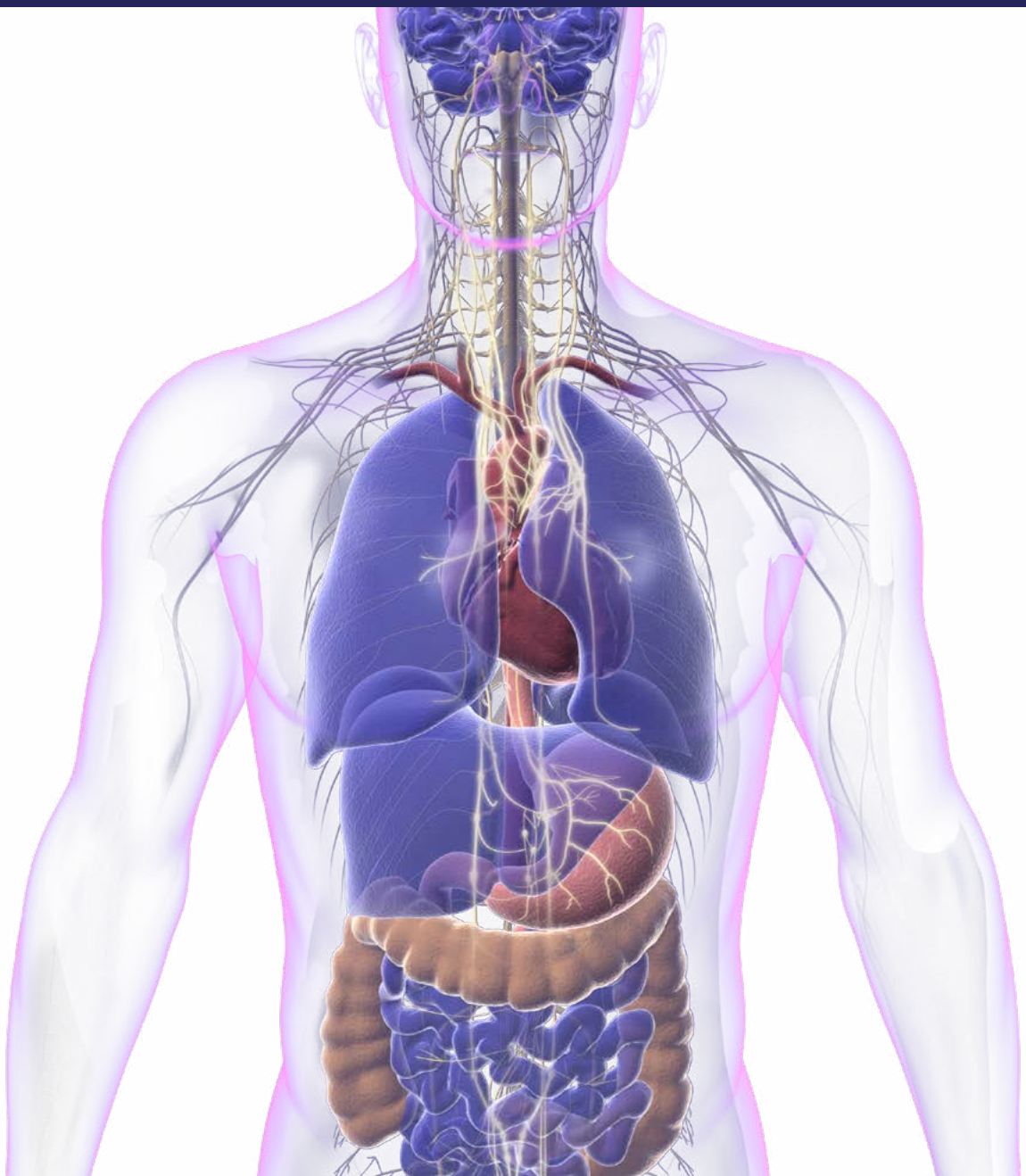
SPARC

ANNUAL REPORT

March 2024



A Message from

LEADERSHIP

We are pleased to share our first annual public report describing highlights and plans for the SPARC platform. We at the SPARC Data and Resource Center (DRC) [1] are on a mission to provide neuroscience researchers with an open platform and ecosystem of FAIR (Findable, Accessible, Interoperable, Reusable) data, models, associated tools, and procedures. The SPARC Portal - **https://sparc.science/** acts as a nexus between researchers, outcomes of the SPARC Consortium, and community support and outreach efforts.

While this is our first public-facing report, the DRC is in our seventh year working together on the SPARC project. As the NIH SPARC program [2] starts to wind down, we are committed to a future that ensures that SPARC continues to serve as a hub of data, knowledge, and resources. To support this, we have taken steps towards sustainability that expand the original focus of SPARC from ANS connectivity to include the broader community of those focusing on bridging the body and the brain. Towards this end, **SPARC is now an open repository** filling a vital niche in the current neuroscience repository ecosystem for housing data and tools focused on the peripheral nervous system (PNS), organ physiology, and PNS and central nervous system (CNS) interactions. In addition, the SPARC platform is now supporting other relevant NIH projects such as RE-JOIN and PRECISION HEAL. We are in the process of updating the SPARC Portal to reflect these changes.

In this report, we discuss progress on both technological development and our efforts to foster and grow the SPARC community over the past year. We offer many opportunities for the community to get involved [3]; we hope to hear from you [4].

1. https://sparc.science/about/team-and-leadership
2. https://commonfund.nih.gov/sparc
3. https://sparc.science/about/get-involved
4. https://sparc.science/contact-us?type=feedback

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OVERVIEW

What is SPARC?

SPARC takes its name from NIH Common Fund Program, SPARC [1], which stands for Stimulating Peripheral Activity to Relieve Conditions. Phase 1 of the project consisted of a large consortium of investigators focused on multimodal basic and translational studies in a number of organs and species. Phase 2 of the project is now underway and focuses on the human vagus. The long-term goal of SPARC is to generate innovative approaches and technologies for novel bioelectronic therapies by creating the opportunity for unique analyses and discovery. SPARC Investigators are charged with sharing their outcomes on the SPARC Portal [2] – an open repository that integrates diverse data and offers technologies that expand on and augment the science arising from this program. The SPARC Portal provides access to digital resources that can be shared, cited, visualized, computed, and used for virtual experimentation. These technologies are developed and maintained by the SPARC Data and Resource Center (DRC) [3].

Who we are: The SPARC Data and Resource Center (DRC)

The DRC is composed of a diverse international team spearheaded by PIs who are all leaders in their respective fields. They developed the SPARC Portal [2] as a multifunctional online hub facilitating coordination, synthesis, and prediction through four Core functions: Data Coordination [4] (DAT-Core), Map Synthesis [5] (MAP-Core), Modeling & Simulation [6] (SIM-Core), and Knowledge Management [7] (K-Core). We also include user experience and communications teams as well as independent anatomical experts. Several others weigh in on the SPARC experience; in addition to NIH program officers, these include members of our DRC Steering Committee, Advisory Committee, user experience teams and change control boards. Visit the SPARC Portal to learn more about our team, leadership, and governance [3], to learn more about our infrastructure, view our 2021 publication [8], [Ref: 1].

The DRC strives to position the SPARC Portal [2] as a foundation for collaborative and FAIR neuroscience and physiology knowledge with a focus on the PNS, data, and community. We are now transitioning the tools, services, and resources developed for SPARC to serve a wider community with the goal of nurturing sustainable growth.

1. https://commonfund.nih.gov/sparc
2. https://sparc.science/
3. https://sparc.science/about/team-and-leadership
4. https://docs.sparc.science/docs/dat-core
5. https://docs.sparc.science/docs/map-core
6. https://docs.sparc.science/docs/sim-core
7. https://docs.sparc.science/docs/k-core
8. https://doi.org/10.3389/fphys.2021.693735

SPARC VISION AND OBJECTIVES

SPARC provides scientists a platform that enables collaborative research through meaningful, impactful, and reusable sharing of research outcomes. The SPARC Portal is much more than a data repository. It encapsulates a data management platform, multiple databases and knowledge bases, maps, spatial mapping tools, organ scaffolds, and a computational modeling and analysis platform, as well as a host of other viewers and supporting tools. These tools give users the power to create an integrated view across functional, anatomical, molecular, quantitative data and computational models. They facilitate running analyses on the available data and models and to share those analyses and the resulting data back to the community. SPARC tools also permit sharing of established computational and experimental workflows created by experts.

Moreover, the components of SPARC are capable of supporting a wide range of other systems. In fact, the DRC has already seen adoption of its tools even beyond peripheral neurosciences. For example, we are seeing strong usage of o^{2}S^{2}PARC for brain stimulation and sensing research, as well as for neuroprosthetics.

Supporting the SPARC Research Community

The first phase of SPARC focused on four priority areas: mapping, technology, translational, and data, funding over 75 research projects. While most of these investigators have completed their projects and shared their results on the SPARC Portal, the DRC continues to work with some of these investigators to complete their projects. SPARC now has nearly **300 datasets, anatomical and computational models available at no cost on the SPARC Portal**.

Some recent publications illustrate use of SPARC data and tools by the scientific community (See Appendix).

