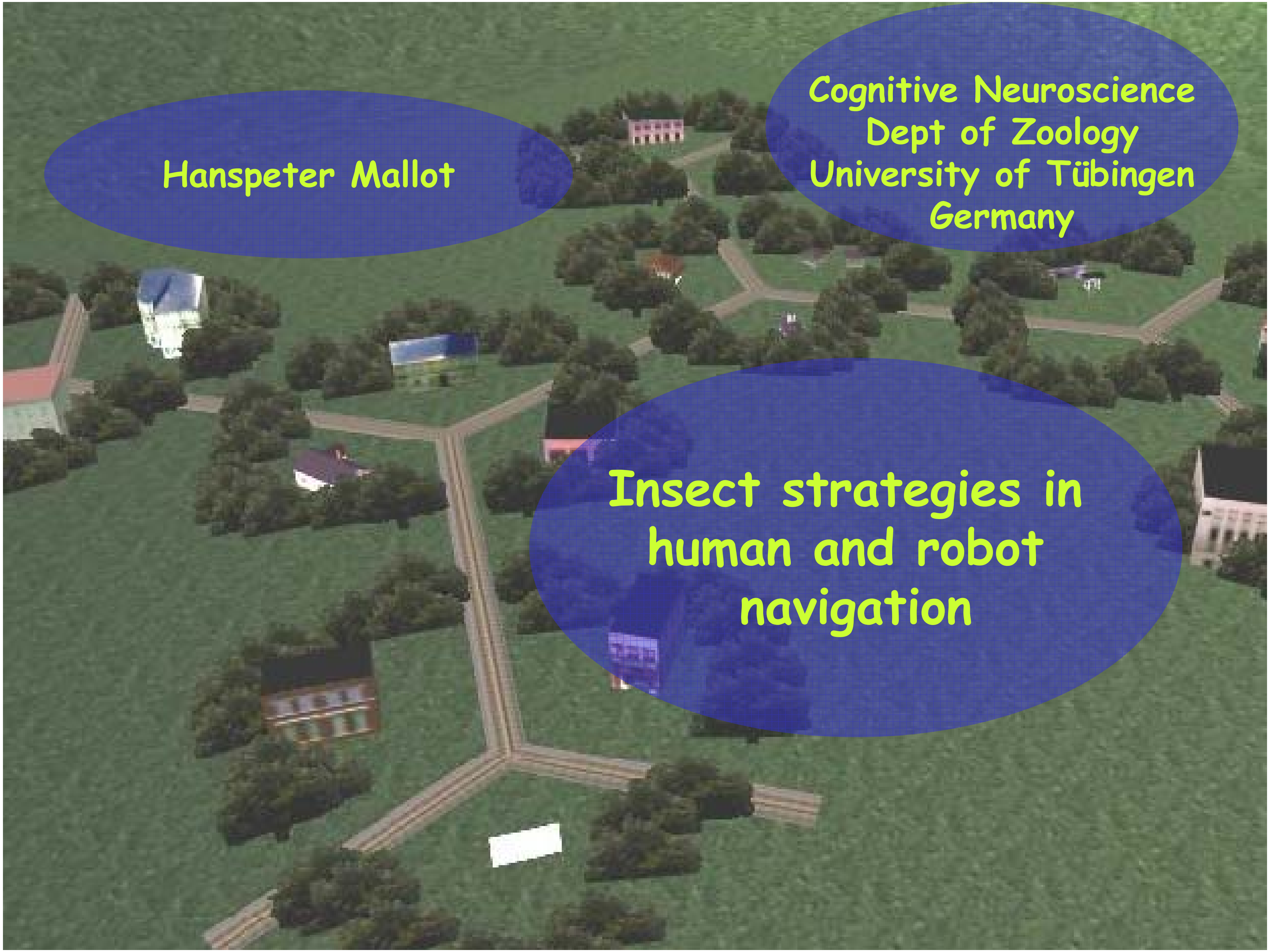


Hanspeter Mallot

Cognitive Neuroscience
Dept of Zoology
University of Tübingen
Germany

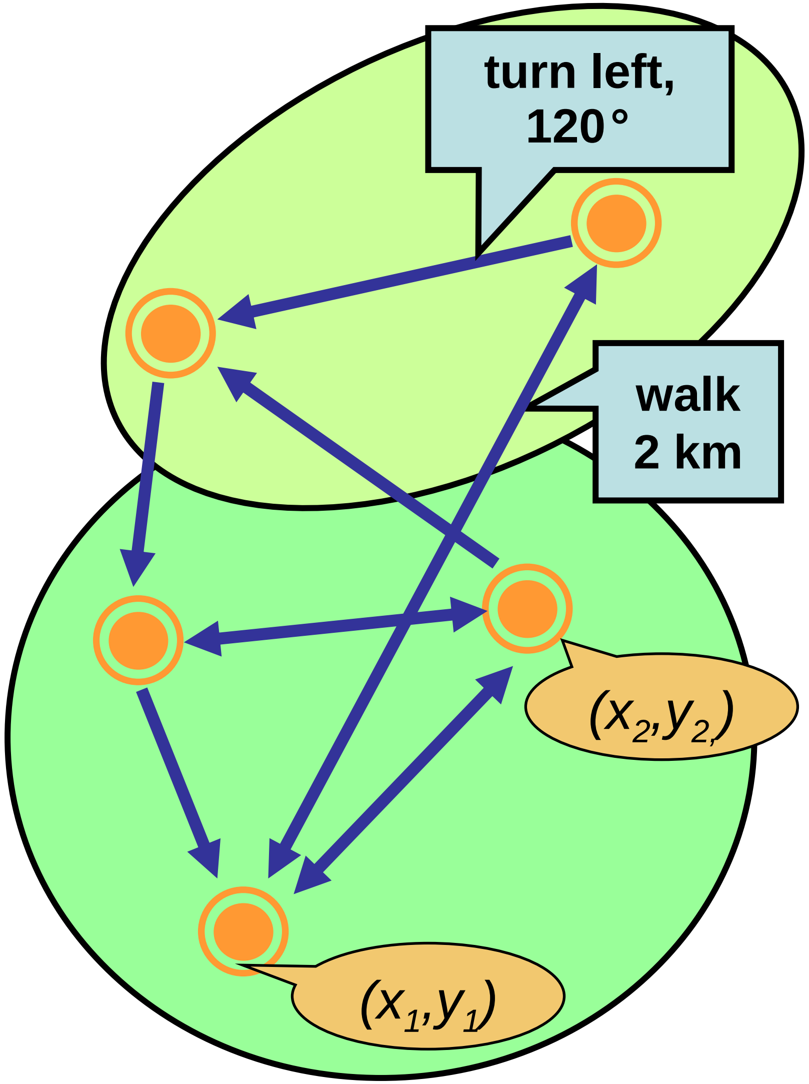
Insect strategies in human and robot navigation

Scaleable model of spatial memory: The view-graph approach

- Path integration
- Place recognition
- Compasses
- Routes (associate places with motor decisions or routines)

____

- Topological navigation: Networks (graphs) of places and connections
- Metric knowledge
- Route planning
- Spatial reasoning and spatial language



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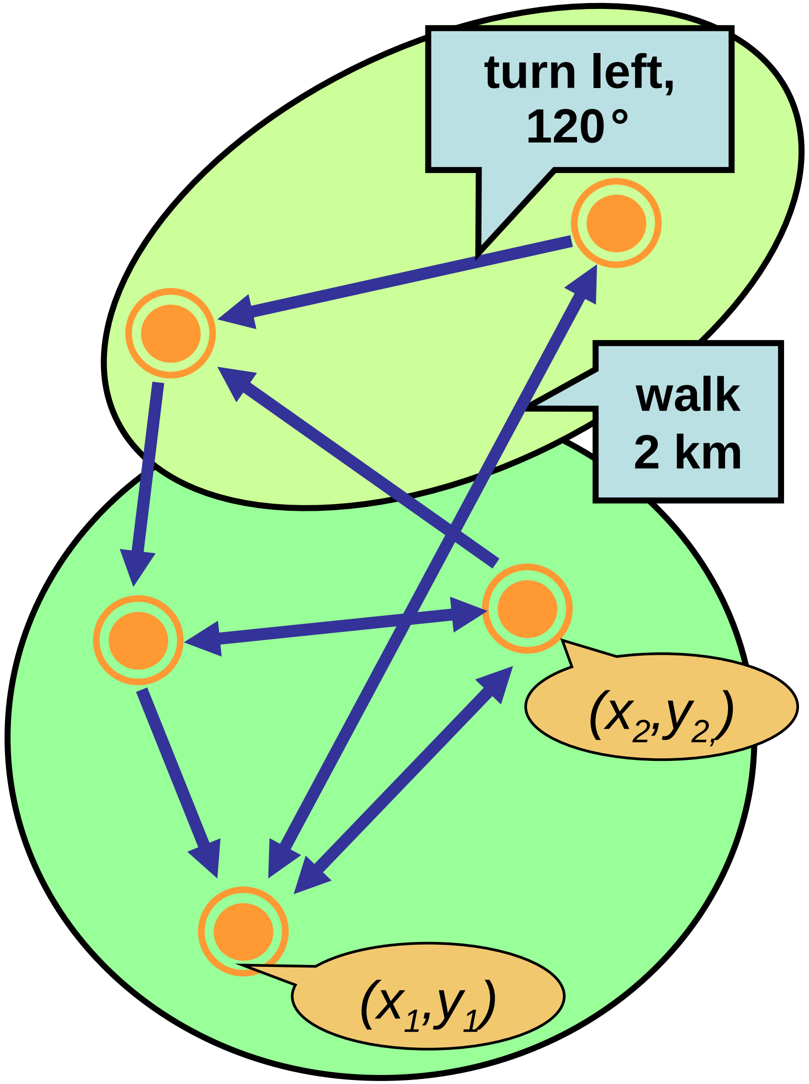
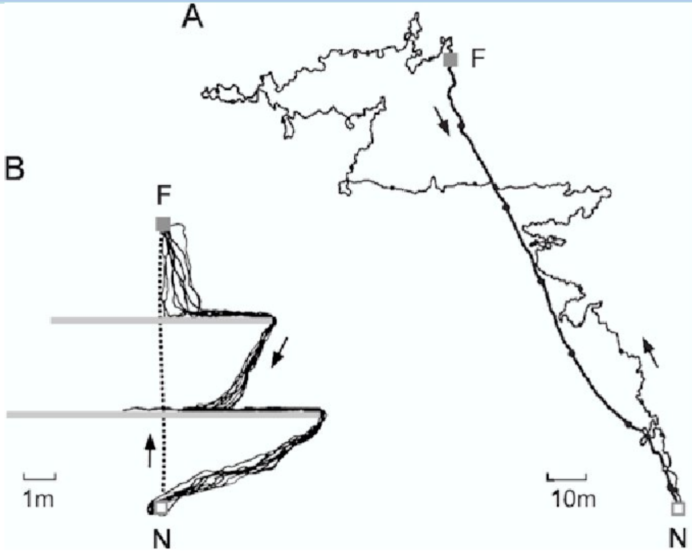
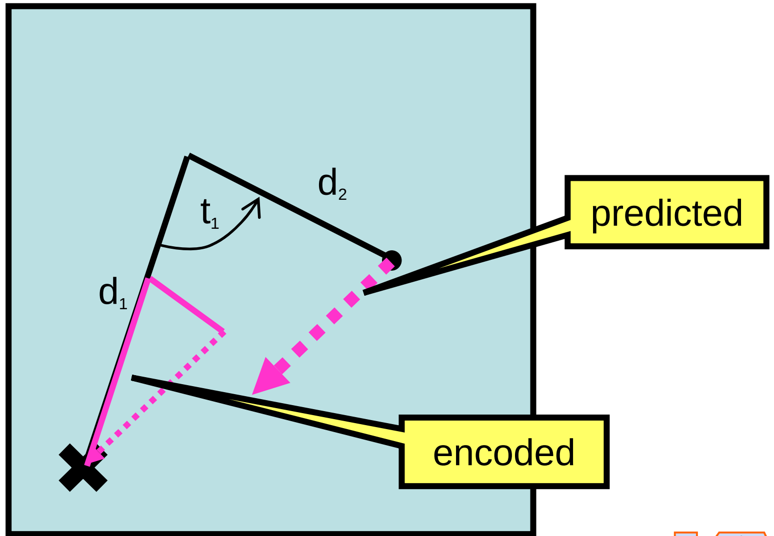


