Second proposal for an ontologically compliant behaviour model

Ditch Townsend

Contents

Inspiration

> “One alternative approach (related to ethograms) comes from the design of ontologies... although... behavioural ontologies still present some difficulties, not least that these large collaborative efforts require consensus on the appropriate conceptualisation and representation of behaviour...” (Mallpress 2022)

> “I would say that any revamp of NBO should driven as much by requirements than by theory.” (Chris Mungall[1])

1 https://github.com/obo-behavior/behavior-ontology/issues/126#issuecomment-1397651952

Introduction

The neurobehavioural ontology (NBO) builds on structures developed directly or inherited from other ontologies since 2011 (Gkoutos, Schofield, and Hoehndorf 2012). It launched with two branches, one for behaviour phenotypes, and the other for behaviour processes. Other ontologies may provide better repositories for behaviour phenotype data. However, none still remain in the OBO network with the extensive and finely scaled behavioural data represented in the behaviour process branch of the NBO (Jackson et al. 2021). But as an early member of the OBO network, the NBO has not faced an openly critical review of its internal systems using more recent expectations.

Opportunities

Moving forward constructively with the NBO, the following needs present significant opportunities:

1. It needs clear **ownership**, even if it is operating in an open way, or it will be difficult to track accountability and make decisions.
2. It needs to develop and uniformly implement a reasonably comprehensive style and convention **guide**, rooted in OBO principles and guidelines.
3. It needs a **model** structure potentially incorporating all behaviour processes, which makes biological sense even if there is not a full consensus, and is consistent with an axiomatic approach.
4. It needs to **refocus**, because its two branches (processes and phenotypes) are pulling strongly in different directions.
5. It needs a consistent **rewrite** of many labels, definitions and annotations.
6. It needs a much more fully **saturated** set of terminal (leaf) classes.
7. It needs a valid **cross-referencing** system.
8. It needs a revamp of its logical **axioms**.

This paper offers a behaviour model to use as the theoretical basis for an enhanced NBO. This responds to opportunity 3 above. *It is the second attempt, having pared down an unnecessarily complex first version dated 18 January 2023*.

Background

Behavioural considerations

There are essentially five ways to conceive a comprehensive behaviour model which could be inclusive at least of all animals having a nerve network.

1. Behaviour **inputs** could be packaged as sets of musculoskeletal movements and ideational units (perhaps mapped to specific brain regions or neuron types). This is almost impossibly reductive for an ontology, since it would become unwieldy before it came close to being explanatory, and would become less and less pragmatic with every scaling increment. (Berman 2018)
2. Behaviour **outputs** could be categorised on the basis of what they achieve. This requires very little interpretation to record and is relatively small in scope, but produces results that can be hard to interpret and lack deep explanatory power. (Aunger and Curtis 2008)
3. Behaviour **outcomes** could be examined at a (generally) whole organism level in relation to its ecology. This is compatible with common experience, classification and terminology for behaviour, although it requires some interpretation by an observer to achieve a reasonable degree of understanding, and has the potential to be expansive. (Mallpress 2022)
4. An attempt could be made to understand a behaviour's **impact** in terms of its meaning and achievements. While deeply satisfying from an explanatory perspective, with a decreasing vocabulary depending on how 'high level' the explanation is, only humans are really amenable to understanding. Little can be said about the multifarious actions and interactions of other animals which form the bulk of ethological observation, without recourse to 'just so' stories. (Kenrick et al. 2010)
5. **Ad hoc** behaviours could be aggregated into clusters based on intuition and apparent association (perhaps using an iterative process until a classification became reasonably saturated and therefore stable). This may allow comprehensive classification and even some unexpected discoveries, but it has no real explanatory power and as has been said, "any list which is convenient is as valid as any other list." (Dunlap 1922) Without a source for the theoretical background to the current NBO structure, it seems to look like this at present.

Ontological considerations

Every ontology is a glossary but not every glossary is an ontology; a suitable ontology would not necessarily be a theoretically perfect glossary. What is needed is a structure which has sufficient to meet all users needs, but only has what is necessary to do so. It also needs to have both a hierarchical structure like a tree, and cross-links like a net. This is far easier with didactic grammar, simplified theory, and distilled vocabulary; encyclopedic elements block networked understanding like the complex ionic composition of mains water furs up a car radiator.

Model

Outcomes

The model I have constructed is based on a classification published recently, as applied to the body of a living agent (or subject). It derives from an outcomes approach, and offers a theoretical comb to tease out its familiar interpretational tangles. It offers what I believe is a reasonable mixture of comprehensiveness, simplicity, understanding and explicitness.

