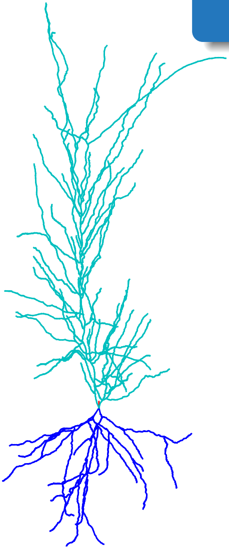
Data-oriented Neuron Classification from Their Parts



Evelyn Perez Cervantes[1]
Cesar Henrique Comin[2]
Roberto Marcondes Cesar Junior[1]
Luciano da Fontoura Costa[2]

[1] Institute of Mathematics and Statistics, University of São Paulo
[2] São Carlos Institute of Physics, University of São Paulo, São Carlos

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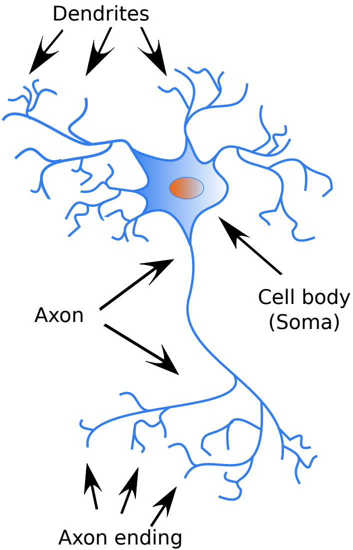
Outline

- It has been addressed from the beginning of neuroscience (Santiago Ramón y Cajal 1955).
- A systematic census of neuronal cell types can provide subsidies for better understanding the brain.
- It can help understanding the relationship between shape and functionality.
- It can help study of the cellular organization (Cytoarchitecture).
- It can help with diagnosis of neurological disorders.

- Nervous system is made up of individual cells (Santiago Ramón y Cajal 1955).
- Neuroinformatics are important for the integration and analysis. Successes and rewards in sharing (Ascoli 2007)
- Some recent approaches consider the neural arbor branch density (Teeter t al. 2011)
- A method based on the relative position of the dendritic arbor (Sümbül et al. 2013)
- Encoding of axonal and dendritic arbors into sequences of characters representing bifurcations (Gillette et al. 2015).

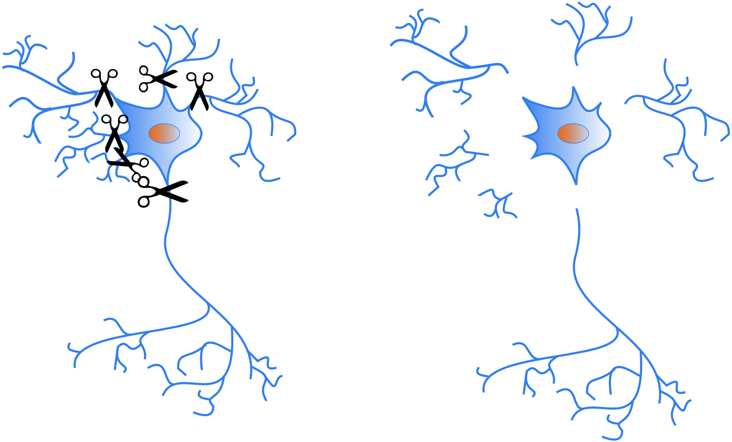
Whole cell

- A standard neuron has the cell body also called soma, the axon and the dendrites.
- Commonly, a neuron is characterized by its morphology, physiology and biochemistry.
- Current consideration of the neuronal morphology typically takes into account whole cells.



