Open Science for the Challenges of Medical Imaging AI

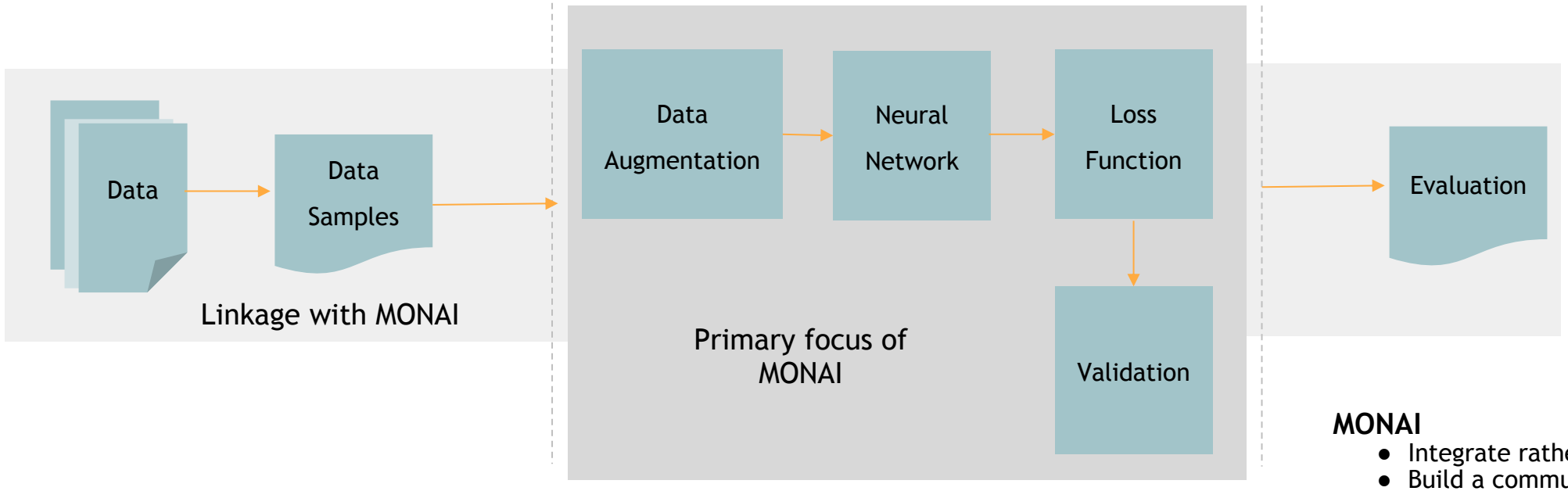
Open Science in Deep Learning

Medical Open Network for A. I. (MONAI):

Goal: Accelerate the pace of research and development by providing a common software foundation and a vibrant community for medical imaging deep learning.

- Began as a collaboration between Nvidia and KCL
- Freely available and community-supported
- PyTorch-based
- Optimized for medical imaging
- Reference implementation of best practices

Accelerate Pace of Research and Innovation With a Common Foundation



End2End workflow facilitated by MONAI

MONAI
- Integrate rather than compete
- Build a community through value

Current Conditions
- Many options
- Incompatible interfaces and formats
- Extended learning curves

NiftyNet (KCL)

DeepNeuro (Harvard)

DLTK (ICL)

TensorFlow

PYTORCH

Clara Train (NVIDIA)

Why is MONAI Needed?

- Biomedical applications have specific requirements
- Image modalities (MR, CT, US, etc.) require specific processing methods
- Data formats (DICOM, NIfTI, etc.) and meta-data (e.g., voxel spacing) require special support
- Certain network architectures are designed for, or are highly suitable for, biomedical applications
- Data augmenting, sample size limitations, annotation uncertainties, etc. are domain specific

Why is MONAI Needed?

- Reproducibility is vital to clinical decision support
- Reduce re-implementation
- Provide baseline implementations
- Demonstrate best practices
- Stand on the shoulders of giants

How Does MONAI Address These Needs?