SPARC Phase 2 Awardees

SPARC Phase 2, focusing on the human vagus, began in late 2022 and comprises three main projects:

- SPARC-V: Vagus Nerve Mapping and Physiology
  - Reconstructing Vagal Anatomy (**REVA**)
    - REVA-The Feinstein Institute for Medical Research, Northwell Health [1]
    - REVA-Case Western Reserve University [2]
  - SPARC VNS Endpoints from Standardized Parameters (VESPA)
    - The **REVEAL** (Research Evaluating Vagal Excitation and Anatomical Linkages [3]) study

1. https://sparc.science/projects/6h8dK9Q0L4rOUrKfsfFvK
2. https://sparc.science/projects/630DLXibx51q6Rv42AwrjB
3. https://sparc.science/projects/12Sx14yHIItQQtfIl2YrID

- SPARC-O: SPARC Human Open Research Neural Engineering Technologies (**HORNET**) Initiative
  - Center for Autonomic Nerve Recording and Stimulation Systems (CARSS) [1]
  - Cleveland Open Source Modular Implant Innovators Community (COSMIIC) [2]
- SPARC-X: Challenge Competition (Neuromod Prize [3]; these awards are "encouraged to share data, but not required to do so")

SPARC-V: Vagus Nerve Mapping and Physiology

REVA and REVEAL are ambitious, exacting research studies that will produce massive amounts of diverse data; giving new insights into the detailed structure and function of the vagus nerve. Not only will these groundbreaking datasets be offered to the public on the Portal, the DRC has taken this opportunity to create new technologies to highlight and support additional use cases. These technologies include the ability to surface analytical data, new visualizations, and query functionality. Crucially, SPARC-V provides rich access to inter-subject variability information, and will be used to build tools that surface and describe this variability, e.g., for in silico study purposes, where device/treatment safety and efficacy must be ascertained across a diverse patient population. The SPARC DRC is developing these as multi-purpose services that can be used to support additional types of studies in the future.

SPARC-O: SPARC Human Open Research Neural Engineering Technologies

HORNET CARSS and COSMIIC are creating open-source device specifications for hardware, software, firmware, and other technology modules needed to build neuromodulation systems. In an example of how SPARC interoperates with the broader tool ecosystem, investigators will use GitHub to share these modules, while making them available for search and display through the SPARC Portal. SPARC is creating a new "Devices" dataset type to support referencing a specific version of the module specifications managed on GitHub. These datasets will be searchable and visualized along with SPARC's other assets.

The new Collections function being developed by the DRC will allow HORNET teams to group the components required for specific applications. Experimental validation studies shared by the HORNET groups will also be published as datasets on the Portal and linked to the appropriate applications. Access through the SPARC Portal to CAD data describing HORNET devices will be facilitated, and users will benefit from o^{2}S^{2}PARC functionality for CAD modification, anatomical insertion modeling, and sharing of modified device geometries and physical-physiological simulations of neural interfaces.

The REVA, REVEAL and HORNET initiatives complement and benefit each other; for example, functionality is being developed to use histological and statistical data from REVA on nerve morphology and its variability to assess the performance and safety of neural interfaces from HORNET.

1. https://sparc.science/projects/Z1X1or4wcgUy1Jk6BYqBD
2. https://sparc.science/projects/HUgp2yySIfGTXty3nXiJ4
3. https://www.neuromodprize.com/phase-1-winners/

HEAL Awardees

The NIH Helping to End Addiction Long Term (HEAL) [1] initiative is a NIH-wide effort to speed scientific solutions to stem the national opioid public health crisis. Researchers are taking a variety of approaches to address the opioid epidemic, such as understanding, managing, and treating pain. As a part of the HEAL Initiative, all HEAL data must be made FAIR through the HEAL Data Ecosystem [2]. HEAL data must be stored in one of the data repositories that meet appropriate standards for data security and privacy (HEAL recommended repositories [3]), which integrate with the HEAL Platform [4].

We are pleased to report that SPARC and the data management platform that underlies SPARC, Pennsieve [5], have both received the designation as HEAL recommended repositories. We can now accept HEAL data from any HEAL funded research. In addition, two HEAL research initiatives are working directly with SPARC to provide data coordination and integration. We are working to implement new technologies and integrations within the SPARC platform for seamless interoperation with the HEAL Data Ecosystem.

RE-JOIN HEAL

The SPARC DAT and K-Cores received support to serve as the data coordinating group (DCG) for the Restoring Joint Health and Function to Reduce Pain (RE-JOIN) [6], a consortium that is looking at the anatomical, molecular and physiological basis of knee and temporomandibular joint (TMJ) pain. The DCG supports RE-JOIN investigators in their efforts to identify and implement manageable integration steps for their diverse projects and their need to meet both HEAL and SPARC standards. RE-JOIN will share their data on the SPARC Portal and to make it available to the broader HEAL Data Ecosystem. The contributions of the RE-JOIN datasets to SPARC will enrich the data and resources available to the SPARC Community. The SPARC Portal is being redesigned to highlight partner programs like RE-JOIN and make it easy to find their products.

PRECISION Human Pain HEAL

The DAT, K, and MAP-Cores received a U24 award to serve as the Data Coordination and Integration Center (DCIC) for the Program to Reveal and Evaluate Cells-to-gene Information that Specify Intricacies, Origins, and the Nature of (PRECISION) Human Pain network. Four U19 centers are working together to create cellular transcriptomic maps of human pain pathways. As the DCIC, we will generate a high-impact resource for sharing, visualizing, and making these datasets actionable for downstream analysis and scientific investigations. Pairing our existing platform technologies and workflows with the HEAL integration progress gained through RE-JOIN, allows us to rapidly engage with the PRECISION Human Pain investigators and lead the effort to develop the knowledge and data integration capabilities needed to support their pioneering research.

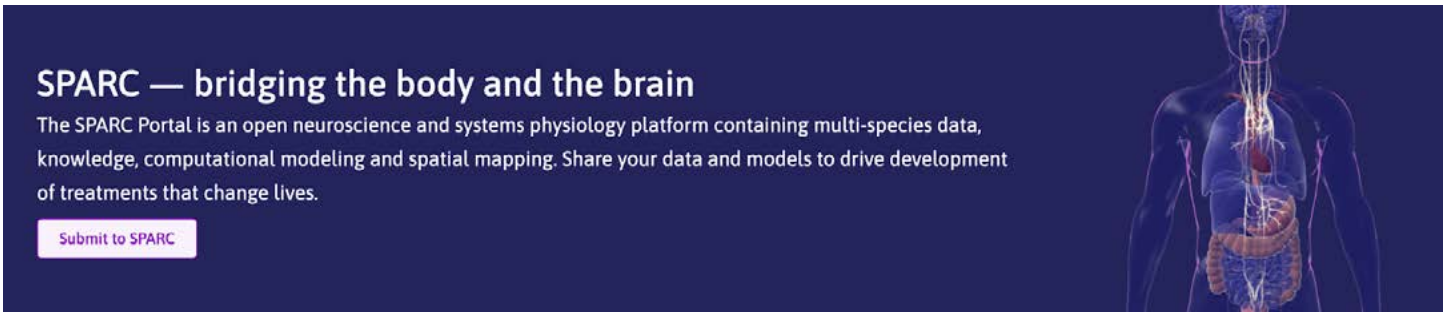
1. https://heal.nih.gov/
2. https://heal.nih.gov/data/heal-data-ecosystem
3. https://www.healdatafair.org/resources/guidance/selection
4. https://healdata.org/landing
5. https://sparc.science/resources/2j9lC0YFl5P34wGlkJOb49
6. https://sparc.science/news-and-events/news/7FQ2RrUh1bTY93BaCPoRUf

SPARC is an Open Repository

In addition to serving the unique needs of large consortia, SPARC is now an open repository [1]; fully compliant with requirements of the NIH data sharing policy, offering FAIR, meaningful sharing of resources for individual investigators [2]. SPARC is the right home for data and models concerning the peripheral nervous system, spinal cord and peripheral organs.

Thanks to the generous support of the NIH SPARC program, for a limited time, we are publishing data and models that fit the mission of SPARC at no cost to investigators, regardless of their funding source. We are pleased that our first external datasets and models are now available on the Portal read about it in this SPARC success story [3]. Our Curation team aids investigators through the data or model submission process for a polished, professional outcome - complete with its own landing page, DOI, and associated protocols. Publishing through SPARC acts as a platform for new collaborations and measuring the impact of your data through monthly metrics to help track impact.

The DRC is committed to a future that ensures continued service to the SPARC community. Data submitted to the repository will be retained for a minimum of 10 years. The Pennsieve platform has institutional support from the University of Pennsylvania for long-term support and maintenance. Learn more about the SPARC data persistence policy [4]



We invite you to contact us [5] to get started now if you have data or models that you would like to submit today; and please consider including us in your grants for future projects. We can fill a critical need in your Data Management and Sharing Plan [6].

The DRC offers a great deal of functionality beyond serving as a trusted data repository; the technologies underlying SPARC were developed as general tools that can be used and supported by other projects. We offer a wide variety of tools, services, and expertise [7], a number of these competencies are highlighted in the next section about some of our other DRC Collaborations. Reach out [9] to talk to us about how we can support your research.

