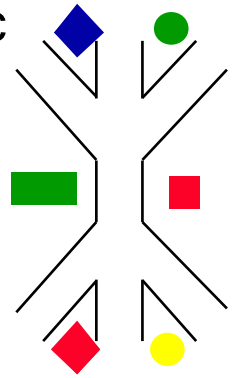
Modelling

location designator **for Localization and Tactical Decision**

- "turn left in front of the church" (routemark, branch)

Route

- homogeneous: ⟨location designator⟩ with fixed tactic
- heterogeneous: ⟨(tactic, location designator)⟩



Location Abstraction

- *source aliasing* from the same direction
- *target aliasing* into the same direction

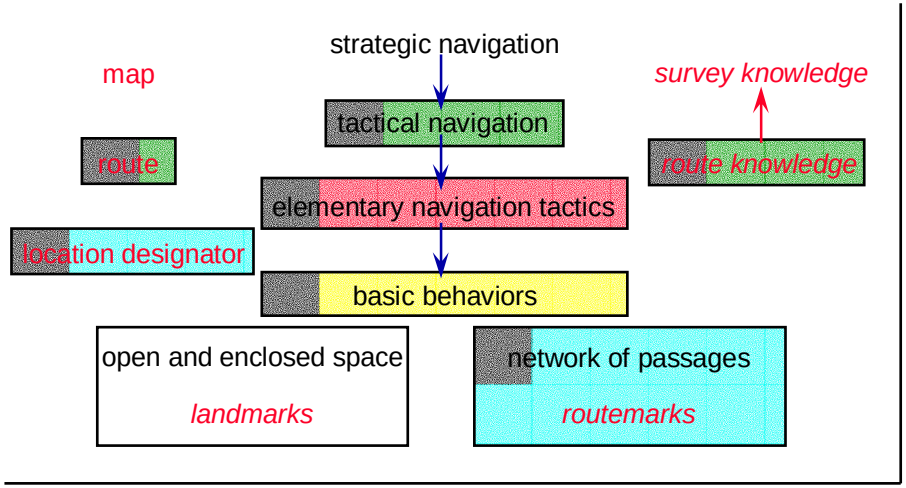
Route Map ({(location, tactic, location designator)}, {location abstraction})

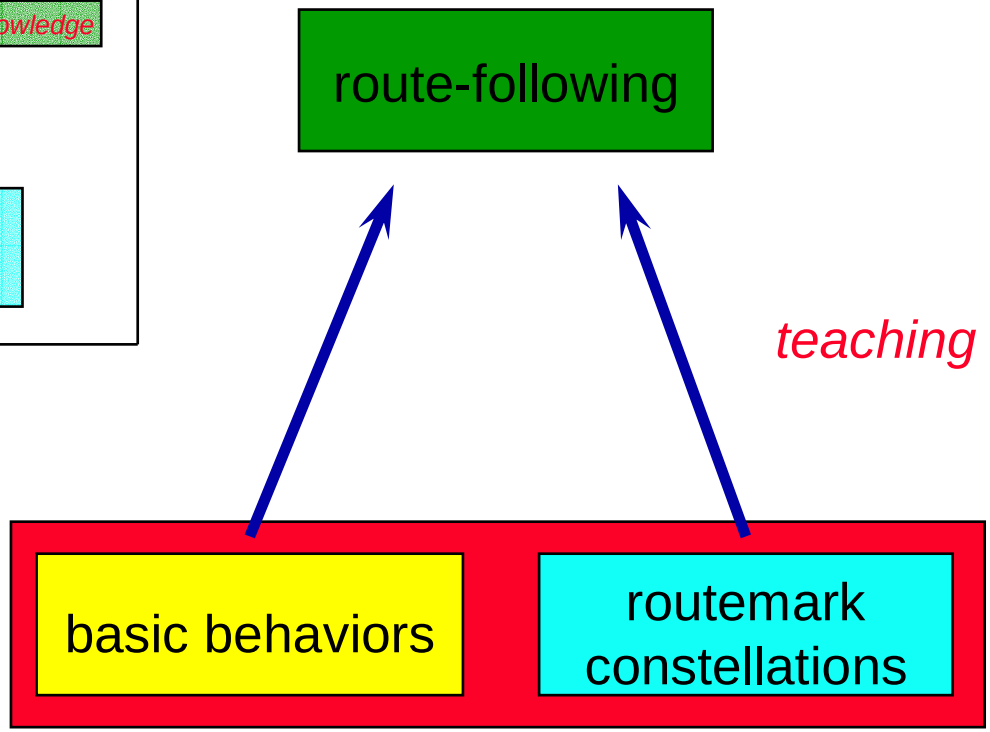
Survey Map (directed) grap ({tactic abstraction}, {location abstraction})

- abstraction from different tactical aspects – overlay of maps
- change of perspective: *field perspective — observer perspective*
- change of reference system: *local chart — global map*

Application to Wheelchair Experiments

Taxonomy





The Bremen Autonomous Wheelchair

1st Prototype Vehicle

- 134 cm x 72 cm
- front driving axle
- back steering axle
- on-board PC + 5 micro-controllers

