Navigation

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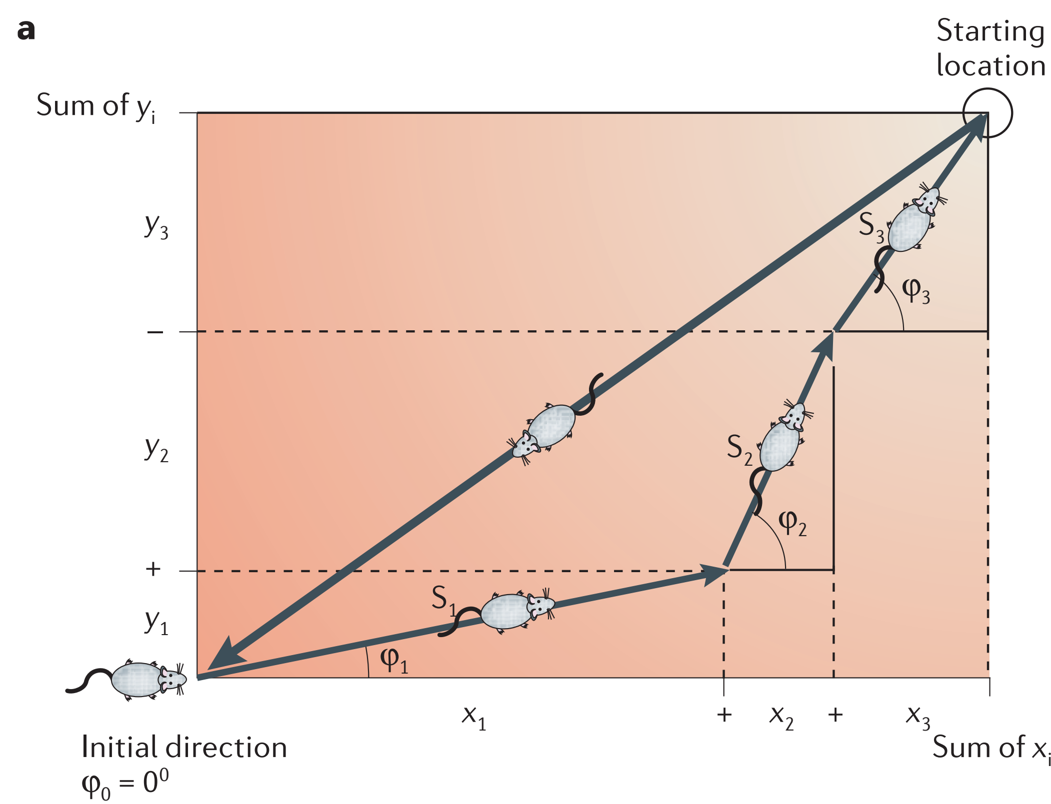
Problem

- we talked about how to plan motion toward targets avoiding obstacles
- in many cases, information about targets may be available through a map that represents where relevant locations are in the world
- to use a map, a robot/organism needs to known "where it is" on the map: ego-location estimation
- that estimate must be updated as a robot/organism moves…

Dead-reckoning/path integration

- if the agent knows its current velocity=heading direction + speed (and keeps track of time), it can estimate its change of position by integration



[McNaughton et al., *Nature reviews neuroscience* 2006]

Dead-reckoning/path integration

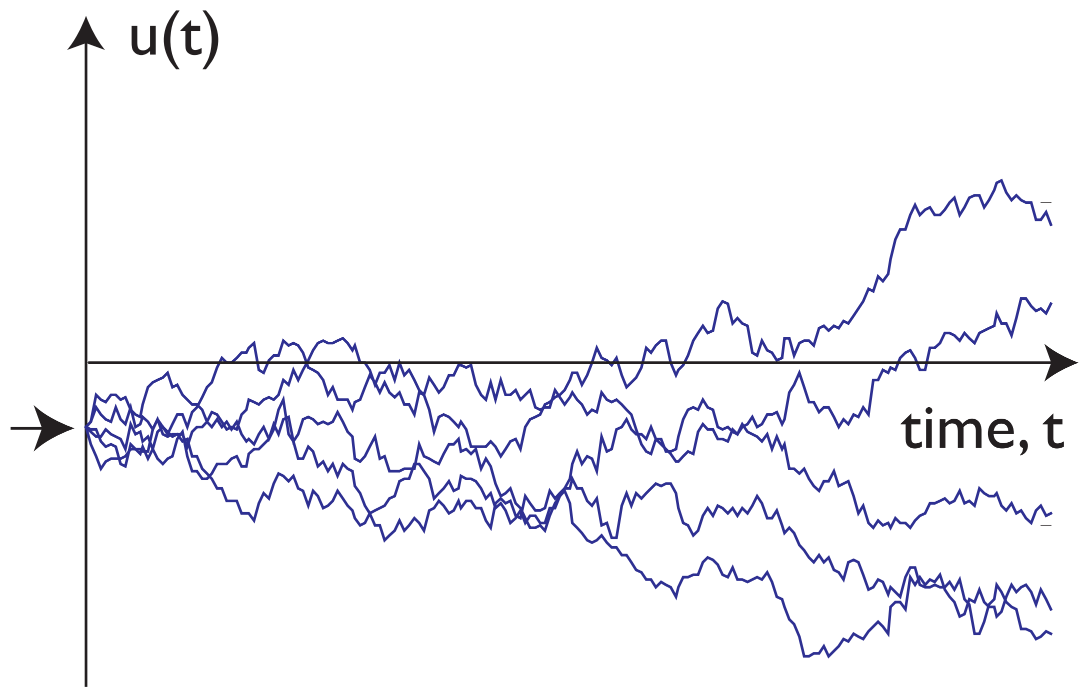
- a long history in technology… dating back to literal "navigation": sailing ships…
  - estimating heading direction based on a compass
  - estimating speed by counting "knots"… which entails an estimate of time
  - updating position in a map

Dead-reckoning/path integration

- modern technology increases the precision
  - e.g. inertial guidance by measuring acceleration
  - precise measurement of time
  - with good control, the control signals can also be used to predict the new state …
  - optimal estimation integrates prediction and measurement…

Dead-reckoning/path integration

- fundamental problem
  - the integration leads to an accumulation of uncertainty…
  - the principle of Brownian motion…

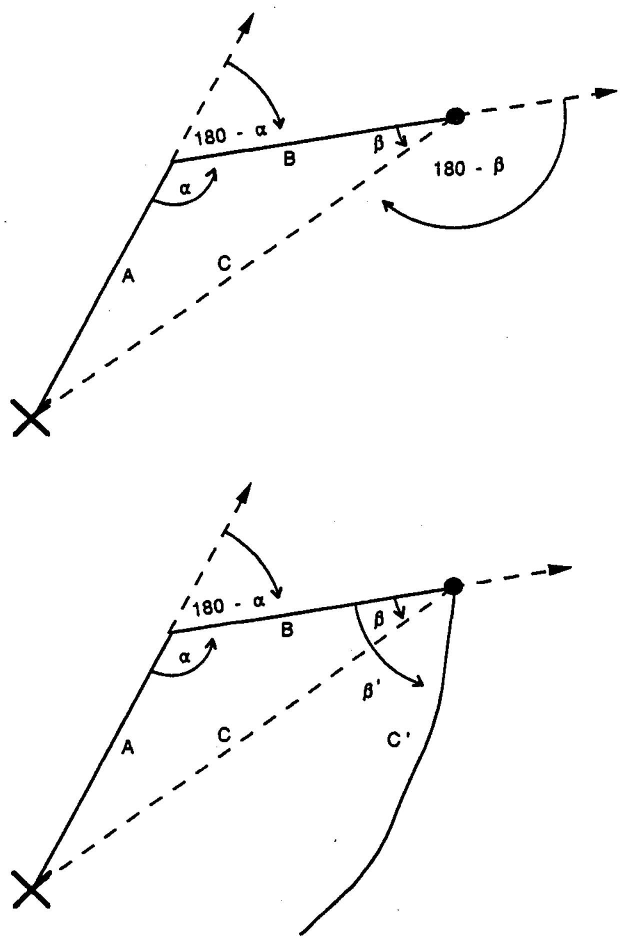


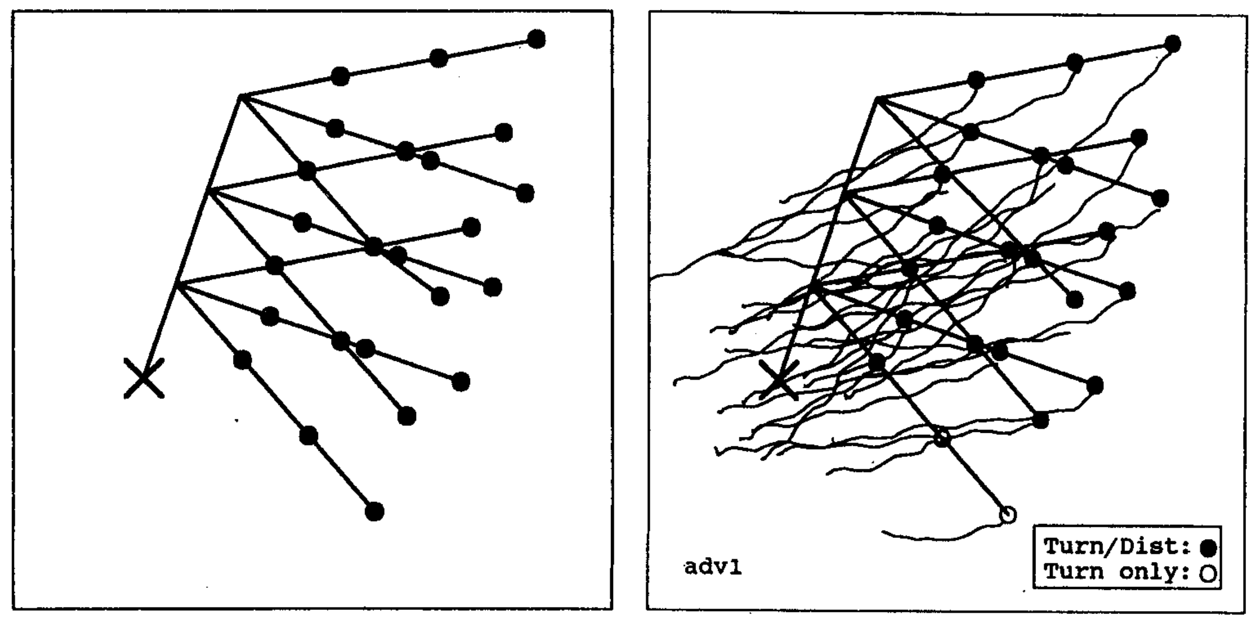
Dead-reckoning/path integration

- a need for “recalibration” or re-setting of the estimate.. based on “recognizing” the true location on the map…
- historical solution:
  - landmark recognition…
  - triangulation
- modern variants based on special beacons, GPS etc

Dead-reckoning/path integration

- animals including humans use path integration

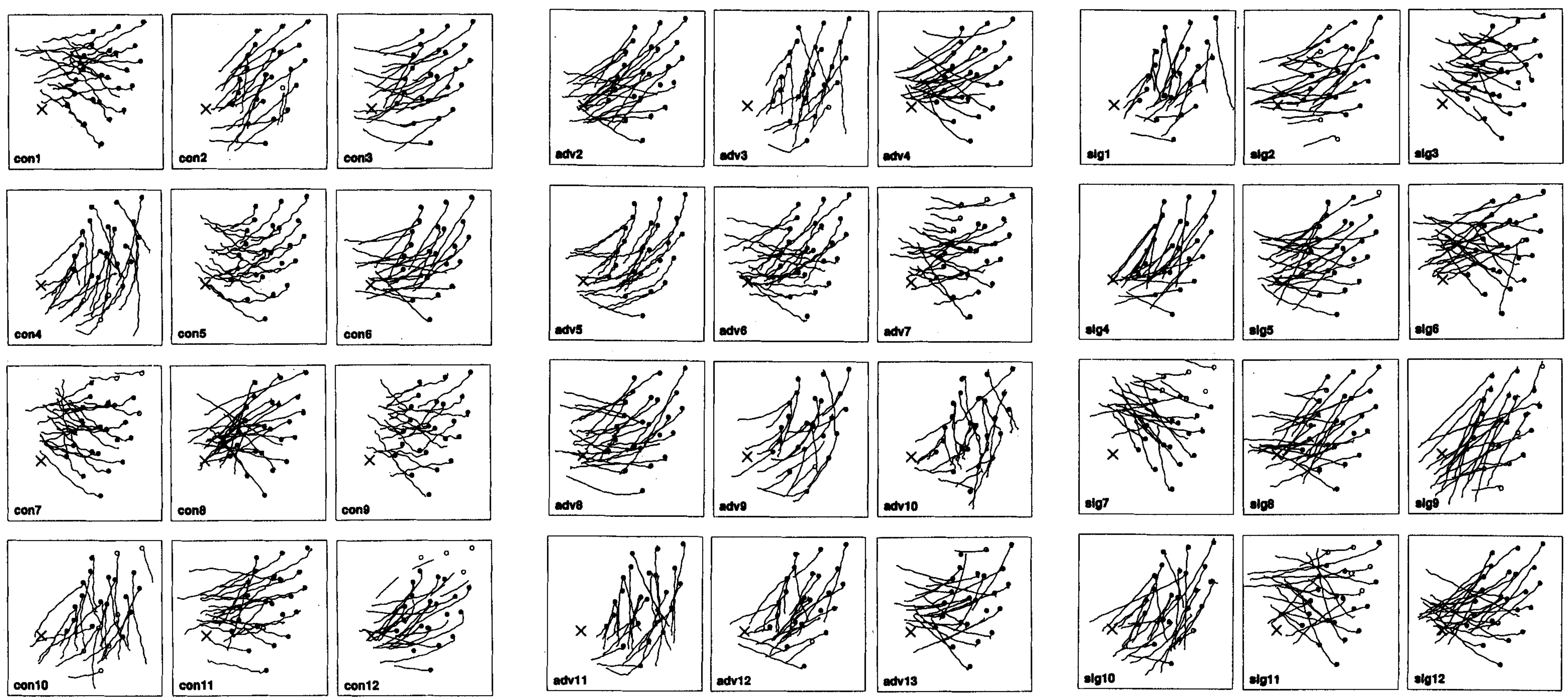




[Loomis, Klatzky, 1993]

