A Decentralised Neural Model Explaining Optimal Integration Of Navigational Strategies in Insects

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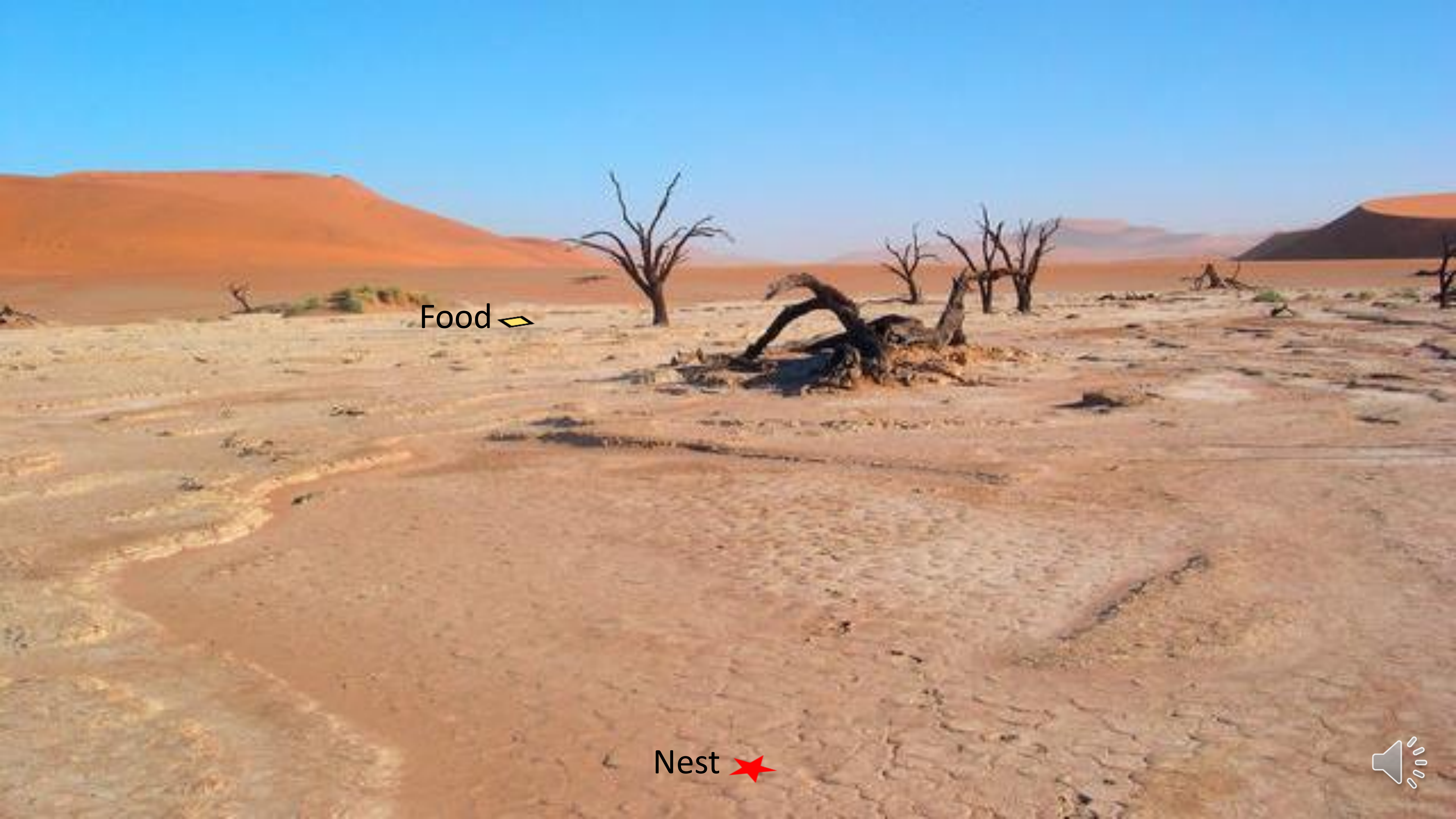
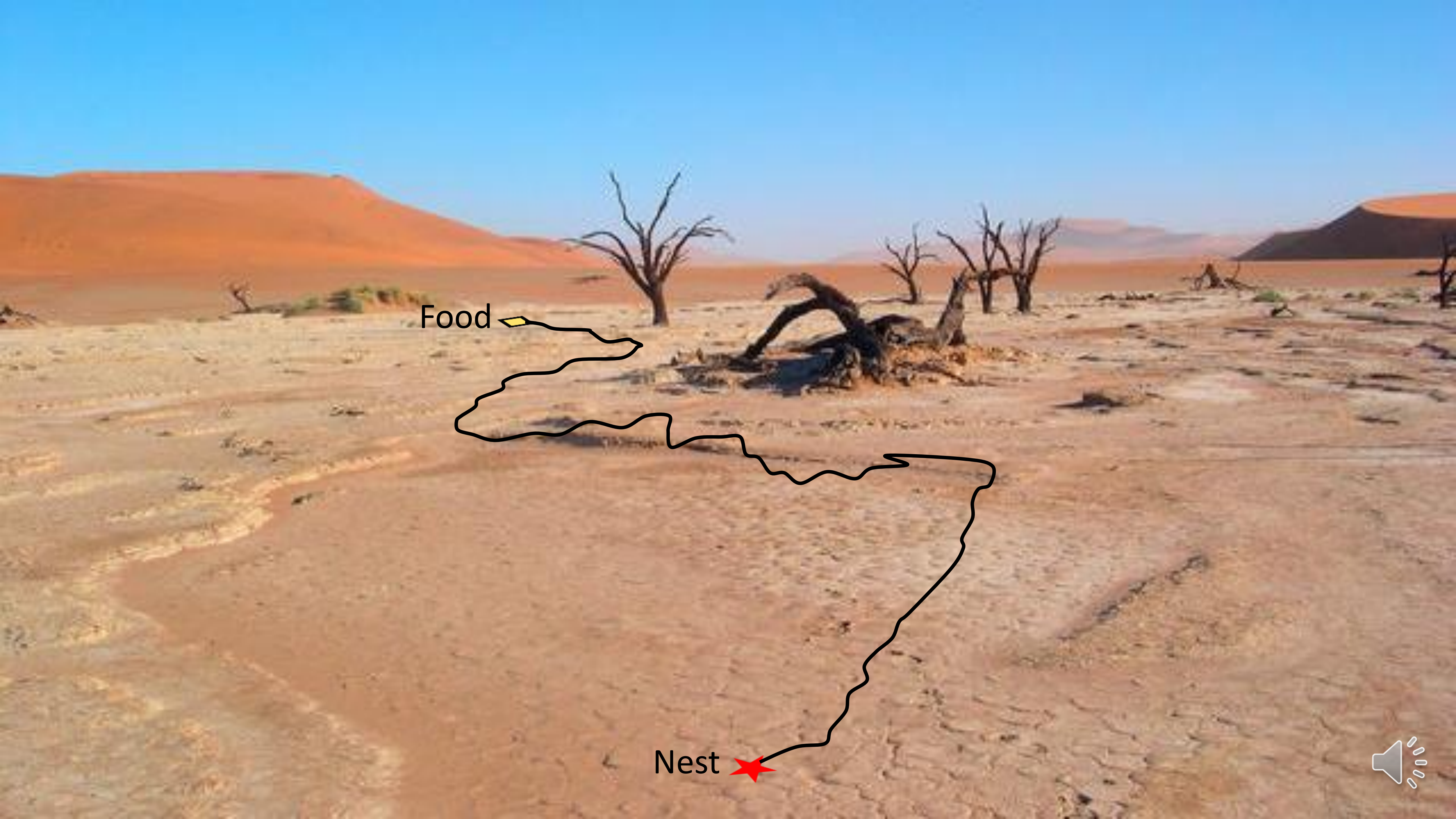
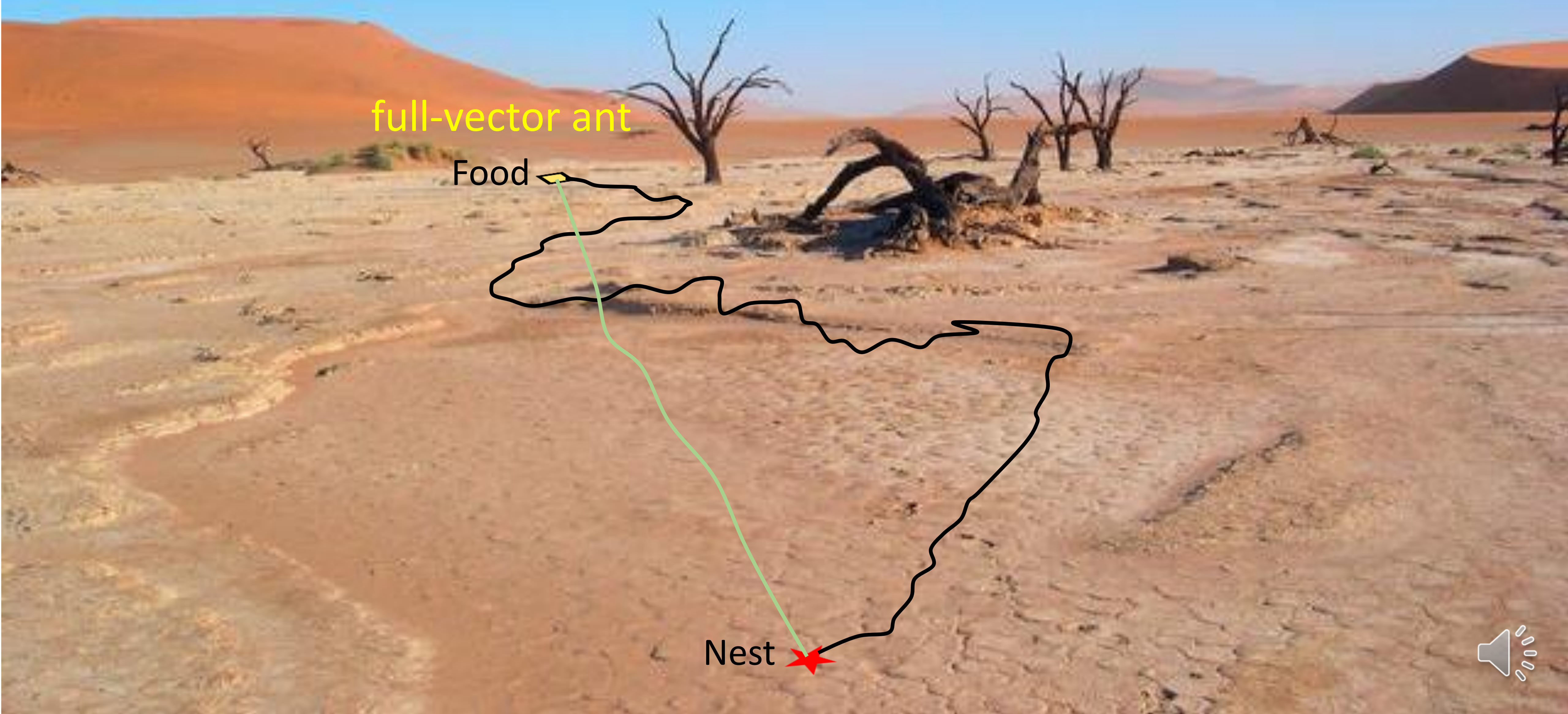
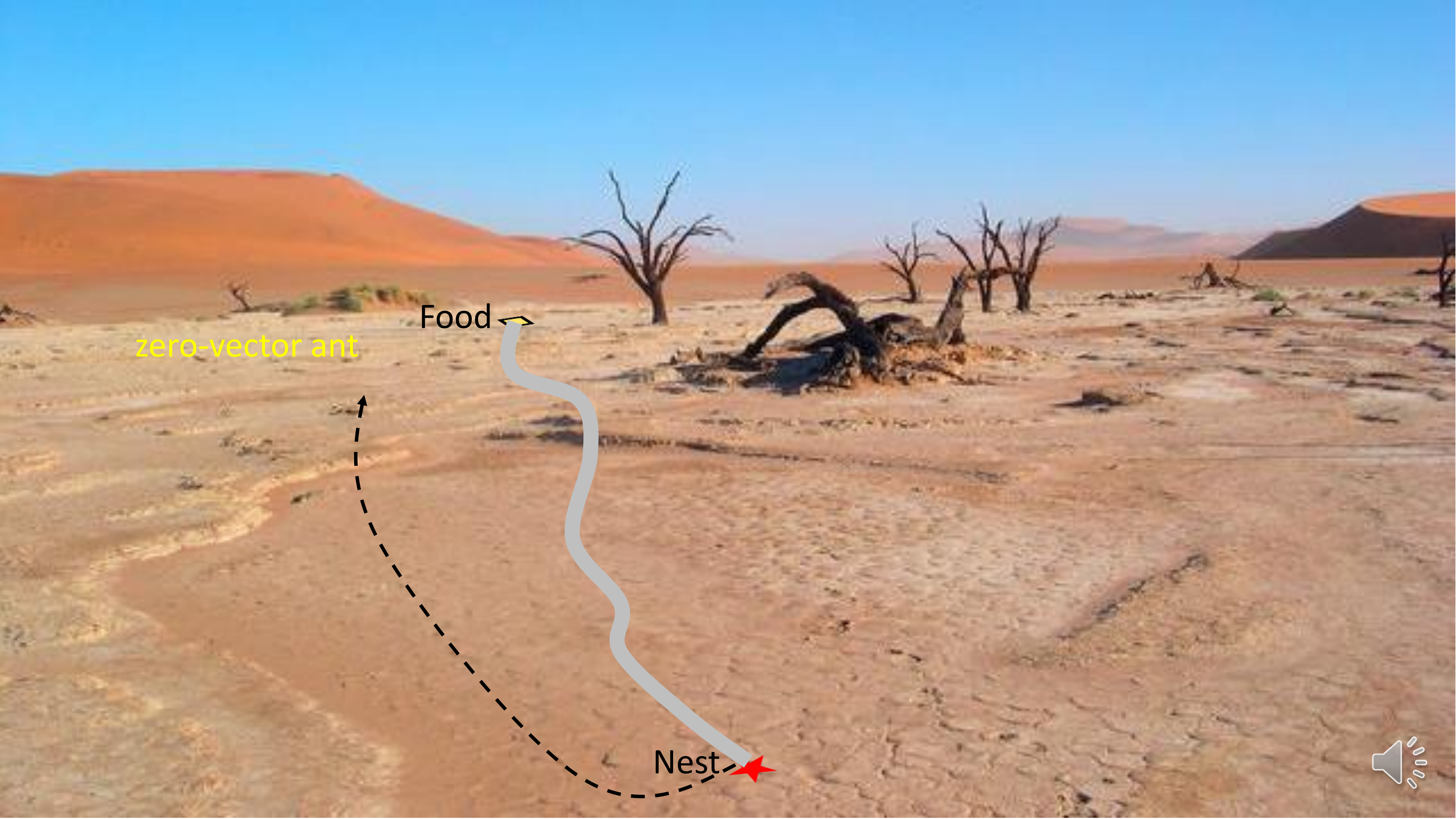
University of Lincoln, UK


