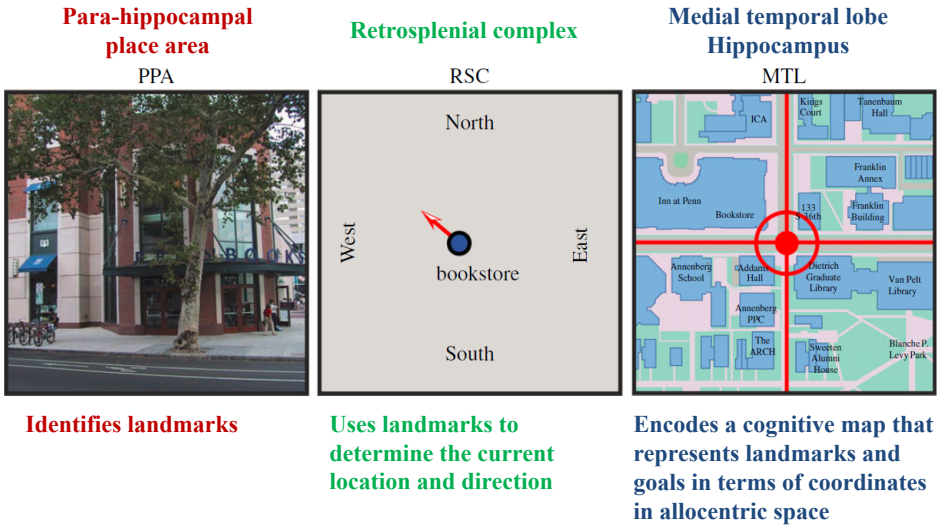
Spatial Navigation in Machines

Recap *division of labor* suggested by neuroscience

- role of different brain areas: PPA, RSC, MTL
- different cell types: place, grid, boundary, head direction

RatSLAM *biologically inspired* navigation system

- mapping the environment for navigation
- mobile robots and autonomous vehicles



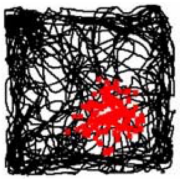
Identifies landmarks

Uses landmarks to determine the current location and direction

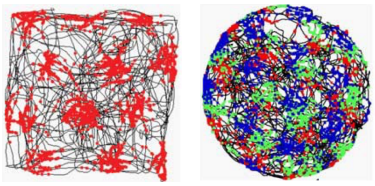
Encodes a cognitive map that represents landmarks and goals in terms of coordinates in allocentric space

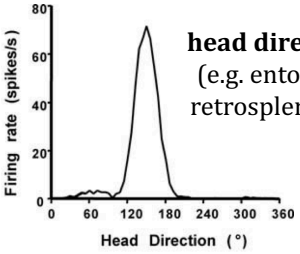
Can we build a navigation system for a mobile robot or autonomous vehicle that embodies similar roles?

place cells
(hippocampus)

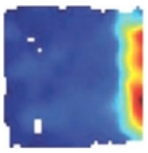


grid cells
(entorhinal cortex)





head direction cells
(e.g. entorhinal and retrosplenial cortex)



boundary cells
(e.g. entorhinal cortex)

Can we build a navigation system for a mobile robot or autonomous vehicle that uses analogous units?

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Recap *division of labor* suggested by neuroscience

- role of different brain areas: PPA, RSC, MTL
- different cell types: place, grid, boundary, head direction

→ RatSLAM *biologically inspired* navigation system

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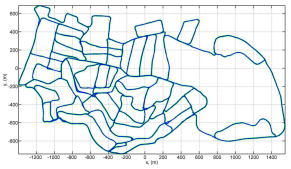
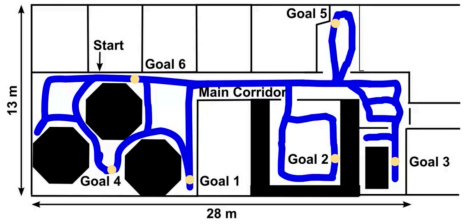
RatSLAM *biologically inspired* navigation system
Milford & Wyeth