Introduction

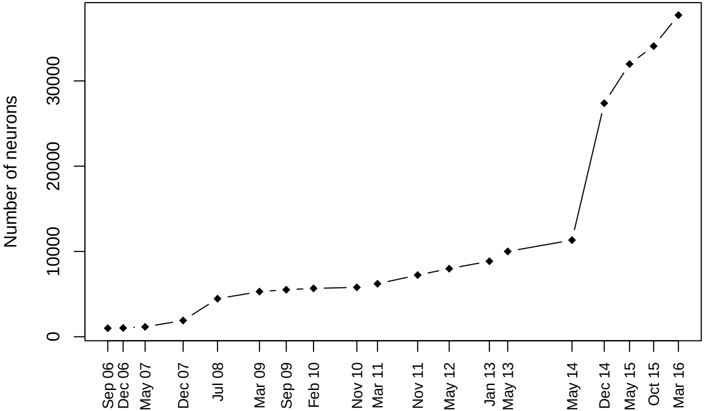
Proposal



It may reveal interesting insights, including whether parts of the neuronal dendritic arborization preserve proper information about the morphology of the whole neuron.

Dataset

NeuroMorpho.org

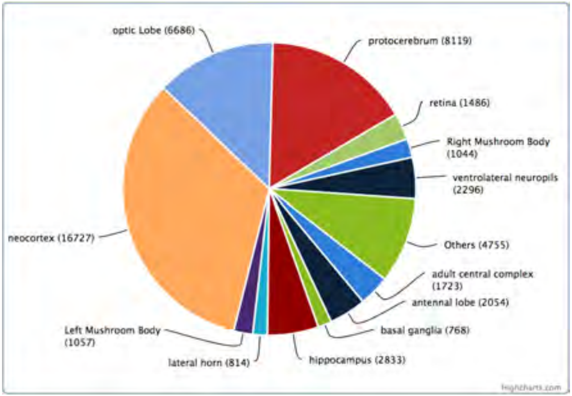


The first release of Neuromorpho was in 2006, with 1000 neuron reconstructions, and this dataset has been growing steadily, its current version contains 37712 neurons.

Dataset

NeuroMorpho.org

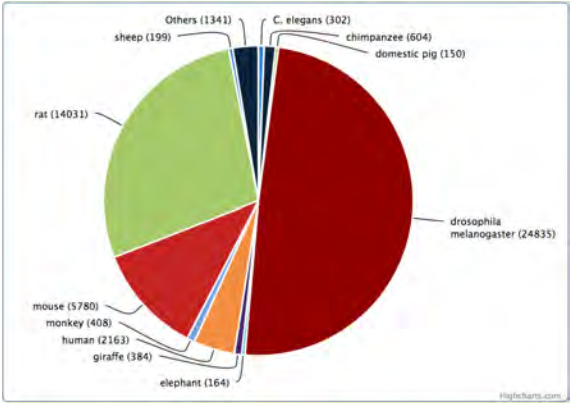
The database contains data from different types of neurons, electrophysiology, laboratories, species, among other properties.



Source: *neuromorpho.org*

Dataset

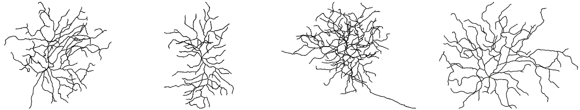
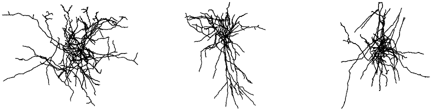
NeuroMorpho.org



Source: *neuromorpho.org*

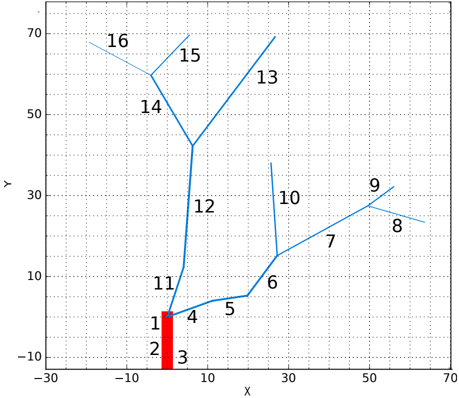
Dataset

Chosen neurons (2140, 530 for each class)

Mouse ganglion (C1)	
Human pyramidal (C2)	
Mouse pyramidal (C3)	
Rat interneuron (C4)	

