

# INCF Standards Review Criteria v.2.0

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## Basic Metadata:

**Title:** Digital SWC reconstructions describing neuron morphology

### Brief description:

SWC files (file extension of .swc) are text-based (ASCII text) files that describe three-dimensional neuronal or glial morphology. These digital reconstructions represent morphology as a vectorized tree structure, made of a series of connected nodes (or compartments). An SWC file contains a series of text-based rows where each neuron node is described by a single row of the following seven space-separated values (hence the whole set of nodes has seven columns):

**(1) Node index:** Represented by the sequence of increasing positive integers, starting at 1 (for the first node) and ending at  $n$ , where  $n$  is number of nodes in the neural arbor.

**(2) Neurite type:** indicated by a positive integer: **1** for soma, **2** for axon, **3** for dendrite (or basal dendrite if apical is present), **4** for apical dendrite, **5** for custom tags (e.g., oblique branches or other user-defined preference), **6** for unspecified neurites, **7** for glial processes.

**(3, 4, 5) Three-dimensional node coordinates:** X, Y, and Z values of the node location, expressed by a double datatype number.

**(6) Radius:** Neurite thickness at the node (compartment) location represented by the radius of the compartment, expressed in micrometers by a double datatype number.

**(7) Parent Node:** Node index (1) of the parent node. The parent node column consists either of a positive integer strictly smaller than the node index of the same row or the value of  $-1$ , which is used specifically in the case of the root node (since the root node has no parent node). The first row of the file must be a root node.

Every node (except for the root) and its parent node form the ending and the beginning, respectively, of the connected compartments that make up the complete arbor. The cell body of the neuron can be represented by a series of connected compartments representing stacked cylinders (multicompartmental soma), as a single compartment representing a sphere or as a three-point soma ([neuromorpho.org/SomaFormat.html](http://neuromorpho.org/SomaFormat.html)).

Lines starting by a “#” constitute comments. These lines may contain unstructured or structured metadata, the latter in form of key-value pairs.

URL: [github.com/INCF/swc-specification](https://github.com/INCF/swc-specification)

Stewards: Giorgio A. Ascoli, Bengt Ljungquist, Sumit Nanda, Lydia Ng

Relevant publication:

Cannon, R.C., Turner, D.A., Pyapali, G.K., Wheal, H. V., 1998. An on-line archive of reconstructed hippocampal neurons. *J. Neurosci. Methods* 84, 49–54.

Nanda, S., Chen, H., Das, R., Bhattacharjee, S., Cuntz, H., Torben-Nielsen, B., Peng, H., Cox, D.N., De Schutter, E., Ascoli, G.A., 2018. Design and implementation of multi-signal and time-varying neural reconstructions. *Sci. Data* 5, 170207.

## Summary of Discussion

With a 25 year history and over 1,000 publications, the SWC format was considered a strong candidate for INCF endorsement by the INCF Standards and Best Practices Committee. It is open, has strong documentation, is well conceived and executed, and supports FAIR reasonably well. It has strong evidence of community support and use outside of the core group involved in its specification and development. Many tools have been developed to support the format. While it has an established governance framework that clearly defines the composition of the Governing Board and the election process, details about governance (e.g. who makes decisions, how conflicts are resolved) are needed.

## Recommendation

The INCF Standards and Best Practices Committee unanimously voted to put the SWC format forward for Community Review.

## Conflicts of Interest

The reviewers declared no conflicts of interest.

## Open criteria

It is essential that a FAIR supporting standard is open and allows free use by the community. Open development practices are also strongly encouraged to facilitate transparency and adoption. If questions do not apply, leave them blank or mark N/A.

1. Is the SBP covered under an open license so that it is free to implement and reuse by all interested parties (including commercial)? ([List of open source licenses](#))

Yes, the SBP is covered under a CC BY-ND 4.0 license.

2. What license is used?

The SBP uses an Attribution-NoDerivatives 4.0 International (CC BY-ND 4.0) license. (<https://creativecommons.org/licenses/by-nd/4.0/>)

3. Does the SBP follow open development practices?

The governance policy allows for anyone to request changes to the file format; the request must be approved by the SWC File Format's Governing Board.

4. Where and how are the code/documents managed?

The SWC standard definition is described at <https://swc-specification.readthedocs.io/en/latest/>. and with the tools and sources to build it at <https://github.com/INCF/swc-specification>. Users can interact through GitHub tools such as feature requests.

5. Any additional comments on the openness of the SBP?

For more than 15 years, NeuroMorpho.Org has standardized reconstructions from other data formats into SWC, which has helped the general adoption of this format by the research community. To support the adoption and usability of the format more generally, NeuroMorpho.Org is releasing a conversion and standardization tool deployed as a free, publicly available web service, which may be interacted with in any programming language supporting HTTP requests. The beta version of this tool is available at <https://neuromorpho.org/xyz2swc/ui/>

## FAIR Criteria

Considers the SBP from the point of view of some (not all) of the FAIR criteria ([Wilkinson et al. 2016](#)). Is the SBP itself FAIR? Does it result in the production of FAIR research objects? Note that many of these may not apply. If so, leave blank or mark N/A.