1. https://sharing.nih.gov/data-management-and-sharing-policy/sharing-scientific-data/repositories-for-sharing-scientific-data
2. https://sparc.science/contact-us?source_url=%2Fshare-data
3. https://sparc.science/news-and-events/community-spotlight/success-stories/unraveling-cardiac-autonomic-innervation-for-precision-neuromodulation
4. https://docs.sparc.science/docs/sparc-data-persistence-policy
5. https://sparc.science/share-data
6. https://sharing.nih.gov/data-management-and-sharing-policy/planning-and-budgeting-for-data-management-and-sharing/writing-a-data-management-and-sharing-plan#after
7. https://sparc.science/about/what-we-offer/sparc-services-offered
8. https://sparc.science/contact-us?source_url=%2Fshare-data

DRC Collaborations

Members of the DRC participate in a diverse array of projects that help us further develop the SPARC platform and associated tools:

Common Fund Data Ecosystem (CFDE)

SPARC is a member of CFDE [1], an effort to accelerate discovery by enabling the broad use of the wide range of diverse and valuable data and knowledge arising from Common Fund data. Common Fund Data Coordinating Centers (DCCs) share metadata in a common format, allowing users to search across all the DCCs [2]. SPARC plays a leadership role in several aspects of the collaboration and participates in working groups and partnerships to integrate other key pieces of Common Fund resources.

HuBMAP

A new collaboration underway between SPARC and another CFDE member, HuBMAP, will ultimately provide a straightforward mechanism to align and enhance use of terminology for anatomical structures, cell types, and biomarkers across the two platforms. The focus of HuBMAP is to create a global atlas of the human body at the cellular level. They capture the hierarchical structure of human organ systems from the gross anatomical structure scale to subcellular biomarker scale in anatomical structures, cell types, and biomarkers (ASCT+B) tables. A key deliverable of SPARC is SCKAN, a semantic store of detailed connectivity information on the autonomic nervous system. This collaboration between SPARC and HUBMAP is building enhanced ASCT+B tables covering the PNS using SCKAN's sophisticated connectivity knowledge model.

Acupoints

Members of K, MAP and SIM are participating in the Acupoints project unded through the NIH's National Center for Complementary and Integrative Health to develop a database detailing the structural and functional details of points in human anatomy that are relevant to traditional eastern medicine. In particular, the goals are to: [a] Collect and organize knowledge about the location and usage of acupuncture points from clinicians and acupuncture researchers; [b] Generate an in-depth mapping of acupoints using magnetic resonance imaging in live subjects; [c] Create functional anatomical models based on SPARC's ApiNATOMY [3] to organize multiscale anatomical schematics with associated phenotypic information; [d] Build a relational database linking the anatomical location of acupoints to other important existing databases including SPARC. The Acupoint effort will allow the integration of existing knowledge on the neural effects of acupuncture with new knowledge in other domains as it emerges, such as on the relationship of acupoints to paths of interstitial fluid flow. SPARC DRC functionality is used throughout, from registration, to the simulation of nerve recruitment.

FAIR DOs

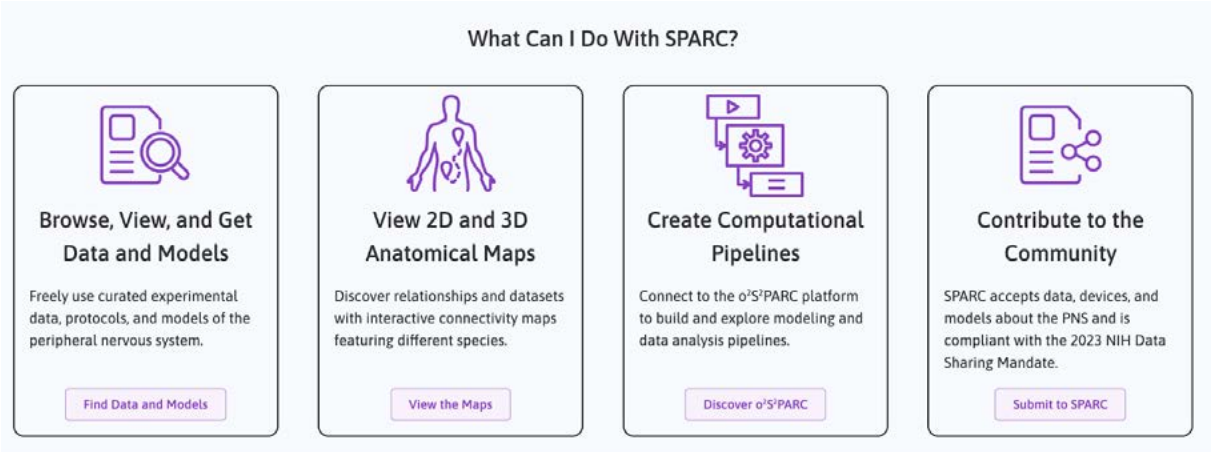
Findable, Accessible, Interoperable, Reusable: Development Of Simulations (FAIR DOs) is a 5-year NIDDK research education program to K and MAP in the modeling and simulation of digestive and renal neurobiology.

1. https://commonfund.nih.gov/dataecosystem
2. https://app.nih-cfde.org/
3. https://sparc.science/resources/1ZUKXU2YmLcn2reCyXjlew

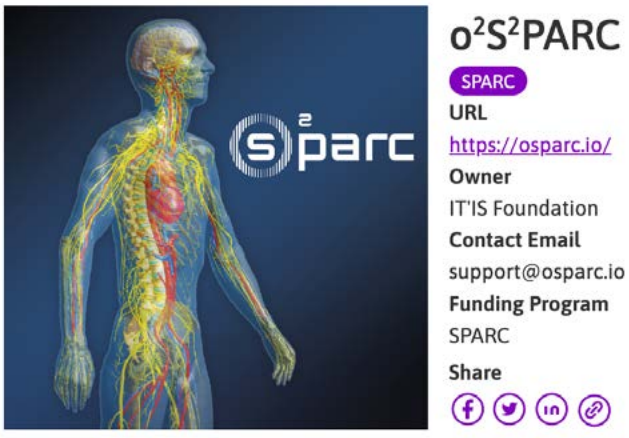
The main thrust of FAIR DOs is to educate the next generation of researchers and clinicians in the neural regulation of digestive and renal epithelia through modules taught online and supervised modeling projects that make use of SPARC datasets, maps and models. Overall, FAIR DOs aims to provide about 40 hours of training to about 50 students over the proposed five year project, with each student research project producing one publication. The SPARC Portal will provide findability to these student-generated open-access models and associated data via its Search and Flatmaps functions, as well as accessible interactivity via the o²S²PARC simulation platform. Overall, the FAIR DOs effort will provide a unique educational, mentored experience that will also generate a SPARC ecosystem of interoperating models that coherently study the neurobiology of digestive and renal epithelial transport.

Advancing Portal Functionality

The SPARC Portal acts as the interface between the resources created by SPARC and the broader scientific community. In addition to open-source data and models, we offer anatomical connectivity maps, a computational platform and access to other tools and resources. As such, the DRC works to improve Portal functionality, increase integration of DRC resources and technology, create new documentation and tutorials, and opportunities for community interactions.



Integration of Computational Models via o²S²PARC



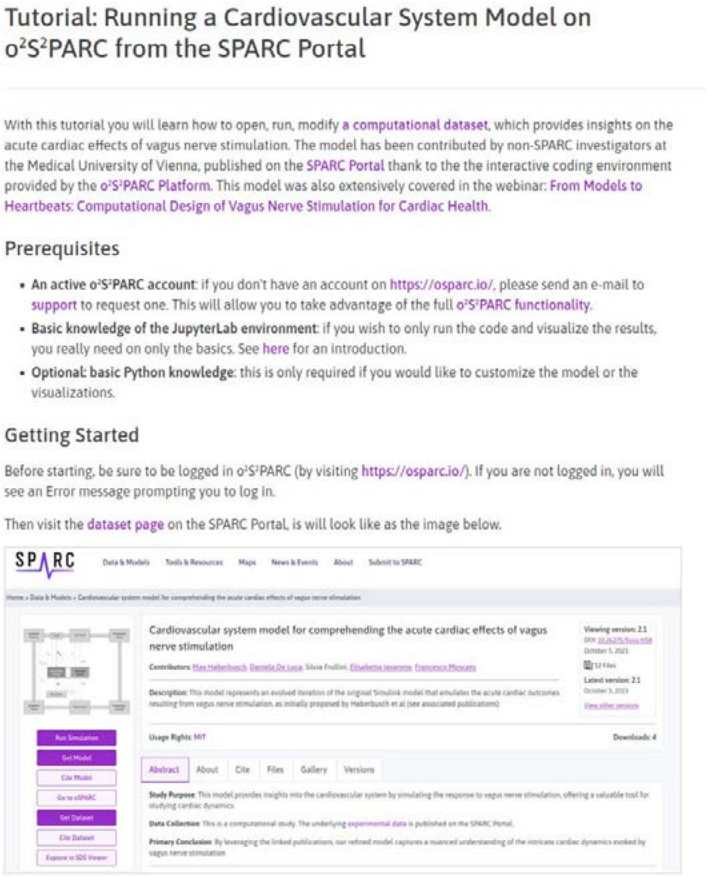
The computational o²S²PARC platform is an open, cloud-based, powerful DRC resource. It allows researchers to develop and share simulations according to the FAIR principles, allowing simulations to be launched from the SPARC Portal. o²S²PARC is now highlighted on the homepage to improve discovery and a dynamically updated list of o²S²PARC Services is accessible on a dedicated page [1], allowing users to initiate that service directly from the Portal. Any data item from the Portal can now be transferred to o²S²PARC for further analysis through a

1. https://sparc.science/resources/osparc-services

dedicated button, and advanced o²S²PARC processing functionalities compatible with specific data types are suggested in a dialog.