- MONAI provides flexible, Pytorch-compatible methods:
  - Data loading and handling library for biomedical file types
  - Data transforms to process, regularize, and augment image data
  - Library of general-purpose network and loss function definitions
  - Numerous metrics for evaluating results during and after training
  - Jupyter Notebooks and Ignite Workflows to simplify training
  - Efficient and fast data loaders for fast batch generation
  - Support for multi-GPU and multi-node multi-GPU training

Open Science: Reproducibility

- MONAI aims to help researchers write reproducible experiments more easily
  - Reusable and accessible code in a modular design (pick-and-choose)
  - Accessible data
  - Ready-made training paradigms as well as an extensible platform
  - Permissive licensing
  - Reference implementations of published methods and experiments with proven replicable performance

Ease-of-use Example

```
net = monai.networks.nets.UNet(
    dimensions=2,           # 2 or 3 for a 2D or 3D network
    in_channels=1,          # number of input channels
    out_channels=1,         # number of output channels
    channels=[8, 16, 32],   # channel counts for layers
    strides=[2, 2]          # strides for mid layers
)
```

2D UNet network

- 2 hidden layers: outputs has 8 channels, and the bottom (bottleneck) layer has outputs with 32 channels
- Stride values state the stride for the initial convolution, ie. downsampling in down path and upsampling in up path

MONAI

ADVISORY BOARD

Sebastien Ourselin

Stephen Aylward
Chair of
Advisory Board

Klaus Maier-Hein

Jayashree
Kalpathy-Cramer

Jorge Cardoso

Daniel Rubin

Kevin Zhou

Nasir Navab

Andrew Feng

NVIDIA

KING'S College LONDON

MGH & BWH CENTER FOR CLINICAL DATA SCIENCE

dkfz. GERMAN CANCER RESEARCH CENTER IN THE HELMHOLTZ ASSOCIATION

Stanford University

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

Working Groups of MONAI

Liaison with the community:
Recommend policies and priorities to development team

1. *IMAGING I/O* - *Stephen Aylward*
2. *DATA DIVERSITY* - *Brad Genereaux*
3. *REPRODUCIBILITY* - *Lena Maier-Hein*
4. *TRANSFORMATIONS* - *Jorge Cordoso*
5. *FEDERATED LEARNING* - *Jayashree Kalapathy*
6. *ADVANCED RESEARCH* - *Paul Jaeger*
7. *COMMUNITY ADOPTION* - *Prerna Dogra*

I/O Working Group

Goal: Define how data is read into and written out from memory in MONAI.

Tasks

#1: Support reading and writing common research image file formats: NRRD, Nifti, DICOM (objects), JPG, PNG, TIFF, MetaIO, ...

#2: Simplify interfacing MONAI with clinical systems such as PACS and health records systems: DICOM, HL7, ...

Members

- Stephen Aylward (Kitware)
- Marco Nolden (DKFZ)
- Jayashree Kalpathy-Cramer (MGH)
- Brad Genereaux (Nvidia)
- Ben Murray (KCL)
- Wenqi Li (Nvidia)
- Jorge Cardoso (KCL)
- Prerna Dogra (Nvidia)

Proposal #1: Create a single reader that handles a diversity of file formats in a consistent manner and that user-defined "experiments" can override to use a specific reader when I/O reproducibility is a concern.

Solution #1: Default image loader uses ITK Python. Scripts can specify alternative loaders. Available starting in MONAI v0.3.

Suggestions for next steps and alternatives:

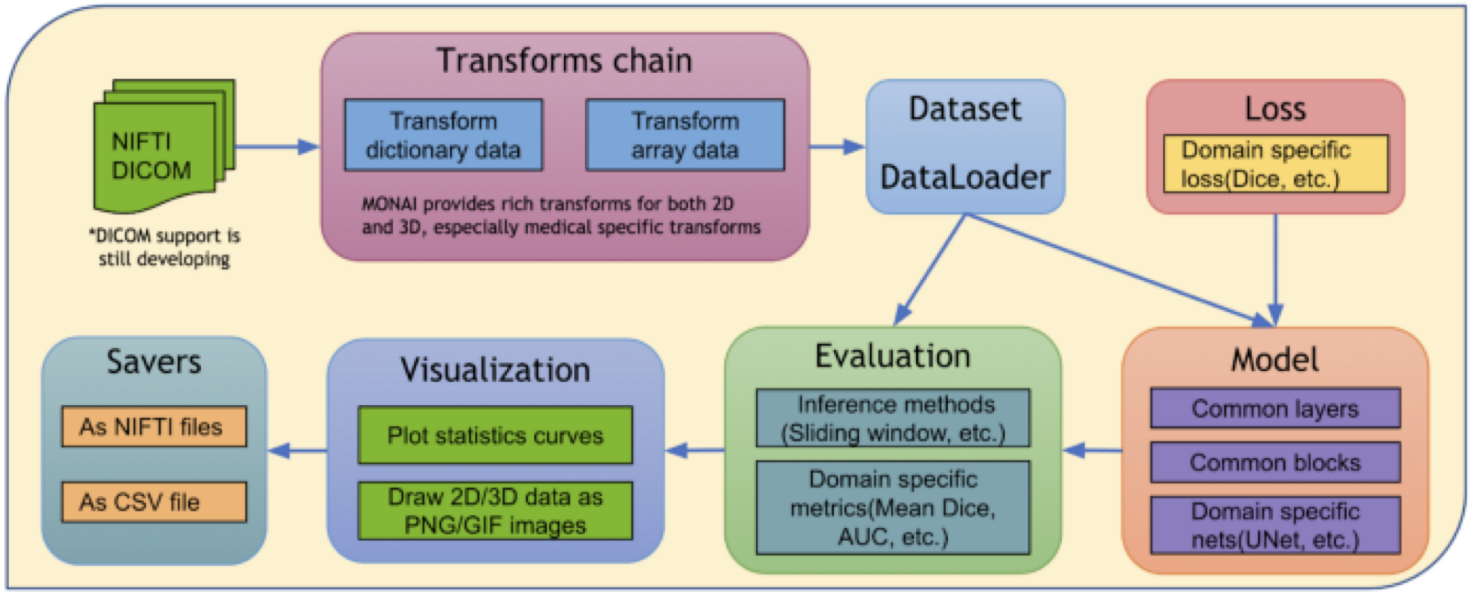
Stephen.Aylward@Kitware.com

MONAI DATA WORKING GROUP

Data: Images, Biomarkers, Demographics, Outputs and Outcomes

Group Lead: Brad Genereaux

A key part of Project MONAI is the ingestion of data. This working group will focus on defining support for bioinformatics (e.g., images), biomarkers, and metadata (e.g., patient demographics, outcomes). Part of the focus explores the use of ontologies, various representations of the data, and what is in-scope for MONAI and what is left to other projects to define. Some of the image representations, for example, include data relating to dimensionality, spacing, components/channels, data orientation, and time (multiple studies/prior exams).



Working Group Homepage:
https://github.com/Project-MONAI/MONAI/wiki/Data-Working-Group

Reach Out if you have any feedback, questions, or thoughts on data structures to be processed in MONAI.

We want to hear from you for your preferred data types, data you need to capture, and where the challenges are!

MONAI WORKING GROUP: EVALUATION, REPRODUCIBILITY, BENCHMARKS

Lena Maier-Hein
Working Group Lead
German Cancer Research Center (DKFZ)

S. Kevin Zhou
Working Group Lead
Chinese Academy of Science (CAS)

Carole Sudre
Lead of task force
Metrics
University College London (UCL)

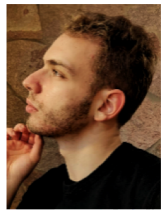
Michela Antonelli
Lead of task force
Quick data access
King's College London (KCL)

Annika Reinke
Lead of task force
Benchmarking
German Cancer Research Center (DKFZ)

Nicola Rieke
NVIDIA GmbH
Technical University of Munich (TUM)

M. Jorge Cardoso
King's College London (KCL)

Jens Petersen
German Cancer Research Center (DKFZ)



Dan Tudosiu
King's College London (KCL)

David Zimmerer
German Cancer Research Center (DKFZ)

Jayashree Kalpathy-Cramer
Harvard Medical School (MGH)

Mission

The core goal of the Working Group is to provide the **software infrastructure** and **tools for quality-controlled validation and benchmarking** of medical image analysis methods.