Sensors

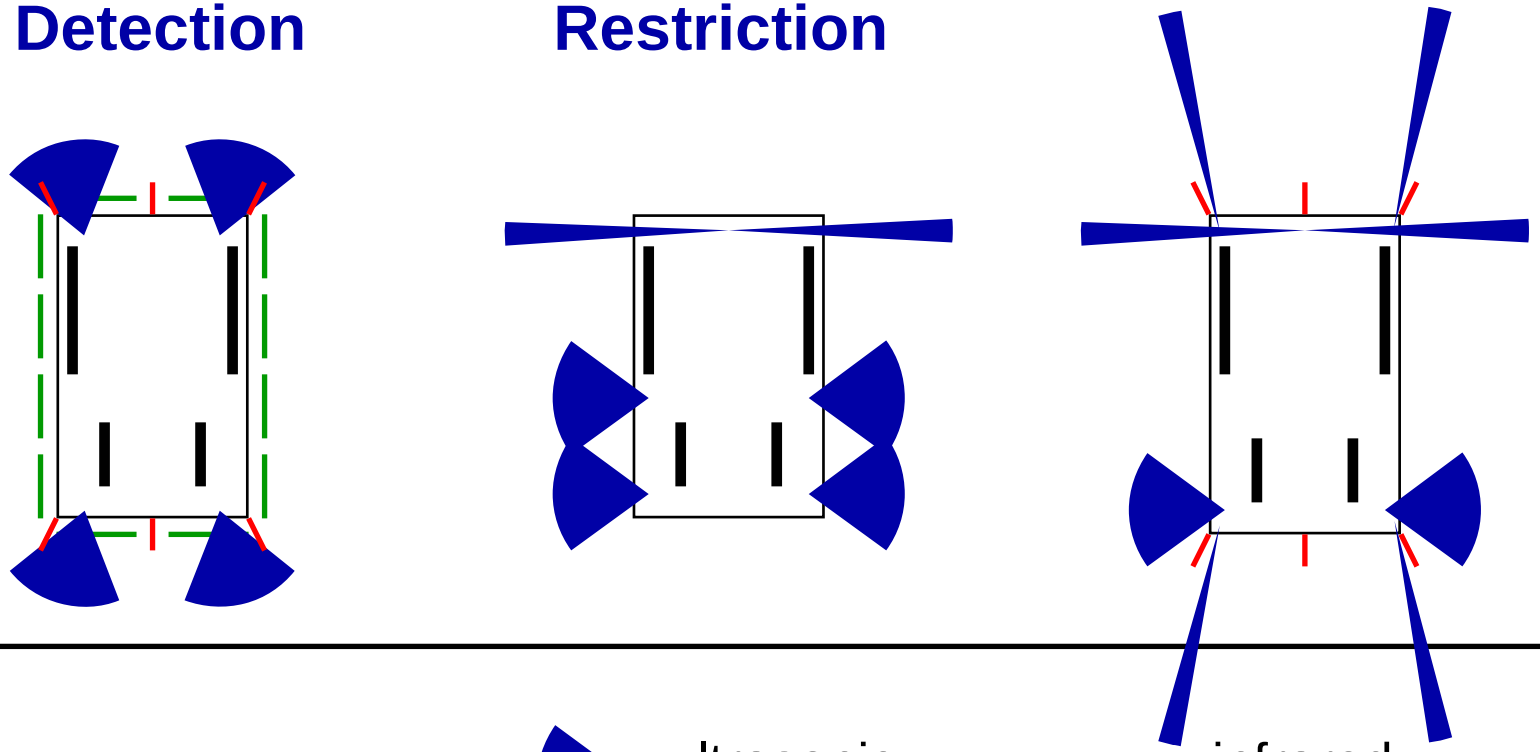
- 12 tactile sensors
- 6 infrared sensors
- 8 wide-angle ultrasonic sensors (80°)
- 8 narrow-angle ultrasonic sensors (7°)
- 1 camera on a pan-tilt-head
- odometry

Sensor Control Subsystems

Collision Detection

Steering Restriction

Navigation



tactile sensors

ultrasonic sensors

infrared sensors

Local Obstacle Map

Short Term Memory

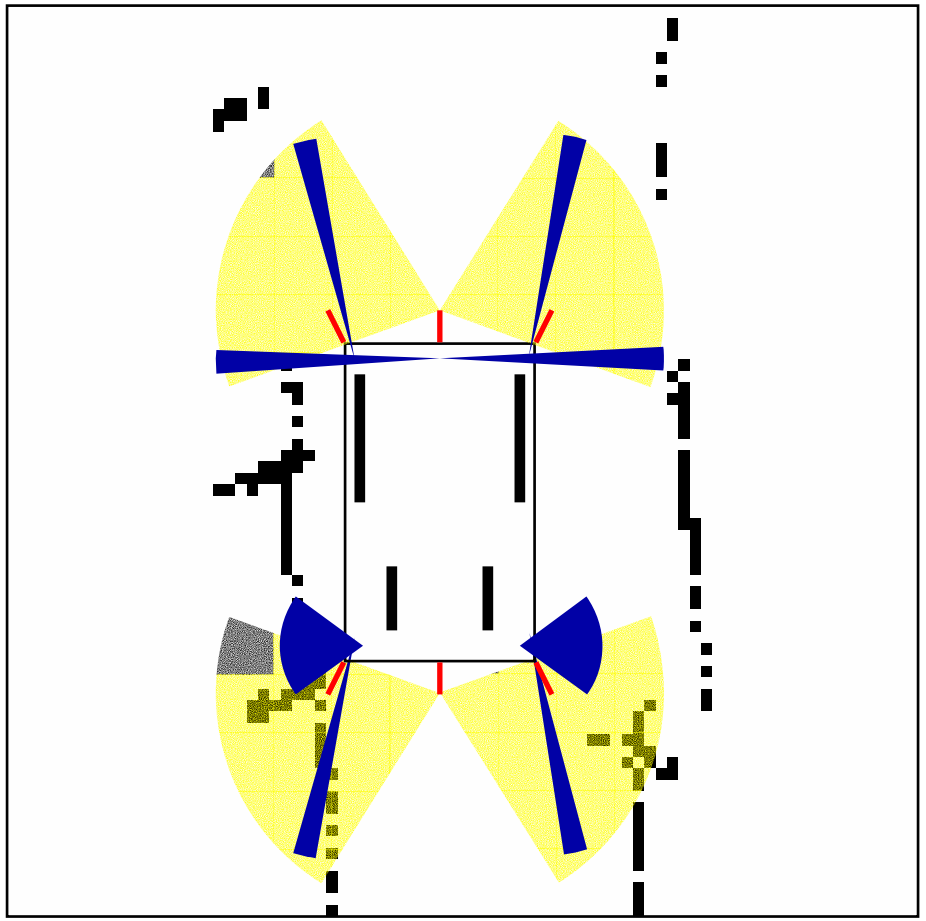
- stores local surroundings of the wheelchair
- size 4 x 4 m²
- entries purged after 30 seconds to cope with dynamic obstacles