1. SBP uses/permits persistent identifiers where appropriate (**F1**).

Yes: the SBP permits a unique identifier (UID) for an SWC file as part of its metadata section.

2. SBP allows addition of rich metadata to research objects (**F2**).

Yes: The SBP allows addition of metadata as comments in the SWC files.

3. SBP uses/permits addition of appropriate PIDs to metadata (**F3**).

Yes, it is possible to add PIDs to the metadata field.

4. The protocol allows for an authentication and authorization when required (**A1.2**).

N/A.

5. SBP uses or allows the use of vocabularies that follow the FAIR principles (**I2**).

Yes, this SBP allows use of vocabularies such as those widely used by NeuroMorpho.Org, which have been created and harmonized in collaboration with more than 900 labs worldwide.

6. SBP includes/allows qualified links to other identifiers (**I3**).

Any identifier may be added as part of the metadata.

7. Does the standard interoperate with other relevant standards in the same domain? (**I1**).

N/A.

8. Does the SBP provide citation metadata so its use can be documented and tracked? (**R1.2**).

Yes, the metadata supports referencing publications as well as unique identifiers.

9. Does the SBP have a clear versioning scheme and appropriate documentation?

Yes, it is maintained and versioned at the Read the Docs and GitHub pages, as new releases are published. It is possible to link and mark compliance to a specific version of the specification, e.g. <https://swc-specification.readthedocs.io/en/v1.0.1/> .

10. Any additional comments on aspects of FAIR?

The SWC file format is easy to interact with, is both human- and machine-readable, and is compatible with many existing FAIR tools, some of which are listed at <https://neuromorpho.org/tools.jsp>.

# Design, Testing, and Implementation

These may not all apply, if so, leave blank or mark N/A. Proper design, testing, and implementation, in addition to supporting tools greatly aid in adoption of a standard.

1. What is the technical expertise level required to implement this? Even if it is quite difficult, should it be implemented anyway?

The format is simple and intuitive. A parser or writer to the format could be implemented by anyone with knowledge of any programming language. Further interaction with the format, for example visualization, may require basic technical expertise to transfer coordinates and radii to a graphic model for rendering. Multiple examples of such parsers and tools are listed at <https://neuromorpho.org/tools.jsp>

2. Does the SBP provide an architectural concept to understand its implementation and relationships to external entities?

N/A

3. Does the SBP have a reference implementation?

NeuroMorpho.Org serves as a reference implementation of the SWC format by having all published files standardized according to the specified format.

4. What software artifacts (resources files/scripts/libraries/tools) are available to support the SBP?

See <https://neuromorpho.org/toolsTable.jsp> for a non-exhaustive list.

5. Are the supporting software resources tools and implementations covered under an open source license?

Most of the software resources in the above table are available open source.

- a. Are the supporting software resources well documented (documentation of I/O operations, programming interfaces, user interfaces, installation)?

Most of the software tools that support the SWC format are well documented. Almost all are described in peer reviewed publications.

- b. Were the supporting software resources validated?

The supporting software are all peer reviewed. Most of the tool creators also freely share their source code for others to review and contribute.

- c. What is your assessment of the quality of the code/document?

Majority of the listed tools are well maintained. The most commonly used have feedback systems implemented and regular releases with new features and/or bug fixes.

- d. Have the supporting software resources been deployed, is there any experience or references to their use by the community?

Many of the tools listed at <https://neuromorpho.org/toolsTable.jsp> have references to their peer reviewed description and use. NeuroMorpho.Org maintains a curated bibliography that indicates that over 1000 publications directly used the standardized neuronal reconstructions.

6. Any additional comments on design, testing, and implementation?

N/A

## Governance

Ongoing governance is key to ensuring the transparency about how a standard was created, and ensuring the stewards are responsive to the needs of the community. Standards require transparent governance practices; however it is possible some of the following questions do not apply; if so, leave blank or mark N/A.

1. Does the SBP have a clear description of how decisions regarding its development are made?

Yes, please see (<https://swc-specification.readthedocs.io/en/latest/governance.html> ).

2. Is the governing model document for maintenance and updates compatible with the [INCF project governing model document](#) and the open standards principles?

Yes, the project is co-developed and maintained by two major but independent actors already on its governance board, NeuroMorpho.Org and the Allen Institute for Brain Sciences.

3. Is the SBP actively supported by the community? If so, what is the evidence?

Yes, as indicated by <https://neuromorpho.org/toolsTable.jsp>, the SBP is widely supported and used. NeuroMorpho.Org also lists over 1000 peer reviewed publications that have used its provided standardized reconstructions in SWC format.

