

Bees and the Traveling Salesman Problem

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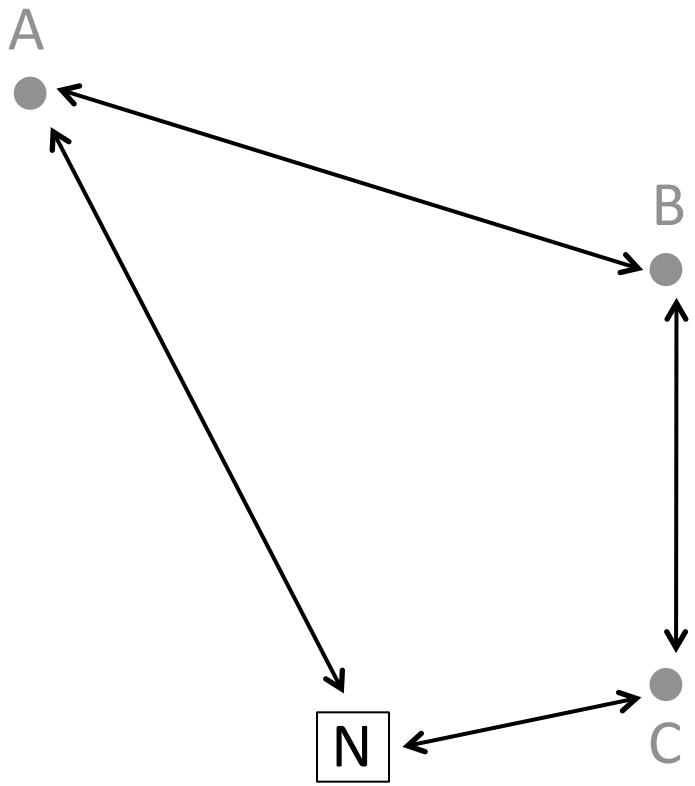
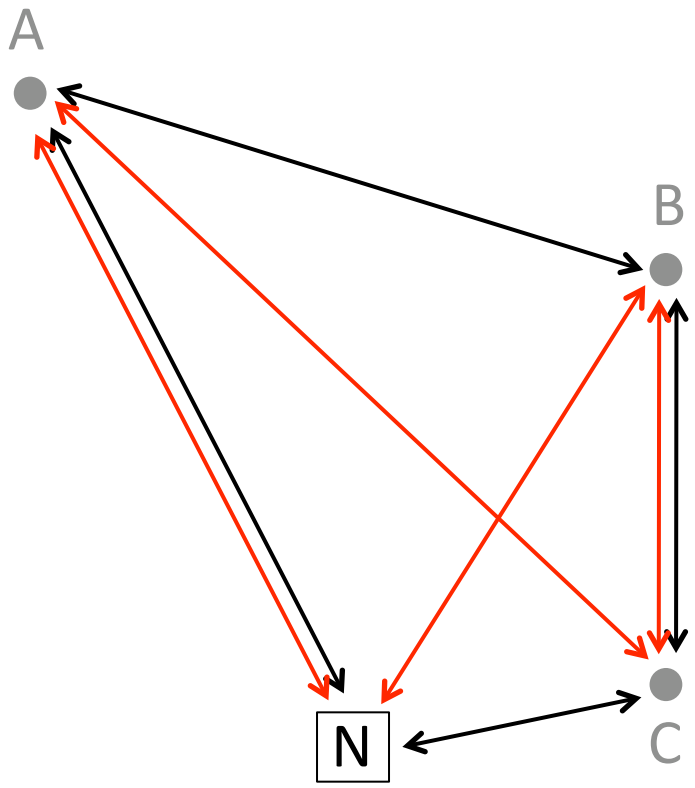
N

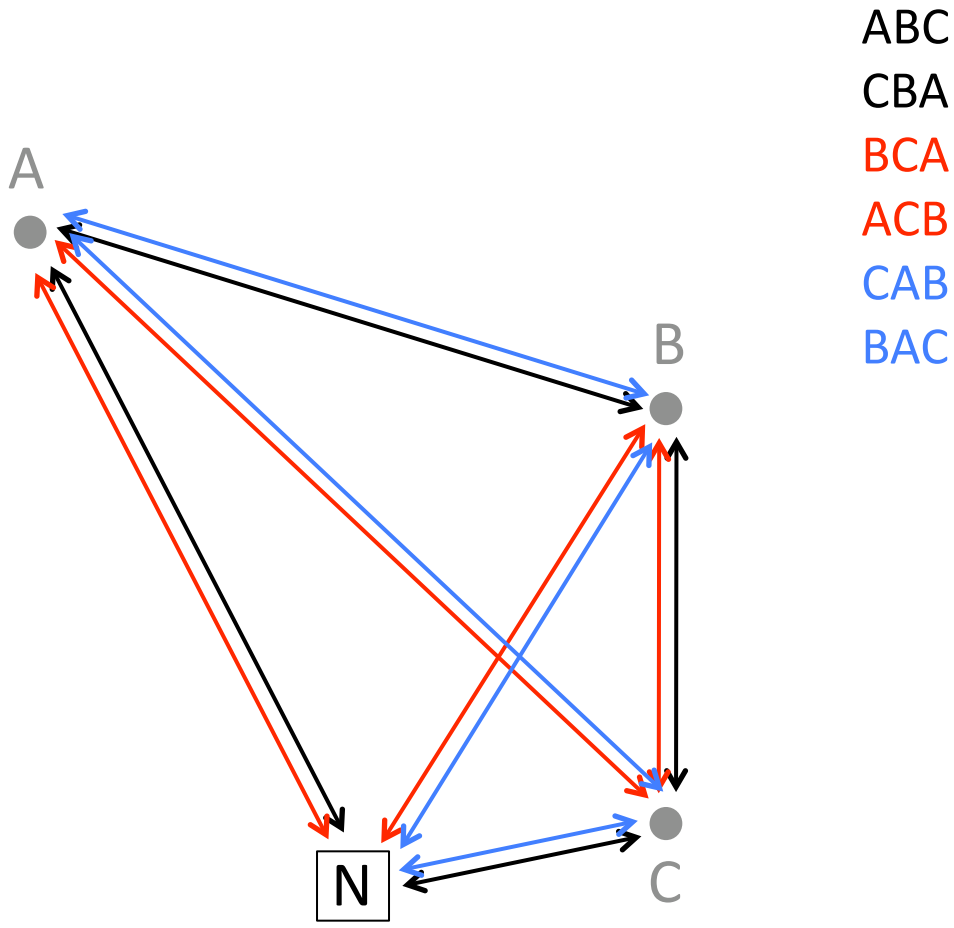

A
B
C
N

ABC
CBA



ABC
CBA
BCA
ACB




A
B
C
N
ABC
CBA
BCA
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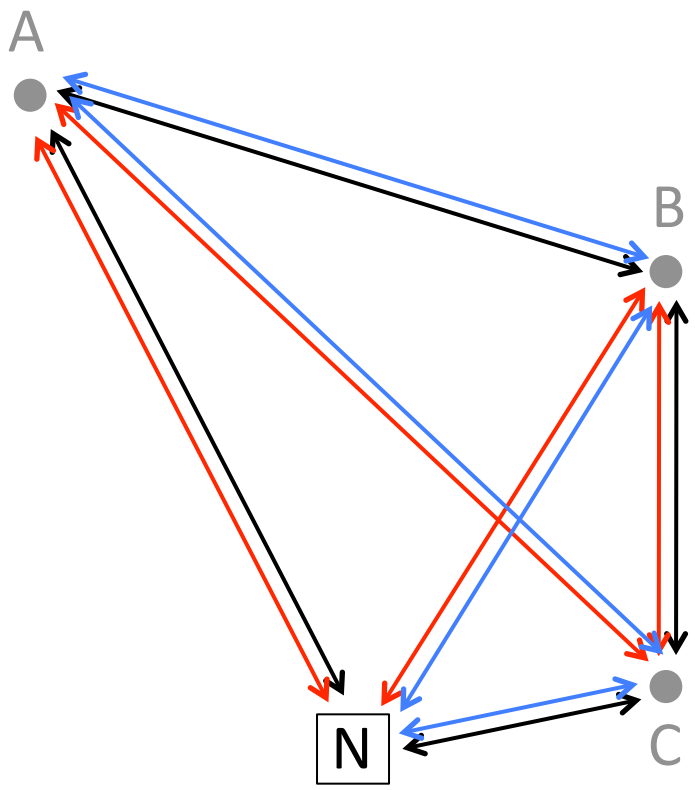
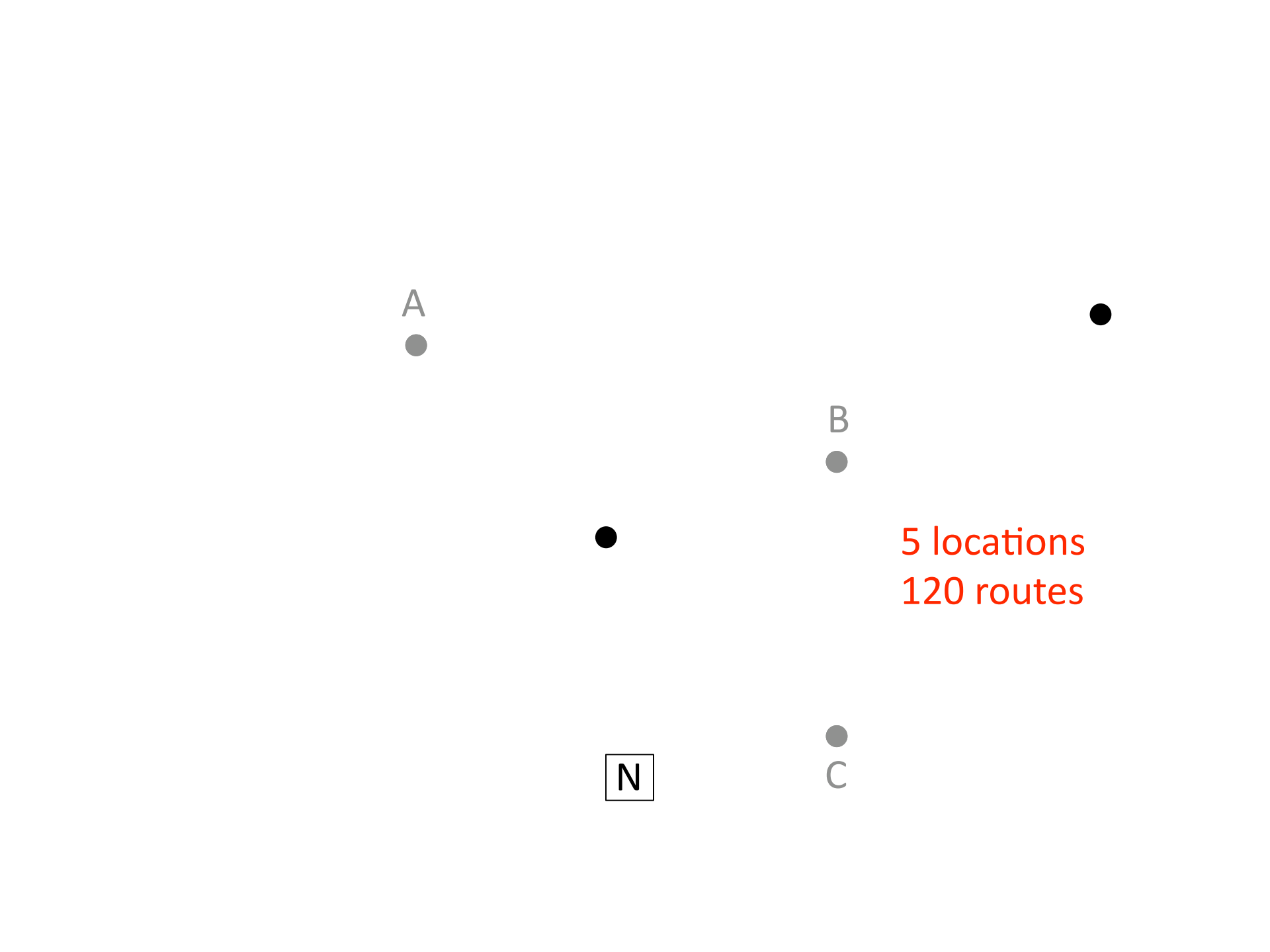
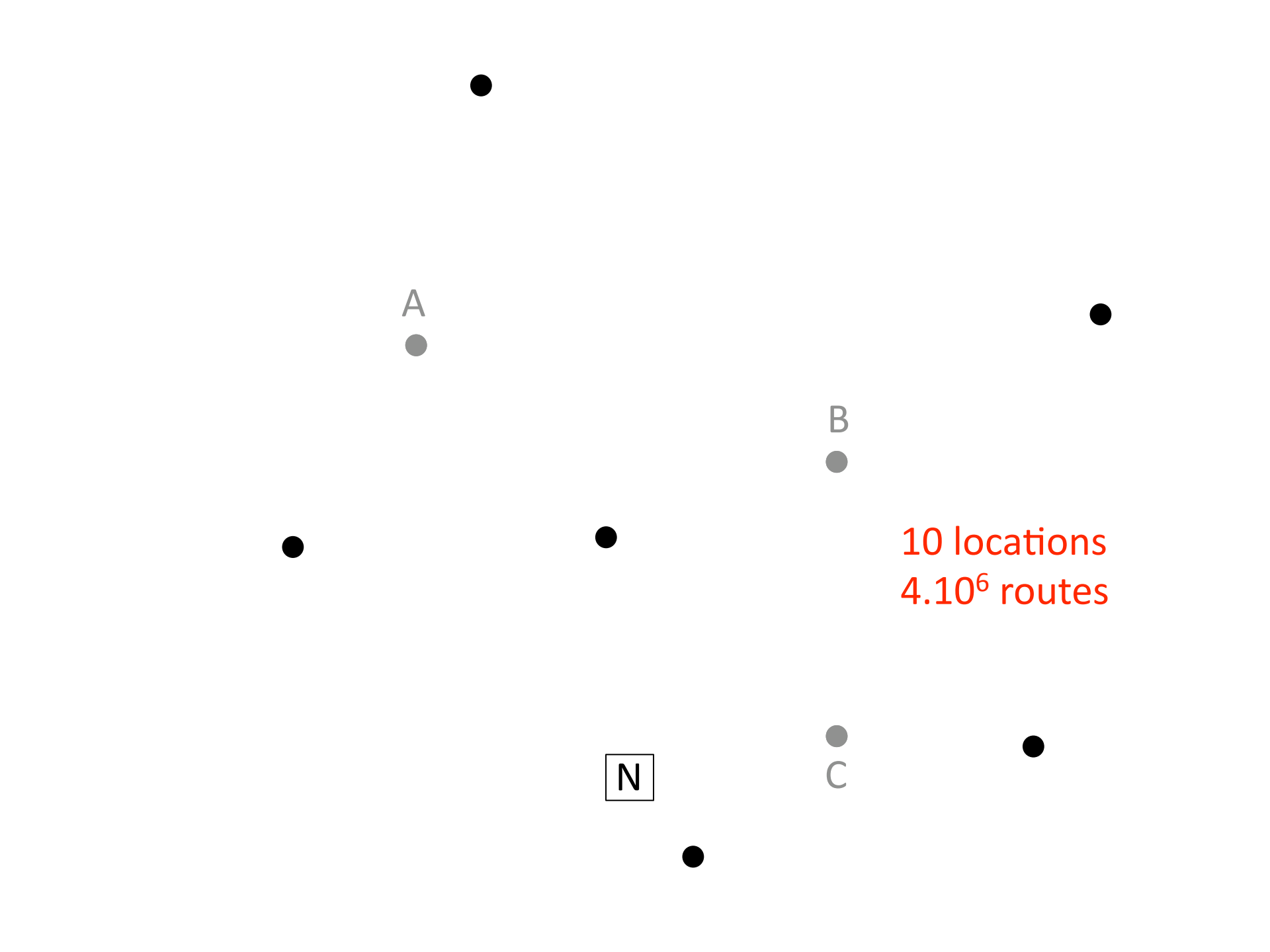
CAB
BAC