The original classification (Mallpress 2022) saw each behaviour process as one of nine possibilities (labelled with Greek letters)[2]. I have used six of them to fashion my x-axis:

- (Θ) physiological; (Λ) physical exchange, consumption and excretion
- (K) environment and object modification; (Σ) social, signalling
- (I) information seeking; (Ψ) cognition

The other three relate to the spatial and temporal domains: object handling, subject mobility, and subject immobility (labelled ‘rest’ in the source). If they are arranged as a y-axis, together they form a grid with 18 spatio-temporal-associated outcomes[3] (none specifically labelled in the source).

Triggers and stimuli

This model differentiates between behaviours, but not necessarily triggers or stimuli. Unless behaviours change to match them, triggers and stimuli will not be used to subdivide behaviour classes. However, adding gloss in an annotation would be the ideal place to mention relevant ones.

Synthesis

Root level (0º)

The root level of the model comprises two fundamental categories (or axes) into **each** of which **every** behaviour can be allocated: functional (x), and spatio-temporal (y). In our ontology, these[4] will define our top-most class:

> **behaviour process**: A body process that has a functional outcome.

2 Three others are mentioned in the source, but not actively incorporated into my model: Ω) Survival and reproduction are effectively **impacts**, α) Specific body position changes or ‘primitive actions’ are effectively **inputs**, γ) Non-functional behaviour.

3 See the darker grey column and line in tables 1-3.

4 One of the spatio-temporal modes being effectively null makes it redundant for the purpose of the definition.

Function level (1º)

The first level contains the six functional classes defined as:

morphophysiology function: A function that leverages a body system.

exchange function: A function that optimises an internal resource.

modification function: A function that reconfigures a habitat.

sociality function: A function that communicates signals.

sensation function: A function that acquires information.

cognition function: A function that develops meaning.

Outcome level (2º)

The second level incorporates spatio-temporal modes to form 18 outcome classes defined as:

handling [function]: A [functional] outcome that involves moving objects.

> e.g. **handling modification**: An environmental outcome that involves moving objects.

mobile [function]: A [functional] outcome that involves relative[5] subject motion without object handling.

> e.g. **mobile sociality**: A social outcome that involves relative subject motion without object handling.

immobile [function]: A [functional] outcome that can be achieved while relatively[5] stationary.

> e.g. **immobile morphophysiology**: A morphophysiological outcome that can be achieved while relatively stationary.

Functional outcome level (3º)

From the third level, terminal (leaf) classes may begin to appear (see tables 1-3). Behaviour labels from Mallpress (**119 in bold**) have been allocated by his x- or y-axis, and by me for the other axis. Added to this are 22 novel examples from Aunger & Curtis, allocated by their general x-axis, which overlaps Mallpress, and by me for the y- and specific x-axes. (*Examples I reworded are in italics*. Increased shading marks Aunger & Curtis' reactive/motivation/executive control levels, but is only a link back to my first version model and not essential to this one. I have shaded functional outcomes in some of the farthest corners of the table **black**, to indicate that great caution and strong justification is needed before introducing classes from there to the ontology; in the cognition case, it should not be exclusively human; in the morphophysiological case, it should not be imperceptible.

5 With reference to the flow of the medium unless the subject is attached to a substrate.

Tables

Table 1: Object handling-related functional outcomes (3º)

FUNCTION ► / SPATIO-TEMPORAL ▼	MORPHOPHYSIOLOGY (Θ)	(PHYSICAL) EXCHANGE (Λ)	(ENVIRONMENTAL) MODIFICATION (Κ)	SOCIALITY (SIGNALLING) (Σ)	(INFORMATION) SENSATION (Ι)	COGNITION (Ψ)
HANDLING (OBJECT) (Π)	**1. pushing** **2. pulling** **3. dragging** **4. launching** **5. tossing** **6. placing** **7. carrying** - -	***8. operating powered machinery*** **9. riding** **10. maintaining territory** **11. hiding ownership**	**12. bio-extrusion engineering** **13. building** **14. burrowing** **15. opening** **16. burying** **17. mixing** **18. sorting** **19. closing** **20. rearranging** **21. dividing** **22. combining** **23. destroying** **24. digging** **25. dismantling** **26. cutting** **27. breaking** *28.* acquiring *property* **29. tool manufacturing** **30. cooking** **31. preparing** *32. organising*	- 33. offspring investment 34. mate investment 35. status improvement **36. doing art** **37. making music**	- - 38. skill practising	- - 39. creating

Table 2: Subject mobility-related functional outcomes (3º)