Input

- 6 narrow-angle and 2 wide-angle ultrasonic sensors
- 6 infrared sensors

Output

- 4 “virtual sensors”



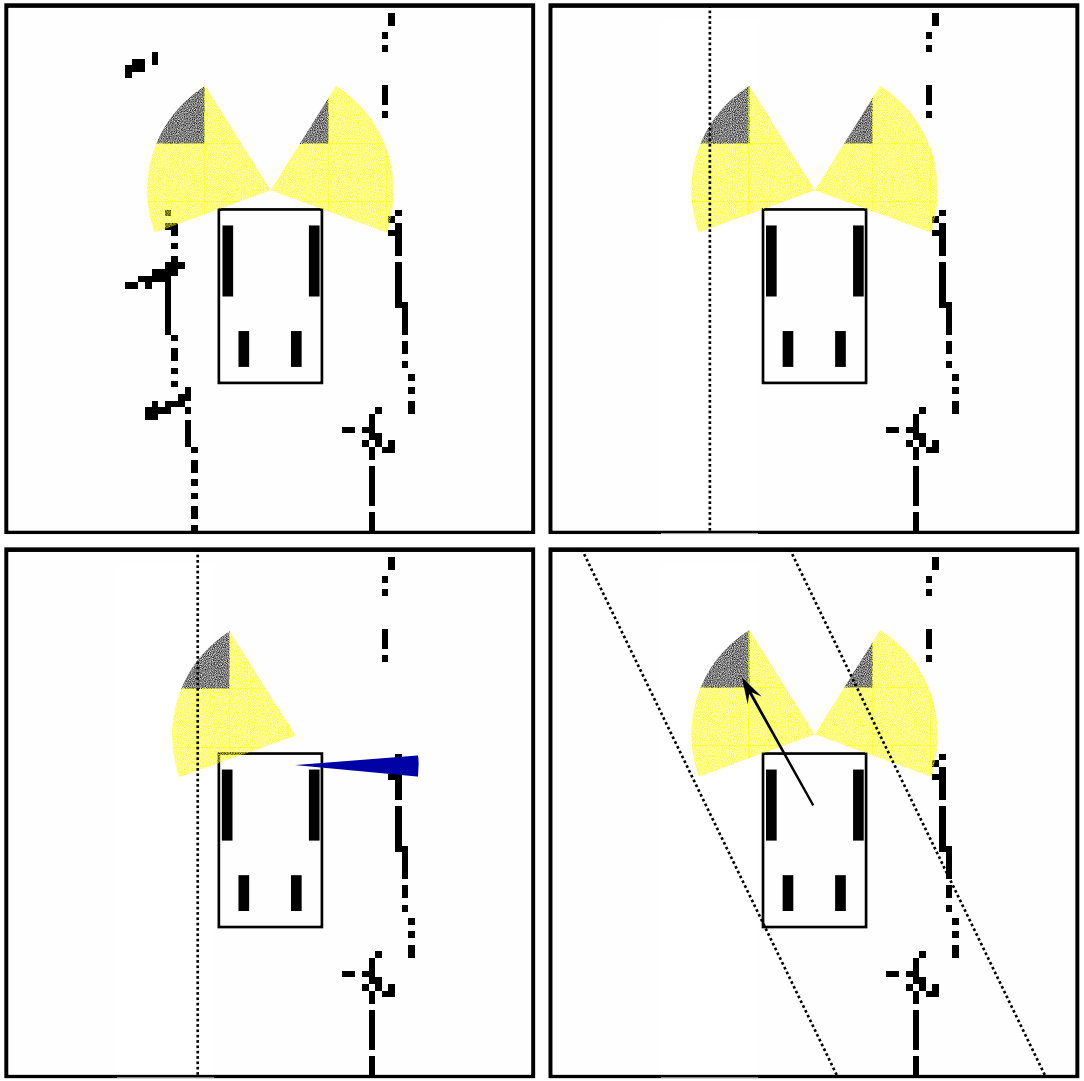
Basic Behaviors

Behaviors

- wall-centering
- wall-following left/right
- turning into left/right door
- direction-following forwards/backwards
- stop