Dead-reckoning/path integration

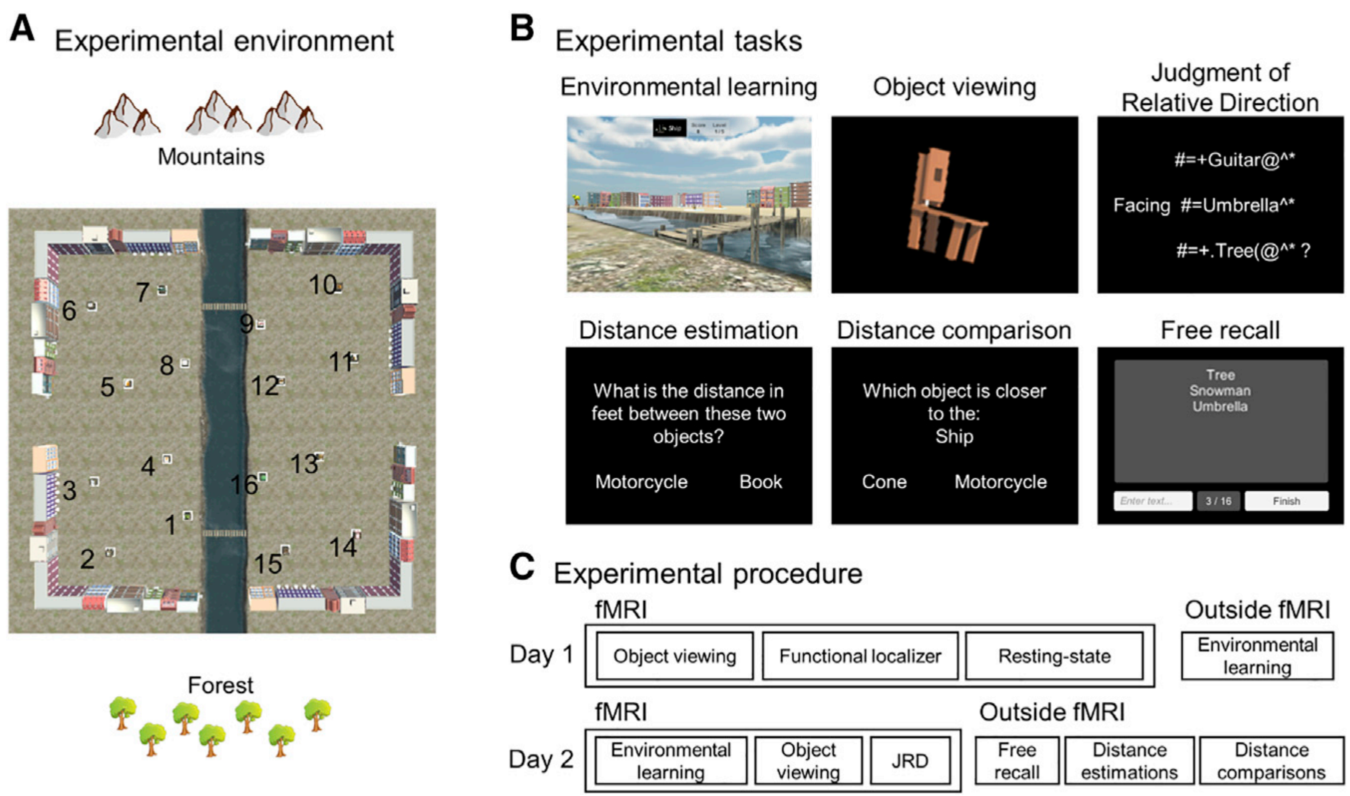
- animals including humans use path integration



blind from birth | blind from accident | seeing

Landmark recognition

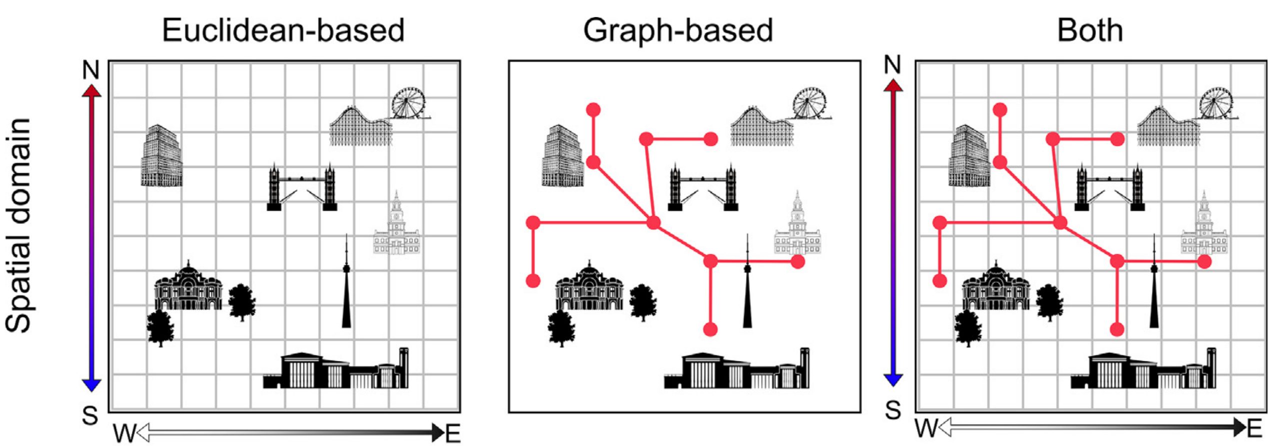
- landmarks are not necessarily objects…
- empirical evidence that views serve to estimate ego-position and pose
- evidence for views used from animal behavior and neural data



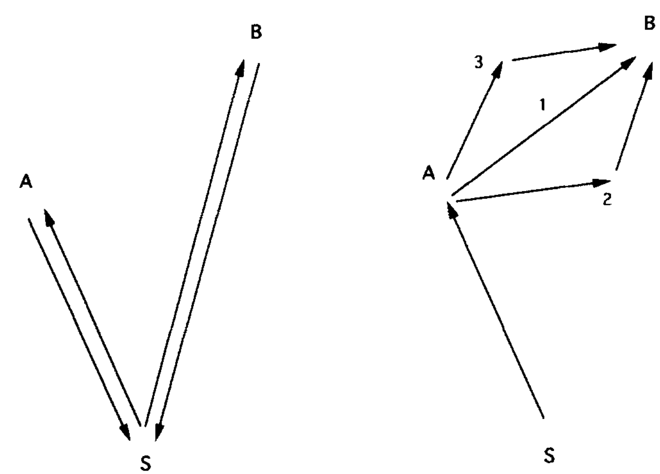
[Peer, Epstein, 2021]

Maps

- when can we say does an animal use a map?
- rather than use stimulus-response chaining
- => when it can take short-cuts



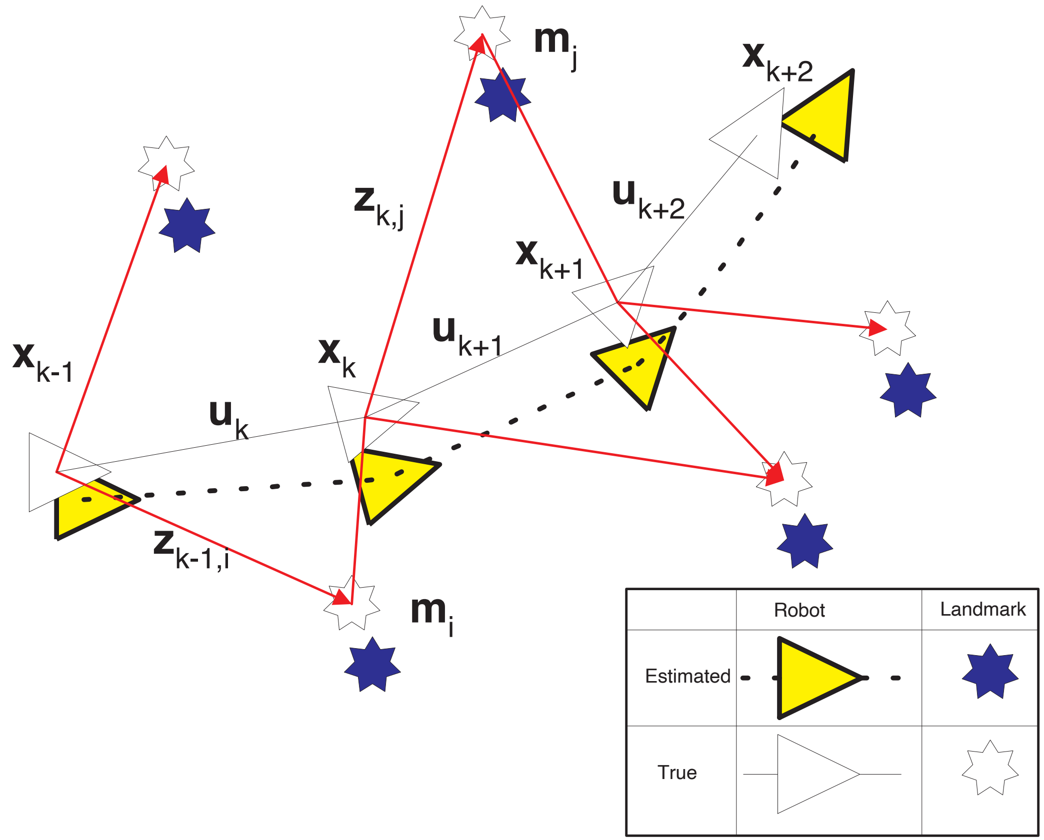
[Peer et al, 2020]



[Poucet, 1993]

SLAM

- Simultaneous Localization and Mapping

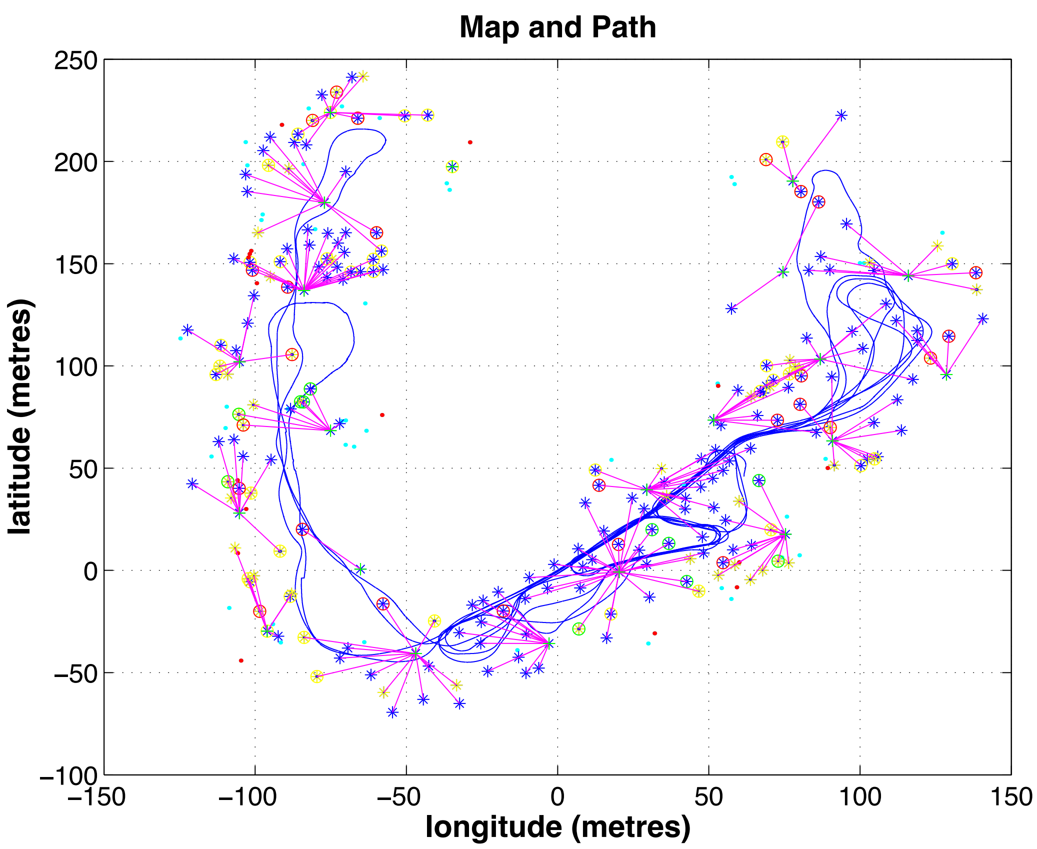


[Durrant-Whyte, Baily, 2006]

SLAM

- problem of learning/optimizing path integration… and using this to associated landmark information with locations

- problem of loop closure



(Neural) dynamics of navigation

- dynamics for ego-position estimation
- dynamical approach to learning the map: network of locations (home bases) at which the agent knows where it is relative to others
- dynamics of path planning

ELSEVIER

Robotics and Autonomous Systems 20 (1997) 133–156

Robotics and Autonomous Systems

Self-calibration based on invariant view recognition: Dynamic approach to navigation

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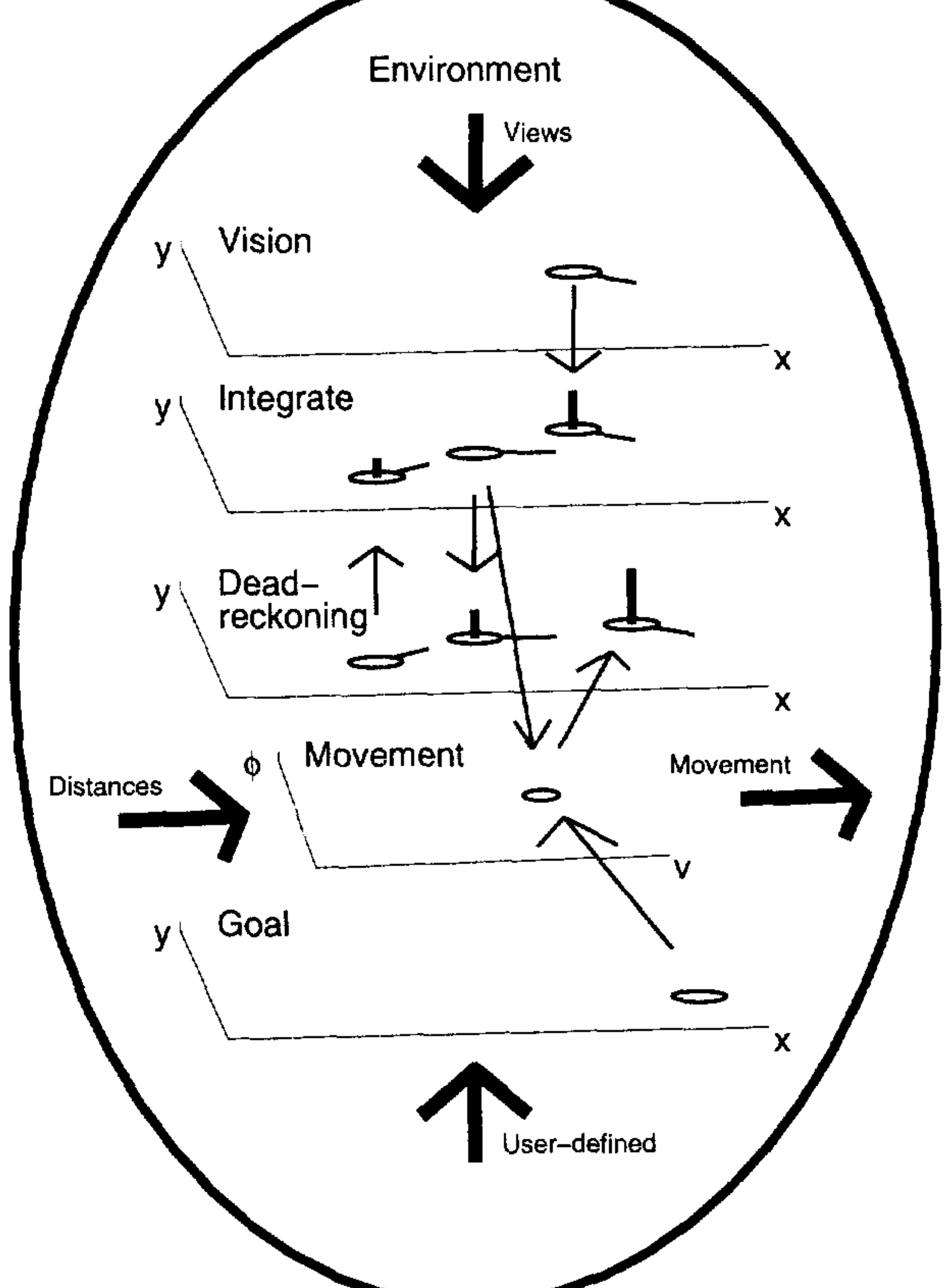
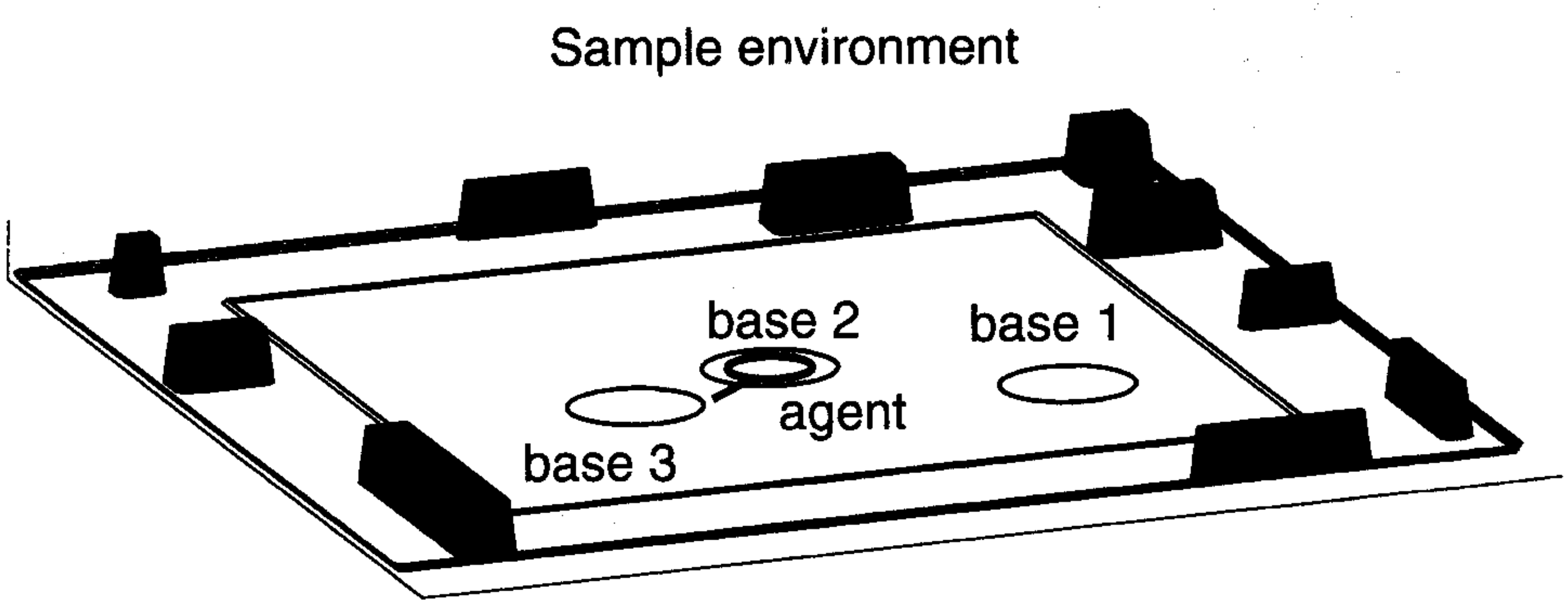
[b] Centre de Recherche en Neurosciences, Cognitives, CNRS 13402 Marseille, Cédex 20, France

