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Enabling Global Image Data Sharing in the Life Sciences

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Abstract

Despite the importance of imaging in biological and medical research, a large body of informative and precious image data never sees the light of day. To ensure scientific rigour, as well as the reuse of data for scientific discovery, image data needs to be made FAIR (Findable, Accessible, Interoperable, Reusable). Image data experts are working together globally to agree on common data formats,

metadata, ontologies and supporting tools towards image data FAIRification. With this paper we call on public funders to join these efforts to support their national scientists. What researchers most urgently need are openly accessible resources for image data storage which are operated under long-term commitments by their funders. Although existing resources in Australia, Japan and Europe are already collaborating to enable global image data sharing, these efforts will fall short unless more countries invest in operating and federating their own open data resources. This will allow us to harvest the enormous potential of existing image data, preventing significant loss of unrealised value from past investments in imaging acquisition infrastructure.

Introduction

Image data are not only intriguing to look at but they are also the fastest growing data resource in the life sciences. Biological and medical images are complex and deep in information content based on the nature of many imaging modalities making the data conducive to reuse. With simultaneous rapid advances in and access to computation power, the scientific community is only beginning to tap into this invaluable resource. Acquiring and managing image data according to the FAIR principles [1] (Findable, Accessible, Interoperable, Reusable) is therefore being requested by major public funders such as the European Union (https://digital-strategy.ec.europa.eu/en/policies/data-act) and NIH (https://grants.nih.gov/grants/guide/notice-files/NOT-OD-21-013.html). Beyond supporting their Open Science policy objectives, many of the most exciting opportunities for deriving value from sharing and reusing imaging data at scale rely on the ability to curate and centrally access those data. This aggregation based on common standards not only enables very large scale AI/ML model training, but also the creation of cross-modality and cross-domain benchmarks and reference datasets. These gains are not possible when FAIR data are siloed and fragmented in many different places, often without public access or consistent organization. The key to easy data access lies in consolidating data in a limited number of locations that are connected with each other and which follow compatible standards for data and metadata storage, i.e., they are interoperable.

Australia, Japan, and the European Union have established nationally funded, coordinated research infrastructures (RIs) for life science and biomedical imaging (collectively "BioImaging"). These BioImaging RIs are the output of concerted long-term strategic planning efforts from key stakeholders that include academic, funding, political as well as industrial partners. They are now in operation and deliver technology and community support for quality image data acquisition, management, analysis, and publication for their stakeholders. They are supported by dedicated image data repositories, like the BioImage Archive[2], IDR[3] and EMPIAR[4] in Europe, SSBD[5] in Japan, and AIS repository in Australia (https://australian-imaging-service.github.io/) that together hold around 6 PB of image data. Publicly funded projects and community initiatives are also actively building and supporting image data formats (https://ngff.openmicroscopy.org/) and applications for managing, analysing, and sharing data using the most advanced technologies, including AI (https://ai4life.eurobioimaging.eu/). Collaboration between academic and commercial organizations is maturing and beginning to provide a powerful ecosystem for development and eventual scaling of new technologies and products.

However, these regionally limited efforts are only a starting point of a future global ecosystem for sharing image data. We therefore urge funders to invest in open access infrastructure supporting image data acquisition, management, and sharing, which then can be coordinated around the world. This is a necessary step towards realizing the significant value that is currently lying dormant in underutilized image data and instead can catalyze the exploitation of this invaluable resource which was largely generated through previous public investments.

Image data sharing – Cui bono?

Everyone can benefit tremendously if open access image data resources were available to them (Figure 1). Life scientists, as producers of large image datasets, can strengthen their research output by opening up the data that supports their publications and exchange the data more easily with existing and future researchers. AI experts, data analysts, and software developers can use the available image datasets for training, testing, and developing their tools. Trainers and educators can expand their portfolio of training material and expedite the sharing of knowledge and new tools. Researchers can follow their data management plan and upload their final data for publication in these resources, meaningfully fulfilling the requirements of their funders and publishers. Funders can sustain their research investments and enable the reuse of existing research data for creation of new knowledge. Finally, the image data becomes accessible to the general public, which can lead to increased trust in and support of public research and education, as well as new and unanticipated discoveries.

