pyNAVIS: An open-source cross-platform software for spike-based neuromorphic audio information processing

Juan P. Dominguez-Morales [a,b,*], D. Gutierrez-Galan [a,b], A. Rios-Navarro [a,b], L. Duran-Lopez [a,b], M. Dominguez-Morales [a,b], A. Jimenez-Fernandez [a,b]

[a] *Robotics and Technology of Computers Lab, ETSII-EPS, Universidad de Sevilla, Seville, Spain*
[b] *Smart Computer Systems Research and Engineering Lab (SCORE-I3US), Seville, Spain*

Keywords:
Neuromorphic engineering
Audio processing
AER

ABSTRACT

Visualizing the output from event-based sensors and analyzing the information within it is crucial when developing new neuromorphic systems. A novel open-source, cross-platform Python package called pyNAVIS is proposed, which provides a set of functionalities to analyze and process spiking information obtained from neuromorphic cochleas, along with other tools to generate files and datasets for machine learning tasks. This modular package can be integrated in complex and higher-level projects, which could be useful for researchers working in neuromorphic audio processing tasks.

1. Introduction

Neuromorphic computing has gained popularity in recent years, since it allows developing bio-inspired, real-time systems to solve complex tasks related to robotics [1] and machine learning [2], among others. In particular, neuromorphic retinas [3] and cochleas [4,5] mimic the human vision and hearing, respectively, and are useful for real-time applications. Neuromorphic cochleas decompose the input stimulus into frequency bands, as the basilar membrane in the inner ear does, generating output spike trains depending on the features of the input sound. These spike streams can be used to train Spiking Neural Networks (SNNs), which model the information transfer in biological neurons. To this end, the output information from the neuromorphic sensor is commonly analyzed and processed to identify and enhance relevant features. In this work, a novel software tool to analyze and post-process the output information from neuromorphic cochleas is presented.

2. Problems and background

There is a wide range of software tools for user-level audio analysis and processing. One from which we took inspiration is Audacity, which is an open-source, cross-platform audio software that is able to load discrete audio samples and perform a wide set of functionalities to analyze it. However, Audacity cannot work with spiking information. A well-known software in the neuromorphic community is jAER,[1] which supports this kind of information. jAER is capable of directly receiving the information from a neuromorphic sensor online and saving it into AEDAT[2] files, while also being able to develop and apply different filters to process it in real-time. On the other hand, NAVIS [6] was built for providing a tool for researchers to analyze spiking information obtained from a neuromorphic cochlea. As a counterpart, NAVIS is only available for Windows OS users due to its User Interface (GUI) framework dependency and, although it has been updated with requests from the community, most of it demands a cross-platform alternative for spiking audio processing tasks. Table 1 presents a brief comparison between these tools, focusing on their main aspects.

3. Software framework

3.1. Software architecture

The pyNAVIS is formed by a set of modules, each of them consisting of python classes. The figure that can be seen in the

* Corresponding author.
E-mail address: jpdominguez@atc.us.es (J.P. Dominguez-Morales).

[1] http://jaerproject.org (accessed December 9, 2020)
[2] https://inivation.github.io/inivation-docs (accessed December 9, 2020)

Table 1
Comparative study between different well-known tools and pyNAVIS.

	Open source	Cross platform	Audio analysis	Spike based	Dataset generation	Integration with other tools	GUI
Audacity	✓	✓	✓	✗	✗	✗	✓
jAER	✓	✓	✗	✓	✗	✗	✓
NAVIS	✓	✗	✓	✓	✗	✗	✓
pyNAVIS	✓	✓	✓	✓	✓	✓	✗

