ITK, 3D Slicer, and MONAI:

Creating and sustaining impact with open-science

Stephen R. Aylward, Ph.D.
Chair of MONAI Advisory Board
Senior Director of Strategic Initiatives, Kitware

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What is open science?

"Reproducible Science"

Writing open-source code,

sharing data, and

sharing publications

so that others can fully replicate your work…

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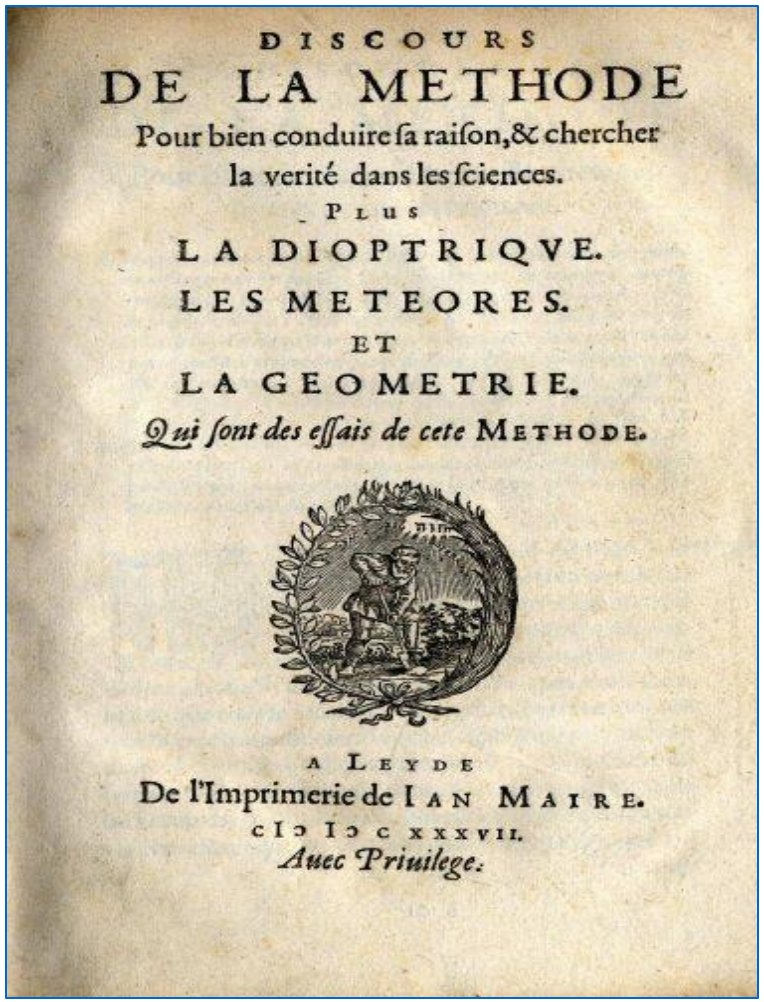
DISCOURS
DE LA METHODE
Pour bien conduire ſa raiſon,& chercher
la verité dans les ſciences.
PLUS
LA DIOPTRIQVE.
LES METEORES.
ET
LA GEOMETRIE.
Qui ſont des eſſais de cete METHODE.
A LEYDE
De l'Imprimerie de IAN MAIRE.
cIↃ IↃ c xxxvii.
Auec Priuilege.

"DOUBT EVERYTHING and only believe in those things that are evidently true (reproducible)"