4. Does the SBP provide tools for community feedback and support?

The GitHub page allows for feature requests, and also specifies a single point of contact for users who prefer email interaction.

5. Any additional comments on governance?

NA

## Adoption and Use

The standard must have substantive evidence of use outside of the group or individual that develops and maintains it. However, different levels of adoption and use will be taken into consideration depending on the purpose of the standard and the size/type of audience that might implement the standard. Because INCF represents organizations world-wide, evidence of international use is highly desirable.

1. Is there evidence of community use beyond the group that developed the SBP?

Please see <https://neuromorpho.org/toolsTable.jsp>. Also, as previously mentioned, over 1000 publications have used NeuroMorpho.Org-provided SWC reconstructions.

2. Please provide some concrete examples of use, e.g., publications where the use of the SBP is cited; databases or other projects that have adopted the SBP.

For a partial list of references using curated, standardized reconstructions in the SWC format, please see:

[https://neuromorpho.org/LS\\_queryUsage.jsp?usage=USING&page=0](https://neuromorpho.org/LS_queryUsage.jsp?usage=USING&page=0)

3. Is there evidence of international use?

NeuroMorpho.Org usage statistics (<https://neuromorpho.org/statistics.jsp>) shows that standardized SWC files has been downloaded and used in almost every country around the world.

4. Any additional comments on use?

The format has been used for over 25 years, with a user base that has both produced new reconstructions as well as developed tools and databases that continue to develop.

# Stability and Support

Standards need some sort of ongoing stability and support to ensure it will be useful in the future. However, given the nature of research projects, the level of acceptable stability and support is somewhat at the discretion of the SBP Committee and reviewers.

1. Does the SBP have a clear description on who is maintaining the SBP?

The SWC format standard is maintained jointly by a group of experts on neuronal morphology and neuroinformatics, including senior personnel from NeuroMorpho.Org and Allen Institute for Brain Sciences.

2. How is it currently supported?

In addition to <https://neuromorpho.org/toolsTable.jsp>, a universal conversion and standardization tool is being developed by NeuroMorpho.org scientists together with community developers.

3. What is the plan for long term support?

NeuroMorpho.Org is an NIH funded project and will continue hosting SWC reconstructions for the foreseeable future.

4. Are training and other supporting materials available?

Documentation and supporting materials are available in the GitHub repository and the supporting details page of NeuroMorpho.Org.

5. Any additional comments on sustainability and support?

N/A

# Extensibility

If it is possible to update or potentially apply the standard to other areas, that should be indicated. The ability for a standard to be extensible is highly desirable, but not required. This is an area where having this knowledge is valuable to INCF and the community in general.

1. Can the SBP be extended to cover additional domains/use cases?

While SWC reconstructions were primarily invented to digitally describe neural morphology, this system can also be seamlessly adopted to describe any arbor-like structure such as angiographic data (e.g., <https://www.nitrc.org/projects/breva/>). SWC reconstructions have



also been extended to produce multi-signal neural reconstructions, as well as dynamic time-varying neural reconstructions ([doi.org/10.1038/sdata.2017.207](https://doi.org/10.1038/sdata.2017.207)).

2. If so, how is the process documented and managed?

Advancements of the format produced by the scientific community in the future will be discussed by the governing board and documented in the existing GitHub repository. The new version of the SWC format and will then be released via the GitHub repository for public use.

3. Any additional comments on extensibility?

N/A

## Comparison

This information is important to INCF and the community. It may be important for evaluating one standard vs. another, or where INCF may help facilitate interoperability between complementary standards within a similar area.

1. Are there other similar SBPs available?

A similar SBP to the SWC reconstruction system is the MBF neuron reconstruction format version 4.0, which is based on the XML (eXtensible Markup Language). Other file formats for neuronal reconstructions include both commercially maintained specifications such as Amira and Neurolucida ASCII, as well as community and non-commercial formats like SNT. A more closely related format to this SBP is the “SWC plus” format. A description of this format can be found in [neuroinformatics.nl/swcPlus/](http://neuroinformatics.nl/swcPlus/). This format is also based on XML, similarly to the MBF reconstruction format.

2. If yes, how do they compare on key INCF criteria?

SWC is the most commonly used and has become the de facto standard in neuronal morphology. It is maintained by scientists at different non-commercial organizations. The MBF format is closely associated with the Neurolucida software and its developer MBF Bioscience, a commercial entity, and is thus more influenced by a single commercial organization.

3. What are the key advantages of the SBP when compared to other SBPs?

Compared to other similar SBPs, this SBP is more compact and has less overhead relative to an XML format. Due to its stability and long term use over 25 years, many research groups have developed numerous tools for the format suggested by this SBP, including many published in peer-reviewed articles.

4. Any additional comments on comparison with other SBPs?

N/A