New Tutorials Illustrating Advanced Computation Use Cases

A new tutorial [1] on SPARC's help pages gives visitors step by step information on how to run and adapt a sophisticated cardiovascular regulation model realized on o²S²PARC (M. Haberbusch et al., , 2023 [2]) using an experimental dataset published on the SPARC Portal (B. Kronsteiner et al., 2023 [3]). This work was also featured in a webinar that described the use of SPARC resources, such as o²S²PARC, for the design of a novel regenerative neural interface, for the optimization of stimulation parameters, and for model-based intelligent closed-loop control using the cardiovascular regulation model from the tutorial.


Tutorial: Running a Cardiovascular System Model on o²S²PARC from the SPARC Portal

With this tutorial you will learn how to open, run, modify a computational dataset, which provides insights on the acute cardiac effects of vagus nerve stimulation. The model has been contributed by non-SPARC investigators at the Medical University of Vienna, published on the SPARC Portal thank to the the interactive coding environment provided by the o²S²PARC Platform. This model was also extensively covered in the webinar: From Models to Heartbeats: Computational Design of Vagus Nerve Stimulation for Cardiac Health.

Prerequisites

- An active o²S²PARC account: if you don't have an account on https://osparc.io/, please send an e-mail to support to request one. This will allow you to take advantage of the full o²S²PARC functionality.
- Basic knowledge of the JupyterLab environment: if you wish to only run the code and visualize the results, you really need on only the basics. See here for an introduction.
- Optional: basic Python knowledge: this is only required if you would like to customize the model or the visualizations.

Getting Started

Before starting, be sure to be logged in o²S²PARC (by visiting https://osparc.io/). If you are not logged in, you will see an Error message prompting you to log in.

Then visit the dataset page on the SPARC Portal, is will look like as the image below.

A second new tutorial [4] details how to run ASCENT (Automated Simulations to Characterize Electrical Nerve Thresholds), a pipeline for sample-specific computational modeling of electrical stimulation of peripheral nerves on the o²S²PARC platform (Marshall et al., 2023 [4]; Marshall et al., 2023 [76]). The ASCENT Pipeline was developed by SPARC investigators at the Grill Lab, Duke University [Ref: 2].

SPARC Connectivity Knowledge Base (SCKAN)

SCKAN is a unique resource developed to capture expert knowledge about ANS connectivity in a machine computable knowledge base that allows query and reasoning. SCKAN models connections at the neuron population level, specifying the locations of cell bodies, axons, axon terminals and synapses, and synaptic targets via the Neuron Phenotype Ontology [Ref: 3].

SCKAN is currently used to generate the connections seen in SPARC Maps [7]. The DRC has been working on a suite of tools around SCKAN to make it more easily accessible to Portal visitors with the ultimate goal of encouraging contributions to the contents of SCKAN from the greater scientific community. SCKANNER [8] is

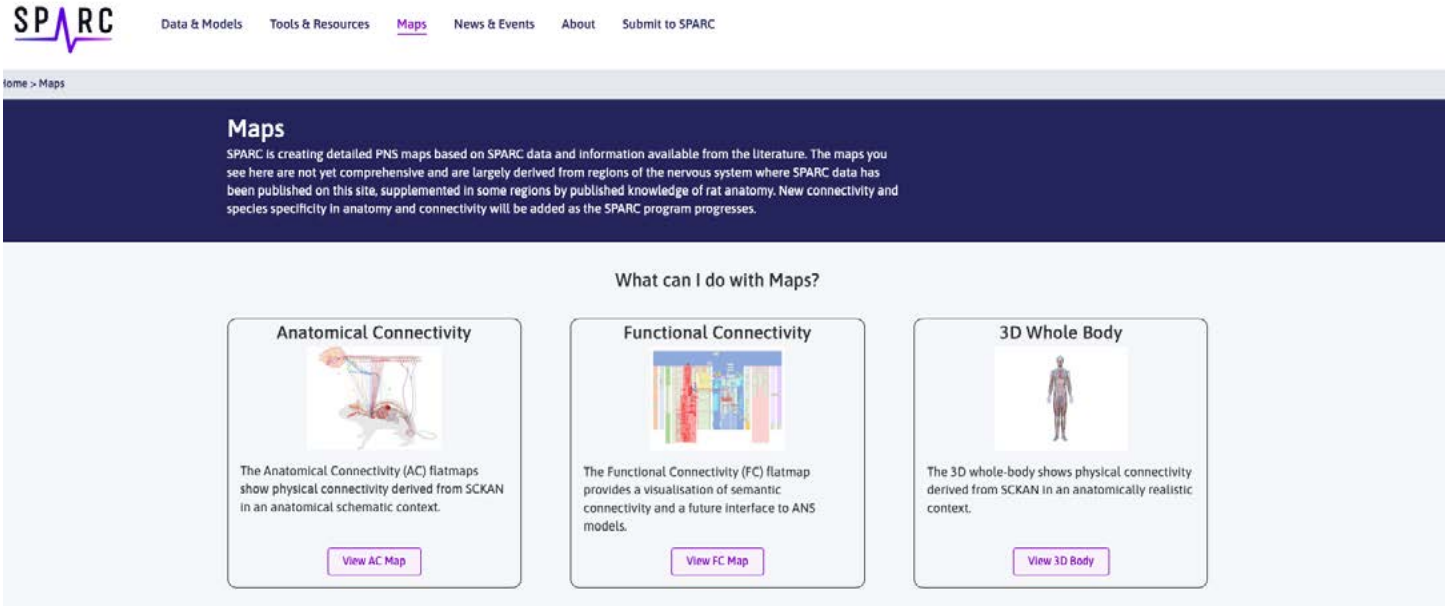
1. https://docs.sparc.science/docs/tutorial-running-a-cardiovascular-system-model-on-o2s2parc
2. https://doi.org/10.26275/5YVU-TR0D
3. https://doi.org/10.26275/gfwu-pi0p
4. https://docs.sparc.science/docs/tutorial-running-ascent-on-o2s2parc-from-the-sparc-portal
5. https://doi.org/10.26275/3d2g-d3xd
6. https://doi.org/10.26275/0jz3-zrlo
7. https://sparc.science/maps?type=ac
8. https://sparc.science/resources/3Ad4kbyYnXsUtzRFzUguwg

a new tool that allows users to quickly visualize and explore the contents of SCKAN; SCKAN Composer [1] is a specialized interface used to help author and QC connectivity statements in SCKAN. SCKAN Composer will be released to a larger audience later in 2024.

Maps

The SPARC Portal offers detailed PNS maps based on SPARC data and information collected from literature and expert knowledge. Currently three different maps are available:

1. **Anatomical Connectivity (AC)**. The AC flatmaps show physical connectivity derived from SCKAN in an anatomical schematic context (e.g. a schematic of these connection locations in the body).
2. **Functional Connectivity (FC)**. The FC map was introduced to the Portal in spring of 2023 with significant user interface and user experience design modifications including a legend to help control use/ navigation. The purpose of the FC map is primarily to represent the semantics and connectivity of the body's anatomical and physiological organization. The connectivity information is provided by SCKAN and is consistent with the AC flatmap. In the near future, it will provide a user interface to modeling studies that will be designed to address the integrative physiological function of the body.
3. The **3D whole-body map** shows physical connectivity in an anatomically realistic context.

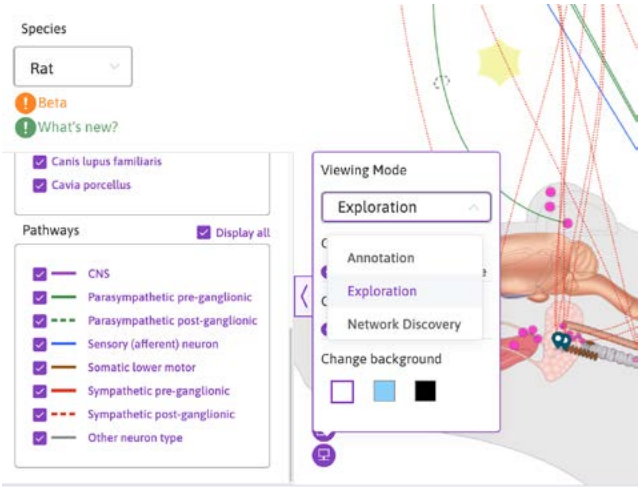


New functionality has been developed for the viewing and exploration of these three types of maps. In addition to the standard default **exploration** mode, two others have been added:

1. **Annotation mode** - when a specific feature on the map is selected, a pop-up appears with the ability to add comments. This feature is currently only available to invited users who are logged into the SPARC Portal. Comments will be curated and new information made available via SCKAN.