-- Descartes 1637
Discourse on the (Scientific) Method

"Open Science" began in 17th century with the advent of the academic journal

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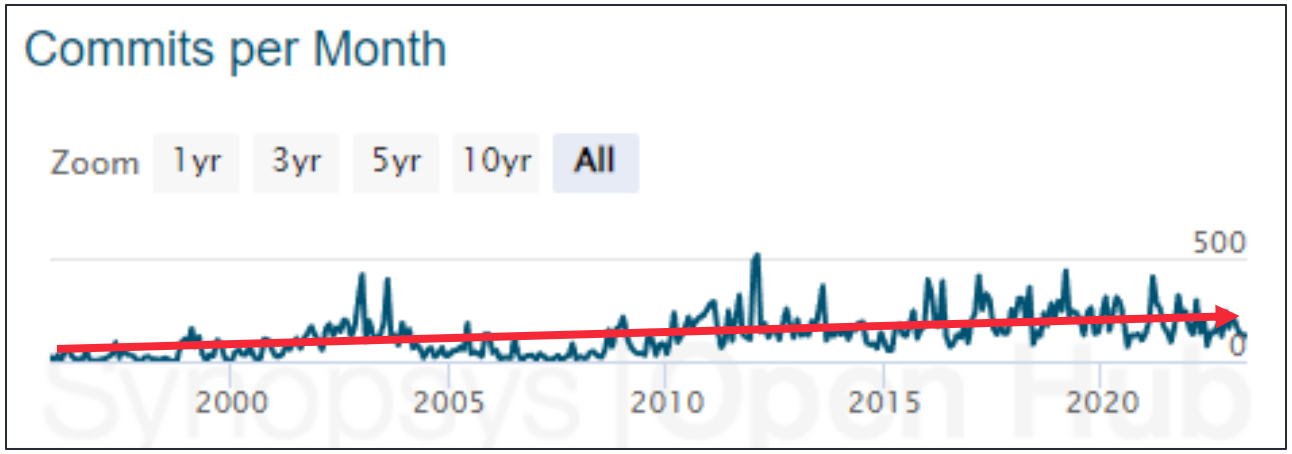
Outline

- **ITK:** Mainstream open science for medical imaging
- **3D Slicer:** Accelerating clinical translation
- **MONAI:** The best of open science and beyond

The Insight Toolkit (ITK): Open source since 1999

- **1999: “I can do it better on my own…”**
- **ITK 1999-2005**
  - $13.5M (NIH + 6 teams)
- **ITK 2023**
  - 41,085 commits
  - 302 contributors
  - 1,253,083 lines of code



  - C++ and Python
  - DICOM and 40 other image formats
  - Image Segmentation
  - Image Registration
  - GPU Acceleration, Distributed Processing
  - Pathology / microscopy (massive image) support
  - Integrated into BioImage Suite, Osirix, MeVisLab, **3D Slicer, MONAI,** …

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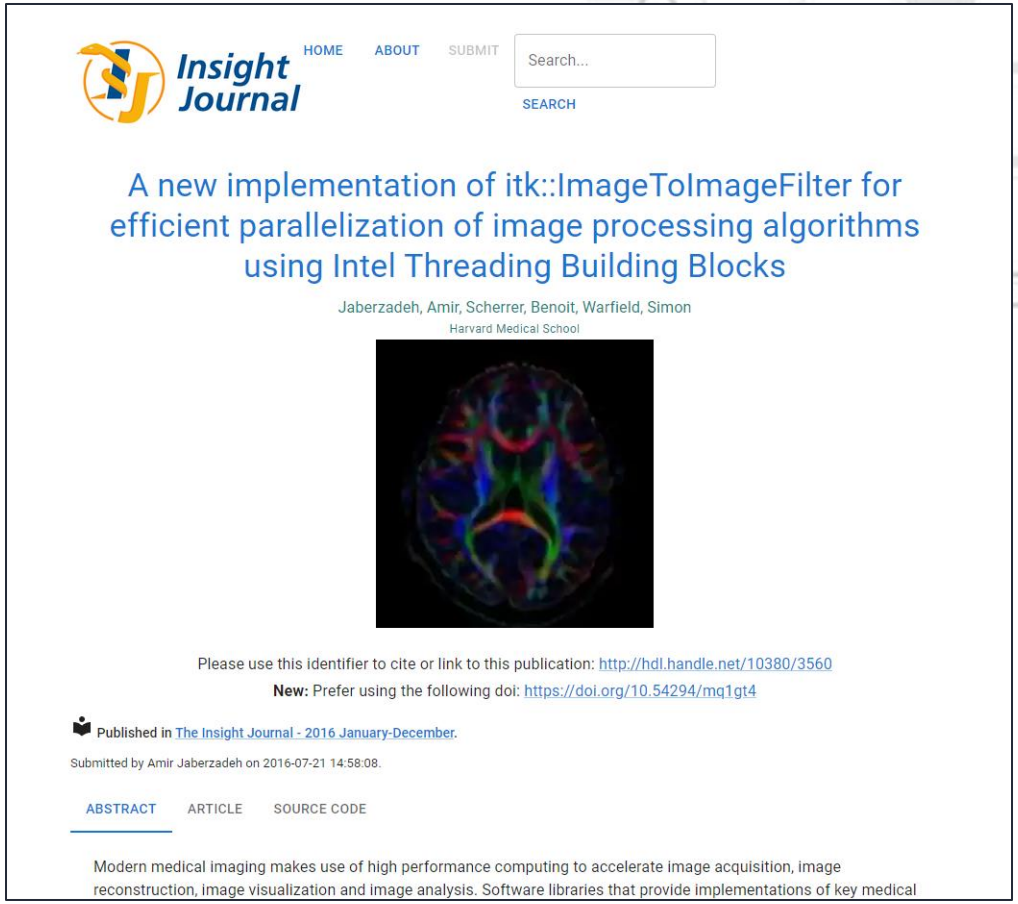
The Insight Toolkit

