Name-calling in the hippocampus (and beyond): coming to terms with neuron types and properties

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Abstract Widely spread naming inconsistencies in neuroscience pose a vexing obstacle to effective communication within and across areas of expertise. This problem is particularly acute when identifying neuron types and their properties. Hippocampome.org is a web-accessible neuroinformatics resource that organizes existing data about essential properties of all known neuron types in the rodent hippocampal formation. Hippocampome.org links evidence supporting the assignment of a property to a type with direct pointers to quotes and figures. Mining this knowledge from peer-reviewed reports reveals the troubling extent of terminological ambiguity and undefined terms. Examples span simple cases of using multiple synonyms and acronyms for the same molecular biomarkers (or other property) to more complex cases of neuronal naming. New publications often use different terms without mapping them to previous terms. As a result, neurons of the same type are assigned disparate names, while neurons of different types are bestowed the same name. Furthermore, non-unique properties are frequently used as names, and several neuron types are not named at all. In order to alleviate this nomenclature confusion regarding hippocampal neuron types and properties, we introduce a new functionality of Hippocampome.org: a fully searchable, curated catalog of human and machine-readable definitions, each linked to the corresponding neuron and property terms. Furthermore, we extend our robust approach to providing each neuron type with an informative name and unique identifier by mapping all encountered synonyms and homonyms.

Keywords Hippocampus · Neuron · Type · Property · Nomenclature

1 Introduction

From its beginning, neuroscience has been tied to ad hoc neuron naming, which is subject to the whims of researchers with diverse interests. It has always been the inclination of neuroscientists to name neurons based on certain observed properties. Already in the 1800s, researchers leveraged ongoing progress in optical microscopy and newly discovered staining techniques to identify neuron types and their morphological features. Historical examples include Betz’ naming of “giant pyramids” [1] and Cajal’s description of “psychic cells” (nowadays known as pyramidal neurons) as characterized by “…a dendritic shaft and tuft directed toward the cerebral surface [and] the existence of collateral spines on the dendritic processes…” [2]. Thousands of reports describing neurons and their characteristics have been published since, and several dozens of distinct types of neurons had already been recognized before the turn of the millennium in each of several prominent neural systems, such as among the “GABAergic non-principal cells” of the hippocampus [3].

The often subjective and arbitrary naming of neurons led to a cluttered literature landscape in which breakdowns in
communication can hinder the understanding of the structure and function of the brain. A comprehensive solution would require establishing a broadly applicable and widely accepted classification scheme defining neuron types based on their properties. However, despite early efforts focused on identifying key neuronal properties with precise terminology [4], to this date there is a high level of disorganization when it comes to reporting neuronal property information. Although community efforts exist for the expert curation of neuroanatomical terms pertaining to brain regions [5] and grass root scholarly collation of neuroscience terminology [6], the continuously increasing pace of data acquisition is paradoxically yielding an ever more fractured lexicon, creating serious impediment to progress.

We have previously proposed an ontological approach to defining neurons based on necessary and sufficient part-relation-value triple-store techniques [7]. In the absence of comprehensive data and unbiased sampling, however, it may be impossible to select a priori the appropriate defining properties [8]. Using too few or too many constraints results in under-defining or over-defining a neuron type. The former case (“over-lumping”) leads to a few large groups of neurons that share very few properties; the latter (“over-splitting”) leads to myriad types of doubtful interpretation. To complicate this matter further, the continuous gradation of key properties may require a shift to fuzzy classification approaches [9].

A recent empirical assessment of inter-investigator agreement on morphological classes of neocortical interneurons demonstrated a variable level of consensus across neuron types and properties [10]. One of the most reliable identifiers of neuron types is the presence or absence of axons and dendrites within well-defined neuroanatomical boundaries. Spotlighting this, Hippocampome.org [11] recently established unambiguous definitions of neuron types primarily based on axonal and dendritic distributions across all the main subregions and layers of the hippocampal formation. This classification approach yielded an initial catalog of 122 neuron types identified from the scientific literature. It is important to stress that the classification criteria employed by Hippocampome.org operate independently of previously used names.