Path integration in insects and humans

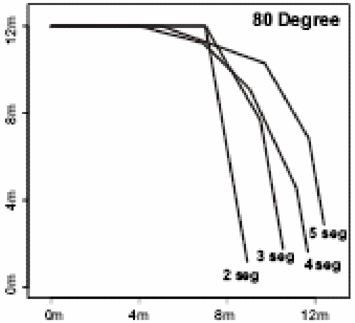
- Insects (Wehner 2003):
  - continuous update of home vector
  - no memory of places past
- Humans (Fujita et al. 1993):
  - experiments mostly study polygonal paths
  - Encoding error model: length and distances of polygonal path are stored and home vector is calculated as needed

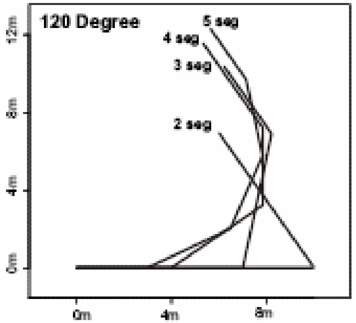




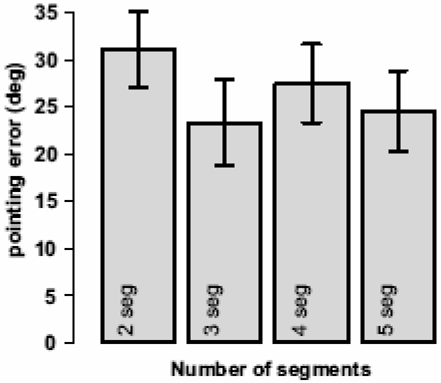
Path complexity does not impair visual path integration

Jan M. Wiener, submitted

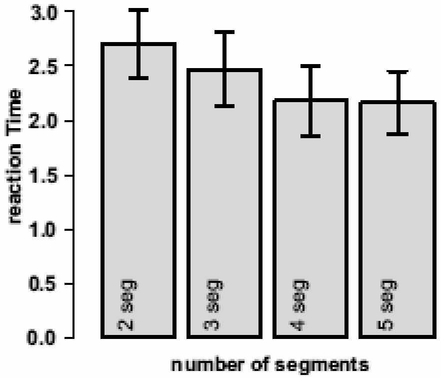




absolute pointing error

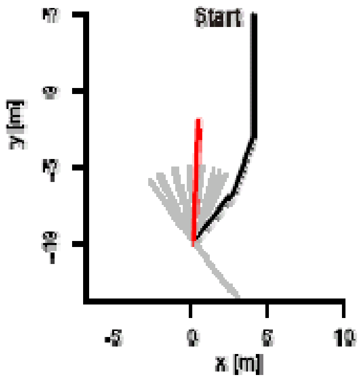


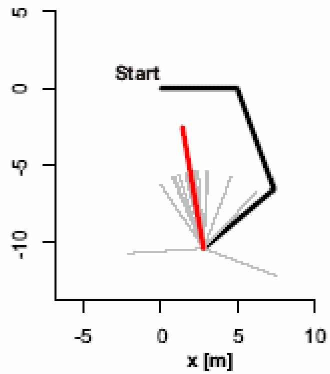
response time



- Virtual Reality experiment with large-field screen and seated subject
- 18 subjects
- 6 total turning ang-les, 8 numbers of segments varied independently

- **Result:** No effect of number of segments





Conclusion:
- **No evidence for polygonal representation**
- **Consistent with continuous (insect-like) update**

Scaleable model of spatial memory: The view-graph approach

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____

- Topological navigation: Networks (graphs) of places and connections
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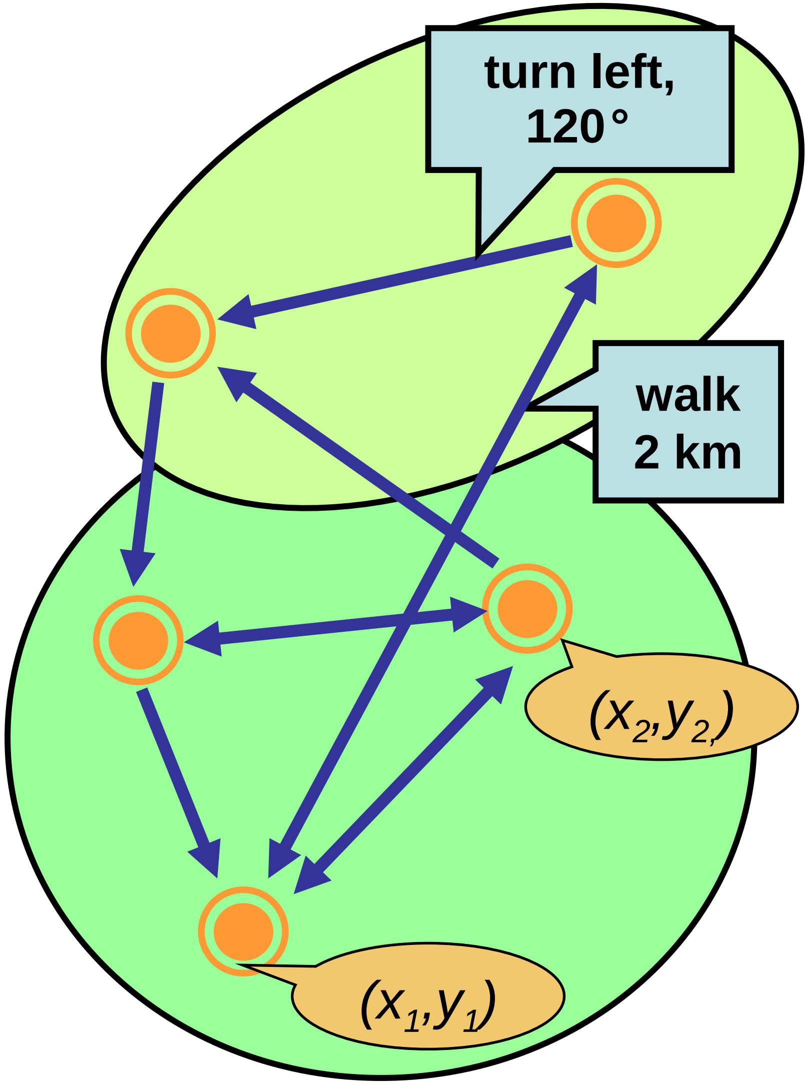
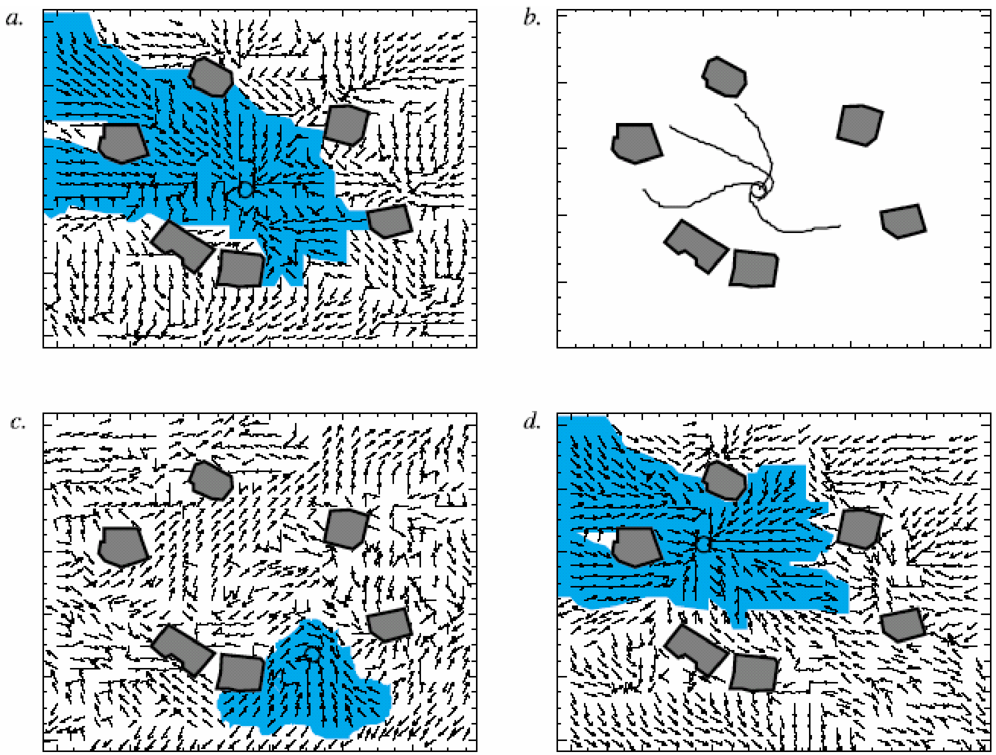
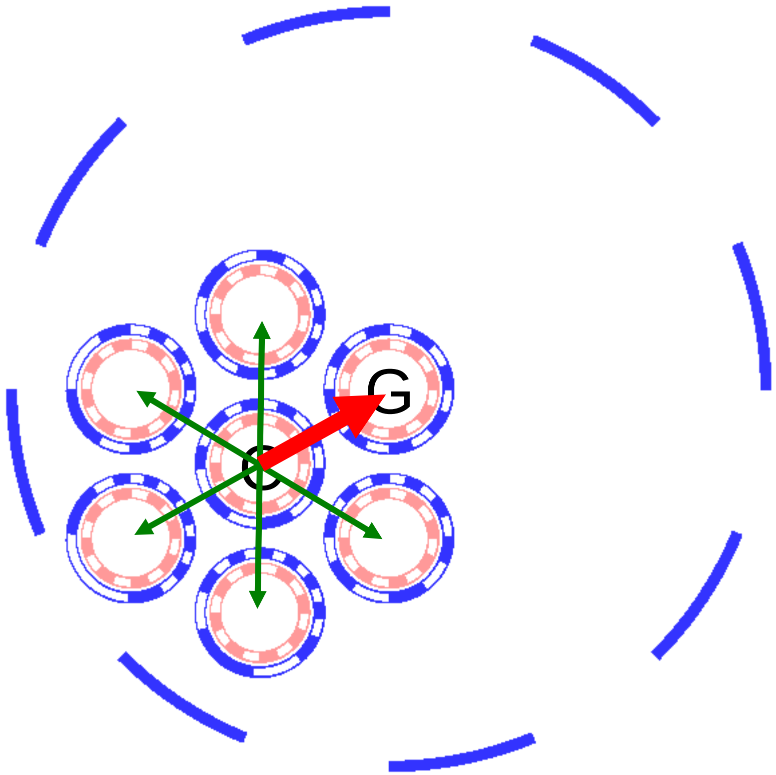


