Repositioning the NBO

Thoughts for a behaviour ontology workshop on 6th July 2023 by Ditch Townsend

Key points

The draft agenda for discussion includes:

1. *Brief intro of all participating ontologies*: Hopefully Nico and others can comment in addition to this paper regarding the NBO.

2. *GO:behaviour, quo vadis?* I think there is lots there that the NBO could absorb (someone has focused extensively on insects which would be a great boon), some are duplicates already, and some we couldn't. But this is something I'd be happy poring over in future.

3. *NBO future*. This paper explores a non-radical way forward, simply comprising remapped connections in a nod to the action-function dichotomy, but a suggestion we focus on the NBO as a network of practical connections rather than a group of allied hierarchies. It places much greater importance than previously on two more pragmatic tasks:

   - a consistent rewrite of most labels, definitions and annotations,
   - a much more fully saturated set of terminal (leaf) classes.

4. *Alignment between BCIO, NOFO, NBO, GO, NCIT and a common message to biocuration which ontology to use for what.* **I think the NBO should be for**:

   - natural non-human animal behaviours (except where they are inclusive),
   - field and captive observation, but only with minimally invasive intervention (e.g. facial wind puff, feeding delay, normal range temperature adjustment),
   - only the superficial interface with morphophysiology (e.g. appendage movements with words like pronation or supination in the descriptions but not labels),
   - only the superficial interface with neurophysiology (e.g. the existing range of reflexes essentially delimits us),
   - memory and sensation behaviours in the cognitive space, and probably learning, but without directly referencing 'intelligence',
   - fear-related behavior is the only 'emotion' we'd retain by name within the NBO; other primordial reactions are covered by agonistic, social, play, and avoidance terminology,
   - naturally observable impairment behaviour (e.g. autotomy or distress signalling).

5. *Discuss a common model of behaviour across species, including the separation of activities, functions, phenotypes, and add to COB*. My experience rethinking the NBO suggests that the most pragmatic approach will be the most useful; we have struggled to obtain consensus thus far regarding theoretical models of behaviour, and I don't think we can reliably distinguish functions and activities.

6. *Joint submission to grants bodies (or not).* I came to the NBO for access to a viable animal behaviour ontology and ended up a volunteer administrator. I have no problem with someone else managing the process, with their own emphases, so long as it works.

Contents

Background

NBO quality

The integration of an emerging NBO and ABO has been incomplete, not least as ownership evaporated a few years ago. Voluntary efforts within the last year have been made to reinvigorate the NBO, but several commentators have suggested that only funding can provide the resources needed for sustainable quality improvements. Specific attempts have been made to remodel the NBO,[1] and to agree styles and conventions.[2]

Traits and phenotypes

The phenotype branch of NBO is due for deprecation.[3, 4] Within the process branch are also some terms which it has been argued belong in the phenotype branch. These are **wakefulness**, **awareness**, and **being conscious** and will be deprecated in due course alongside **asleep** which is already in the phenotype branch. Note that **sleeping behavior** will remain within the process branch.[5]

Disease, disorder, and disability

Almost all NBO references to these are contained in the phenotype branch and will be deprecated.[6] There is no intention to incorporate any related classes within NBO except perhaps in relation to parasitism that changes animal behaviour, recuperative behaviour, natural self-medication, and **distress signalling** such as after an injury.

NBO use cases

Discussion earlier in 2023 has led us to the following:[7]

1. Ethology along the lines of an original proposal for an Animal Behavior Ontology (ABO) designed to support more standardised use of ethograms.

2. Observational behavioral research in the laboratory.

3. Field behavior cataloguing (not least by citizen scientists).

Note that behavioral testing on model organisms and in clinical settings were mentioned as use cases for traits and phenotypes. This remains a laudable aim but responsibility for this will be passed on along with deprecations of trait and phenotype components of the phenotype branch.

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1 https://github.com/obo-behavior/behavior-ontology/issues/126
2 https://github.com/obo-behavior/behavior-ontology/issues/122
3 https://github.com/obo-behavior/behavior-ontology/issues/131
4 https://github.com/obo-behavior/behavior-ontology/issues/162
5 https://github.com/obo-behavior/behavior-ontology/issues/29
6 https://github.com/obo-behavior/behavior-ontology/issues/163
7 https://github.com/obo-behavior/behavior-ontology/issues/127

Taxon specificity

Since at least 2004, a desire from the ethology perspective has been to limit the specificity of behaviors in the NBO, even for animal models.[8] With a move away from phenotypes comes a good opportunity for the NBO to deprecate its most specific references in the process branch, not least to mouse models in the **aggressive behavior by intent** sub-branch.

NBO has struggled to appropriately incorporate human behavior,[9] and has generally related it to a **consumption behavior** sub-branch.[10, 11] The advent of BCIO and other initiatives gives us an opportunity to resolve this, although it may not be easy to directly deprecate some of the classes which have found their way into the NBO in recent years when it was in some ways 'hacked'. Rather than others adopting all NBO terms, it may be necessary for NBO to obsolete a handful of terms, with synonymous references to external terms where possible.