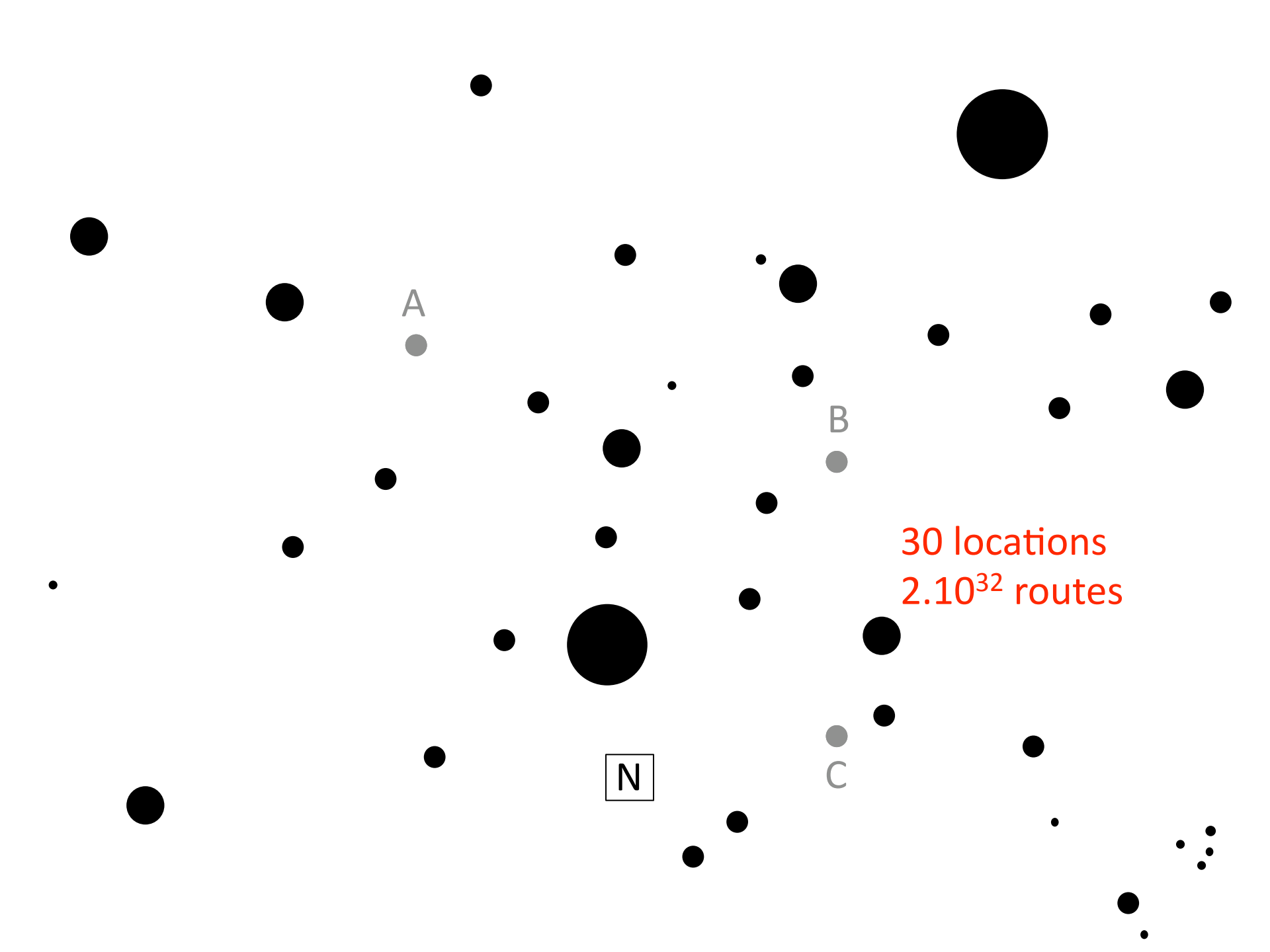


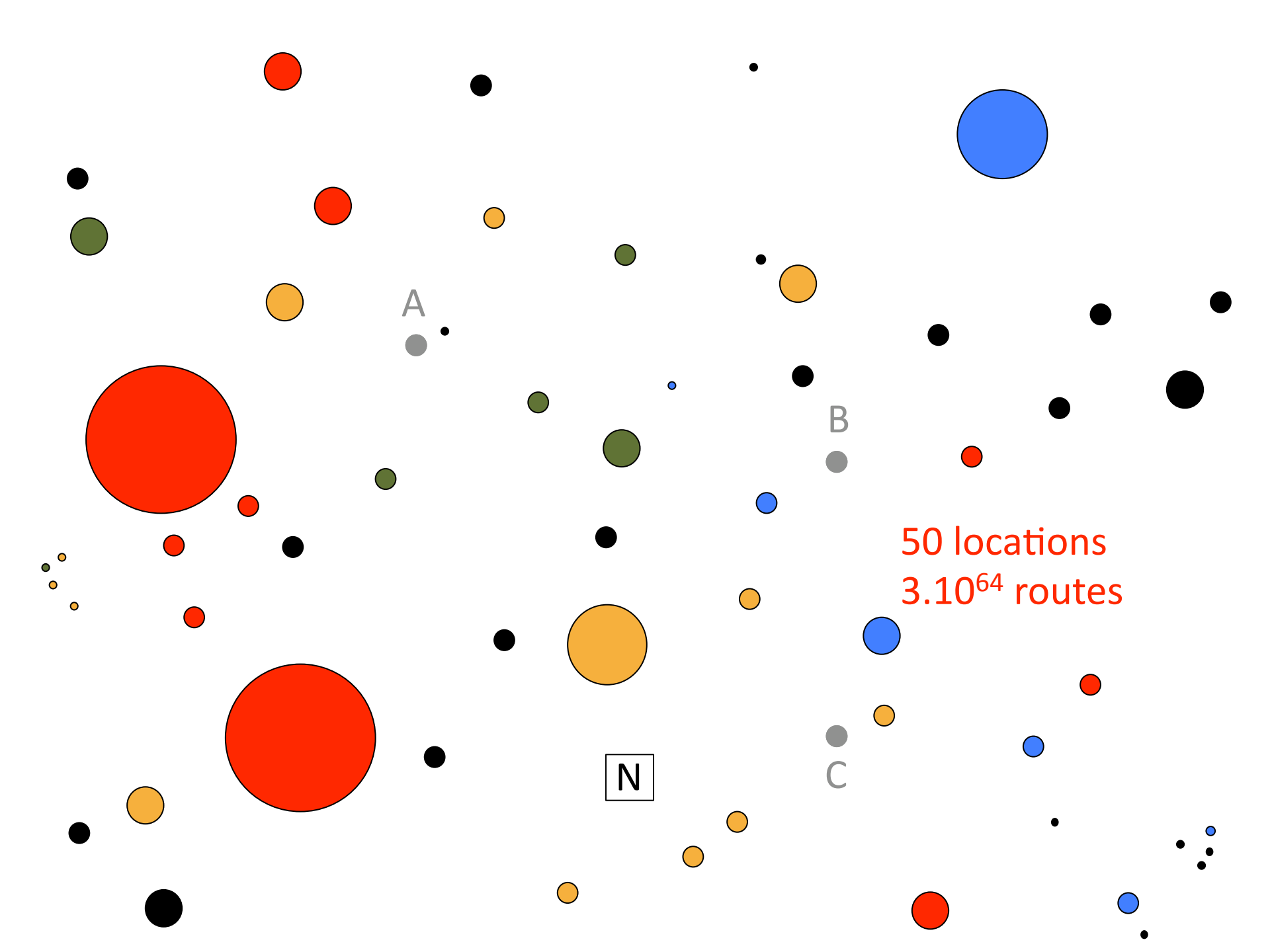
ABC
CBA
BCA
ACB
CAB
BAC

3 locations
3 x 2 x 1 = 6 routes


A
B
C
N
5 locations
120 routes


A
B
C
N
10 locations
4.10^6 routes

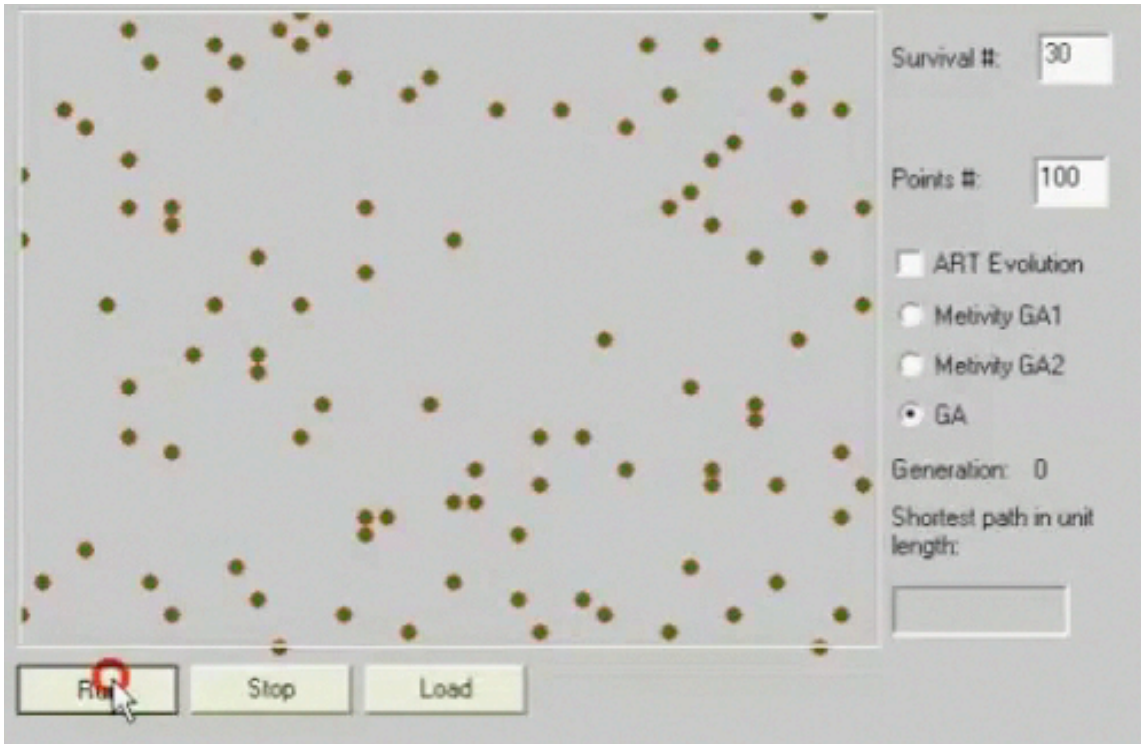

A
B
C
N
30 locations
2.10^32 routes


A
B
C
N
50 locations
3.10^64 routes

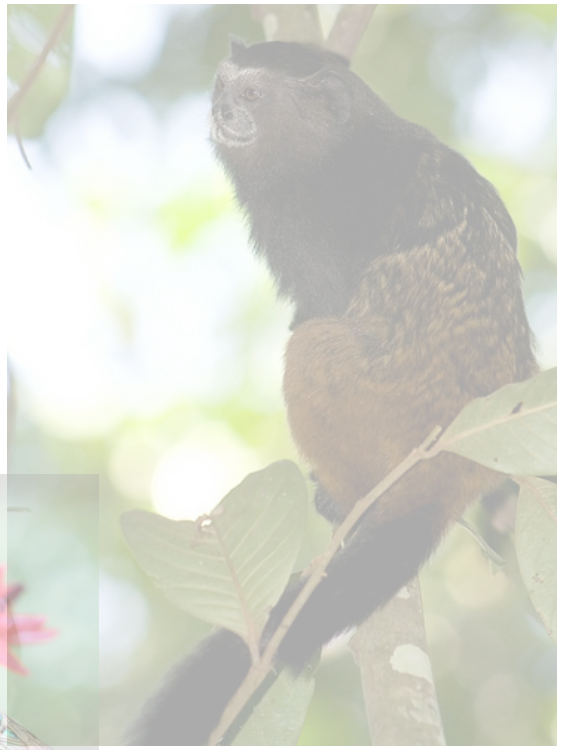
The Travelling Salesman Problem

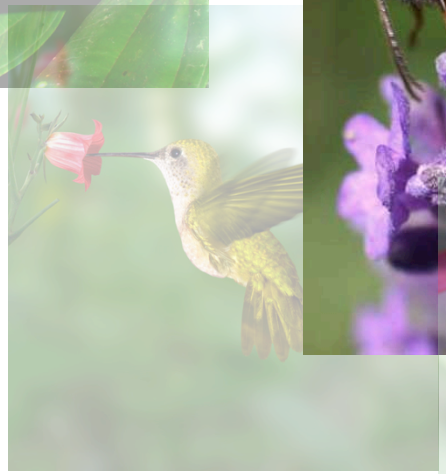
"Finding the shortest path that passes through a set of locations once and return to the origin"

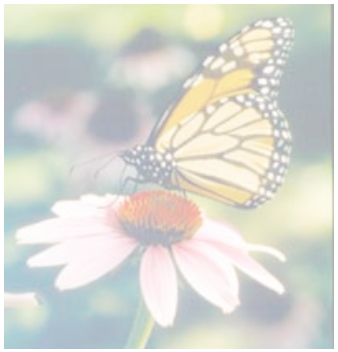
RW Hamilton (1805-1855)