- **Mainstream Open Science for Medical Imaging = Insight Journal, 2006**
  - ITK contribution = Insight Journal publication
    - PDF
    - Code
    - Data
  - 1,900+ publications
  - 360,000+ downloads
  - DOI for citations
  - Continuous testing
  - Apache 2.0: Commercial use allowed!
    - Rigorous evaluation and bug fixing



- Open Science -> ITK Growth and Stability -> 3D Slicer (and others)

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3D Slicer

- Graphical User Interface to ITK
- Advanced visualizations
- Analysis of medical, biomedical, and other 3D images and meshes
- Planning and navigating image-guided procedures
- Customized into regulatory approved, commercial applications (**commercial use**)
- **Vehicle for the development and delivery of AI (MONAI)…**

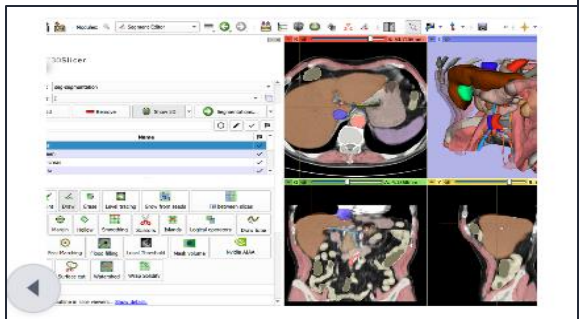
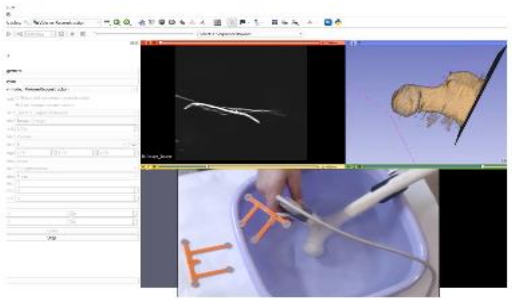


Image segmentation

Create surgical plans, create high-quality atlases, or training data sets for deep learning using the Segment Editor module.



Real-time 3D ultrasound reconstruction

3D volume is reconstructed from real-time tracked ultrasound using SlicerIGT and SlicerIGSIO extensions video > learn more >

Surgical navigation

3D Slicer is used in real-time navigation of breast cancer surgery. video > journal article > learn more >