We will address **open technical challenges** and **research questions** related to a variety of topics, ranging from **best practices** to performance aspects and implementation efficiency.

Working Group Homepage: https://github.com/Project-MONAI/MONAI/wiki/Evaluation,-Reproducibility,-Benchmarks-Working-Group-Meeting-Notes

MONAI WORKING GROUP: EVALUATION, REPRODUCIBILITY, BENCHMARKS

Your feedback is important!

What do you want from our MONAI Working Group?

- What are current problems with respect to *metrics*, *benchmarking and challenges*?
- What should we prioritize?
  - Best practice recommendations for metrics?
  - Easy access to existing data sets?
  - …

Let your voice be heard:
https://www.surveylegend.com/s/2mes

Word cloud created from the Working Group's meeting notes.

You have further feedback or questions? Use the slack channel or contact us via monai-evaluation-benchmarking-wg@dkfz.de

MONAI WORKING GROUP: TRANSFORMATION & AUGMENTATION

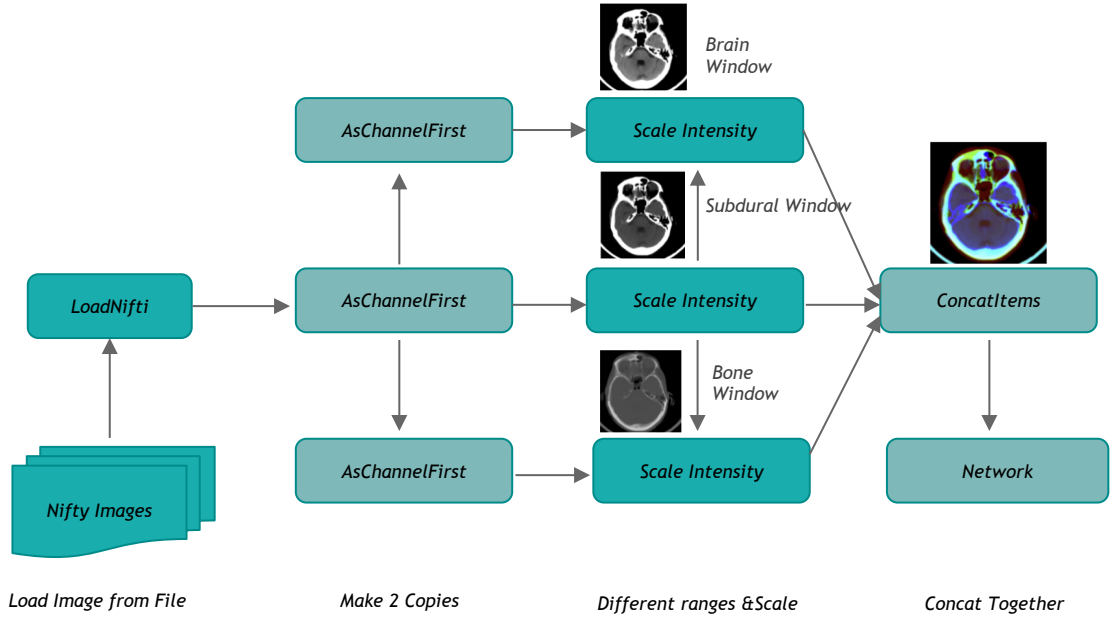
Generic | Vanilla |Dictionary-based Transforms

Medical Specific Transformations

- LoadNifti | Spacing | Orientation
- RandGaussianNoise |Normalize Intensirt
- Rand2DElastic | Rand3DElastic

Fused Spatial Transforms & GPU Optimization

- Affine Transform
- Random sampling: Class balanced fixed Ratio
- Deterministic training controlled by setting random seed



Group Lead: Jorge Cardoso

This working group covers the topics related to data preprocessing and augmentation modules for MONAI. In terms of functionality, these include patient-level transforms, such as simulating body habitus variations, aging; spatial geometric transforms, intensity transforms and acquisition transforms such as simulating medical imaging modalities, artefacts. In terms of technical implementations, these include differentiability, multi-dimensional data representation, lazy evaluation, caching, reproducibility, etc