The case of pollinators





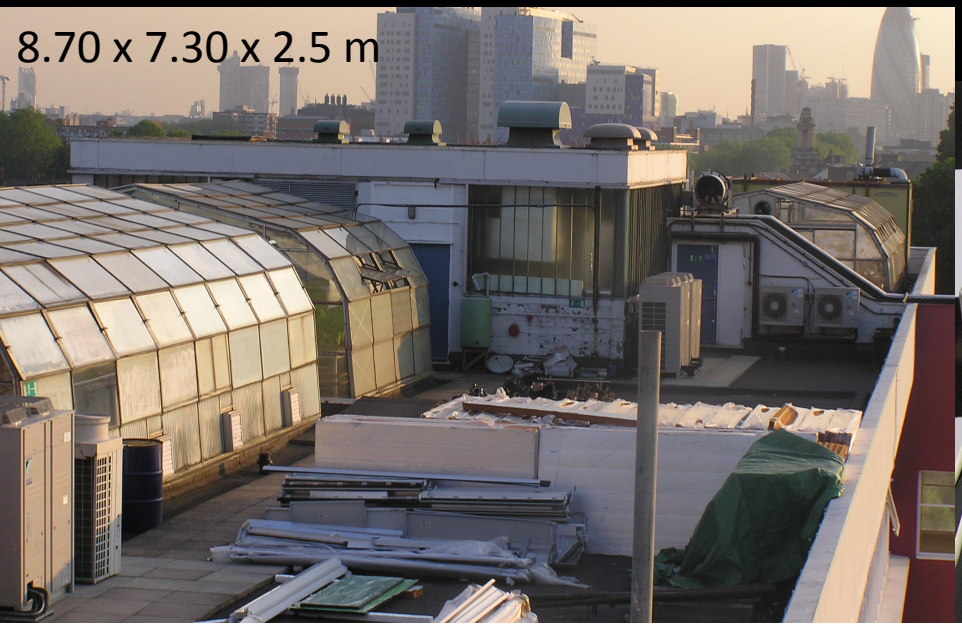


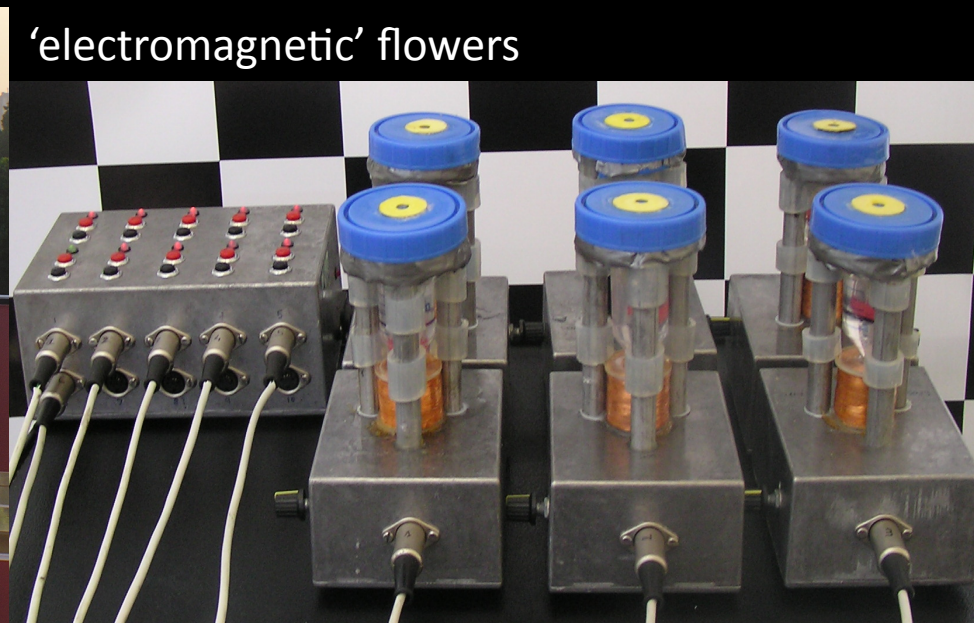
Outline

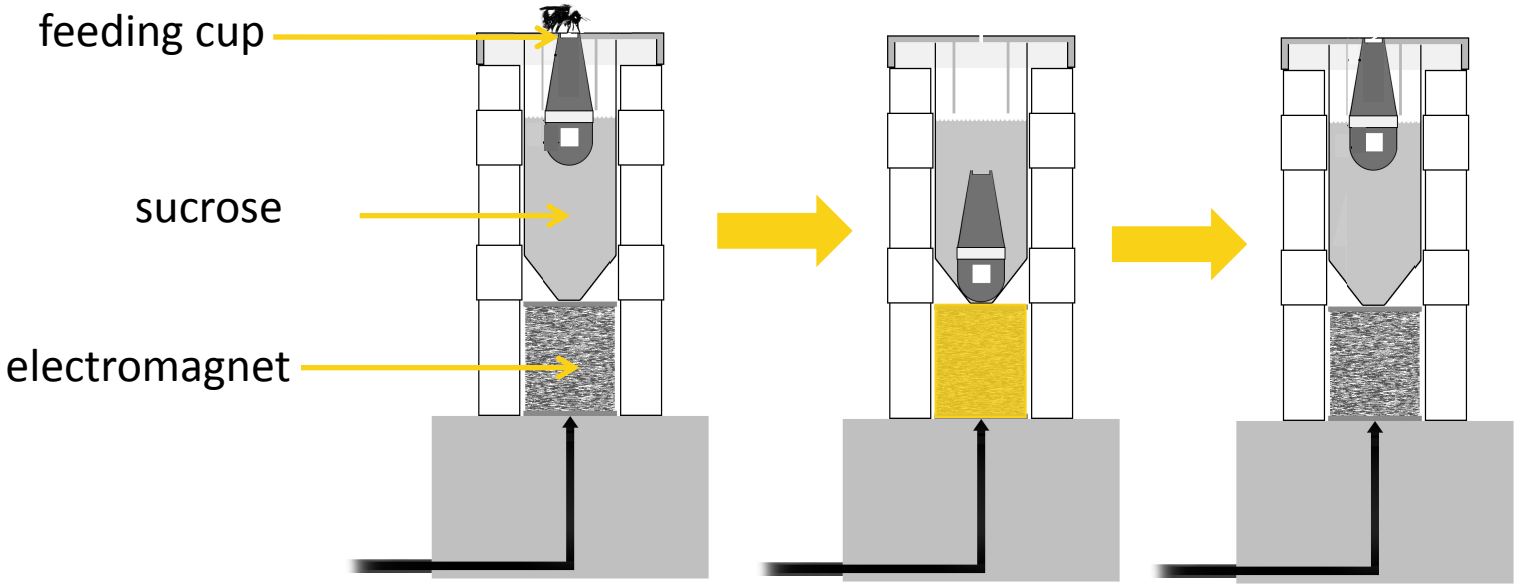
1. Forming routes

   - one forager

Foraging in the lab

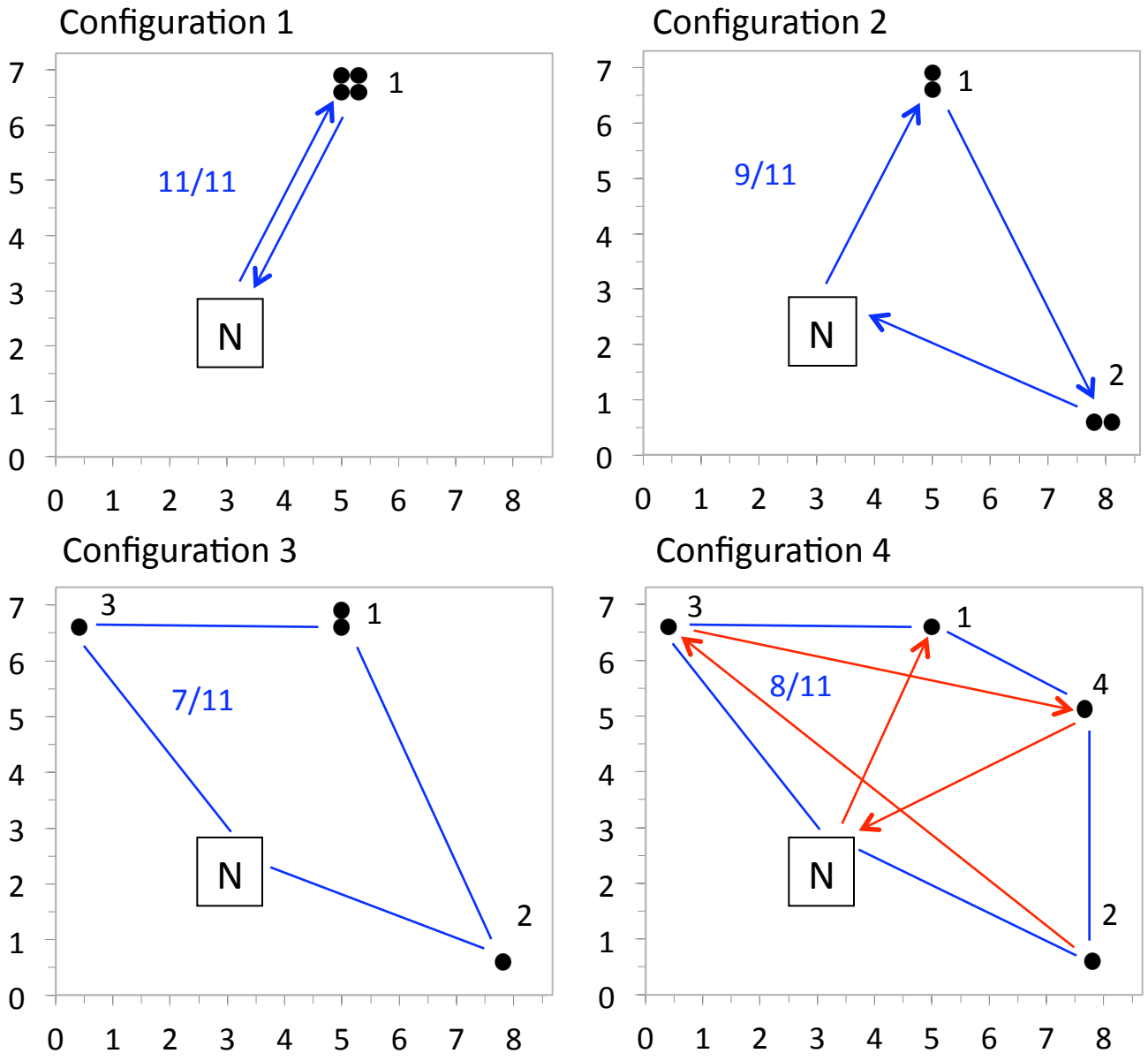






Flower discovery order

20 bouts/config
N = 11 bees

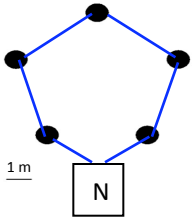


Bees develop flexible and near-optimal 'traplines' with experience.

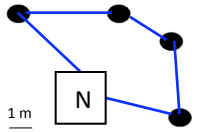
Lihoreau, Chittka, Raine (2010) Am Nat

Overall travel distances

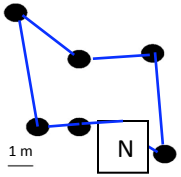
Lihoreau et al. (2011) Funct Ecol



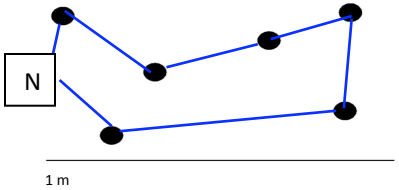