Intensity-based homing algorithm

Franz MO, Schölkopf B, Mallot HA, Bülthoff HH, Biol. Cybern 79:191-202, 1998

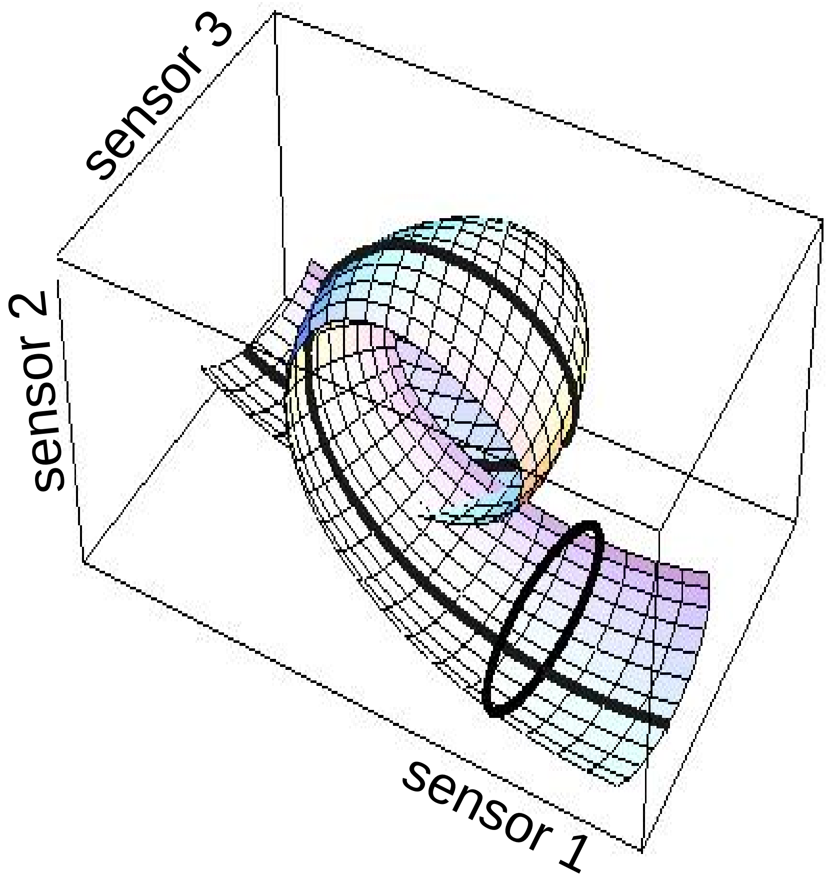




- record snapshot at goal G
- at current position C
  - estimate image resulting from all possible movements
  - calculate image distance to goal
- perform movement leading to most similar image

A Prediction of Intensity-Based Homing

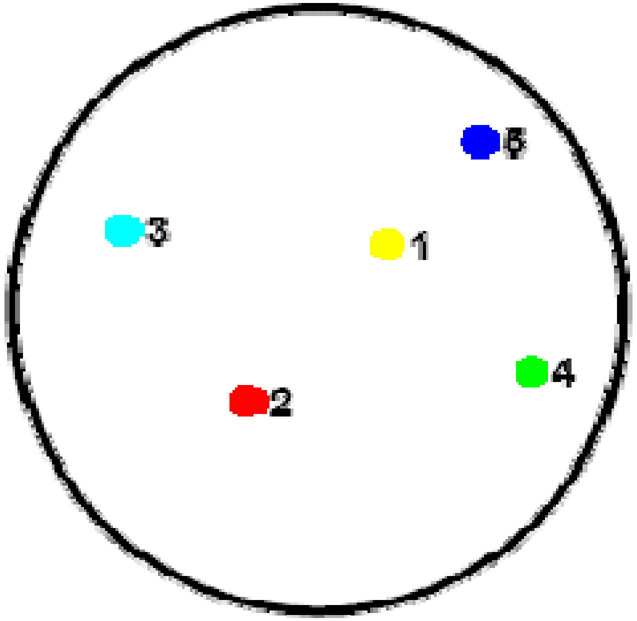
- Image manifold: Image $I_{\mathbf{p}}(\mathbf{x})$ for each pose vector **p**. (Local position information of Trullier et al.)
- Local image variation: first fundamental form ("magnification") of image manifold
- Homing accuracy depends on l.i.v.
  - accuracy decreases with contrast
  - accuracy decreases with mean landmark distance

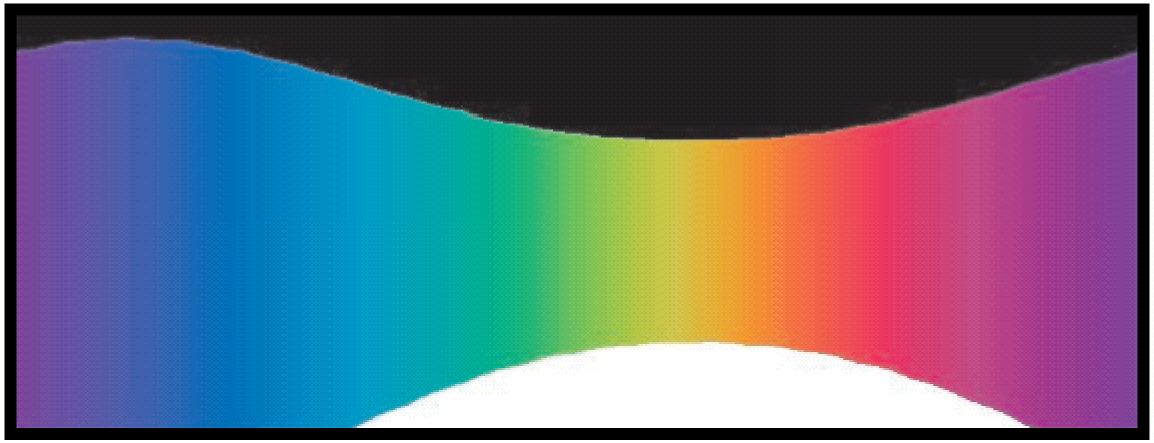


Snapshot-based homing in humans

Sabine Gillner, unpublished

- Subject with HMD in 5 x 5 m tracked walking arena
- Circular room with homogeneous color gradient
- Task:
  - Subject at position 1
  - View scene at position 2
  - Walk to position 2
  - View scene at position 3
  - ...
- Dependent measure: trajecory, homing error



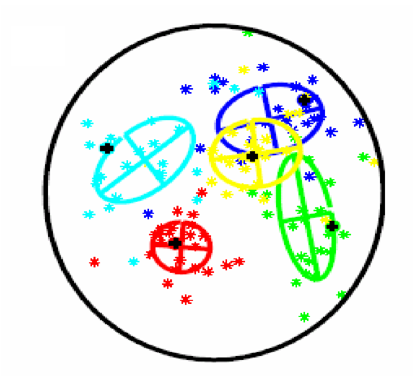


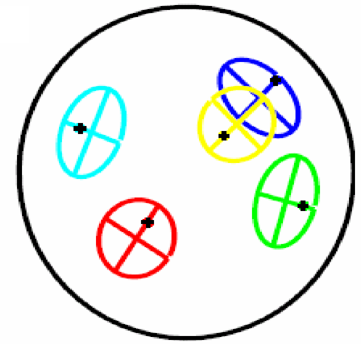
Dependence on Color Modulation

homing in 6 subjects, 4 repetitions

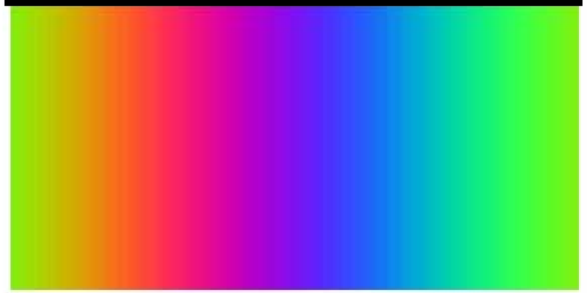
prediction from squared image difference algorithm