Food
Nest

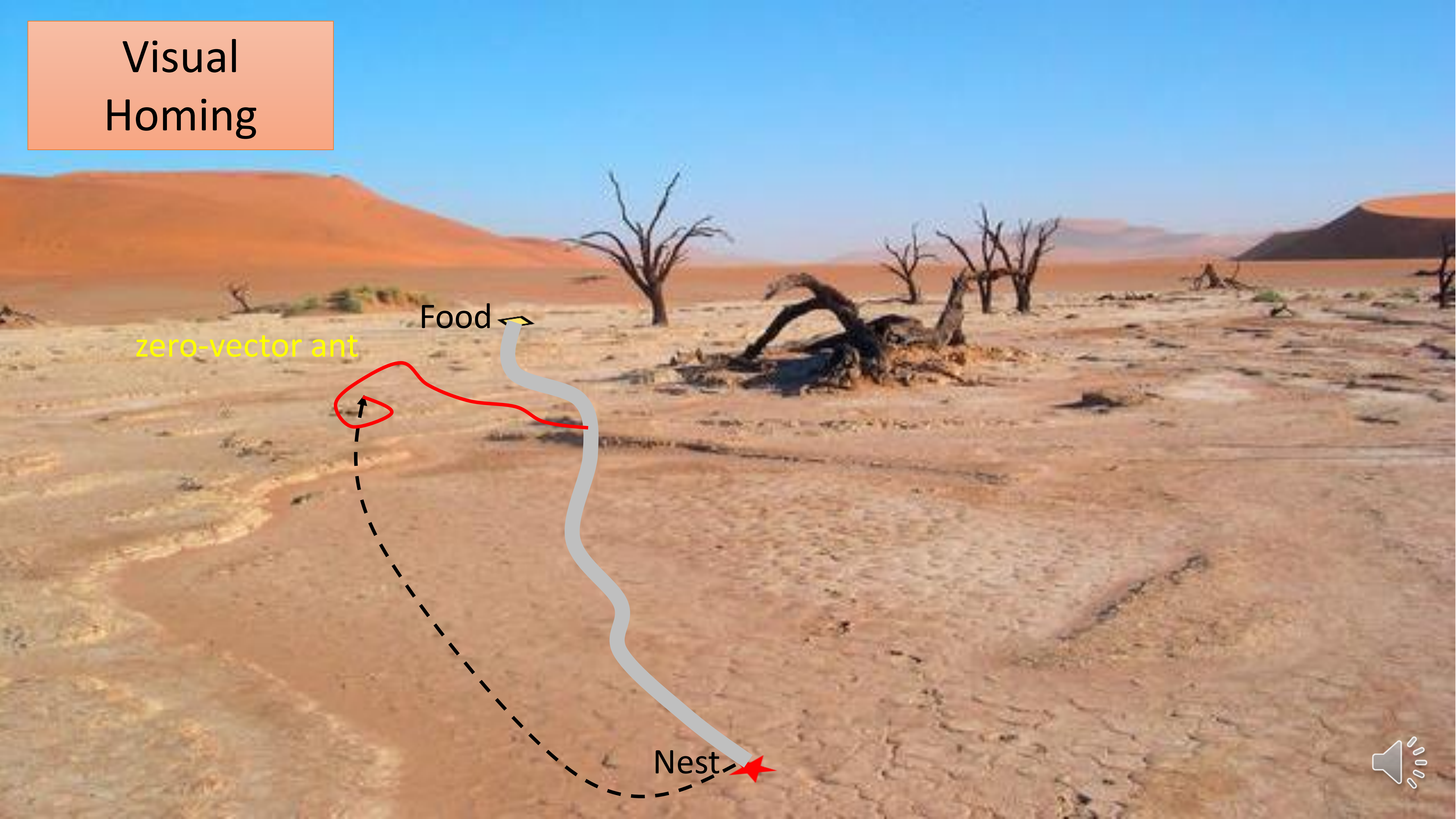

Food
Nest

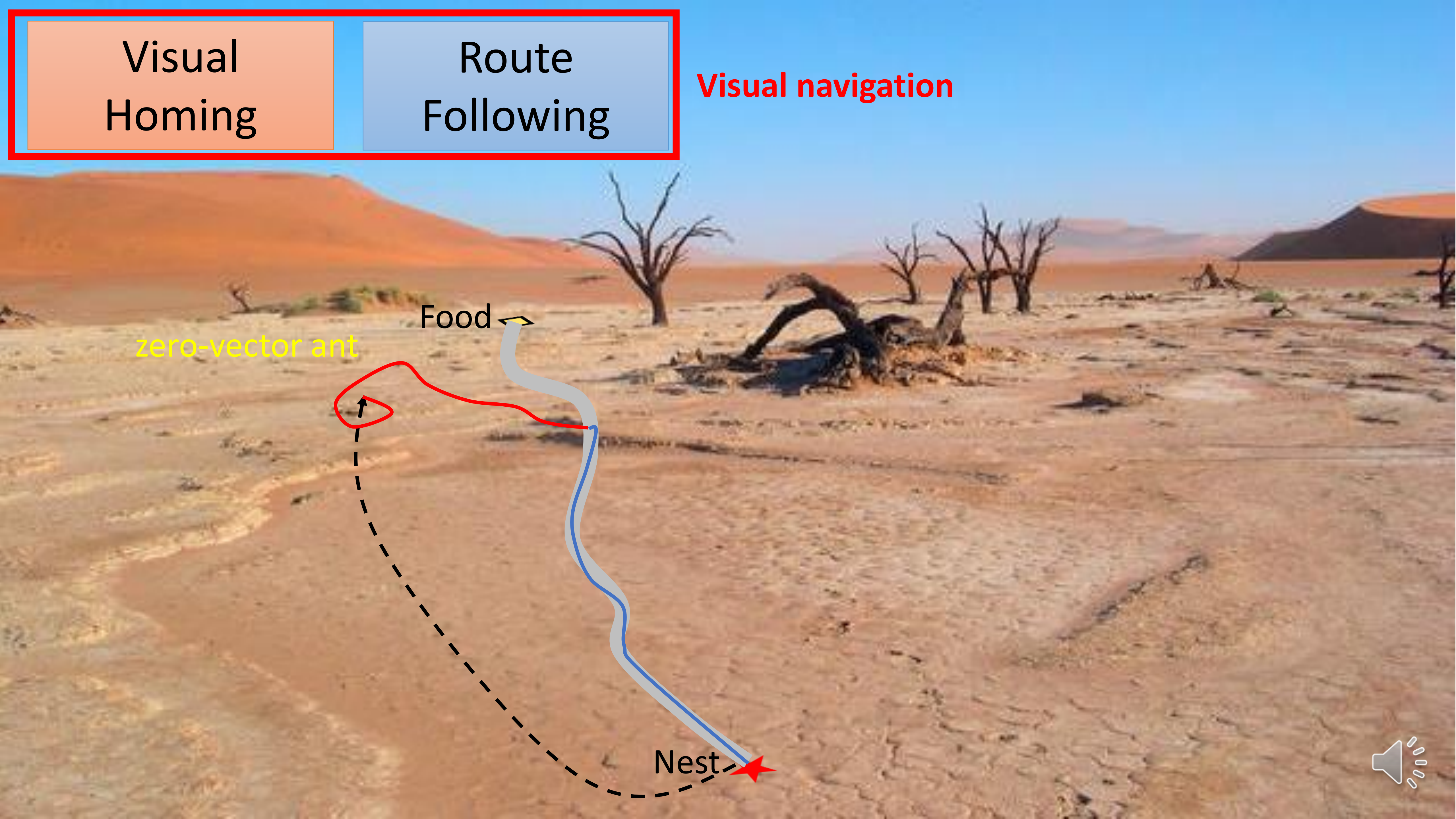
Path Integration

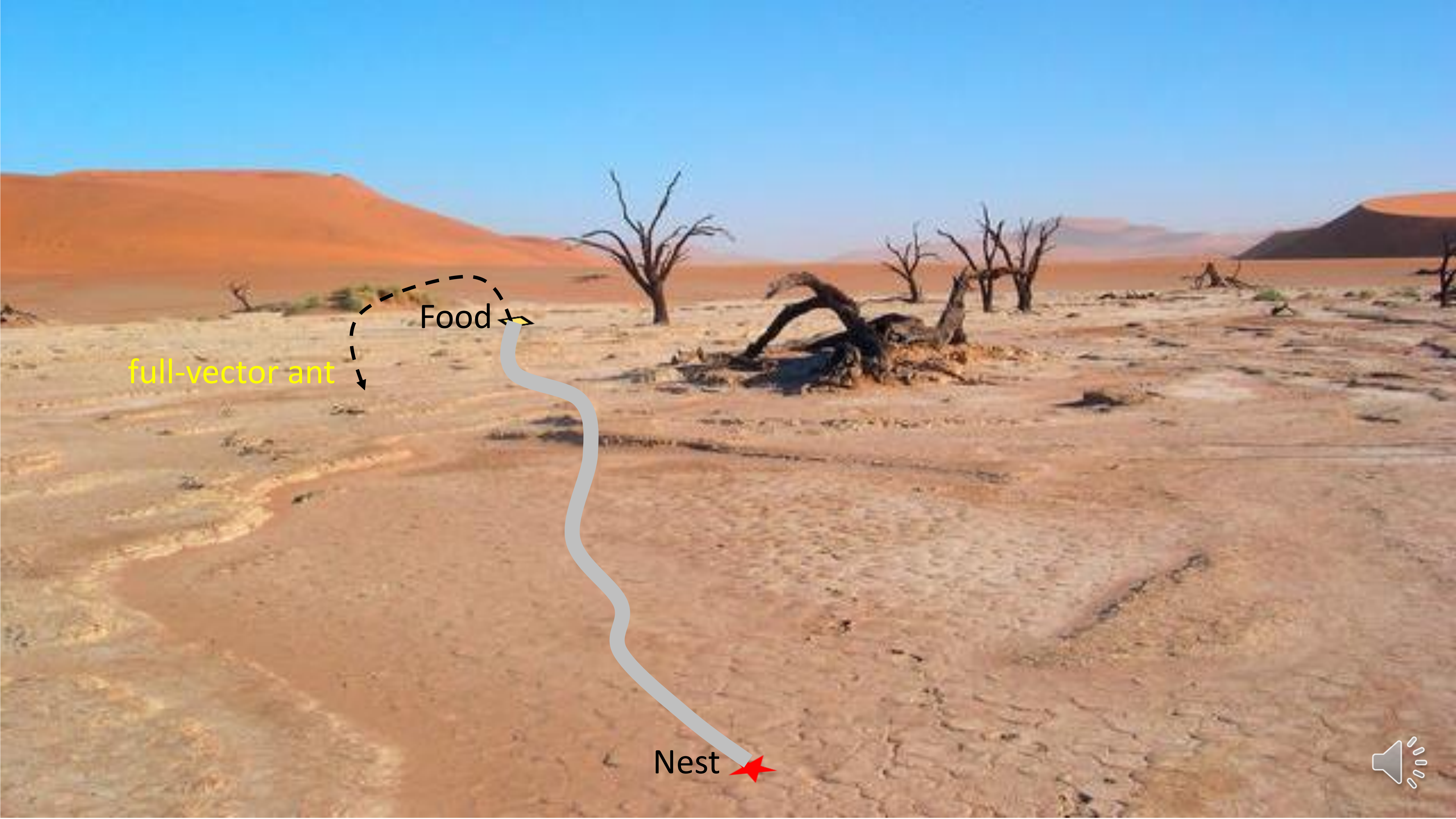



Food
zero-vector ant
Nest

Visual Homing

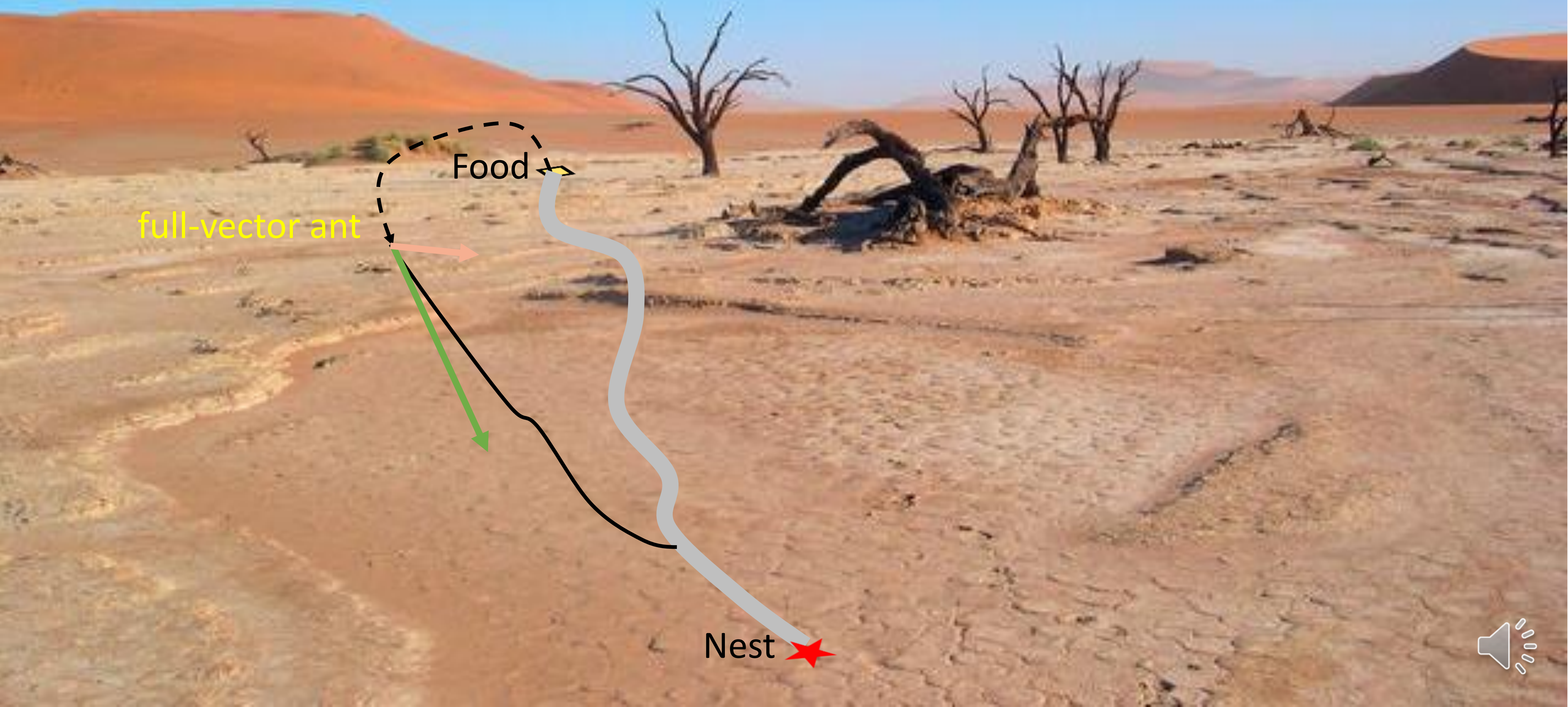



Visual Homing
Route Following
Visual navigation
Food
zero-vector ant
Nest


Food
full-vector ant
Nest

Path Integration

