Invertebrate cognition: Slugs & bugs are smarter than you think

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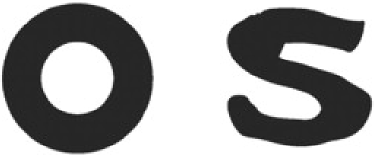
Outline

A simple experiment

Based on what you learn from a few training trials, can you choose the right image?

Training



Experiment 1

Experiment 2

Experiment 3

Experiment 4

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- We tend to assume that richness of motor and behavior repertoire, memory, and learning capacity are proportional to brain size (mass or # of neurons).

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- That doesn't seem to be the case!
- **Cognitive capacties depend on modularity and interconnectivity, regardless of size.**

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- We tend to think that neural architecture must mimic computer architecture.
- If learning requires an algorithm, and that algorithm would require a large processor or storage unit, then an animal that implements the algorithm must have a big brain.
- **There are lots of ways (structurally and algorithmically) to implement learning.**

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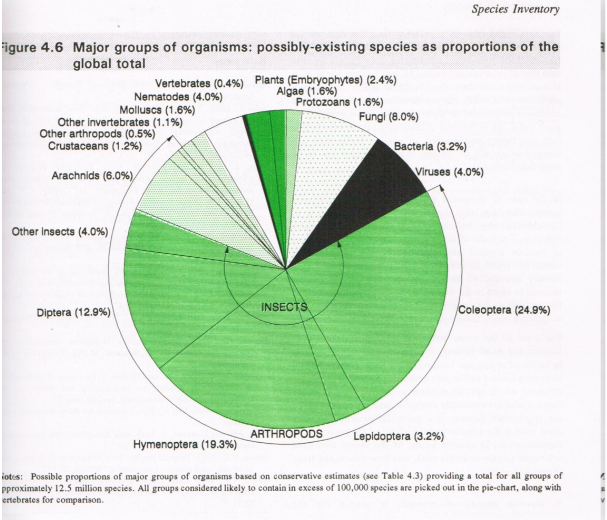
1. Introduction
2. A very, very brief overview of invertebrate cognition
3. The Little Brains Argument
4. What we can learn from robots

To a first approximation, it's all insects



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    - learn from observation ▸ Video

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- Garden snails have spatial navigation skills that let them return home to within 30° over distances of up to 40 m
- Slugs can learn via classical conditioning, blocking, and other higher-order learning schemas

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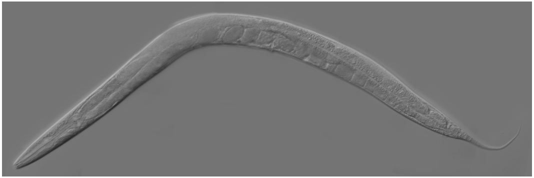

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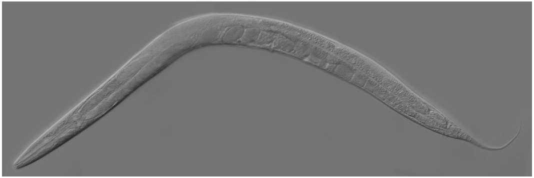

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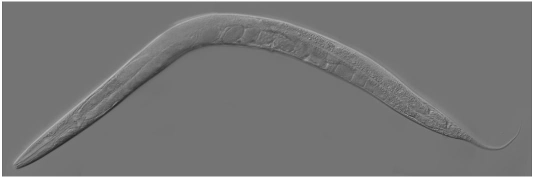

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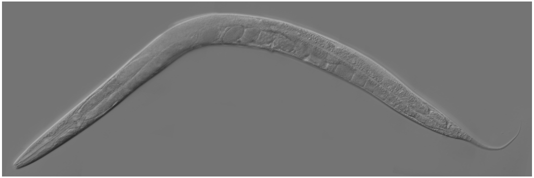

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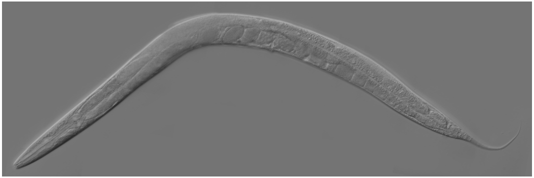
- There are some suggestions that even box jellyfish can learn and remember.