Mode of operation

- forward until collision
- then 50 cm back
- forward again



Semi-Local 3D-marks

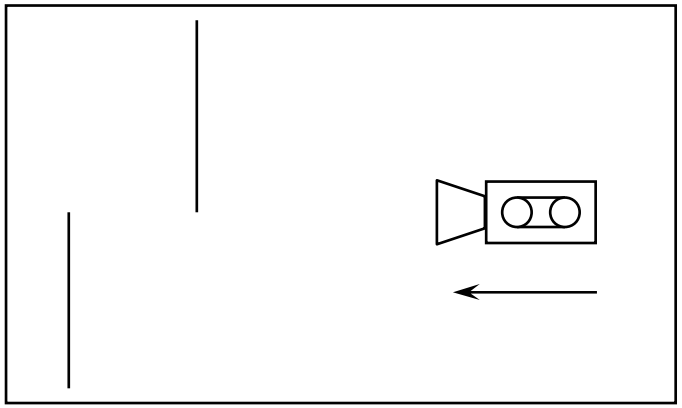
Preliminary Work

image sequence

→ small (semi-local) image regions

→ normal flow field

→ focus of expansion

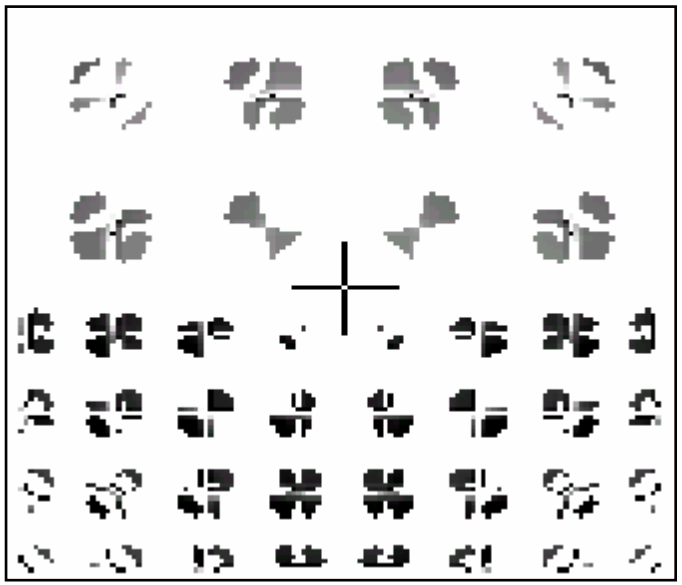


