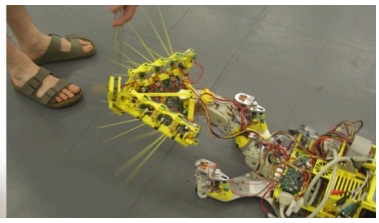
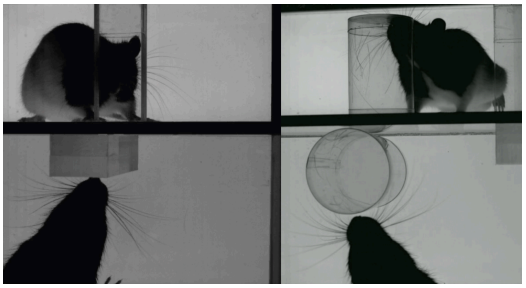
Spatial navigation in humans (mostly)

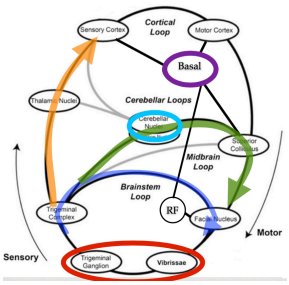
- Sensing the world with whiskers in rats and robots
- Homing behavior in desert ants
- Navigation strategies:
  - (1) path integration or dead reckoning
  - (2) route or landmark based navigation
  - (3) navigation with a cognitive map or survey knowledge
- Spatial representations to support human navigation
  - Navigation in the world of immersive virtual reality
  - Representing space with a "labeled graph"

Modeling "whisking" in rats with whiskered robots

Tony Prescott, University of Sheffield

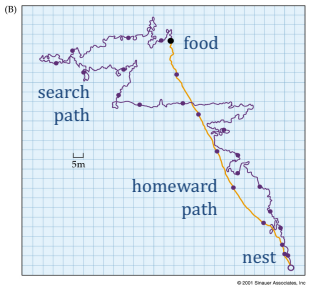


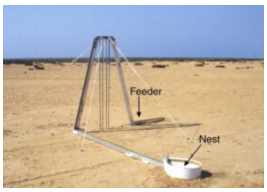




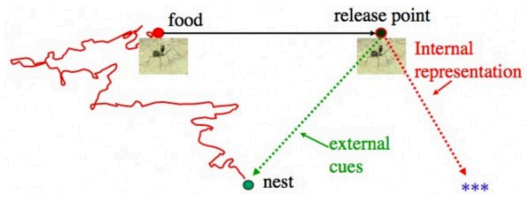
Homing behavior in desert ants

Desert ants compute straight path home after circuitous outward path

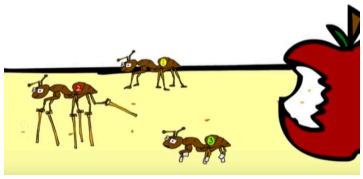




Location represented in 2D or 3D space?



"… desert ants must have developed some other *cognitive mechanism* to find their way back home"



Do ants count steps?

Scientific American, *The Thoughtful Animal*

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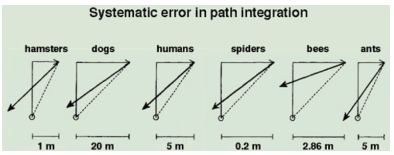
Navigation strategies

Path integration (aka *dead reckoning*)

- update distance and direction traveled from a starting point
- standard test for path integration ability: *triangle completion task*



Route or landmark based navigation

- remember specific sequences of positions, turns, landmarks, junctions
- series of place-action associations
- detours can be challenging if only use remembered routes

Navigation guided by a cognitive map or survey knowledge

- map may encode metric distances and angles between objects
- enables *novel shortcuts*, general route planning
- but routes still helpful to avoid constant planning from map
- path integration and routes can be used to build cognitive map

Spatial navigation with immersive virtual reality

- immersive virtual reality gives subjects a realistic interactive environment
- subject moves freely in a 12m x 12m room
- 3D location and orientation is tracked continuously, visual input updated
- cues: stereo/motion vision, proprioception, vestibular

From *route* knowledge to *survey* knowledge?

It has often been suggested that...

When learning the layout of a new environment, humans first learn particular routes to important locations, then gradually build up survey knowledge of the environment

Many researchers have assumed that...

We ultimately build a cognitive map that captures metric information about distances and angles

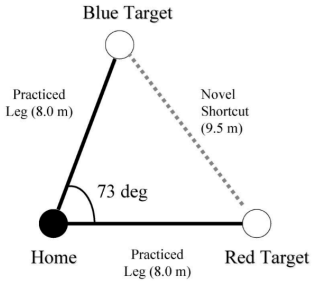
Questions: Foo, Warren, Duchon & Tarr (2005, 2007)

Do humans integrate route-based knowledge into survey knowledge of environmental layout?

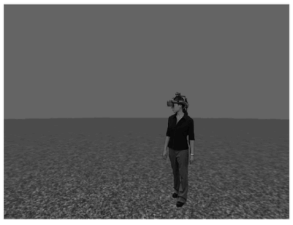
If so, what is the geometric structure of this spatial knowledge?

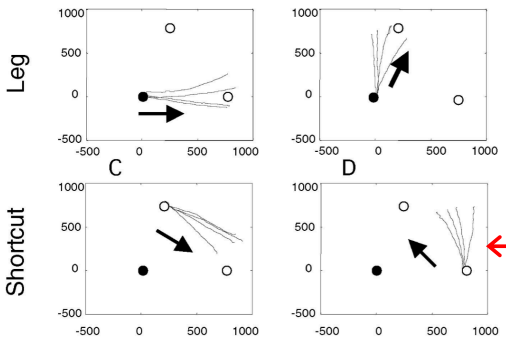
- do we represent metric properties e.g. distances, angles between known locations?
- or "weaker" geometric knowledge of layout?