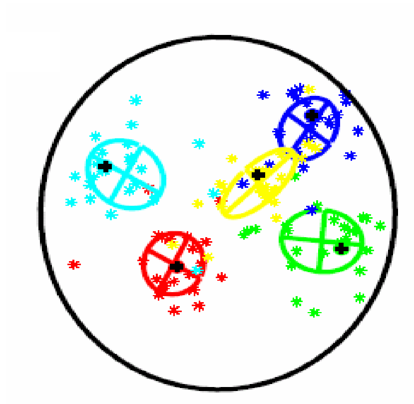
Color modulation 10%

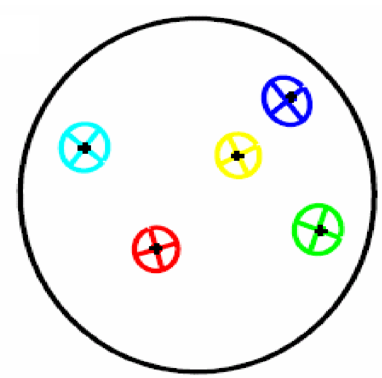




Color modulation 100%

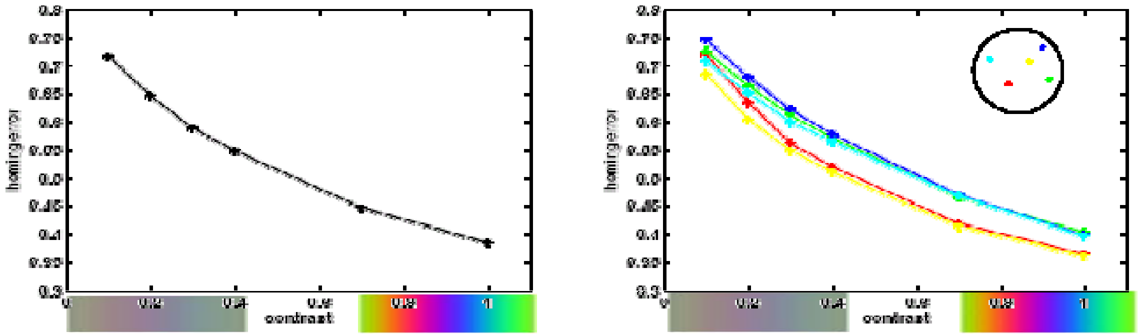




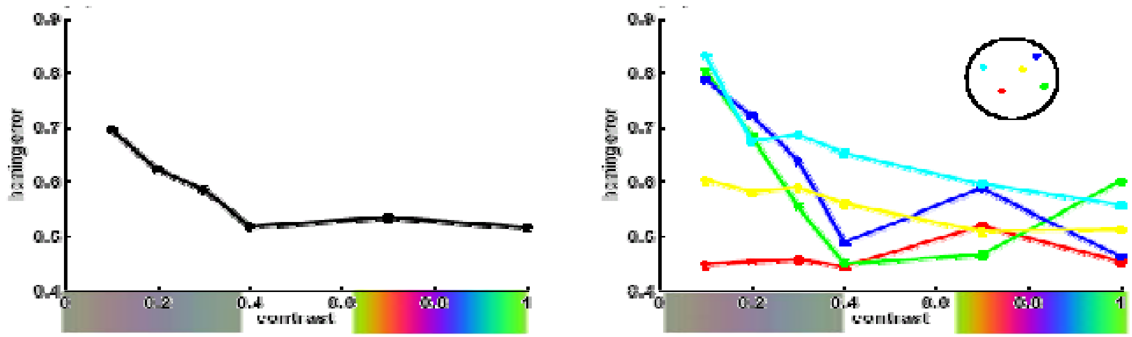


Dependence on Color Modulation

Model Prediction

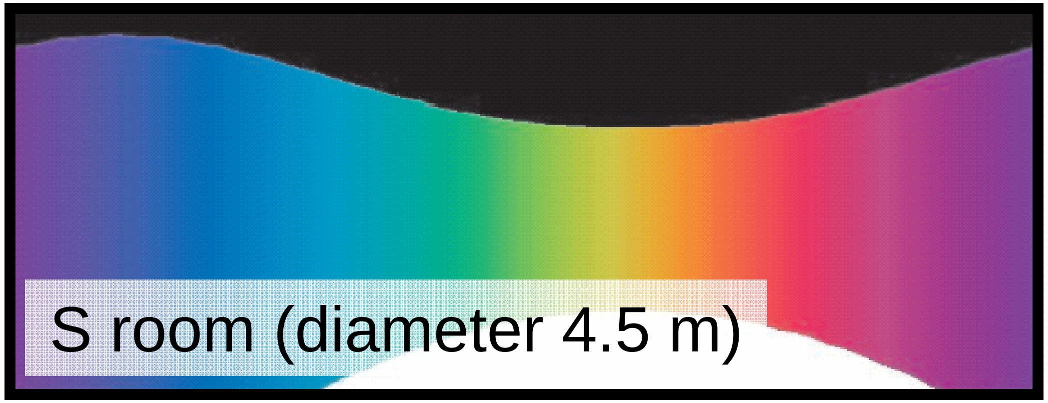


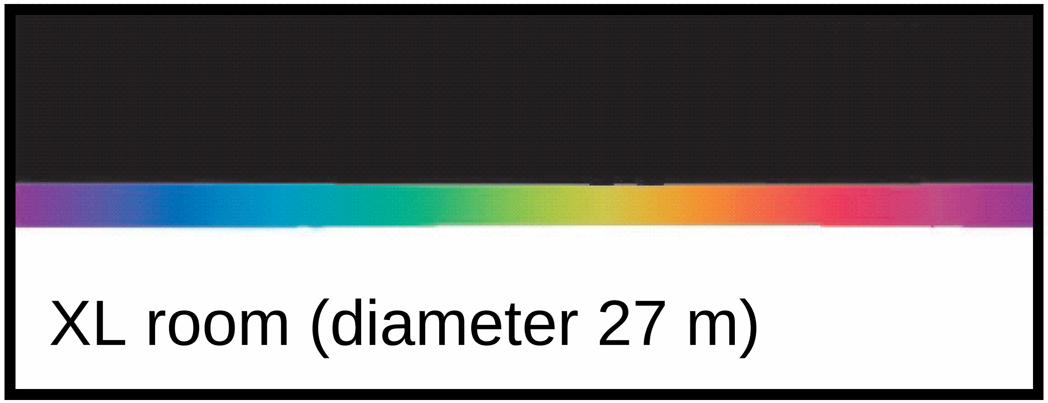
Experimental Data

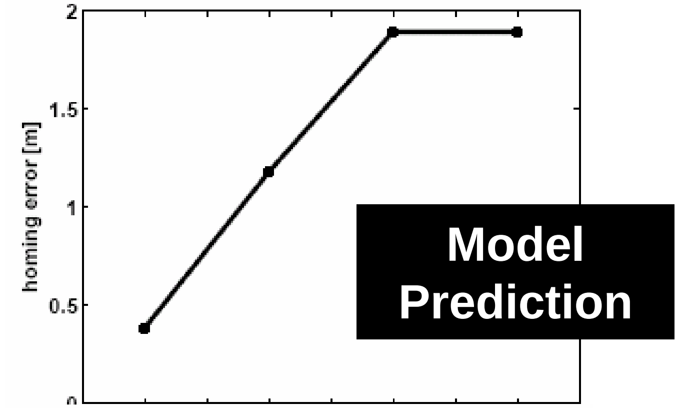


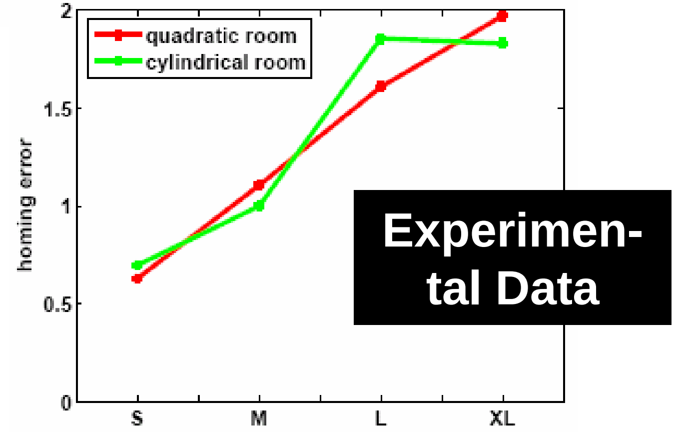
- Overall significant effect of color modulation
- Per point, effect is significant only for the three peripheral points
- Threshold effect for higher modulations

Dependence on Room Size









- Human visual homing in featureless environment depends on contrast and rom size, i.e. on local image variation, l.i.v.

Scaleable model of spatial memory: The view-graph approach

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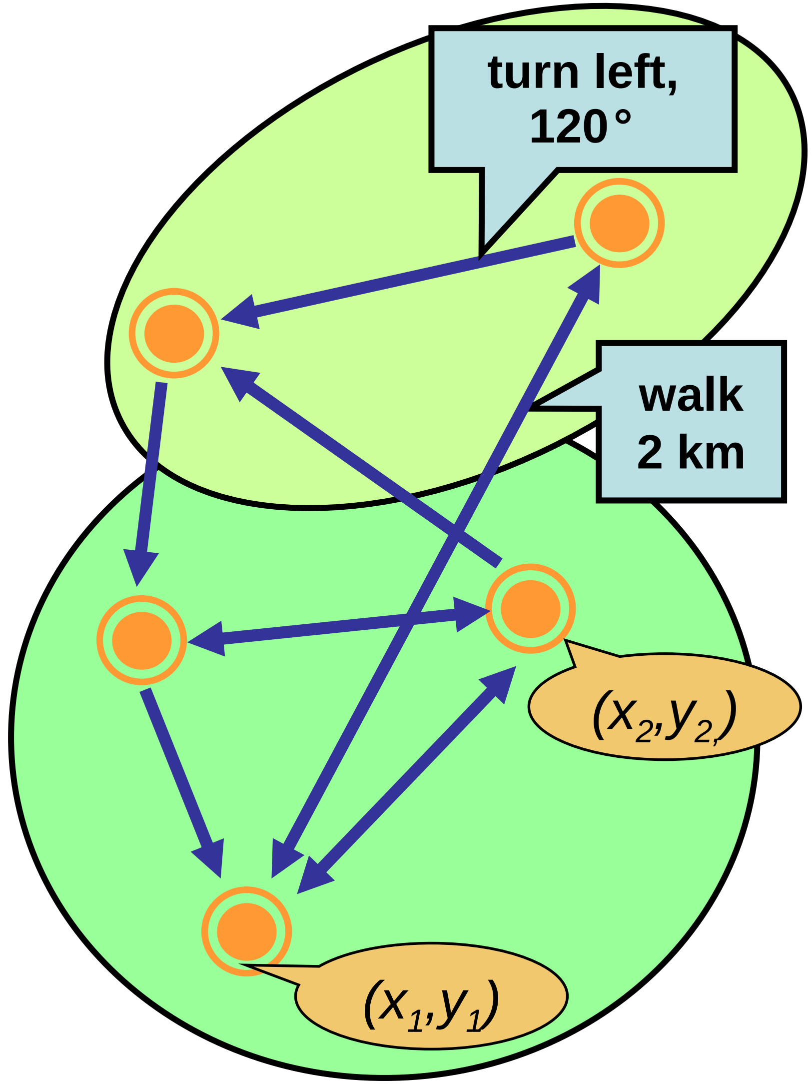


Efficient visual homing based on Fourier transformed panoramic images

W. Stürzl, HA Mallot, *Robotics and Autonomous Systems* 54:300-313, 2006

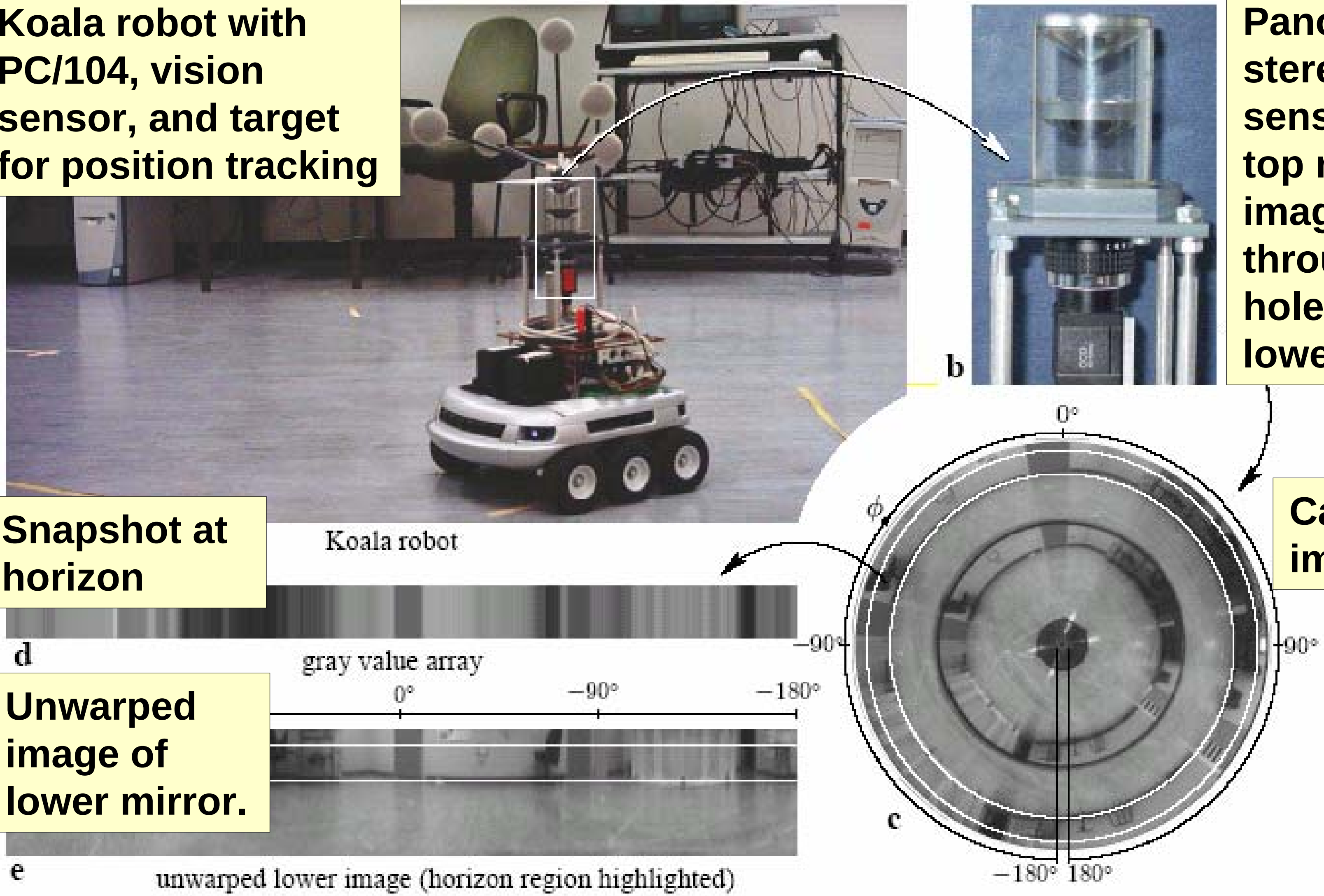
Koala robot with PC/104, vision sensor, and target for position tracking

Panoramic stereo sensor. The top mirror is imaged through a hole in the lower mirror.