Neural and behavioral architecture



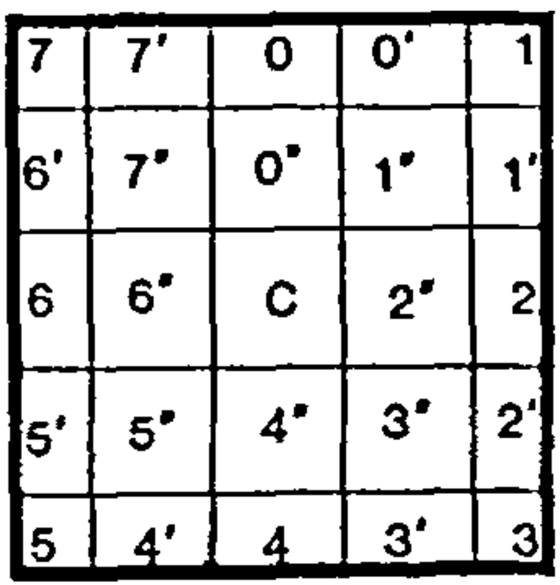
Visual place navigation

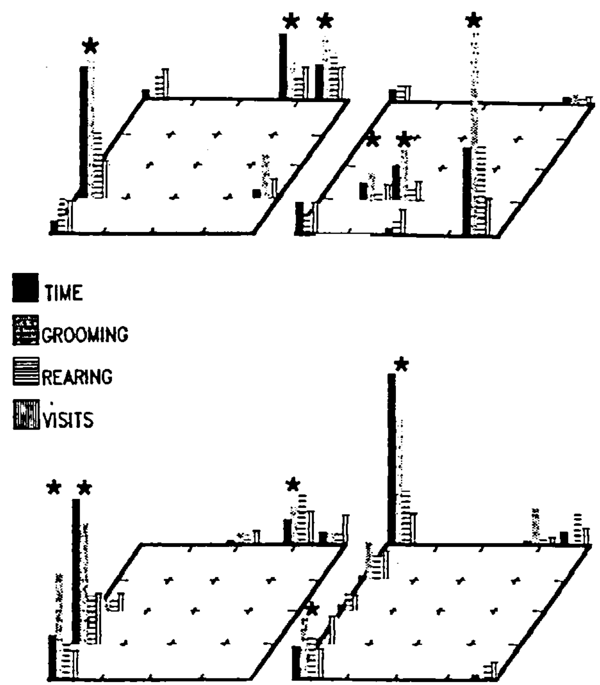
- a visual surround (unsegmented) acquired in clusters around particular locations (home bases)
- views are stored together with current position estimate (translation/rotation)

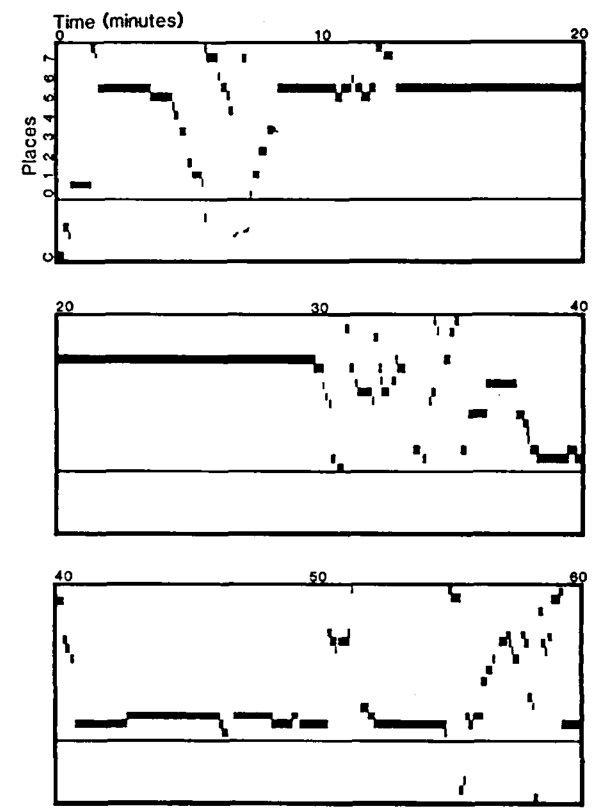


Evidence for home bases

- animals in given terrain build home bases by rearing in locations where they spend most of their time



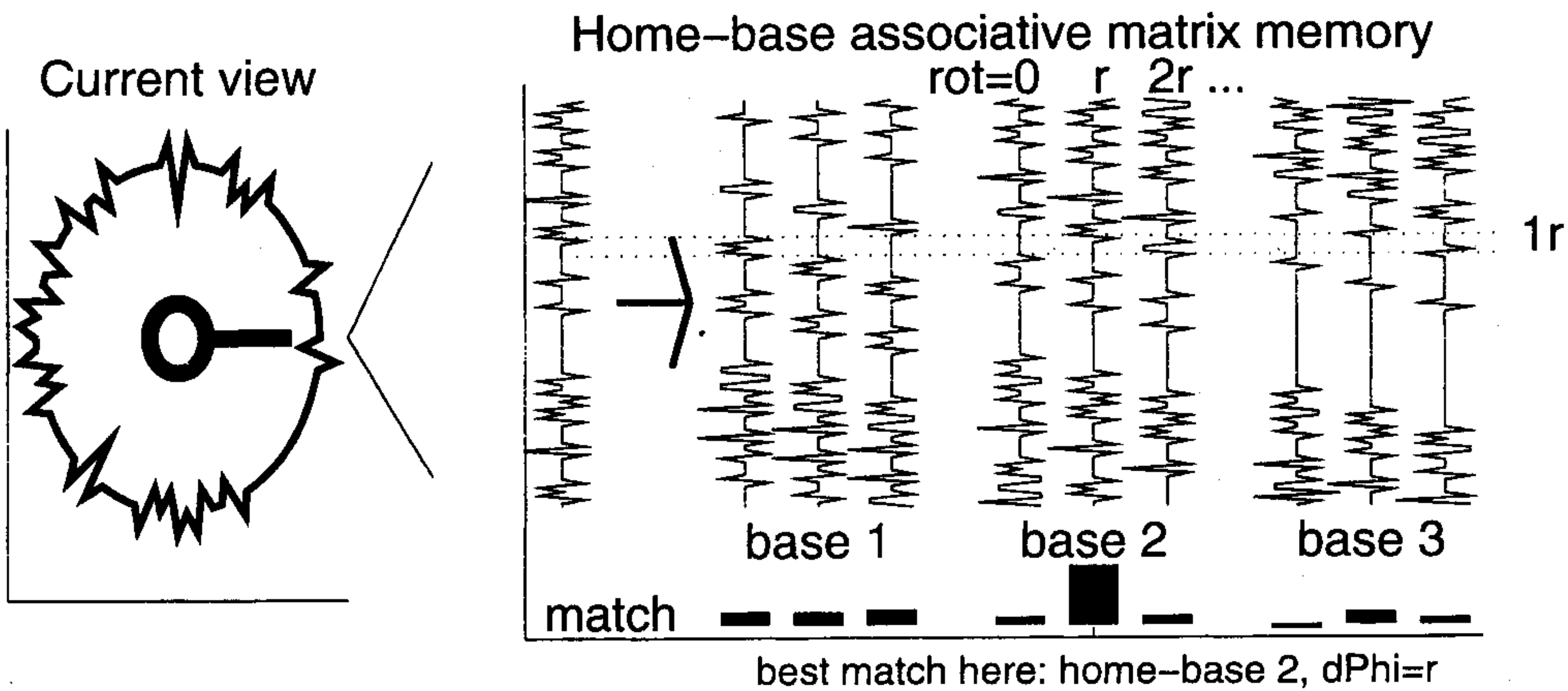




[Eilam, Golani, 1989]

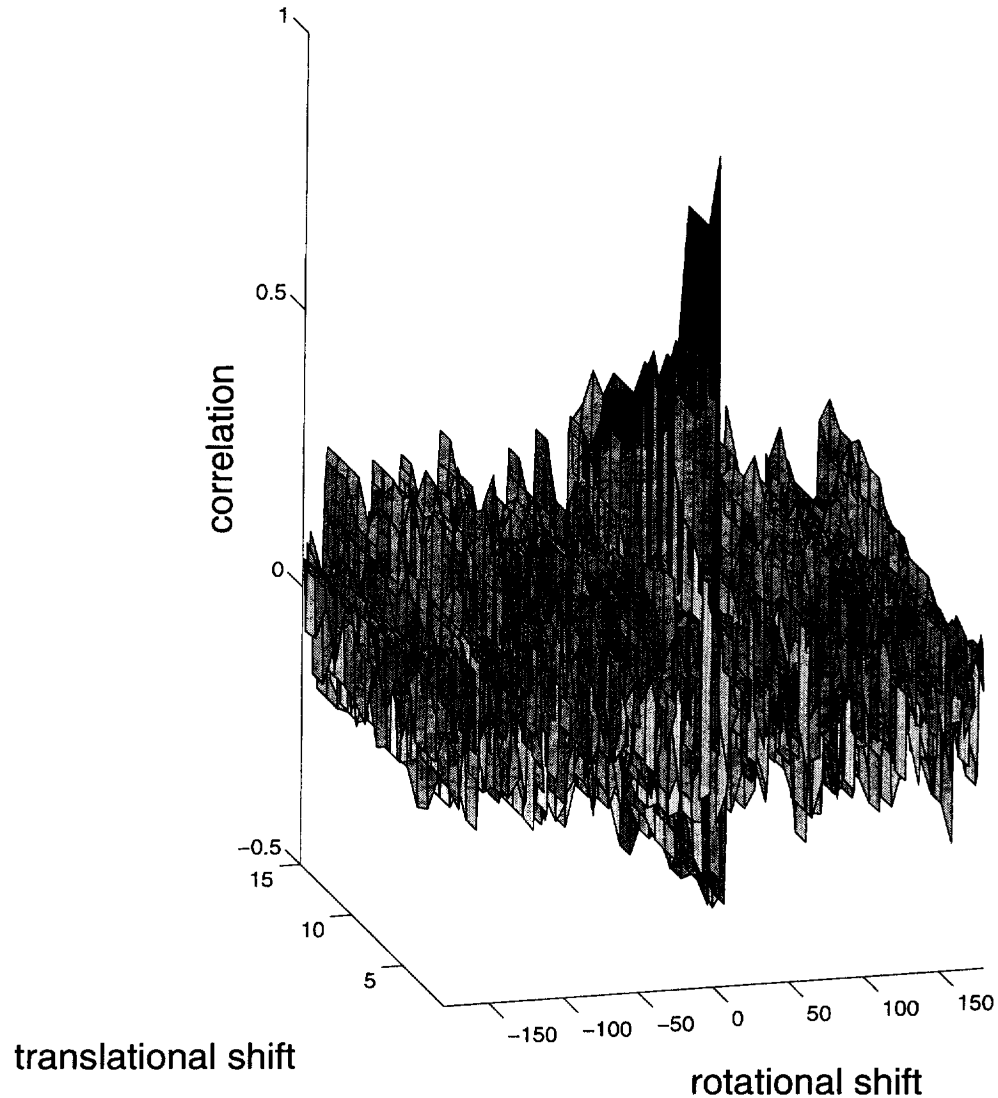
Visual place navigation

- Each view in home base is matched to current view…. with all possible rotations actively generated from memorized view



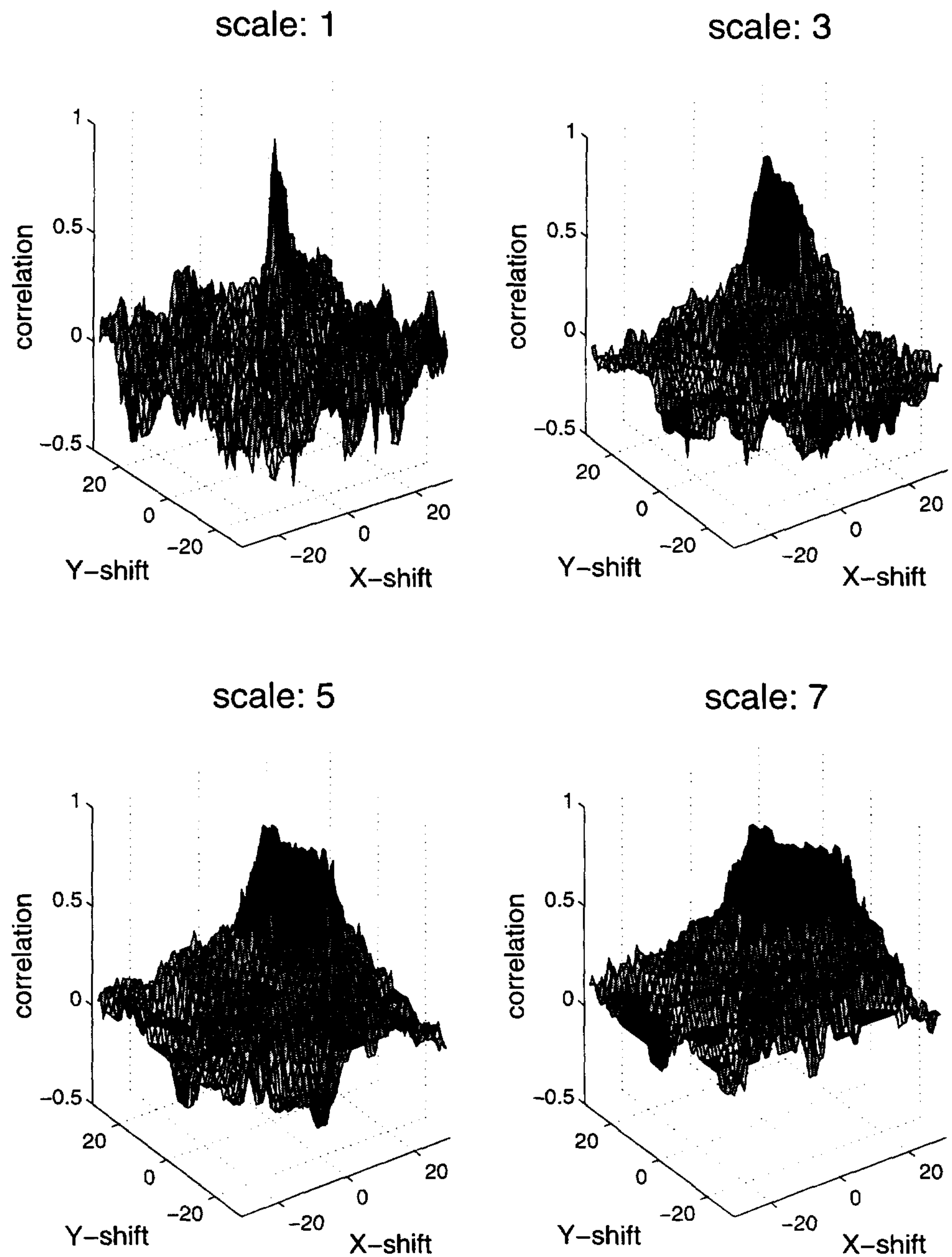
Visual place navigation

- Correlation function across rotation angle peaks sharply at true angular orientation of agent, even if translatior is not precise…
- so that estimation of orientation is possible while agent is in recepti field of place cell