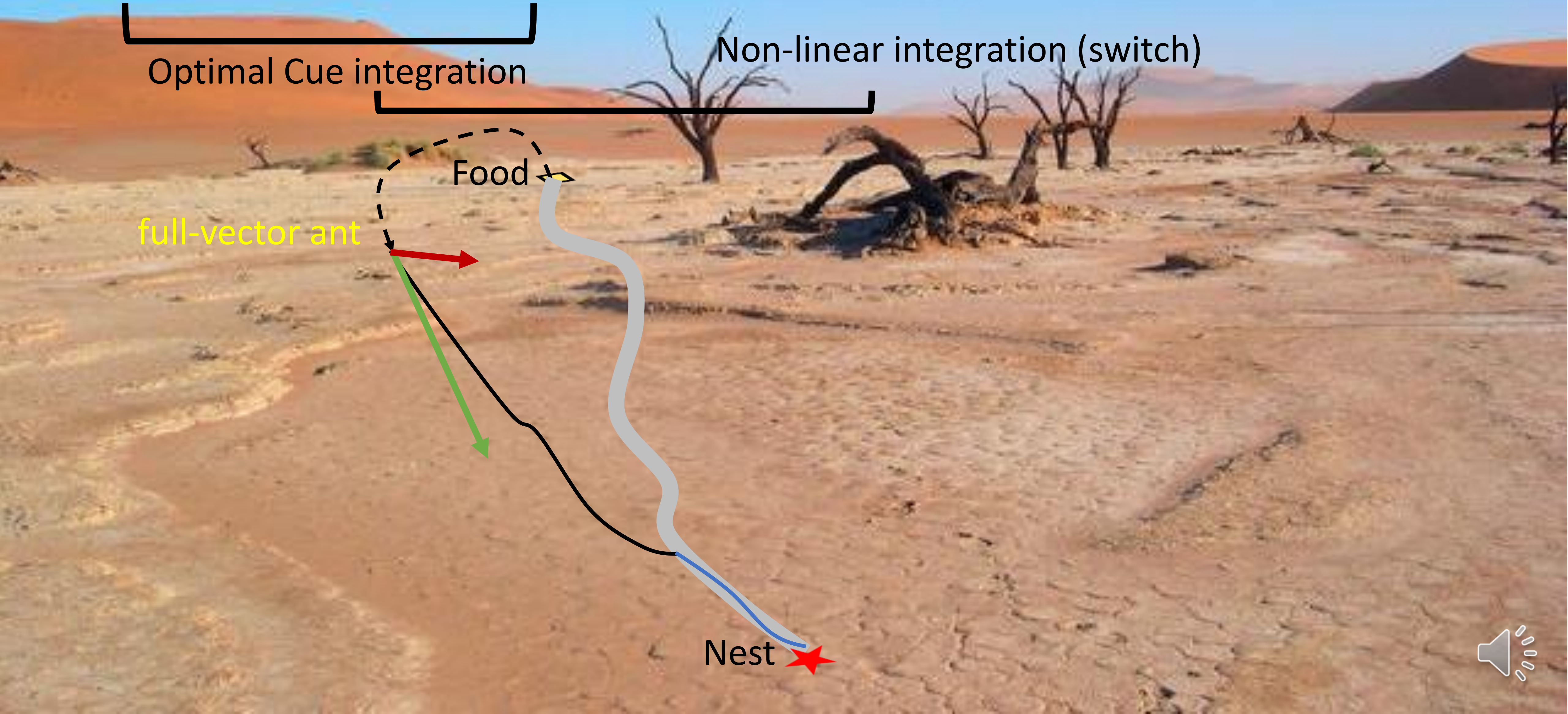
Visual Homing



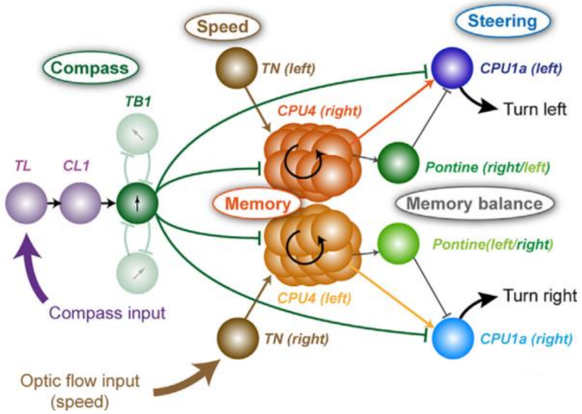
Path Integration

Visual Homing

Route Following

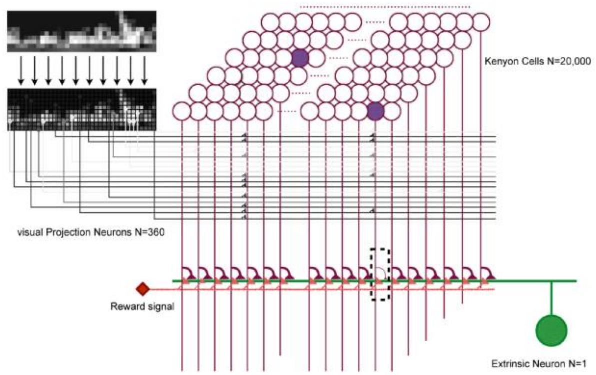


Stone et.al 2017



?

Paul et.al 2016



Path Integration

Visual Homing

Route Following

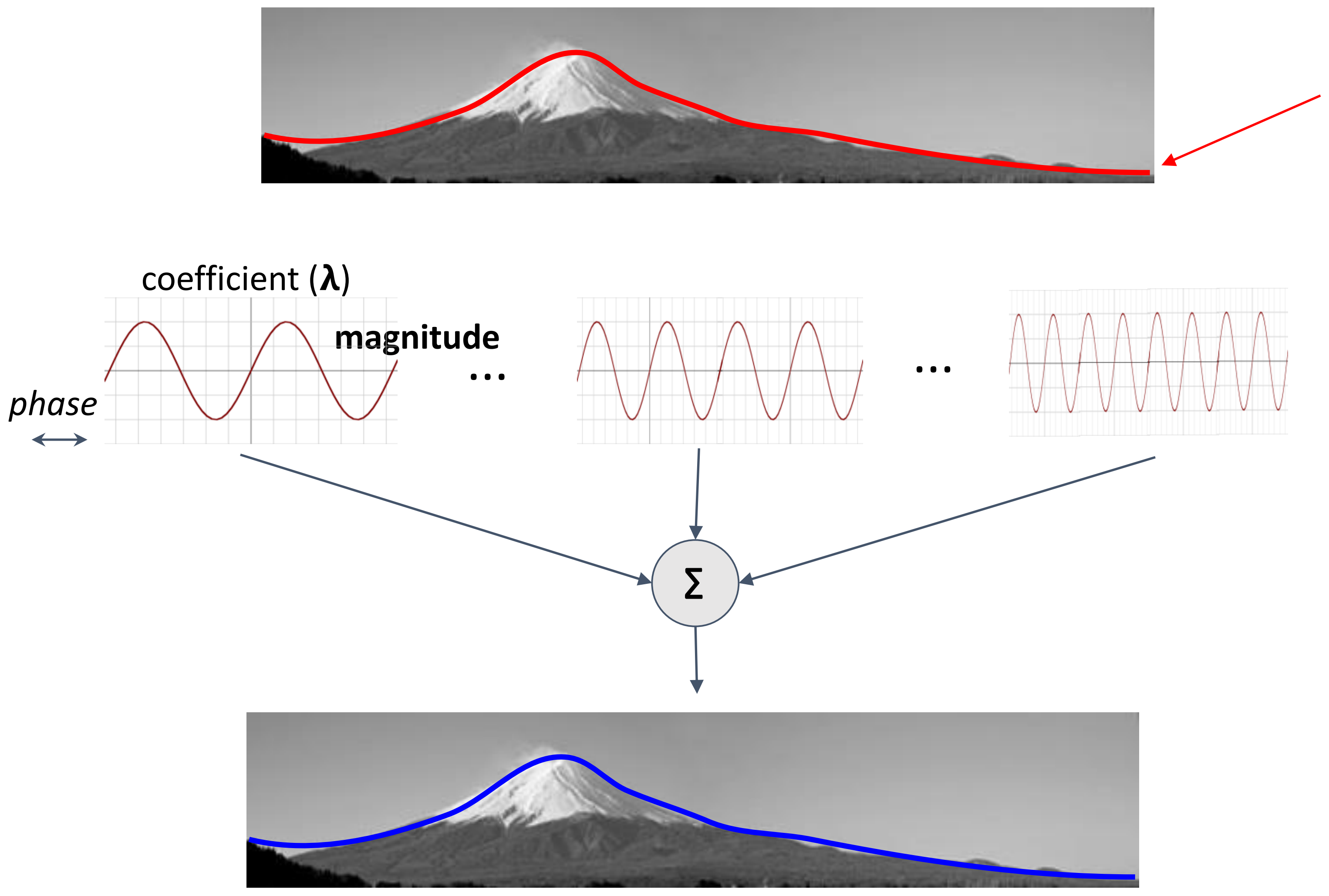
?

Optimal Cue integration

Non-linear integration (switch)

?