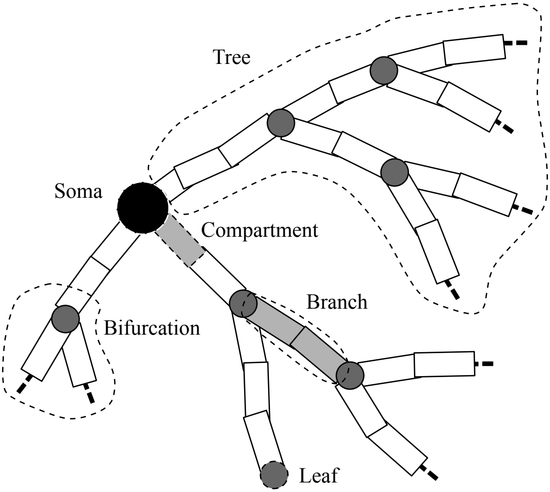
NeuroMorpho.Org provides information about neuronal structures as a plain text file, organized according to a format called swc.

Index	Type	X	Y	Z	Radius	Parent
1	1	0.0	0.0	0.0	11.555	-1
2	1	0.0	11.55	0.0	11.555	1
3	1	0.0	-11.56	0.0	11.555	1
4	3	11.12	3.99	2.62	1.885	1
5	3	19.8	5.28	1.53	1.885	4
6	3	27.17	15.17	2.47	1.885	5
7	3	49.56	27.46	-1.78	1.23	6
8	3	63.6	23.4	-1.78	0.82	7
9	3	55.94	32.16	-1.78	1.23	7
10	3	25.64	37.99	-1.68	1.39	6
11	3	4.04	12.27	-0.63	1.885	1
12	3	6.28	42.25	-0.93	1.555	11
13	3	26.63	69.2	-4.0	1.64	12
14	3	-4.04	59.74	-0.88	1.64	12
15	3	5.43	69.63	-0.22	1.065	14
16	3	-19.32	67.89	0.03	0.575	14



Concepts and methods

Terminology



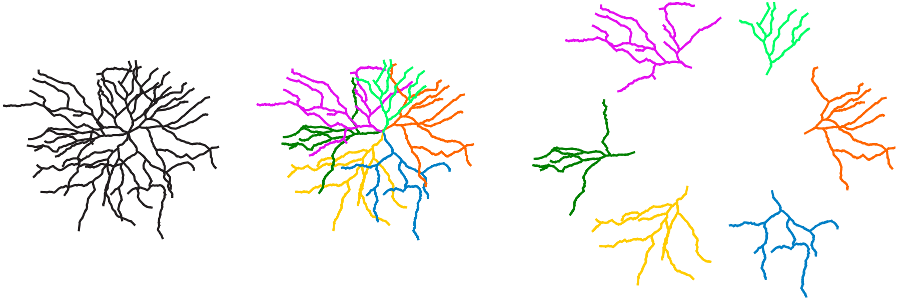
- A tree is a structure, representing dendrites or axons, attached to the soma.
- Each tree is composed by a group of branches.
- A branch is a segment between two bifurcations or between a bifurcation and a termination point, called a leaf.