A list of learning processes in insects I

1. Associative recall: Here, the triggering of route memory by exposure to a scent formerly paired with the target of the route; honeybees [73].
2. Attention: An ‘inner eye’ allowing the nervous system to ‘focus’ on limited aspects of incoming information; flies [69], honeybees [70].
3. Binding: The ‘tying together’ of features analysed separately in the visual system into a coherent image; bumblebees [78], honeybees [79].
4. Blocking: After stimulus A has been associated with a US, presenting a compound AB with US may not lead to conditioning of B; honeybees [68].

A list of learning processes in insects II

5. Category learning: Learning to identify different items as members of a class, for example ‘plants’, ‘chairs’, ‘dogs’; honeybees [71].
6. Concept of symmetry: Learning that any symmetrical (or asymmetrical) target is a member of a category; honeybees [7].
7. Concept of sameness/difference: Learning a rule to ‘always choose the same one’ or ‘always choose the odd one’; honeybees [27].
8. Context learning: Learning the appropriate response to a stimulus not via the stimulus itself, but by the context in which it occurs; cockroaches [119], fruit flies [91], honeybees [7].

A list of learning processes in insects III

9. Delayed matching to sample: Keeping a stimulus in working memory and match one from a set of options later; honeybees [27].
10. Generalisation: The tendency to respond similarly to stimuli that are similar to one that has previously been associated with a US; bumblebees [143], fruit flies [91], honeybees [68].
11. Interval timing: Learning to predict the timing of a future event from past experience with intervals between events; bumblebees [72].
12. Latent learning: Learning without rewards, for example in spatial exploration; ants [144], honeybees [68].

A list of learning processes in insects IV

13. Motor learning: Learning movement patterns, as for example in flower handling techniques and wax comb construction in honeybees; bumblebees [108], butterflies [145], fruit flies [121].
14. Numerosity: Responding to the number of items in a display, not to size or other low-level cues; honeybees [74], beetles [146].
15. Negative patterning discrimination: Learning that two stimuli (A and B) are reinforced but the compound (A plus B) is not; honeybees [7].
16. Observational conditioning: A form of second order conditioning where one of the conditioned stimuli is the appearance of a conspecific animal; bumblebees [17].

A list of learning processes in insects V

17. Overshadowing: The inhibition of associating stimulus A with a US in the presence of another stimulus B; honeybees [68].
18. Overtraining reversal effect: If subjects are trained beyond saturation performance, they are more ready to reverse-learn; honeybees [68].
19. Pain relief learning: Learning to identify stimuli associated with the relief from pain as rewarding; fruit flies [147].
20. Peak shift: A bias away from an unrewarded option, arising from differential conditioning; bumblebees [148], honeybees [149].

A list of learning processes in insects VI

21. Reversal learning: Learning that a previously correct option is now incorrect and vice versa; bumblebees [108], honeybees [68]; cockroaches [150].
22. Second order conditioning: Associating stimulus A with a US; if A is subsequently paired with new stimulus B, B will also be learnt as predictor of US; honeybees [68].
23. Sequence learning: For example, learning the sequence of landmarks leading to a food source; bumblebees [21], honeybees [20].
24. State-dependent learnt valuation: The phenomenon that perceived US strength depends on the internal state of animals, for example on hunger levels; locusts [151].[1]

[1] (Chittka and Niven 2009)

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Concept learning Honeybees can learn rules like "always choose the odd one out" or "choose the symmetrical (asymmetrical) target.

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Observational learning : crickets learn to hide under leaves in the presence of wolf spider by observing their conspecifics.