Frequency encoding of panoramic skylines



Skyline silhouette is sufficient for place recognition (Stone et al, 2014)

Complex signal can be decomposed into a series of trigonometric functions

Summing increasing basis functions gives approximation of original signal

Features of frequency encoding panoramic skylines

1.Compression (like jpegs)

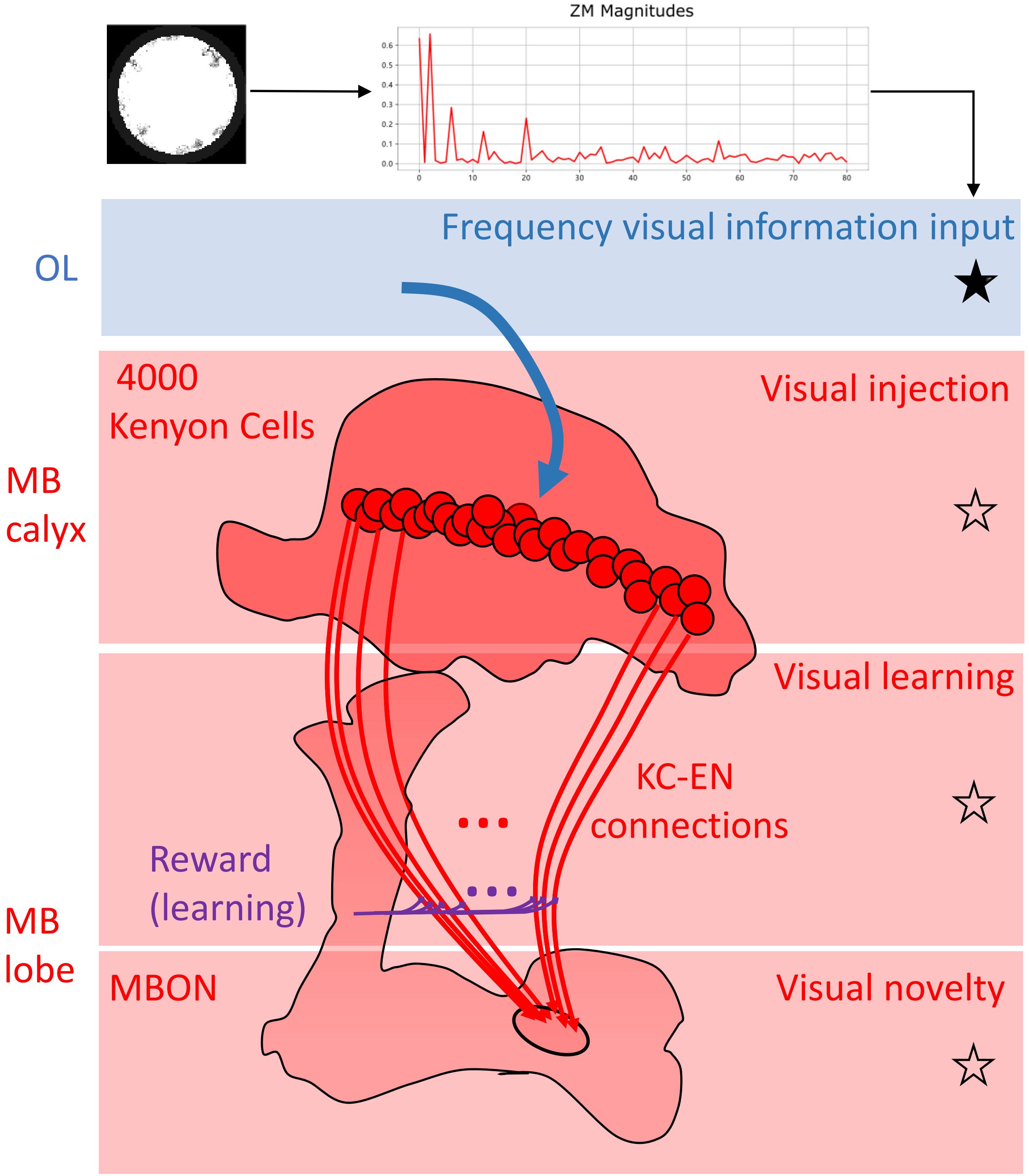
~600 pixels per eye vs 81 magnitudes, 1 phase

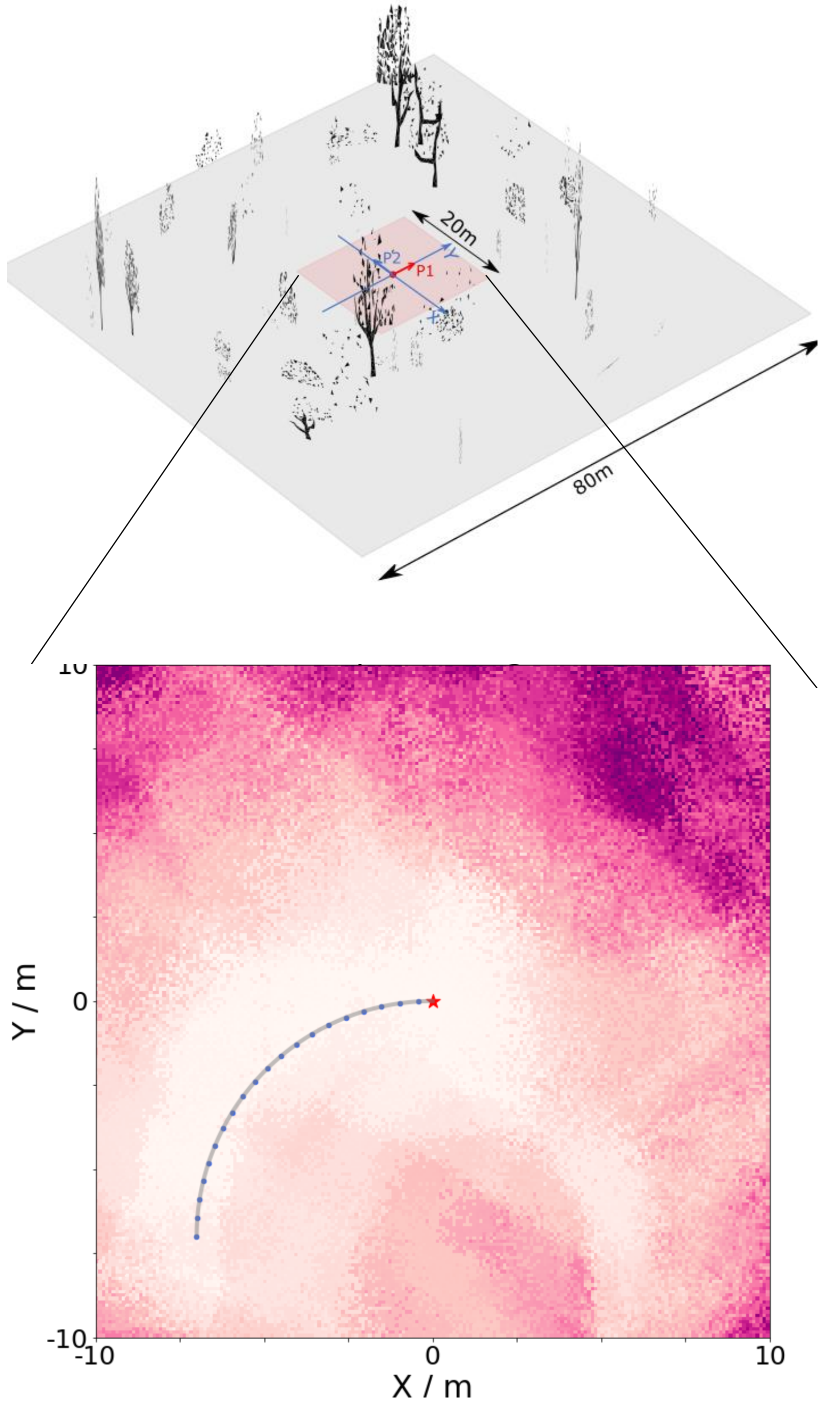
2. Encoding of rotationally invariant **magnitudes** and rotationally varying *phases*

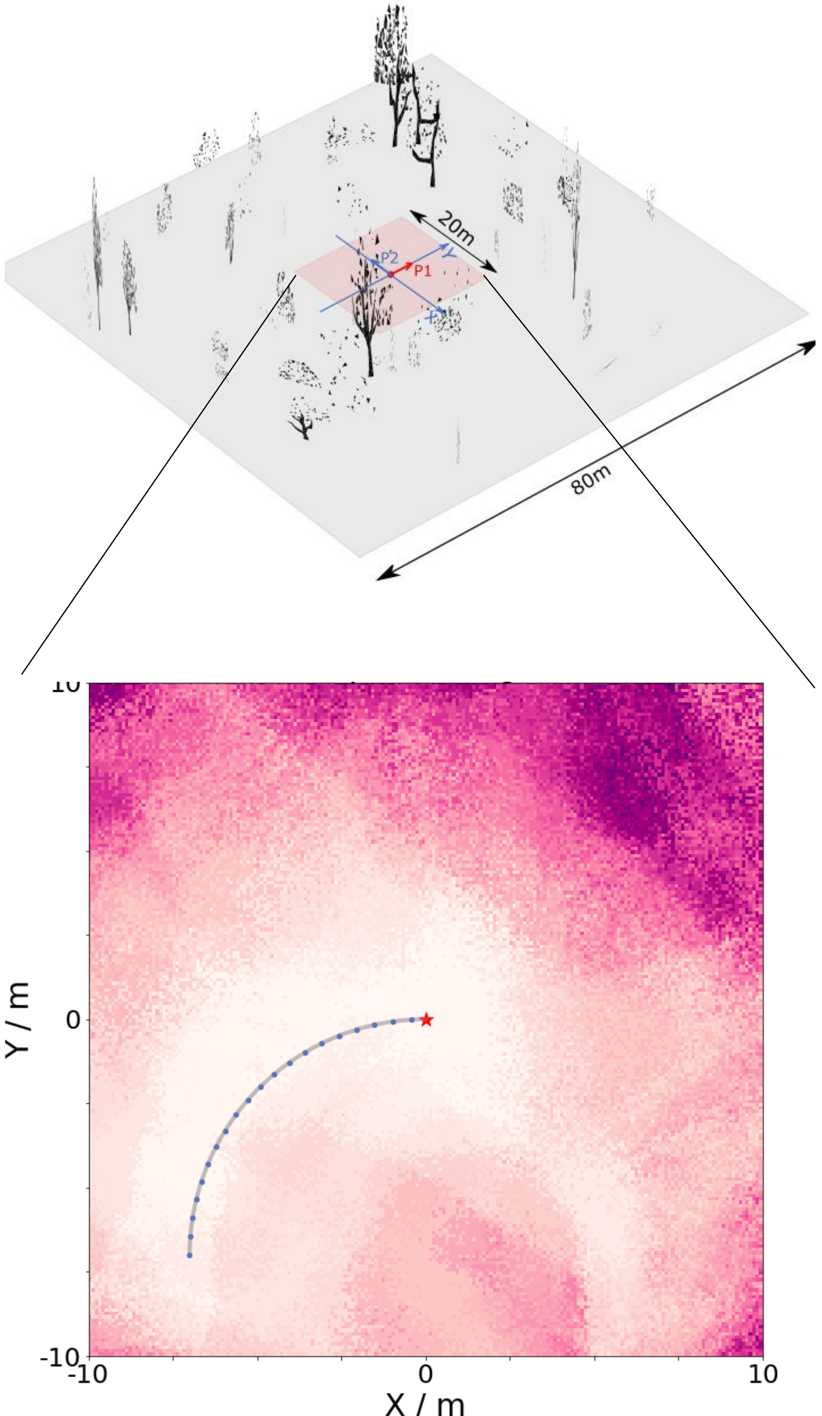
coefficient	**magnitude**	*phase*
1	0.4	20
2	0.4	60
3	0.2	100