Ontology alignments

Much has been said about the historical alignment between NBO and GO.[12] But what was assumed about the stability of GO behavioural references is now up in smoke, adding to the significant quality deficit in NBO it needs to fill up.[13] The NBO has already deferred to COB regarding human activity.[14] The arrival of BCIO has also been considered, although with little action taken so far.[15]

NB: An email from Janna Hastings on 27th May 2023 notes that at the start, NBO and GO developers agreed that, "human behaviour as it is culturally and socially emergent would not be in scope for these ontologies and thus fitted better within the BCIO".

Acts and functions

The ABO initially aimed to split behaviors into acts and functions. A pattern has even been proposed.[16] However, the NBO required a composite approach when integration was agreed. In practice, integration was never fully implemented, so we are left with an incomplete patchwork of elements positioned with a range of sometimes contradictory assumptions.[17, 18]

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8   https://github.com/obo-behavior/behavior-ontology/issues/127
9   https://github.com/obo-behavior/behavior-ontology/issues/109
10 https://github.com/obo-behavior/behavior-ontology/issues/98
11 https://github.com/obo-behavior/behavior-ontology/issues/121
12 https://github.com/obo-behavior/behavior-ontology/issues/101
13 https://github.com/obo-behavior/behavior-ontology/issues/113
14 https://github.com/OBOFoundry/COB/issues/156
15 https://github.com/obo-behavior/behavior-ontology/issues/157
16 https://github.com/obo-behavior/behavior-ontology/issues/27
17 https://github.com/obo-behavior/behavior-ontology/issues/30
18 https://github.com/obo-behavior/behavior-ontology/issues/48

NBO Knowledge Graphs

The following graphs were created in Gephi after downloading a csv using Protégé of all subclass relations in the NBO. The graphs were exported as svg images and this paper has been circulated as a pdf. Viewing on a digital device thus allows deep zooming so the labels become readable. IDs have been excluded to reduce clutter without further reducing the effective font size.

The original ontology (May 2023) only includes the behavior process branch; a decision already taken will deprecate the phenotype branch in due course. In total, 759 classes (nodes) were downloaded but 124 were in duplicated sub-branches leaving 635 unique nodes. Alongside were 758 subclass relations (edges) which after removing the duplicates left 682 unidirectional edges. These are mapped downwards as superclasses (sources) pointing to subclasses (targets). The NBO contains very few classes incorporating properties aside from the subclass relation, and those few present tend to be viewed as problematic (e.g. by_means)[19] so they have all been ignored, as have subclass relations to other ontologies such as the Gene Ontology (GO).

Many subclasses and class relations are missing from the NBO. A significant number may be inadequately labelled. However, the starting point for this exercise is the existing NBO, so no relabelling is offered at this point. And whilst some interpolation has added proposed classes in figures 2 and 3 to aid remapping, minimal extrapolation means few classes have been added as terminal leaves except where it is necessary to assist understanding.

Note that this is merely a conceptual exercise. Components coloured **orange** are for debate in this workshop. Components coloured **yellow** and **blue** will be refined and submitted to the normal NBO edit discussion process via Issues on GitHub if and when considered appropriate. NO PULL REQUESTS HAVE BEEN MADE TO THE NBO MASTER.

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19 https://docs.google.com/document/d/1eSCjQfR5BujtUYw4W2pYOL6rhPPMycJd8u95X1-5U7Q/edit#heading=h.sypswh473g48

Original structure

Overview

The 635 classes are linked by 682 relations. These radiate out from the **behavior process** class – itself a subclass of GO (soon to be deprecated by them). The top level subclasses are **grooming behavior**, **cognitive behavior**, **playing behavior**, **social behavior**, **emotional behavior**, **stress related behavior**, **reproductive behavior**, **motivation behavior**, **impulsive behavior**, **rhythmic behavior**, **consumption behavior**, **kinesthetic behavior**, and **regulation of behavior**.

