Measures of Specialisation

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1 Metrics from the Literature

1.1 Proportion of Items

Source: Ferrante et al 2015 [1]

Description: "Proportion of items retrieved by more than one [agent] over the total number of items retrieved".

Formula:

$$\frac{R_{cooperative}}{R_{total}}$$

where:

$R_{cooperative}$ is Resources retrieved by more than one agent

R_{total} is Total resources retrieved by the team

Pros:

- Simple

Cons:

- Agents can pick up and drop resources without contributing to their transportation e.g. Go to source, pick up and drop on the spot, transport another resource as a generalist.

Thoughts:
It's too easy for non-specialist strategies to look like specialisation. I think this metric should be avoided if possible.

1.2 Action Switching

1.2.1 Frequency of Action Switches

Source: Nitschke et al 2012 [2]

Description: "The frequency with which the controller switches between executing distinct motor outputs (actions) during its lifetime".

Formula:

$$\frac{A}{N}$$

where:

A is Action switches over an episode

N is Number of possible switches over an episode

Pros:

- Calculates an agent's specialisation rather than a team's. Can identify non-specialists on a team.

Cons:

- Only works if the dropper and collector strategies could be executed with just one action.

Thoughts:
This could be good if there's a way to adapt it to slope foraging. Maybe something like number of area switches? A pure collector shouldn't leave the nest and cache and a pure dropper shouldn't leave the source/slope. But then, what if a dropper goes all the way down the slope before dropping? Is it just an inefficient specialist? What if a dropper and collector display perfect specialisation, swap roles mid-episode, then continue displaying perfect specialisation with the reversed roles?

1.2.2 Complement of action changes

Source: Gautrais et al 2002 [3]

Description: Complement of the frequency of an individual changing tasks

Formula:

$$F_i = 1 - 2C_i$$

where:

i is the index of the individual

F_i is the degree of specialisation

C_i is the number of action changes divided by the number of action steps in an episode. 0 is generalist, 1 is specialist.

Pros:

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Cons:

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Thoughts: Specialisation of an individual. Not sure if that's what we want.

1.3 Entropy

1.3.1 Correlation with Diversity

Source: Li et al [4]

Description: The correlation coefficient between diversity and swarm performance. Diversity is calculated by running a clustering algorithm on the genomes and calculating the entropy.

Formula:

$$S = corrcoef(D; R) \times D$$

where:

D is Diversity, measured using entropy

R is Team performance

Pros:

- General
- Based on analysis of metrics in the literature (as at 2004)

Cons:

- Complicated.
- Computationally expensive? Have to run a clustering algorithm each time.

Thoughts: I don't fully understand the diversity measure. I don't think you can apply clustering in slope foraging. Intentionally decides that specialisation is a team measure not an individual one. Intentionally decides that teams are only specialised when they perform well, otherwise it is just diversity.

1.3.2 Entropy of activity

Source: O'Donnell et al 1990 [5]

Description: Entropy of an agent's focus on different materials being foraged. Low entropy means an agent is specialised because it focuses on less activities.

Formula:

$$H(x) = -\sum p(x) \log_2 p(x)$$

where:

$p(x)$ is the proportion a forager's effort devoted to a given material(x)

Pros:

- Has theoretical underpinning
- Generalisable

Cons:

- Requires the high level a priori knowledge of what each activity/sub-task is
- An individual that does one task and then switches half-way is the same as one that alternates throughout

Thoughts:

1.4 •

Source:

Description:

Formula:

Pros:

-

Cons:

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Thoughts:

1.5 Other

1.5.1 Counting actions

Source: Pini et al 2011 [6]

Description: Count the number of times agents chose to use the corridor (i.e. slope) vs the cache and use that in a bar graph to show which strategies partition (i.e. specialise) vs not.

Formula:
N/A

Pros:

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Cons:

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Thoughts: You could turn this into a metric. Number of times an agent went onto the slope? But doesn't quite work because in the Pini version, a specialist only ever needs to touch the 'slope' once, whereas in mine a dropper has to go on it every time it drops.

1.5.2 Time spent changing role

Source: Gigliotta et al 2018 [7]

Description: Not a metric. But count the number of time steps spent changing roles as an indicator of specialisation.

Formula:
N/A

Pros:

-

Cons:

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Thoughts:

2 Metrics by Me

- Number of area transitions
- Number of slope-to-cache and cache-to-slope transitions
- Time spent on slope

3 Thoughts on Specialisation

How do I define specialisation, verbally? Is there a way to define specialisation that is not unique to this application? Is an agent specialised or is a team? An agent is specialised if they perform a behaviour that cannot complete the task alone. Does specialisation have to be successful? What if an agent performs a behaviour that can't complete the task but is unproductive? If specialisation is only specialisation when it succeeds, doesn't that bias the results?

References

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[2] G. S. Nitschke, M. C. Schut, and A. Eiben, "Evolving behavioral specialization in robot teams to solve a collective construction task," *Swarm and Evolutionary Computation*, vol. 2, pp. 25–38, 2012.

[3] J. Gautrais, G. Theraulaz, J.-L. Deneubourg, and C. Anderson, "Emergent polyethism as a consequence of increased colony size in insect societies," *Journal of theoretical biology*, vol. 215, no. 3, pp. 363–373, 2002.

[4] L. Li, A. Martinoli, and Y. S. Abu-Mostafa, "Learning and measuring specialization in collaborative swarm systems," *Adaptive Behavior*, vol. 12, no. 3-4, pp. 199–212, 2004.

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[6] G. Pini, A. Brutschy, M. Frison, A. Roli, M. Dorigo, and M. Birattari, "Task partitioning in swarms of robots: An adaptive method for strategy selection," *Swarm Intelligence*, vol. 5, no. 3-4, pp. 283–304, 2011.

[7] O. Gigliotta, "Equal but different: Task allocation in homogeneous communicating robots," *Neurocomputing*, vol. 272, pp. 3–9, 2018.