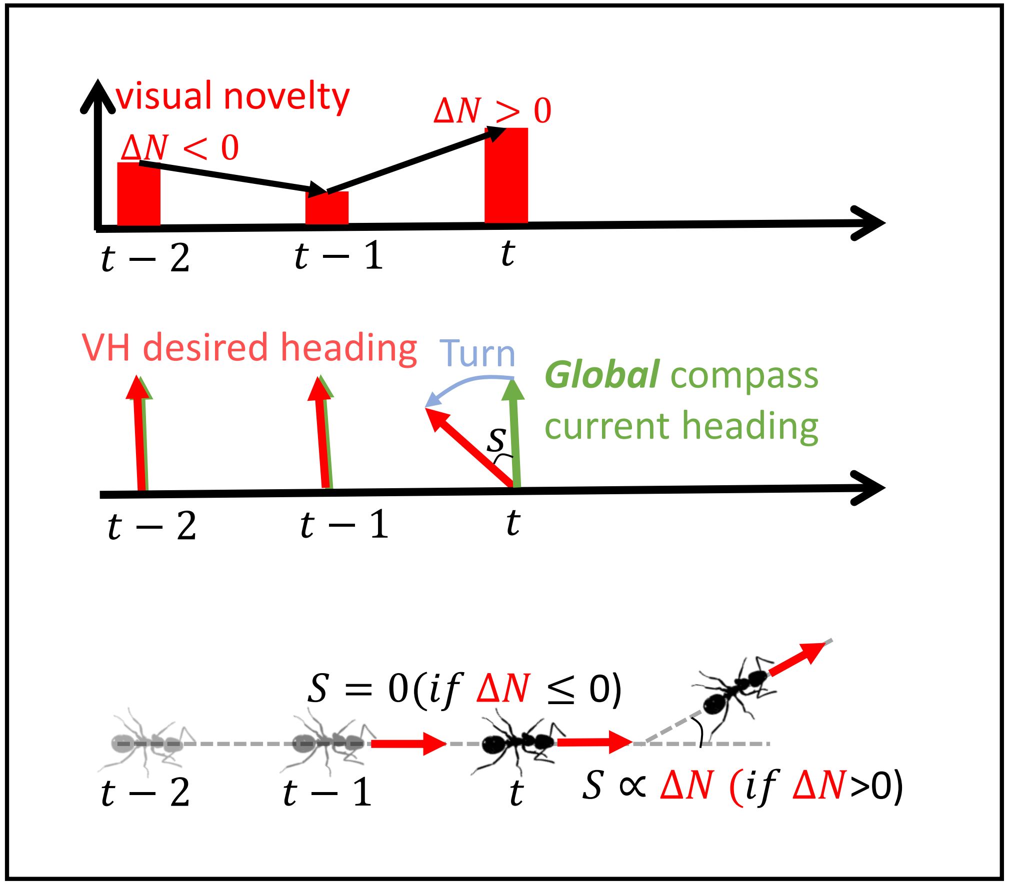
Rotate right 90°

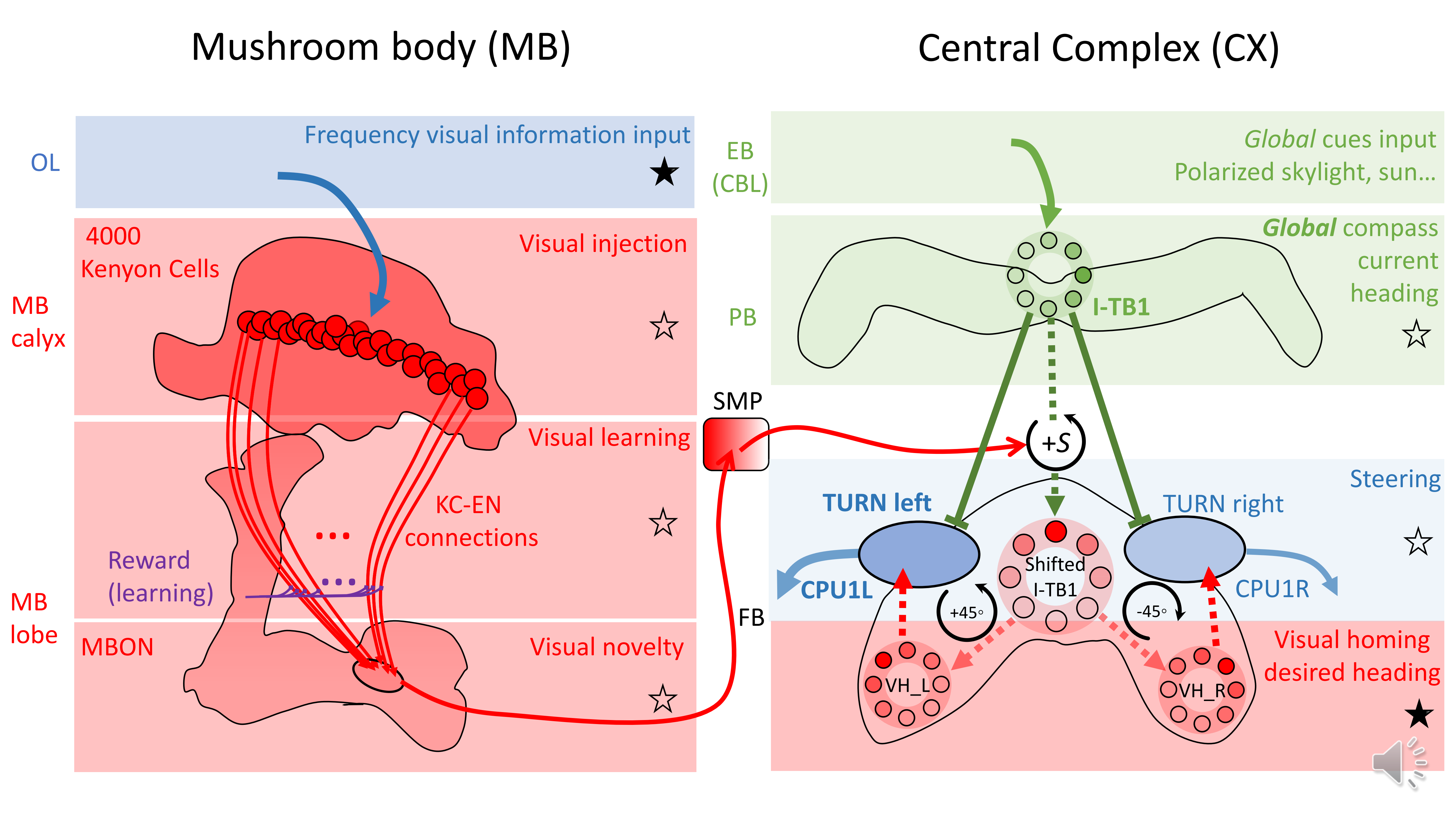
coefficient	**magnitude**	*phase*
1	0.4	90
2	0.4	150
3	0.2	190


ZM Magnitudes
Frequency visual information input
OL
4000
Kenyon Cells
Visual injection
MB
calyx
Visual learning
KC-EN
connections
Reward
(learning)
MB
lobe
MBON
Visual novelty


20m
P2
P1
80m
Y / m
X / m
10
0
-10
-10
0
10

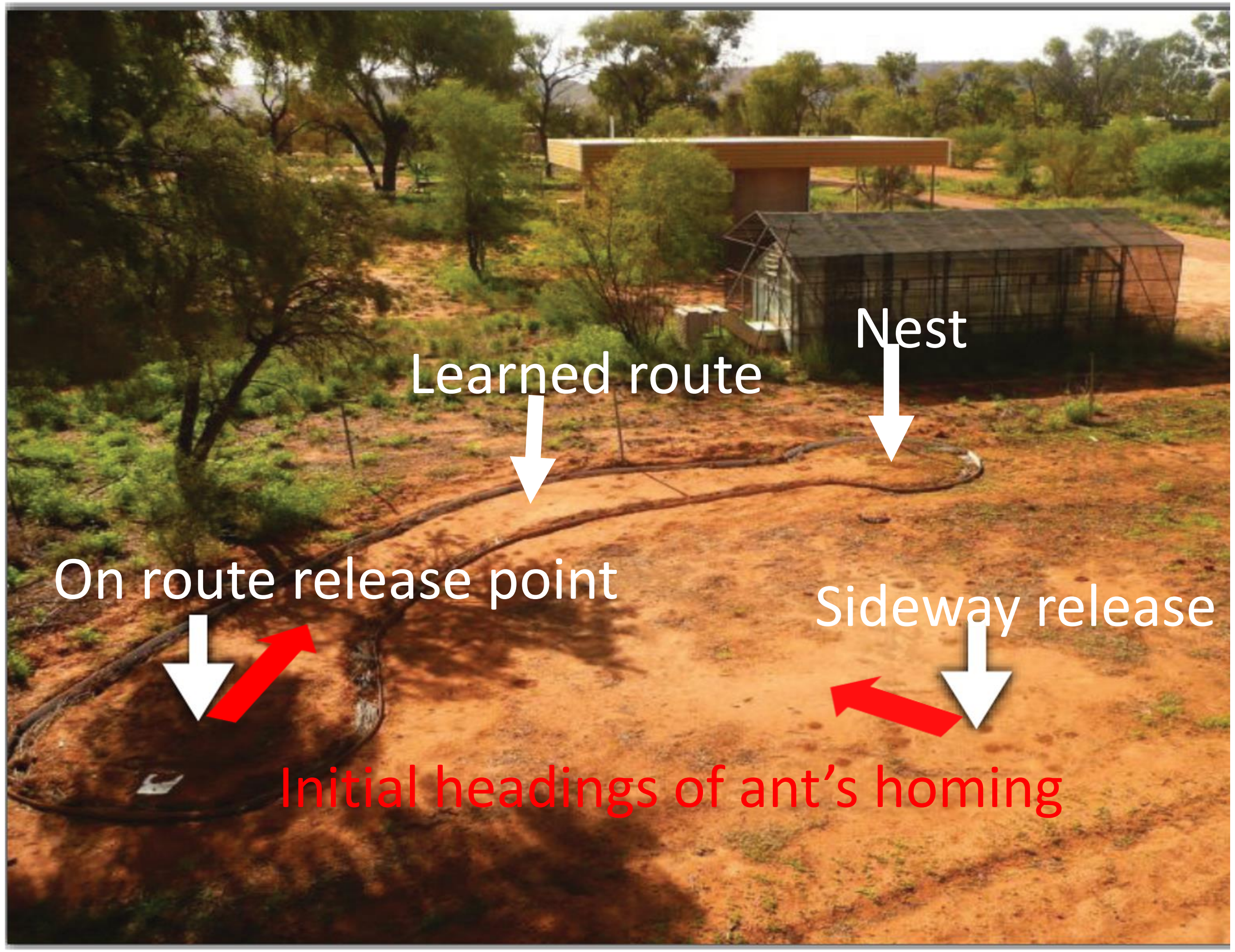

20m
80m
P1
P2
Y / m
X / m
10
0
-10
-10
0
10


visual novelty
$\Delta N < 0$
$\Delta N > 0$
$t-2$
$t-1$
t
VH desired heading
Turn
Global compass
current heading
S
$t-2$
$t-1$
t
$S = 0 (if\ \Delta N \leq 0)$
$t-2$
$t-1$
t
$S \propto \Delta N\ (if\ \Delta N > 0)$



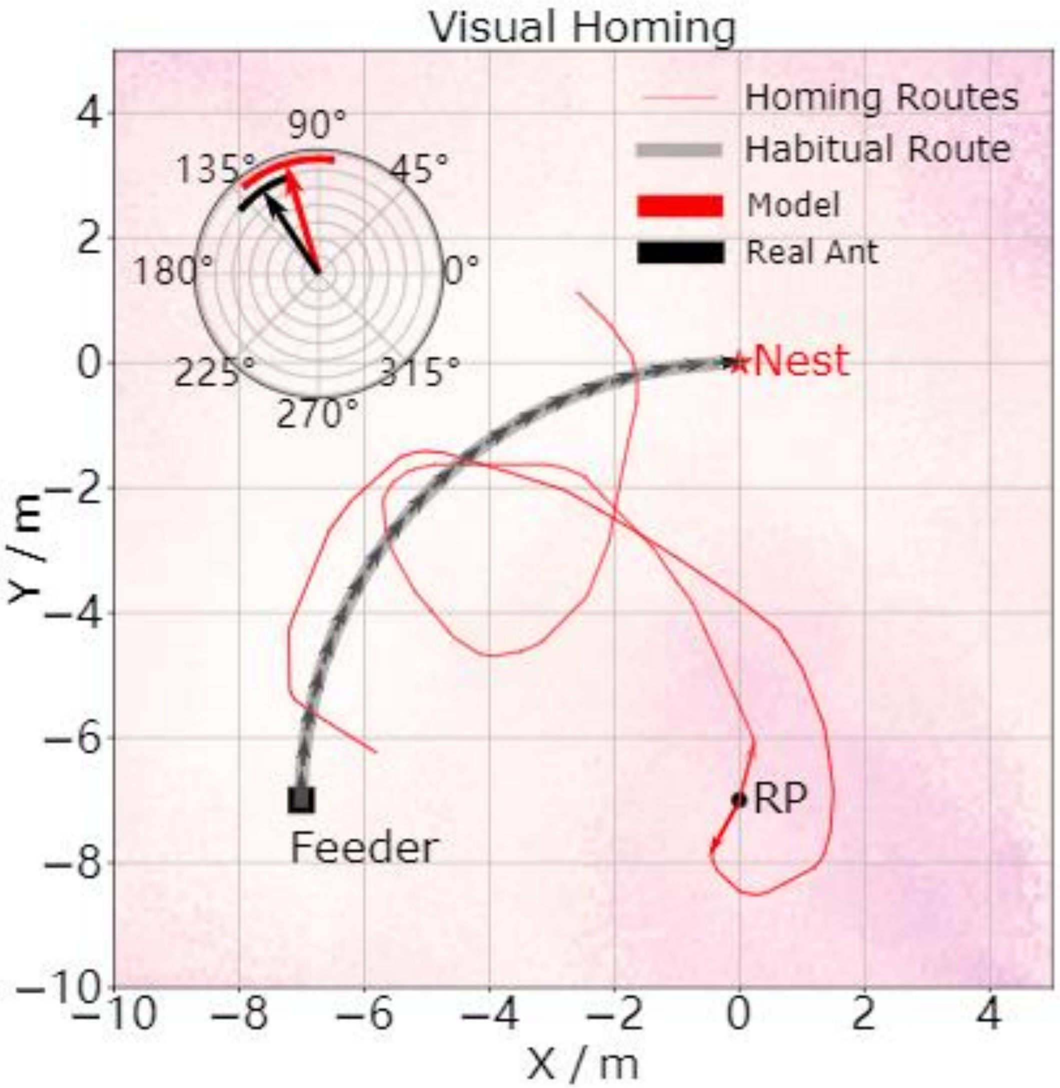
Mushroom body (MB)
Central Complex (CX)
OL
Frequency visual information input
4000
Kenyon Cells
MB
calyx
Visual injection
Visual learning
KC-EN
connections
Reward
(learning)
MB
lobe
MBON
Visual novelty
SMP
EB
(CBL)
Global cues input
Polarized skylight, sun…
PB
Global compass
current
heading
I-TB1
+S
Steering
TURN left
TURN right
Shifted
I-TB1
CPU1L
CPU1R
+45◦
-45◦
FB
VH_L
VH_R
Visual homing
desired heading