Figure 1: Original NBO knowledge graph using a Fruchterman Reingold layout
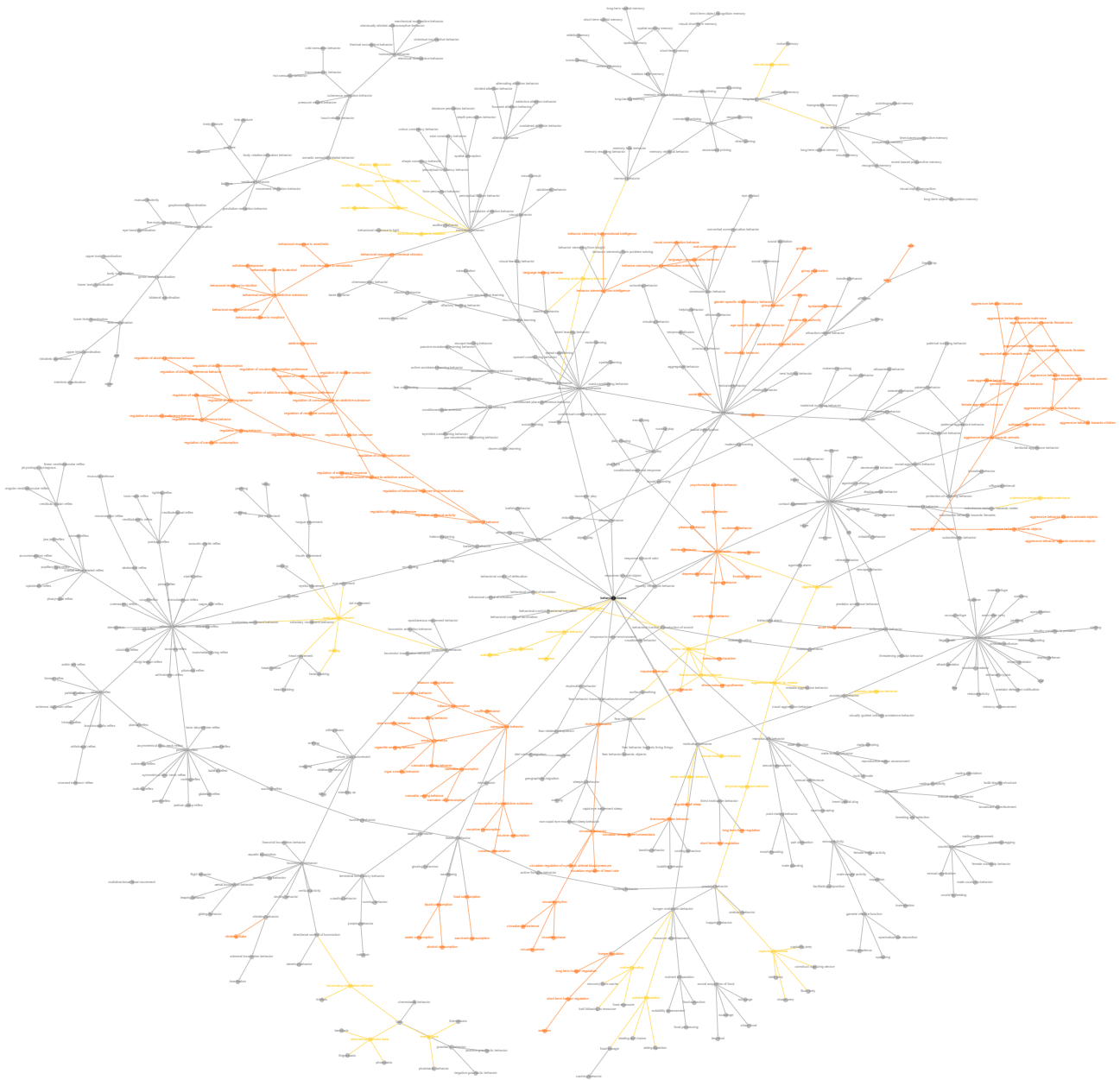
Realignments

A number of **orange coloured nodes** may be usefully adopted by other ontologies and will be discussed in relation to figure 2 (in the next section).

Deprecations

A number of **yellow coloured nodes** are not appropriately located in the NBO:

- **Submissive behavior towards male mice** is taxon specific and probably belongs in an ontology incorporating mouse behaviour models.

- The **consciousness behavior** sub-branch is about traits and phenotypes.

- **Emission behavior** feels contrived as it connects processes by analogy rather than actual activity or function. The subclasses related to excretion and sound production can be more usefully positioned when they are disconnected.

- The **hallucination** sub-branch belongs with a disorder-related and/or trait-phenotype and/or human ontology.

Obsoletions

A number of **yellow coloured nodes** are effectively defunct and obsoletion will be considered:

- **Non-declarative memory** is not the exclusive alternative to **declarative memory** which also has **emotional memory** as a sibling. Nor does it contain positive explanatory meaning as does **declarative memory**. Furthermore, it only has one subclass: **motor memory**. Lastly, if it subsumed **emotional memory**, it would extend, not flatten the network.[20]

- **Learning and/or memory behavior** is redundant as it merely aggregates the two classes: **learning behavior** and **memory behavior**.

- **Fear/anxiety related behavior** is redundant as it merely aggregates the two classes: **fear-related behavior** and **anxiety-related behavior**.

- **Predator avoidance behavior NBO:0015001** directly duplicates **predator avoidance behavior NBO:0000471** and needs removing.

- **Body part movement** unnecessarily aggregates its parts which can easily stand as siblings to **whole body movement**. Removing it also flattens the network to a degree.

- **Shaking** is both a redundant link to **head shaking** and spuriously suggests a common process underlying any other types of shaking which might in future be identified.

- **Locomotory orientation behavior** is a redundant link to **kinesis** and **taxis,** which are good siblings to **steering behavior**, and removing it will help flatten the network.

- **Mechanical stimulus taxis** and **energy taxis** are redundant aggregators which unnecessarily increase hierarchy in the network and divert attention from the more practical difference between kinetic and tactic activities.

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20 See NBO Styles and Conventions at https://github.com/obo-behavior/behavior-ontology/issues/122

- **Behavioral response to radiation** is a redundant link to its solitary member: **behavioral response to light**.

- **Perception behavior by means** involves both a redundant link to its solitary member, and was laid down undefined. It tends to increase confusion.