Camera image

Snapshot at horizon

Unwarped image of lower mirror.



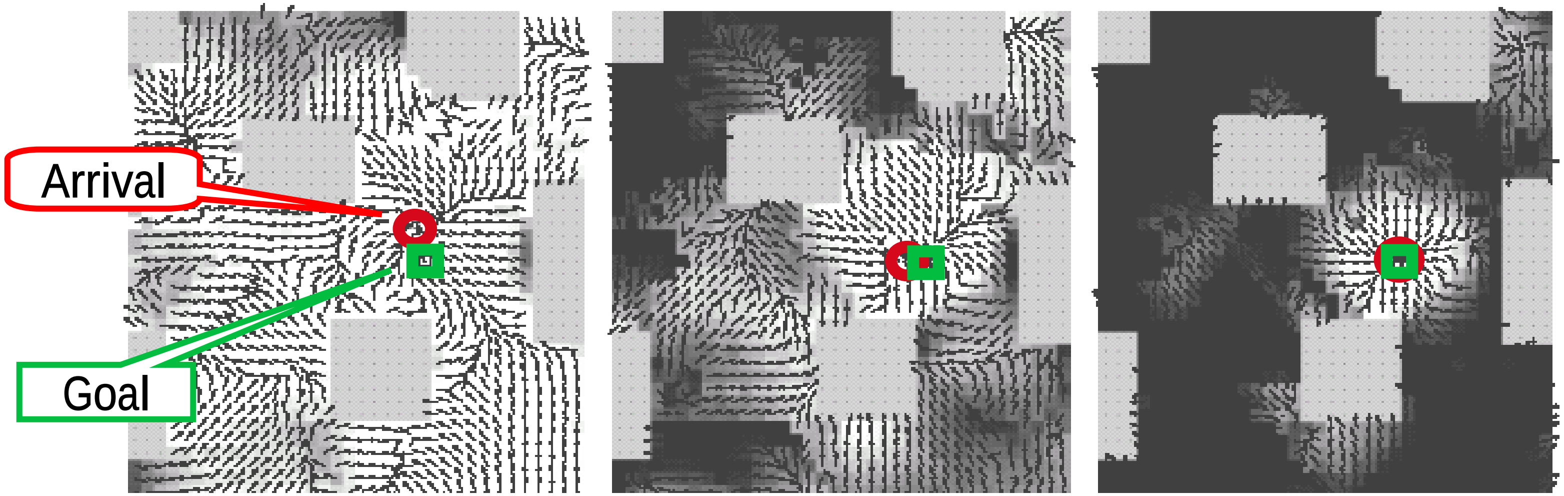
Coarse-to-Fine Homing

Stürzl, Mallot *RAS* 54:300-313, 2006

2 Fourier Components: fast but inaccurate

4 Fourier Components: intermediate phase

10 Fourier Components: final approach



- In insects, image matching is simplified by compass information, allowing alignment to global North
- Fast image alignment can be achieved by low spatial frequency
- Higher frequencies are needed for final approach

Geographical Slant as Compass Information

Restat, Steck, Mochnatzki, Mallot, Perception 2004

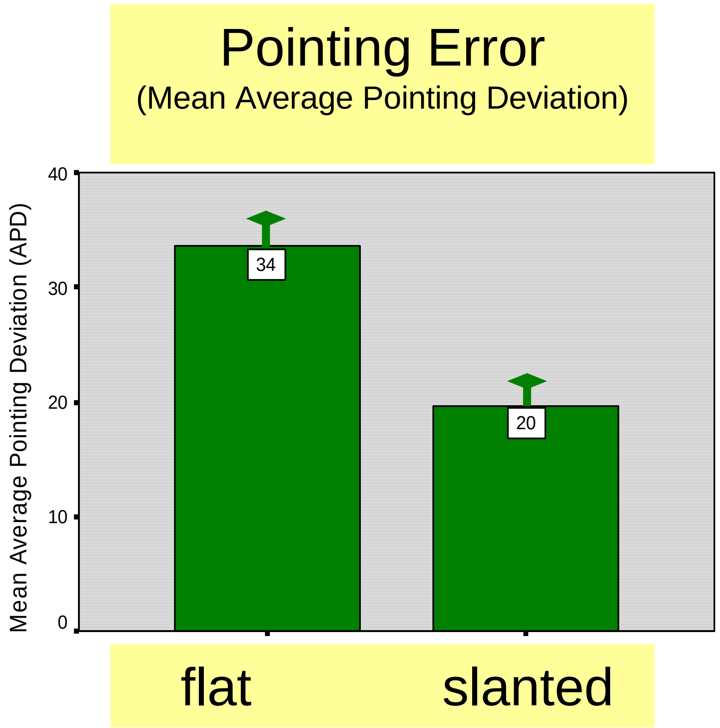
flat

Geographical Slant as Compass Information

Restat, Steck, Mochnatzki, Mallot, Perception 2004

- Ground plane is slanted 4 degrees
- Slant is perceived both visually and via force feedback when cycling.
- Uphill/downhill may be used as global reference frame („compass“).
- Elevation of places may be inferred by „vertical path integration“.
- Does navigation performance improve?

Results

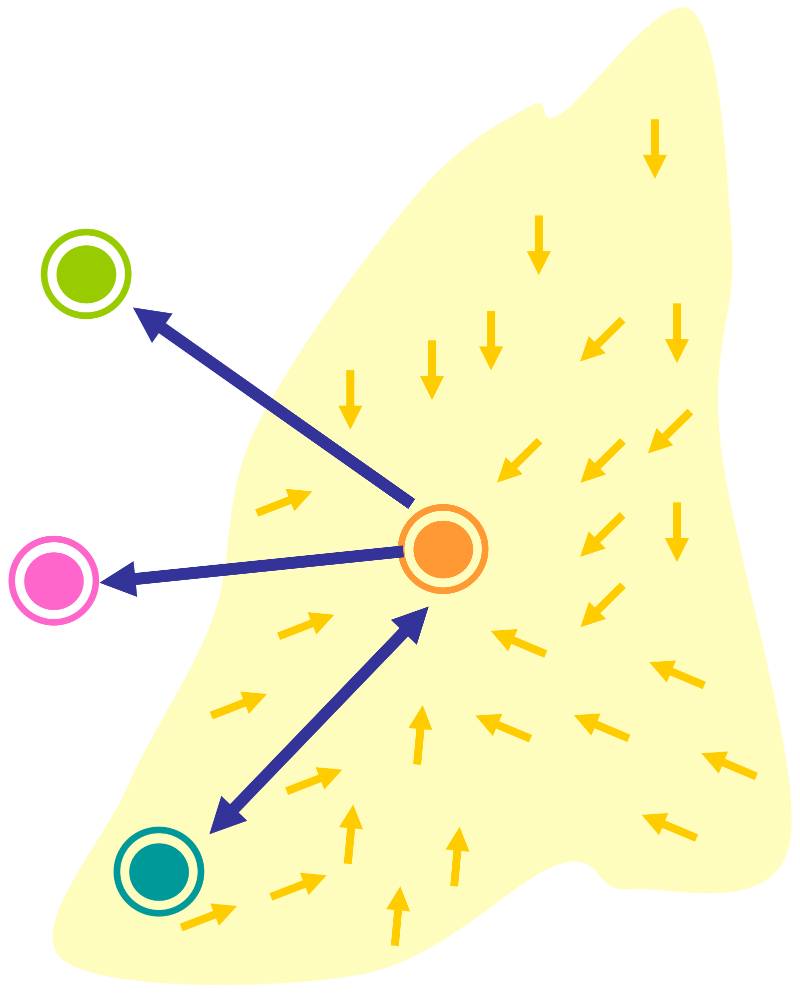


Advantage of slanted environment is significant for way choices and pointing task.

J. Restat et. al, Perception 2004

Beyond Insect Navigation

- Path integration
- Place recognition
  (e.g., snapshot based)
- Routes (associate places with motor decisions or routines)
- ____________________________
- Topological navigation: Networks (graphs) of places and connections
- Metric knowledge
- Route planning
- Spatial reasoning and spatial language