Lihoreau et al. (2010) Am Nat



Lihoreau et al. (2012) Biol Lett

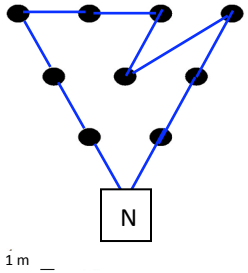


Saleh and Chittka (2007) Oecologia

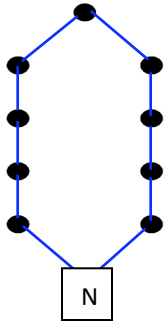


Bees develop flexible and near-optimal 'traplines' with experience.

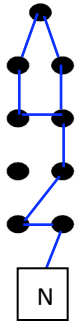
Ohashi et al. (2007) Behav Ecol 2007



Ohashi et al. (2010) BES

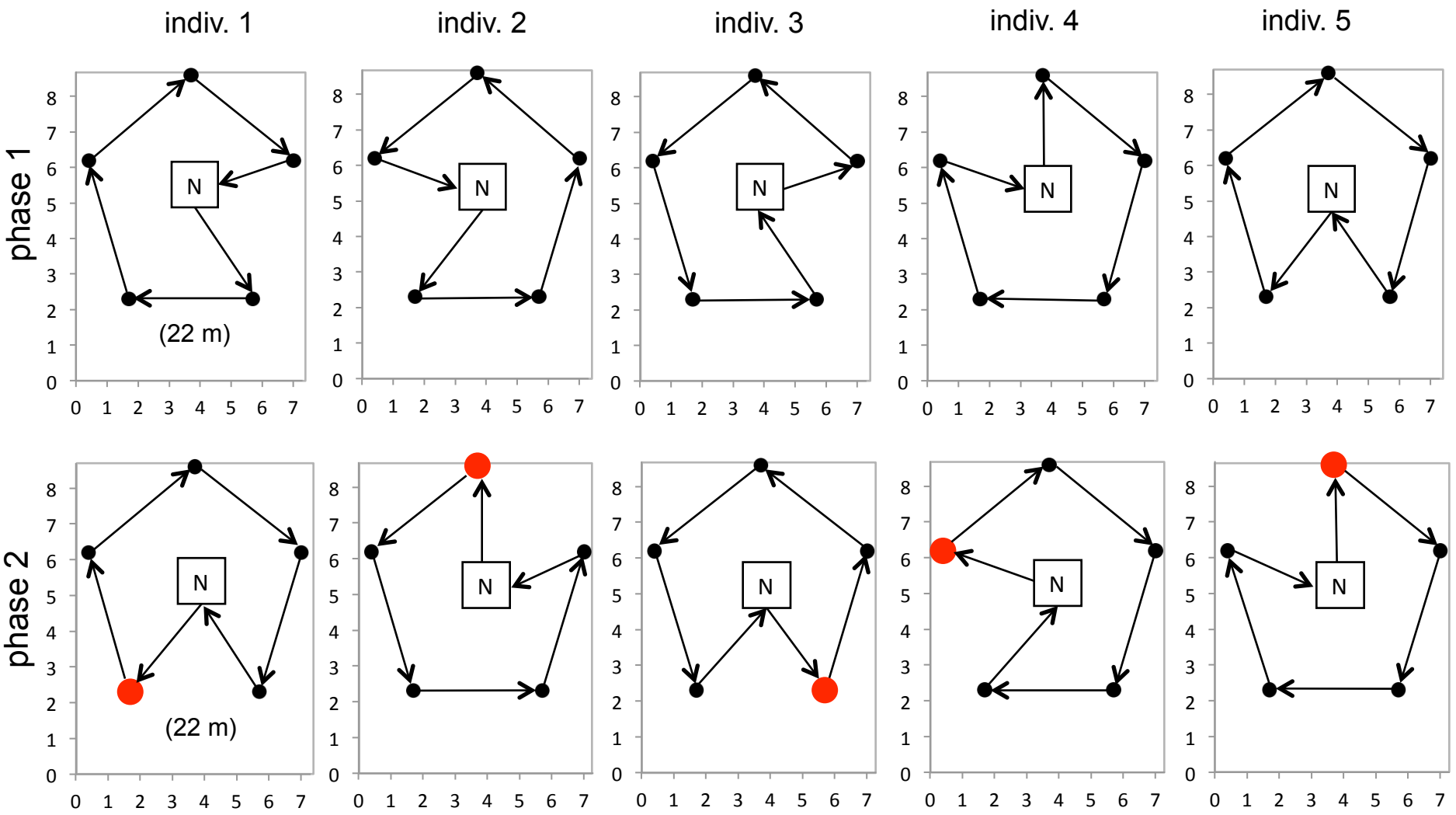


Ohashi et al. (2012) Behav Ecol



Heterogenous rewards

40 bouts/phase
N = 5 bees



Lihoreau, Chittka, Raine (2011) Funct Ecol

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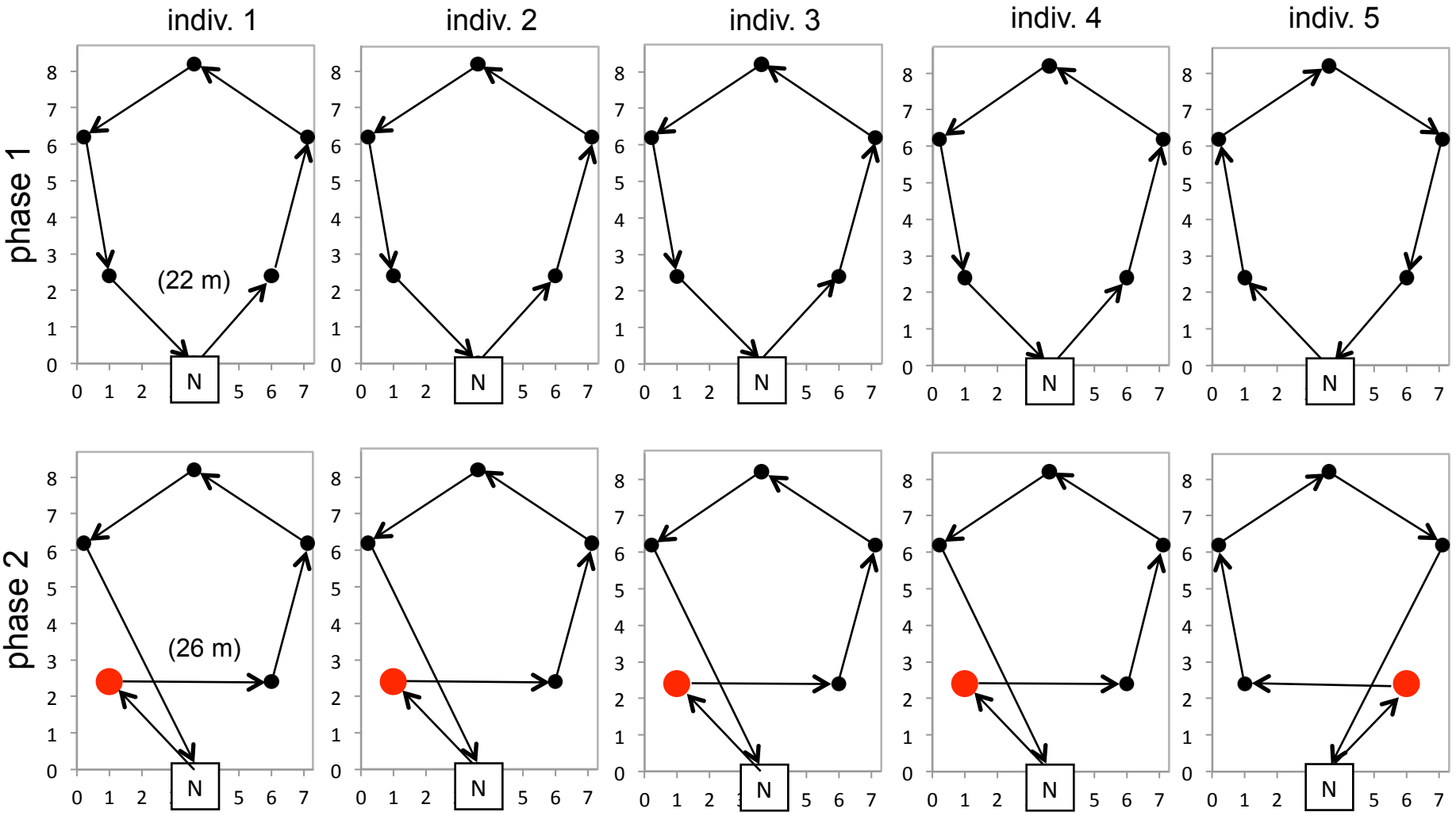
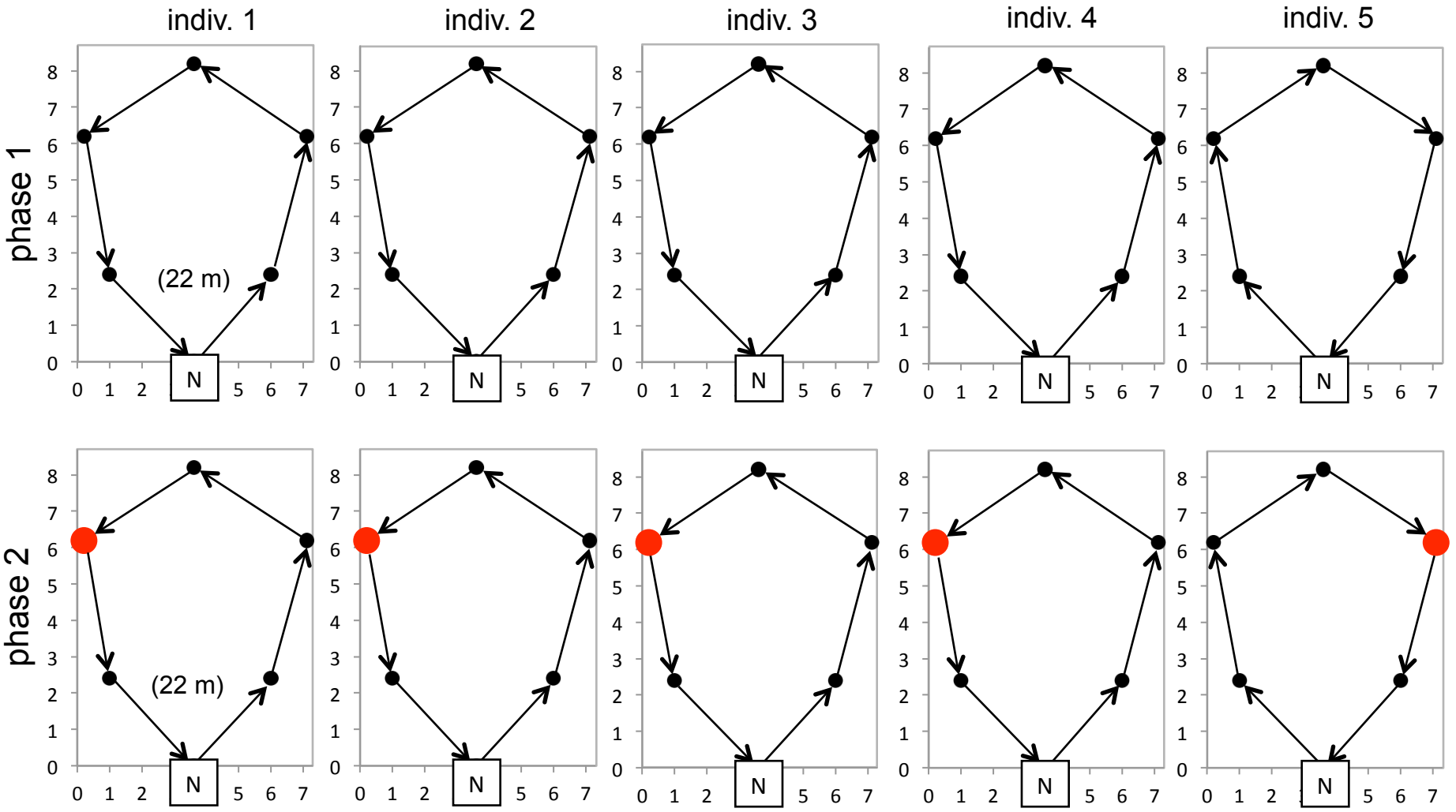