- ABO protagonists in the NBO merger persistently contended against the use of **aggressive behavior** as a real, rather than simply semantic, animal behavior category, preferring the common features and explanatory power of **agonistic behavior**, whilst allowing for specific types of aggressive behavior not necessarily linked by activity or function (e.g. **irritable aggressive behavior** and **vocal aggression behavior**). The evaporation of NBO leadership and the passage of time now allows the ethological case to regain authority on this matter. **Aggressive behavior by means** (which again is undefined) topples too as a domino effect.

- **Stress related behavior** is more usefully understood by exploring its synonymous **acute stress response** (see the discussion of figure 2).

- **Sexual motivation behavior** is more usefully understood as synonymous with **reproductive behavior**.

- **Sleep motivation behavior** is more usefully understood as synonymous with **sleeping behavior**.

- **Capturing behaviour** is closely synonymous with **hunting behavior** which was introduced to the NBO much more recently (e.g. both reference stalking either in their definition or as a subclass). **Capturing prey** is a narrower, more useful class, which alongside **chase prey**, **flush prey** and **stalk prey** fit more neatly into the **hunting behavior** category (itself more commonly used in ethology), thus rendering **capturing behaviour** redundant.

- **Nutrient locating** and **nutrient acquisition** become redundant classes when their subclasses are mapped differently (see the discussion of figure 3).

Pre-amputation structure

Overview

Of the original 635 classes, 21% have been reaggregated (the 132 **nodes coloured orange** in figures 1 and 2) after filtering out the deprecations and obsoletions discussed in the previous section (under figure 1). Four **nodes coloured yellow** have also been added to aid interpretation. One of these – **thirst regulation** – has been added as the missing direct counterpart of **hunger regulation**. The other three are discussed in their own subsections below.

Figure 2: Pre-amputated NBO knowledge graph using a Fruchterman Reingold layout
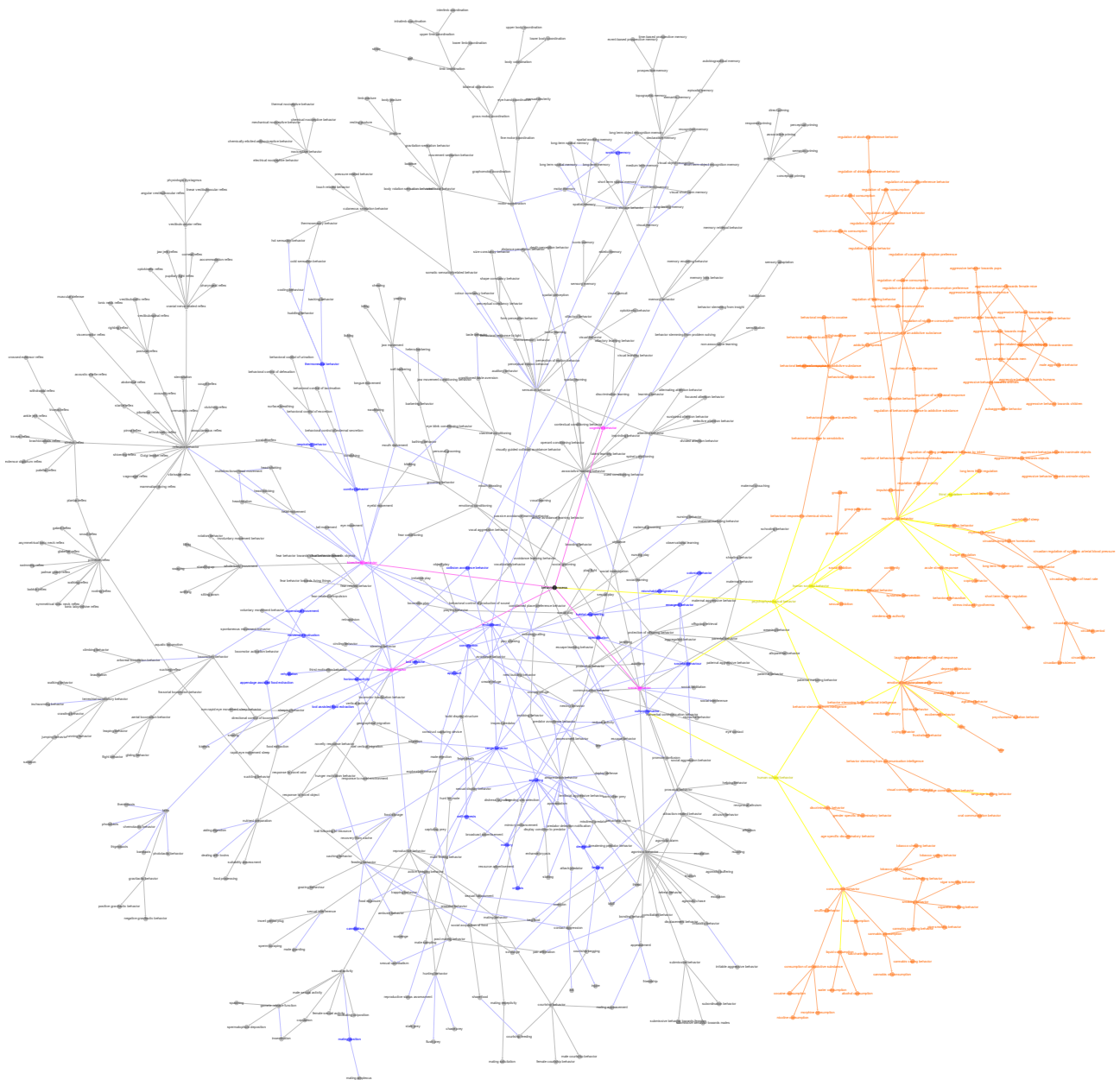
Psychophysiology