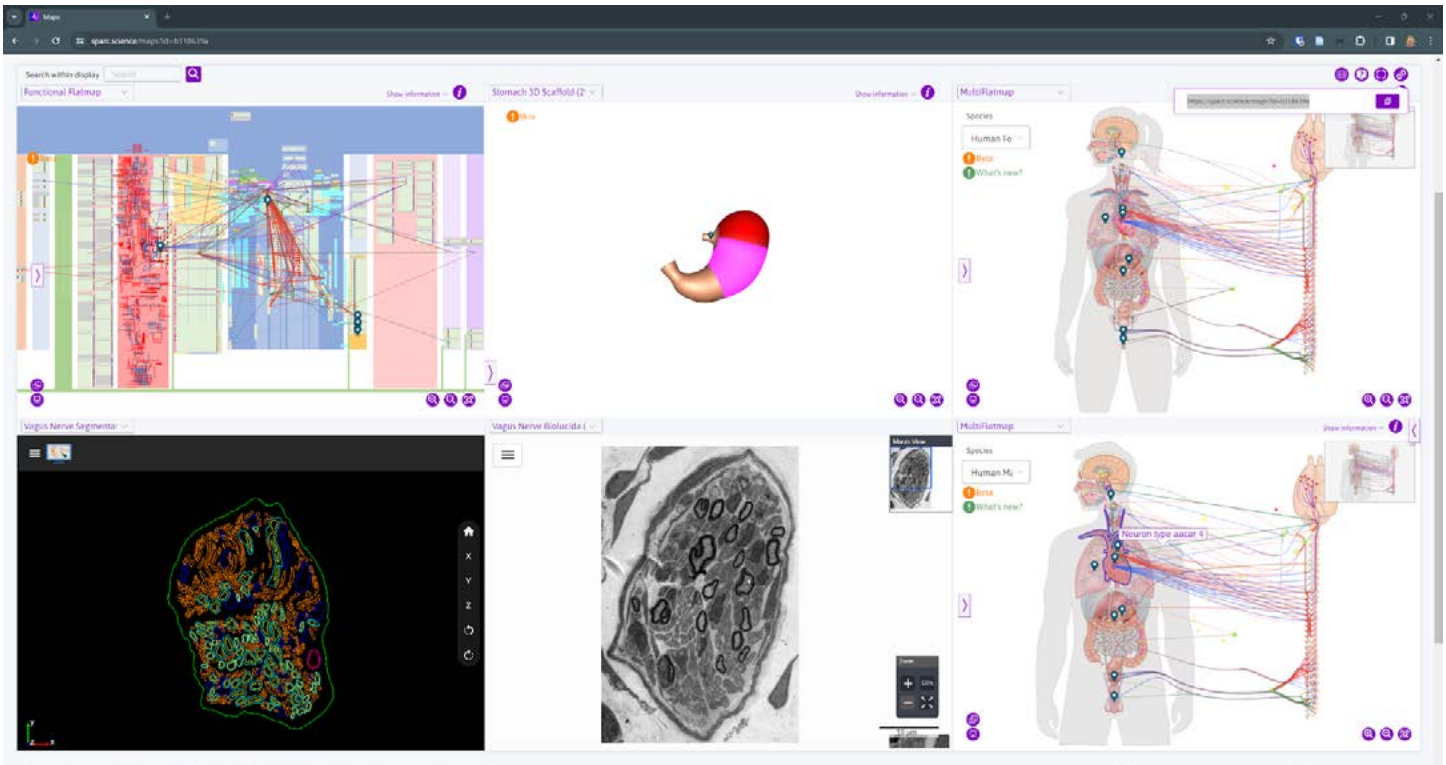
1. https://sparc.science/resources/4oPAixBK4U9vG5UZjddsae

2. **Network Discovery mode** - selecting any feature on the map such as ganglia, neuron, organ, or pathway will highlight everything connected to that feature. The larger (and future) aim of this functionality is the representation of on/off effects of stimulation.



Split Screen Functionality

The map interface on the SPARC Portal was improved with the split screen functionality allowing for viewing/comparison of multiple flatmaps, for example to compare species and sexes. It is now possible to open another map (AC, FC, or 3D) from a currently opened map, and to create split screens where these maps are synchronized (mouse-over on one highlights the corresponding structure on the other). The split screen option has been extended from 4 to 6 panes in response to feedback from Phase 2 awardees.



Contents of SCKAN Visualized in Maps

The connections in the AC and FC maps are automatically populated using the knowledge obtained from SCKAN, allowing us to expand and edit these connections as our knowledge evolves. The SCKAN knowledge model also provides species and sex information, noting the species in which a particular connection was observed. Species-specific information can be selected on AC maps using the legend. We have recently added sex-specific information as well.

Browse, View, and Get SPARC Data and Models

As the number of high-quality FAIR data and computational models on the SPARC Portal continues to grow, we have been implementing improvements to find and access SPARC data.

Facets Expanded

A challenge with offering a wide variety of data and models is ensuring users can find items of interest to them. To aid filtering, SPARC offers both keyword search and structured facets-these are created when our curators map key metadata from each data or model to facets. To help orient users, specific anatomical structures have been added to the system. We recently added hierarchical facets to make it easier to group facets for individual systems.

SPARC Dataset Structure (SDS) and SDS Viewer

The SPARC dataset structure (SDS [1]) is the organizational file system required for all data and models shared on the SPARC Portal [Ref: 4]. This promotes consistency and ensures other investigators can easily understand your data or models. Part of that comes from the folder/file organization and part of it comes from the associated metadata files.

The SDS is extended by a minimal information standard (MIS)[Ref: 5] that strengthens the findability aspect of FAIR by providing rich meta-data and annotation with standardized ontological classifiers. The MIS underlies the SPARC Knowledge Graph that supports search across the Portal. A recent extension for computational models, cMIS, supports aspects related to modeling reproducibility and model quality assurance, e.g., by encompassing a variant of the Ten simple rules for evaluating model credibility [2]. For models that have been onboarded on o^{2}S^{2}PARC, the necessary cMIS documents can be autogenerated.

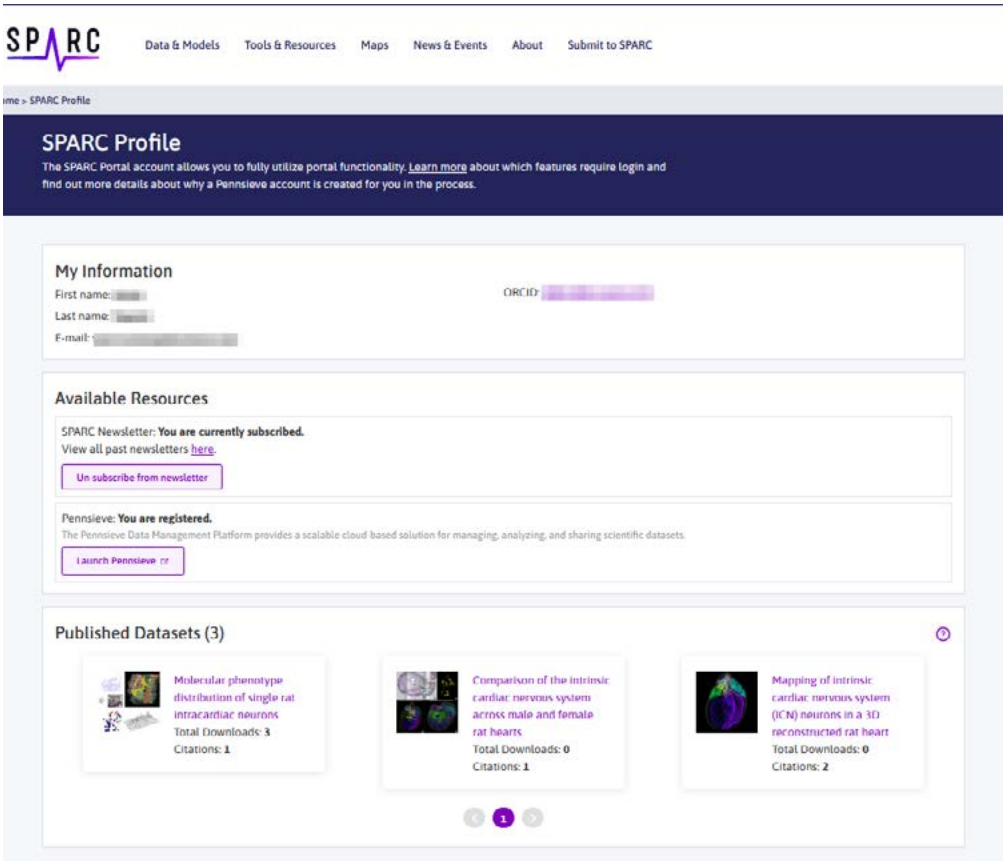
The SDS has recently been endorsed as an INCF Community standard [3]. INCF promotes the uptake of FAIR data management practices through the development of standards and best practices that support open, citable neuroscience.

We recently incorporated an SDS viewer into the SPARC Portal to allow users to more easily understand the overall structure of a dataset and to associate specific metadata with files and folders. The SDS Viewer can now be launched directly from datasets and models on the Portal, allowing visitors to fully explore them before downloading them. The SDS Viewer is one of the first 3rd party tools that has been incorporated into the Portal.

1. https://docs.sparc.science/docs/sparc-dataset-structure
2. https://www.imagwiki.nibib.nih.gov/content/10-simple-rules-conformance-rubric
3. https://www.incf.org/sparc-data-structure

Login Functionality on Portal

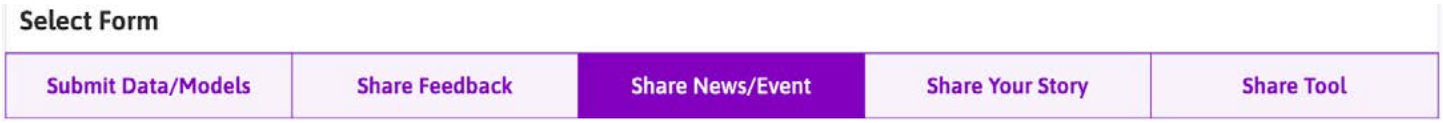
While most resources available publicly on the SPARC Portal do not require an account, some functions, such as requesting access to embargoed data, require that users be logged in. SPARC Portal user credentials are managed by Pennsieve [1], which allows users to register and login with an email and password, or with their ORCID credentials.