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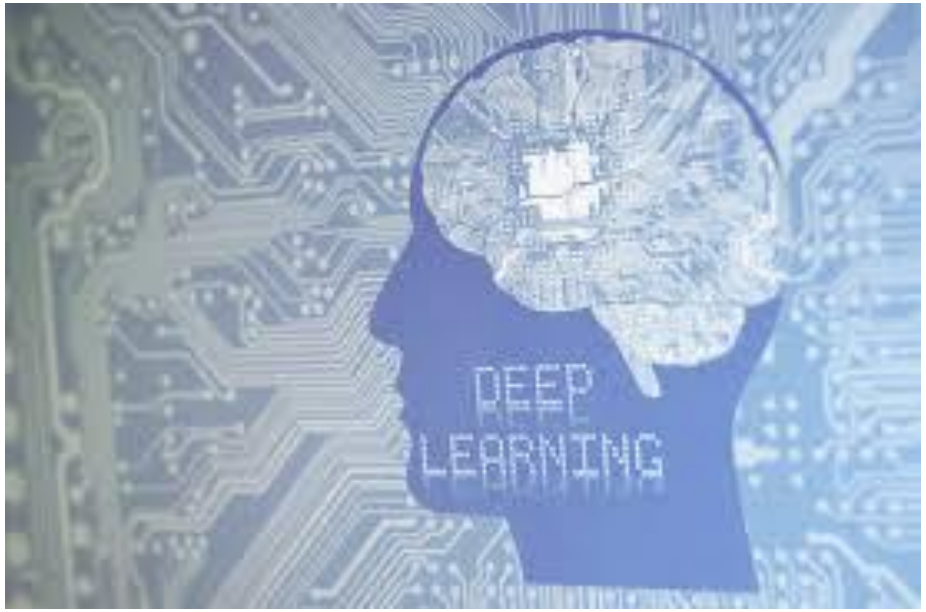
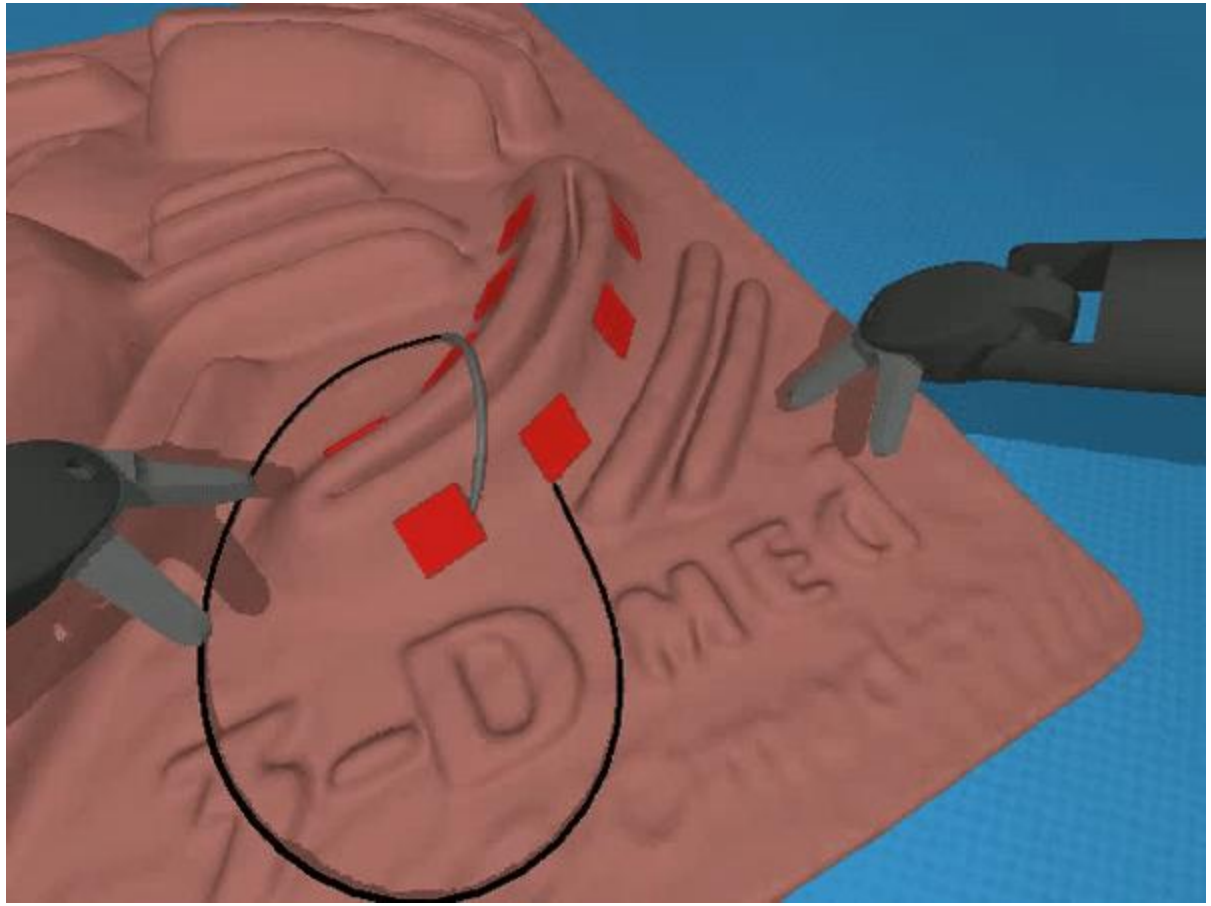
Why is deep learning (AI) succeeding?