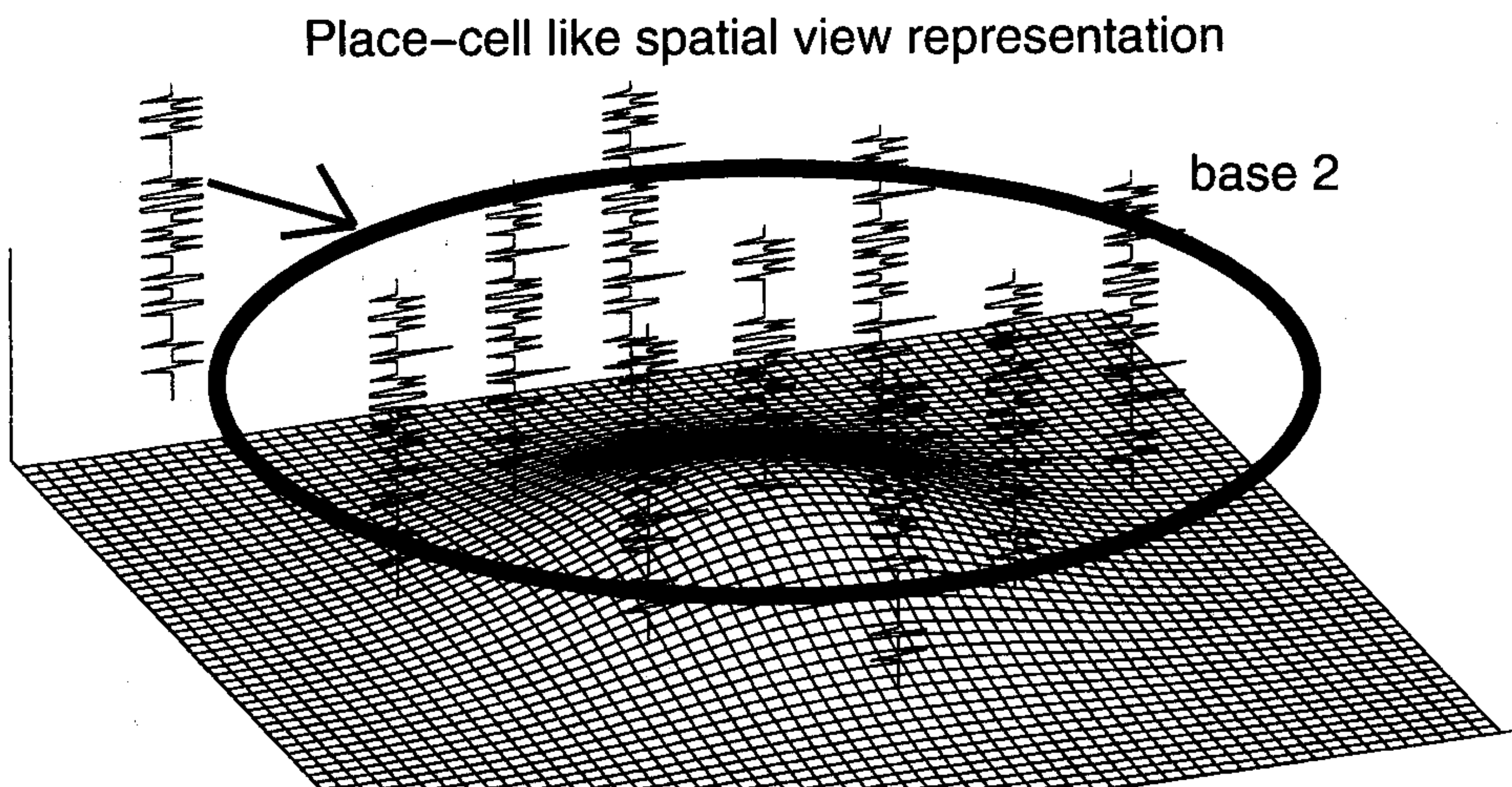
Visual place navigation

- Correlation with actively shifted memory views decays spatially in way that reflects how distal the view is…. place field..

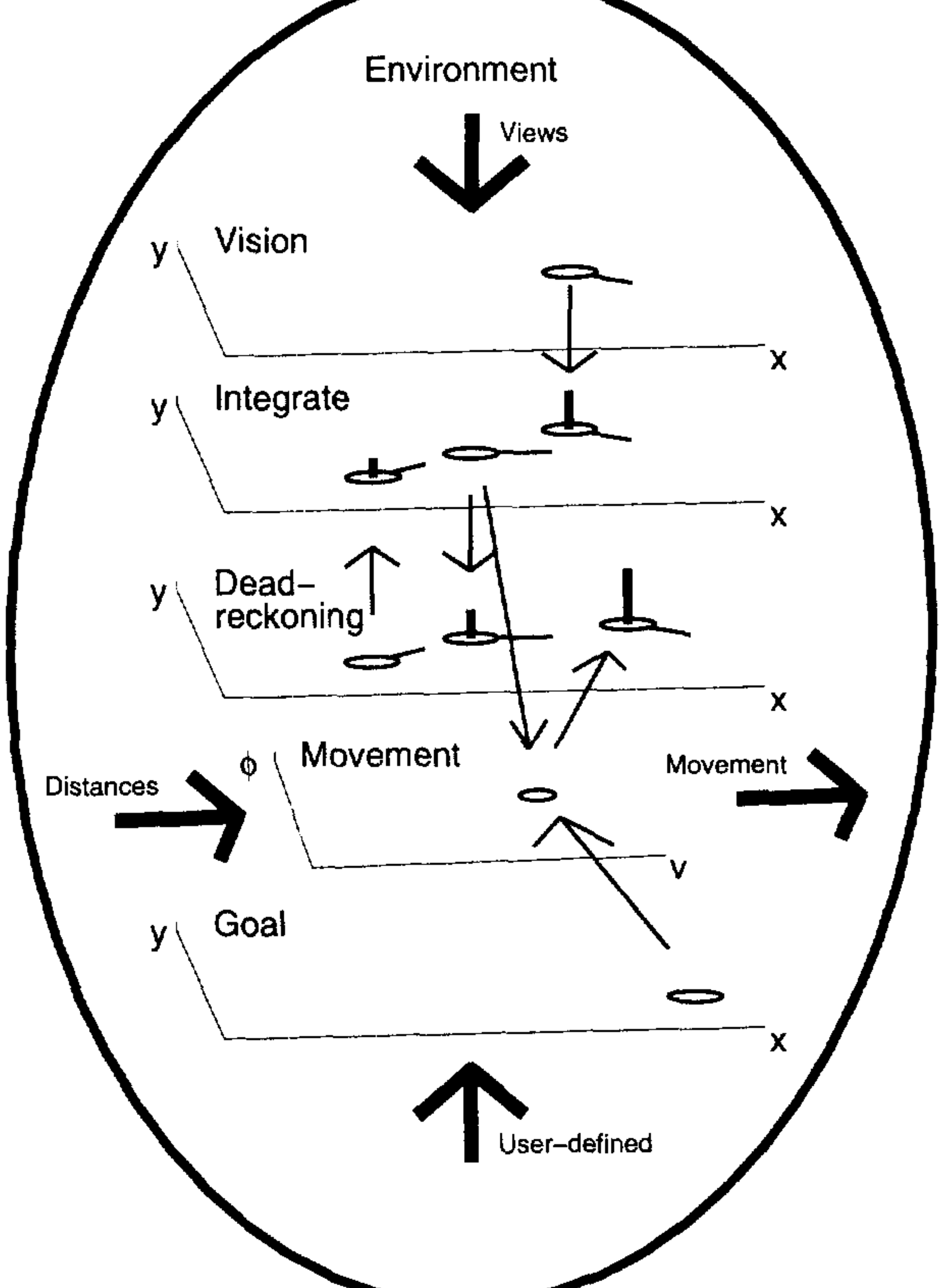


Visual place navigation

- The level of correlation across multiple views within a home base generates a place view representation of translation => position estimate

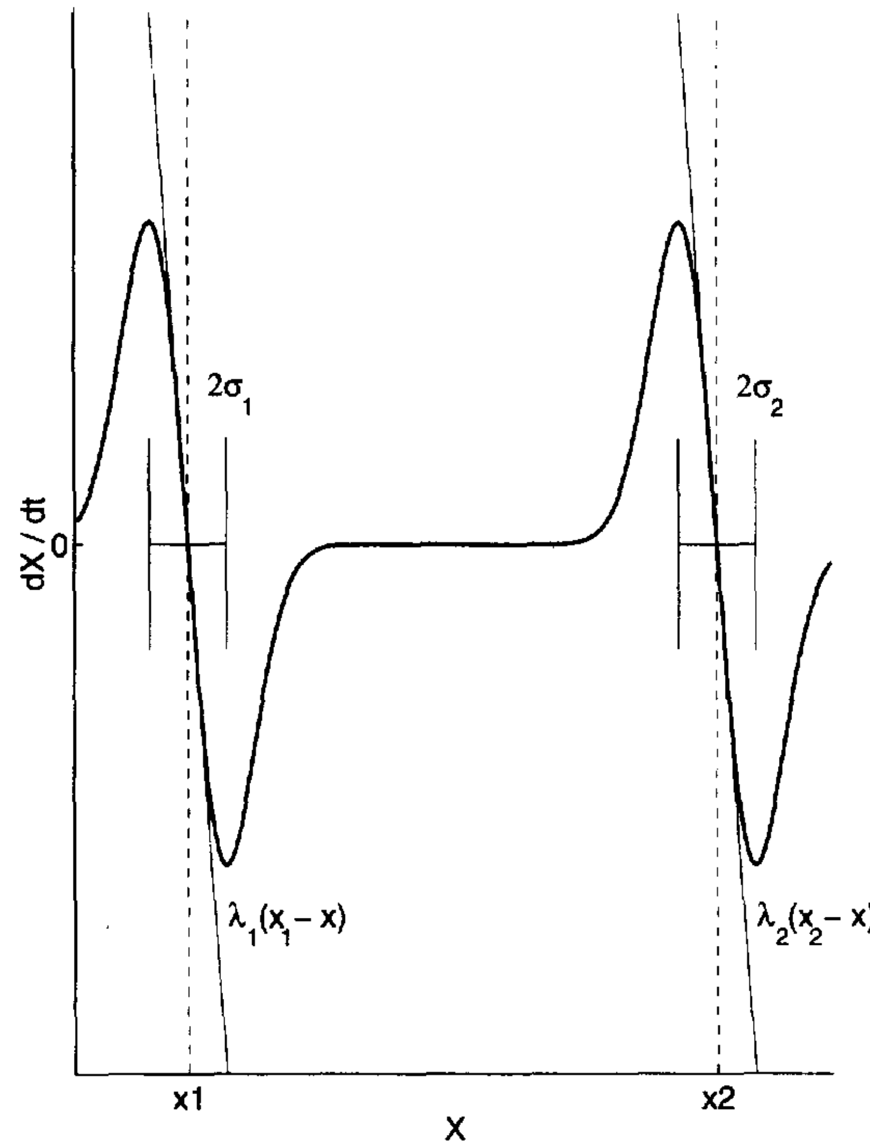


Neural and behavioral architecture



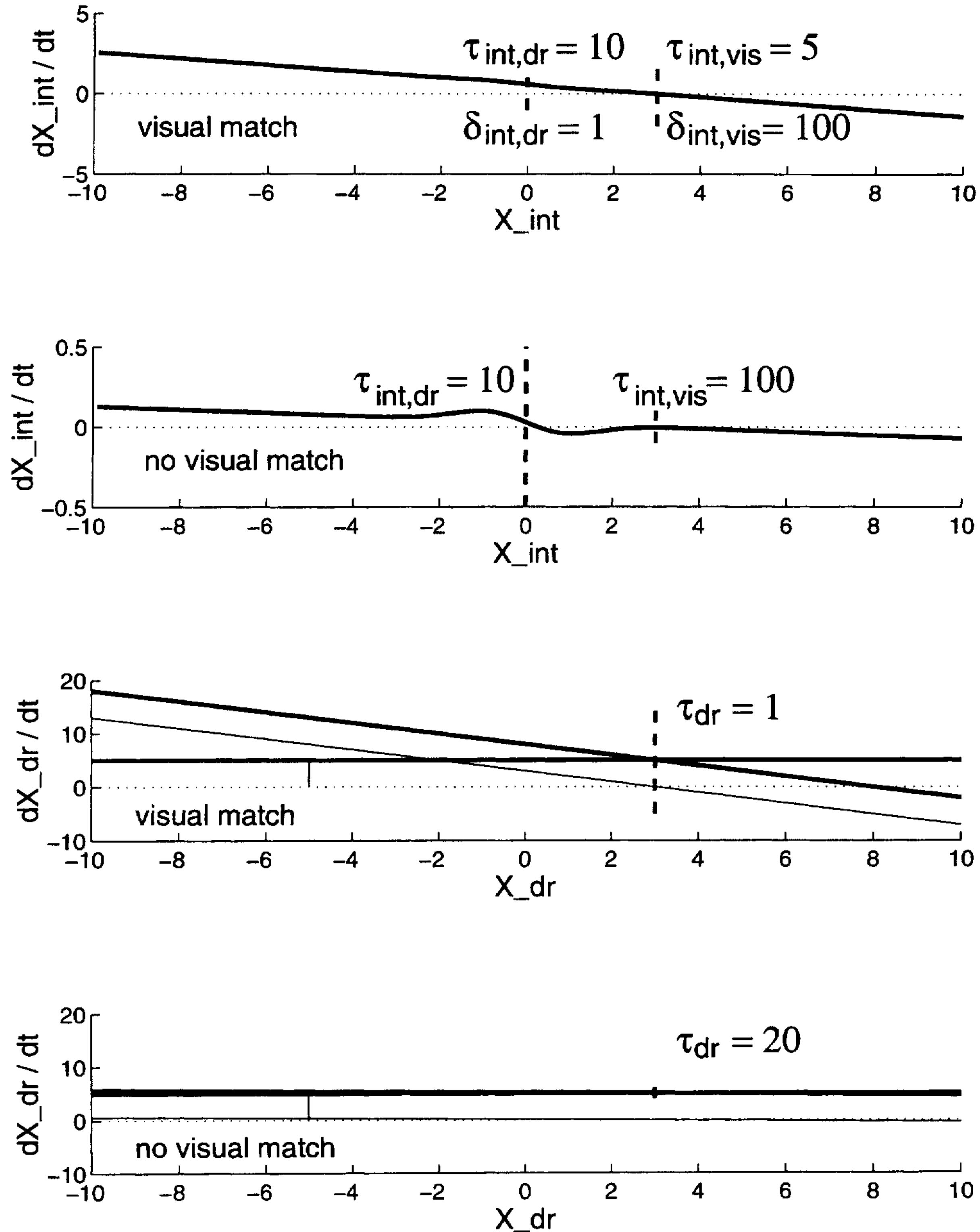
Integration by an attractor dynamics

- every sensory estimate contributes a "force-let" to a dynamical system whose attractor is the estimate of ego-position …
- for vision: space to rate code… removes the problem of normalization



Recalibration from instability

- with visual match, a strong attractor force-let induces instability in which the estimate gets reset to the visually specified estimate
- which resets the dead-reckoned estimate as well