Lihoreau, Chittka, Raine (2011) Funct Ecol

Heterogenous rewards

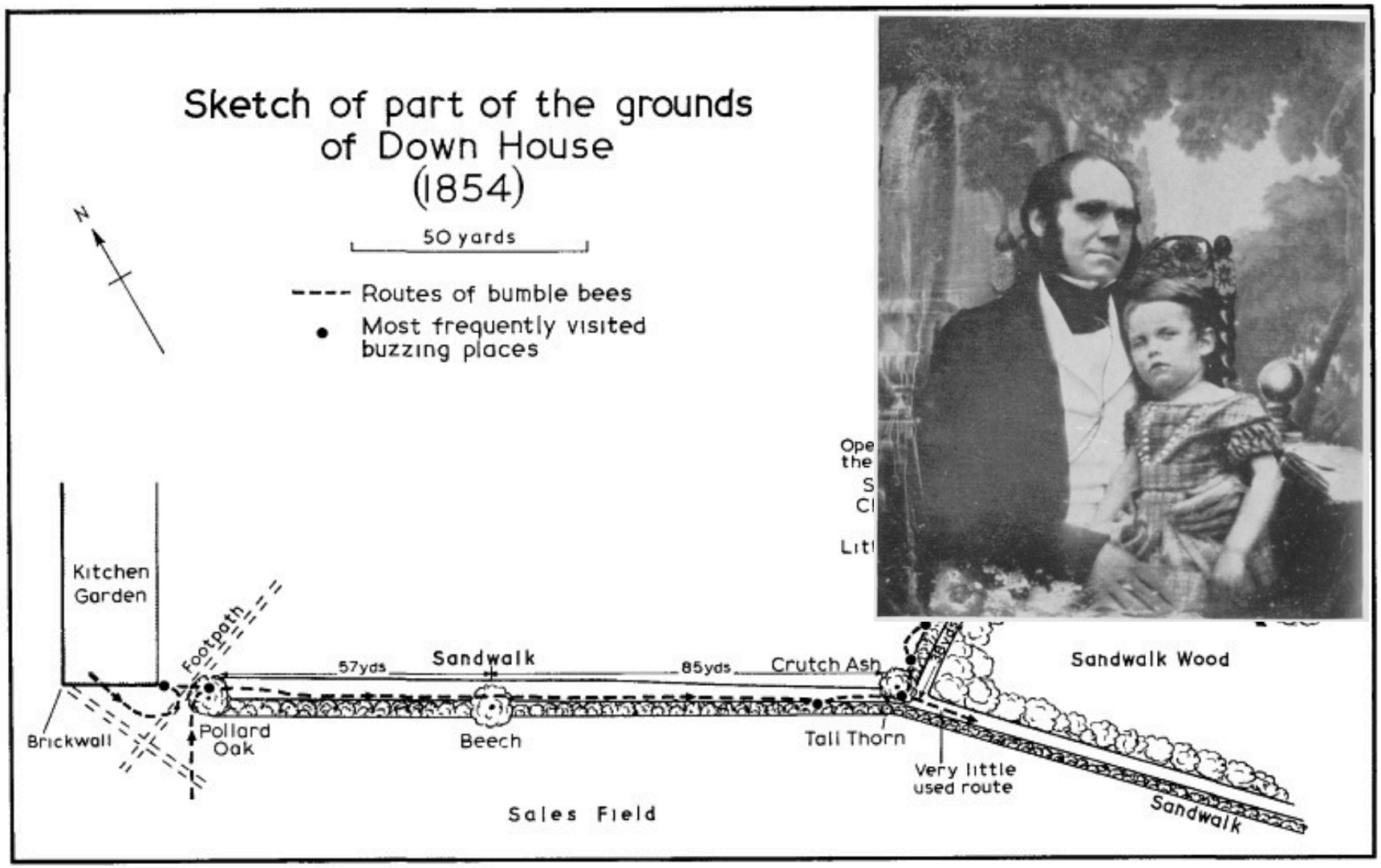
40 bouts/phase
N = 5 bees

Bees trade-off optimisation of travel distances and reward intake rates.



Lihoreau, Chittka, Raine (2011) Funct Ecol

Large spatial scales

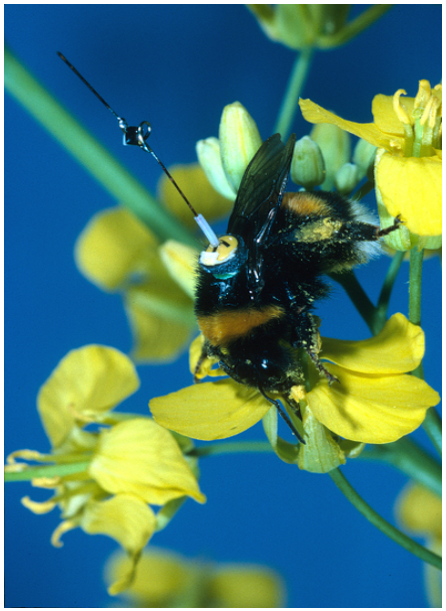


Darwin (1861) Bul Br Mus Nat Hist

Lihoreau, Chittka, Reynolds et al. (2013) Com Int Biol

Large spatial scales

Harmonic radar



Bee with a transponder

Motion detection ‘flowers’

Lihoreau, Raine, Reynolds et al. (2012) PLoS Biology

Large spatial scales

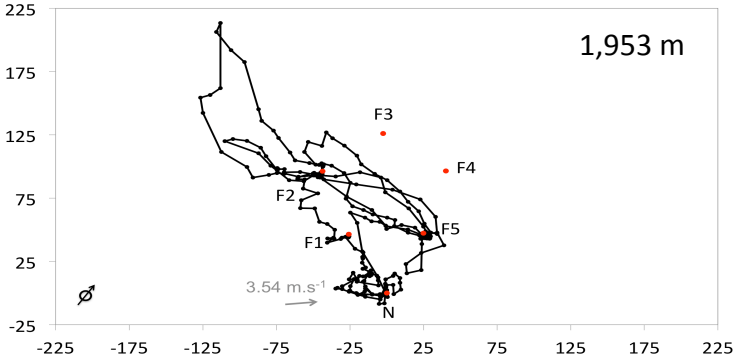
Lihoreau, Raine, Reynolds et al. (2012) PLoS Biology

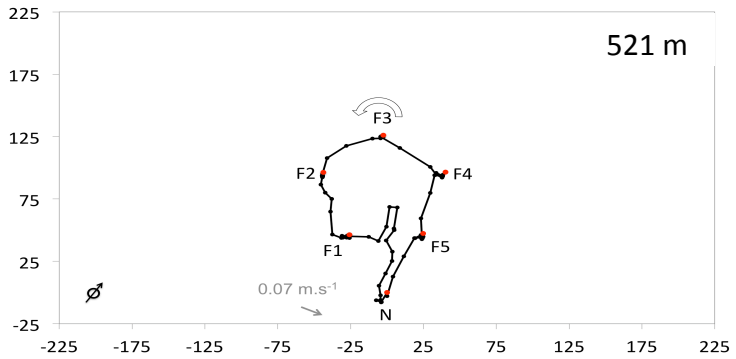
Large spatial scales

naive bees (trial 1)

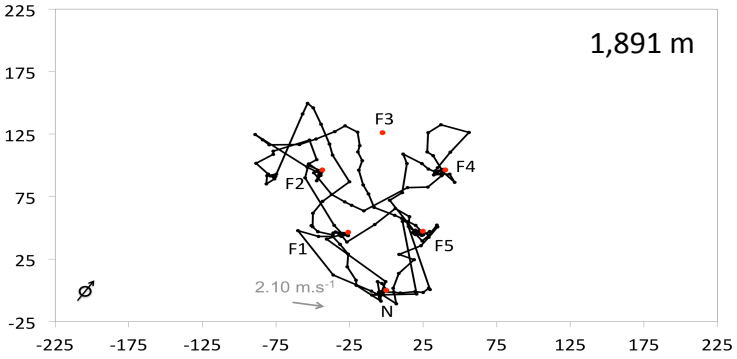
trained bees (trial 25)