FUNCTION ► / SPATIO-TEMPORAL ▼	MORPHOPHYSIOLOGY (Θ)	(PHYSICAL) EXCHANGE (Λ)	(ENVIRONMENTAL) MODIFICATION (Κ)	SOCIALITY (SIGNALLING) (Σ)	(INFORMATION) SENSATION (Ι)	COGNITION (Ψ)
MOBILE (SUBJECT) (Μ)	**40. swimming** **41. running** **42. diving** **43. climbing** **44. walking** **45. jumping** **46. flying** **47. gliding** **48. sliding** 49. withdrawal - -	*50. aerotaxis* *51. thermotaxis* *52. phototaxis* *53. hygrotaxis* **54. escape** **55. migrating** **56. defending ownership** 57. copulating -	58. evade risky habitat (predators, disease) - -	**59. territory marking** **60. scent trailing** 61. impairment **62. alarm calling** **63. dominance displaying** **64. aggression** **65. submission** **66. dawn chorus** **67. courtship displaying** **68. crying** **69. defensive displaying** **70. fitness displaying** ***71. size deceiving*** **72. food begging** **73. *deceptive* ownership** **74. help calling** **75. teaching** **76. gesturing** **77. facial expressing** **78. writing** **79. speaking** ***80. acting***	**81. muscle memory** **82. roaming** **83. playing** **84. searching** **85. feeling** **86. training** **87. testing**	- **88.** curiosity ***89. debating***

Table 3: Subject immobility-related functional outcomes (3º)

FUNCTION ► / SPATIO-TEMPORAL ▼	MORPHOPHYSIOLOGY (Θ)	(PHYSICAL) EXCHANGE (Λ)	(ENVIRONMENTAL) MODIFICATION (Κ)	SOCIALITY (SIGNALLING) (Σ)	(INFORMATION) SENSATION (Ι)	COGNITION (Ψ)
IMMOBILE (SUBJECT) (Ζ)	**90. *cellular* respiration** **91. anabolism** **92. catabolism** **93. circulation** **94. immunity** **95. development** ***96. secretion*** ***97. homeostasis*** 98. pupil 99. blink 100. startle **101. sleeping** **102. hibernation** **103. waiting** **104. resting** -	***105. respiration*** **106. urination** **107. defecation** **108. vomiting** **109. sweating** **110. coughing?** **111. sneezing?** 112. cervical contraction 113. infant suckle 114. absorb nutrients **115. drinking** **116. eating** **117. mobile ownership** -	118. cue association - -	**119. sickness** **120. hiding** ***121. thanatosis*** -	**122. *involuntary* (simple) eye movements** **123. orienting** **124. *perception*** **125. inspection** ***126. memory*** **127. learning** -	**128. attention** **129. perceptual processing** **130. pattern recognition** **131. categorisation** **132. memory storage** **133. memory retrieval** **134. recognition** **135. problem solving** **136. calculation** **137. decision making** **138. motor planning** **139. abstract thought** **140. imagination** **141. planning**

Integration with NBO

Existing NBO leaf classes will be fitted from the tertiary level, along with viable superclasses, and in due course, new classes will be fitted into the new structure. As before, classes can be subclasses and superclasses in different domains simultaneously. Some class definitions inspired by NBO's stress-related behavior sub-branch are given below (NBO codes are given where they exist, although labels may have changed), diverging from several of the 18 functional outcomes (3º):

(0º) behaviour process: A process that has a functional outcome.

(1º) morphophysiology function: A function that leverages a body system.

(2º) immobile morphophysiology: A morphophysiological outcome that can be achieved while relatively stationary.

(3º) stressing (NBO:0000469): A body system that responds to allostatic overload.[6]

(4º) stress alarm (NBO:0000470): A response to allostatic overload that manages the first stage of adaptation.[7]

(5º) shock: The first phase of the first stage of adaptation that faces collapse.

(5º) antishock (NBO:0000088): The second phase of the first stage of adaptation that activates the fight-or-flight response.

(subclass) tachybranchia – *see below*

(4º) coping (NBO:0000103): A response to allostatic overload that attempts to compensate in the second stage of adaptation.[8]

(5º) stress hyperthermia (NBO:0002569): Adaptive compensation that increases core temperature.[9]

(4º) resolving: A response to allostatic overload that manages the third stage of adaptation.[10]

(5º) recovering: A pathway through the third stage of adaptation, that recuperates towards normal function.

(5º) exhaustion (NBO:0000472): A pathway through the third stage of adaptation, that decompensates from normal function.

(6º) stress hypothermia: Adaptive decompensation that reduces core temperature.[9]

6 https://en.wikipedia.org/wiki/Allostasis#Types
7 https://en.wikipedia.org/wiki/Stress_(biology)#Stage_1
8 https://en.wikipedia.org/wiki/Stress_(biology)#Stage_2
9 https://www.researchgate.net/profile/Takakazu-Oka/publication/329016087_Stress-induced_hyperthermia_and_hypothermia/links/5c635aac299bf1d14cc1f4eb/Stress-induced-hyperthermia-and-hypothermia.pdf
10 https://en.wikipedia.org/wiki/Stress_(biology)#Stage_3

(1º) exchange function: A function that optimises an internal resource.