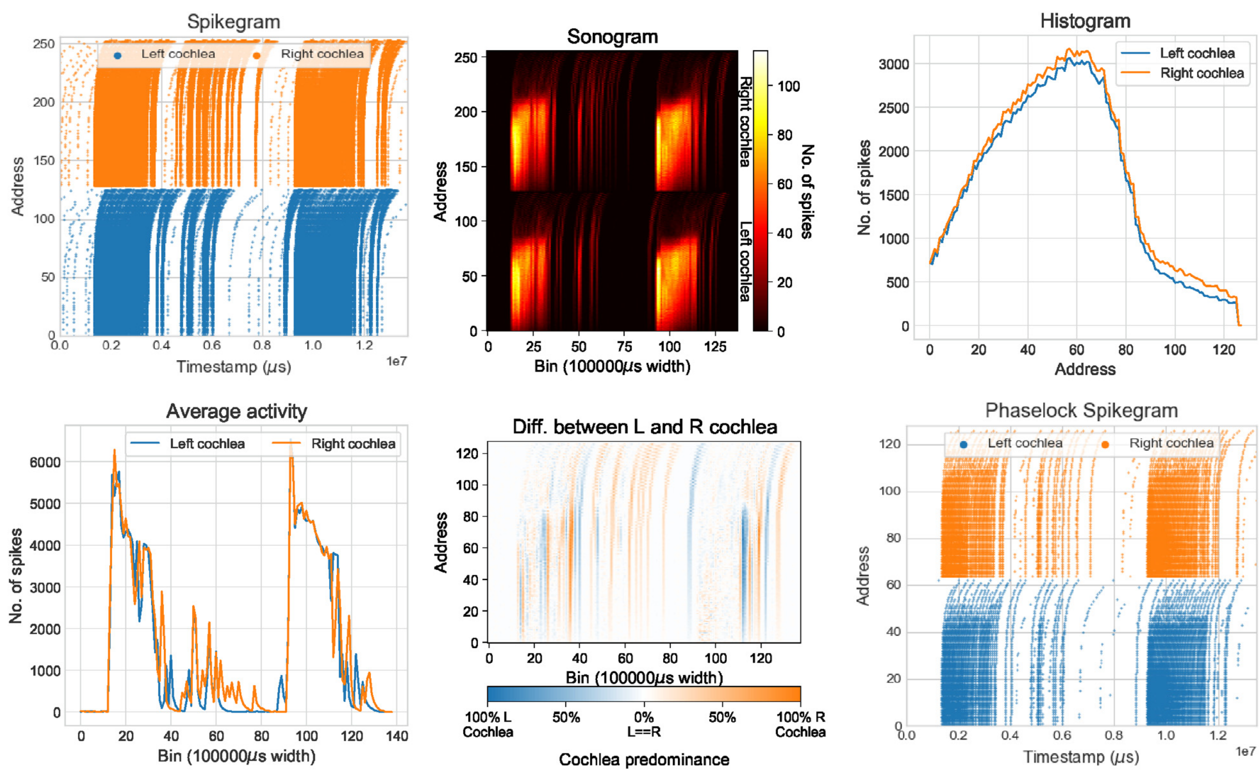


Fig. 1. Spikegram, sonogram, histogram, average activity, difference between cochleas and phaselock plots for the same input file with two words obtained with pyNAVIS.

pyNAVIS package documentation[3] presents a block diagram with the main components of the software architecture. The *main_settings* module contains pyNAVIS's configuration parameters, which are used in other modules and functions for setting up. Other relevant modules are *loaders*, *savers*, *functions* and *plots*. The former contains the Loaders class, which has functions for opening files with spiking data (currently supporting AEDAT, CSV and TXT files) and then storing that information into SpikesFile objects. The Functions class consists of a set of functionalities which are presented in Section 3.2. After generating new SpikesFiles or applying any processing to a loaded one, it can be saved using the Savers class in many different formats.

PyNAVIS was developed following a modular design (similar to Audacity), meaning that new modules can be added in an easy way. Developers can provide new functionalities simply by adding functions to a specific class.