Concepts and methods

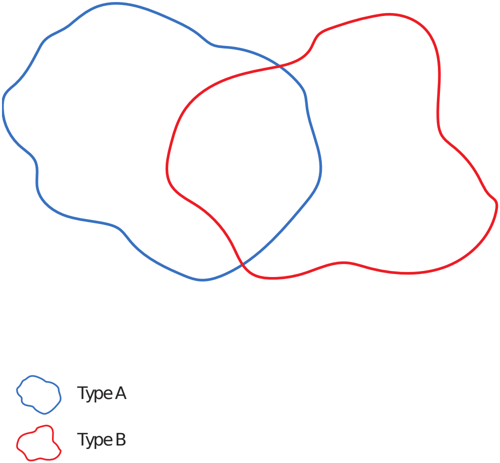
Morphological features

Nº	Measure description	Nº	Measure description
1	Soma surface area	10	Total arborization volume
2	Number of stems (trees) attached to the soma	11	Maximum Euclidean distance between the soma and leafs
3	Number of bifurcations		
4	Neuronal height, difference between maximum and minimum on the x-coordinates	12	Maximum path distance between the soma and leafs
		13	Maximum branch order
5	Neuronal width, difference between maximum and minimum on the y-coordinates	14	Average contraction
		15	Total fragmentation
6	Neuronal depth, difference between maximum and minimum on the z-coordinates	16	Average topological asymmetry
		17	Average Rall's power
7	Average branch diameter	18	Average local bifurcation angle
8	Total arborization length	19	Average remote bifurcation angle
9	Total arborization surface area	20	Fractal dimension

- Traditionally, a set of features is associated with the neuronal arborization.
- The dendritic arborization of a neuron can be seen as a set of trees.
- We analyze to what extent neuronal classes can be described when observing parts, instead of the whole neuron.



We expect that trees from the same neuron will share similar properties.
Yet, a given tree might not be typical of the neuron.



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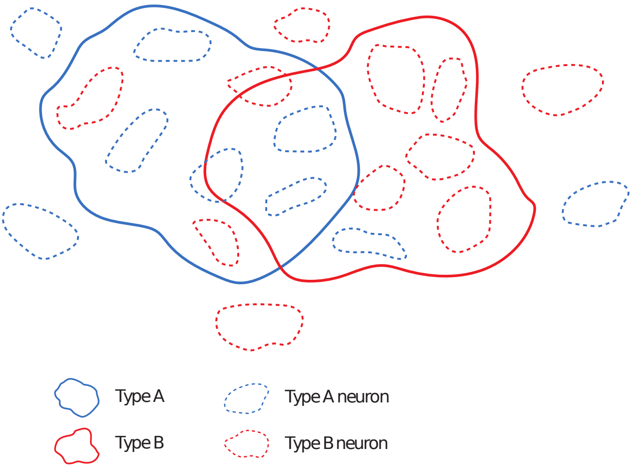

Concepts and methods

Neuron Dismantling

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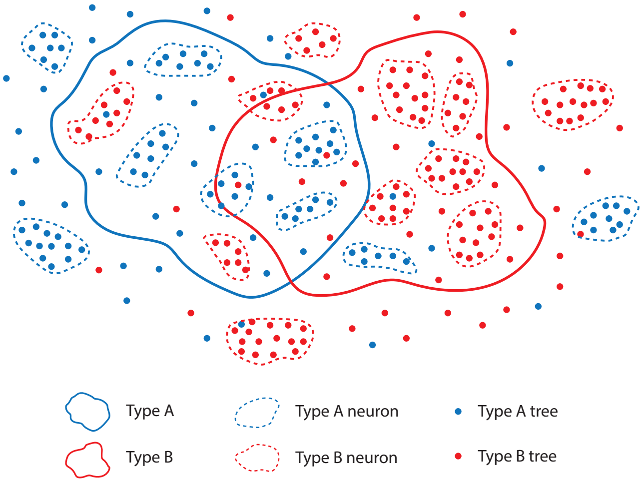