SLAM = **S**imultaneous **L**ocalization **A**nd **M**apping

At a large scale, over long time, in a changing environment

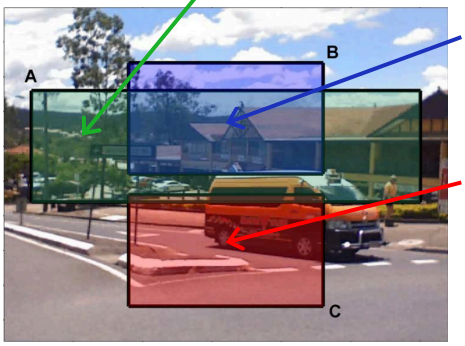


https://www.youtube.com/watch?v=-0XSUi69Yvs

Sensory input from vision

A. Visual landmarks – *local views*

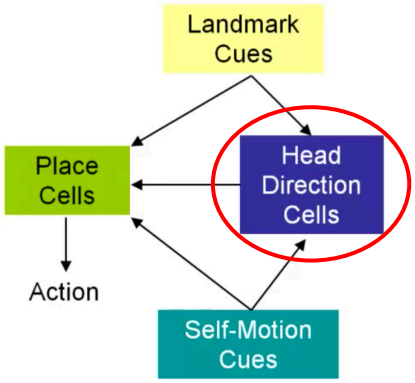


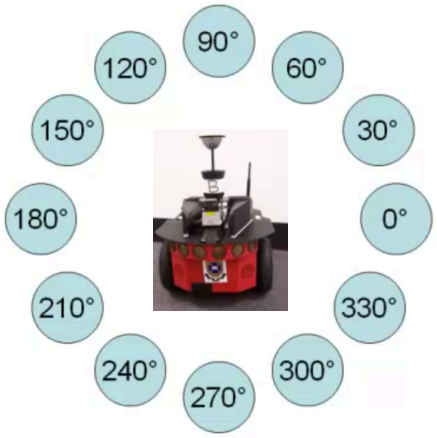
B. Sense *rotation* of car from the shift of visual texture to the left or right

C. Sense *translation* of car from shift of visual texture along ground

Uses methods for measuring image motion and recognizing remembered scenes based on *mean absolute difference*

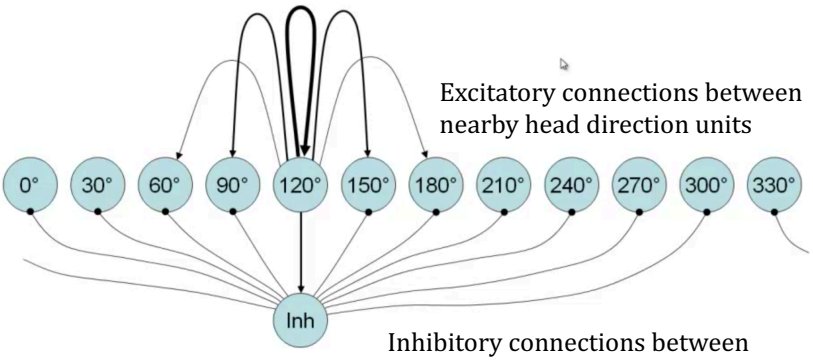
Representing head direction in RatSLAM v1





e.g. vehicle rotation, translation

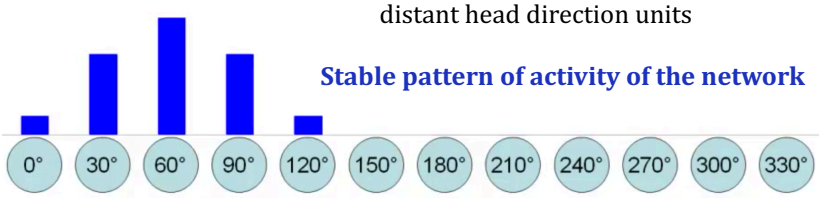
Neural network of head direction units



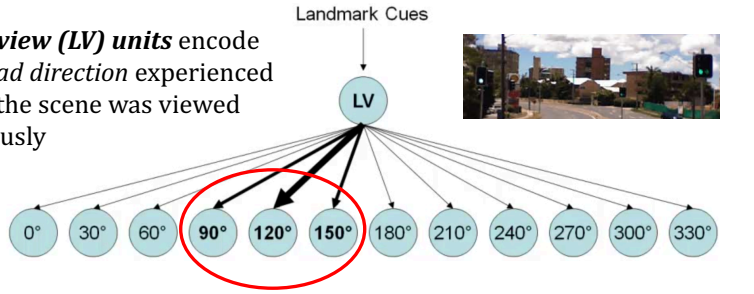
Excitatory connections between nearby head direction units