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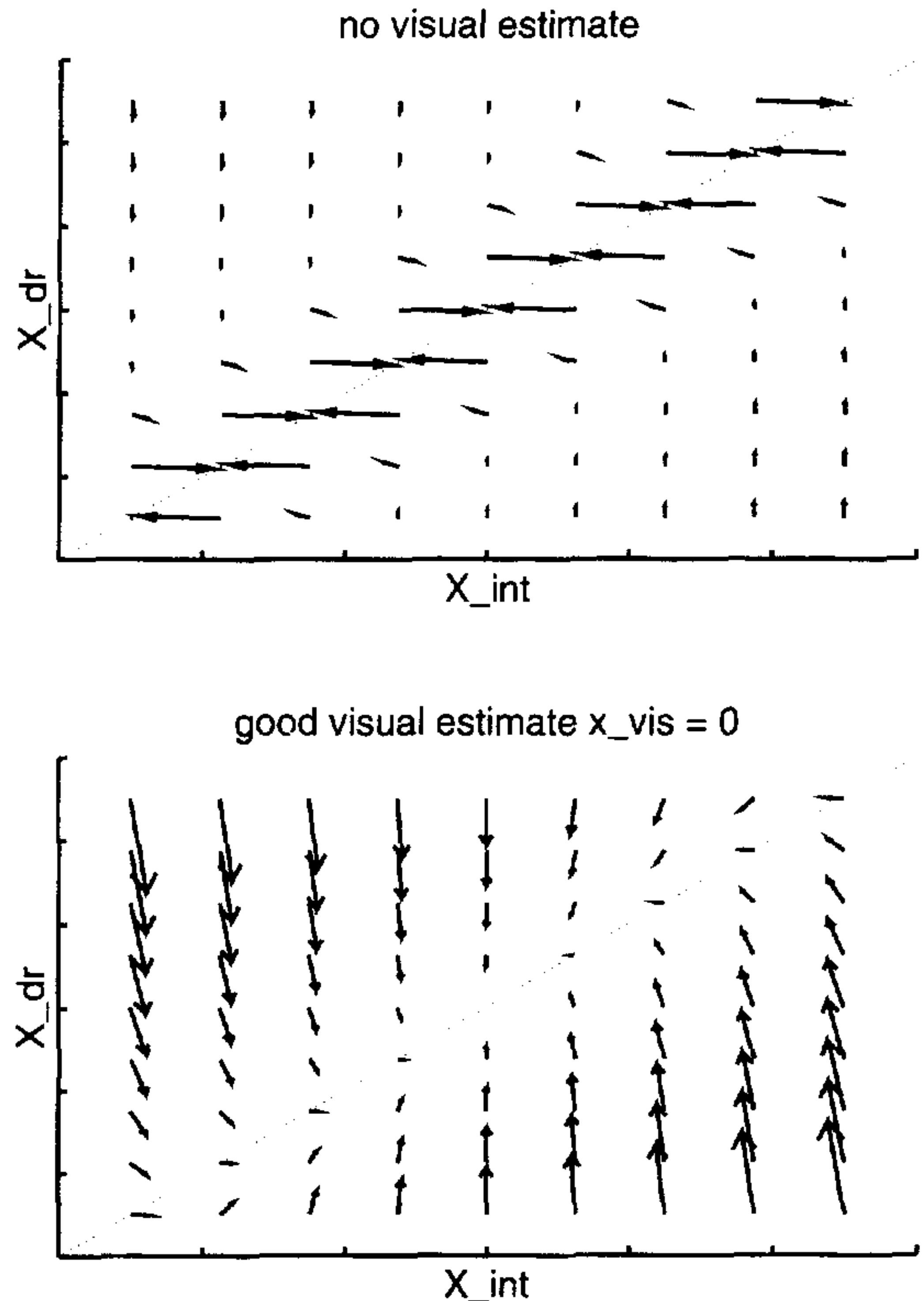
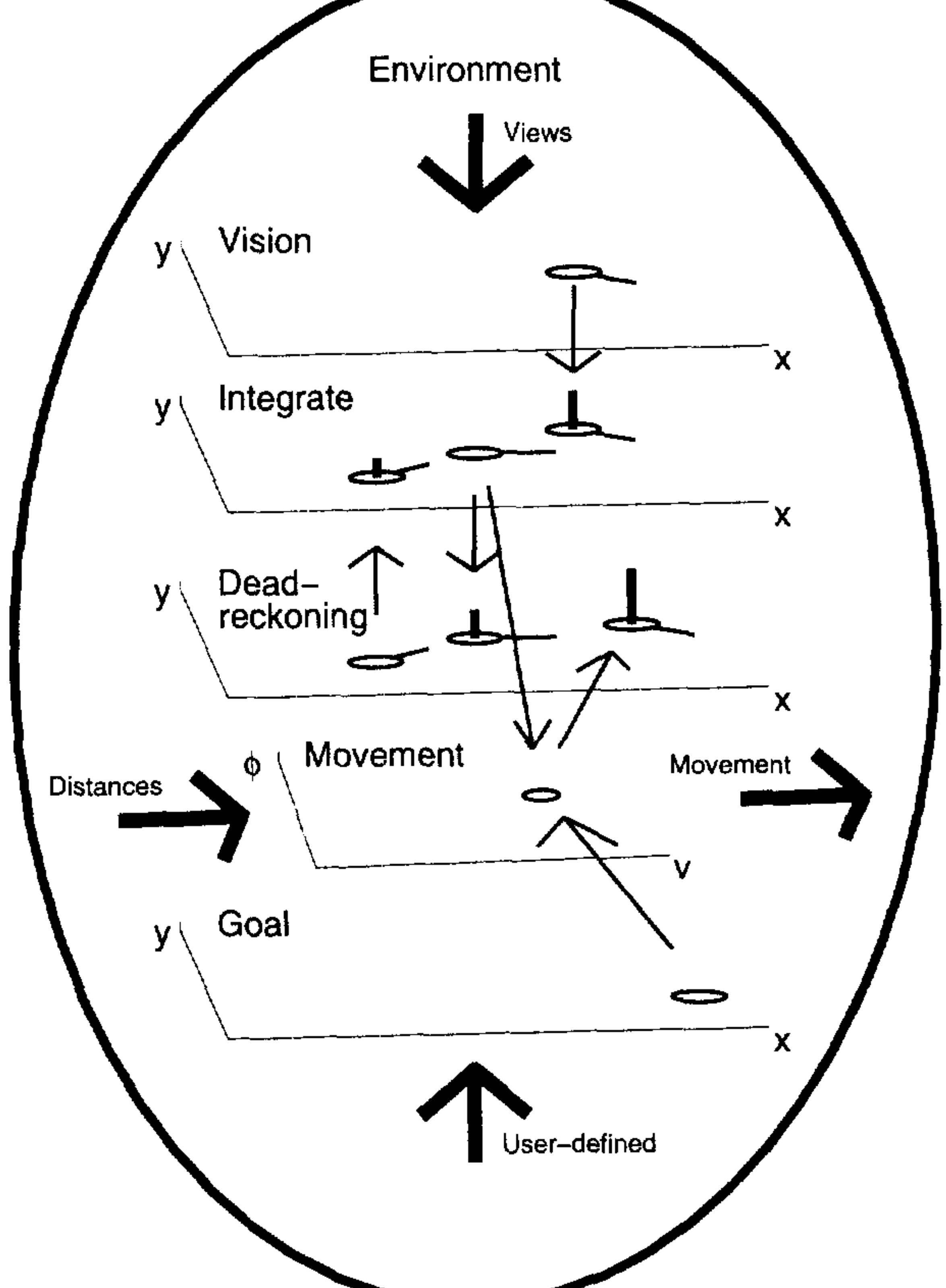
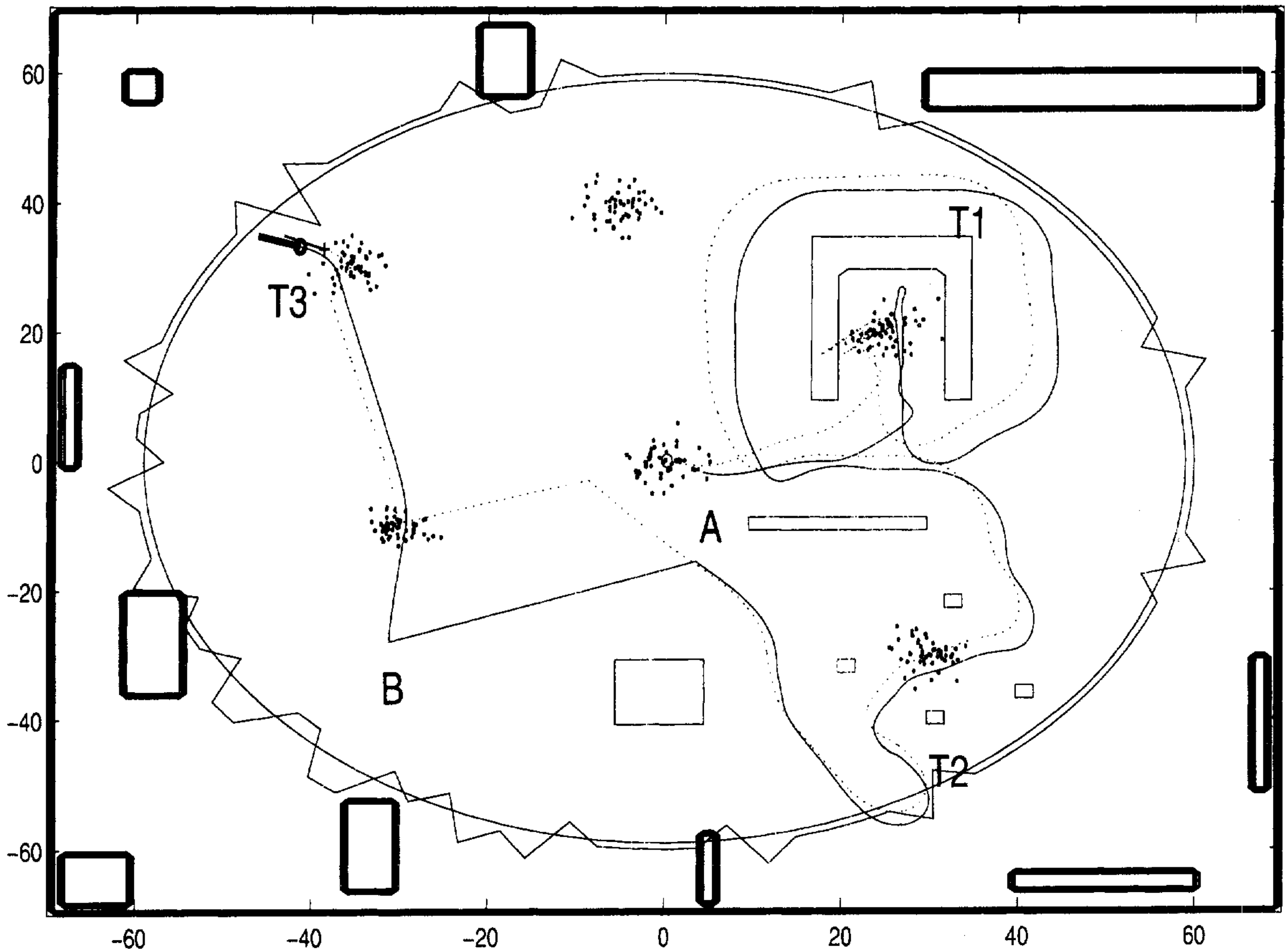


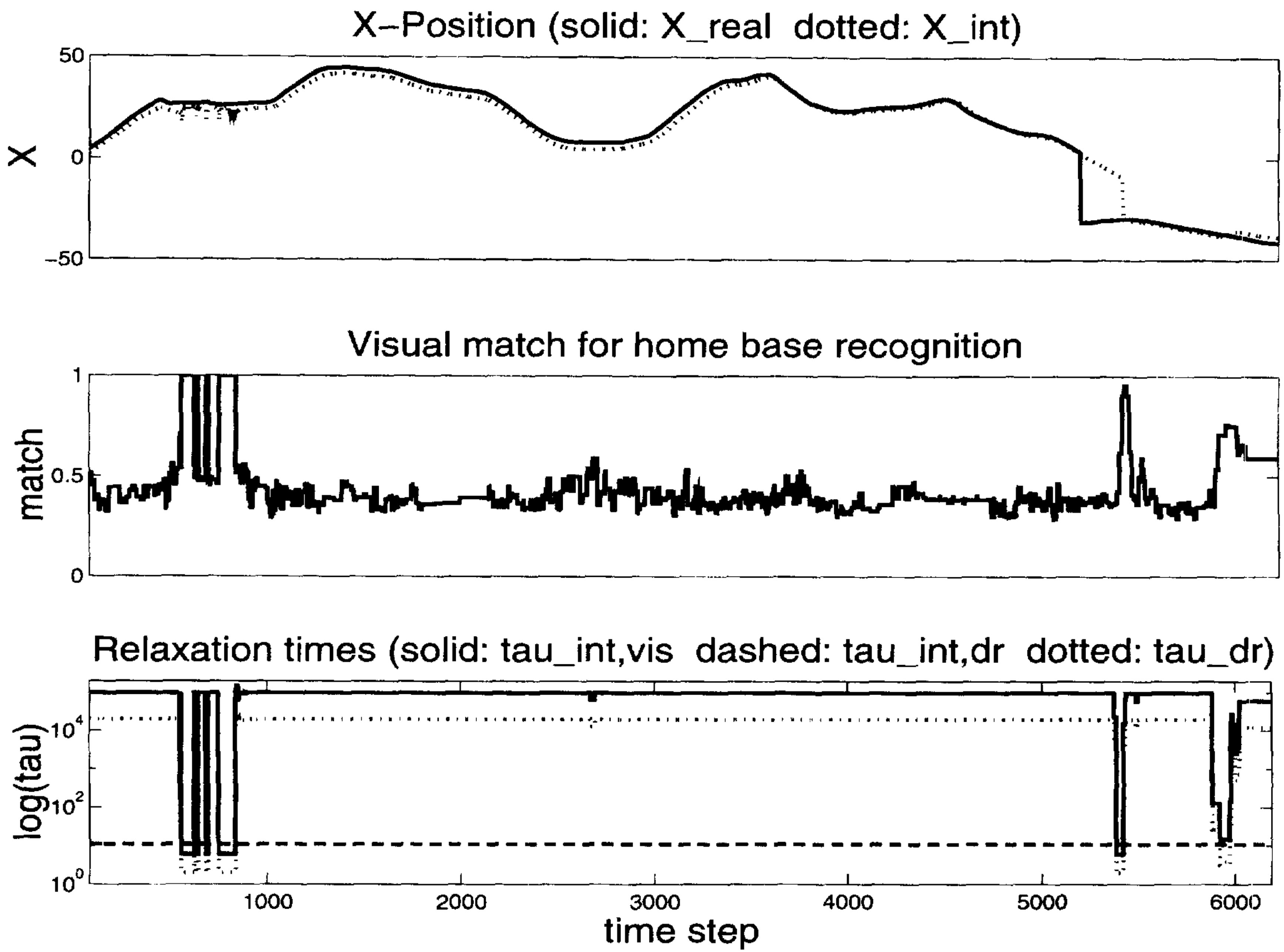
Neural and behavioral architecture



Integrating it all: dynamics all the



a reset event

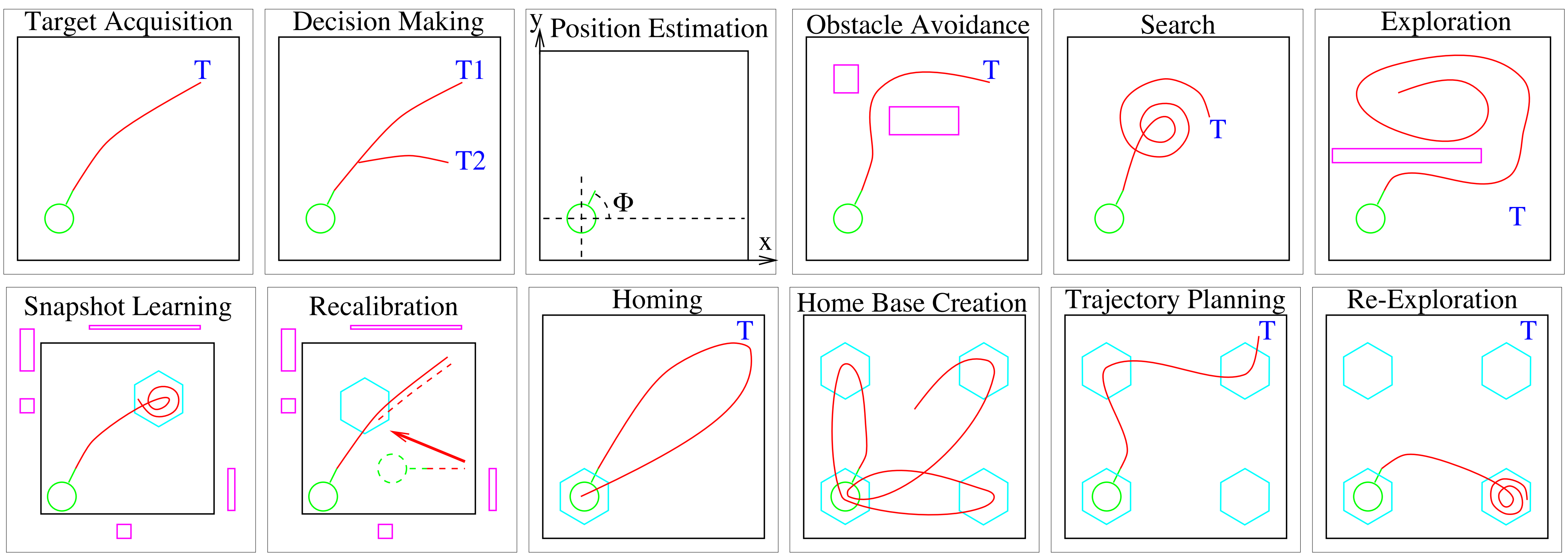


Further development:

- complex behavioral organization
- robotic implementation

Autonomous behavioral organization

- neural dynamics organizes sequence of behaviors…



Autonomous behavioral organization

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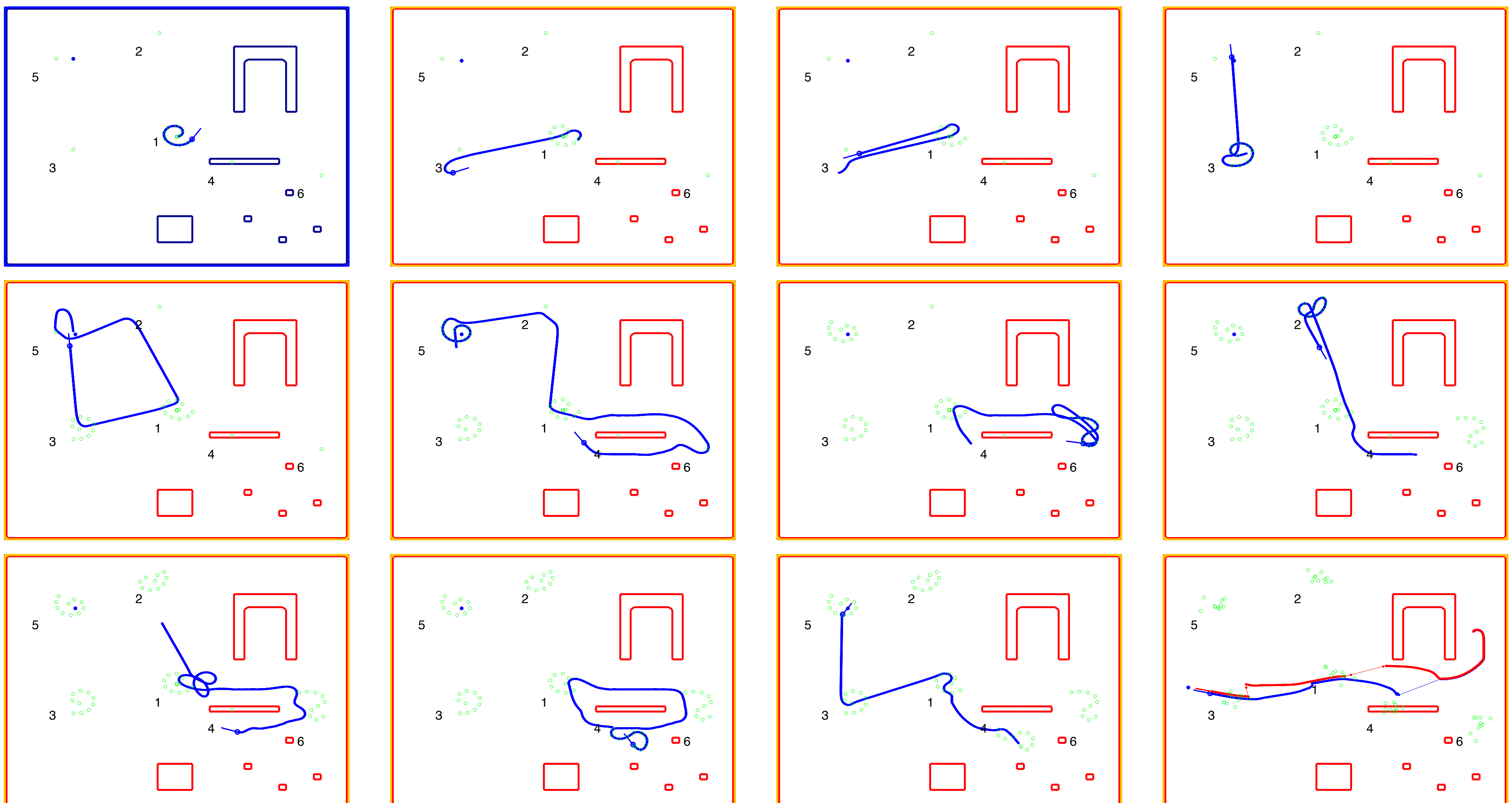
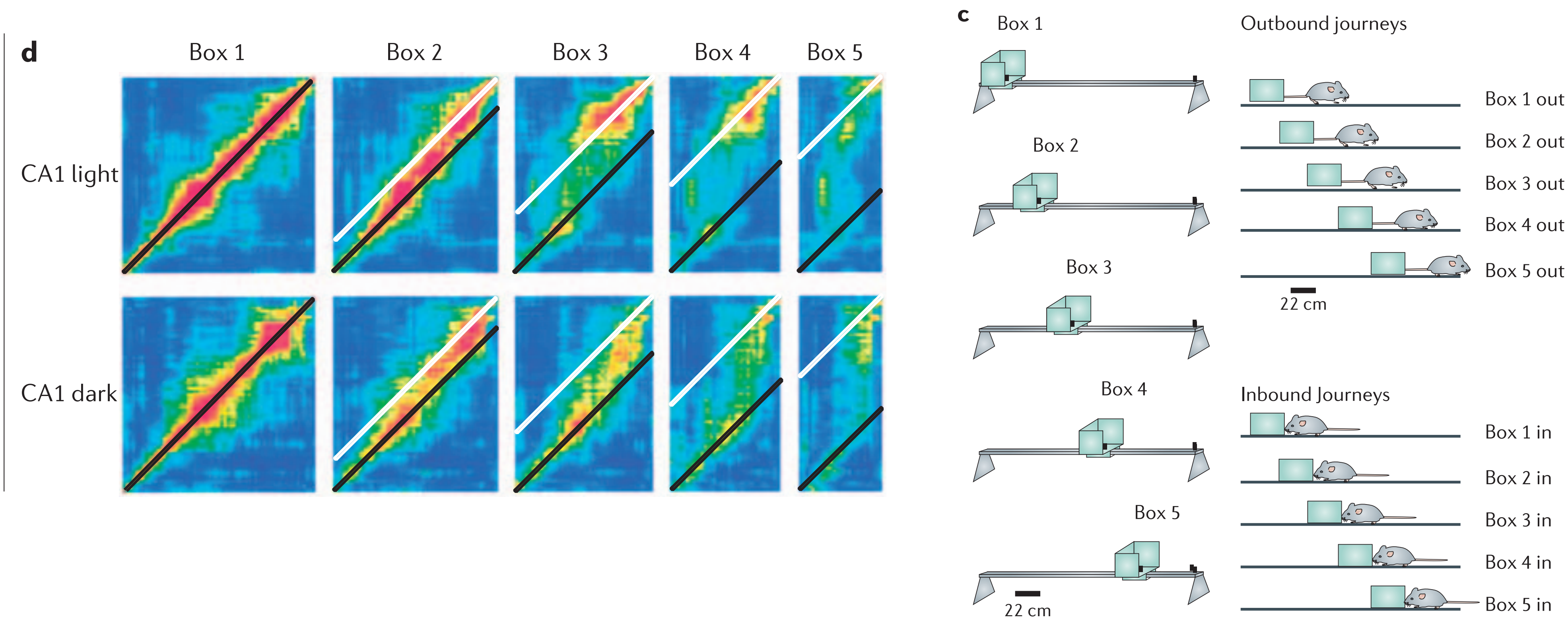


How neurally realistic is this?

Neural mechanisms of navigation

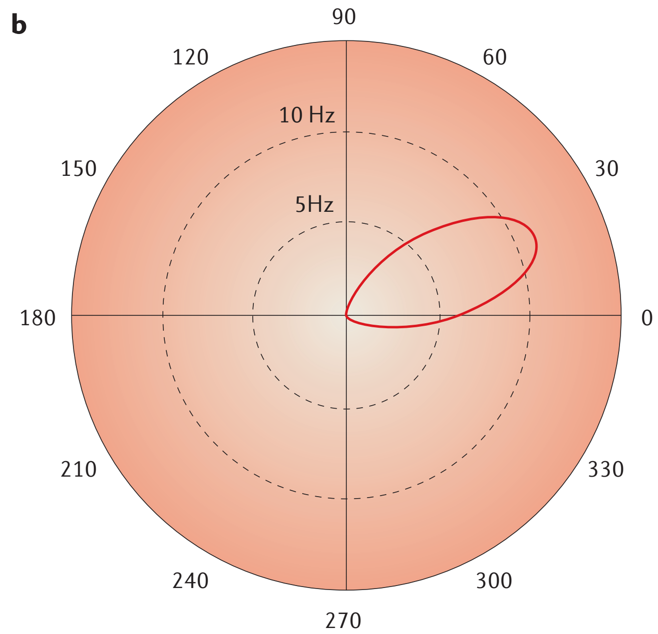
- neural representation of path integration

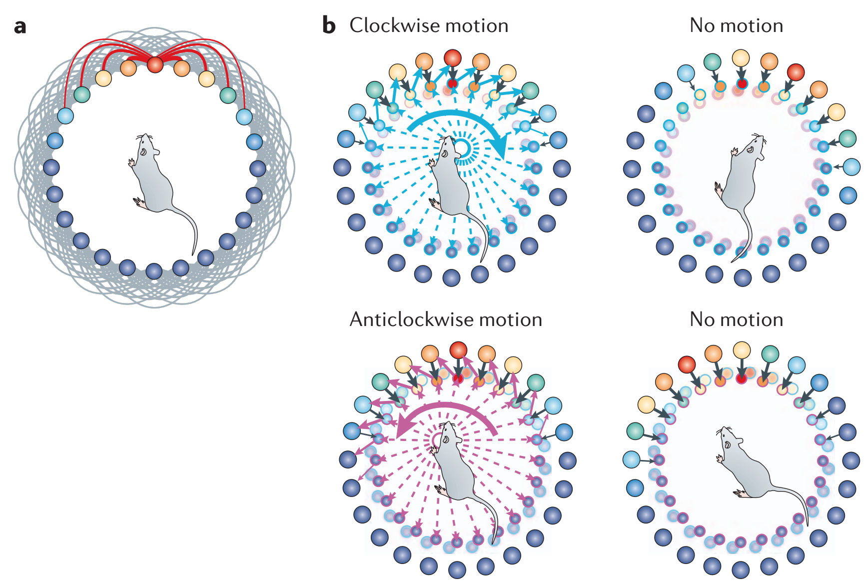


[McNaughton et al., *Nature reviews neuroscience* 2006]

Heading direction

- Neural evidence for head-orientation cells… that function as heading direction representation
- Neural attractor dynamics (neural field) for heading direction

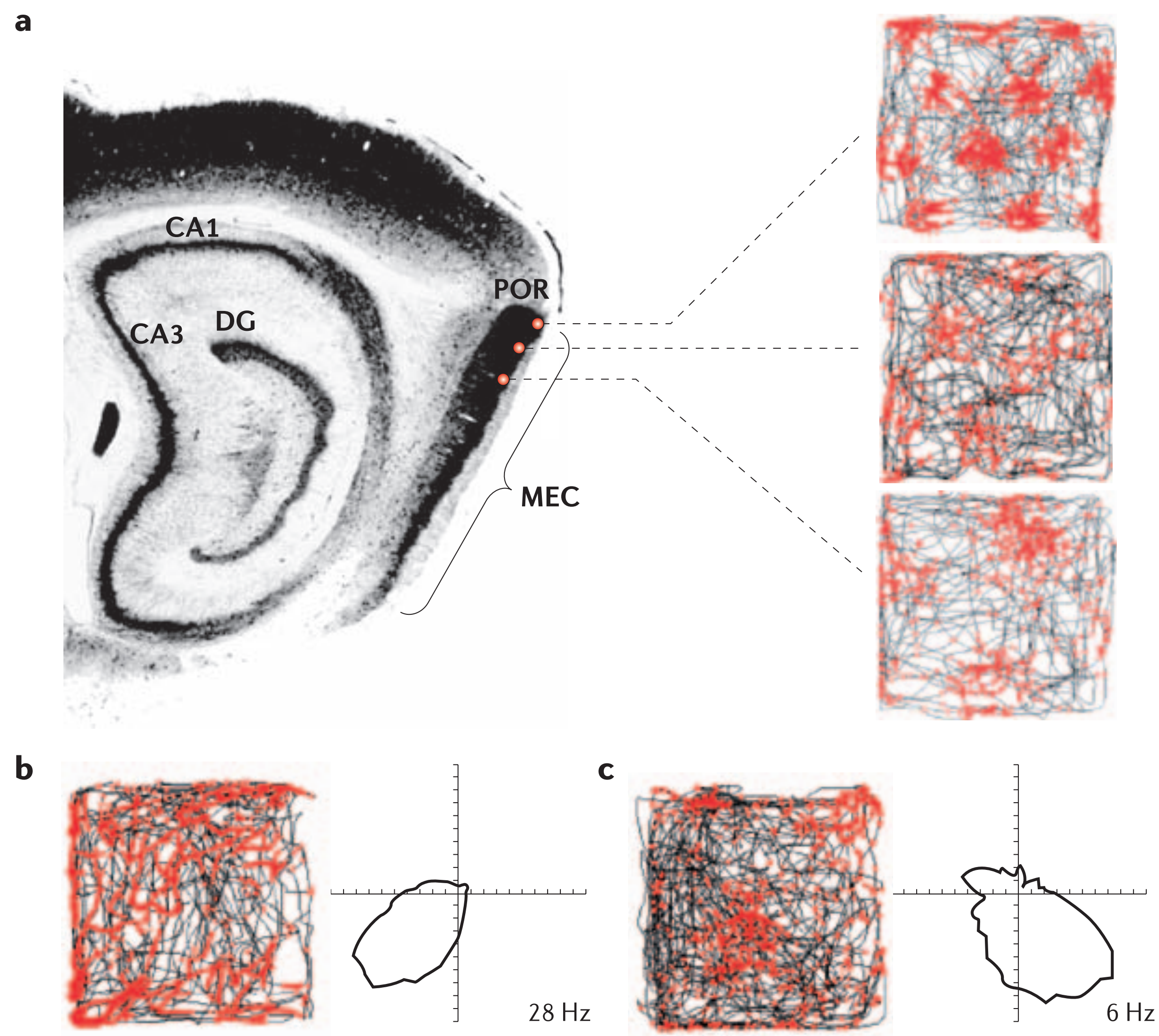




[McNaughton et al., *Nature reviews neuroscience* 2006]

