Charting the structure of neuroscience

Matteo Carandini

University College London

SUMMARY

What are neuroscientists actually interested in? To find out, I studied their itineraries at the annual meeting of the Society for Neuroscience. I used them to build a chart where topics that were commonly in the same itineraries form clusters. The empty spaces between these clusters might constitute opportunities for future efforts.

When the Society for Neuroscience was conceived in 1969, there was debate as to whether "Neuroscience" should be singular or plural. Singular was ultimately preferred, to summon a new "single, unified field" (Society for Neuroscience, 2018). The Society fostered interactions in this field through its annual meetings. The first was small and could be arranged in a single track (Fields, 2018), but subsequent ones grew vastly in size and scope. The last meeting, in 2018, featured 13,747 presentations on a broad range of topics.

How unified is neuroscience today, and what is its structure in terms of topics of study? Does it contain distinct clusters of interests? Seeking answers to these questions, I analyzed the itineraries made by attendees of the 2018 meeting, where 8,329 neuroscientists used the online tools offered by the Society to select presentations. Each presentation is in turn associated with one or two "Topics" selected by the authors among 499 options. The itineraries can thus reveal the proximity of these 499 Topics to each other: Topics are close if they frequently appear in the same itineraries, and distant if they rarely do so.

To perform this analysis and chart the structure of neuroscience, I used methods that are common in genomics. Starting from anonymized itineraries, I constructed a matrix of 499 Topics vs. 8,329 itineraries, where each entry counts how many presentations with a given Topic appear in a given itinerary. I then obtained a 2-dimensional chart by using t-SNE (van der Maaten and Hinton, 2008; Wattenberg et al., 2016). A similar approach is common in genomics, for matrices that quantify the expression of genes in cells (Amir el et al., 2013). Though capturing all the structure would generally require more dimensions, t-SNE does its best to maintain proximity: if two Topics commonly occurred in the same itineraries, t-SNE places them close to each other in the chart. Absolute position, however, will be arbitrary: Topics placed at the bottom are no less important than those at the top.

In the resulting chart, each dot is a Topic, and many Topics are so close to each other that they form clusters (Figure 1). For instance, on the far left is a cluster of Topics on Parkinson's disease and another on Alzheimer's disease and Tauopathies. At the far right is a cluster on hippocampus and another on human long-term memory. At the bottom is a cluster on Drugs of Abuse and Addiction. At top left is one on Pain and Somatosensation. At the opposite end, bottom right, are topics in Vision, with a large cluster on Visual Cortex.

The colors in the chart indicate the Themes used by the Society for Neuroscience, and these often but not always reflect the actual proximity of the Topics. Examples of cohesive Themes are Theme A, *Development* (yellow) and Theme H, *Cognition* (gray). Other Themes, instead, are dispersed across the chart. For instance, consider Theme D, *Sensory Systems* (light blue). Some of its Topics appear on the top left (Pain, Somatosensation, and Touch). Some others appear below the center (Plasticity and Reorganization, Somatosensory Thalamus and Cortex, Olfaction and Taste). Many others appear in the bottom right (Audition, Vision). A lone Topic on Visual Decisions lies among Topics in Theme H, *Cognition*. One on Visually Guided Reaching lies amidst Theme E, *Motor Systems*. Themes whose Topics are so widely dispersed might perhaps benefit from reorganization.

Not far from the center of the chart one finds psychiatric conditions such as depression, bipolar disorder, anxiety (dark blue) or schizophrenia (gray). Perhaps appropriately, these clusters lie right below a cluster on Stress (green), and are flanked by Topics in Theme A, *Development* (yellow) and in Theme H, *Cognition* (gray). If descriptions of these diseases eventually turn to the level of circuits and systems, we may see these islands move closer to Topics such as Network Interactions (purple).

It is perhaps surprising that Alzheimer's Diseases and Tauopathies (teal, on the far left) lie far from most of Human Cognition (gray, on the far right). The only exception are two Topics on cognitive aging (gray), which appear in the left of the chart. Similarly, the Topics in Drugs of Abuse and Addiction (bottom, dark blue) are cohesive but are far from both Pain (at the top) and Basal Ganglia (center-right, in red). Basal Ganglia, in turn, lies next to Reward and Dopamine (dark blue), but far from other motor systems (bottom right, in red) and from related diseases such a Parkinson's and Huntington's (far left).

These are all examples of Topics that might appear related but were in fact distant. In principle, this distance could be simply due to the difficulty of plotting in 2 dimensions what may be a higher dimensional structure, and to the fact that t-SNE favors local relationships at the expense of global structure. However, an alternative analysis that respects long distance structure, Multidimensional Scaling, gave similar results (not shown). Therefore these distances are likely to reflect realities: those who are interested in Tauopathies rarely selected presentations on Human Cognition, and those who study Basal Ganglia rarely attended presentations on Addiction or Parkinson's.