During previous attempts to remodel the NBO from a theoretical base, arguments have arisen about the appropriateness of using classes which are explicitly physiological.[21] If an ethological use case is also the prime one, physiology is arguably too reductionist and some related classes need deprecating from the NBO. Furthermore, behavioral testing on model organisms is arguably a use case too far for the NBO once the phenotype branch is deprecated, so we need to look for behaviour classes in the process branch which need to be passed on to other ontologies. Lastly, distinctly human behaviour is too taxon specific for the NBO.

But physiology remains a potentially fertile aggregating device for all these themes, although by itself it is too broad given the NBO's need not to forget muscles (for movements) and peripheral nerves (not least for reflexes and sensation). Without renaming the ontology, I have looked for a unifying category which is physiological, and inclusive yet specific; a superclass which can link directly to our core **behavior process** class. Behavioral physiology is too broad a term. I feel drawn to **psychophysiological behavior** not just because of its links to human psychology, and because the animal models we are flirting with are used to emulate aspects of human behaviour, but the hormonal components are bound up with brain structures.[22]

- **Behavioral response to chemical stimulus** provides the direct route via **behavioral response to xenobiotics** to various types of **behavioral response to addictive substance**. In the original structure, it is also superclass to chemosensory behavior, but is defined in a near-synonymous way. Chemosensory behavior remains in NBO as a useful superclass to **taste behavior** and **olfactory behavior** and perhaps future classes involving naturally occurring chemically mediated heat and pain sensation without recourse to addiction.

- **Emotional behavior** can be defined in subjective terms, which excludes its direct investigation in animals, but offers a direct link to human-type ontologies. This is not to say that emotion-related behaviours don't exist in animals, but an ethological use case can be made without the absolute need to invoke the word 'emotion'. Incidentally, whilst **anxiety-related behavior** in animals is more of a hypothetical analogue to the human emotion, **fear-related behavior** is not only very visible in many animals, but can be argued to be more primordial than classically defined emotions, being more immediate, behavioural, and survival focused (a high level function), and hence I have retained it in the NBO.

- **Regulation of behavior** offers a link to invisible factors involving physiology and psychology. Aside from cortical processes related to self control in humans, it is hard to see regulation in behavioural practice. Arguably, it was never appropriately located in the NBO anyway, given its frequent dependence on hormonal processes.

- **Aggressive behavior by intent** provides a window to another anomalous area for NBO. Being undefined, it already requires some interpretation, but its subclasses reveal a strong orientation towards the mouse model. Linking intent to regulation allows what seems like an appropriate way out of the NBO, although it may become a redundant term in itself when the subclasses are adopted by another ontology.

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21 https://github.com/obo-behavior/behavior-ontology/issues/123
22 In the diencephalon, incorporating the hypothalamic-pituitary axis (HPA)

- **Rhythmic behavior** is arguably a spurious aggregation device, being more semantic than identifying a similar underlying process in each case. However, underlying processes do tend to relate to physiological activity, either endogenous or responding to exogenous stimuli. And of course they are regulatory processes, so they fit well here.

- **Hunger regulation** and **thirst regulation** are fundamentally hormonally connected and invisible.

- The **acute stress response** has a number of components closely tied to adrenaline and cortisol and unless physiological measures like blood pressure can be taken, their visible effects are essentially secondary.

Human society

Whilst the NBO has a key focus on **social behavior**, it has not explored issues around animal society or emergent group behavior, save for reference to fish **shoaling behavior**. In the mean time, Janna Hastings has referred to the need for ontological space to explore, "human behaviour as it is... socially emergent". In response, I have made suggestions in figure 3 which can expand our horizons usefully into the highly observable world of animal colonial, societal, engineering, and maybe even super-organismal, behaviours. A proposed **societal behavior** class will allow exactly what Janna has proposed via a **human societal behavior** subclass, whilst keeping it connected to the wider animal behaviour world.

- **Regulation of behavior** in humans is often sociologically mediated.

- **Social inhibition**, **sexual inhibition**, and the **social influence related behavior** sub-branch might well be considered under **regulation of behavior**, but I simply propose to leave these in the hands of an alternative ontology to reinterpret and map appropriately.

- **Group behavior** as defined by its subclasses in NBO (**groupthink** and **group polarization**) is more of an emergent outcome than a considered one, but most profitably explored from a human perspective I think. NB: NBO would retain the subclasses **social facilitation** and **social interference** as more general animal behaviours, but would not need the aggregating term **group behavior** itself.