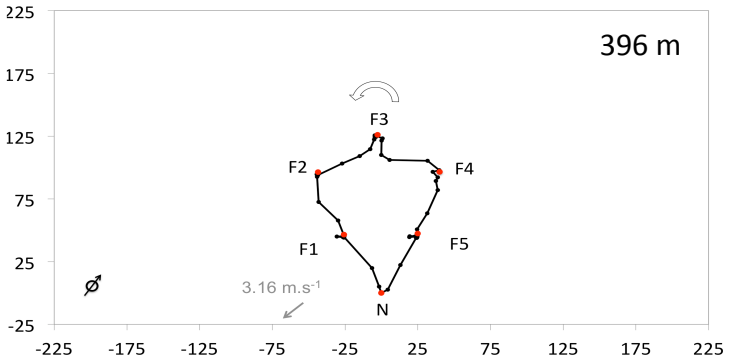
indiv. 1



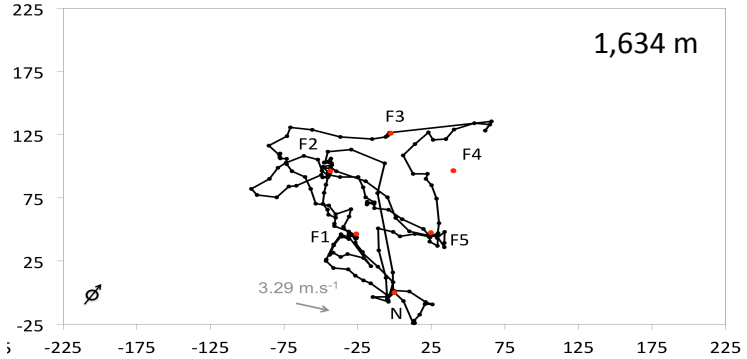


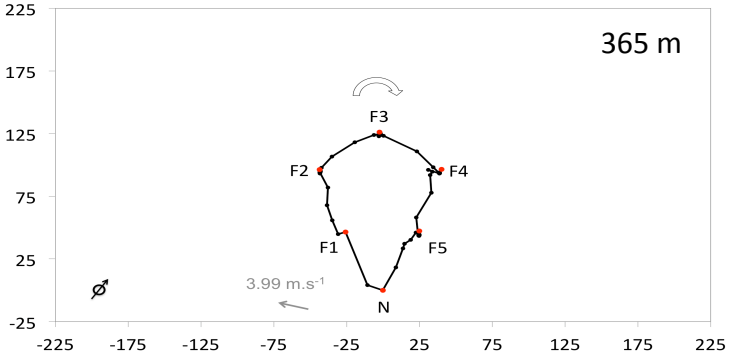
indiv. 2





indiv. 3



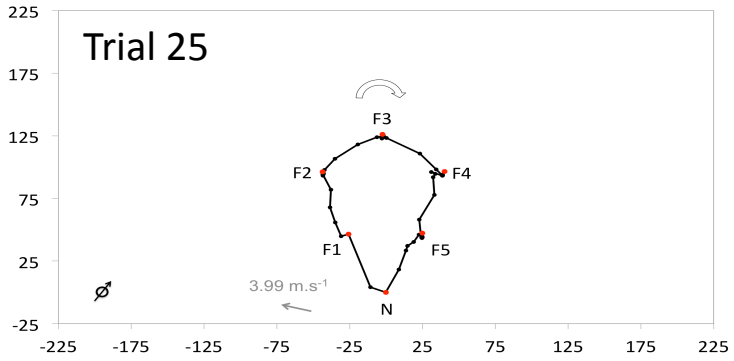


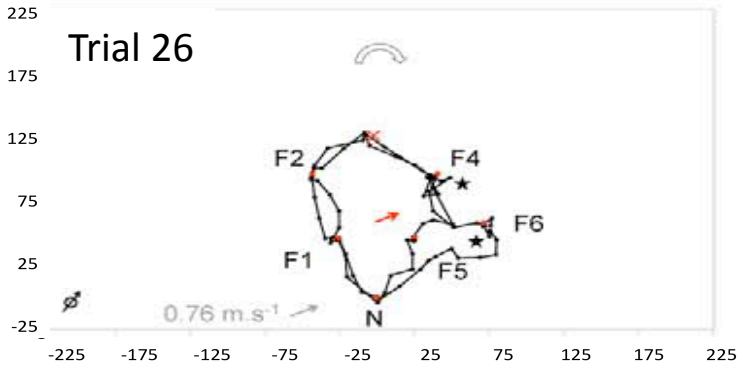
Lihoreau, Raine, Reynolds et al. (2012) PLoS Biology

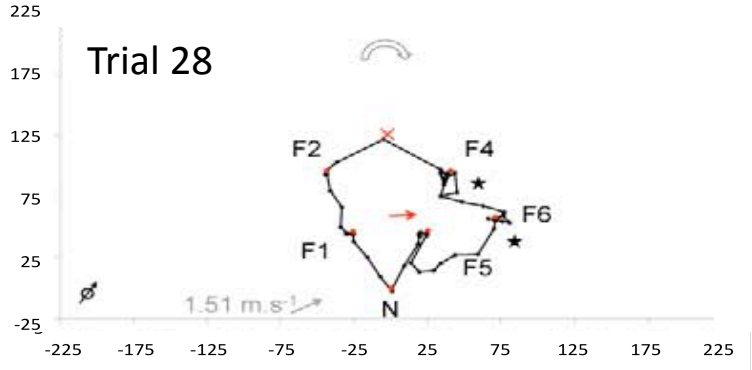
Large spatial scales

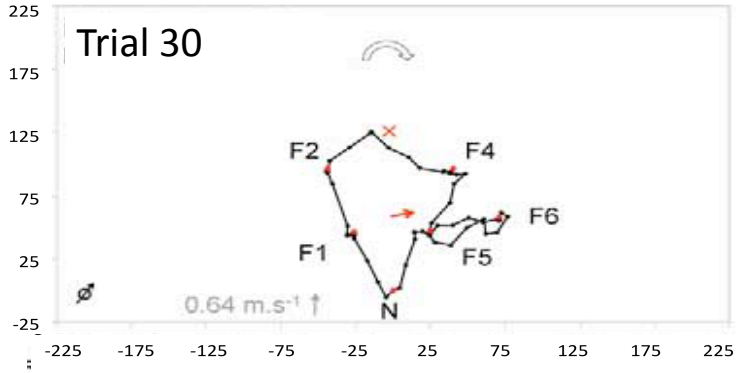
Lihoreau, Raine, Reynolds et al. (2012) PLoS Biology

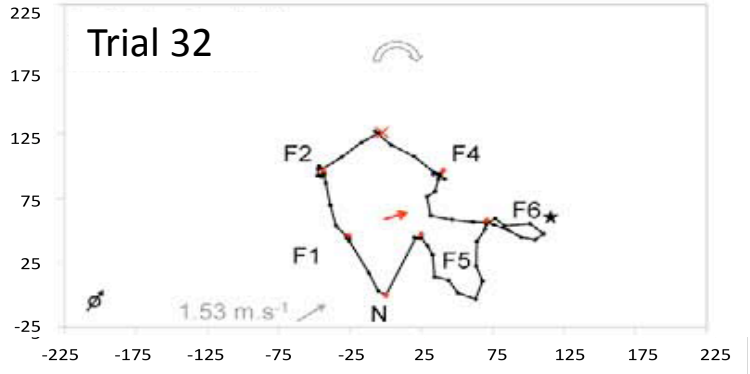
Large spatial scales

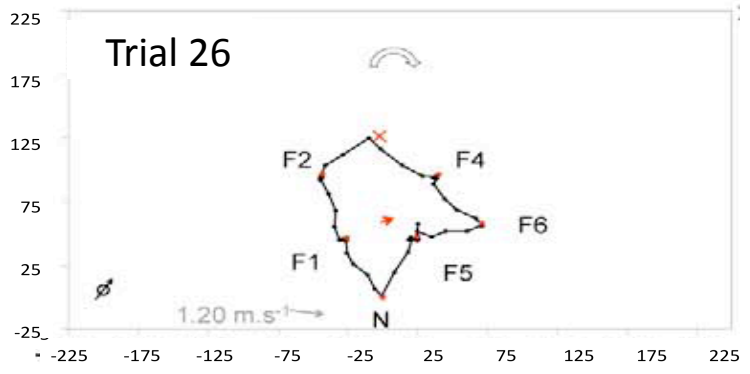








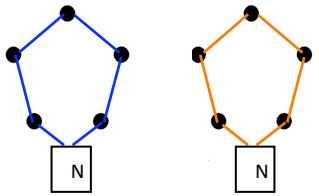




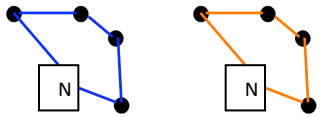
Lihoreau, Raine, Reynolds et al. (2012) PLoS Biology

The traplining model

Lihoreau et al. (2011) Funct Ecol
Lihoreau et al. (2012) PLoS Biol



Lihoreau et al. (2010) Am Nat



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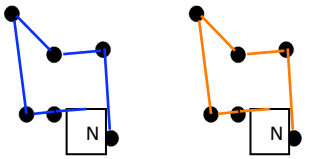

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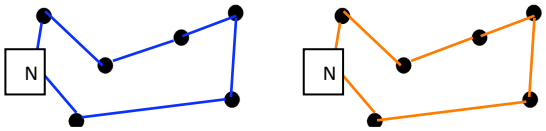

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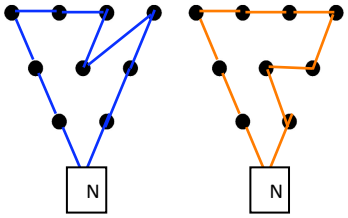

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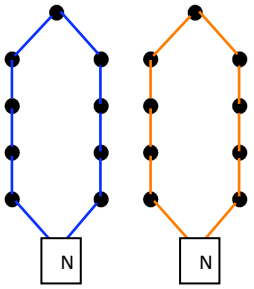
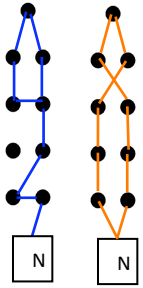
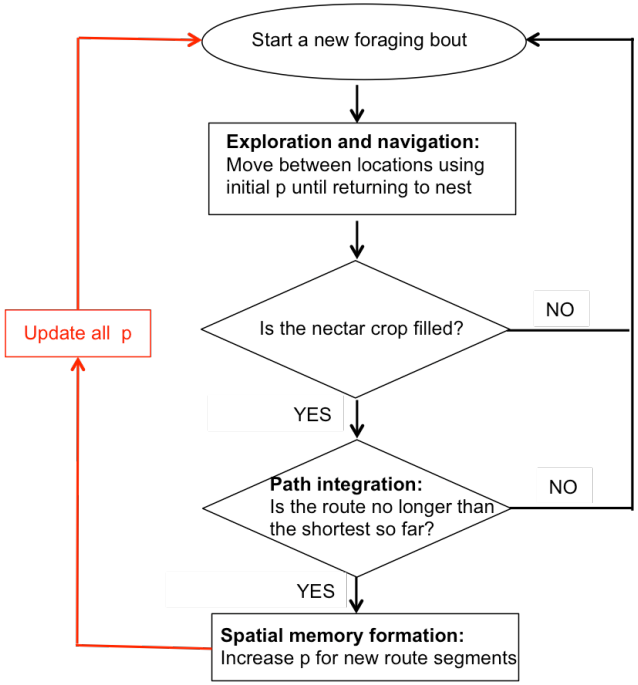


Ohashi et al. (2012) Behav Ecol





Accurate replication of trapline formation by bees across spatial scales and flower arrangements.