Place and grid cells

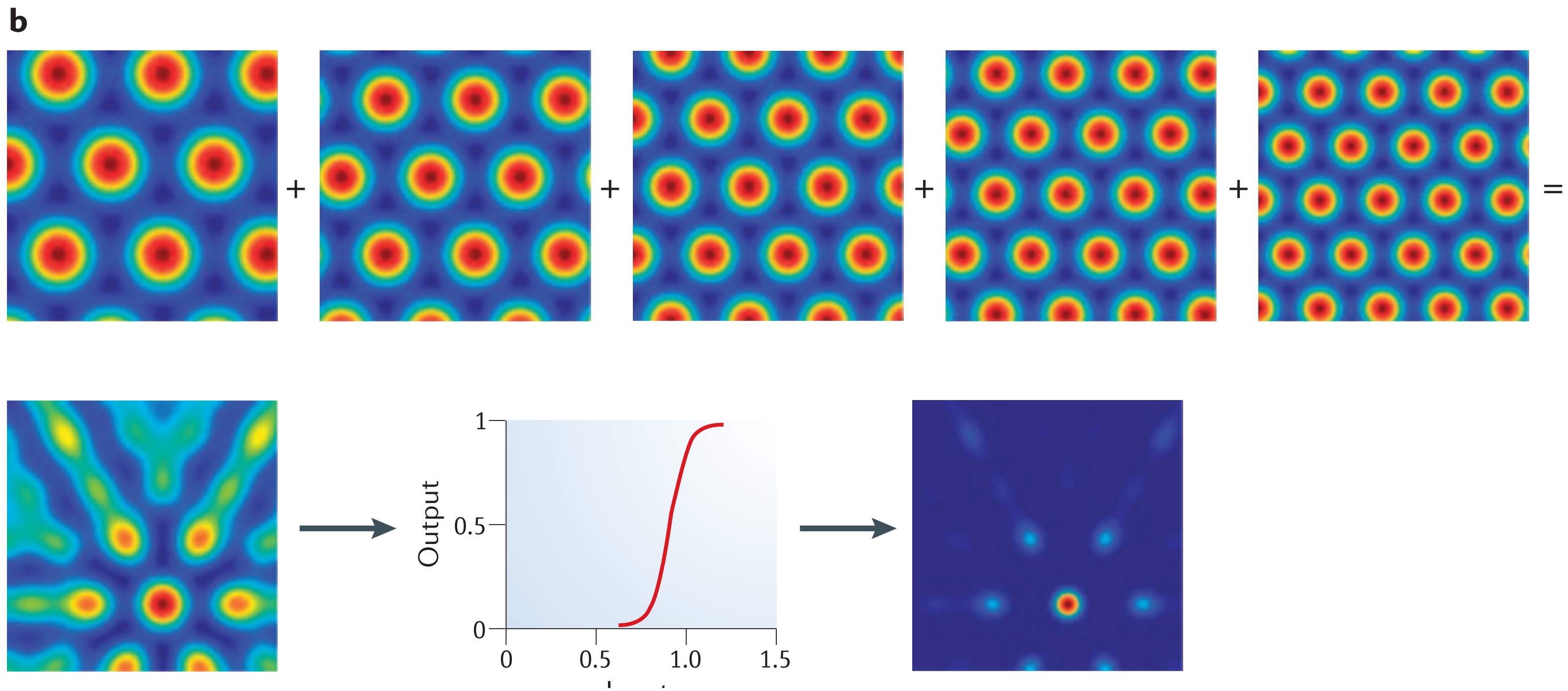
- neural representation of location in Hippocampus and Entorhinal Cortex



[McNaughton et al., *Nature reviews neuroscience* 2006]

Place and grid cells

- support building a place representation by a neural field



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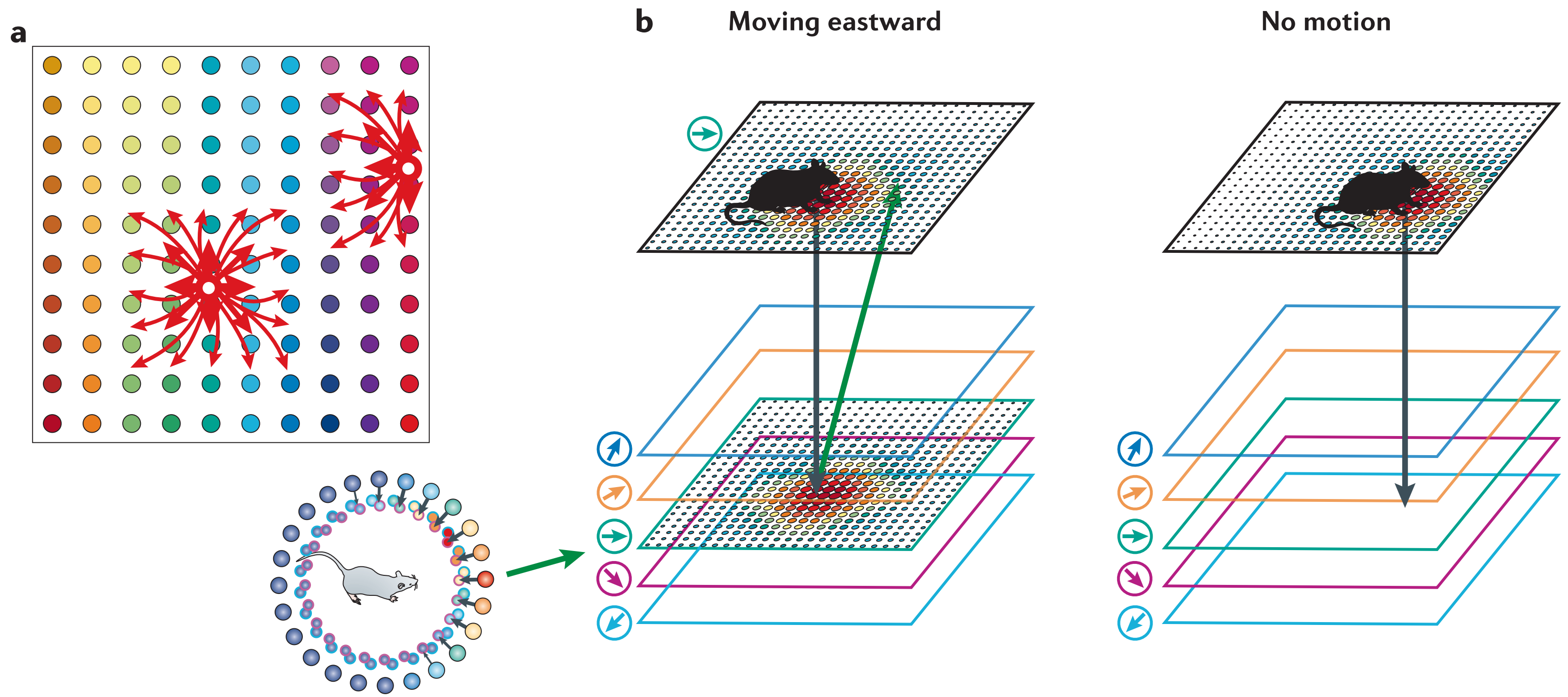
Neural dynamics of path integration



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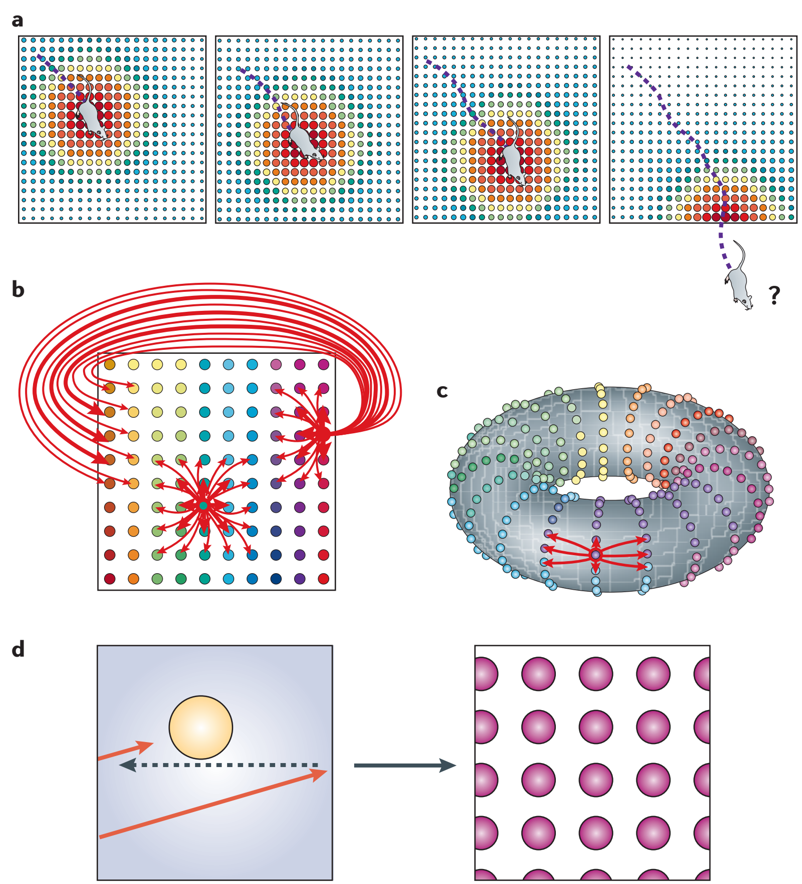

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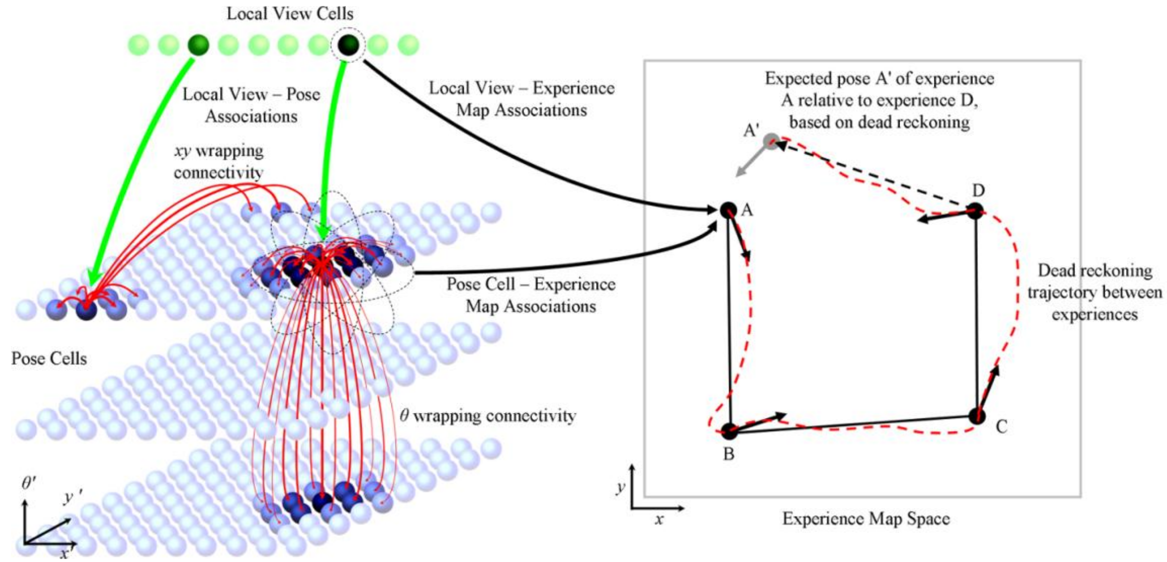
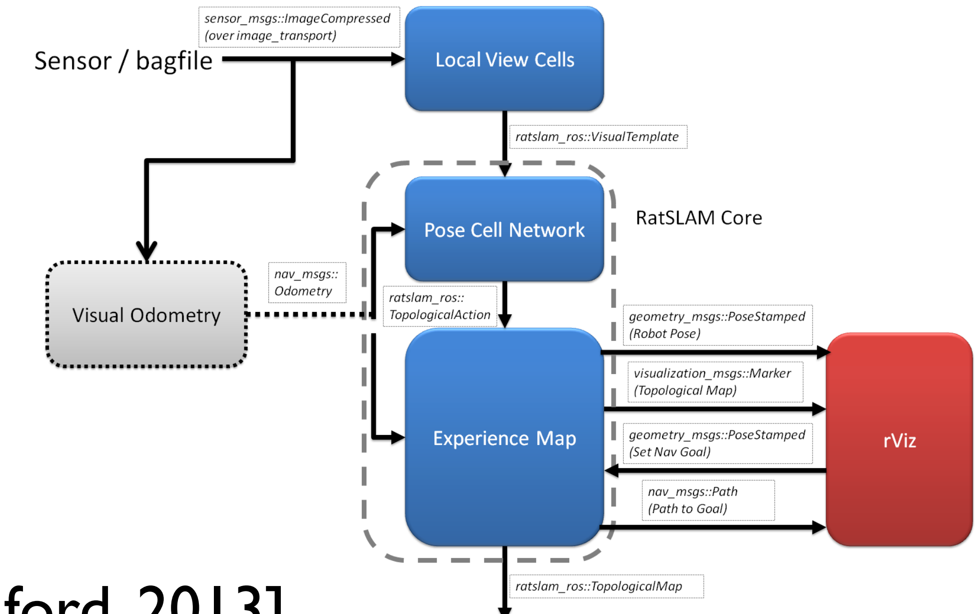
Neurally inspired technical solution

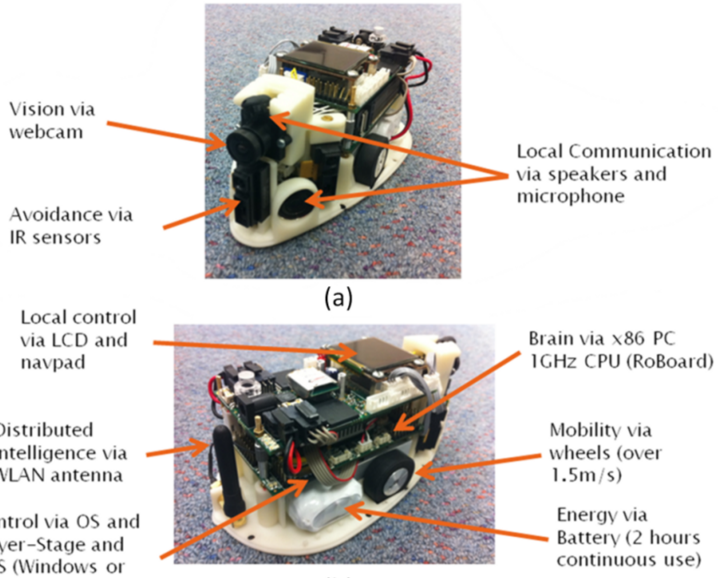
- RAT-Slam





[Ball, Wyeth, Cork, Milford, 2013]

RAT-Slam



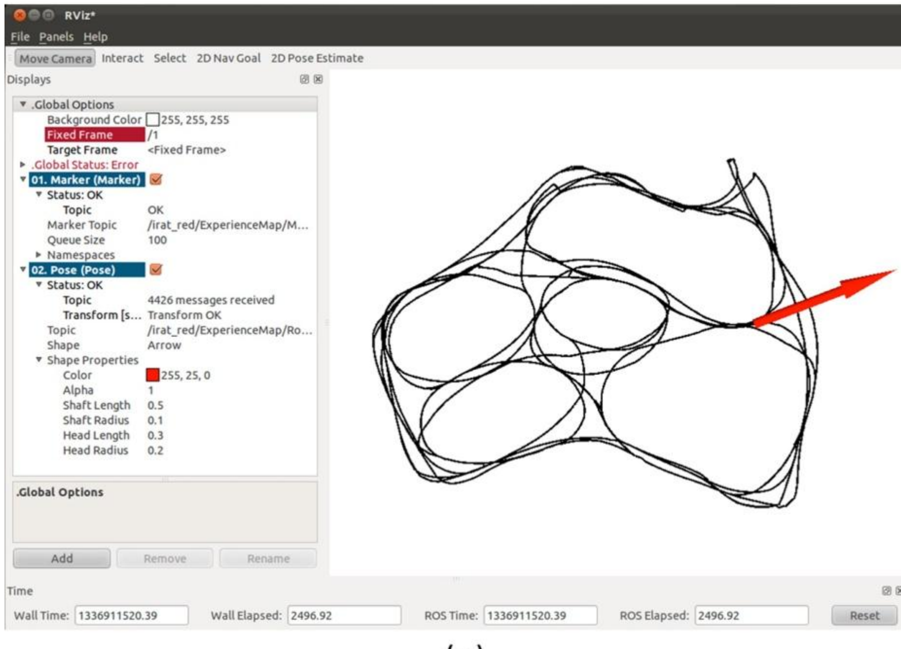
(a) (b)