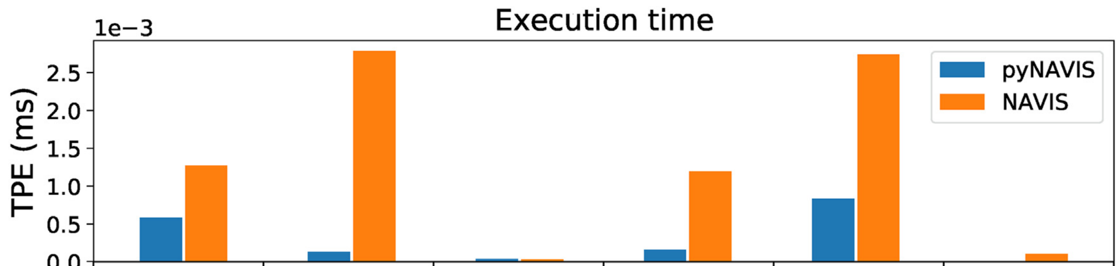
3.2. Software functionalities

PyNAVIS implements a wide set of tools to analyze, visualize, and post-process spiking information obtained from neuromorphic cochleas. The spikegram (Fig. 1 top left panel) represents spikes over time, with their corresponding addresses. The sonogram (Fig. 1 top center panel) is a heatmap-like plot that shows spiking rate activity after binning the information. The histogram and the average activity plots report information about the spiking rate against frequency and time, respectively. When working with binaural information, pyNAVIS can also plot the activity difference between both cochleas, as shown in the bottom center panel of Fig. 1. Apart from plots, pyNAVIS also provides other useful functionalities to phase-lock [7] the spiking information, to extract a set of addresses, to cut a specific portion of the file, and also to convert from stereo to mono files and vice versa (adding a configurable delay between both cochleas). Other functionalities to generate sonogram, histogram and phase-lock datasets were implemented for further machine learning tasks. PyNAVIS can be easily integrated into bigger projects as a Python library in order to benefit from these functionalities.

4. Performance analysis

The output firing rate of neuromorphic cochleas is, commonly, very high. As an example, the Neuromorphic Auditory Sensor (NAS)' firing rate can be up to 3 MEvents/s ($3 * 10^6$ events/s)

[3] https://pynavis.readthedocs.io/en/latest/pyNAVIS.html (accessed December 9, 2020)



	Load AEDAT	Sonogram	Histogram	Avg. activity	Diff. L/R	Manual Split
pyNAVIS	5.81e-04	1.30e-04	3.50e-05	1.61e-04	8.31e-04	6.45e-09
NAVIS	1.27e-03	2.78e-03	3.30e-05	1.19e-03	2.74e-03	1.05e-04
Speedup	119%	2038%	0%	639%	230%	1627806%

Fig. 2. Performance comparison between NAVIS and pyNAVIS.

[4]. Therefore, code optimization is critical to speed up the information loading and processing. In order to measure pyNAVIS's performance, the Time Per Event (TPE) was calculated for its main functionalities, and then compared to NAVIS's performance, using the same processor (Intel i7-4770, 3.5 GHz) and AEDAT file (containing more than 1 MEvents). The results are shown in Fig. 2. PyNAVIS achieves an average improvement of one order of magnitude in terms of speed-up.

5. Conclusions

In this work, a novel, open-source, cross-platform software named pyNAVIS was presented. This package offers a set of modules and functionalities to visualize, analyze and post-process the information obtained from neuromorphic cochleas, improving current state-of-the-art software in terms of performance and capabilities. This software has been developed following a modular design that allows updating the software with new functionalities easily. It can also be integrated into larger projects to benefit from its tools. The dataset generators that pyNAVIS implements speed up this laborious process and could be very useful for researchers working in recognition, classification and sound source localization tasks using machine learning algorithms.

Required metadata

Current executable software version

See Table 2.

Current code version

See Table 3.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was partially supported by the Spanish grant (with support from the European Regional Development Fund) COFNET (TEC2016-77785-P) and by the Spanish This work was funded by Spanish Agencia Estatal de Investigación (AEI) project MINDROB: "Percepción y Cognición Neuromórfica para Actuación Robótica

Table 2
Software metadata (optional)

Nr.	(executable) Software metadata description	Please fill in this column
S1	Current software version	1.0.9
S2	Permanent link to executables of this version	https://pypi.org/project/pyNAVIS
S3	Legal Software License	GPL
S4	Computing platform/Operating System	Any OS that supports Python 3.
S5	Installation requirements & dependencies	Python 3
S6	If available, link to user manual	https://pynavis.readthedocs.io
S7	Support email for questions	jpdominguez@atc.us.es

Table 3
Code metadata (mandatory).

Nr.	Code metadata description	Please fill in this column
C1	Current code version	1.0.9
C2	Permanent link to code/repository used of this code version	github.com/jpdominguez/pyNAVIS
C3	Legal Code License	GPL
C4	Code versioning system used	Git
C5	Software code languages, tools, and services used	Python
C6	Compilation requirements, operating environments & dependencies	Python 3
C7	If available Link to developer documentation/manual	https://pynavis.readthedocs.io
C8	Support email for questions	jpdominguez@atc.us.es

de Alta Velocidad (PID2019-105556GB-C33/ AEI/10.13039/ 501100011033).

References

[1] D. Gutierrez-Galan et al., NeuroPod: a real-time neuromorphic spiking CPG applied to robotics, Neurocomputing 381 (2020) 10–19.

[2] G. Indiveri, et al., Neuromorphic architectures for spiking deep neural networks, in: 2015 IEEE International Electron Devices Meeting (IEDM), IEEE, 2015, pp. 4–2..