Scaleable model of spatial memory: The view-graph approach

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- **Metric knowledge**
- Route planning
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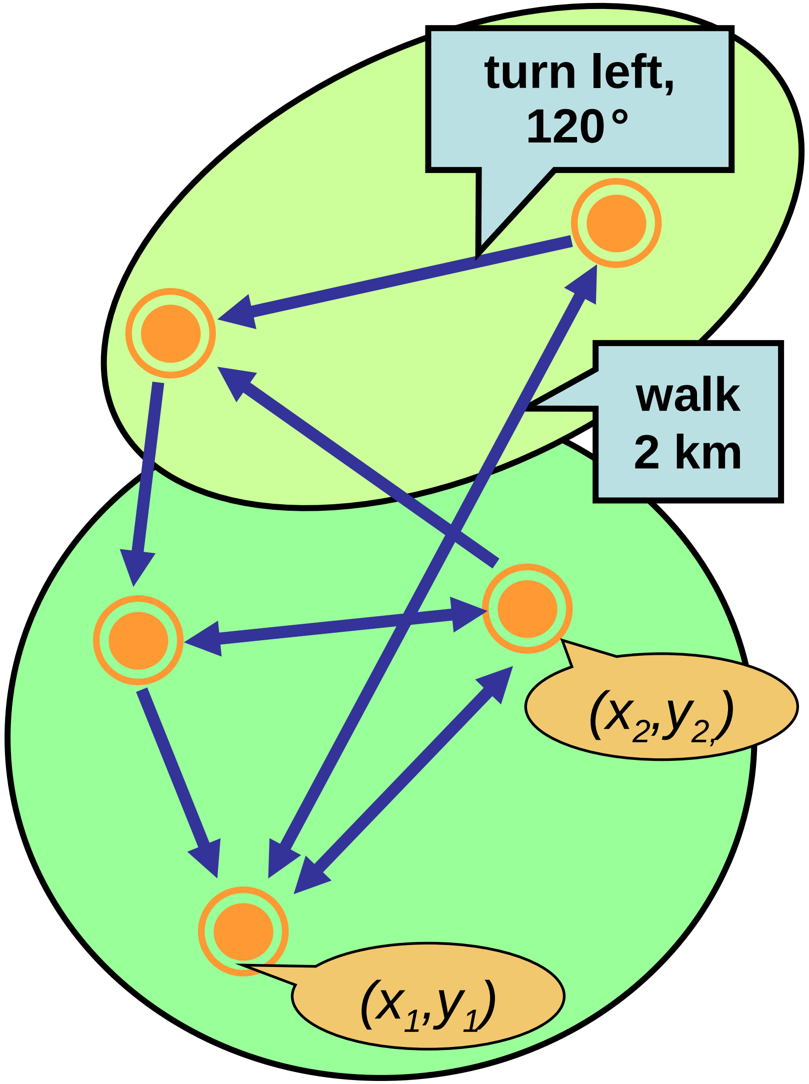
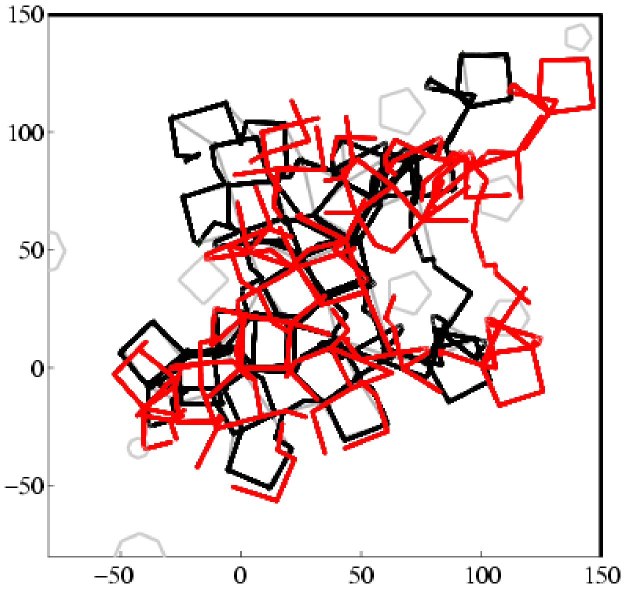


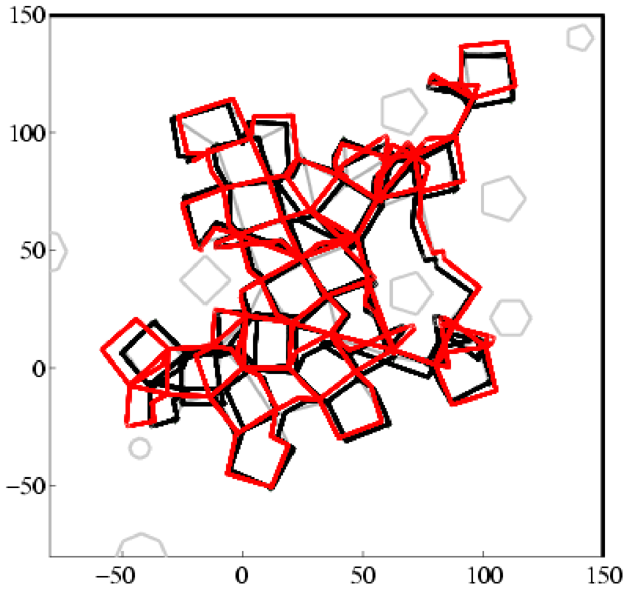
Global Metric Embedding of Landmark Graphs

W. Hübner, PhD Thesis 2005

path integration



metric embedding



- place recognition by panoramic view comparison
- view graph for topological navigation
- egomotion estimates from odometry or optical flow

Scaleable model of spatial memory: The view-graph approach

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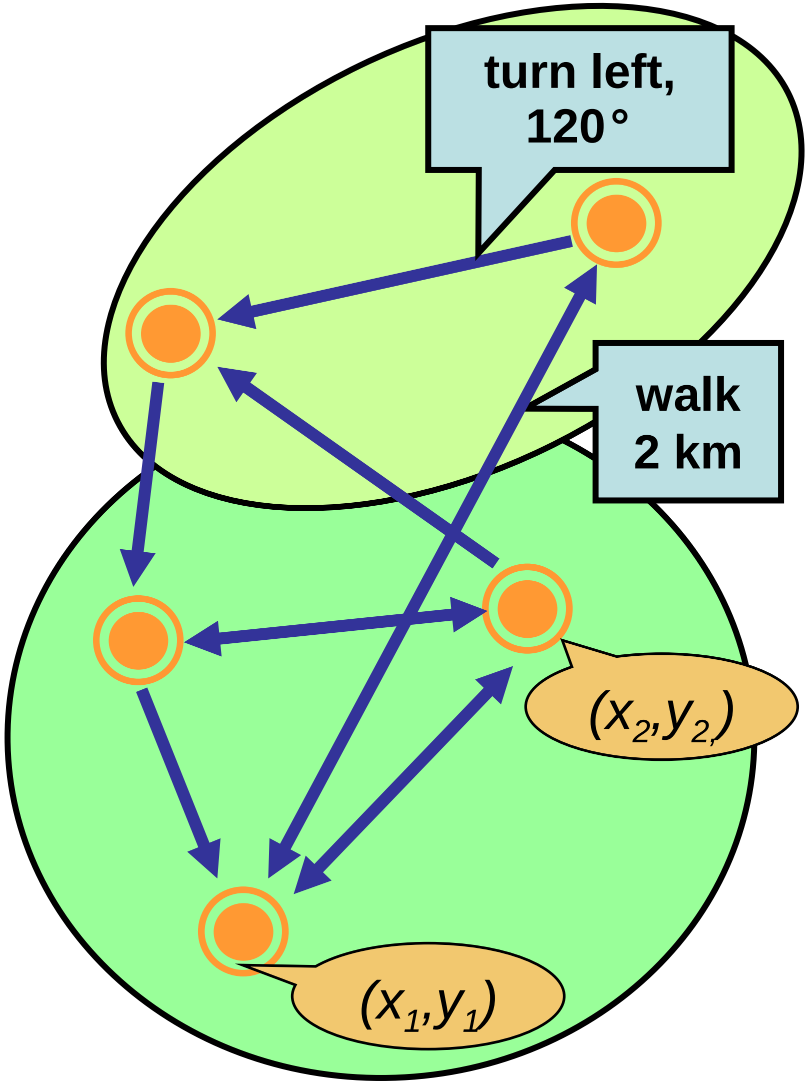
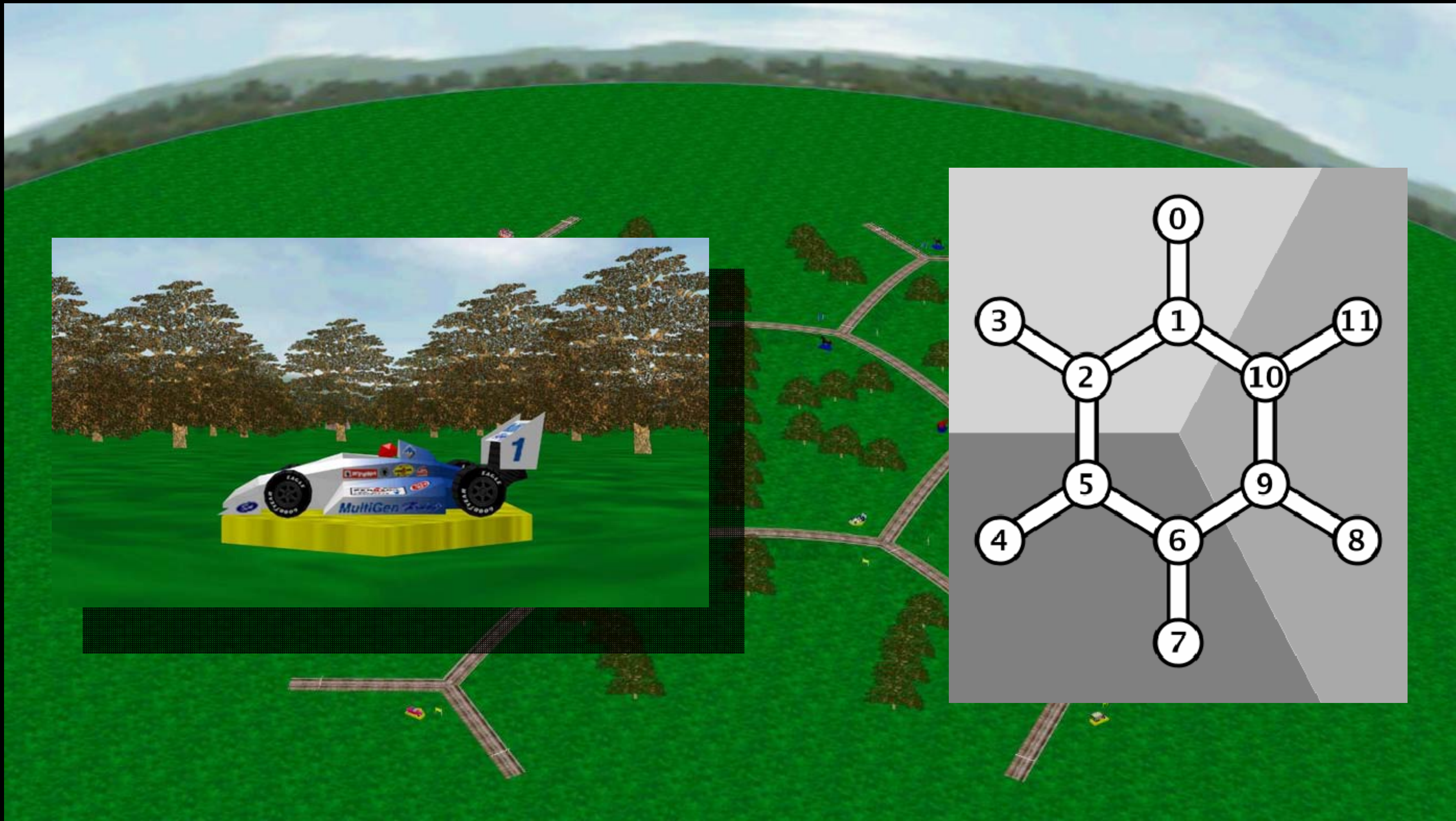