In this framework, a neuron type is initially identified by its (putative) neurotransmitter and the presence of axons and dendrites in the distinct layers of dentate gyrus, CA3, CA2, CA1, subiculum, and entorhinal cortex. Each type is further characterized by available information on biomarker expression and electrophysiological features. This relatively simple characterization allows dense curation of the published literature through text mining and annotation. The resulting information is instantiated as a machine-readable electronic relational knowledge base that is publicly and freely available, facilitating web accessibility and computational analytics. With critical properties compiled in an easily accessible portal, Hippocampome.org provides a unique opportunity to establish a consistent set of definitions and a naming protocol that could be expanded to other cortical areas, aiding research and scientific communication.

The remaining of this report is organized as the following. The next section provides illustrative examples of the terminological confusion regarding neuron types and properties from the hippocampal literature. The following section outlines the three steps toward a solution: first, we describe the design of a database to define, store, browse, search, and retrieve human-interpretable but machine-readable definitions of neuron types based on their properties, as recently implemented at Hippocampome.org. Second, we introduce a newly deployed functionality that maps all relevant property terms to corresponding concepts, linking their occurrence in the published evidence to community-accepted definitions. Third, we offer a formal definition of the resulting neuron types and detail the process to assign each of them with a unique common name. The last section closes the paper with concluding remarks.

2 A neuronal “Tower of Babel”

The nomenclatures of neuron types and of their features are both vexed with ambiguities, resulting in a “many-to-many” mapping between neurons and names as well as inconsistent definitions of properties. We illustrate below representative examples of the most common scenarios from the hippocampal literature.

When neurons are described in a publication, they are typically named in isolation, out of context with respect to the rest of the brain circuit and the literature. Sometimes neuron types or individual neurons are indicated solely by a non-descriptive label (e.g., “Type I” cells [12] or “cell #7” [13], and occasionally they are not named at all. When proper terms are used, it may still be difficult to discern whether a word is meant to be a name or merely a description, as when referring to “multipolar cells” [12, 14]. The result is often a baffling web of associations between names and neuron types.

Consider for instance the term “CA1 Bistratified cell” originally chosen over 20 years ago to name a group of hippocampal neurons with axons and dendrites prominently invading the oriens and radiatum layers without crossing into lacunosum-moleculare [15]. Different authors later used the exact same noun referring to the morphological pattern of a different neuron type with axons.
distributed in the CA1 oriens and radiatum layers (though also extending into the subiculum), but dendrites limited to oriens [16]. Unfortunately, neurons with these distinct characteristics had already been bestowed the different name of “CA1 trilaminar cells” in an earlier article [17]. Nevertheless, the label “CA1 trilaminar cell” was also used to describe yet another neuron type that had a similar axonal distribution, but dendrites invading lacunosum-moleculare [16]. But the confusion does not end here, as other labs independently referred to this latter morphology as either “CA1 Schaffer-associated” [18] or “CA1 apical dendrite innervating” [19].

We should note that these are not exceptional instances, but absolutely frequent occurrences, as depicted by several additional examples in Fig. 1 [20–29]. There are also multiple cases of the same referencing article calling a morphologically defined type by different synonyms, such as “perforant path-associated” and “CA1 R-LM” referring to neurons with axons and dendrites in CA1 stratum lacunosum-moleculare and dendrites in radiatum [18] (Fig. 2a). At the same time, these are not sterile spelling quibbles, because the specific laminar pattern of dendrites and axons defines the potential connectivity of the circuit and therefore the computational functions of neurons.

The confusion is not limited to neuron types but also affects the nomenclature of neuronal features, including morphological, electrophysiological, and molecular terminology. Qualitative phraseology is especially common in reporting morphological properties. An examination of the evidence collated in Hippocampome.org pertaining to the relative abundance of axons in an anatomical location of interest reveals ample use of terms such as “most,” “majority,” and “usually.” Furthermore, categorical terms are often employed to indicate continuous spatial distributions, as in “superficial/deep layer X,” “proximal/distal area Y,” and “septal/temporal region Z.” A clear consensus of how such terms should be adopted and interpreted, and what terms are to be avoided, reduces ambiguity. Hippocampome.org proposes a set of protocols for the description of neurites and their locations (hippocampome.org/full-interp).