Human culture

The NBO's only foci relating to culture appear to be human related. There are a range of observable animal cultural behaviours which have not yet made their way through the NBO, except perhaps implied in some forms of **food extraction** and **sexual display behavior**. Janna needs ontological room for, "human behaviour as it is culturally... emergent". A proposed **cultural behavior** class will allow exactly what Janna has proposed via a **human cultural behavior** subclass, whilst keeping it connected to the wider animal behaviour world.

- It is hard to see the NBO's **discriminatory behavior** belonging elsewhere than in a human ontology.

- **Behavior stemming from intelligence** is contentious in an animal context, and the subclasses proffered relate (in their definitions or labels) to 'representations' (**visual**

communication behavior), 'word messages' (**oral communication behavior**), and **language communication behavior** (to which has been appended **language learning behavior**). Given the previous discussion about emotions, **behavior stemming from emotional intelligence** lines up alongside these as most clearly human behaviour, and language is often considered a key to human culture. Incidentally, language's apparent dependence on human neurophysiology suggests a direct relation to **psychophysiological behavior**.

- **Consumption behavior** is another contentious item within NBO.[23] On the surface it can be mistaken for a synonym of **feeding behavior**, which remains tightly bound to the NBO. But it was created in the NBO context as a psychological/anthropological corollary to the physiology of addictive chemical substance. Whatever label it uses, it is clearly focused on humans and their experimental animal models.

- Hiking behavior and its ilk have been actively resisted up to this point on the grounds of scope creep rather than a well defined scope.[24] I think we need to define our scope explicitly to exclude such human-specific behaviors.

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23 https://github.com/obo-behavior/behavior-ontology/issues/121
24 https://github.com/obo-behavior/behavior-ontology/issues/109

Refreshed structure

Overview

There are 391 classes in my newly imagined baseline NBO structure. Of these, 31 (8%) are completely new. Only four of the original 15 top level superclasses are retained: **kinesthetic behavior**, **cognitive behavior**, **motivation behavior**, and **social behavior**.

Figure 3: A refreshed NBO knowledge graph using a Fruchterman Reingold layout
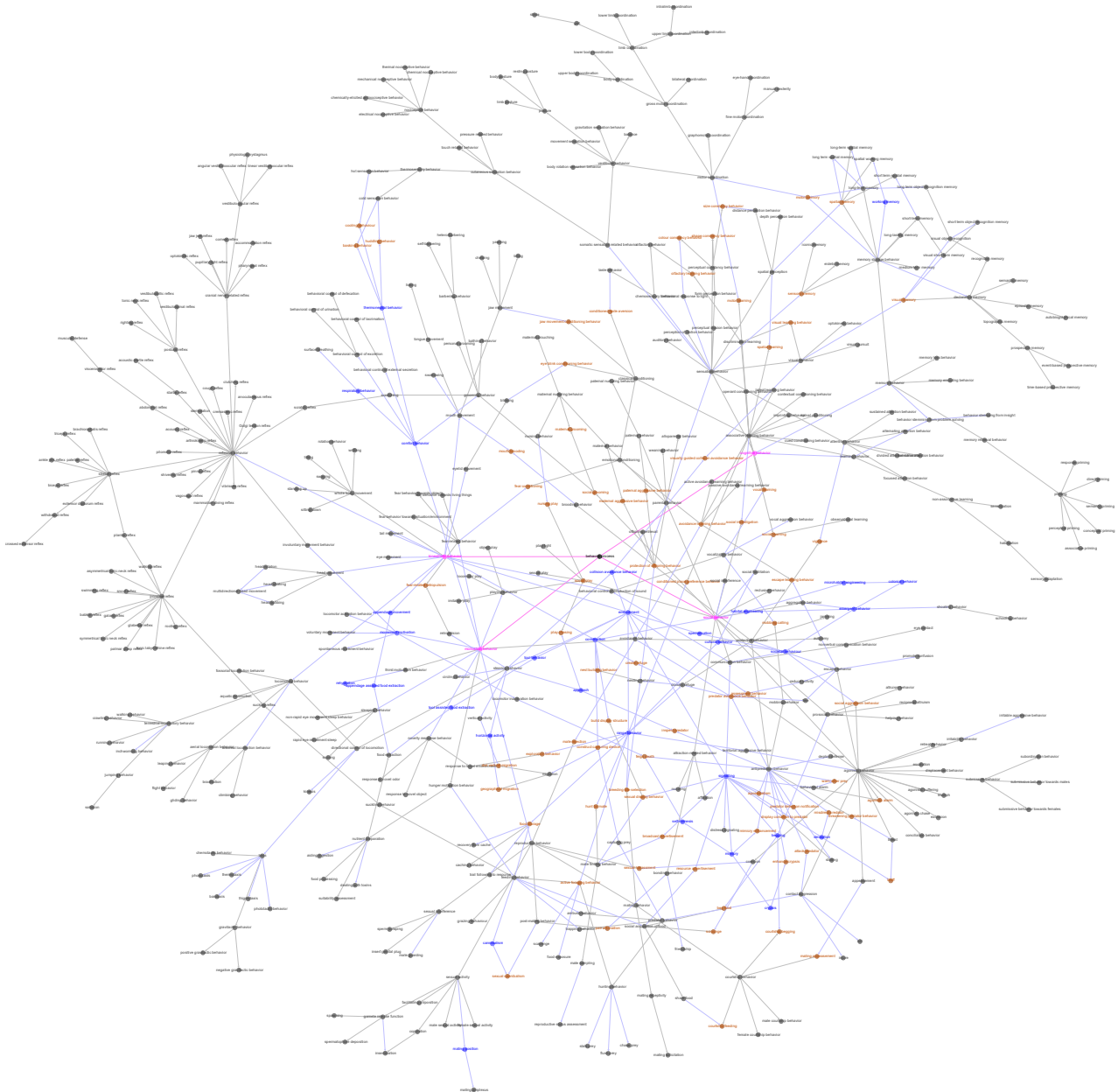
Kinesthesis