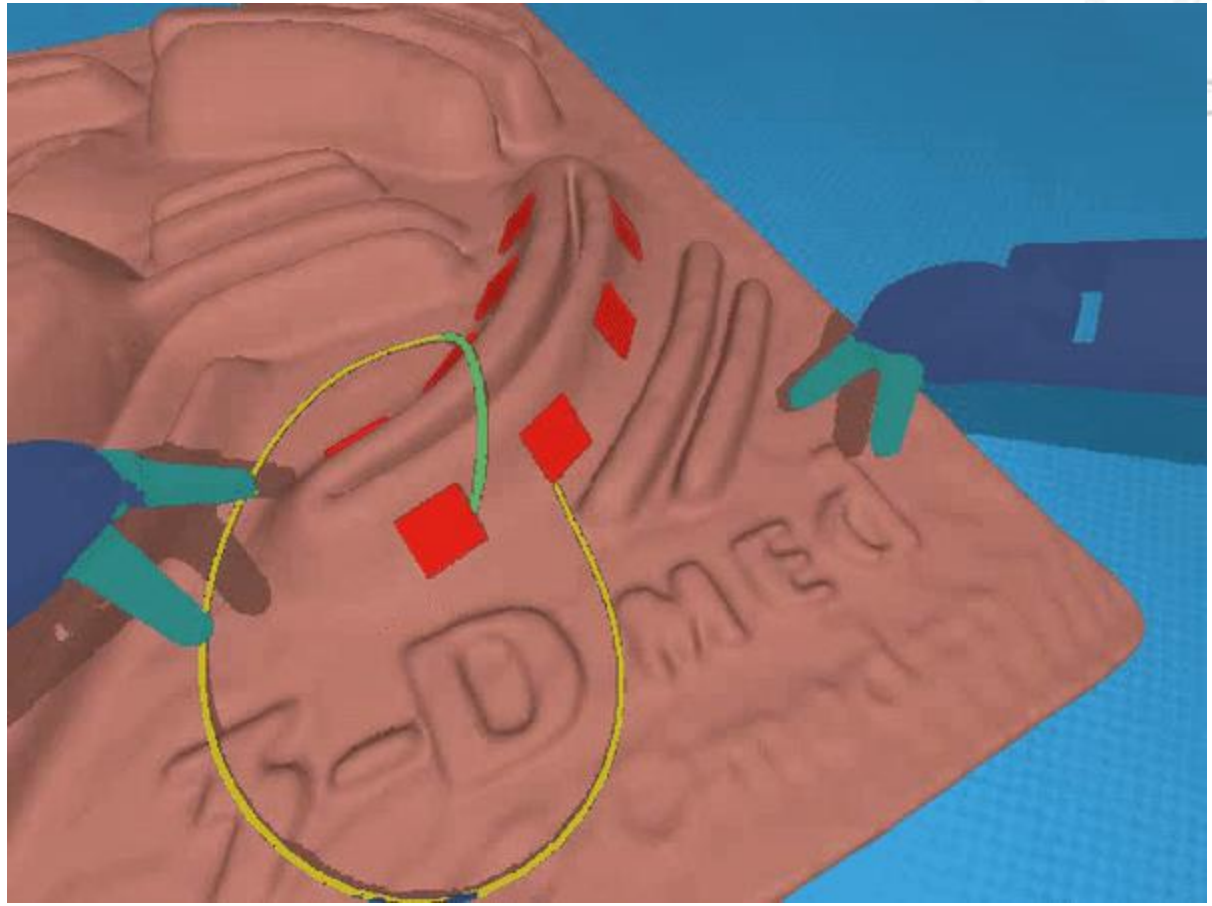
1. **Performance**
2. **Open Science**



-- Forbes.com

Deep Learning Success: MONAI Performance





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Deep Learning Success: Open Science

Open science is pervasive in deep learning

- Open access **publications**: **arXiv**
- Open access **data**: **TCIA** (IDC), ImageNet, DICOM, FIHR
  - License = CC By (not CC NC)
- Open access **software:** PyTorch, **MONAI**
  - License = Apache 2.0

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 King's College London
  - Prerna Dogra (**NVidia**) and Jorge Cardoso (KCL)
- Freely available and community-supported
- PyTorch-based
- Optimized for medical imaging
- Prioritizes reproducibility

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MONAI is…

Impacting the entire imaging workflow…

MONAI is...
Image Reconstruction

SKM-TEA: A Dataset for Accelerated MRI Reconstruction with Dense Image Labels for Quantitative Clinical Evaluation

Arjun D. Desai*, Andrew M. Schmidt, Elka B. Rubin, Christopher M. Sandino, Marianne S. Black, Valentina Mazzoli, Kathryn J. Stevens, Robert Boutin, Christopher Ré, Garry E. Gold, Brian A. Hargreaves, Akshay S. Chaudhari