Conversely, there are interesting areas of aggregation, where Topics from different Themes cluster together. For instance, the aforementioned Topics on Basal Ganglia (in red) appear firmly in the center-right, near Motivation and Reward (blue). Another an area of aggregation could be termed "Social Neuroscience" (top right), and includes Topics such as vocal/social communication (green), social behavior (blue), social cognition (gray), and oral movement and speech (red).

Also of interest are the white, empty spaces between clusters, as these represent opportunities for relating Topics that are currently disconnected. For instance, recent work from the author's laboratory focuses on the relationship between vision and navigation (Saleem et al., 2018). If there were a Topic for this subject, it would presumably lie on the right of the chart, in the empty sea between vision (light blue) and hippocampus (gray). As more research is performed on how navigation uses vision and how vision is influenced by navigation, these distinct clusters might approach each other, or new Topics might appear between them.

This chart shows a glimpse of what could be accomplished with further analyses of these data. The anonymized data that I used are publicly available, and so is the code that I wrote to analyze them (Carandini, 2019). Colleagues who are more expert in data science will undoubtedly be able to analyze these data in better ways.

Moreover, the structure that appears in the chart (Figure 1) reflects choices made by three actors: not only the attendees, but also the authors and the Society for Neuroscience. The attendees selected presentations, the authors that selected one or two Topics for their presentations, and the Society selected the 499 Topics that authors could choose from, and arranged them in Themes which might in turn influence both attendees and authors. Further analyses could be more independent of the last two factors, for instance by focusing on the text of the abstracts. Such a textual analysis would be beyond this author's capabilities but is becoming routine in multiple fields, including neuroimaging (Alhazmi et al., 2018).

These analyses might also reveal more meaningful ways to parcellate the field. Many of the Topics currently in the chart involve some anatomical concept (i.e. a subcellular structure or a brain region), some process (e.g. a disease or a brain function), or a combination of the two. This organization echoes the division in chapters of a classical textbook (e.g. Kandel et al., 2012), and may become surpassed as research increasingly reveals the interactions of multiple anatomical substrates in multiple processes.

Despite its imperfections, a chart of Neuroscience can still be useful: both to understand our field's current structure and to help shape its future structure. For instance, institutions such as universities, funding agencies, and journals may want to use a chart to ensure appropriate coverage (if they are going for coverage) or the appropriate focus (if they are going for focus). They might also want to foster interactions between Topics that are currently distant, but show promise to coalesce into new areas of inquiry and discovery. The Society for Neuroscience itself may want to use a chart to ensure its committees cover the field appropriately. Students may use a chart for much the same reasons: to see where their research lies and where it could go. Their research will surely make the present map obsolete.

Acknowledgements

Many thanks to Kyle Hayden and to the Society for Neuroscience for releasing anonymized data about the 2018 itineraries and allowing them to be publicly shared. The author holds the GlaxoSmithKline/Fight for Sight Chair in Visual Neuroscience.

References

Alhazmi, F.H., Beaton, D., and Abdi, H. (2018). Semantically defined subdomains of functional neuroimaging literature and their corresponding brain regions. Human brain mapping *39*, 2764-2776.

Amir el, A.D., Davis, K.L., Tadmor, M.D., Simonds, E.F., Levine, J.H., Bendall, S.C., Shenfeld, D.K., Krishnaswamy, S., Nolan, G.P., and Pe'er, D. (2013). viSNE enables visualization of high dimensional single-cell data and reveals phenotypic heterogeneity of leukemia. Nature biotechnology *31*, 545-552.

Carandini, M. (2019). Charting the Structure of Neuroscience. Figshare https://doi.org/10.6084/m9.figshare.8061401.v1

Fields, R.D. (2018). The First Annual Meeting of the Society for Neuroscience, 1971: Reflections Approaching the 50th Anniversary of the Society's Formation. J Neurosci *38*, 9311-9317.

Kandel, E.R., Schwartz, J.H., Jessell, T.M., Siegelbaum, S., and Hudspeth, A.J., eds. (2012). Principles of Neural Science, 5 edn (New York: McGraw-Hill).

Saleem, A.B., Diamanti, E.M., Fournier, J., Harris, K.D., and Carandini, M. (2018). Coherent encoding of subjective spatial position in visual cortex and hippocampus. Nature *562*, 124-127.

Society for Neuroscience (2018). Chapter II: Establishing the Society for Neuroscience, 1968-1970. In History of SfN. https://www.sfn.org/About/History-of-SfN/1969-1995/Chapter-2

van der Maaten, L., and Hinton, G. (2008). Visualizing data using t-SNE. Journal of machine learning research *9*, 2579-2605.