(2º) immobile exchange: An exchange outcome that can be achieved while relatively stationary.

(3º) active ventilation: Internal rebalancing that alters gas exchange by pumping of an aerated medium.[11]

(4º) tachybranchia: Increased gas exchange that follows increased volume of pumped gill irrigation.

(4º) tachypnoea: Increased gas exchange that follows increased breathing rate.[12]

(2º) mobile exchange: An exchange outcome that involves relative subject motion without object handling.

(3º) passive ventilation: Internal rebalancing that alters gas exchange by changing the through flow rate of an aerated medium.[13]

(4º) ram ventilation: Gas exchange that varies with speed through an aerated medium.[11]

(3º) aerotaxis: Internal rebalancing that alters gas exchange by changing position on a gas concentration gradient.[14]

(4º) aquatic surface respiration (NBO:0040004): Increased gas exchange that comes from surface water.[15]

(4º) aquatic aerial respiration: Increased gas exchange that comes from gulping air. This may cross the gills, aerate the mouth cavity, or enter modified organs.[11]

(1º) sociality function: A function that communicates signals

(2º) mobile sociality: A social outcome that involves relative subject motion without object handling.

(3º) threatened (NBO:0000018): Signalling that responds to danger.[16]

(4º) anxious (NBO:0000092): A response to danger that is imagined and future.[16]

(4º) fearful (NBO:0000091): A response to danger that is real and present.[16]

11 https://en.wikipedia.org/wiki/Fish_physiology#Respiration
12 https://en.wikipedia.org/wiki/Tachypnea
13 https://en.wikipedia.org/wiki/Respiratory_system
14 https://en.wikipedia.org/wiki/Taxis#Examples
15 https://en.wikipedia.org/wiki/Hypoxia_in_fish#Aquatic_surface_respiration
16 https://en.wikipedia.org/wiki/Anxiety

Conclusion

Maybe all that is needed for the NBO is some housekeeping: a consistent rewrite of the labels, definitions and annotations (opportunity 5), a style guide (opportunity 2), better cross referencing and axioms (opportunities 6 and 7). Without doubt, obtaining a consensus on a new model structure and repopulating it (with all the disruption it could entail) are significant challenges. But the original promise of the NBO seems to some to have fallen on its face. I started my interest in behavioural ontologies with a very pragmatic hat – essentially, I just wanted a decent set of pigeon holes to put instances into – my main interest is observing fish behaviour after all. But attempting to formalise a theoretically consistent set of pigeon holes for an ontology of behaviours seems a worthwhile enough objective to focus some effort on. And the fear of losing stakeholders seems to be a case of locking the stable after the horses have fled. To flourish, the NBO needs to reinvent itself. Otherwise it will fade away.

References

Aunger, Robert, and Valerie Curtis. 2008. ‘Kinds of Behaviour’. *Biology & Philosophy* 23 (3): 317–45.

Berman, Gordon J. 2018. ‘Measuring Behavior across Scales’. *BMC Biology* 16 (1): 1–11.

Dunlap, Knight. 1922. ‘The Identity of Instinct and Habit’. *The Journal of Philosophy* 19 (4): 85–94.

Gkoutos, Georgios V., Paul N. Schofield, and Robert Hoehndorf. 2012. ‘Chapter Four - The Neurobehavior Ontology: An Ontology for Annotation and Integration of Behavior and Behavioral Phenotypes’. In *International Review of Neurobiology*, edited by Elissa J. Chesler and Melissa A. Haendel, 103:69–87. Bioinformatics of Behavior: Part 1. Academic Press. https://doi.org/10.1016/B978-0-12-388408-4.00004-6.

Jackson, Rebecca, Nicolas Matentzoglu, James A Overton, Randi Vita, James P Balhoff, Pier Luigi Buttigieg, Seth Carbon, et al. 2021. ‘OBO Foundry in 2021: Operationalizing Open Data Principles to Evaluate Ontologies’. *Database: The Journal of Biological Databases and Curation* 2021 (October): baab069. https://doi.org/10.1093/database/baab069.

Kenrick, Douglas T., Vladas Griskevicius, Steven L. Neuberg, and Mark Schaller. 2010. ‘Renovating the Pyramid of Needs: Contemporary Extensions Built upon Ancient Foundations’. *Perspectives on Psychological Science* 5 (3): 292–314.

Mallpress, Dave EW. 2022. ‘Towards a Functional Classification of Behaviour: A Taxonomy Based on Outcomes’. *Adaptive Behavior* 30 (5): 417–50.