The specific effects of suggested deprecations, obsoletions, and realignments above will not be repeated, but their effect overall is to flatten/shorten the relational chains between classes. Some highlights and all new nodes will be mentioned below:

- **Behavioral control of production of sound** is now reckoned as a **kinesthetic behavior**, at last granting it a definitively neuromuscular basis.

- **Appendage assisted food extraction** is interpolated from the definition of **food extraction**, and with it **appendage movement** must pop into existence.

- **Steering behavior** now adds the new classes **horizontal activity** and **approach** to **vertical activity**, **retropulsion** and **circling behavior**.

- **Construction** is a process mentioned in the original ABO structure (as 'build') and is a useful activity-type class to aggregate multiple existing NBO composite classes (e.g. **construct capturing device**).

- **Embodiment** recognises the interaction of an organism's physicality with its environment and is increasingly seen as having strong explanatory abilities within zoology. Whilst not trying against the odds to design our ontology around a fixed theoretical perspective, it helps that this concept offers particularly useful ways to meaningfully organise animal behaviour categories. As well as new links to the existing categories of **steering behavior** and **assessment behavior**, it offers a rationale for the new classes **tool behavior**, **construction**, **range behavior**, **signalling**, and **specialisation**.

- **Signalling** was a key function in the ABO and is referenced in multiple NBO class definitions, yet went unacknowledged as a useful organising and explanatory category in the original NBO. I have brought it back along with several intermediaries to existing classes which otherwise would tend to flap in the breeze (**mimicry**, **self-mimesis**, **crypsis**, **deception**, and **begging**).

Cognition

This remains a relatively stable NBO class. I have added a number of relations from learning behavior subclasses to their existing subject classes but generally do not mention them. However:

- Many of the detailed elements of **learning behavior** will most likely only be explored in our second use case - observational laboratory research. Were the NBO to be limited essentially to field based ethology, there could be merit in exploring an alternative ontology for learning behavior. There is some notable overlap with the *BCIO:050239 learning* sub-branch.

- A similar argument applies to **memory behavior**, although to a lesser degree. Field ethologists will frequently encounter visible memory-related behavior and BCIO mirrors the very limited *GO:0007613 memory* sub-branch.

- A new **working memory** class has been inserted as sibling to **short-term memory**, **long-term memory**, and **long-lasting memory**. It fills a hiatus which otherwise leaves **spatial working memory** dangling.

- **Sensation behavior** remains near the heart of ethology and provides the other key plank supporting **embodiment**.

Motivation

Admittedly, the concept of motivational behaviour may not be sufficiently mechanistic for all ethologists. It has been questioned again fairly recently within NBO.[25] To handle this:

- I have inserted the class **comfort behavior** as an alternative to the ABO's original concept of *maintenance* which was never absorbed into the NBO and was defined there in homeostatic (or even allostatic) terms.[26] I have reintroduced the ABO's **respiratory behavior** as a subclass, and added **thermoneutral behavior** to compensate for losing thermoregulation behavior to **psychophysiological behavior**. **Comfort behavior** also allows grafting on of **behavioral control of excretion**, **behavioral control of external secretion**, and **grooming behavior**.

- I have treated **motivation behavior** to some extent as a semantic aid, admitting it might not be sufficiently explanatory, but it allows us to manhandle some other apparent anomalies in the original NBO:

  - The disconnection of **sexual motivation behavior** by simply connecting up **reproductive behavior**; similarly, **sleep motivation behavior** and **sleeping behavior**.

  - I have used it to lower **playing behavior** by one level which still allows it to assume a functional role without suggesting it is as important as the things it simulates.

  - It provides a home for **fear-related behavior** in the absence of **emotional behavior**.

- I imply that spontaneous action involves motivational stimuli.[27] This offers me a new home to **novelty response behavior**. I can also use it to nail back on **locomotor activation behavior**, **voluntary movement behavior**, **spontaneous movement behavior**, **locomotor inactivation behavior**, and **involuntary movement behavior**, all via a new class called **movement motivation**.

