Using agent-based models to examine eco-evolutionary feedbacks

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I’m an evolutionary ecologist...

Mussel movement & cooperation

Seed dispersal via water

Seed dispersal & facilitation
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I’m an evolutionary ecologist...

Seed dispersal & facilitation

Seed dispersal via water
My 3-year old:

‘WHY??’

It’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase, it’s just a phase

I never left this phase...
Why do individuals cooperate?
Why do mussels aggregate?
Why do individuals move?
Why do some plants limit their dispersal?

Why do plants produce seeds of different sizes?
Why are some seeds buoyant and others not?

Why facilitate other species?

Why do we find spatial patterns in nature?
Why move the way we move?

WHY??
Often, such questions are not easy to answer with a simple model...

- Fitness differences between individuals
- Large-scale ecological processes
- Collective behaviour
- Traits / behaviour of an individual
- Evolution

Eco-evolutionary feedbacks!
Often, such questions are not easy to answer with a simple model...

Eco-evolutionary feedbacks! Agent-based modelling combined with adaptive dynamics
Why do individuals cooperate?

Why do mussels aggregate?

Why do individuals move?

Why do some plants limit their dispersal?

Why move the way we move?

Why do plants produce seeds of different sizes?

Why do individuals behave the way they do?

Why are some seeds buoyant and others not?

Eco-evolutionary feedbacks!

Agent-based modelling combined with adaptive dynamics
Search strategies

Directed search

Random search

+ Information about target location -
Random searches in 2D

Random displacements & reorientation events
Step lengths and turning angles are drawn from frequency distributions

Angle $\beta$

Step length $\lambda$
Random search strategies

Step lengths and turning angles are drawn from frequency distributions

Brownian walk
Brownian walk in 1D

Equal chance to go right or left and chance to stay:
Brownian walk in 1D

Equal chance to go right or left and chance to stay:

![Graphs showing Brownian walk at time 0 and time 1.](image-url)
Brownian walk in 1D

Equal chance to go right or left and chance to stay:
Brownian walk in 1D

Equal chance to go right or left and chance to stay:
Brownian walk in 1D
Brownian walk in 2D
Random search strategies

Brownian walk ($\mu \geq 3$)

Levy walk ($1 < \mu < 3$)

$$F(l) = C \cdot l^{-\mu}$$
Viswanathan *et al.* (1996): Wandering albatrosses do a Levy walk!

However: duration of dry period of wet/dry recording devices used as measurement...
Sims et al. (2008): Marine predators do a Levy walk!
Empirical data versus theoretical models!

**Empirical studies:**

Levy walks abundant in nature

**Theoretical models:**

Levy walks are only optimal when:

- Resources are limited,
- Indestructible,
- Patchily distributed,
- At unknown locations
Empirical data versus theoretical models!

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<table>
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<tr>
<th>Nature:</th>
<th>Theoretical models:</th>
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<td>Animals respond to <strong>AND</strong> shape the environment!</td>
<td>Animals merely respond to their environment</td>
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Empirical data versus theoretical models!

Nature:

Animals respond to AND shape the environment!

Theoretical models:

Animals merely respond to their environment

(Searching for conspecifics, redistribution of items, consumption, ...)

Simple models do not consider eco-evolutionary feedbacks...

Fitness differences between individuals

Evolution

Traits / behaviour of an individual

Collective behaviour

Large-scale ecological processes

Eco-evolutionary feedbacks!

Agent-based modelling combined with adaptive dynamics

Levy walks?
Food Competition

Cooperation
Building an agent-based model of mussel movement into patterned mussel beds...

Move around, until local density is sufficiently high (dislodgement risk) and long-range density is low enough (food competition).

How much movement is needed before a pattern is achieved?

Simulate for:
- Straight-line dispersal ($\mu \rightarrow 1$)
- Levy walk ($1 < \mu < 3$)
- Brownian walk ($\mu \geq 3$)
Levy walks are most efficient in creating patterned mussel beds

![Diagram showing the efficiency of different types of walks in pattern formation. The diagram plots the rate of pattern formation against the Lévy exponent. At an exponent of 2, the Lévy walk is most efficient, with ballistic and Brownian movements showing lower and higher efficiency, respectively.](image-url)
Levy walks are most efficient in creating patterned mussel beds

But is it evolutionarily stable?
Levy walks are most efficient in creating patterned mussel beds

But is it evolutionarily stable?

Compare efficiency of few mutants (with a different movement strategy) to efficiency of residents...
Levy walk with $\mu \approx 2$ is evolutionarily stable
Feedback between traits/behaviour & environment is important!

Evolutionary ecology: a complex system study!
Thanks for your attention 😊

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After the break (10 minutes):

A practical example of how to make an individual-based model using NetLogo!