Inhibitory connections between distant head direction units

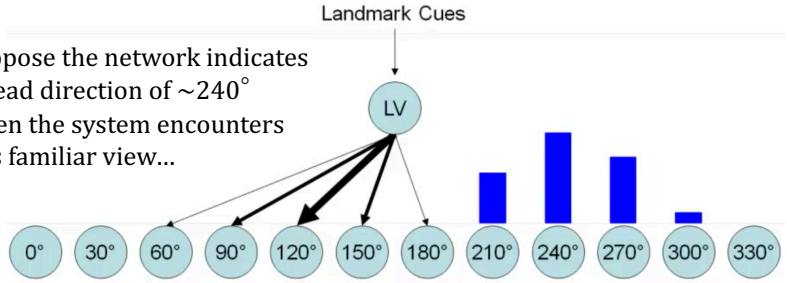
Stable pattern of activity of the network



Local view (LV) units encode the *head direction* experienced when the scene was viewed previously

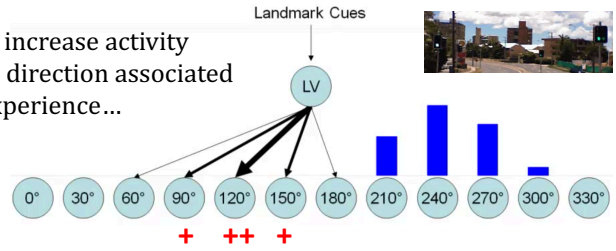


Suppose the network indicates a head direction of ~240° when the system encounters this familiar view…

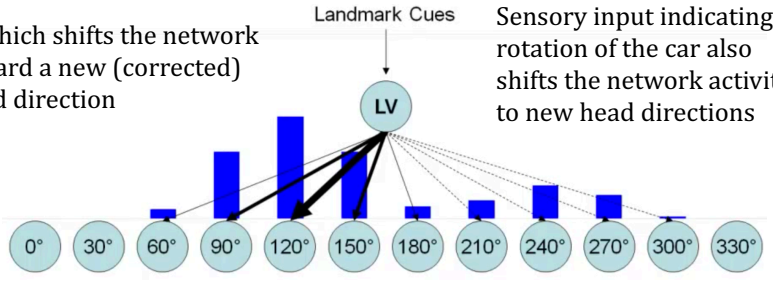


Updating the head direction network

Local view units increase activity around the head direction associated with previous experience…

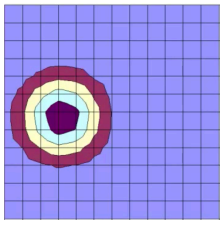


… which shifts the network toward a new (corrected) head direction



Sensory input indicating rotation of the car also shifts the network activity to new head directions

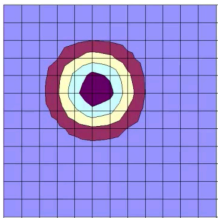
2D neural network of place units



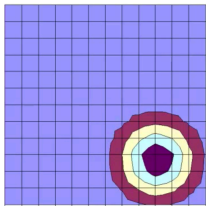
Each location on the grid represents a *place unit* that is active when the agent is at a particular location on a 2D grid (ground or floor)

Bulls' eye pattern of activation shows a stable pattern of activity of the place network