- Separating out **feeding behavior** from **food consumption** left a hole where liquids had sloshed. But **thirst motivation behavior** was already separate from **hunger motivation behavior** in the NBO, so I added **rehydration** as one of my few extrapolations in this exercise, both to indicate that water was not about hunger, but to acknowledge that some organisms obtain water from food and not from drinking. (In future, drinking and other approaches to rehydration could be added.)

- I inserted **cannibalism** between **feeding behavior** and **sexual cannibalism** in the expectation that several other forms will be added in due course. It's also worth noting the extensive remapping of **feeding behavior** when I moved it between the worlds of **consumption behavior** and **hunger motivation behavior**.

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25 https://github.com/obo-behavior/behavior-ontology/issues/30
26 "Behaviors designed to maintain current condition or promote internally stimulated shifts between conditions."
27 Incentive Salience Theory

- **Avoidance behavior** now links to a new **collision avoidance behavior** to give a basis to the pre-existing **visually guided collision avoidance behavior**, bearing in mind that sonar (bats) and electromagnetic (fish) systems will eventually be needed.

- The only significant change to **reproductive behavior** is the insertion of **mating position** to better explain **mating amplexus** (and other future forms should stop it appearing to be a redundant link).

Social

Very little has been directly tweaked regarding **social behavior**. But the place of **aggregation behavior** in generating new opportunities is now emphasised:

- The new **emergent behavior** class better explains **shoaling behavior**.

- Alongside **construction** it can explain **habitat engineering**, not least the **microhabitat engineering** (such as termite mounds) which emergent **colonial behavior** enables.

- **Emergent behavior** along with **communication behavior**, **protective behavior** and **specialisation** then leads to **societal behavior**.

- And **societal behavior** in company with **social learning** and **range behavior** can also facilitate **cultural behavior** (limited in animals but more extended in humans probably because of **behavior stemming from communication intelligence**).

Common behaviour model

Acts and functions

In a recent exercise debriefed with Nico, I could neither satisfactorily disaggregate the NBO's existing composites into existing classes, nor consistently repackage classes into existing composites as if they were action-function dyads. Designating intermediate classes as consistent activities or functions becomes almost arbitrary. Hunting behavior is an example which some will argue passionately both ways; even OpenAI's ChatGPT admits to confusion about it.[28]

What I am aware of is that some categories are generally more active and some generally more functional: **reflexive behavior** is at one end, passing through **steering behavior** and then **chase prey** through to **hunger motivation** and beyond to **courtship feeding**, then out the other side to **pair affirmation** and **protection of offspring behavior**.

This suggests to me that the action-function relationship only works effectively in relative terms. In this case, better terms might be 'purpose' or 'reason'. Then a dyadic model will need to look up and down stream for a feature such as trail lengths if done automatically, and perhaps be guided by a person, because there will be relations which are non-purposive. I can see this taking at least four forms:[29]

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28   https://chat.openai.com/share/df522bba-a0e0-4942-aa34-33b6d5a16e9d
29   NB: I am not a biological systems analyst and may actually be inventing a square shaped wheel.

1. non-purposive sub-categorisation such as **jaw movement** (being a choice of **chewing**, **yawning** or **biting**),[30]

2. semi-purposive suites and sequences such as **hunting behavior** (involving **stalk prey** or **flush prey** plus **chase prey**); semi-purposive because it could be argued that the leopard stalks prey for the reason that it is hunting,

3. simple purposive hierarchy (i.e. subclasses) such as **sperm scraping** for the purpose of **sexual interference**, or **sexual interference** for the purpose of **reproductive behavior**,[31]

4. purposive composites offer predigested dyads, usually between fairly well separated concepts for which judgments about purpose are entered in the definition if not the label (NB: it is sometimes difficult to consider that either component is an activity). In figures 2 and 3, I have **coloured original NBO classes brown** if I think they represent a composite and they tend to be targets of at least two sources.[32] For example, **active foraging behavior** would be 'ranging for the purpose of feeding', **eye blink conditioning behavior** would be 'blinking for a conditioned reason', and **threatening predator behavior** would be 'a threat for an antipredatory purpose'.[33]

I increasingly believe that an ontology is most useful as a complex network, not a collection (or bisection) of simple hierarchies.

Phenotypes

I think we have minimal problems now with identifying traits and phenotypes. I have done a lot of work to disaggregate traits[34] and phenotypes[35] and make users of our phenotype branch aware of upcoming changes.[36, 37] What remains is to find the right place and enough administrative time in the new host ontologies for them to go.

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30 Non-purposive because otherwise the source-target direction would artefactually reverse, e.g.: 'the reason it moves its jaw is to chew'

31 This would be less clumsily stated 'for the purpose of reproduction' but this exemplifies how a pattern might be forced to use the existing NBO terminology.

32 Some of the blue nodes could also fit in this category but I left them blue to emphasise their novelty in preference.

33 Not the current NBO definitions.

34 https://github.com/obo-behavior/behavior-ontology/issues/131

35 https://github.com/obo-behavior/behavior-ontology/issues/162

36 https://github.com/obo-behavior/behavior-ontology/issues/159

37 https://github.com/obo-behavior/behavior-ontology/issues/160