The electrophysiological lexicon suffers not only from ambiguous descriptors but also from inconsistent definitions of the parameters themselves. For example, some investigators measure action potential amplitude from the resting membrane potential to the peak of the spike [30]. A complementary subset of studies, however, calculates action potential amplitude relative to the spike threshold

![Figure 1](https://example.com/figure1.png)

**Fig. 1** Relationships between cited names [3, 15–29] and neuron types. This bipartite graph highlights the naming confusion that is typical within the neuroscience community today.
potential [31]. The relationship between the minimum and the steady-state membrane potentials resulting from a hyperpolarizing current is similarly ambiguous. The sag ratio quantifies the relative difference between the peak hyperpolarization and steady-state hyperpolarization [32]. Alternatively, the sag percentage reports the fractional change in membrane potential from peak to steady state relative to the steady state [33]. Figure 2b schematically shows the differences between these parameter definitions. Plainly, the use of identical or similar names for terms with different electrophysiological meanings can lead to the propagation of confusion and, worse, incorrect interpretations of data that are incorporated into the literature moving forward.

Molecular biomarkers bear an overabundance of synonyms, homonyms, hyponyms, hypernyms, and abbreviations. There is movement toward standardizing the naming of proteins, but it is debatable whether the efforts are alleviating or augmenting confusion. For instance, the entire family of mammalian neuronal transporters has been given the official name of “solute carrier family [X] member [Y].” The new names confer that the proteins are transporters, but provide little information beyond that. As an example, some authors now refer to vesicular glutamate transporter 2 (Gene ID: 84487, ncbi.nlm.nih.gov/protein/NP_445879.1) by the abbreviation Slc17a6, short for the official full name “solute carrier family 17, member 6,” while others keep the familiar vGluT2. If these two alternatives were not enough, the marker is also known by the symbols Dnpi and Vgl [34–37] (Fig. 2c).

One of the worst cases of molecular biomarker terminology confusion in neuroscience involves glutamate receptors. Metabotropic glutamate receptors (mGluRs) are not to be confused with three classes of ionotropic receptors (GlurRs): AMPA, kainate, and NMDA, sometimes referred to as AMPARs, KAs, and the NRs [38]. In the promising new naming schema for glutamate receptors, metabotropic receptors retain use of mGluR, while AMPA receptors use GluA, kainate GluK, and NMDA GluN [39]. It is yet to be seen how widely used either of these schemata will be. Alas, even if the entire research community compactly embraced them today, the problem of linking new information with previous publications would remain.

3 Resolving the neuron-type crossword puzzle

The solution to both the naming dilemma and property-based neuronal classification lies in establishing and consistently applying an unambiguous, clearly defined, unique nomenclature with links to antecedent synonyms. With property terms, scholarly resources can serve as broadly accepted references and dictionaries, such as the Medical Subject Headings (MeSH) by the US National Library of
Medicine [40] and NeuroLex by the National Institutes of Health-contracted Neuroscience Information Framework [41]. However, using such services requires turning attention away from the material with the confusing or unknown term, navigating external web site(s), finding and processing the definition(s), then refocusing attention to the original material. A terms portal integrated into the original material would greatly simplify the process.

3.1 Data schema for property-based classification of hippocampal neurons

To solve the neuronal naming problem, the neuroscience community would ideally adopt a robust approach to classification. Using the distributions of axons and dendrites across identifiable anatomical areas is advantageous for a number of reasons. Axonal and dendritic patterning is fundamental to all neurons, yet sufficiently information-rich to allow grouping at a useful level of abstraction on the spectrum from considering all neurons the same (as would be the case if spike integrator were the chosen property) and each individual neuron unique (as would result if using exact matches of the neurite arbors). In addition, neurite patterns are more stable and less dependent upon experimental conditions than molecular markers and electrophysiology, respectively. Lastly, as demonstrated below, this approach naturally provides the means of creating unique, concise, informative names of neuron types.