Outline

Honeybee ethogram I

Behavioural repertoire of the honeybee worker.
An overview of distinct and (at least in part) hard-wired behaviour patterns that excludes simple motor patterns, such as locomotion, or various types of inactivity.

1. Aggressive flight: irritated bees fly at intruder with distinct pitch, preceding stinging [22].
2. Alarm fanning: bee stands with abdomen raised, pheromone is released, sting extended; wings whirred [22].
3. Antennation: mutual antennal contact between workers without food transfer, e.g. to assert hive membership [129].
4. Attend dance: following dancing bee to obtain information about target location [129].

Honeybee ethogram II

5. Attend queen: being part of the queen's 'entourage', at times licking or antennating her [129].
6. Biting an intruder: intruders are sometimes not stung but bitten [130].
7. Beg food: antennating another worker's head to solicit food [129].
8. Brief piping: a signal by dance followers inducing termination of dance [131].
9. Brood incubation: pressing body against brood cell and heating, using thoracic muscles [132].

Honeybee ethogram III

10. Build comb: shaping of newly secreted wax into cells; worker, male and queen larvae require different cell sizes, thus different motor routines are needed for construction [129].
11. Buzz run: in bee swarm cluster, a specific mode of running through the cluster to signal and induce the swarm departure [133].
12. Cap brood: sealing cell with larva about to pupate [129].
13. Cell cleaning: removal of debris from empty honeycomb cells [134].
14. Chew at pollen on worker: chewing at pollen in another bee's pollen baskets [129].

Honeybee ethogram IV

15. Chew on hive: using mandibles to chew on walls surrounding combs [129].
16. Colony fission: large number of workers leaves old hive with old queen to relocate into new home. Process and its preparation involves multiple stereotyped individual behaviours [134].
17. Corpse removal: removal of dead bees from the hive [135].
18. Dorsoventral abdominal vibration: standing bee vibrates abdomen up and down, often while holding on to another worker, in preparation for greater activity levels [129].
19. Egg laying: laying unfertilised egg into brood cell [134].

Honeybee ethogram V

20. Expulsion of drones: at end of summer, drones are bitten and dragged out of the hive by workers, sometimes also stung [136].
21. Extend mouthparts: extending proboscis to ripen a small drop of nectar [129].
22. Fan wings: ventilation of hive by fanning the wings [129].
23. Feed larva: inserting head into larval cell to provide food [137].
24. Feed queen/worker: regurgitating drop of nectar which receiver imbibes [129].
25. Get fed: extending proboscis between mandibles of other worker to receive nectar [129].

Honeybee ethogram VI

26. Get groomed: Standing with extended wings to be cleaned by mandibles of other bee [129].
27. Groom self: cleaning self with mouthparts or legs [129].
28. Groom worker: cleaning hive mate with mandibles [129].
29. Guarding: at hive entrance, inspect landing individuals and attack possible intruders [130].
30. Inspect brood cell: inserting head into larval cell to inspect a larva [129].
31. Inspect potential nest sites: probing cavities for suitability [137].
32. Lateral shake ('cleaning dance'): standing worker shakes her body from side to side; this often results in grooming by another bee [129].

Honeybee ethogram VII

33. Mouth wax — capped cells: worker walks over capped brood, or capped food reserves, touching the wax with rapid mandibular movements [129].
34. Nectar foraging: imbibing nectar from flowers [22].
35. Nectar storing: in-hive worker receives food from forager and deposits it in nectar cell [134].
36. Orientation flights: flights around hive to learn its landmark surroundings [138].
37. Packing pollen: tight packing of pollen into special pollen cells [137].
38. Piping in swarms: occurs in the preparation of lift-off to a new hive location [139].