(c)


(a) (b) (c)

[Ball, Wyeth, Cork, Milford, 2013]

RAT-Slam




(a) (b) (c)

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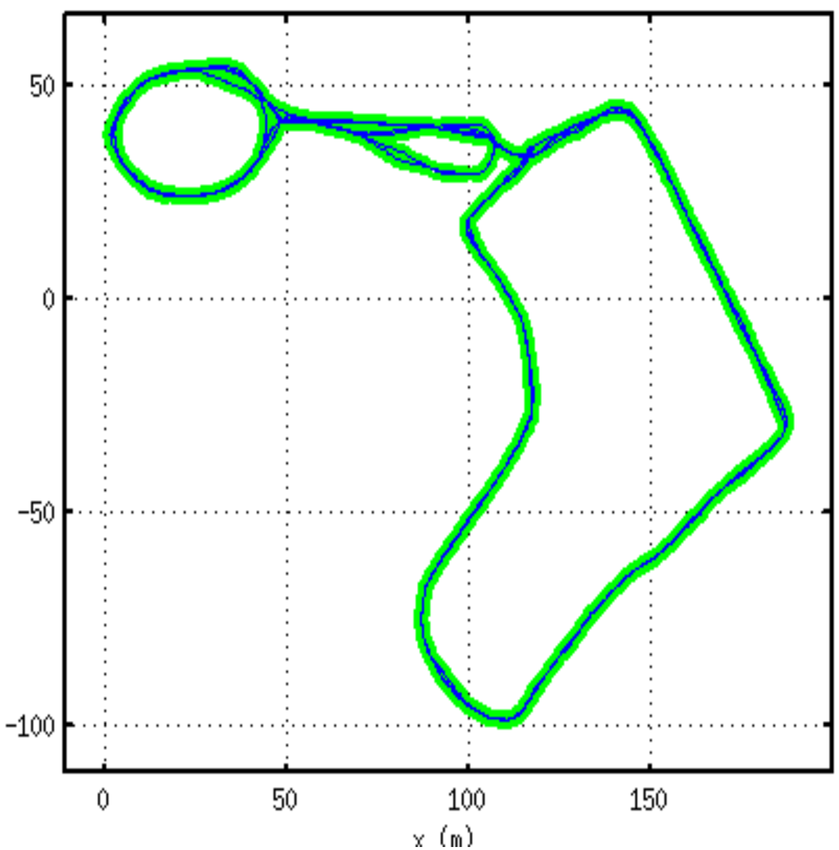
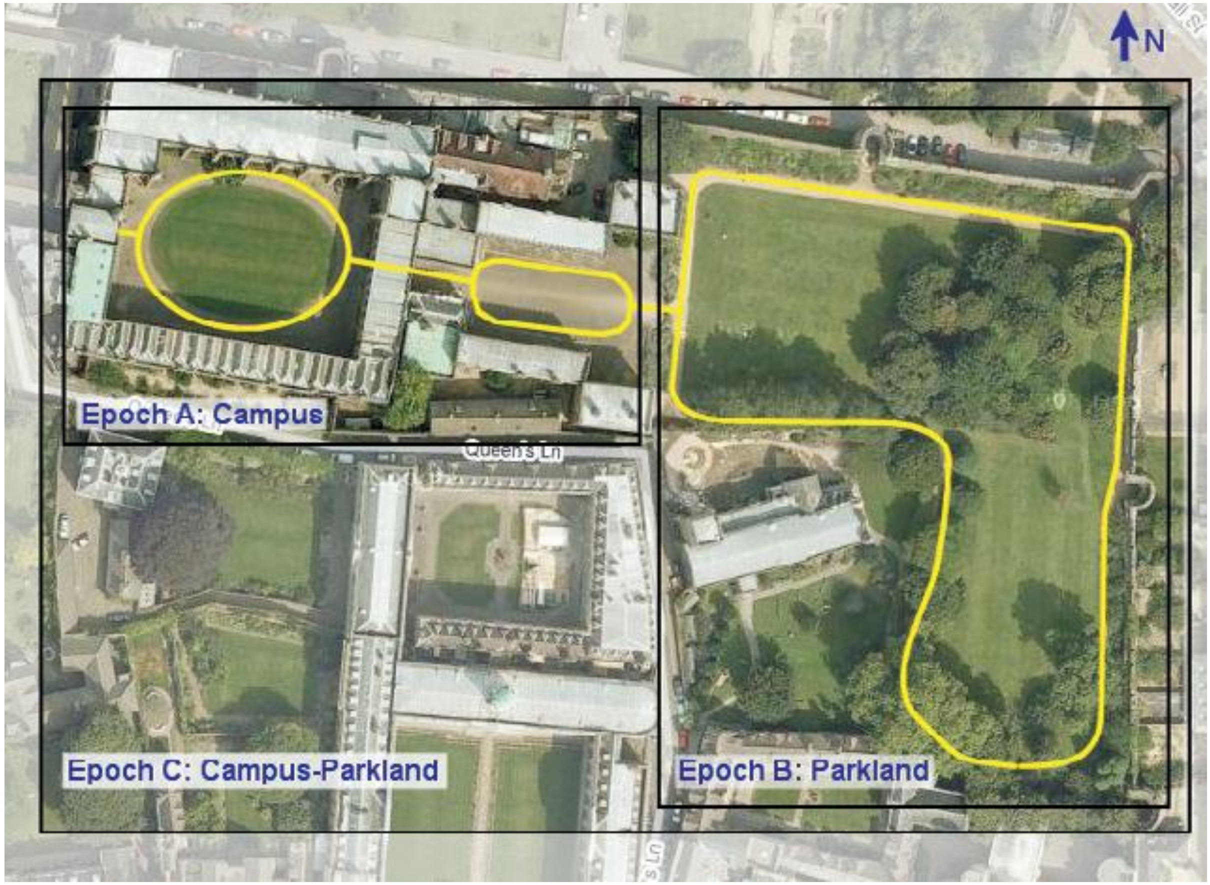
RAT-Slam



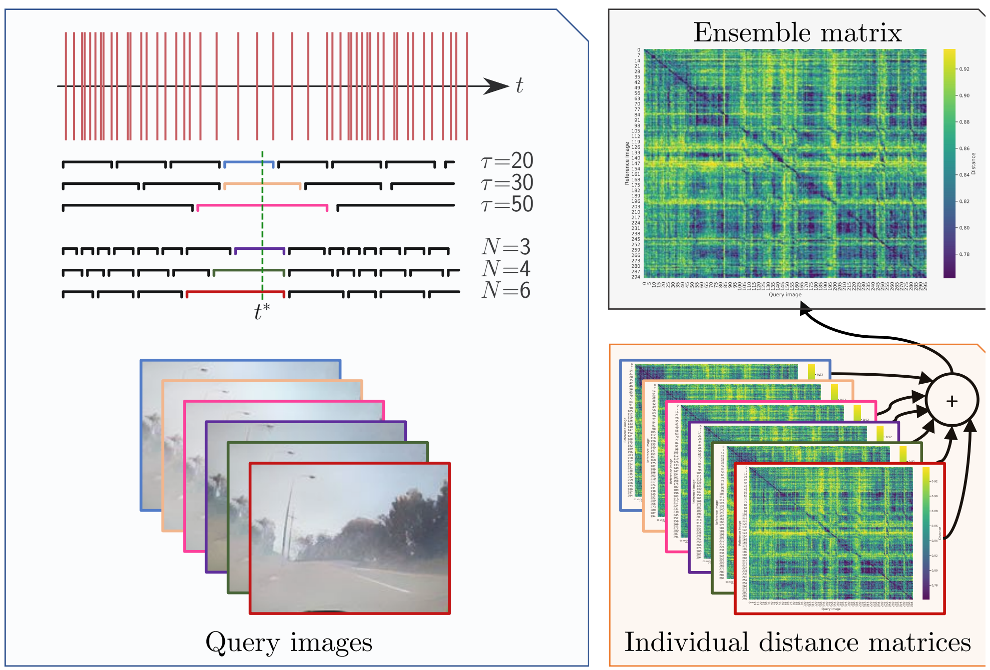
(b)



[Ball, Wyeth, Cork, Milford, 2013]

Event-based place recognition

- spiking neural vision system…



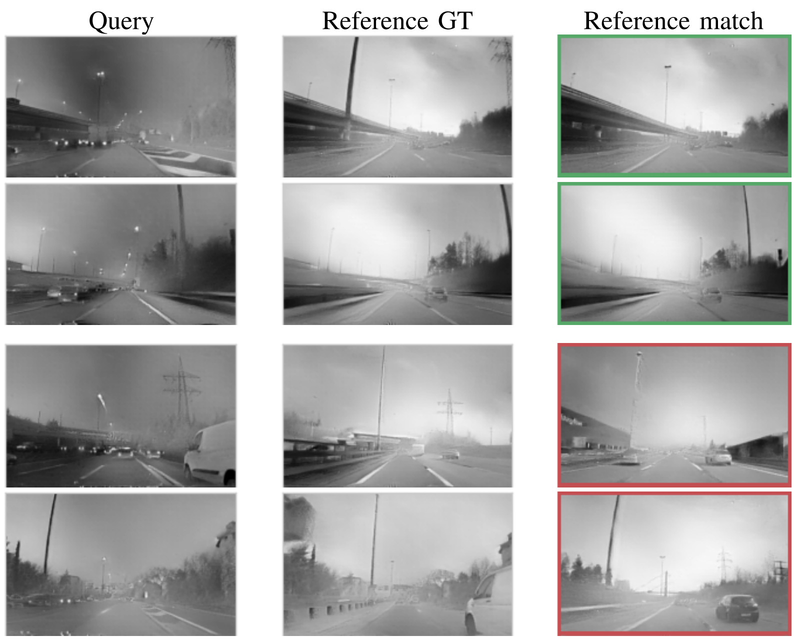
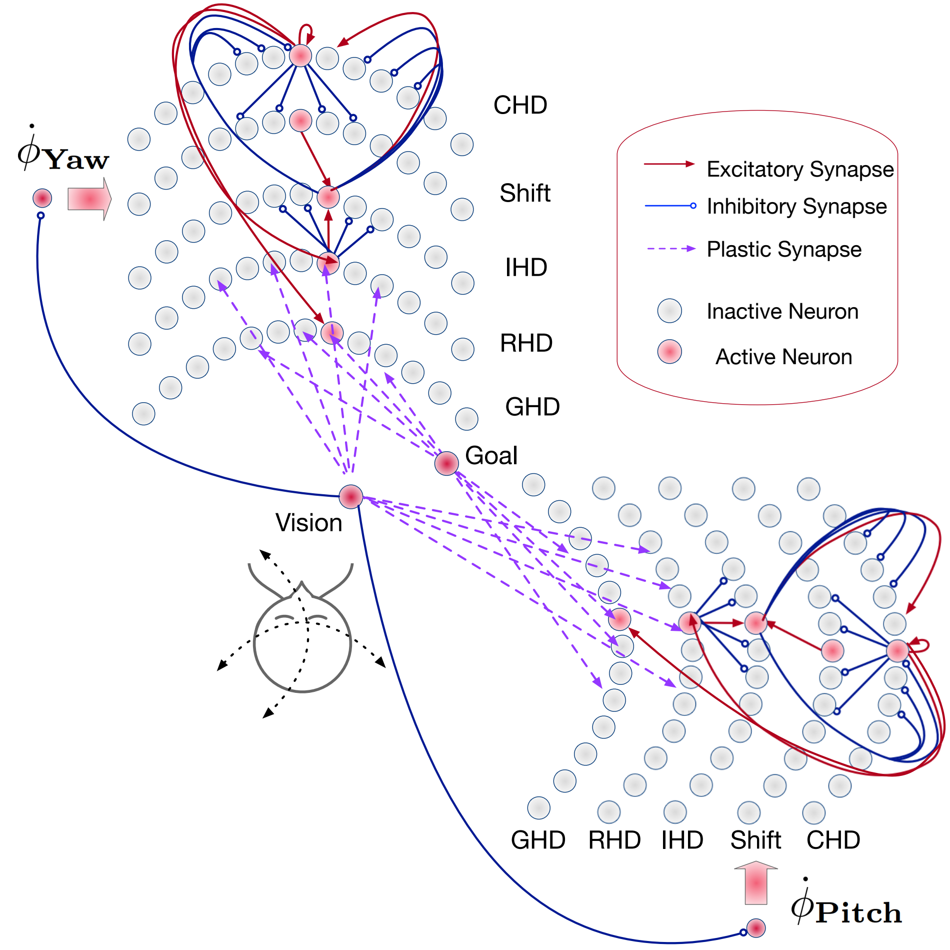


Fig. 8: Example matches of the ensemble and ground-truth (GT) matches on the DDD-17 dataset. Top two rows: success cases where the majority of individual methods failed. Bottom two rows: failure cases.

[Fischer Mildord, 2020]

Neuromorphic head-direction estimate

- using DFT



[Kreiser et al. Sandamirskaya, Frontiers 2019]

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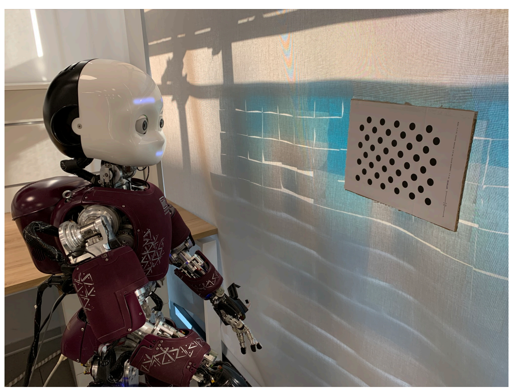

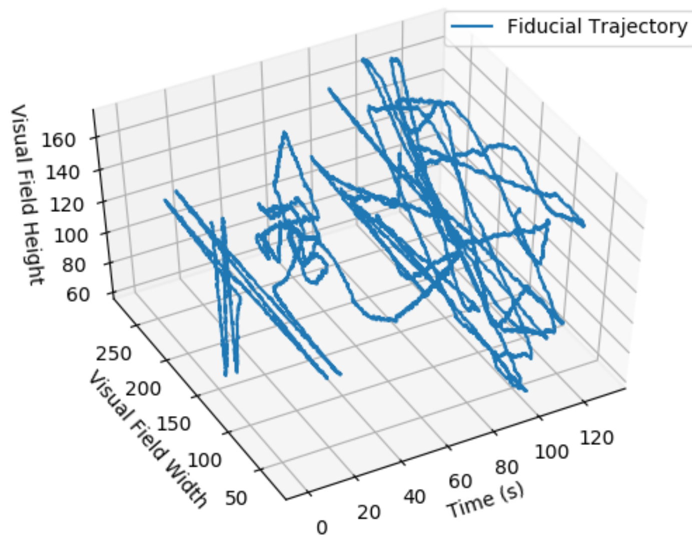

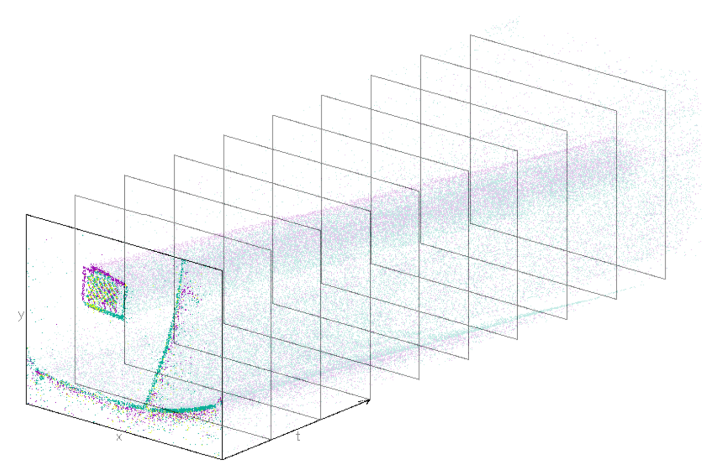

[Kreiser et al. Sandamirskaya, Frontiers 2019]

Conclusions

- the navigation problem entails both knowing where you are and how to go places
- navigation can be performed by behavioral and neural dynamics
- recalibration of location based on recognition … can be view-based
- integration by (neural) dynamics … in which space-time continuous processes… lead to discrete transitions at instabilities