We designed an open-source online system enabling machine-readable information accessibility. Knowledge about each Hippocampome.org neuron type, including the names, synonyms, properties, and evidence, is stored in a relational database sourcing a user-friendly web-accessible interface. Figure 3 depicts the conceptual organization of the database based on three general categories: neuron types, neuron properties, and published evidence. Links between data and relations are captured in separate relation tables, to both increase flexibility and reduce complexity, thereby facilitating continuous development and long-term maintainability.

Converting information published for human consumption into machine-readable form dictates system level decisions to minimize the energy cost of processing. We chose a three-step workflow. The first step is for researchers (doctoral students, postdocs, and faculty) to identify and study relevant articles, gleaning salient information and encoding it into spreadsheets. The second step involves python code to ingest these spreadsheets into data tables, populating along the way relation tables. The third step consists of rendering the resulting structured data in web pages dynamically leveraging the database. Performing the most time consuming tasks up front (steps one and two) allows for fast web-based lookup access by the end-user community. The data/relation table design adds a layer of complexity to the database, but simplifies the resultant query implementation complexity, considerably speeding up real-time interactive retrieval.

3.2 Neuron term machine-readable definition identifier

In order to facilitate the collation of machine-readable definitions of relevant terms, we designed and implemented a novel functionality of Hippocampome.org for online assistance in disambiguating neuron property nomenclature (Fig. 4). This new resource (Hippocampome.org) integrates key neuron term descriptors into a curated catalog of web-accessible human- and machine-readable definitions. Users can browse, search, and filter terms from drop-down menus augmented with autocomplete-as-you-type function. After selecting one or more terms, the portal returns the mapped concept with mouse/cursor-layover display of all available synonyms and the context in which they appear, along with a list of available definitions and direct hyperlinks to the corresponding source providers. Users can also search for specific keywords of interest within the definitions. Furthermore, when browsing Hippocampome.org and all cited evidence within, terms with available definitions are now highlighted: users can display a definition...
The first challenge in deploying this novel functionality was to identify the set of terms requiring machine-readable definitions. This research leveraged two primary sources of terms: Petilla [4] and the article excerpts cited as evidence in Hippocampome.org [11]. The Neuron Registry [7] constituted a third minor source of terms. The Petilla terminology consists of a finite list of (~232) published terms. Hippocampome.org, in contrast, contributes a less neatly bounded set of terms exceeding 10 K discrete tokens (as estimated by the wordle.net utility, Fig. 5). To parse these tokens into a manageable set, we filtered the Hippocampome.org terms at each extreme of the occurrence count spectrum. This preprocessing step eliminated words with very large (>1000) occurrence counts, including uninformative strings such as “a,” “the,” and “of,” as well as words with very small (<100) occurrence counts, representing rare and typically uninteresting terms like “outside-out” and “sheetlike.” Lastly we hand-curated the remaining set of approximately 700 terms to remove non-scientifically relevant words yielding a final corpus of 490 evidence-derived terms. An additional 782 terms corresponded to neuron names, anatomical regions, biomarkers, and electrophysiological parameters stored in Hippocampome.org. In all, due to minor overlaps among the above lists, this collation accounted for 1478 distinct terms.

To find machine-readable definitions we devised a preferred portal/repository approach. For general neurobiological terms, we first searched Neurolex.org, MeSH browser (nlm.nih.gov/mesh), the Bioportal services from the National Center for Biomedical Ontology [42], and the US Public Health Service CRISP database [43]. The terms from Hippocampome.org evidence primarily refer to the rodent hippocampus, thus it is essential that the extracted definition be relevant to these target domains. Since the same word can have different meanings, most definitions retrieved by the initial automated search were largely out of context, requiring a slow step of manual curation. We preferentially assigned evidence terms from Hippocampome.org definitions and links most relevant to the rodent hippocampal formation. Similarly, we linked the Petilla terms to definitions in the context of GABAergic interneurons of the cerebral cortex.