Future

→ depth

→ semi-local 3D-structures

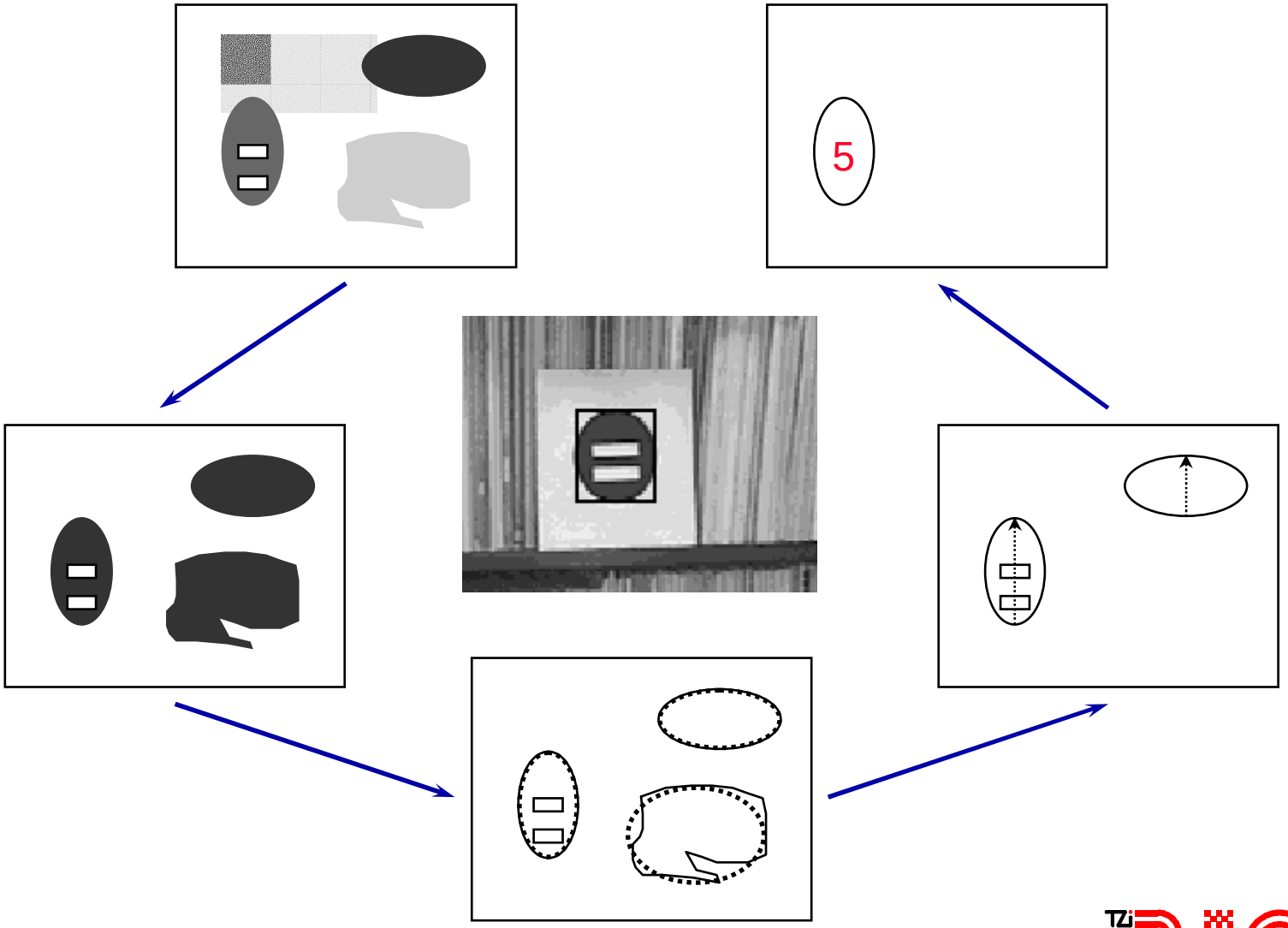
→ 3D-marks



Advantages

- efficient (real-time)
- robust against noise

Artificial Routemarks



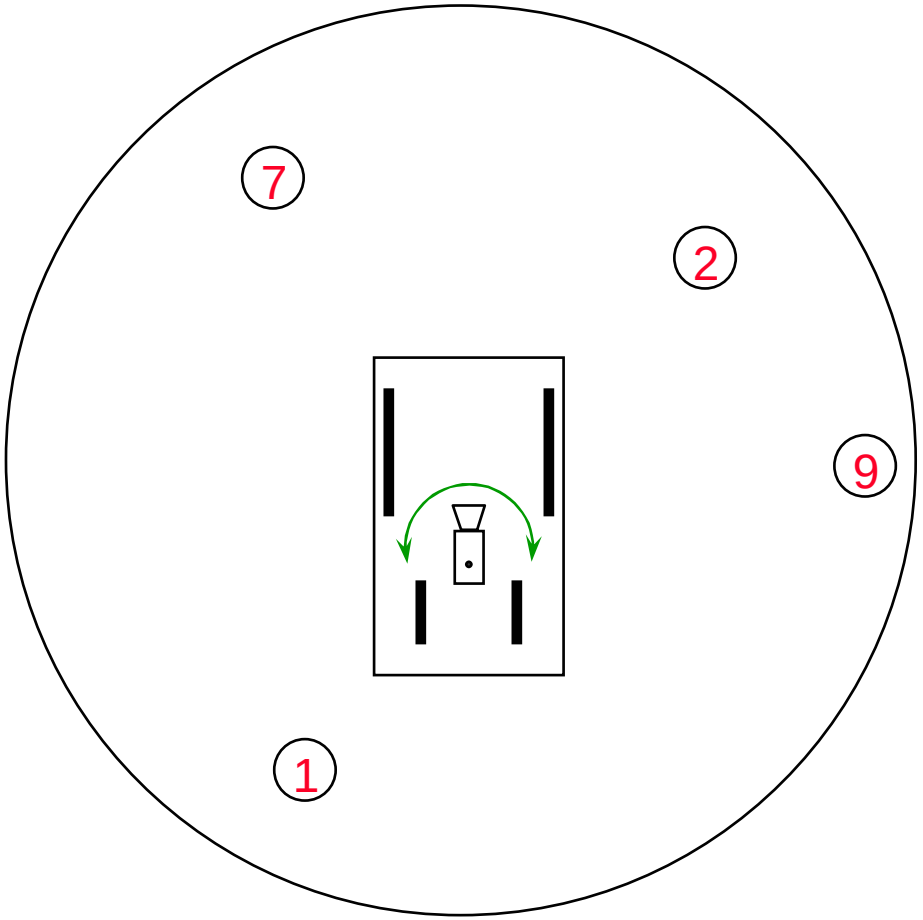
Local Routemark Map

Short Term Memory