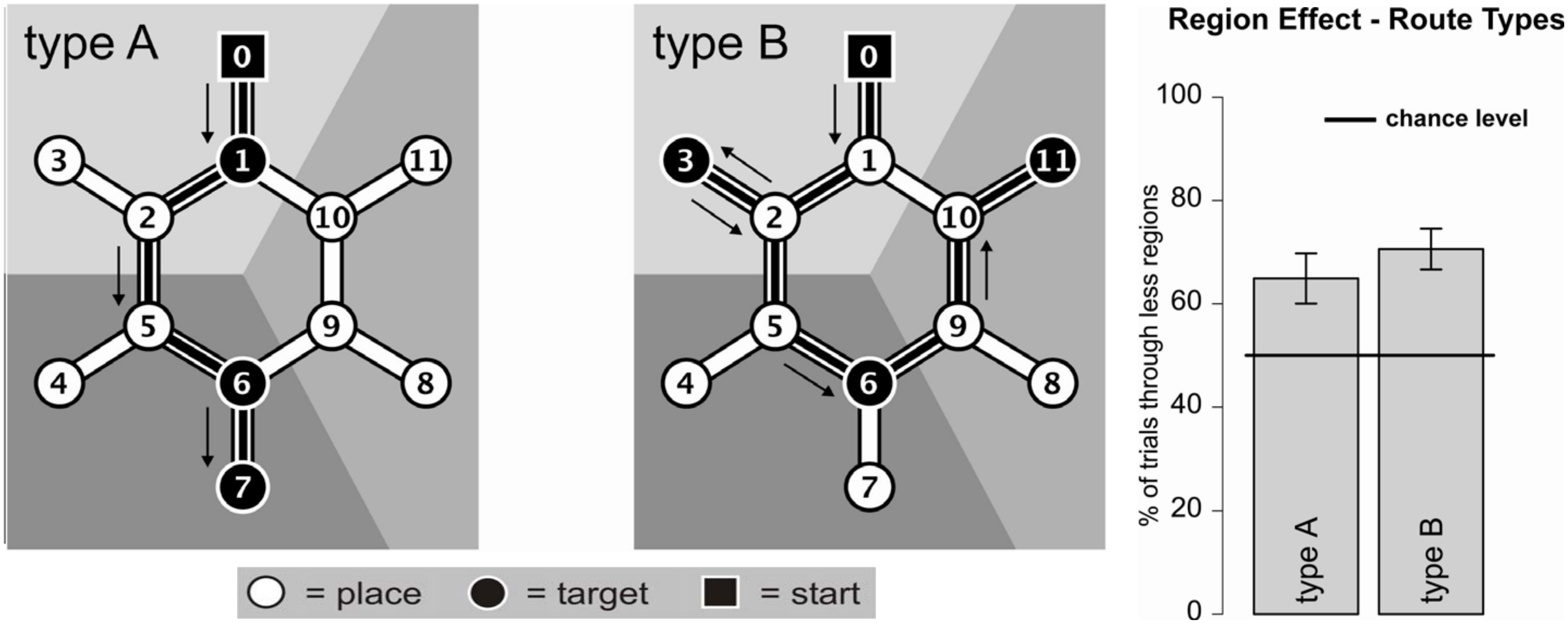
Regions and Route Planning

Wiener & Mallot, *Spatial Cognition and Computation* 2003



Regions and Route Planning

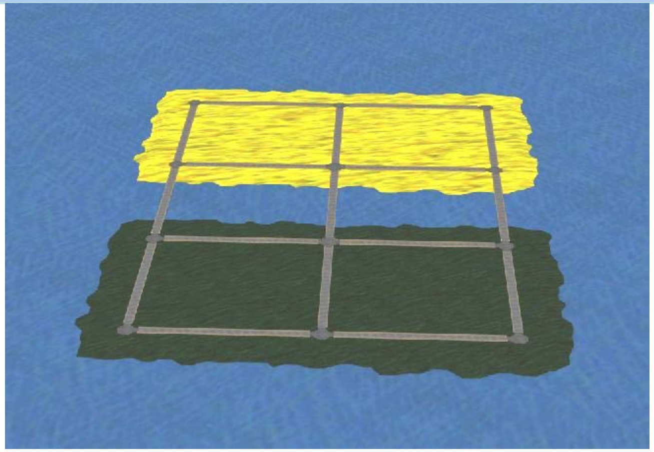
Wiener & Mallot. *Spatial Cognition and Computation* 2003

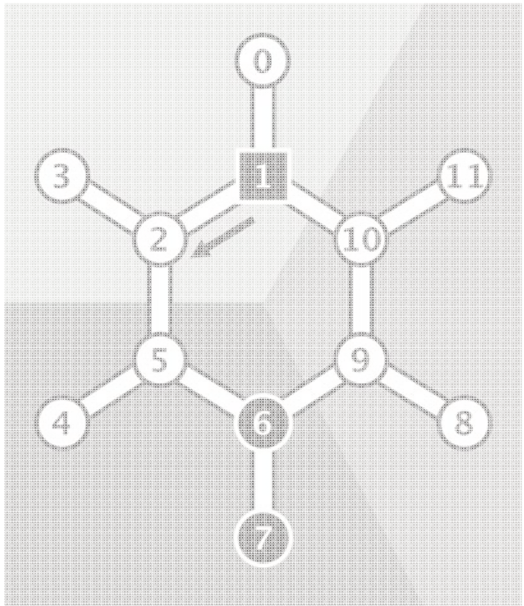


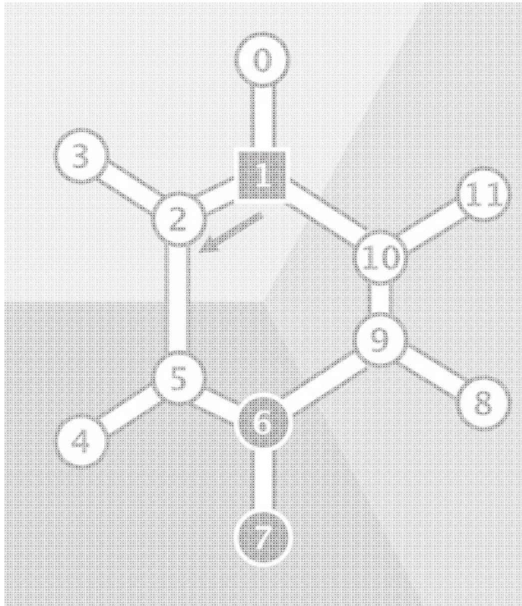
- 25 Subjects, 24 trials with route types A and B
- Subjects report regions in debriefing
- Subjects prefer routes crossing fewer region boundaries (2 in type A, 3 in type B): 67 vs. 33 % (deviation from chance level, $p < 0.001$)

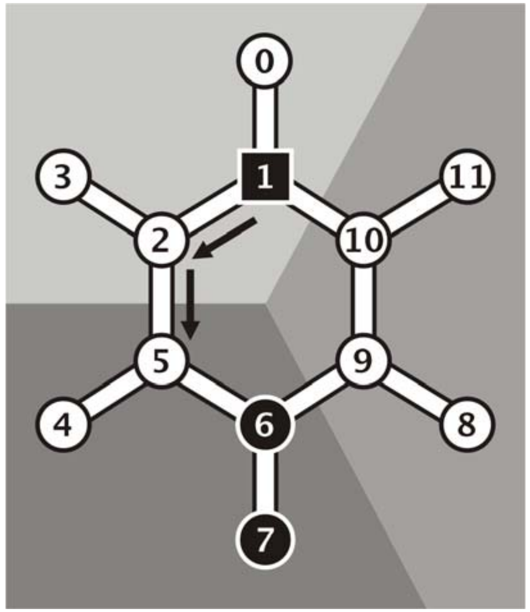
Possible Explanations

- Persistence (stay in region as long as possible)
- Distorted representation
  (additional cost of region crossing)
- Hierarchical route planning
  (go to goal region as fast as possible)