For protein definitions, we harnessed the Ontology Look-up Service [44] of the Gene Ontology Consortium [45] as the sole reference given the depth and breadth of coverage for this type of molecular data. Because the molecular terms are generally regular and systematically databased, we successfully automated API-based pulling from established sources (e.g., the National Center for Biotechnology Information). For term not found in these primary resources, we reverted to Google searches, prioritizing definitions from scholarly or institutional sources such as the Allen Brain Atlas [46], Scholarpedia.org, and the US National Institute of Standards and Technology (nist.gov). For residual blanks, we resorted to dictionaries like Merriam-Webster or Wikipedia.

The last step of manual curation involved concept mapping to group together distinct terms linking to textually different but logically analogous definitions. For
example, “action potential” and “spike” are synonyms for which multiple machine-readable definitions exist. This mapping yielded 810 distinct concepts from the 1478 unique terms, with a total of 924 unique definitions from 1378 distinct resource links. Table 1 summarizes the neuron term counts, including number per category (i.e., morphological, molecular, and electrophysiological) and unique instances. Table 2 organizes this information by resources providing the machine-readable external links to the term definitions.

3.3 Neuron type naming

The classification schema introduced by Hippocampome.org [11] defines neuron types based on their properties, starting from morphological patterns and with the added specification of molecular and electrophysiological features. For example, Hippocampome.org defines dentate gyrus granule cells as excitatory neurons with axons in the hilus, CA3 lucidum/pyramidale, and CA2 pyramidale, dendrites in the inner and outer molecular layer, and soma in the granular layer. These definitions are now available as an explicit list (hippocampome.org/neuron-types) and linked from the term definition portal described above.

It is difficult to quantify how many unique neuron types have been defined to date in the hippocampal formation due to ambiguity and overlap of descriptors across research labs. We constrain the number of Hippocampome.org neuron types (e.g., 122 in the initial release) by limiting the primary characterization properties to axonal/dendritic patterns and excitatory/inhibitory neurotransmitters.

Furthermore, Hippocampome.org neuron types are assigned both a formal name and a unique number identifier (e.g., DG (e) 2201p-CA3_00110 Granule; type 1000). The formal name contains several components (hippocampome.org/formal-name): (a) the abbreviation of the subregion where the soma is located, (b) a symbol specifying the putative major neurotransmitter (i.e., “e” for glutamatergic, excitatory neurons or “i” for GABAergic, inhibitory neurons), and (c) a numeric encoding for the presence or absence of neurites within the subregion of soma location. In neuron types whose axons extend outside of their home subregion, the numerical encoding continues with a “p” (for projecting) followed by codes analogous to (a) and (c) to specify the subregions receiving the projection. Finally, the formal name ends with a unique, human-friendly label that attempts to maximize usability and understanding of neuron types within the research community. Figure 6 illustrates the selection process for determining this “common name.”

In the most clear-cut cases, a single name dominates the literature as universally recognized and understood. In such “canonical” cases, we adopt these standard names, as in Granule, Mossy, CA3 basket, and CA1 pyramidal cells. In other situations, a neuron type may not be as broadly known, but is only cited in a single way. In these cases, we straightforwardly adopt the single cited name, such as in Semilunar Granule, CA3 Giant, and CA3 Granule cells. The remaining cases represent the confusing scenarios in which the literature describes the same neuron types with multiple names and different neuron types with the same name.