Since this feature was first introduced in December 2022, we have been expanding the login functionality to other features, such as implementing access control to the annotation tools being deployed in SPARC maps and for the forthcoming unified login for o^{2}S^{2}PARC.

Contribute to the SPARC Community

The SPARC Community can communicate with us through forms tailored to gather information for communications directly with the DRC, such as sharing feedback, bug reports, collaboration requests, or special contact requests. People can also share items such as a tool or resource that would be suitable for listing in our resource catalog. We also welcome relevant news, events or user stories highlighting how you have used the SPARC Portal to further your own work.



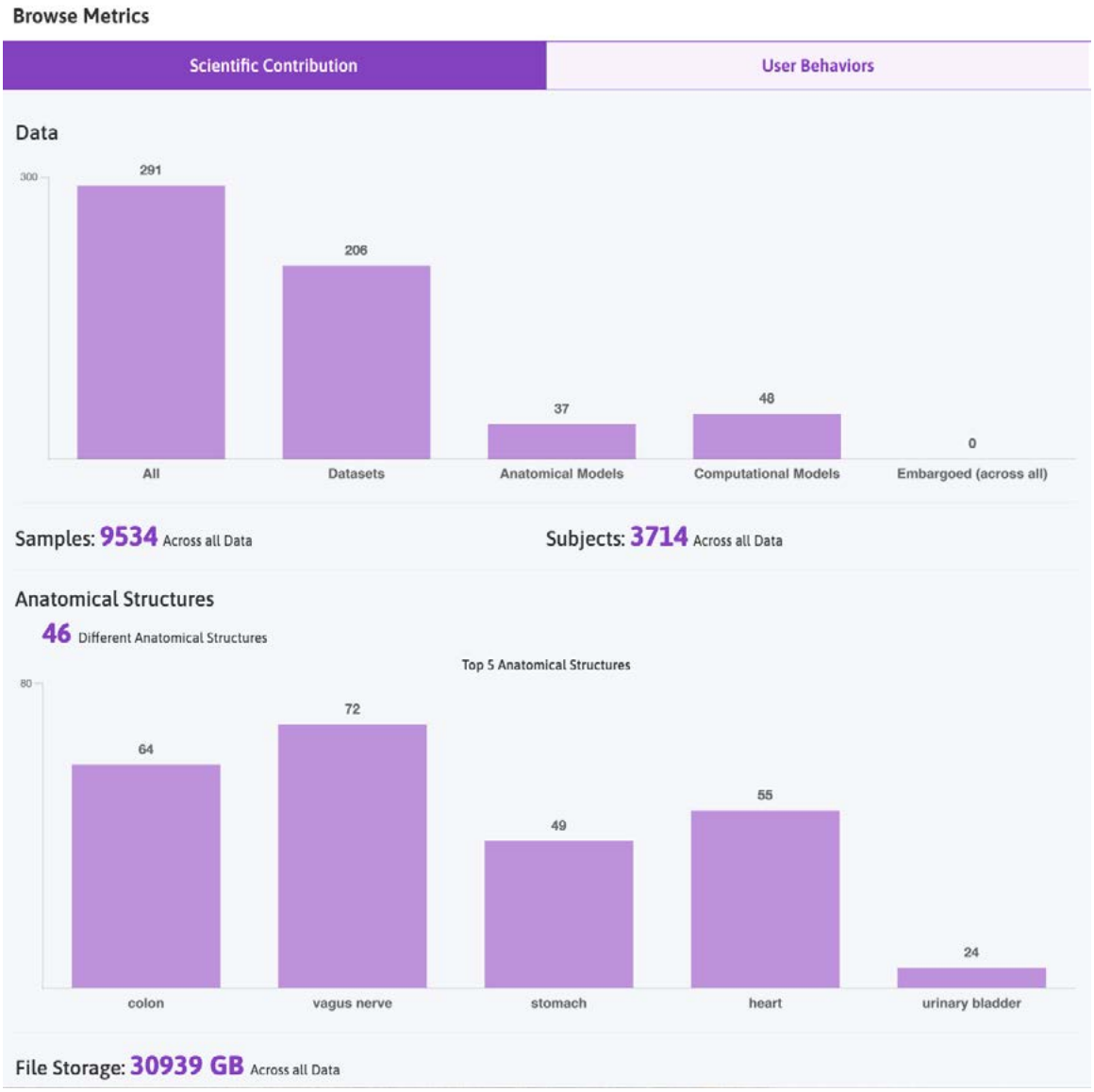
1. https://sparc.science/resources/2j9lC0YFl5P34wGlkJOb49

General SPARC Portal Enhancements

In addition to the newly introduced functionalities highlighted above, we have made several other changes to the Portal to ensure that our users have the information and functionality they require in a clear and user friendly manner.. Most of these changes are a result of direct user feedback via our on-line form or through direct interactions with our communities. An overview of updates and modifications can be found in our changelog [1].

Metrics

The DRC has recently invested in automating and enhancing metrics collection to better gauge our users' interest in what we offer and overall efficacy of our outreach efforts. An exciting new addition is public-facing metrics [2] on the Portal. These show a breakdown of types of data and models hosted on the Portal, the number of new additions in the past month, information about the number of computational studies and analyses conducted and associated resource use, as well as some basic user behaviors.



1. https://docs.sparc.science/changelog
2. https://sparc.science/about/metrics?metricsType=scientificContribution

New Features-Coming Soon!

The DRC is preparing to make significant changes to the Portal this next year with new datatypes and collections functions. Each consortia will receive their own landing page to highlight each project, and provide easy access to their products.

Devices Category

To support HORNET and others in our community developing open-source devices, we will be adding a new category to SPARC Data & Models called **Devices**. Similar to datasets found under the Dataset, Computational, and Anatomical Models categories, datasets in this category will include a landing page, a DOI, specifications and other key information to aid those interested in using these important products. The device pages will also offer direct access to device CADs and the ability of leveraging them in simulation studies.

New Dataset Types

SPARC is expanding our dataset feature. We are adding two new dataset types to support our Phase 2 projects and other groups submitting their research outcomes to SPARC. As with other SPARC datasets, they will include a landing page, a DOI, and key information to aid those interested in doing more with these important findings.

GitHub Release Dataset Type: To support HORNET and others in our community developing devices and open-source device software and other code, we will provide a mechanism to publish a specific release of a public GitHub repository with a DOI to ensure citability, documentation traceability, and provenance to the contributors and users.

Collection Dataset Type: Collection type datasets can be used to group together related datasets, models, or devices. Stay tuned for details and examples!

New Features to Explore Vagus Nerve Data

The DRC will combine their expertise to build technical tools around the data being generated in Phase 2 to explore datasets and for use in modeling the vagus nerve.

Dashboard - Integrated Navigation of Vagus Nerve Datasets: To allow users to explore, visualize, and navigate SPARC 2 data, the DRC is creating a dashboard feature that can access different DRC tools, resources, and services as applications or widgets. This new capability is being created as an interface to surface the location of vagus nerve data, visualize vagus nerve imaging, and to graphically display quantitative information collected in the experiment. This is another example of the DRC's commitment towards integrating and amplifying the impact of research.

Quantitative Database: A quantitative database (QDB) is also being developed that will be used to capture and serve values and measurements shared by SPARC 2 projects. These values will be utilized to feed the Dashboard or to provide information about probability distributions and variability that can be propagated through o^{2}S^{2}PARC computational pipelines, to quantify uncertainty and assess variability, e.g., the In Silico Neural Interface Safety Assessment.

Neural Interface Information

As part of HORNET, implantable neuro-stimulation and -sensing hardware is being developed. While the actual designs are hosted on git-repositories, the Portal will not just link to these repositories, but will offer advanced functionality:

- CAD Modeling and Publication: Neural interface CAD models can be inspected on o²S²PARC and CAD editing functionality is offered through the Sim4Life service on o²S²PARC that permits to adapt the neural interface geometry and to publish design variants.
- Integration of Neural Interface Designs with Anatomical Models: CAD modeling functionality also permits to integrate neural interface models with anatomical models of nerves and their environment. Once REVA data is published, functionality to easily generate nerve models from REVA histological data and integrate neural interface geometries will be released.
- Neural Interface Safety Assessment: During the current SPARC year, in silico neural interface safety assessment is being performed for a specific HORNET interface (see as well In Silico Neural Interface Safety Assessment). That study will be made accessible through the SPARC Portal and is meant to serve as guidance for realizing similar studies for other nerves and interfaces.

In Silico Neural Interface Safety Assessment

The ultimate goal of this activity is to establish an in silico pipeline for quantifying a wide range of safety relevant metrics (charge accumulation, dosimetric exposure metrics, a tissue damage predictor, heating) for a given stimulation electrode design and stimulation condition. The pipeline is designed to be able to run as high-throughput screener, once the required vagus nerve data from REVA becomes available and the quantitative database has been populated. This will enable developers and users of neural interfaces to create supporting regulatory evidence, but also to optimize safety. Information about variability will be derived from the Quantitative Database, while the meta-modeling functionality of o²S²PARC is used for uncertainty propagation.