Reynolds, Lihoreau, Chittka (2013) PLoS Comput Biol

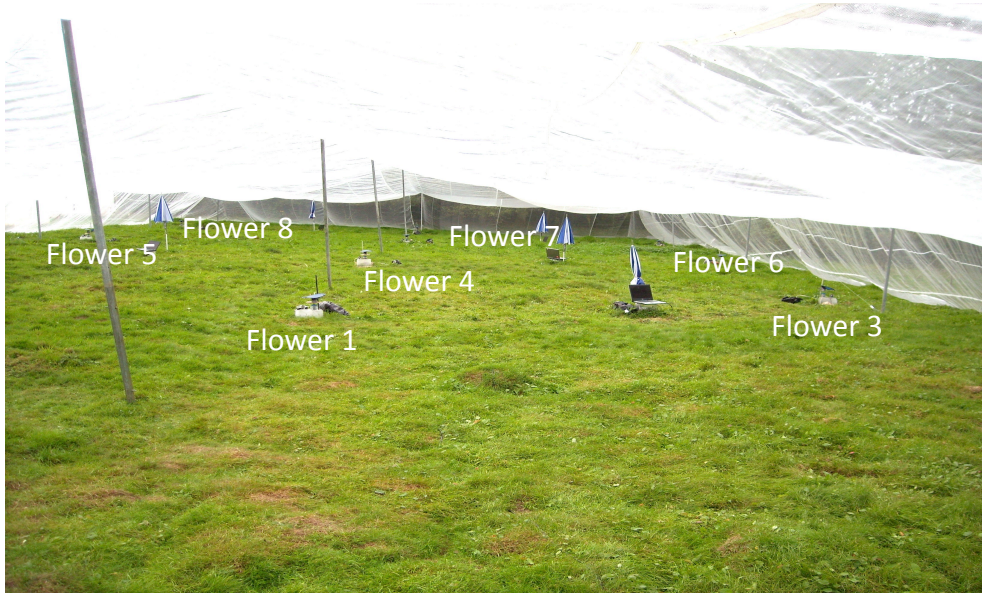
Outline

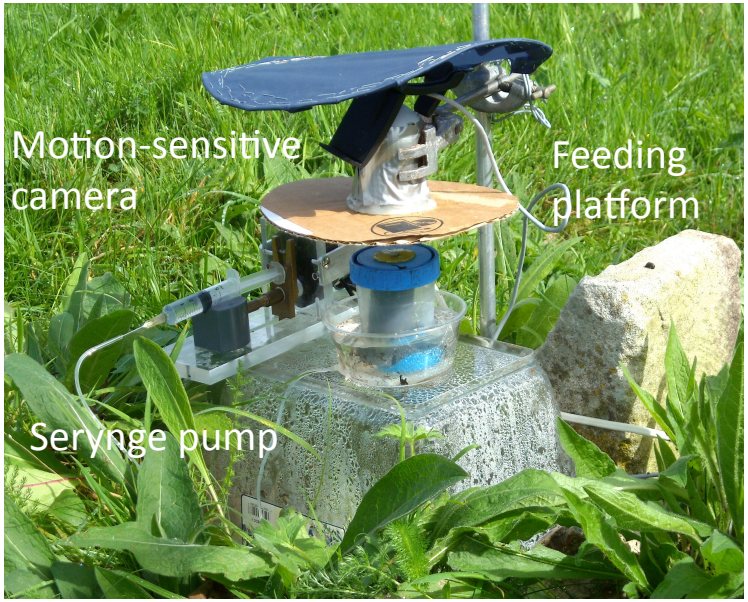
1. Forming routes

   - one forager

   - multiple foragers

Multiple interacting bees

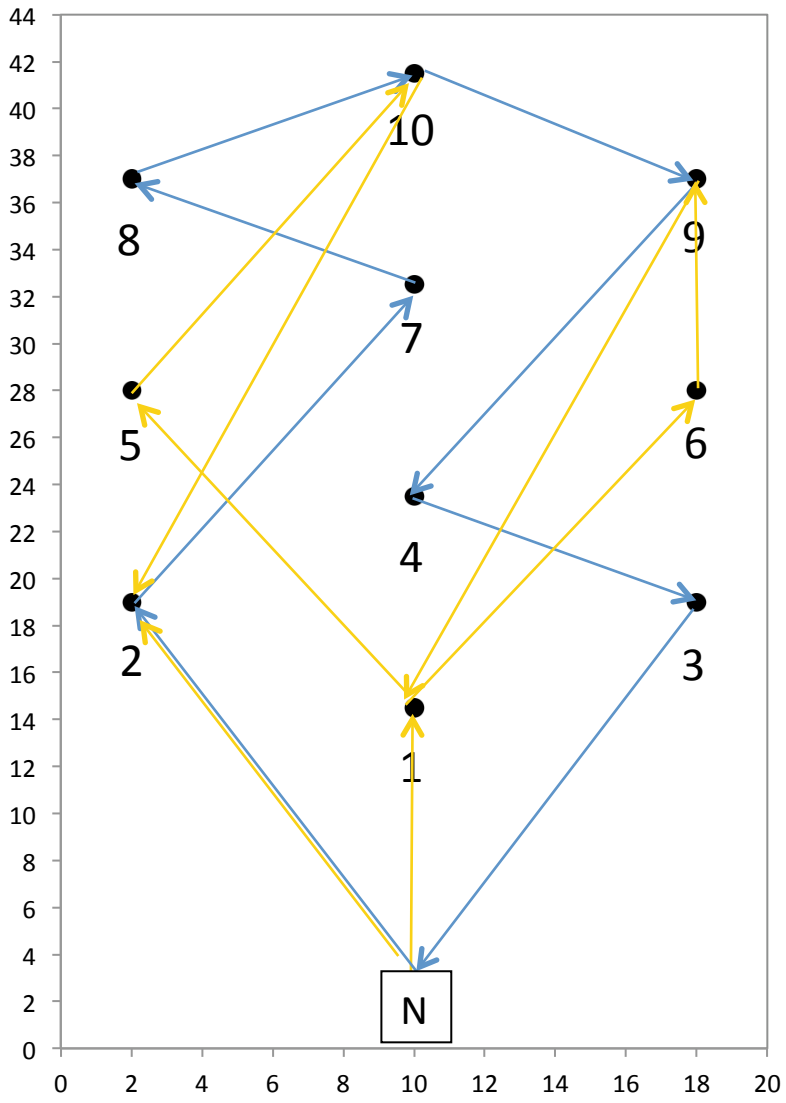




Lihoreau, Chittka, Raine, under review

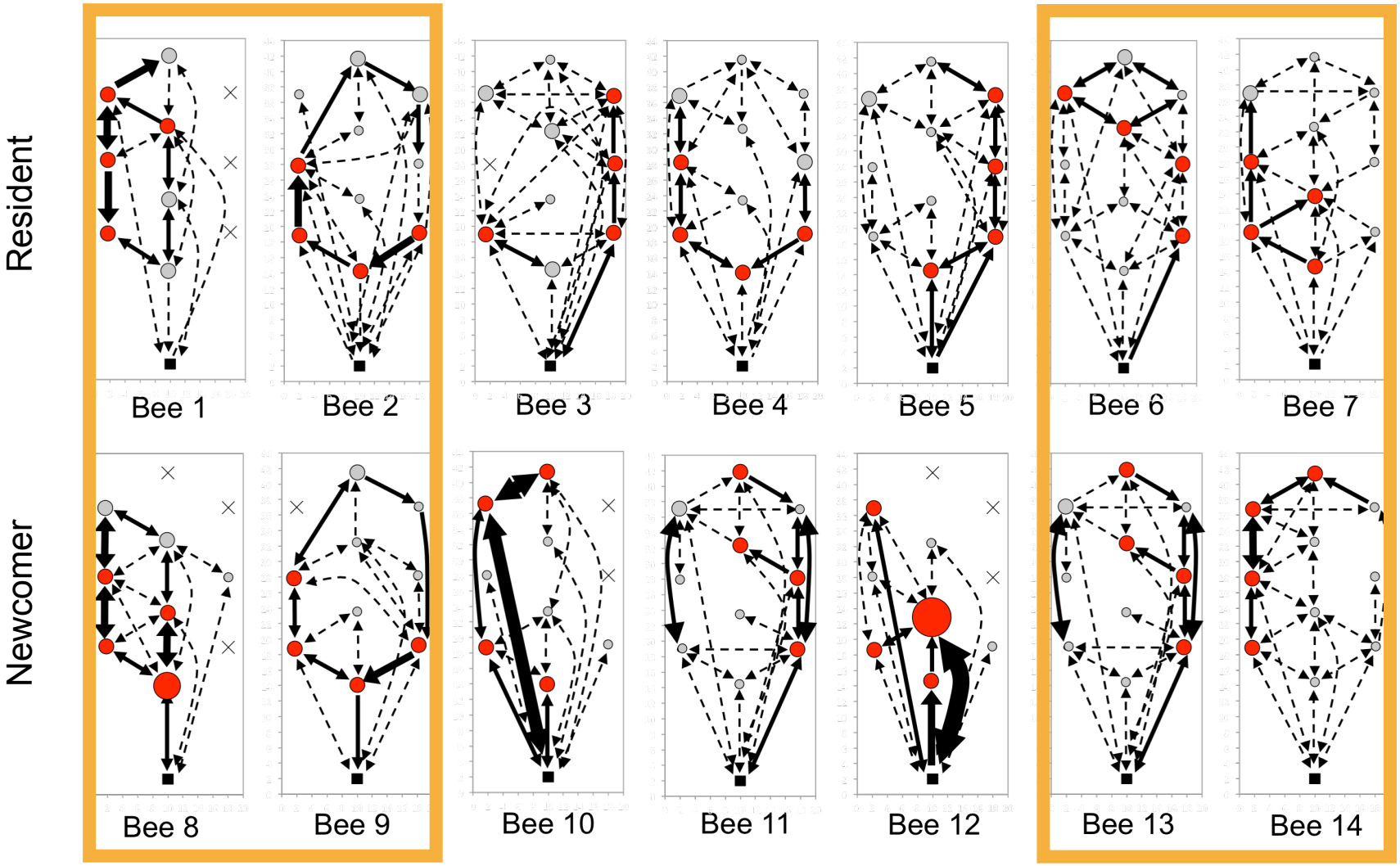
Resource partitioning between foragers

Phase 1: 1 bee for 25 bouts
Phase 2: 2 bees for 25 bouts
N = 7 pairs



Lihoreau, Chittka, Raine, under review

Resource partitioning between foragers



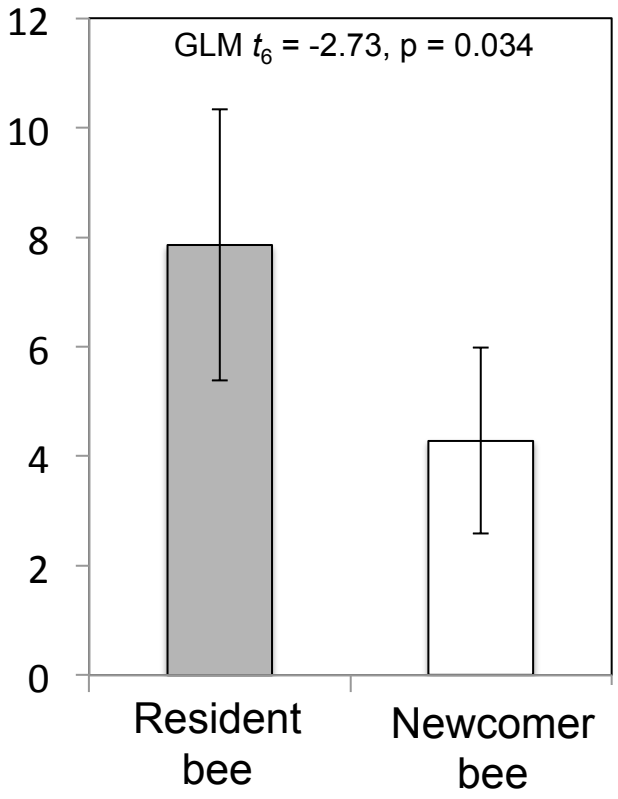
Lihoreau, Chittka, Raine, under review

Resource partitioning between foragers

20 % of encounters: no aggression

80 % of encounters: eviction

Number of evictions



Experienced bees defend flowers by evicting newly arrived foragers.