As a key technology in the biological and biomedical sciences and beyond, imaging is enabling scientists to map and understand the complex spatiotemporal patterns of biological processes in greater detail than ever before. While other fields like genomics, proteomics etc., have benefited heavily from investing into extensive data sharing mechanisms and practices, recent advances in computational infrastructure have only now given the imaging community the same level of aspiration to make image data an accessible, shared global resource.

We are convinced that sharing of FAIR image data from all domains will significantly increase interoperability among the different research fields in the life sciences. Most importantly, it will allow a comprehensive view of biological processes at different levels of organization, from molecular to cellular to whole organism and thereby will advance both basic biological as well as translational research. The integration of microscopy and medical imaging can provide a better understanding of disease mechanisms, particularly in the context of complex diseases that involve multiple organ systems and cellular processes. Preclinical and clinical imaging techniques, such as magnetic resonance imaging (MRI), provide valuable data on anatomical structures and physiological functions. Integrating this data with light microscopy images can provide a more accurate and detailed understanding of the underlying biology. Such image data integration will support and grow the field of bioimage informatics and trigger advancements in drug discovery and development and help to identify potential therapeutic targets, as well as to evaluate drug efficacy and safety. If we foster image data sharing across domains, then we will not only democratize science but also enable new discoveries by linking different types of image data sets across the entire spectrum of life.

What are the technical challenges?

There are several technical challenges that make sharing image data more difficult than sharing genomic data[6] or protein structures[7], which are currently the best examples of open shared data and data repositories. One is that the data may be very large with individual files of sizes from 100 GBs to 10 TBs, and beyond[8] and require either high-speed internet connections to be uploaded and downloaded or physically transported on external drives. These practices lead to duplication of data making data management and sharing expensive and complex for large datasets over time. For supporting interconnectivity between research institutions and data repositories, a robust technical infrastructure, including large data storage capacity and powerful computing resources is therefore required, as many research institutions still do not have the necessary infrastructure to support image data sharing.

Another key challenge is the need for careful management and organisation to ensure that image data are accessible and, ideally, reusable by other researchers. While medical images typically are easily shared, since most are acquired in DICOM format[9,] biological imaging data sharing is still limited because of the lack of standardisation in image data formats, ontologies, and metadata. This makes it

difficult for researchers to compare and analyse data from different sources. Ensuring that the data are properly labelled, annotated, and stored in a standardised format can require significant time and resources[10], however, it is an essential, yet often underappreciated process. In addition, proper curation and harmonization of imaging data and associated metadata are needed to ensure machine actionability in future use of data sets at scale.

Finally, depending on the context, intellectual property issues, questions of ownership, and data privacy concerns may arise. Because of this, researchers may be reluctant to share their image data, and in case of medical imaging data, they must take steps to ensure that the data are de-identified and cannot be traced back to individual patients. Medical image datasets must remain in their country of origin, and the researchers together with the legislative authorities need to find common legal and ethical solutions. Also, there may be cultural barriers, such as a lack of trust or reluctance to share image data due to concerns about competition or ownership.

Which solutions are currently developed?

Despite these challenges, community initiatives around the world are actively working on solutions to share image data globally[11]. However, those developments aren't sustainable without funding to support open access image data storage. We must move forward with the input from all stakeholders involved in the process of image data production, sharing and analysis, including scientists acquiring data, operators of large-scale data infrastructures, and data experts. Educational opportunities addressing the importance of quality-managed and harmonized data are increasing, but they need to be scaled and embedded in each researcher's training curriculum from the beginning. It is essential to recognise and reward the efforts of everyone involved in producing and curating FAIR data, including specialized data support staff, such as FAIR data stewards, data curators, research software engineers, etc. Many current funding plans to promote data sharing fail to adequately include these roles, resulting in poor implementation and limited uptake of developed solutions. While establishment of these positions is on the rise , wider recognition and sustained funding is essential to support and secure these invaluable positions. Efforts similar to those driven by Global BioImaging for imaging scientists working in core facilities[12], are needed to define the career progression and to develop measures to support professional development and job security of these important positions.