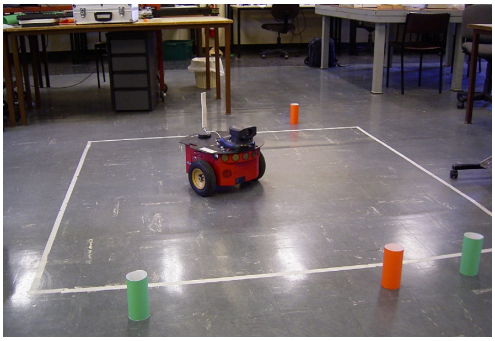
Sensory input indicating small translations shifts activity of the network to a new location

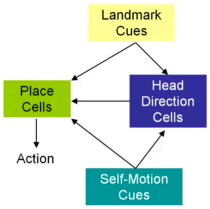


Local view (LV) units also encode the *place* experienced when the scene was viewed previously, and increase activity in a new (corrected) place in the network



Testing RatSLAM v1



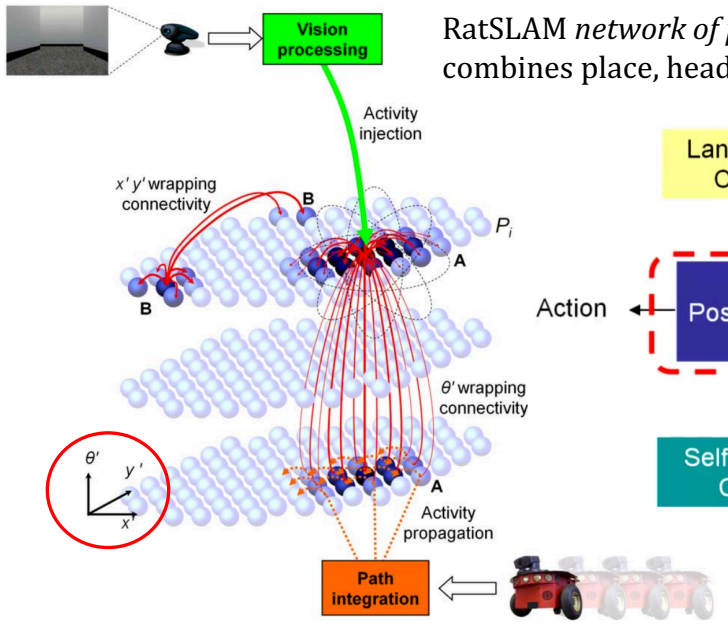


Could robot keep track of its location in a 2m x 2m arena with colored "landmarks"?

(Milford & Wyeth, 2003)

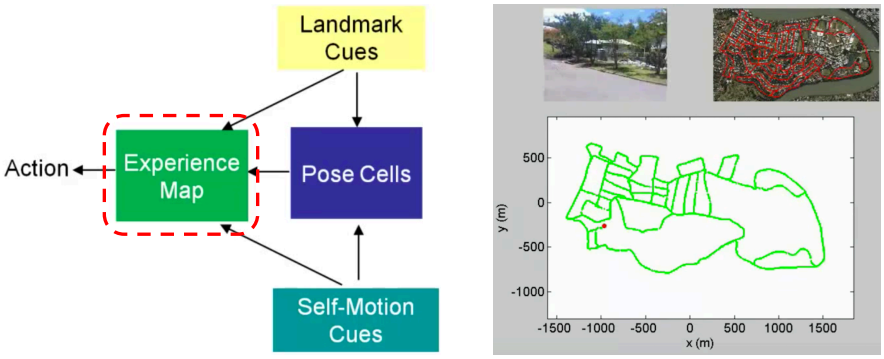
Localization was successful in the short term, but performance of the simple place and head direction networks ***failed over the long term***

Why??