If one name or acronym is clearly dominant, with more frequent citations than all other names, we adopt it as the common name, as in the cases of HIPP, MOPP, HICAP, and MOLAX interneurons. Other neuron types, however, have multiple, approximately equally cited names, especially in the less-studied entorhinal cortex. In these cases, to avoid playing favorites, we hybridize the cited names, as is LI-II Multipolar-Pyramidal, LI-II Pyramidal-Fan, and MEC LII-III Pyramidal-Multiform. Lastly, there are neuron types for which all cited names entail potential confusion with similar or identical names already assigned to other neuron types based upon the rules above. In these scenarios, we are forced to either modify a cited name in order to differentiate it (e.g., Mossy MOLDEN, DG Basket CCK+, and CA3c Pyramidal) or to create a new name altogether (e.g., AIPRIM, HIPROM, MOCA, CA3 SO–SO). We try to use this final clause sparingly (only 4 names out of 122 in Hippocampome.org are entirely new), but minor modifications of pre-existing names are often unavoidable (46 out of 122).

4 Discussion

The basis of communication is language. Unfortunately, the language of neuroscience is lacking a common terminology with respect to neuron types and their associated discriminating properties. Paraphrasing Shakespeare: “What’s in a name? That which we call a [neuron] by any other name would [fire] as [frequently].” By first establishing neuron types based on their necessary and sufficient common characteristics, and then methodically applying a naming protocol, it is possible to establish a basis for systematic neuron naming. This work differs from prior efforts in the level of comprehensiveness. There have not been any all-inclusive compilations of neuron types within the entire rodent hippocampal formation based on peer-reviewed published literature for the past two decades [3]. Scientific laboratories most often work independently, and researchers performing experiments typically name neurons for their convenience. Hippocampome.org dynamically integrates these data across all known experimental evidence.
### Table 1: Neuron term summary and examples

| Category          | Term source     | Summary                  | Examples                                                                 |
|-------------------|-----------------|--------------------------|--------------------------------------------------------------------------|
| Neuron type       | Hippocampome.org | 641 122 1 122            | CA1 ivy interneuron                                                      |
|                   | http://hippocampome.org/formal-typedefs | Inhibitory neuron with axons in [CA1:SR CA1:SP CA1:SO], dendrites in [CA1:SR CA1:SP CA1:SO], and soma in [CA1:SR or CA1:SP or CA1:SO]; PV- SOM-nNOS+ |
| Morphology        | Petilla         | 38 41 75 64              | Soma - Shape -Triangular                                                |
|                   | http://neurolex.org/wiki/Category:Pyramidal | Generally triangular-shaped soma with a dendrite emerging from the apical pole and basal dendrites emerging from two or more basal poles |
| Hippocampome.org  | 34 34 32 33     | CA1:SP  CA1:SP           | Field CA1, pyramidal layer                                              |
| Molecular marker  | Petilla         | 175 176 752 183          | Transcription factor - Nkx2.1                                           |
|                   | http://www.ncbi.nlm.nih.gov/gene/25628 | Transcription factor that binds and activates the promoter of thyroid specific genes such as thyroglobulin, thyroperoxidase, and thyrotropin receptor; may play a role in organogenesis and/or reproductive maturation and development [RGD, Feb 2006] |
| Hippocampome.org  | 97 95 95 95     | PV  Parvalbumin           | http://nakama.berkeleybop.org/amigo/gene_product/MGI:MGJ:97821          |
|                   | parvalbumin; Symbol:Pvalb; Type:protein; Taxon:Mus musculus; Synonyms: Parv, PV, Pva | Nerve action potential amplitude |
| Electrophysiology | Petilla         | 19 20 36 28              | Spike amplitude                                                         |
|                   | http://bipoportal.bioontology.org/ontologies/42295?=terms&conceptId=X77KG | Average amplitude of the first AP (measured from AP threshold to AP peak) |
| Hippocampome.org  | 10 10 8 14      | APampl  APampl            | http://neurolex.org/wiki/Category:Spike_Amplitude                       |
| Evidence & notes  | Hippocampome.org| 490 429 434 436          | Gap junction Electrical synapse                                         |
|                   | http://www.nlm.nih.gov/cgi/mesh/2011/MB_cgi?mode= &term= Electrical+Synapses&field= entry | Specialized junctions between neurons which connect the cytoplasm of one neuron to another allowing direct passage of an ion current |
| Sum               | 1504 1049 1434 1097 |                                           |
| Distinct          | 1478 810 1378 924 |                                           |
We have striven to find human-friendly names that are recognizable to, at the least, those who are familiar with hippocampal neurons. In many cases, however, these names have minimal informational content to those unfamiliar with the type. The part of the formal name that is most informative is the numeric encoding of the neurite pattern (detailed description: hippocampome.org/find-term). Knowledge of the pattern of dendrites and axons confers information about potential connectivity of the neuron type within the circuit. Therefore, incorporation of this pattern into the name allows instantaneous envisioning of the location of the neurites and by extension the connectivity of the type. In addition, this numeric encoding is unique for most neuron types with only subtypes discriminated by their primary neurotransmitter, post-synaptic target specificity, or molecular marker and/or electrophysiology profiles having the same pattern. In these cases, the human-friendly part of the name provides uniqueness (e.g., “CA1 2232 Basket” and “CA1 2232 Basket CCK+”). This method of naming neurons results in extremely informative, concise names without necessitating the memorization of many acronyms. Furthermore, it is applicable to any brain region that is divisible into parcels.