MONAI WORKING GROUP: TRANSFORMATION & AUGMENTATION

Post-Processing & Integrate Third Party Transforms

3rd Party OSS Packages & MONAI adapter Tools

- Interoperability with other open source packages
- Accommodate different data for 3rd party Transforms
- Utility Transforms: ToTensor, ToNumpy, SqueeseDim

```
transform = Compose(monai_transforms + [
    itk_transforms,
    # add another dim as BatchGenerator and Rising expects shape [B, C, H, W, D]
    AddChanneld(keys=['image', 'label']),
    adaptor(batch_generator_transforms, {'image': 'image'}),
    ToTensord(keys=['image', 'label']),
    adaptor(rising_transforms, {'image': 'image', 'label': 'label'}),
    # squeeze shape from [B, C, H, W, D] to [C, H, W, D] for TorchIO transforms
    SqueezeDimd(keys=['image', 'label'], dim=0),
    adaptor(torchio_transforms, 'image', {'image': 'data'})
])
```

Compose all Transforms

- BatchGenerator

```
batch_generator_transforms = ContrastAugmentationTransform(data_key="image")
```

- TorchIO

```
torchio_transforms = RescaleIntensity(out_min_max=(0., 1.), percentiles=(0.05, 99.5))
```

- Rising

```
rising_transforms = Mirror(dims=DiscreteParameter((0, 1, 2)), keys=["image", "label"])
```

Federated Learning Working Group

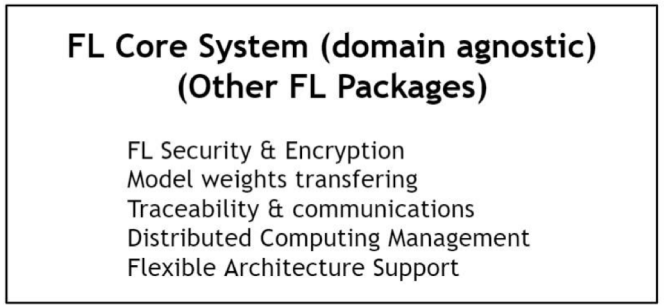
Goal: Support federated learning and other collaborative learning approaches.

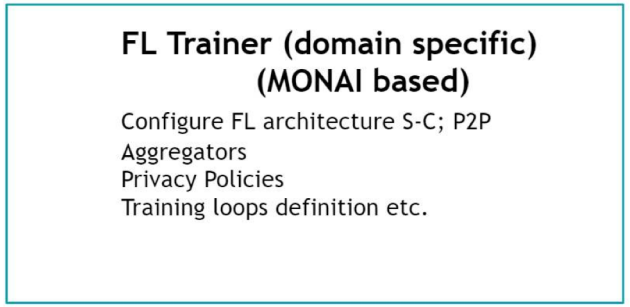
Tasks

#1: Develop reference implementations of MONAI FL with Clara-FL
#2: Develop example implementations of MONAI train with Substra/PySyft/??
#3: Perform a real-life federated learning experiment with interested members of community

Members

- **Daniel Rubin (Stanford)**
- **Jayashree Kalpathy-Cramer (MGH)**
- Marco Nolden (DKFZ)
- Stephen Aylward (Kitware)
- Holger Roth (Nvidia)
- Wenqi Li (Nvidia)
- Jonas Scherer (DKFZ)
- Andriy Myronenko (Nvidia)
- Jorge Cardoso (KCL)
- Prerna Dogra (Nvidia)
- Nicola Rieke (Nvidia)
- Shadi Albarqouni (TUM)





Proposal #1: Create interfaces to allow external FL packages to connect to MONAI trainers

jkalpathy-cramer@mgh.Harvard.edu
rubin@stanford.edu

Research Working Group

●Goal: Guide the integration of new methodologies and tools into MONAI by focusing on community-driven progress and good scientific practice

For feedback/questions
please contact p.jaeger@dkfz.de

Previous Work:

Before filling MONAI with Research Content,
We focused on **establishing a systematic process** behind integration of methodologies in MONAI including:

- Clear definition and categorization of methodologies:
  Components / Tutorials / Reserach Contributions
- Code location and entry points via the monai.io webpage
- Internal structure / taxnomoy ensuring scalability
- Guidelines for contributions by the community

Future Plans:

- Prioritize and guide **implementation of new methods** such as Object Detection, Registration, etc.
- Contribute towards an **online benchmarking platform** in MONAI including standardized datasets, Baselines/Model-Zoo and evaluations.