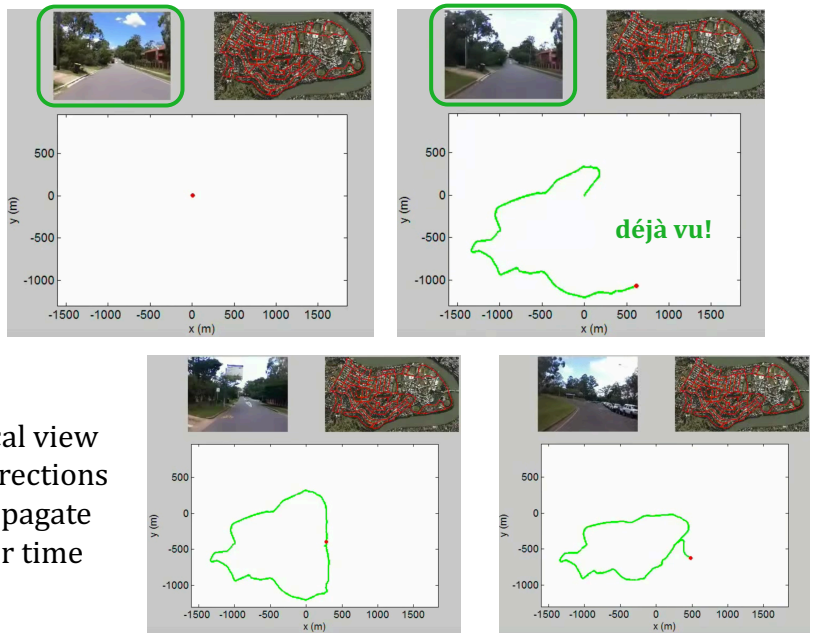


RatSLAM *network of pose cells* combines place, head direction

Experience map resembles a cognitive map

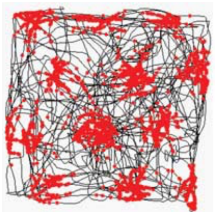


Experience map combines *path integration* during exploration of new areas with *local view calibration* (corrections) when past landmarks are revisited



Local view corrections propagate over time

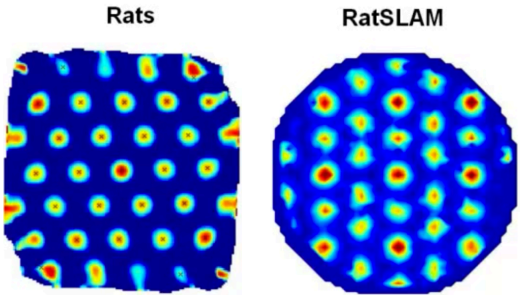
Pose cells behave like grid cells



Conjunctive grid cells in deeper layers of entorhinal cortex respond in a grid-like pattern, for a particular head direction

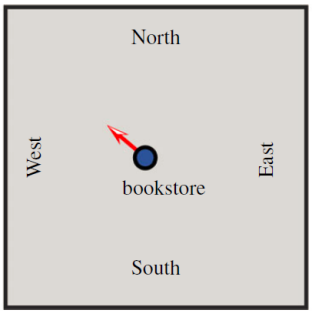
Replicating the seminal Moser experiments in simulation…

… *Pose cells* in RatSLAM behave in a similar way



Para-hippocampal place area
PPA

Retrosplenial complex
RSC



Medial temporal lobe Hippocampus
MTL

Identifies landmarks

Uses landmarks to determine the current location and direction

Encodes a cognitive map that represents landmarks and goals in terms of coordinates in allocentric space

Can we build a navigation system for a mobile robot or autonomous vehicle that embodies similar roles?

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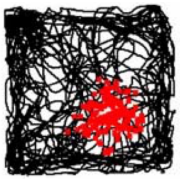
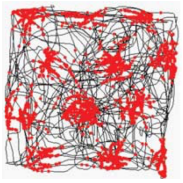
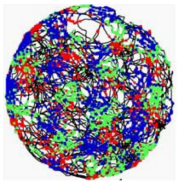
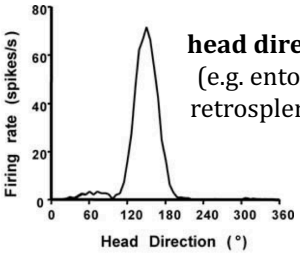


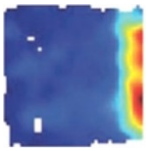
grid cells
(entorhinal cortex)







head direction cells
(e.g. entorhinal and retrosplenial cortex)



boundary cells
(e.g. entorhinal cortex)

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Modeling “whisking” in rats with whiskered robots

Tony Prescott, University of Sheffield