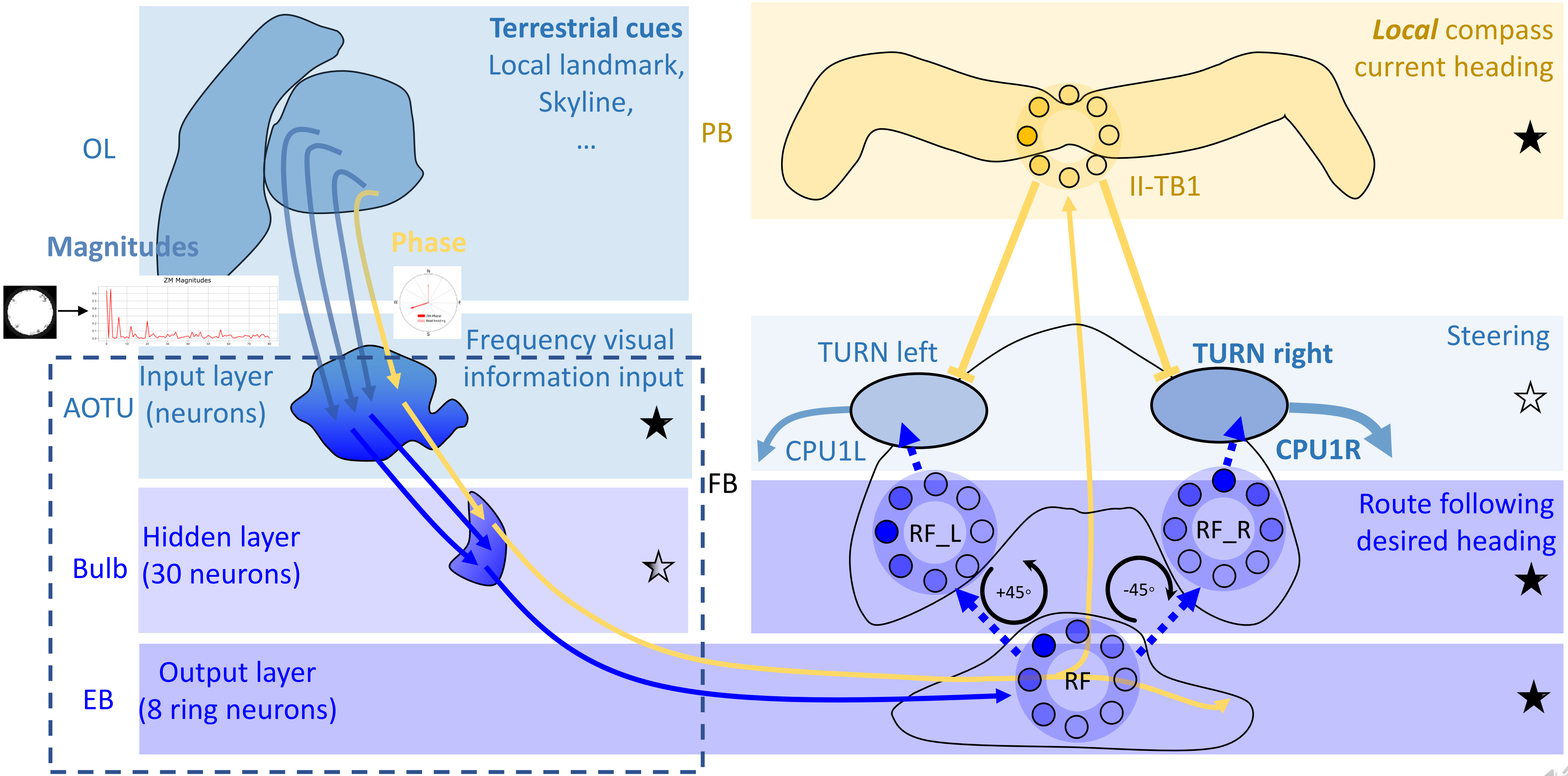
Ants



Wystrach et.al 2012

Model

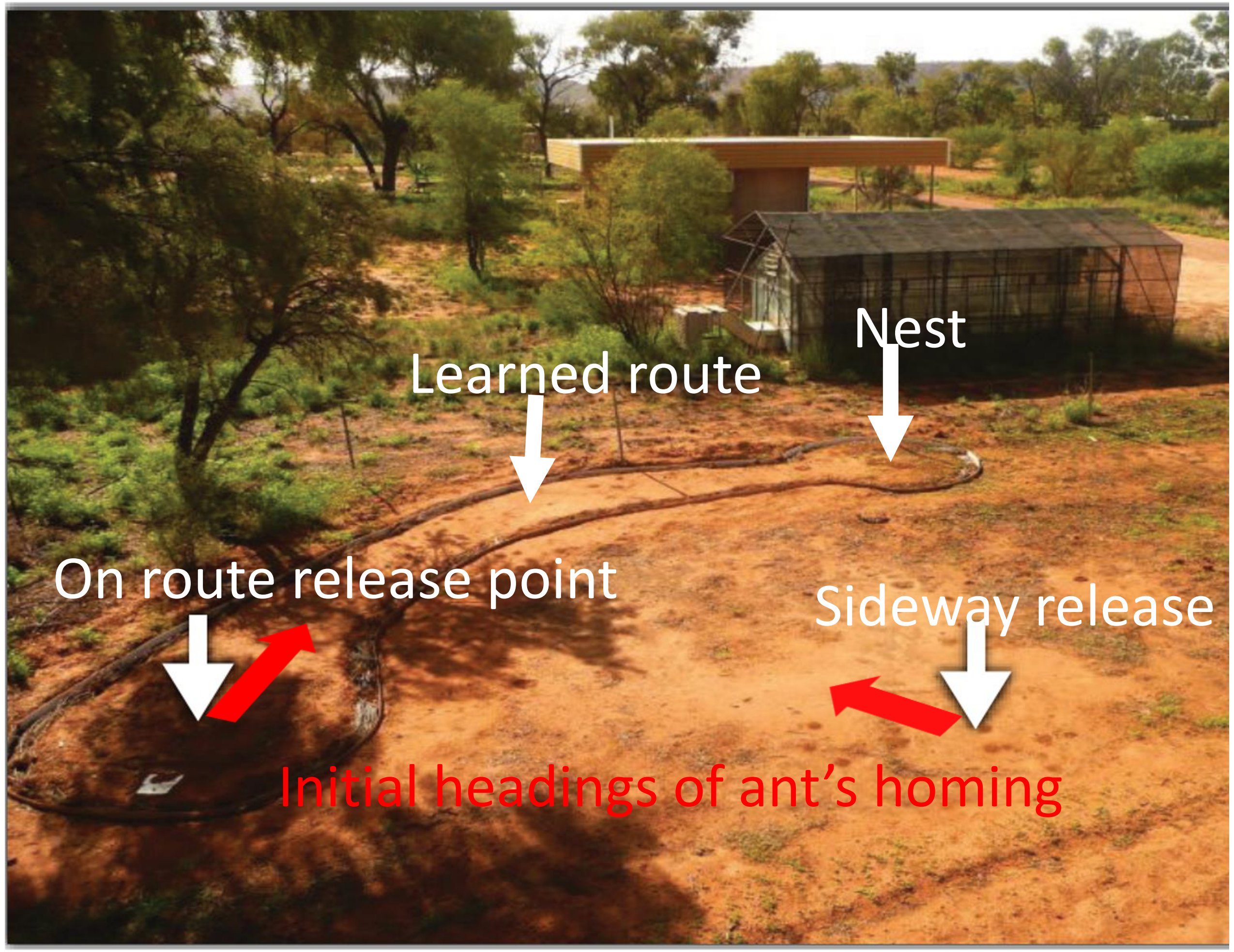


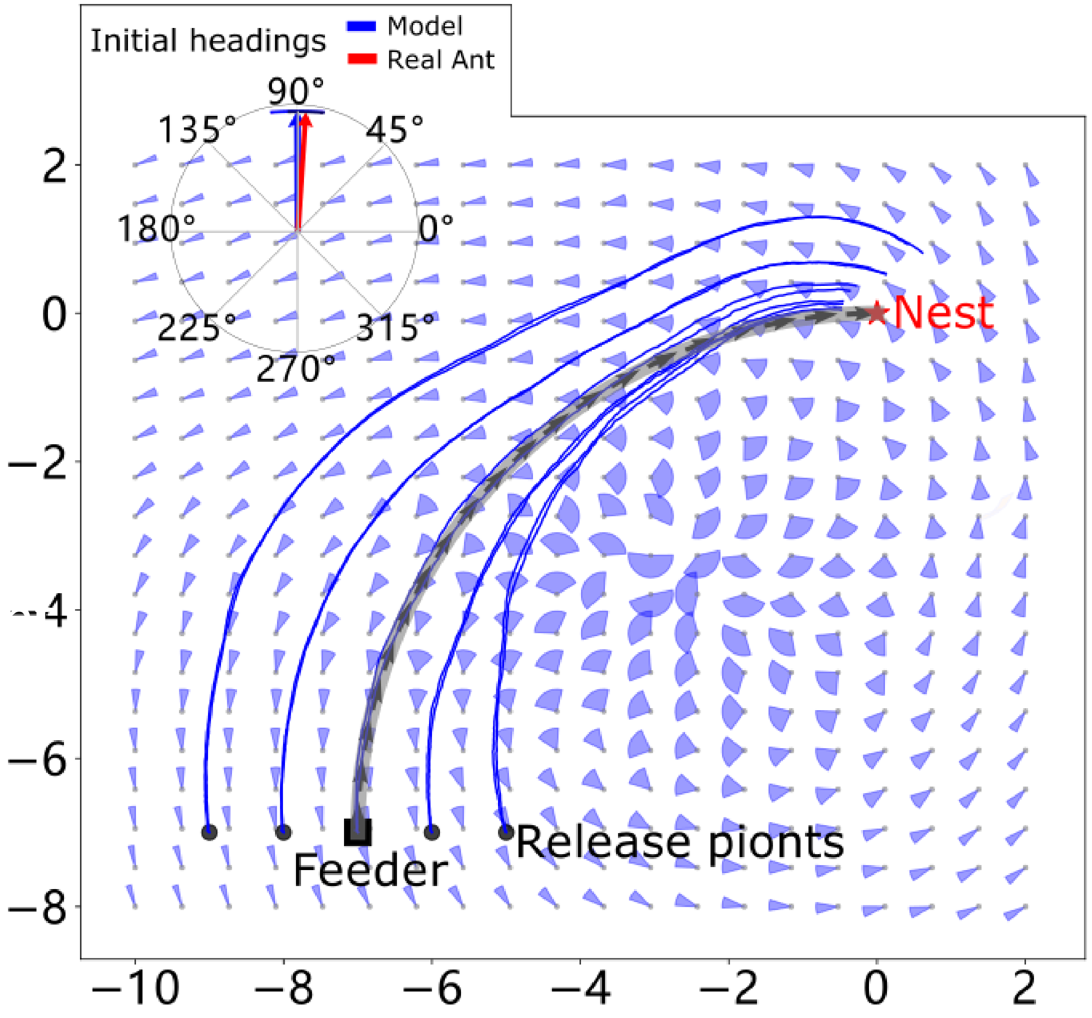


ANN to link the **magnitudes** with *phase* of memorized images sampled along the route

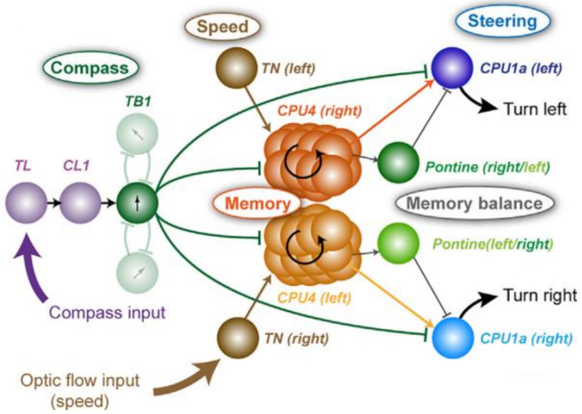
Ants

Model


Nest
Learned route
On route release point
Sideway release
Initial headings of ant's homing


Initial headings
Model
Real Ant
90°
135°
45°
180°
0°
225°
315°
270°
Nest
Feeder
Release pionts
2
0
−2
−4
−6
−8
−10
−8
−6
−4
−2
0
2