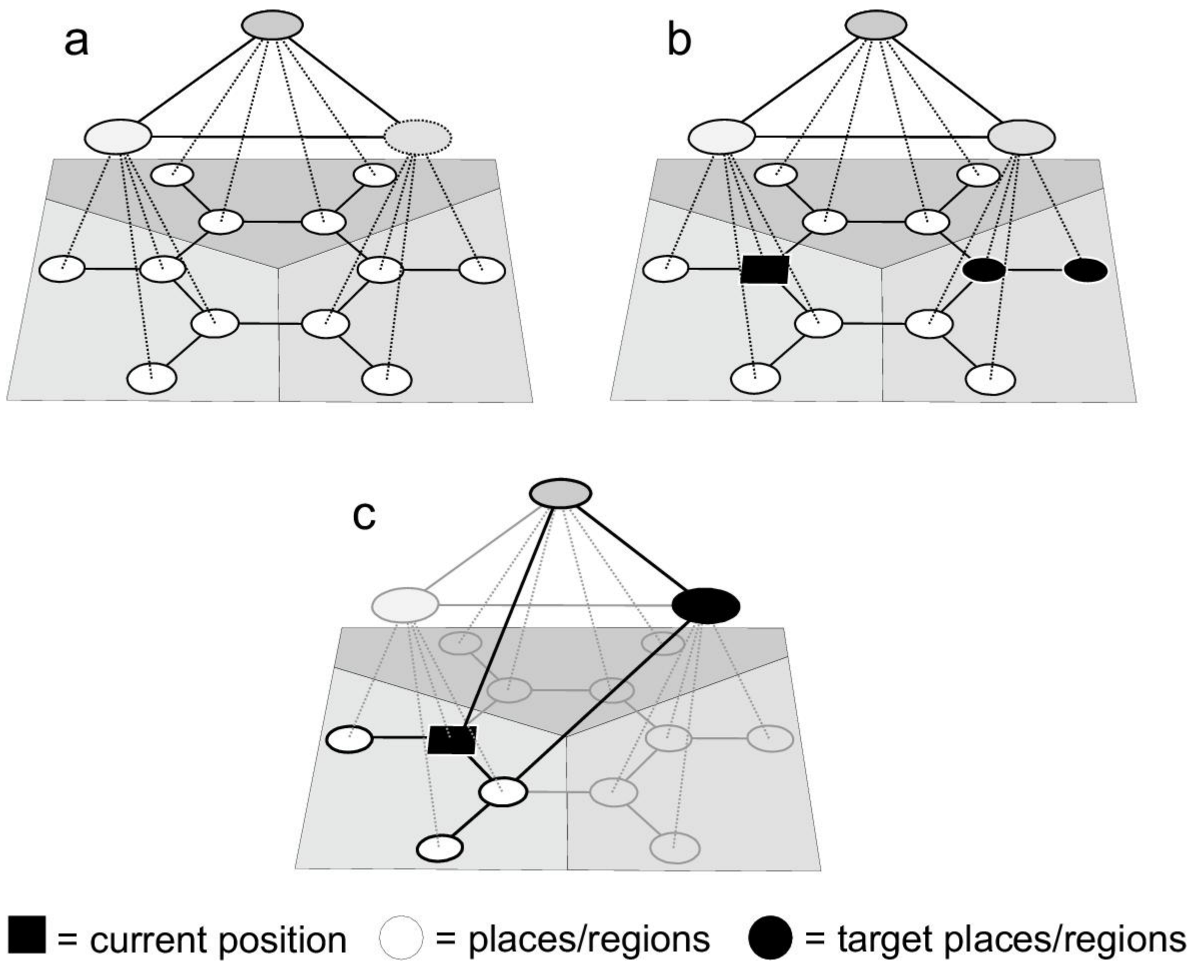






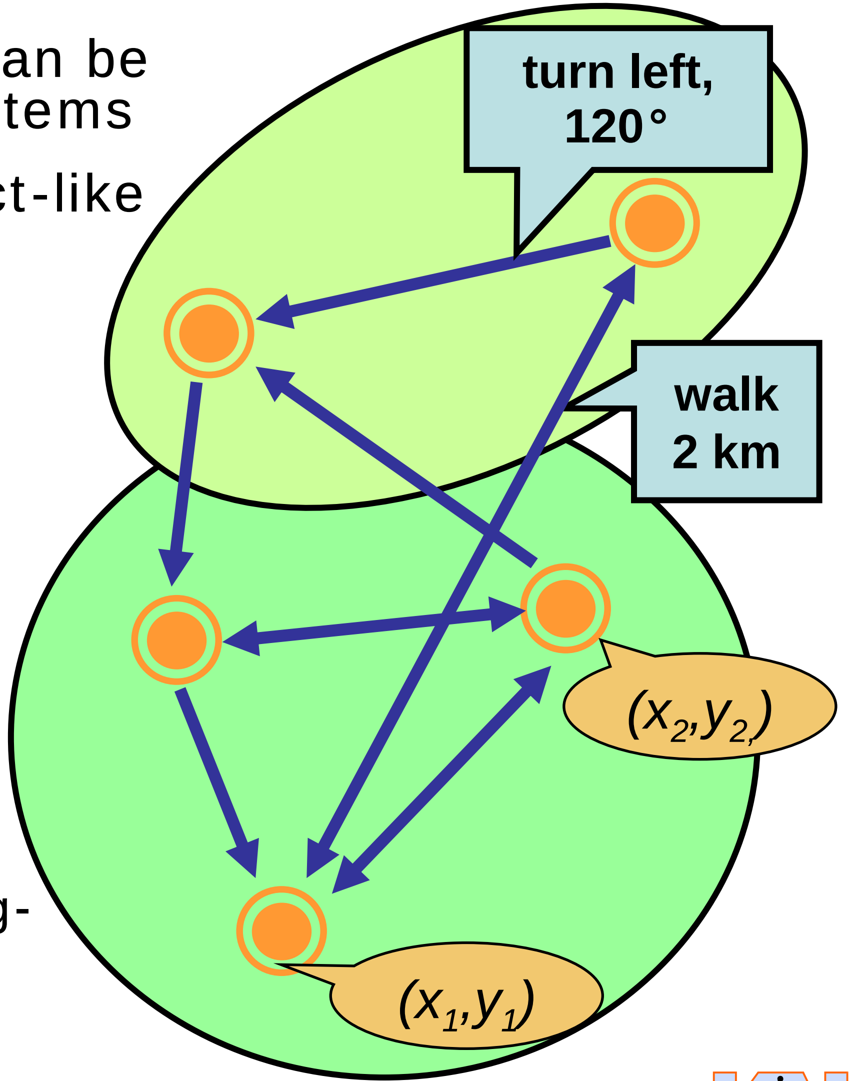
Focal Representation for Fine-to-Coarse Route Planning

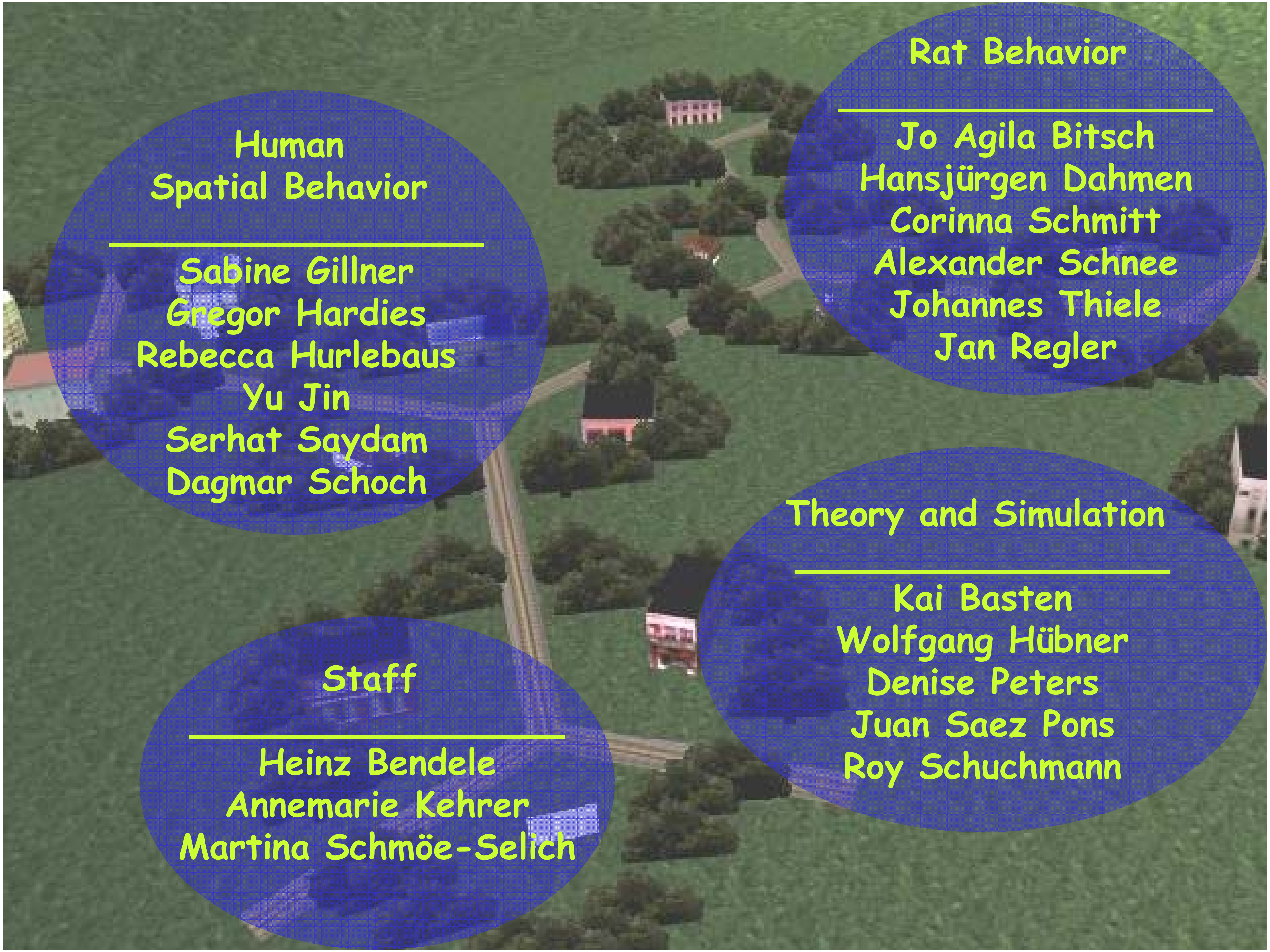
Wiener & Mallot. *Spatial Cognition and Computation* 2003



Conclusion: Insect-like Navigation

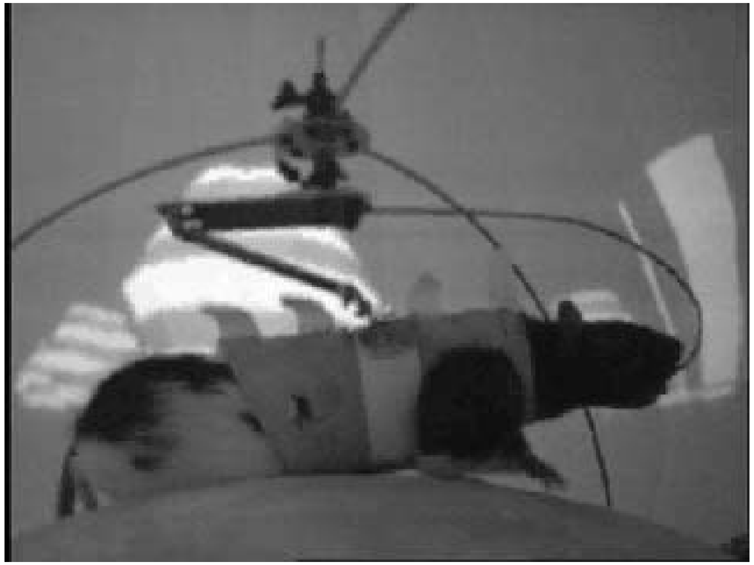
- Mechanisms of insect navigation can be used to implement wayfinding systems
- Human navigation uses both insect-like and additional mechanisms
- Features exceeding present insect-like systems include
  - Recombining route segments into novel routes
  - Longterm metric knowledge
  - Route planning
    - selecting route alternatives
    - perspective taking
  - Interactions of spatial and social behavior based on individual recog-nition (e.g., territorial neighbors)
  - Spatial language

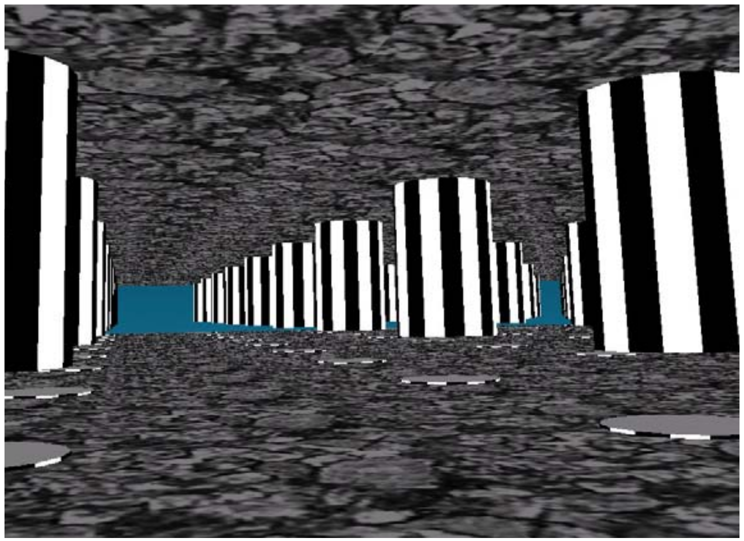


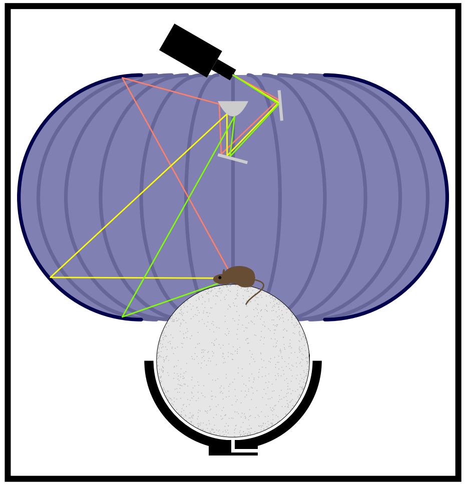

Human
Spatial Behavior
Sabine Gillner
Gregor Hardies
Rebecca Hurlebaus
Yu Jin
Serhat Saydam
Dagmar Schoch
Rat Behavior
Jo Agila Bitsch
Hansjürgen Dahmen
Corinna Schmitt
Alexander Schnee
Johannes Thiele
Jan Regler
Theory and Simulation
Kai Basten
Wolfgang Hübner
Denise Peters
Juan Saez Pons
Roy Schuchmann
Staff
Heinz Bendele
Annemarie Kehrer
Martina Schmöe-Selich

Rats are able to navigate in virtual reali

Hölscher, Dahmen, Schnee, Setia, Mallot. *J. Expt. Biol.* 2005







- Environment composed of drum objects hanging from a ceiling
- Reward given when rat moves under drum
- Drum spacing: 2m