Going beyond Hippocampome.org, the same approach to defining neuron types can be extended outside the hippocampal formation. For example, CA1 neurons that project to other brain regions such as the lateral septum, medial septum, and/or hypothalamus can be characterized by extending the axonal/dendritic patterns to encompass those regions.

Nomenclature confusion could be mitigated with increased awareness of the neurons, molecules, and properties and how they fit in the historical context. This is a lot to ask of researchers, but resources like Hippocampome.org provide significant assistance. Hippocampome.org demonstrates that the necessary and sufficient discriminating property of neurite patterning is a workable and advantageous foundation upon which to build a neuron type library. Enhancing such a library with a terms definition portal further reduces terminology confusion. Coupled, these resources begin clarifying the muddied state of the literature and re-illuminating the path to neuroscience progress.

| Table 2 Term resource summary | Rank | Resource | Terms | Concepts | Definitions |
|-------------------------------|------|----------|-------|----------|-------------|
| 1                             |      | BIOPORTAL | 53    | 53       | 32          |
|                               |      | CRISP    | 33    | 33       | 30          |
|                               |      | Gene ontology | 119 | 100      | 105         |
|                               |      | Hippocampome.org | 649 | 130      | 130         |
|                               |      | MeSH     | 176   | 168      | 111         |
|                               |      | NCBI gene | 112   | 111      | 6           |
|                               |      | NCBI protein | 103  | 102      | 7           |
|                               |      | Neurolex | 429   | 354      | 311         |
|                               |      | Protein ontology | 121 | 120      | 6           |
|                               |      | Allen Brain Atlas | 35  | 35       | 33          |
|                               |      | ChEBI    | 1     | 1        | 1           |
|                               |      | MBF bioscience | 1   | 1        | 1           |
|                               |      | Medical College of Wisconsin | 1 | 1       | 1           |
|                               |      | Merriam-Webster medical | 69 | 68       | 68          |
|                               |      | NeuroElectro | 1   | 1        | 1           |
|                               |      | NIST InChI trust | 1  | 1        | 1           |
|                               |      | Scholarpedia | 6   | 6        | 6           |
|                               |      | UTHHealth neuroscience | 1  | 1        | 1           |
|                               |      | Wolfram mathworld | 4  | 3        | 3           |
| 3                             |      | Cambridge dictionaries | 1  | 1        | 1           |
|                               |      | Macmillan dictionary | 1  | 1        | 1           |
|                               |      | Merriam-Webster dictionary | 39 | 38       | 38          |
|                               |      | Oxford dictionaries | 2   | 2        | 2           |
|                               |      | TheFree dictionary | 22  | 20       | 20          |
|                               |      | Wikipedia | 16   | 16       | 14          |
|                               |      | Wiktionary | 5   | 5        | 5           |
|                               |      | Sum      | 2001  | 1372     | 935         |
|                               |      | Distinct | 1478  | 810      | 924         |
Fig. 6  Decision logic for assigning common names to Hippocampome.org neuron types

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