Results and discussion

The features obtained from the whole neurons

	Mouse ganglion (530)	Human pyramidal (530)	Mouse pyramidal (530)	Rat interneuron (550)
Soma surface area (µm^2)	955.01 (1225.78)	1169.00 (467.63)	652.21 (276.94)	907.42 (510.71)
Number of stems	5.44 (2.74)	6.00 (1.29)	6.11 (2.95)	6.32 (2.13)
Number of bifurcations	73.76(41.99)	25.6(7.61)	28.75(28.73)	203.55(143.78)
Height (µm)	245.76(112.54)	317.05(72.15)	236.07(250.34)	475.53(231.02)
Width (µm)	274.85(127.23)	301.78(73.04)	436.07(413.06)	638.38(293.54)
Depth (µm)	22.58(21.14)	102.71(17.84)	50.32(41.95)	185.84(128.33)
Avg. branch diameter (µm)	0.83(0.94)	1.03(0.24)	0.68(0.49)	0.33(0.15)
Total length (µm)	4674.64(1821.82)	3777.9(1187.58)	3097.25(3696.01)	17555.14(8954.96)
Total surface area (µm^2)	15604.31(26110.79)	12016.5(3935.43)	6113.42(7491.46)	17558.46(13061.73)
Total volume (µm^3)	15586.25(36156.97)	10274.76(4852.46)	3897.63(3937.08)	7020.61(6433.81)
Max. Euc. dist. (µm)	227.59(98.17)	255.16(47.57)	353.95(340.34)	613.74(270.50)
Max. path dist. (µm)	290.87(130.3)	317.09(59.87)	443.95(457.1)	999.7(406.39)
Maximum branch order	16435.58(20143.35)	1158.57(550.55)	20537.86(45339.7)	100601.17(91793.83)
Average Contraction	0.88(0.04)	0.89(0.03)	0.87(0.06)	0.83(0.04)
Total fragmentation	3062.32(2836.02)	431.79(162.77)	3760.58(6233.94)	10702.2(6964.99)
Average top. asymmetry	0.5(0.07)	0.42(0.08)	0.51(0.12)	0.55(0.06)
Average Rall's power	9.54(17.21)	6.43(5.09)	10.76(16.04)	27(33.66)
Average local bif. angle	80.59(18.1)	66.33(7.61)	74.08(14.93)	86.61(4.78)
Average remote bif. angle	73.71(10.08)	56.53(6.87)	63.81(14.06)	75.93(6.79)
Fractal dimension	1.03(0.02)	1.04(0.01)	1.03(0.02)	1.05(0.02)

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Fractal dimension	1.03(0.02)	1.04(0.01)	1.03(0.02)	1.05(0.02)

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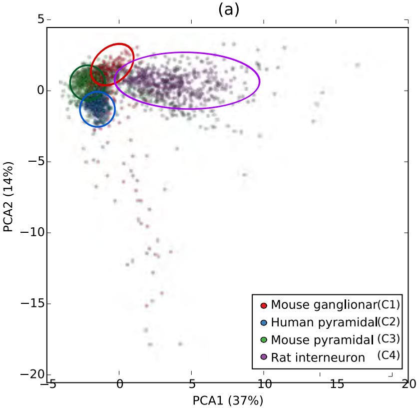
Average remote bif. angle	73.71(10.08)	56.53(6.87)	63.81(14.06)	75.93(6.79)
Fractal dimension	1.03(0.02)	1.04(0.01)	1.03(0.02)	1.05(0.02)