Lihoreau, Chittka, Raine, under review

Outline

1. Forming routes

   - one forager

   - multiple foragers

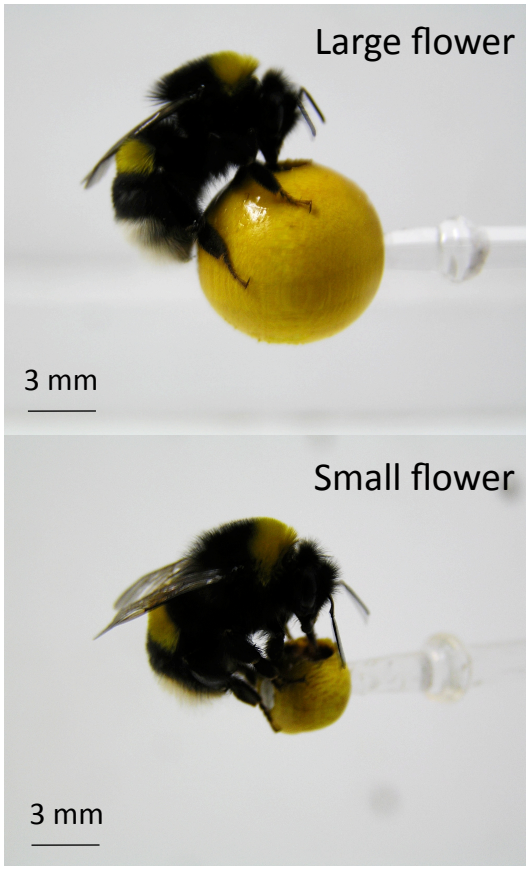
2. Locating new flowers

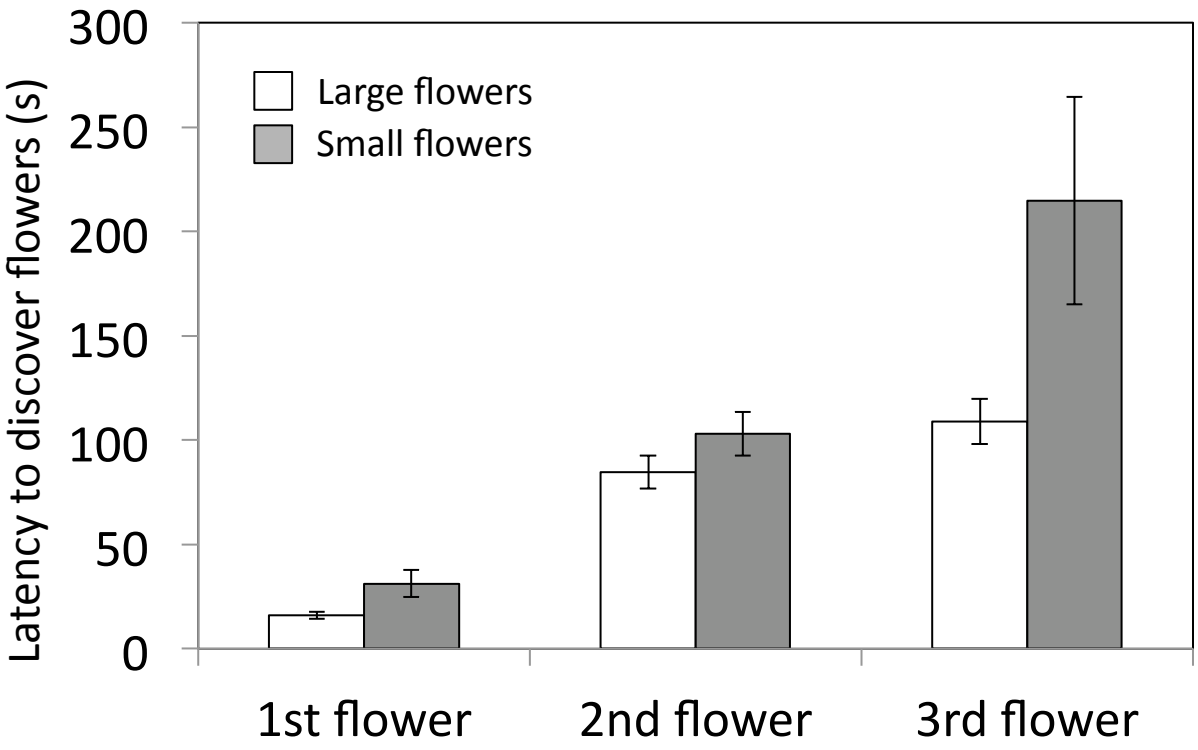
How do bees search for flowers?

3D tracking of search flights

Lihoreau, Ings, Chittka et al. Under Review

Search performance





Bees find large flowers faster than smaller ones.

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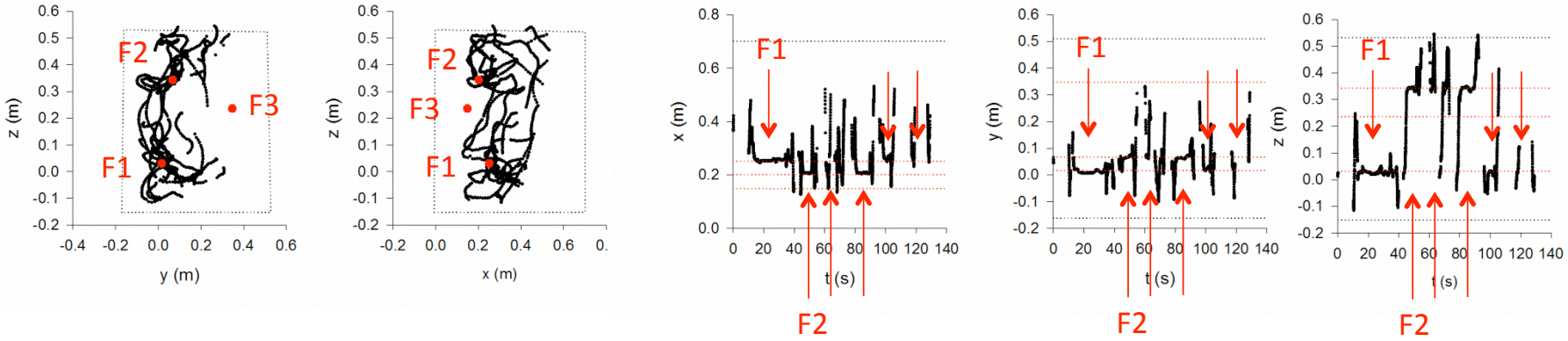
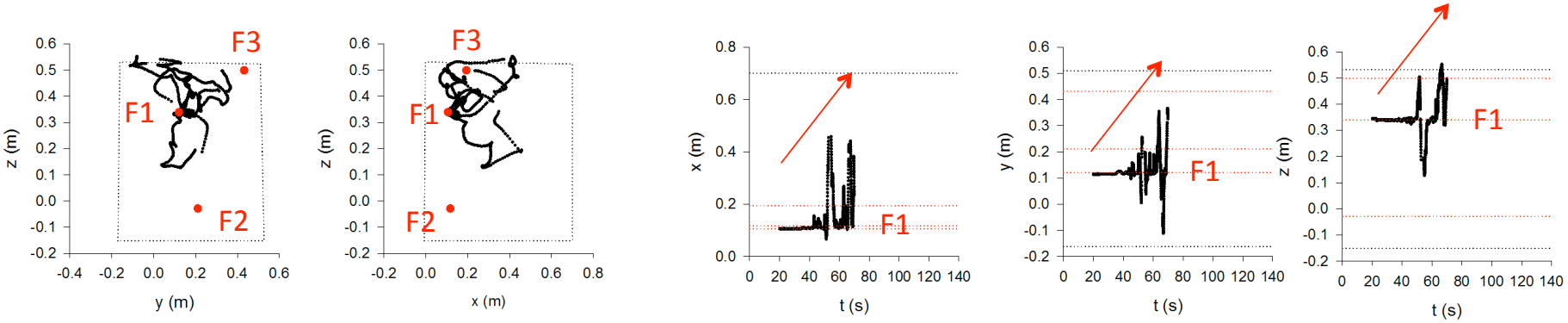
Search loops of ever increasing sizes

Indiv. B66 with large flowers



Indiv. B66 with small flowers



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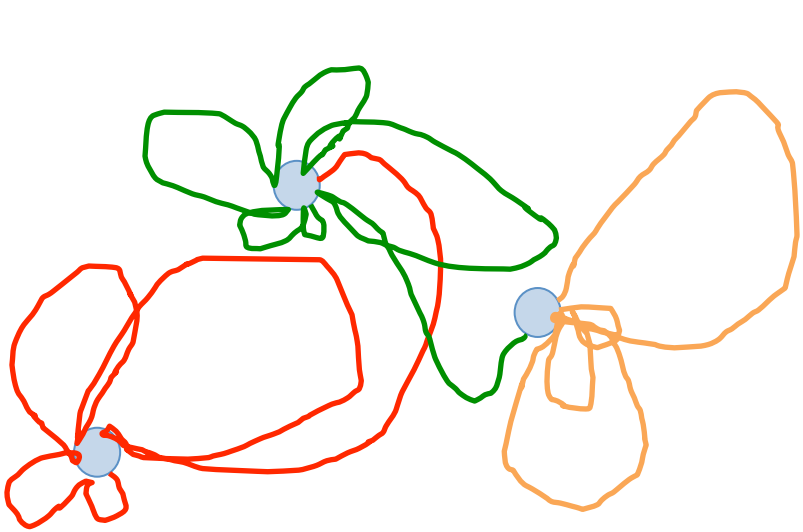
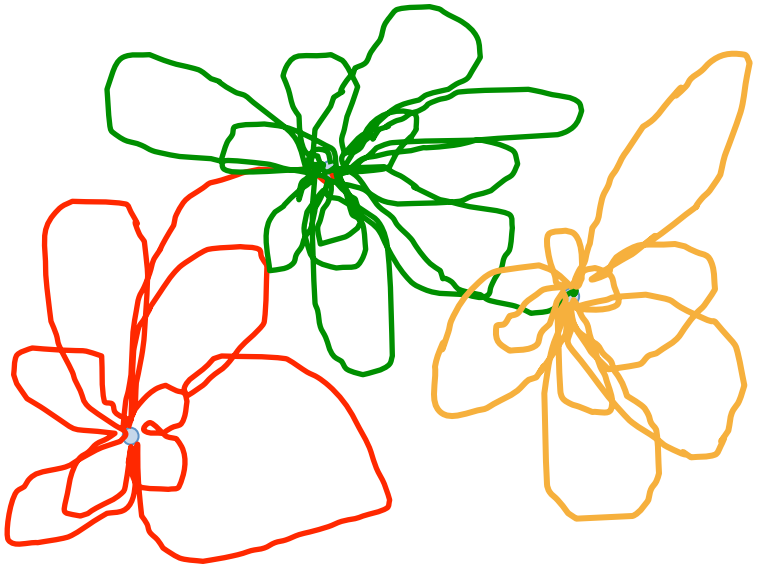
Search loops of ever increasing sizes





Signatures of ‘simulated annealing’ patterns in search flights irrespective of flower size and arrangement.

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Outline

1. Forming routes

   - one forager

   - multiple foragers

2. Locating new flowers

3. Conclusions/projects

Towards an integrated analysis of pollinator movements

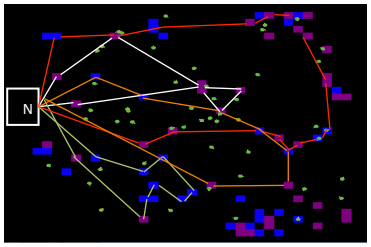
Route learning

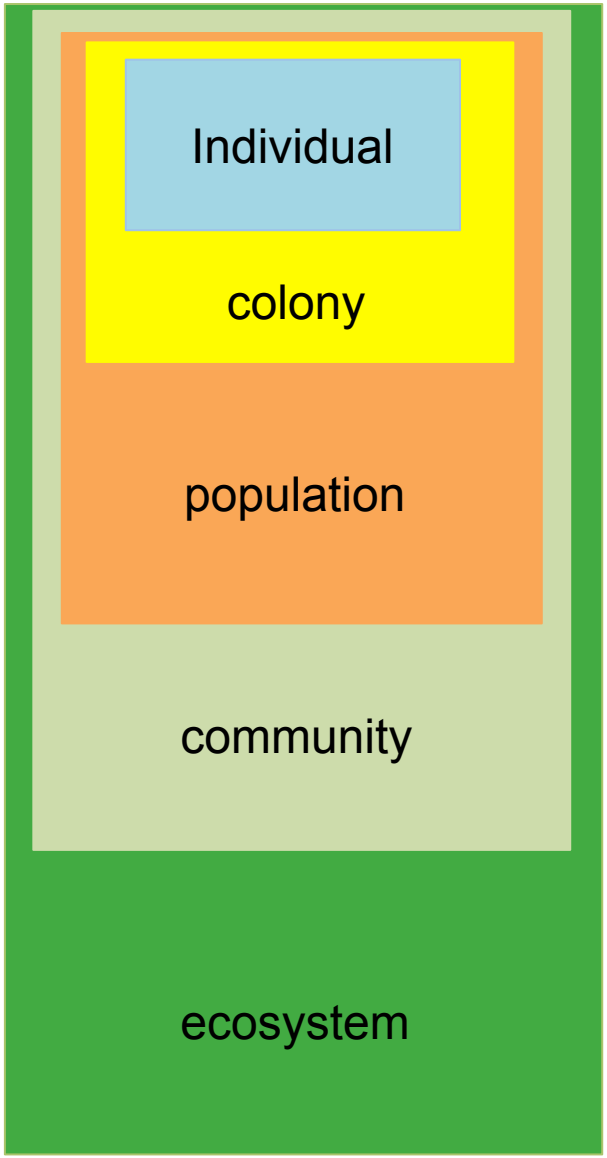
Social interactions

Intra sp. competition

Inter sp. competition

Impact on pollination





Lihoreau, Buhl, Charleston et al. Ecol Lett 2015