Do humans combine traveled routes into a survey representation that permits metric navigation in the environment?



- two virtual worlds: desert or forest (8 subjects each)
- subjects learn two paths (home-blue, home-red) to *remembered target locations*, with fixed *angle* between the paths, until consistent, high accuracy
- after training, walk novel shortcut between endpoints
- if subjects represent *metric* information about distances and angles, should accurately walk novel shortcut
- if subjects rely on landmarks, expect more accurate performance for forest scene



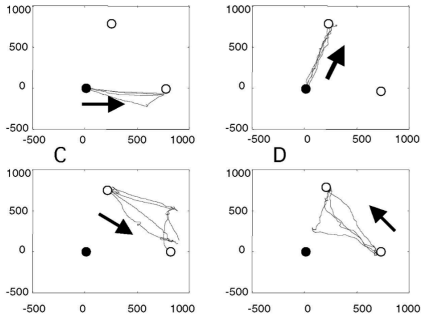


Do humans build survey knowledge from learned routes?

Does such survey knowledge preserve metric distances, angles?

Desert: initial bearing and distance to target was good for practiced legs, but large accumulated errors over path, not accurate shortcuts, undershoot turning angle and distance, no corrections

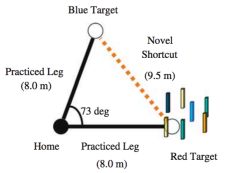
Forest: greater accuracy in reaching targets for both practiced paths and shortcuts, midcourse corrections

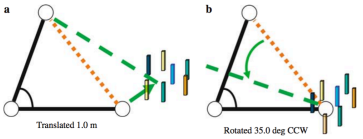


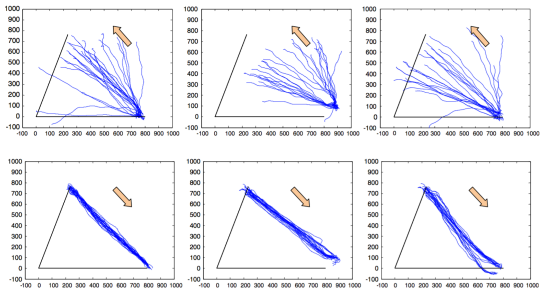
Without landmarks, humans cannot accurately perform simple shortcuts, spatial knowledge does not support navigation based on survey knowledge of metric distances, angles

Further exploring the role of landmarks to guide navigation

- same task as before
- virtual world: desert with 7 posts
- after training, translate or rotate posts near red target, on some trials (different subject groups)





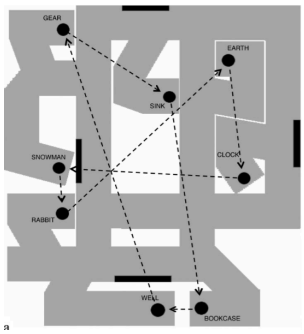


no change **translated** **rotated**

- landmarks near start of shortcut helped initial bearing, but then large errors accumulated
- landmarks at end of shortcut: rely on as "beacons" for navigation

Also suggests that our "survey knowledge" is not accurate

Exploring sources of spatial knowledge



Virtual world: hedge maze

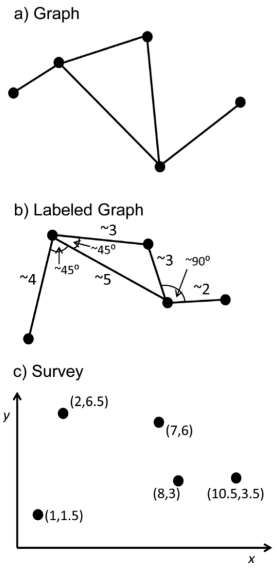
Subjects explored maze for 10 minutes to learn locations of 8 objects
- *active vs. passive* exploration (free vs. guided)

Different cue combinations during exploration:
- visual + vestibular + podokinetic (walking)
- visual + vestibular (wheelchair)
- visual (video)

Testing:
- walk along novel shortcut between pair of learned objects ...
  - ... using *remembered* locations
- *survey knowledge* needed for this task

Spatial knowledge based on labeled graphs

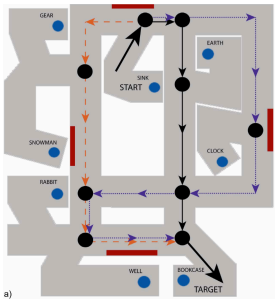
Chrastil & Warren (2014)



Graph-like representations of spatial knowledge

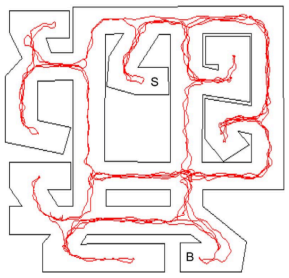
Graph in (a) only captures connectivity
- nodes represent places visited
- edges represent connectivity (routes)
- enables detours

Labeled graph in (b) includes metric info
- connections have distances, nodes have angles between paths that meet at node
- may be less precise than survey knowledge
- good enough for finding efficient routes or detours, novel shortcuts

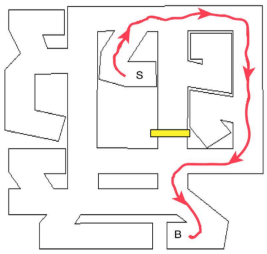


After training, walk between two learned objects using shortest path possible

40% trials: barrier appears, requiring detour from plan



Experienced paths between sink and bookcase



During test, walked the shortest *novel path* between sink & bookcase