SPARC's Open Development Framework

The DRC embraces an open development framework, key components of the SPARC infrastructure are open-source projects [1]; the SPARC GitHub organization [2] provides access and documentation for these projects. For access to SPARC data, models, tools, and resources, we have released a new SPARC Python Client [3] that provides an installable client for data analysts and others to access and analyze SPARC datasets to discover new insights and research outcomes. With centralized client-based infrastructure, users can now access essential functions in python modules from each DRC-Core's services from one entry point and centralized authentication. Tutorials ranging from 'how to get started' to demonstrating cross-core service integration can be found in the SPARC Help Center [4].

1. https://docs.sparc.science/docs/sparc-sustainability-statement#open-source-projects
2. https://github.com/nih-sparc
3. https://docs.sparc.science/docs/sparc-python-client
4. https://docs.sparc.science/docs/getting-started-with-the-sparc-python-client

The DRC continues to expand its documentation and tutorial offerings to promote users tapping into the potential of the SPARC open-source framework. Use the SPARC Python Client to:

- Programmatically access the data published on the Portal and develop tools on top of this functionality
- Search metadata of content on the Portal
- Setup, execute, and monitor computational pipelines using o²S²PARC resources
- Develop guided applications leveraging SPARC modeling functionalities (e.g., for treatment planning)
- Run parallel data analysis and set up on-demand computational cloud infrastructure on o²S²PARC (along with resource and usage tracking)

SPARC APIs and Open Access Code

Additional functionality is offered in other SPARC services.

- Manage your data submissions within Pennsieve [1], a scalable, cloud-based solution for collaborative scientific data management
- Prepare datasets for submission using SODA [2] (Software to Organize Data Automatically). An open-source and free cross-platform desktop software intended to facilitate the process of preparing and submitting datasets according to the FAIR SPARC data curation guidelines
- Map your own data to SPARC resources and explore the unique integrated visualizations SPARC provides using Scaffold Mapping Tools [3] and documentation
- Set up a web-based display and interaction with maps with Map Integrated Vuer [4]
- Programmatically access the Anatomical Connectivity flatmaps [5] server, viewer, maker and associated tools
- Launch customized simulations on o²S²PARC infrastructure directly from the SPARC Portal and visualize results on the Portal or in o²S²PARC (see the Simulation Vue component [6])
- Graphically create step-by-step guided applications for non-modeling experts out of complex o²S²PARC modeling pipelines into (see o²S²PARC manual [7] and webinar [8]).
- Access and query connectivity information in SCKAN [9]
- Interact with the Ontologies used by SPARC and SPARC vocabularies [10]

1. https://github.com/orgs/Pennsieve
2. https://github.com/fairdataihub/SODA-for-SPARC
3. https://sparc.science/resources/1mv8q3JckdpSYpPK9dvdKx
4. https://github.com/ABI-software/mapintegratedvuer
5. https://github.com/AnatomicMaps
6. https://github.com/ABI-software/simulationvuer
7. https://docs.osparc.io/#/docs/platform_introduction/appmode?id=app-mode
8. https://youtu.be/iUURTgYteEc
9. https://github.com/SciCrunch/NIF-Ontology/releases
10. https://github.com/SciCrunch/NIF-Ontology

- Utilize SDS validator and curation and knowledge management workflow tools [1] for SPARC datasets, protocols, and anatomical connectivity.
- View SPARC datasets using the SDS viewer [2] which is able to graphically represent datasets that follow the SPARC Dataset Structure
- Contribute to the SPARC Portal (SPARC App [3]) which is built using the SPARC Portal API [4]

Supporting User Developed Tools and Resources

SPARC Annual Codeathon

The SPARC DRC hosts an annual virtual codeathon (2024 [5] coming soon!) to foster a collaborative developer and analytical PNS community. Codeathon themes focus on novel ways to use and further develop interactions between SPARC Data, Models, and/or SPARC Tools and Resources by enhancing, demonstrating, or measuring their FAIRness. Codeathon projects need to demonstrate the value of SPARC's public data, and/or directly integrate with SPARC Tools and Resources to improve or extend their existing capabilities via the various open-source resources. Did you know that the SODA [6] tool was initially developed as a codeathon project? Read all about it in their success story [7]. The 2023 FAIR Codeathon Grand Prize winner, SPARC-me [8], a python tool created to explore, enhance, and expand SPARC datasets is still in use today by an external project that has adopted the SPARC dataset structure. Codeathon projects from previous years are also published on the SPARC Portal and can be interactively explored on the o^{2}S^{2}PARC Platform (see search result on the Portal [9]).

Software to Organize Data Automatically (SODA)

SODA for SPARC [6] was developed during the inaugural 2018 SPARC Codeathon. It has grown into an integral SPARC tool that is professionally developed and maintained by the FAIR Data Innovations Hub, a division of the California Medical Innovations Institute (CalMI2). This open-source, cross-platform desktop software utilizes SPARC open development resources to guide users through the process of preparing their data and metadata in line with the SDS and uploading the resulting dataset for publication on SPARC.

SODA has inspired several other tools developed by the FAIR Data Innovations Hub such as FAIRshare [10] through support from the NIAID and fairhub.io [11] through support from the NIH Bridge2AI [12] Program. The codebase of SODA was also forked by another team that is developing a tool called NWB GUIDE [13] to simplify the process of preparing and sharing data from the NIH Brain Initiative Program.

1. https://github.com/SciCrunch/sparc-curation
2. https://github.com/MetaCell/sds-viewer
3. https://github.com/nih-sparc/sparc-app
4. https://github.com/nih-sparc/sparc-api
5. https://sparc.science/news-and-events/events/2024-sparc-fair-codeathon
6. https://sparc.science/resources/3tqPcCS1kPTkCIwrvPDIcB
7. https://sparc.science/news-and-events/community-spotlight/success-stories/sharing-is-caring-making-sparc-data-fair-with-soda
8. https://sparc.science/resources/3rj8s43aRzhOx5SbYzmFe3
9. https://sparc.science/data?type=simulation&search=codeathon
10. https://github.com/fairdataihub/FAIRshare
11. https://github.com/AI-READI/fairhub.io
12. https://commonfund.nih.gov/bridge2ai
13. https://github.com/NeurodataWithoutBorders/nwb-guide

SPARC Vocabularies

SPARC has developed a large corpus of terms called the SPARC vocabulary [1], [Ref: 6] that represents terms and relationships to encode knowledge and annotate data. This includes community ontologies as well as a large number of terms vetted by SPARC anatomical experts. When new terms are created that are appropriate for an existing ontology, they are submitted for addition to that ontology. The SPARC vocabulary is programmatically available via SciGraph [2] and will be available in the Python Client in the future. This past year we have created a special list of terms for the REVA project that includes over 1000 terms, over 80% are unique ones specifically for annotation of their datasets using MBF [3] tools. Each term is engineered to integrate within the existing ontological hierarchy to allow computational reasoning.

Cultivating the SPARC User Community

We offer several options to stay abreast of how to touch base with us. Visit our News & Events [4], sign up for our mailing list [5], join or follow our LinkedIn page [6], or follow us on X (formerly Twitter) [7]. Or join us at our next virtual SPARC Codeathon [8]!

In-Person Outreach Efforts

Come and meet us! In 2024 you can find us in the SPARC exhibitor booth at:

- North American Neuromodulation Society (NANS)
- American Physiology Summit (APS)
- 11th Annual Minnesota Neuromodulation Symposium (Neuromod)
- International Society for Autonomic Neuroscience (ISAN)
- Society for Neuroscience (SfN)

In addition to the booths, members of the DRC often present workshops or other symposia. Two such workshops will be offered at APS 2024 [9], “SPARC as a FAIR community resource” and “Using SPARC to ignite the power of FAIR data.” A joint DRC and SPARC investigator symposia is planned for ISAN.

We frequently have a presence at other meetings such as the Neuroinformatics Assembly, the American Autonomic Society, and the Society for Pelvic Research.

1. https://sparc.science/resources/5sLm5voiQkkTUenmhIyshf
2. https://github.com/SciCrunch/sparc-curation/tree/master/resources/scigraph
3. https://www.mbfbioscience.com
4. https://sparc.science/news-and-events
5. https://science.us2.list-manage.com/subscribe?u=e60c48f231a30b544eed731ea&id=c81a347bd8
6. https://www.linkedin.com/company/86939679/
7. https://twitter.com/sparc_science
8. https://sparc.science/news-and-events/events/2024-sparc-fair-codeathon
9. https://www.physiology.org/professional-development/meetings-events/american-physiology-summit?SSO=Y

SPARC Webinars

SPARC offers a number of webinars, with a range of topics: hot research, education around SPARC resources, interviews, and news. Explore the diverse offerings on the SPARC.SCIENCE YouTube channel [1]. Two recent webinars offered by the American Physiology Society highlighted DRC accomplishments and competencies,

From Models to Heartbeats: Computational Design of Vagus Nerve Stimulation for Cardiac Health [2] included presentations by Max Haberbusch, PhD and the DRC's Esra Neufeld. This webinar can be viewed on demand and provides a view on the ongoing research on model-based intelligent control and in silico regulatory evidence and trials for safety and efficacy assessment. This well-attended webinar was promoted by the following societies: American Autonomic Society, American Physiological Society, Society for Neuroscience, and Federation of European Neuroscience Societies. This webinar was accompanied by the publication of an experimental and a model dataset, see New Tutorials Illustrating Advanced Computation Use Cases for more information.