[3] A. Lakshmi et al., Neuromorphic vision: From sensors to event-based algorithms, Wiley Interdisciplinary Reviews, Data Mining and Knowledge Discovery 9 (4) (2019) e1310.

[4] A. Jiménez-Fernández et al., A binaural neuromorphic auditory sensor for FPGA: A spike signal processing approach, IEEE Transactions on Neural Networks and Learning Systems 28 (4) (2016) 804–818.

[5] M. Yang, et al., A 0.5 v 55μw 64$\times$2 channel binaural silicon cochlea for event-driven stereo-audio sensing, IEEE Journal of Solid-State Circuits 51 (11) (2016) 2554–2569..

[6] J.P. Dominguez-Morales et al., NAVIS: Neuromorphic Auditory VISualizer tool, Neurocomputing 237 (2017) 418–422.

[7] A.R. Palmer, Chapter 3 - neural signal processing, in: Hearing, Handbook of Perception and Cognition, Academic Press, 1995, pp. 75–121.

Juan P. Dominguez-Morales was born in Sevilla (Sevilla, Spain) in 1992. He received the B.S. degree in computer engineering, the M.S. degree in computer engineering and networks, and the Ph.D. degree in computer engineering (specializing in neuromorphic audio processing and spiking neural networks) from the University of Seville, in 2014, 2015 and 2018, respectively. From October 2015 to December 2018, he was a PhD student in the Architecture and Technology of Computers Department of the University of Seville with a research grant from the Spanish Ministry of Education and Science. Since January 2019, he has been working as Assistant Professor in the same department. His research interests include medical image analysis, convolutional neural networks, computer-aided diagnosis systems, neuromorphic engineering, spiking neural networks, neuromorphic sensors and audio processing. In 2016 he became a member of the European Neural Network Society, he has been a member of IEEE for four years.

Daniel Gutierrez-Galan received the B.S. degree in computer engineering in 2014 and the M.S. degree in computer engineering and networks in 2016, both from the University of Seville, Sevilla, Spain. Since September 2017, he has been a Ph.D. student in the Department of Computer Architecture and Technology, at University of Seville. His research interests include embedded systems programming, digital design, FPGA, spiking neural networks in embedded systems for audio processing, neuromorphic auditory sensors and neuromorphic robots.

Antonio Rios-Navarro received the B.S. degree in computer science engineering, the M.S. degree in computer engineering, and the Ph.D. degree in neuromorphic engineering from the University of Seville, Seville, Spain, in 2010, 2011, and 2017, respectively. He currently holds the post-doctoral position at the Computer Architecture and Technology Department, University of Seville. His current research interests include neuromorphic systems, real-time spikes signal processing, field-programmable gate array design, and deep learning.

L. Duran-Lopez received the B.S. degree in Biomedical Engineering in 2016 and the M.S. degree in Biomedical Research in 2017, both from the University of Seville (Sevilla, Spain). On September 2017, she started her Ph. D. in the department of Computer Architecture and Technology, at the University of Seville. Since 2017, she has worked as a Research Fellow in the Robotics and Technology of Computers Lab. from the University of Seville. Her research interests include image processing, medical image analysis, computer-aided diagnosis systems and deep learning, particularly, convolutional neural networks.

Manuel J. Dominguez-Morales received the B.S. degree in computer science engineering, the M.S. degree in software engineering, the M.S. degree in computer engineering, and the Ph.D. degree in industrial informatics from the University of Seville, Spain, in 2008, 2009, 2014, and 2014, respectively. From 2009 to 2014 he has worked as an Assistant Professor with the Computer Architecture and Technology Department, University of Seville, where he has been working as a Postdoctoral Researcher and a Lecturer, since 2014. His research fields are focused on computer vision, image processing, signal processing, embedded systems, programmable hardware design, computer architecture, robotics, and e-Health.

Angel F. Jimenez-Fernandez received the B.S. Degree in Computer Engineering in 2005, the M.S. Degree in Industrial Computer Science in 2007 and the Ph.D. in Neuromorphic Engineering in 2010 from the University of Seville, Sevilla, Spain. Since October 2007, he has been an Assistant Professor of Computer Architecture and Technology at the University of Seville. In April 2011, he was promoted to Associate Professor. His research interests include neuromorphic engineering applied to robotics, real-time spikes signal processing, neuromorphic sensors, field programmable gate array (FPGA) digital design, embedded systems development, high-speed serial communications, and smart sensors networking.