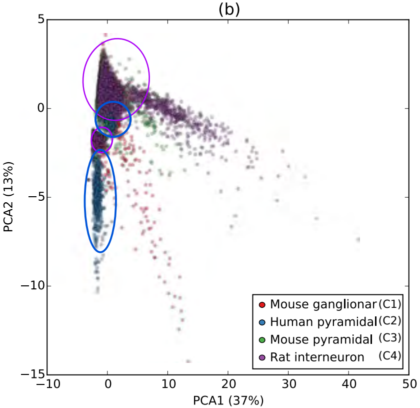
Results and discussion

The features obtained considering the neuronal trees

	Mouse ganglion (2881)	Human pyramidal (3177)	Mouse pyramidal (3237)	Rat interneuron (3473)
Soma surface area (μm^2)	27.9(72.5)	335.87(324.26)	16.13(29.38)	28.33(27.35)
Number of stems	1(0.02)	0.99(0.09)	1(0.04)	1(0.02)
Number of bifurcations	14.36(21.73)	5.09(3.26)	5.54(9.33)	33.02(81.52)
Height (μm)	119.65(83.63)	138.4(76.07)	88.93(132.01)	151.73(181.91)
Width (μm)	128.62(94.85)	140.63(72.56)	114.97(176.22)	202.02(232.07)
Depth (μm)	9.79(12.88)	63.15(31.46)	22.96(25.12)	73.31(80.62)
Avg. branch diameter (μm)	0.65(0.8)	1.45(1.37)	0.61(0.51)	0.65(0.34)
Total length (μm)	857.39(1072.02)	671.43(435.87)	503.4(1093.52)	2770.11(6213.00)
Total surface area (μm^2)	2702.92(8761.73)	2181.85(1165.08)	882.97(2044.06)	2619.33(5613.28)
Total volume (μm^3)	1782.82(9393.96)	1071.39(1295.79)	231.47(739.74)	431.97(981.57)
Max. Euc. dist. (μm)	143.95(84.9)	179.01(70.37)	137(189.06)	222.32(220.05)
Max. path dist. (μm)	194.01(111.9)	260.5(88.57)	179.65(247.45)	328.6(351.06)
Maximum branch order	3017.12(8555.5)	193.53(206)	3358.04(16033.11)	15902.81(49519.20)
Average contraction	0.87(0.05)	0.82(0.09)	0.83(0.07)	0.82(0.06)
Total fragmentation	564.81(1113.73)	74.58(54.53)	617.99(1635.15)	1694.37(3992.69)
Average top. asymmetry	0.42(0.25)	0.41(0.25)	0.42(0.28)	0.48(0.24)
Average Rall's power	1.92(6.17)	1.24(1.43)	1.85(4.4)	4.7(13.14)
Average local bif. angle	63.47(38.85)	53.45(29.76)	55.24(38.62)	71.44(34.16)
Average remote bif. angle	56.02(35.1)	45.69(25.78)	45.66(33.74)	57.75(30.81)
Fractal dimension	1.04(0.03)	1.04(0.14)	1.05(0.07)	1.05(0.05)

A PCA technique was used to project the data from the original 20-dimensional space into a 2-dimensional one. The PCA were calculated for features of (a) whole neuron and (b) neuronal trees.





In order to better understand this effect, we estimated the scatter distances between each pair of neuron classes.

	C2	C3	C4
C1	11.59	2.29	3.41
C2	-	3.12	11.47
C3	-	-	2.64

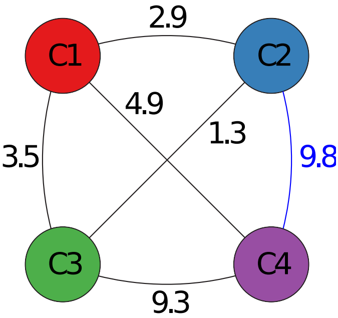
Considering whole neuron features.

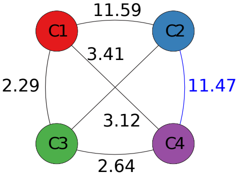
	C2	C3	C4
C1	4	0.65	0.7
C2	-	2.33	1.17
C3	-	-	0.28

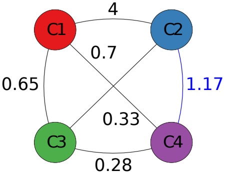
Considering neuronal tree features.

Results and discussion

Scatter matrix







Each circle represents a neuron class, and the numbers placed near the lines connecting circles indicate the respective ratio of scatter distances computed for the two classes connected by the line.

Conclusions

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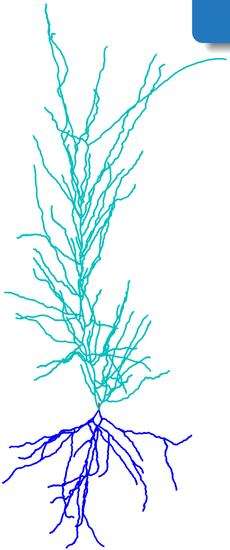
- The results obtained indicate that the features characterizing the neuronal morphology extend from the whole cells to the smaller spatial scale of the respective neuronal trees, suggesting that the relevant differentiating characteristics are already found at this level.
- This preservation of discriminability was not identical for all the four classes, with one of the categories deviating more markedly.
- Future works could consider more neuronal types, other features, and extend to the classification level.
- It would also be interesting to dismantle the neuronal cells not at the soma level, but along the hierarchy of the trees.

Data-oriented Neuron Classification from Their Parts



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[1] Institute of Mathematics and Statistics, University of São Paulo
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