Stone et.al 2017



Frequency encoding

Magnitudes

Phase

MB associative learning

Correlating the **magnitudes** and *phase*

CX steering

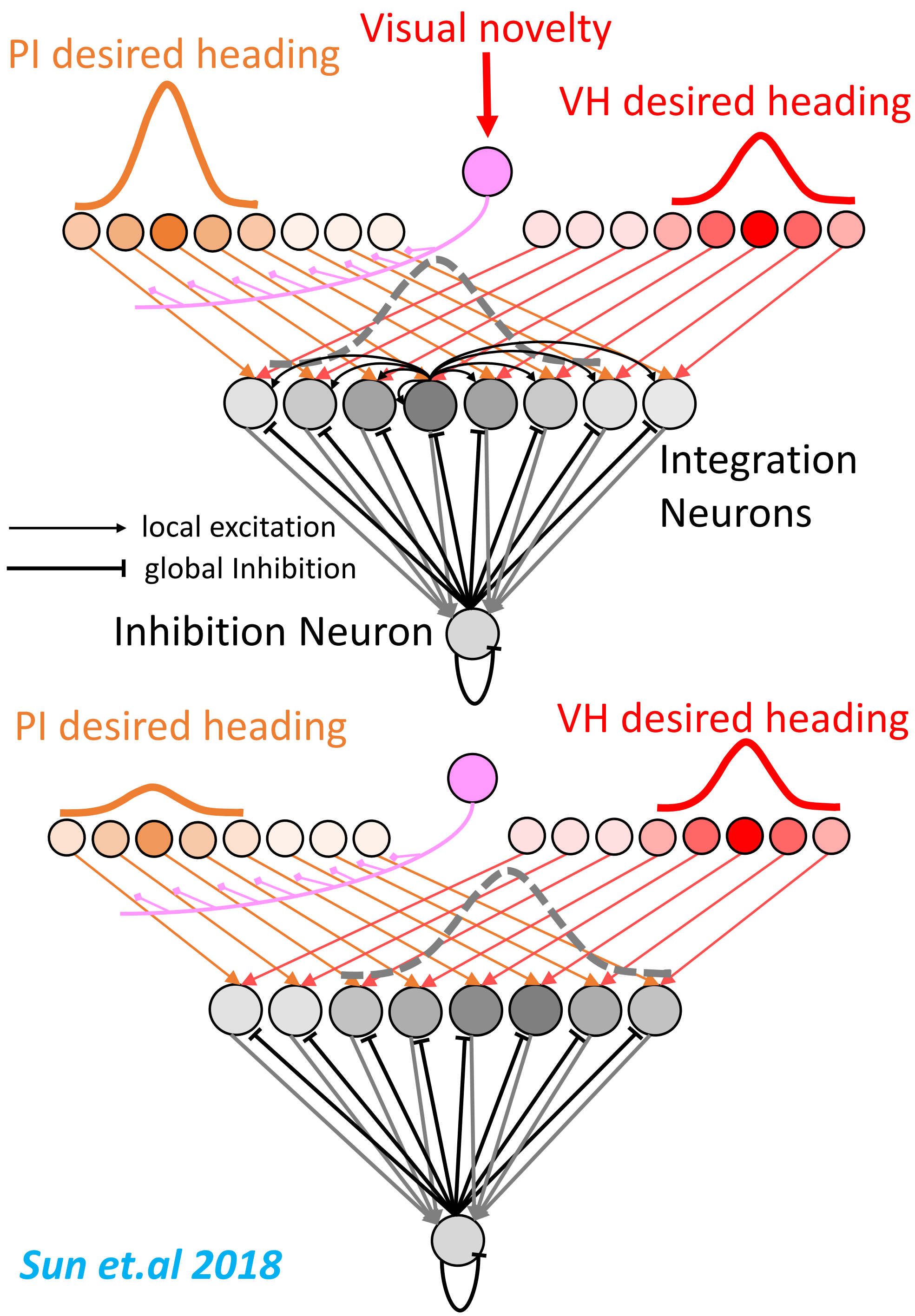
Path Integration	Visual Homing	Route Following

?

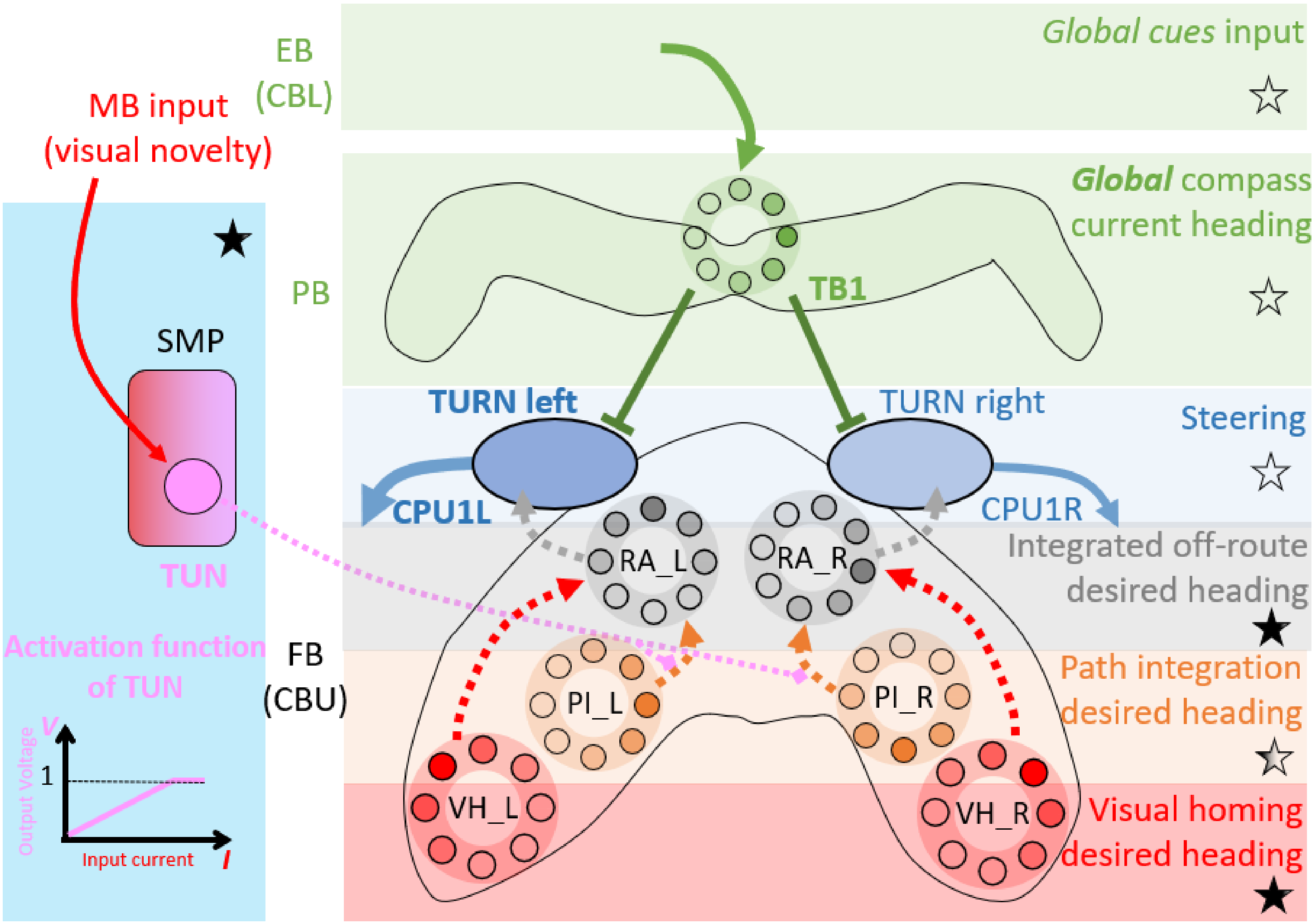
Optimal Cue integration

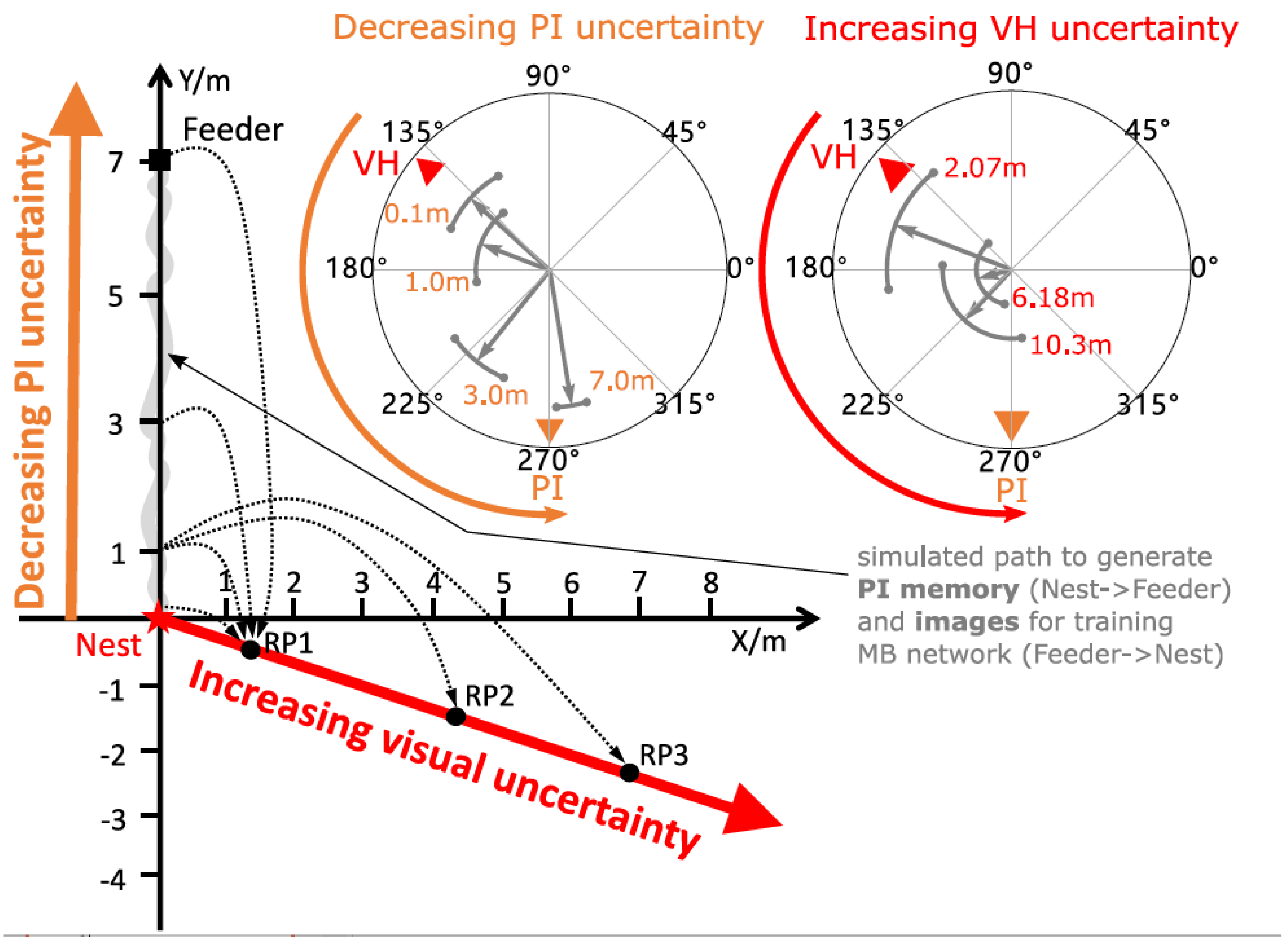
Non-linear integration (switch)

?



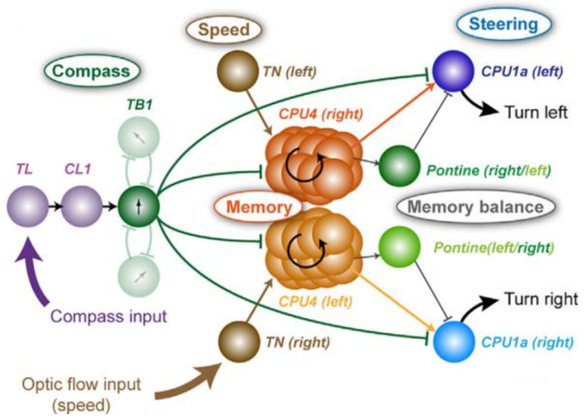
Sun et.al 2018





Decreasing PI uncertainty
Increasing VH uncertainty
Decreasing PI uncertainty
Y/m
Feeder
7
5
3
1
-1
-2
-3
-4
1
2
3
4
5
6
7
8
X/m
Nest
RP1
RP2
RP3
Increasing visual uncertainty
90°
135°
45°
180°
0°
225°
315°
270°
VH
PI
0.1m
1.0m
3.0m
7.0m
2.07m
6.18m
10.3m
simulated path to generate
PI memory (Nest->Feeder)
and images for training
MB network (Feeder->Nest)