- stores routemarks in the local surroundings of the wheelchair
- radius 5 m

Symbols

- routemark X
- camera on turn-table



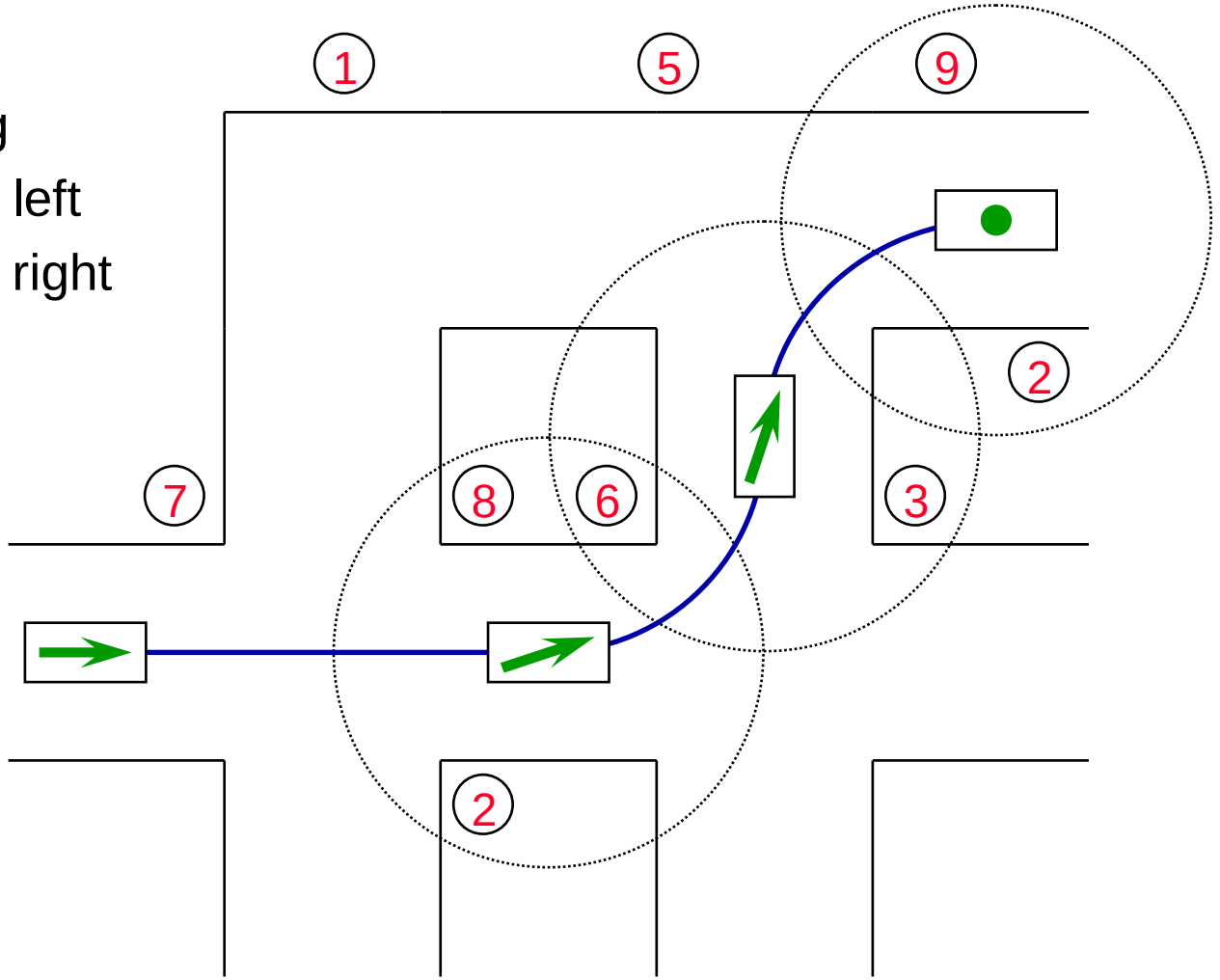
Teaching

Behaviors

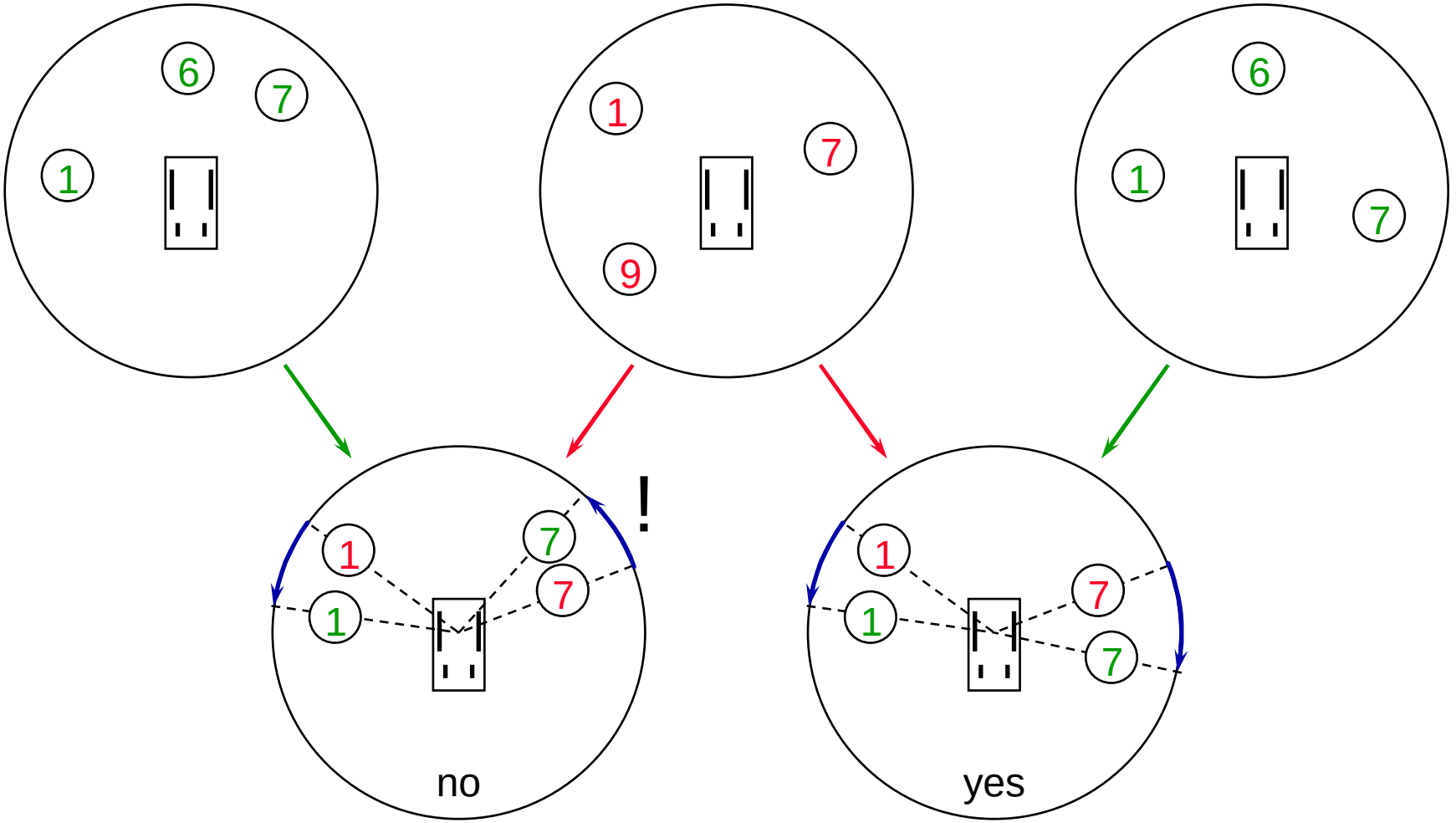
- wall-centering
- wall-following left
- wall-following right
- stop