In the long term, global sharing of image data can only be achieved with a globally federated model. This requires that added value data resources dedicated to particular use cases or domains are stored and made available through a small number of centralized data archives or other open access servers. These archives must provide both direct data hosting as well as indexing and search capabilities. This model must be built on shared core metadata models for interoperability based on international guidelines, such as REMBI[13], which can be extended for domain-specific applications such as MITI for highly multiplexed tissue images[14]. In addition to metadata formats, effective use of data requires standardised image formats. In light of the exponential growth in the volume of new image data, it is critical that the imaging community collectively agrees on standard image formats with immediate effect. To guarantee the widest possible adoption, it is essential to define these formats in discussion with vendors, a process that has long been carried out by tireless community efforts driven by initiatives like OME [15], which is now working towards future proof Next Generation File Formats designed for large-scale, cloud-enabled use, such as OME-Zarr[16,17]. Allowing data to be easily located, accessed through consistent mechanisms in standardised formats, and coupled with rich metadata unlocks valuable large-scale applications. These include training universal image classifiers to support automated quality control pipelines for researchers and instrument manufacturers, automated segmentation of common cell structures for use as biomarkers of disease or to better understand mechanisms of action, and prediction of physiological or biomolecular properties of cells to speed up bio-manufacturing and reduce assay variability and consumable use etc. By adopting these approaches, we can transform petabytes to exabytes of immensely valuable scientific data,

representing enormous funder investments, into a global resource that will be maximally useful for the global community.

How to go forward?

While enabling global image data sharing requires a concerted effort and endurance from researchers, institutions, publishers, and industry to establish internationally recognized best practices, it foremost requires a long-term commitment by public funders and their investments in essential technical infrastructure and data resources. Funders need to recognise that they currently lose significant value from their previous investments into imaging acquisition infrastructure unless they provide the essential resources for storing and making the resulting image data accessible. It is essential that the imaging community and funders join forces to establish a sustainable and profitable image data ecosystem ensuring optimal output for all stakeholders (Figure 2). The authors of this paper are looking forward to an exciting and fruitful dialogue with national funders on the suggested action items presented here.

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Author Contributions

This manuscript is authored and reviewed by members of an ad-hoc International Working Group who are listed alphabetically as co-authors of the manuscript.. I.K. prepared the figures.

Ethics Declaration

Disclaimer: Commercial products are identified in this document in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the products identified are necessarily the best available for the purpose.

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Figure Legends

Figure 1. Data sharing: too impactful not to do. An outline of the tremendous benefits of globally shared image data. Data sharing drives Open Science, empowers life scientists, and enables reuse of valuable FAIR image datasets for creating new knowledge.

Figure 2: How public decision-makers, funders and the scientific community together can enable Global Image Data Sharing.