Members:

- Paul Jaeger (DKFZ)
- Dan Tudosiu (KCL)
- Dong Yang (Nvidia)
- Michael Baumgartner (DKFZ)
- Jorge Cardoso (KCL)
- Holger Roth (Nvidia)
- Ziyue Xu (Nvidia)
- Wentao Zhu (Nvidia)
- Chayanin Tangwiriyasakul (KCL)
- Ben Murray (KCL)

See also our site on the MONAI wiki

Community Outreach Working Group

Goal: Establish MONAI as a common software foundation that the Medical Imaging research and development community can build upon.

Tasks:

- Developing technical training and onboarding content
- Organize workshops and boot camps to educate and engage
- Define the infrastructure and processes needed to support and grow a transparent, honest, and open community
- Establishing best practices for giving appropriate recognition to those who are promoting and making significant contributions back to MONAI

How to Engage:

- See our Community Onboarding guide: https://github.com/Project-MONAI/MONAI#community
- For feedback or questions, contact mzephyr@nvidia.com

Members:

- Michael Zephyr (Nvidia)
- Prerna Dogra (Nvidia)
- Stephen Aylward (Kitware)
- Julia Levites (Nvidia)
- Paul Jaeger (DKFZ)
- Wenqi Li (Nvidia)
- Nicola Rieke (Nvidia)

How to Engage with MONAI

Understand the different options you have to engage with the MONAI community, developers, and working groups

Where to go to get started with MONAI

- Getting Started (Installation, Examples, Demos, etc.) https://monai.io/start.html
- GitHub
  - Community Guide: https://github.com/Project-MONAI/MONAI#community
  - Contributing Guide: https://github.com/Project-MONAI/MONAI#contributing
  - Use GitHub Issues for Small Concrete Tasks and use the community tag.
  - Looking to get started contributing? Look at our Good First Issue tag! https://github.com/Project-MONAI/MONAI/labels/good%20first%20issue
- PyTorch Forums. Tag @monai or see the MONAI user page. https://discuss.pytorch.org/u/MONAI/
- Stack Overflow. See existing tagged questions or create your own: https://stackoverflow.com/questions/tagged/monai
- Follow us on Twitter for the latest updates on releases, research, demos and conference engagements. https://twitter.com/ProjectMONAI
- Join our Slack Channel. Fill out the Google Form here: https://forms.gle/QTxJq3hFictp31UM9
- Transitioning away from Google Groups. Instead use one of the above options.
- For feedback or questions, contact mzephyr@nvidia.com