Routemarks

- routemark X
- routemark constellation



Autonomous Switching of Behaviors



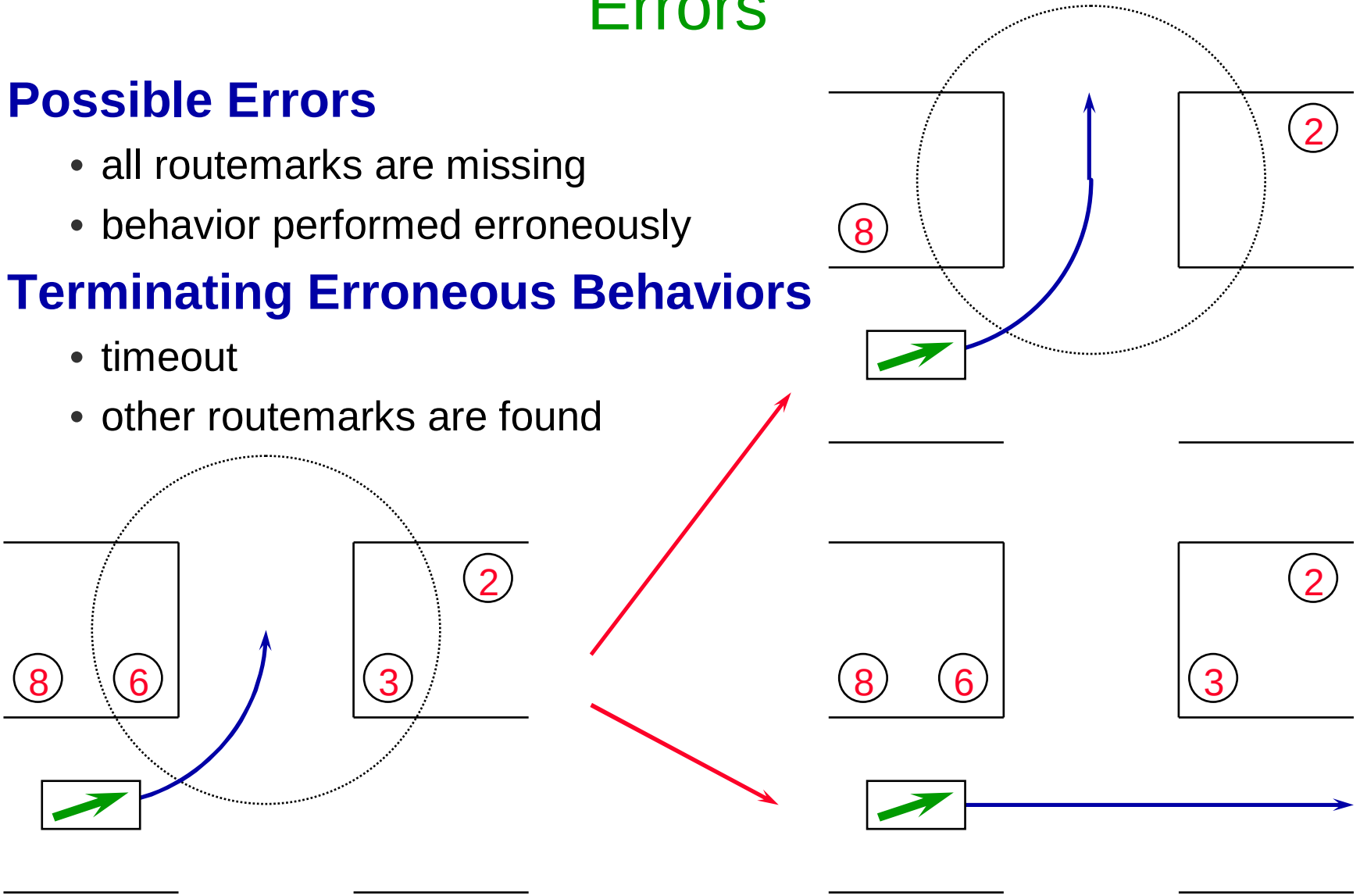
Errors

Possible Errors

- all routemarks are missing
- behavior performed erroneously

Terminating Erroneous Behaviors

- timeout
- other routemarks are found



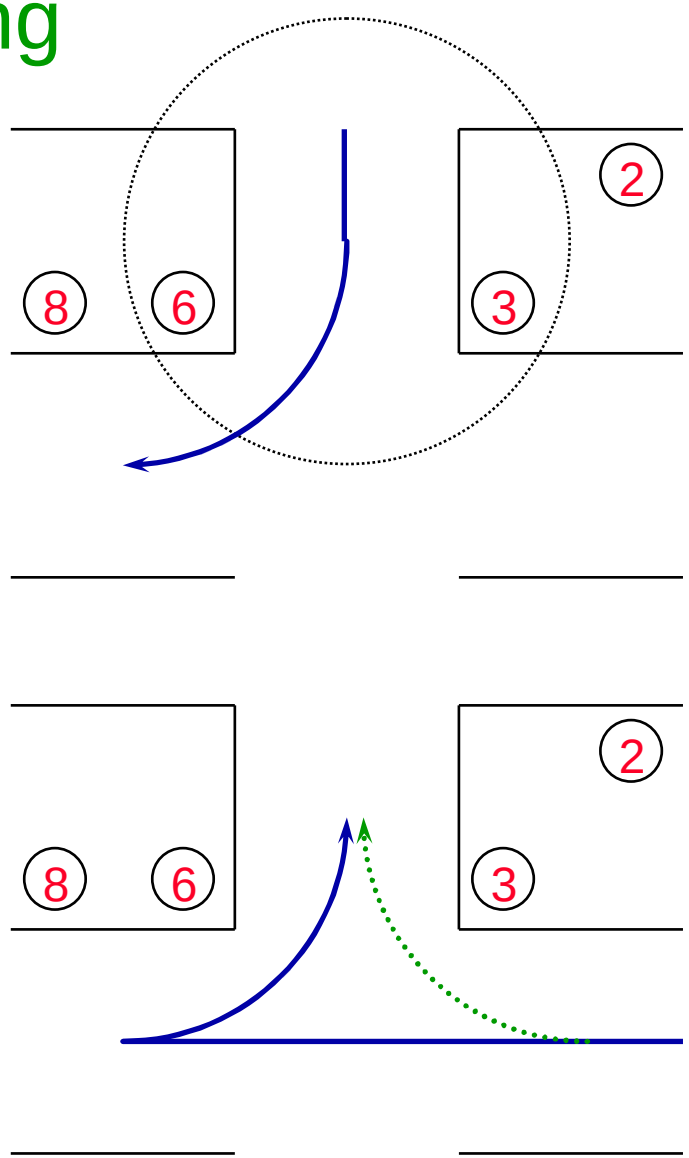
Backtracking

Method

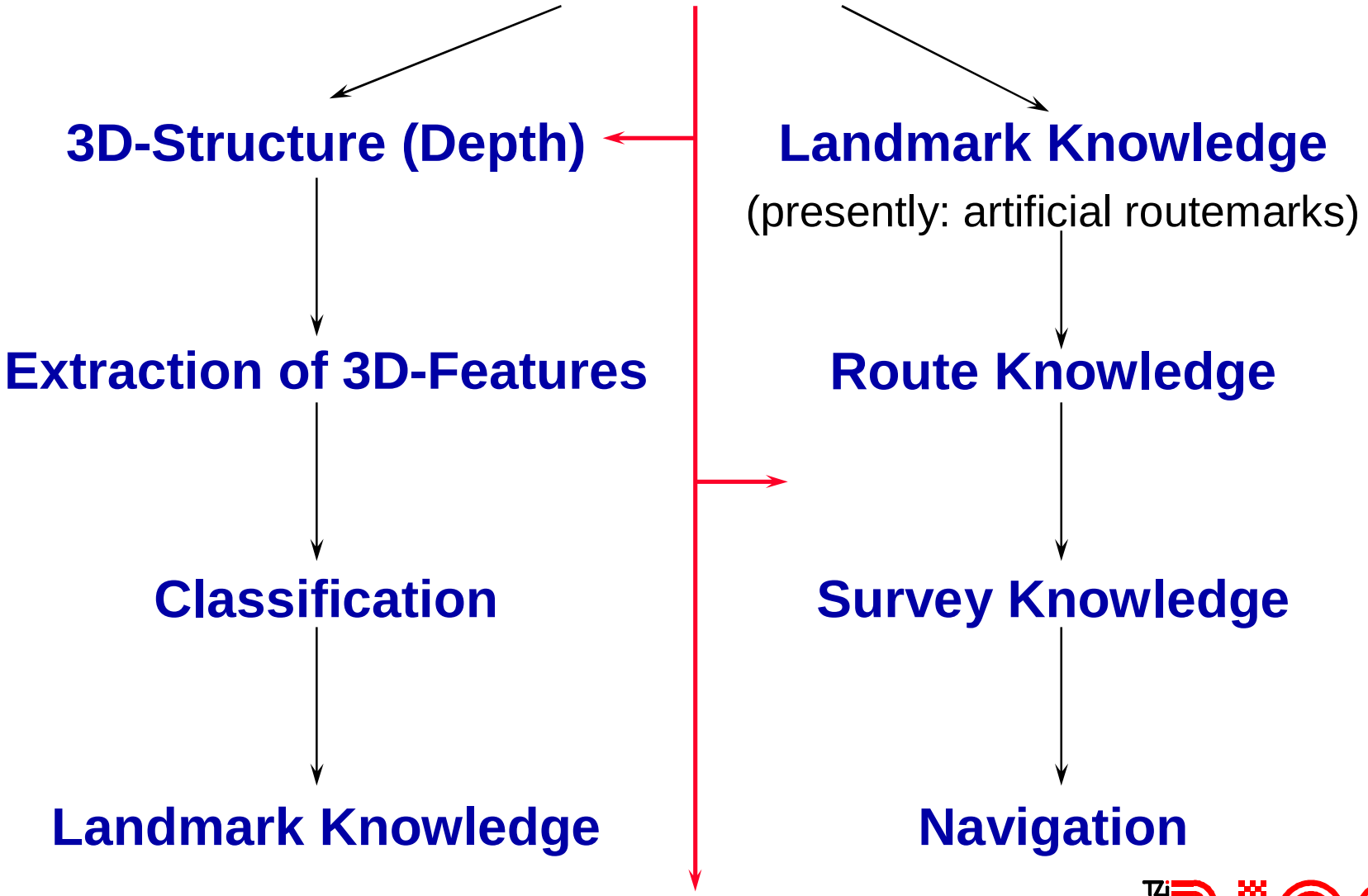
- no inverse behaviors
- threading: recording odometry positions during behavior
- canceling behavior by backtracking recorded positions
- with “direction-following backwards” behavior

Tactic

- backtracking last segment, searching for routemarks
- repeating last segment
- backtracking last two segments
- repeating last two segments etc.



State of Our Work



Spatial Information and Actions

Route Knowledge

- egocentric view in learned direction, self-explored setting

Survey Knowledge

- overview with ability to change viewpoints

Map Knowledge

- viewpoint from above, abstraction for planning

Local Landmarks vs. Global Landmarks for Planning

- *overlay of route and (open) space navigation tactics*

Association of Spatial and Non-Spatial Information

- semantic information/purpose characterizes location/view; "familiarity"
- motor information enhances item-specific (not relational) information
- automatic (unconscious) use; conscious planning only when lost
- *associate purposeful actions (turn, branch, step up, slide, climb)*
- *measure increased familiarity, navigational performance w.r.t. errors*