In SPARC Tools for Integrative Physiological Modeling [3], DRC PIs Maryann Martone, PhD, and Peter Hunter, PhD, discussed the SCKAN knowledge base, SPARC Knowledge Graph and the potential uses of the SPARC Portal for the wider range of physiological processes and modeling. Nearly 250 people registered to attend this webinar.

Education and Training Activities

SPARC resources can also be used for education and training activities. Some examples include:

- FAIR DOs course offered at Carnegie-Mellon University based on SPARC resources.
- Extended and tailored training to various research groups on using o^{2}S^{2}PARC for their research and modeling purposes.
- Incorporation of o^{2}S^{2}PARC as a teaching tool by different institutions e.g., as part of hands-on exercises for a lecture on bioelectronic medicine in Italy, a course on computational life sciences in Switzerland, and an international PhD exchange framework.

User Support and Documentation

In addition to the contact forms we host a large number of documents and tutorials to help users navigate different aspects of SPARC at the SPARC Help Center [4]. For those that prefer videos, visit our SPARC.SCIENCE YouTube channel [1] for documentation, presentations, and discussions. We also offer open office hours [5], where people are encouraged to come and chat with us.

1. https://www.youtube.com/channel/UCCmUx4tOSlTAwlUrjSGz2mw
2. https://insidescientific.com/webinar/from-models-to-heartbeats-computational-design-of-vagus-nerve-stimulation-for-cardiac-health/?utm_bmcr_source=SPARC
3. https://sparc.science/news-and-events/events/webinar-knowledge-base-and-mapping-tools-for-integrative-physiological
4. https://docs.sparc.science/
5. https://docs.sparc.science/docs/sparc-drc-open-office-hours

SPARC Impact and Growth

Since the beginning of 2021, we are seeing significant year over year increase on the number of SPARC dataset and model downloads. The 200+ protocols published by SPARC investigators in protocols.io have been viewed collectively over 50,000 times. Individual protocols reach as many as 2,000 views and many have been exported more than 100 times. The increased interest in the tools and resources developed by SPARC is also demonstrated by the increased number of users registered on the o²S²PARC platform [1]: since the end of 2022, this number has more than quadrupled (from around 200 users to almost 1000). In addition, new usage metrics initiated in 2023, showed increased usage of the platform; for example, since the end of September 2023, 218 studies on the o²S²PARC platform were repeatedly used (i.e. accessed more than 5 times).

We gather metrics about publications that reference dataset DOIs and are beginning to see more publications that use data shared on the Portal by other research groups (see Appendix).

1. https://sparc.science/resources/4LkLiH5s4FV0LVJd3htsvH

What's Next for SPARC

We are looking forward to another growth year as SPARC manages its transition from a resource developed to support a specific NIH program to an open repository model that reaches beyond the original scope of the SPARC program. The SPARC Portal and its underlying components is becoming a critical component of the overall biological open repository landscape. Like any government-funded infrastructure project, we are reviewing methods and capitalizing on opportunities that will offer longer-term support to the SPARC Portal and the technologies that underlie SPARC. We at the DRC are committed to supporting the Portal and the SPARC community. For additional information about specific functionality planned for the next year, please visit the SPARC Portal Roadmap [1].

1. https://docs.sparc.science/docs/sparc-portal-roadmap

References

1. Osanlouy M, Bandrowski A, de Bono B, Brooks D, Cassarà AM, Christie R, et al. The SPARC DRC: Building a Resource for the Autonomic Nervous System Community. Front Physiol. 2021;12: 693735. doi:10.3389/fphys.2021.693735

2. Musselman ED, Cariello JE, Grill WM, Pelot NA. ASCENT (Automated Simulations to Characterize Electrical Nerve Thresholds): A pipeline for sample-specific computational modeling of electrical stimulation of peripheral nerves. PLoS Comput Biol. 2021;17: e1009285. doi:10.1371/journal.pcbi.1009285

3. Gillespie TH, Tripathy SJ, Sy MF, Martone ME, Hill SL. The Neuron Phenotype Ontology: A FAIR Approach to Proposing and Classifying Neuronal Types. Neuroinformatics. 2022;20: 793–809. doi:10.1007/s12021-022-09566-7

4. Bandrowski A, Grethe JS, Pilko A, Gillespie T, Pine G, Patel B, et al. SPARC Data Structure: Rationale and Design of a FAIR Standard for Biomedical Research Data. bioRxiv. 2021. p. 2021.02.10.430563. doi:10.1101/2021.02.10.430563

5. Gillespie TH, de Bono B, Boline J, Martone ME. The SPARC Minimal Information Standard (MIS). doi:10.5281/zenodo.5348190

6. Surles-Zeigler MC, Sincomb T, Gillespie TH, de Bono B, Bresnahan J, Mawe GM, et al. Extending and using anatomical vocabularies in the stimulating peripheral activity to relieve conditions project. Front Neuroinform. 2022;16: 819198. doi:10.3389/fninf.2022.819198

1. https://sparc.science/resources/4LkLiH5s4FV0LVJd3htsvH

APPENDIX

1. A novel statistical methodology for quantifying the spatial arrangements of axons in peripheral nerves [1]
    - Reuse of their own dataset and another SPARC dataset for segmentation model: L. A. Havton et al., "High-throughput segmentation of rat unmyelinated axons by deep learning." SPARC Consortium, 2023. doi: 10.26275/EEFP-AZAY [2]
2. Gut Analysis Toolbox: Automating quantitative analysis of enteric neurons [3]
    - Used two SPARC datasets for segmentation model:
        - K. D. Graham et al., "Robust 3-Dimensional visualization of human colon enteric nervous system without tissue sectioning." SPARC Consortium, 2020. doi: 10.26275/PZEK-91WX [4].
        - L. Wang et al.,, "Antibodies tested in the colon – Mouse." SPARC Consortium, 2021. doi: 10.26275/I7DL-58H1 [5]
3. Closed-loop modeling of central and intrinsic cardiac nervous system circuits underlying cardiovascular control [6]
    - Experimental values derived from SPARC dataset: P. Rajendran, M. Vaseghi, and J. Ardell, "Functional recordings from the pig intrinsic cardiac nervous system (ICN)." SPARC Consortium, 2019. doi: 10.26275/OWRI-MPSX [7].
4. Electroanatomical mapping of the stomach with simultaneous biomagnetic measurements - ScienceDirect [8]
    - Used SPARC scaffold: M. Lin, R. Christie, and P. Hunter, "Generic pig stomach scaffold." SPARC Consortium, 2022. doi: 10.26275/ZFBF-G88T [9].
5. Online Bayesian Optimization of Nerve Stimulation [10]
    - Used SPARC dataset to shape their models: M. Ward, et al., "Influence of left vagal stimulus pulse parameters on vagal and gastric activity in rat." SPARC Consortium, 2019. doi: 10.26275/QH3Q-ELJ6 [11].
6. Diffeomorphic Surface Modeling for MRI-Based Characterization of Gastric Anatomy and Motility [12]
    - Used SPARC scaffold: M. Lin, R. Christie, and P. Hunter, "Generic pig stomach scaffold." SPARC Consortium, 2022. doi: 10.26275/ZFBF-G88T [9].

1. https://www.frontiersin.org/journals/neuroscience/articles/10.3389/fnins.2023.1072779/full
2. https://doi.org/10.26275/eefp-azay
3. https://www.biorxiv.org/content/10.1101/2024.01.17.576140v1
4. https://doi.org/10.26275/pzek-91wx
5. https://doi.org/10.26275/i7dl-58h1
6. https://aiche.onlinelibrary.wiley.com/doi/full/10.1002/aic.18033
7. https://doi.org/10.26275/owri-mpsx
8. https://www.sciencedirect.com/science/article/pii/S0010482523008491
9. https://doi.org/10.26275/zfbf-g88t
10. https://www.biorxiv.org/content/10.1101/2023.08.30.555315v3.full
11. https://doi.org/10.26275/qh3q-elj6
12. https://ieeexplore.ieee.org/document/10011545

7. IMAGE-IN: Interactive web-based multidimensional 3D visualizer for multi-modal microscopy images [1]
    - Used multiple SPARC datasets for tool development:
        - S. Lee and L. Zeltser, "Visualizing sympathetic projections in the intact brown adipose tissue depot in the mouse." SPARC Consortium, 2020. doi: 10.26275/GE74-YPXD [2].
        - M. Howard, "3D imaging of enteric neurons in mouse." SPARC Consortium, 2021. doi: 10.26275/9FFG-482D [3].
        - J. Xia et al., "Submandibular ganglion stained by bungarotoxin and nanosensors in mouse." SPARC Consortium, 2020. doi: 10.26275/PRJD-JHOC [4].
        - P.-Q. Yuan, et al., "CLARITY and three-dimensional (3D) imaging of the mouse and porcine colonic innervation." SPARC Consortium, 2022. doi: 10.26275/SIP4-IOYZ [5].
        - M. Campbell-Thompson, et al., "Human islet microvasculature analysis." SPARC Consortium, 2021. doi: 10.26275/FCRD-LBID [6].

1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9803232/
2. https://doi.org/10.26275/ge74-ypxd
3. https://doi.org/10.26275/9ffg-482d
4. https://doi.org/10.26275/prjd-jhoc
5. https://doi.org/10.26275/sip4-ioyz
6. https://doi.org/10.26275/fcrd-lbid