Wattenberg, M., Viégas, F., and Johnson, I. (2016). How to Use t-SNE Effectively. Distill https://doi.org/10.23915/distill.00002

Figure

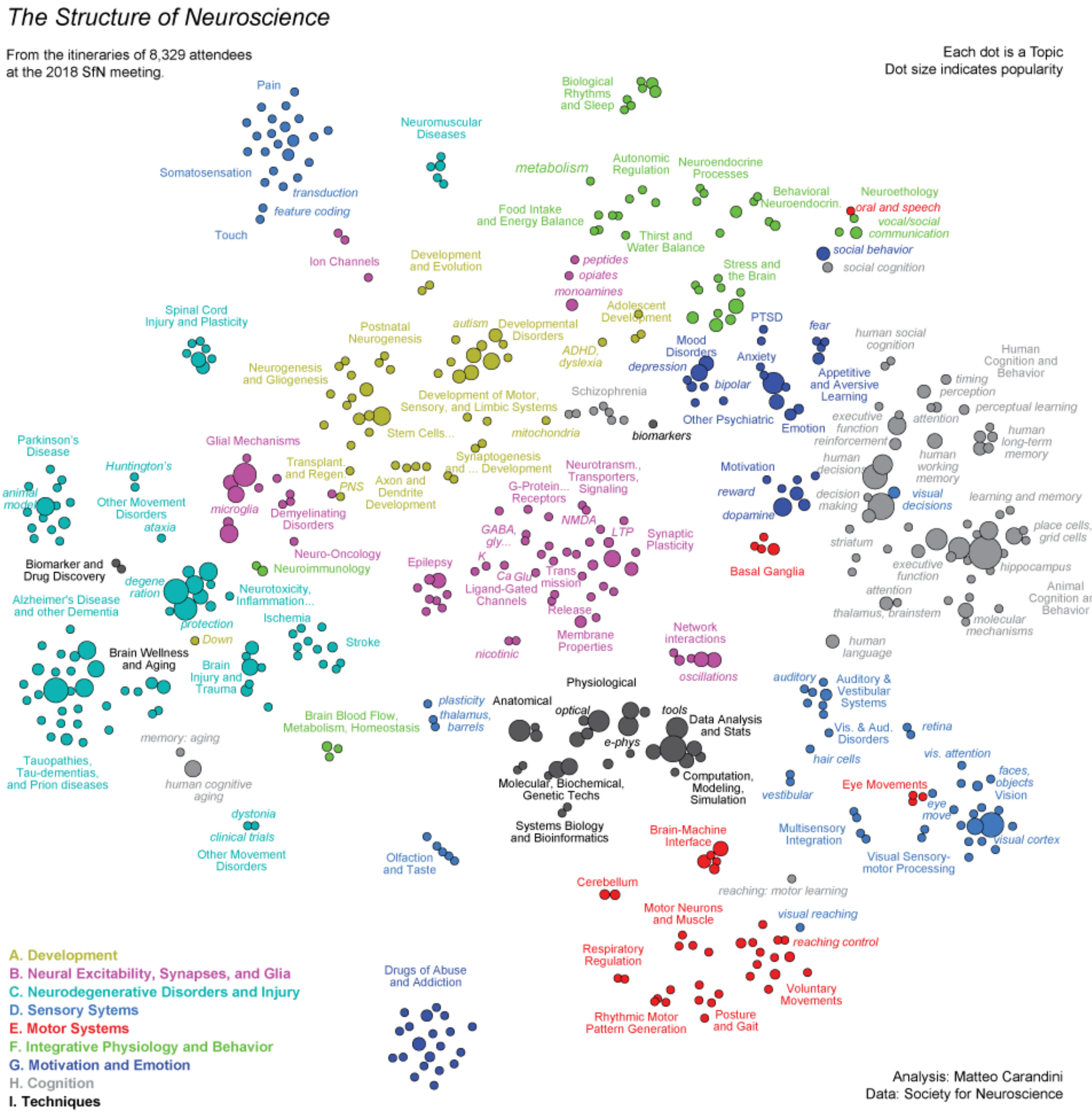

Figure 1. Charting the structure of the itineraries. Two-dimensional chart of the space of Topics, obtained using t-SNE. Each dot represents one of the 499 Topics. Dot color indicates the Theme, and dot size scales with its popularity in the itineraries. Clusters are labeled with the corresponding Themes. Whenever possible, islands are labeled with the name of a Subtheme (collections of Topics). In some places, this was not possible, because nearby Topics belonged to disparate Subthemes or even Themes. In those cases, Topics are identified by brief labels (italics). Modified from (Carandini, 2019).