MONAI IS A GROWING COMMUNITY

Contributors: 1.4 K+ GitHub stars & growing engagement

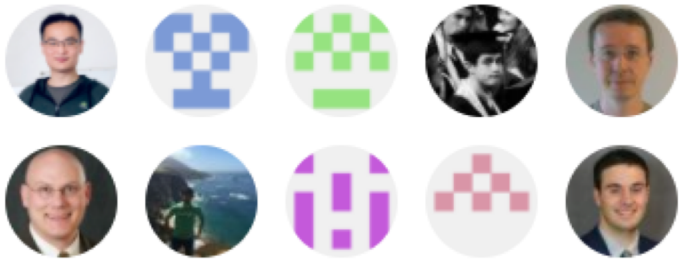
Ignite

Massachusetts Institute of Technology

ITK

Catalyst

kornia



The University of Iowa

中国科学技术大学
University of Science and Technology of China

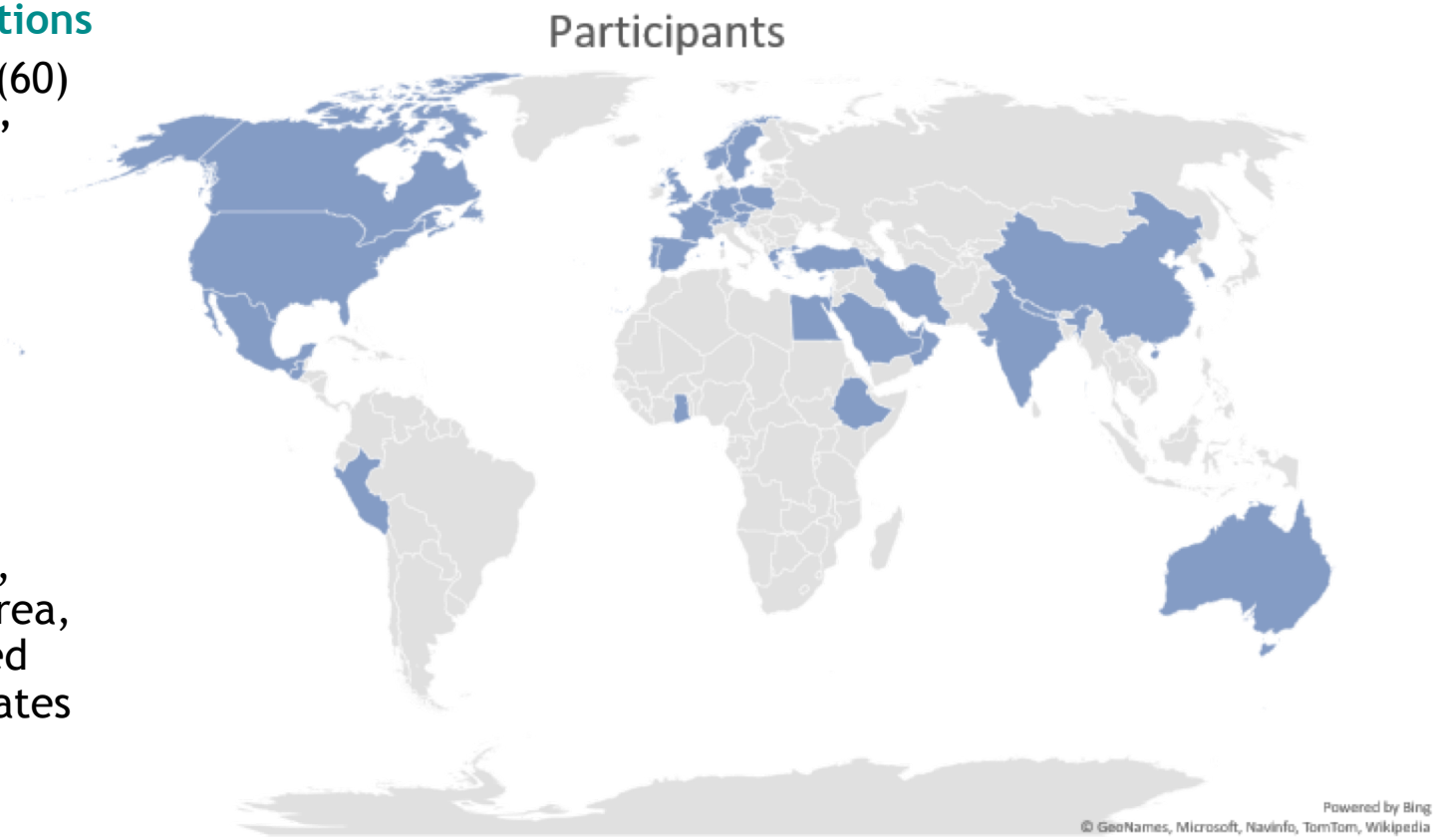
BOOTCAMP - IN NUMBERS

A LOT OF INTEREST IN THE COMMUNITY!