Honeybee ethogram VIII

39. Pollen foraging: requires the collection of powdery pollen from flowers, grooming it off body surface and packaging into specialised hairy structures on legs (pollen baskets) [22].
40. Preventing queen fights: when new queens are raised, workers use multiple tactics to keep them apart [137].
41. Resin foraging: collecting resin from trees and transporting it in 'pollen baskets' to the hive, to be used as 'glue' [22].
42. Resin work in hive: sealing holes and cracks in hive [22].
43. Robbing other hives: the intrusion into other beehives to steal nectar [136].
44. Round dance: motor routine indicating to others that there is food in vicinity of hive [22].

Honeybee ethogram IX

45. Scouting for food: search for suitable flower patches to recruit others to exploit these [134].
46. Searching for nest sites: bees of a swarm search the environment specifically to assess potential nesting sites [134].
47. Sickle dance: occurs at the transition between round dance and waggle dance [22].
48. 'Sterzeln': raising abdomen, release attractive pheromone, and fan wings [22].
49. Stinging: attacking and stinging an animal that is perceived as an intruder [136].

Honeybee ethogram X

50. Streaker guidance: informed scouts guide swarm to new nesting site by performing conspicuous flights at top of swarm [140].
51. Swarm cluster formation: after colony fission, a swarm settles for a temporary bivouac, for example on tree, to search for new home [134].
52. Tremble dance: peculiar ‘twitching dance’; signalling function controversial [141].
53. Turn-back-and-look behaviour: stereotypic flight behaviour to memorise appearance of new food source or hive entrance [142].
54. Uncap brood: using mandibles to remove capping material from brood cell [129].

Honeybee ethogram XI

55. Unload pollen: worker scrapes pollen off legs, and into a storage cell [129].
56. Waggle dance: figure-eight shaped repetitive run, indicating location of food source [22].
57. Water collection: bees seek out freshwater to imbibe and bring back to the hive [22].
58. Water cooling: to prevent overheating, water spread over comb; fanning for evaporation [22].
59. Worker policing: removing eggs that have been laid by other workers [134].

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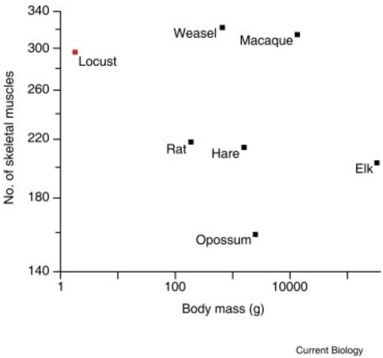
What's the relation between brain size and cognition?



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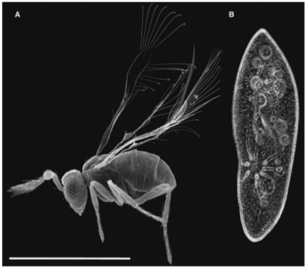
- More neurons can mean more of the same (vision, memory, chemosensation, etc.).
- Smaller brains process information faster and are more energy efficient.
- Even tiny brains can exhibit strikingly complex behavior.



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(Chittka and Niven 2009)

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- count objects in a scene?
  - 50 visual neurons +450 neurons for generating a topographical map + 15 numerosity detector neurons

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- Benefits accrue from compact brains.
- It is sufficient for complex behavior that various complex arrangements of neurons (modular, interconnected) be present, regardless of how many neurons are in the structure.
- Conclusion: Tiny brains can exhibit cognitive capacities of a kind with large brains.

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- We should have looked at the bee brain!

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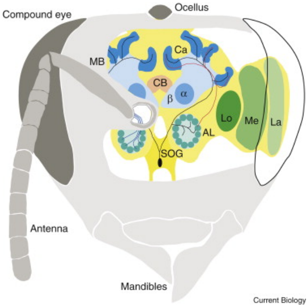
What does it take?

What computational capacity does it take to solve a maze?

▸ Video

Strange invertebrate brains...

- Insect brains are not structured like vertebrate brains



References I

Chittka, Lars and Jeremy Niven (2009). "Are Bigger Brains Better?" In: *Current Biology* 19.21, R995–R1008.

More information

www.ratiocination.org/blog