Stone et.al 2017



Frequency encoding

Magnitudes

Phase

MB associative learning

Correlating the **magnitudes** and *phase*

CX steering

Path Integration

Visual Homing

Route Following

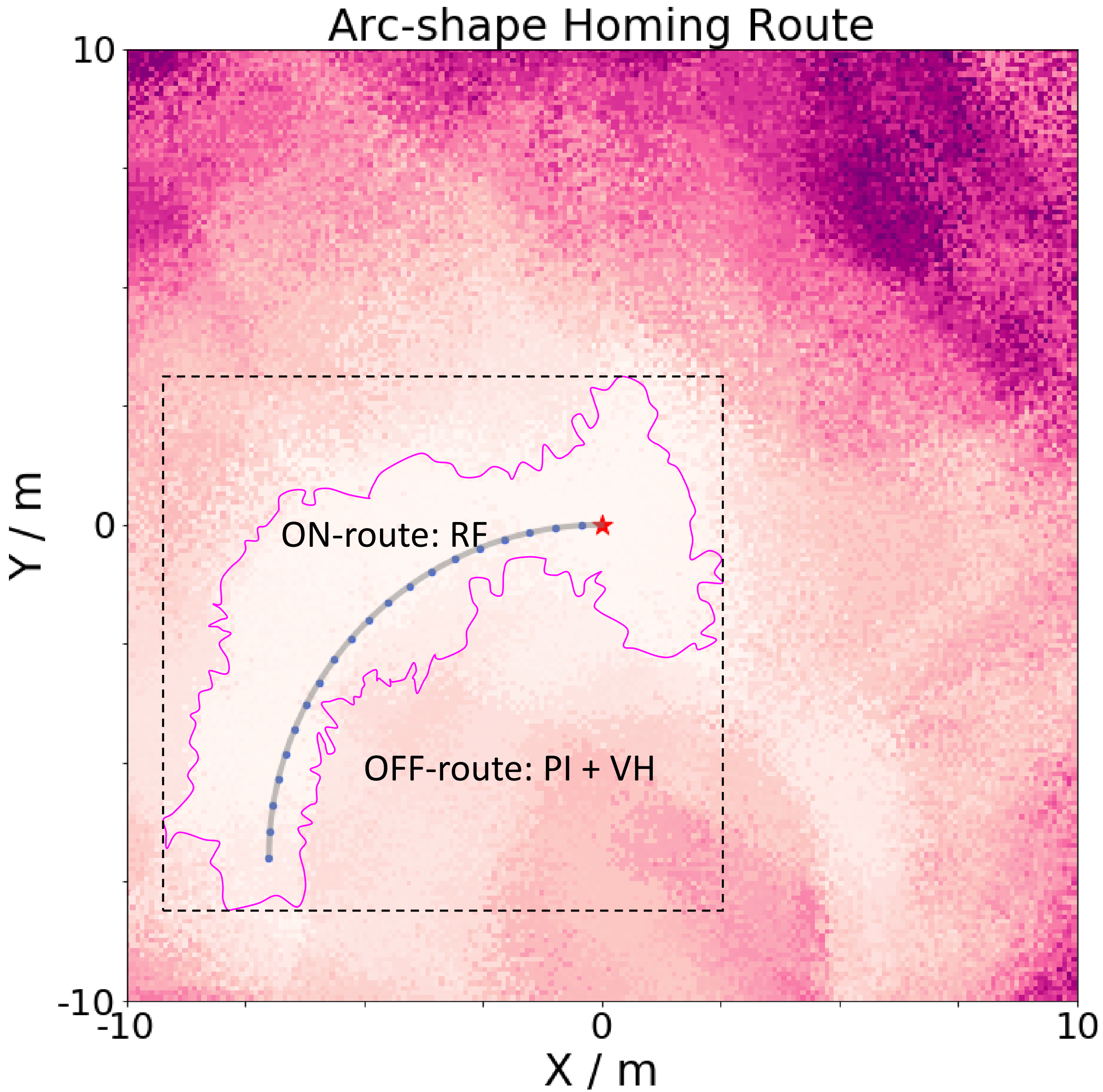
Ring Attractor

Optimal Cue integration

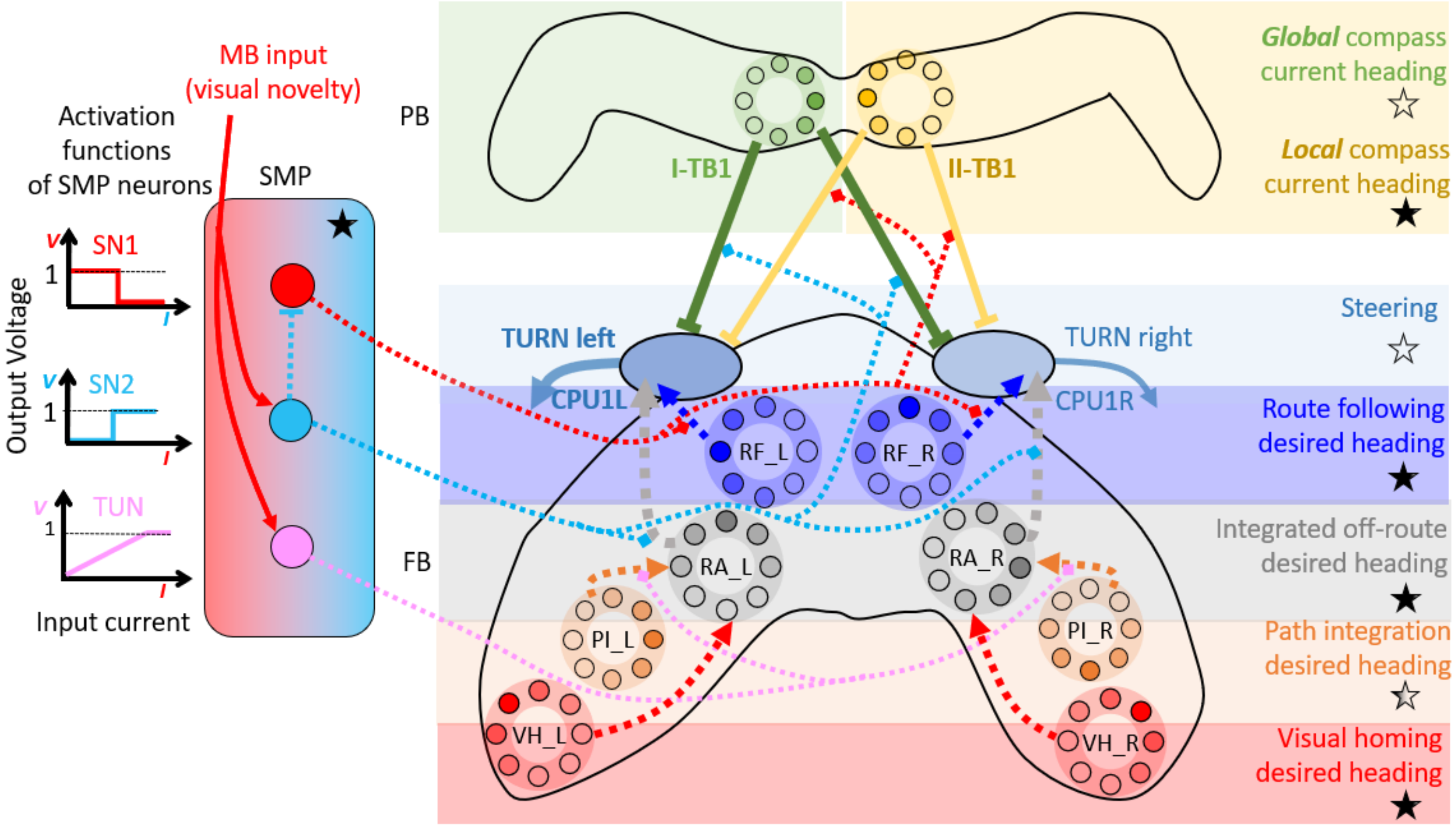
Non-linear integration (switch)

?

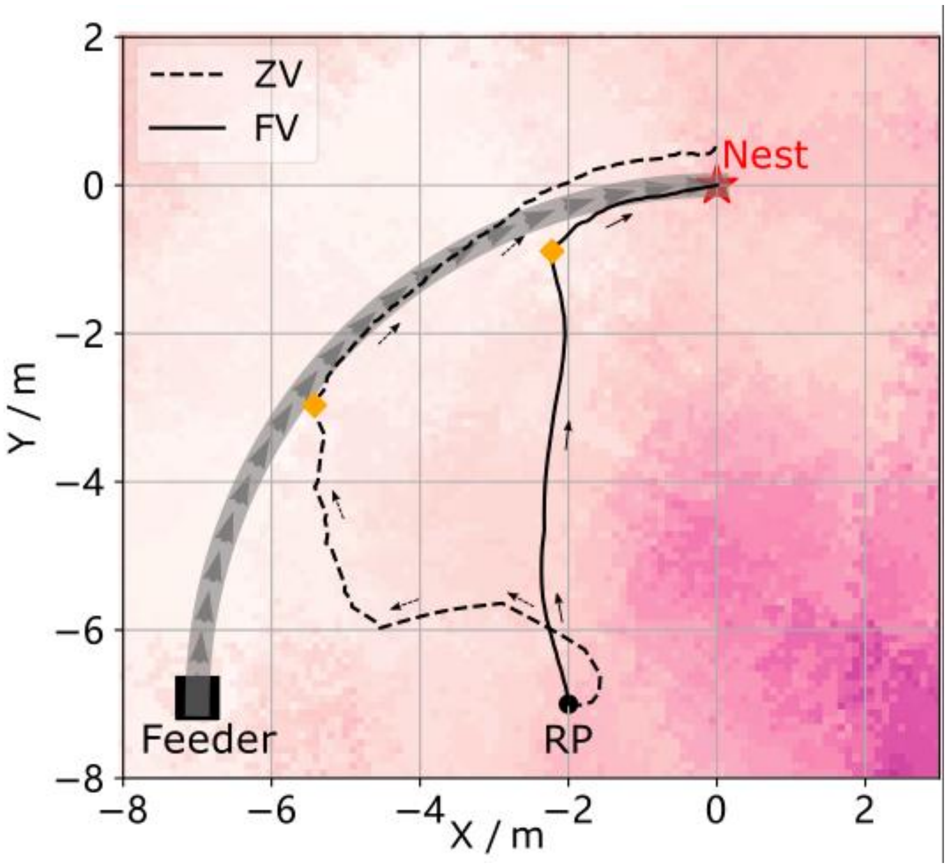
Using **threshold** of the visual novelty to switch



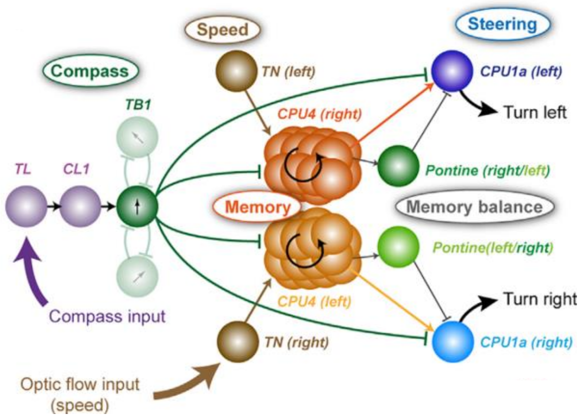
Coordination model



Model performance



Stone et.al 2017



Frequency encoding

Magnitudes

Phase

MB associative learning

Correlating the **magnitudes** and *phase*

CX steering

Path Integration

Visual Homing

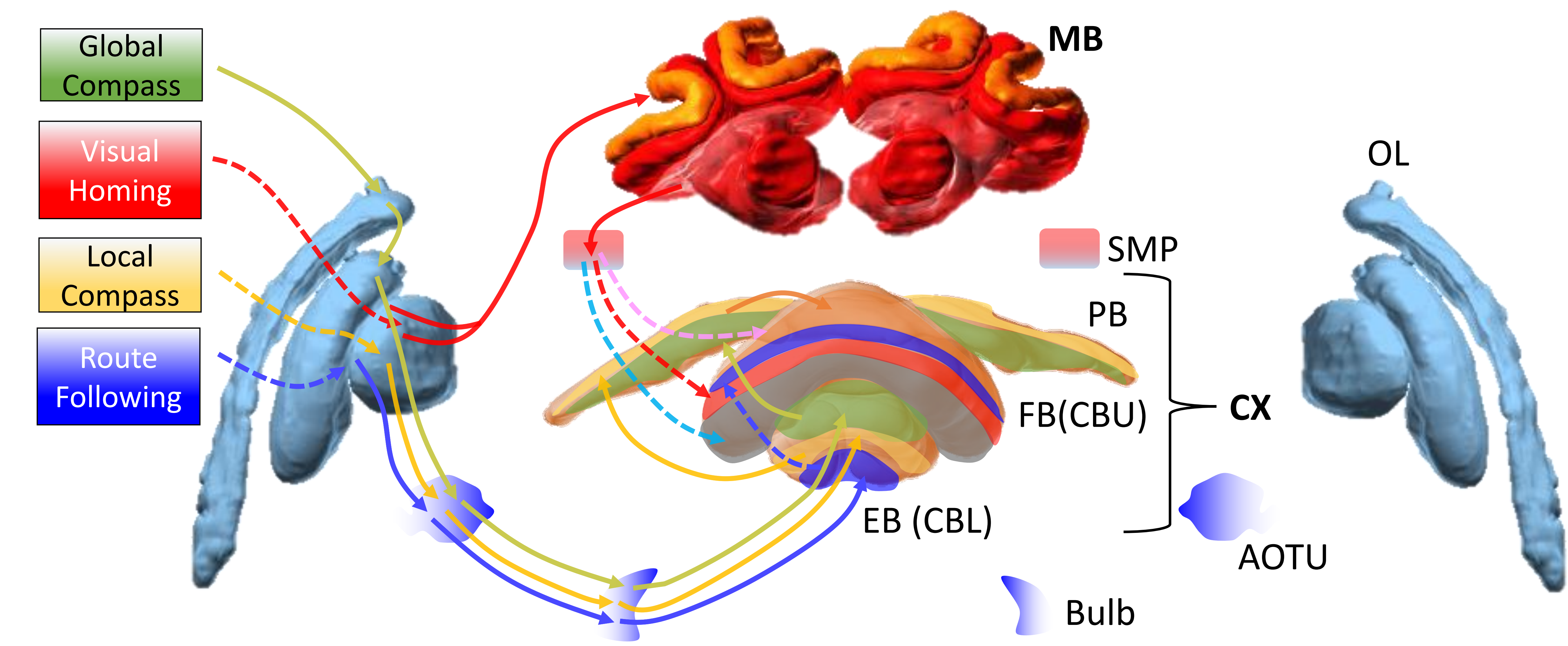
Route Following

Ring Attractor

Optimal Cue integration

Non-linear integration (switch)

Threshold



1. Frequency encoding of views allow both visual homing and route following

2. Optimal integration happens in the CX via a ring attractor circuit

3. A context dependent switch allows the transition from off route to on route strategy

Thanks

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Sincere apologies for that I cannot do the presentation in person.

In any case that I haven't make everything clear:

What we want to address is:

In the field of **insect navigation**, there are good models of PI and RF, **but there is no model for VH, and similarly there is no model to co-ordinate them.**

What you can learn from this talk are:

1. That frequency encoding of views allows rotational invariant information to be separated from place recognition information allows both VH and RF to function separately.
2. Insects have the correct type of neural circuits for VH (MB) and RF (AOTU), and PI (CX with steering)
3. Ring attractors are the perfect mechanism to optimally integrate these systems
4. Context-dependent switches are the last component that give us the full model.

If you are interesting in our research, please refer to the paper.
https://www.biorxiv.org/content/10.1101/856153v2

Feel free to contact me, *xsun@lincoln.ac.uk*