- Number of applicants: **563 attendance applications**
  - Accepted participants with cluster access (60)
  - Additionally other participants “observers” (140)

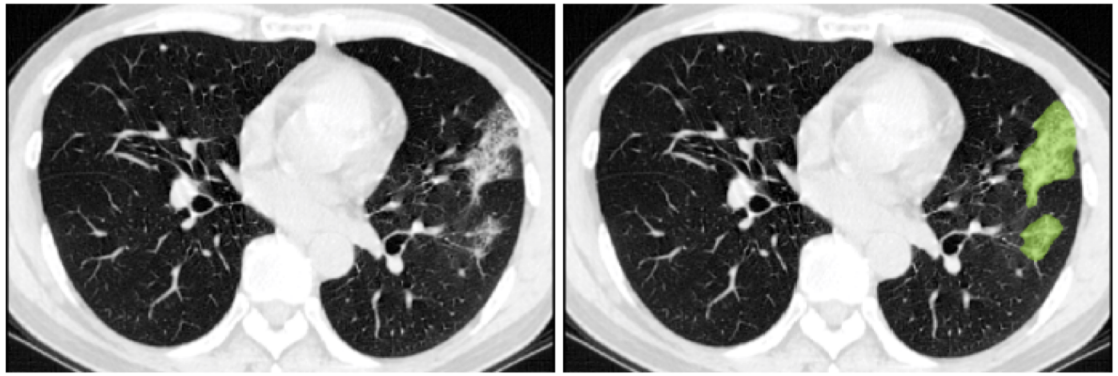
  - From **40 different countries**:

    Australia, Austria, Belgium, China, Cyprus, Czechia, Egypt, Ethiopia, France, Ghana, Germany, Greece, Guatemala, Hong Kong, India, Israel, Iran, Malta, Mexico, Nepal, Netherlands, Norway, Oman, Peru, Poland, Portugal, Saudi Arabia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, United Arab emirates, United Kingdom, United States of America

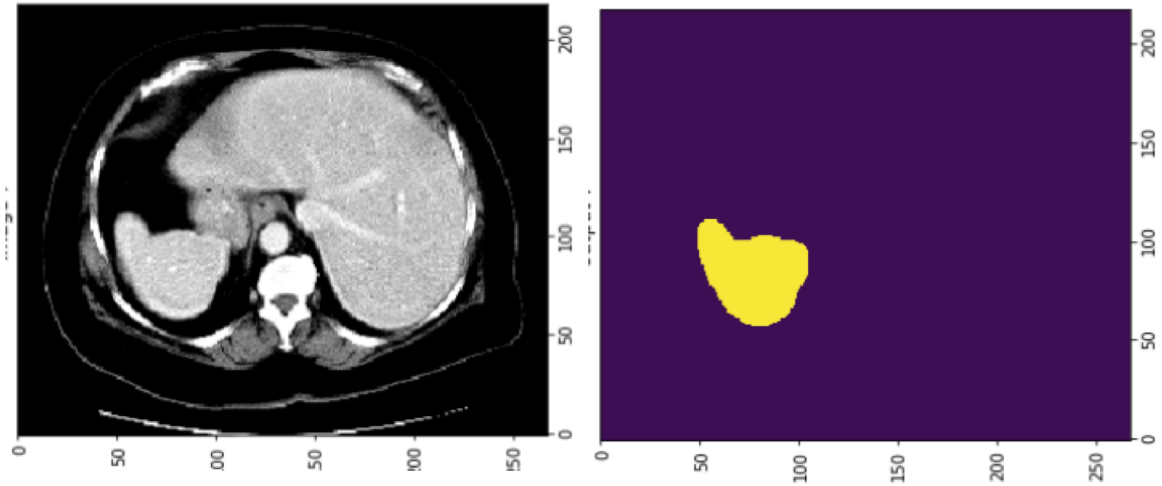


A truly global event!

MONAI Demonstration Applications



G. Wang, X. Liu, C. Li, Z. Xu, J. Ruan, H. Zhu, T. Meng, K. Li, N. Huang, S. Zhang. (2020) "A Noise-robust Framework for Automatic Segmentation of COVID-19 Pneumonia Lesions from CT Images." IEEE Transactions on Medical Imaging. 2020. DOI: 10.1109/TMI.2020.3000314



MONAI Jupyter Notebook Tutorial: Spleen 3D segmentation