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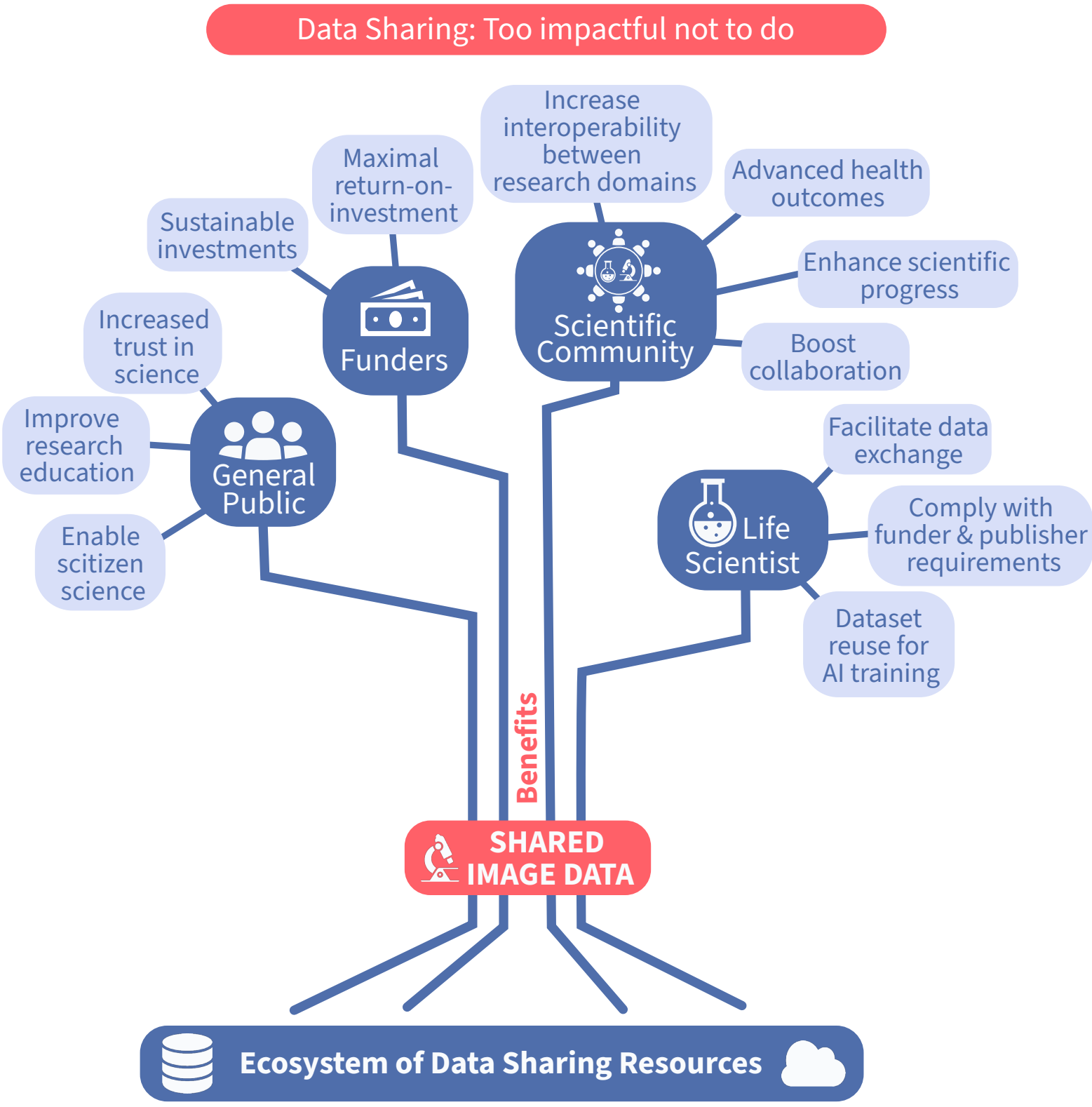
Data Sharing: Too impactful not to do
Increase interoperability between research domains
Maximal return-on-investment
Advanced health outcomes
Sustainable investments
Enhance scientific progress
Scientific Community
Funders
Increased trust in science
Boost collaboration
Improve research education
Facilitate data exchange
General Public
Life Scientist
Enable scitizen science
Comply with funder & publisher requirements
Dataset reuse for AI training
Benefits
SHARED IMAGE DATA
Ecosystem of Data Sharing Resources

Image Data Sharing

ToDo List for **Funders**

To maximize the value of investments in the imaging sector we need funding for:

Open Access Image Data Repositories

Launch, fund and support key public image data repositories long-term, creating an international federated archival system of repositories based on common data architectures supporting benchmark datasets in key areas (e.g. disease models).

Open Access Tools Ecosystem

Fund the creation of a tools ecosystem with access to compute resources to create, analyse and interact with FAIR image data

Open Access Imaging Infrastructures

Fund novel approaches to image data acquisition and sharing, such as coordinated national or regional imaging infrastructures, to maximise return-on-investment.

Specialised Staff

Develop new funding mechanisms for critical but non-traditional work for data support staff in this space e.g., to develop, maintain, and upgrade data sharing pipelines and ecosystems, as well as for software developers, data wranglers, data curators, and FAIR image data stewards

Training and Education

Fund training and education of researchers at all career stages for acquiring and working with FAIR research data.

Image Data Sharing

ToDo List for the **Imaging Community**

To maximize the value of investments in the imaging sector we need to work on:

Metadata and Ontologies

Build useful, accessible, and community recommend ontologies and implementations of metadata standards, and incentivize their uptake

Metrics and Recogition

Develop metrics to recognize and incentivize high-quality, structured data generation that allows easy sharing and re-use.

Training and Education

Educate researchers on benefits of image data sharing and reuse, FAIR data, as well as training and dissemination of tools.

Data Formats

Decide on, implement and maintain standardized data formats that allow data streaming to support navigation and processing of massive image datasets.

Data in Journals

Encourage journals to establish guidelines and develop additional specialist “Data Journals” to support re-use and citation of high value datasets, similar to Methods and Protocols journals

Vendor Engagement

Engage with vendors to mandate that image data is accompanied by well-structured metadata in accepted formats and within data models that thoroughly describe images, with the option to export both image data and metadata into open formats.