Stanford University

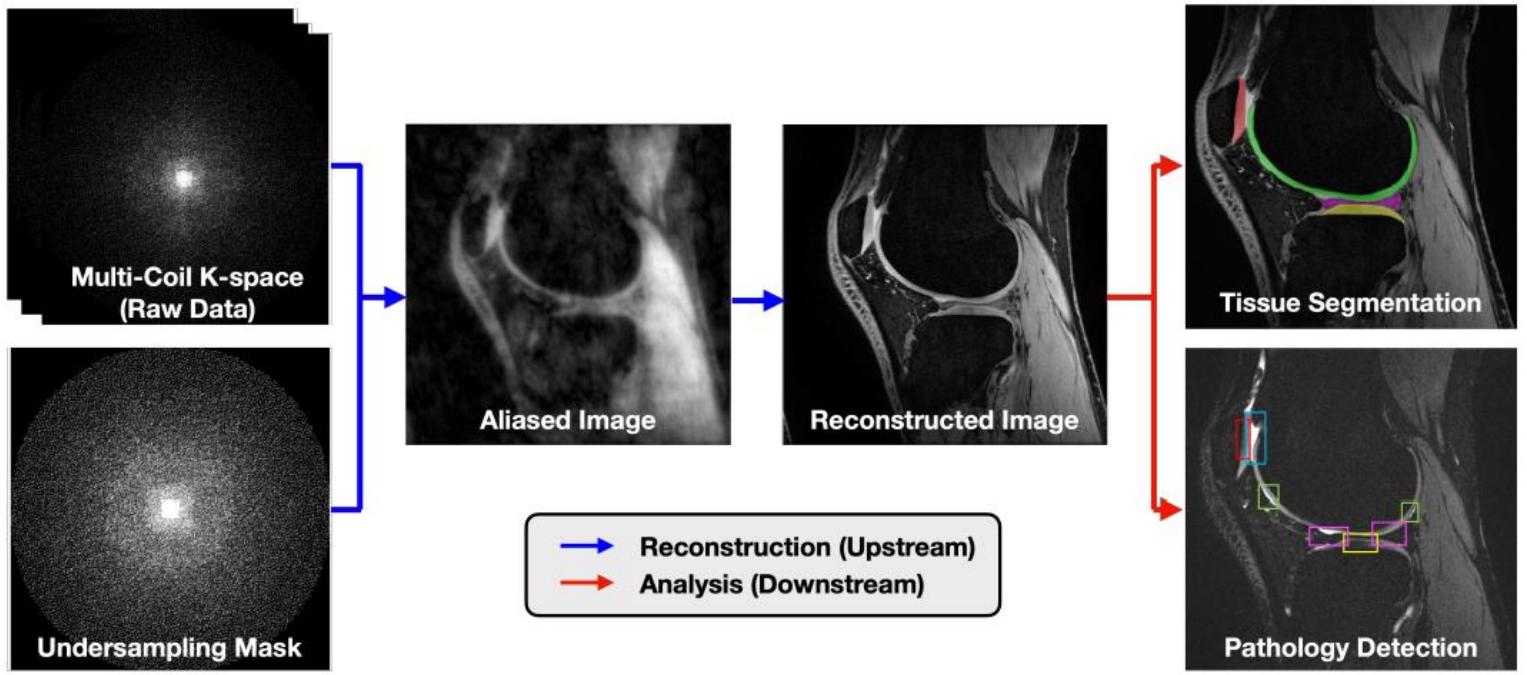

Figure 1: An overview of the end-to-end multi-coil MRI pipeline (and corresponding ML tasks). First, undersampled data acquired by multiple sensor coils is transformed into high quality images (i.e. reconstruction, blue arrow). Then, tissue regions of interest are localized (e.g. segmentation and detection) during image analysis. The SKM-TEA dataset curates raw data, ground-truth images, and dense annotations to enable all tasks. It also offers both a *Raw Data Benchmarking Track*, which supports all these tasks, and the *DICOM Benchmarking* track, which supports all image analysis tasks (red arrow).

MONAI is Image Segmentation

2022 IEEE/CVF Winter Conference on Applications of Computer Vision (WACV)

UNETR: Transformers for 3D Medical Image Segmentation

Year: 2022, Pages: 1748-1758
DOI Bookmark: 10.1109/WACV51458.2022.00181

Authors

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- Transformers
- Contrastive learning
- Auto3DSeg
- nn-UNet
- …

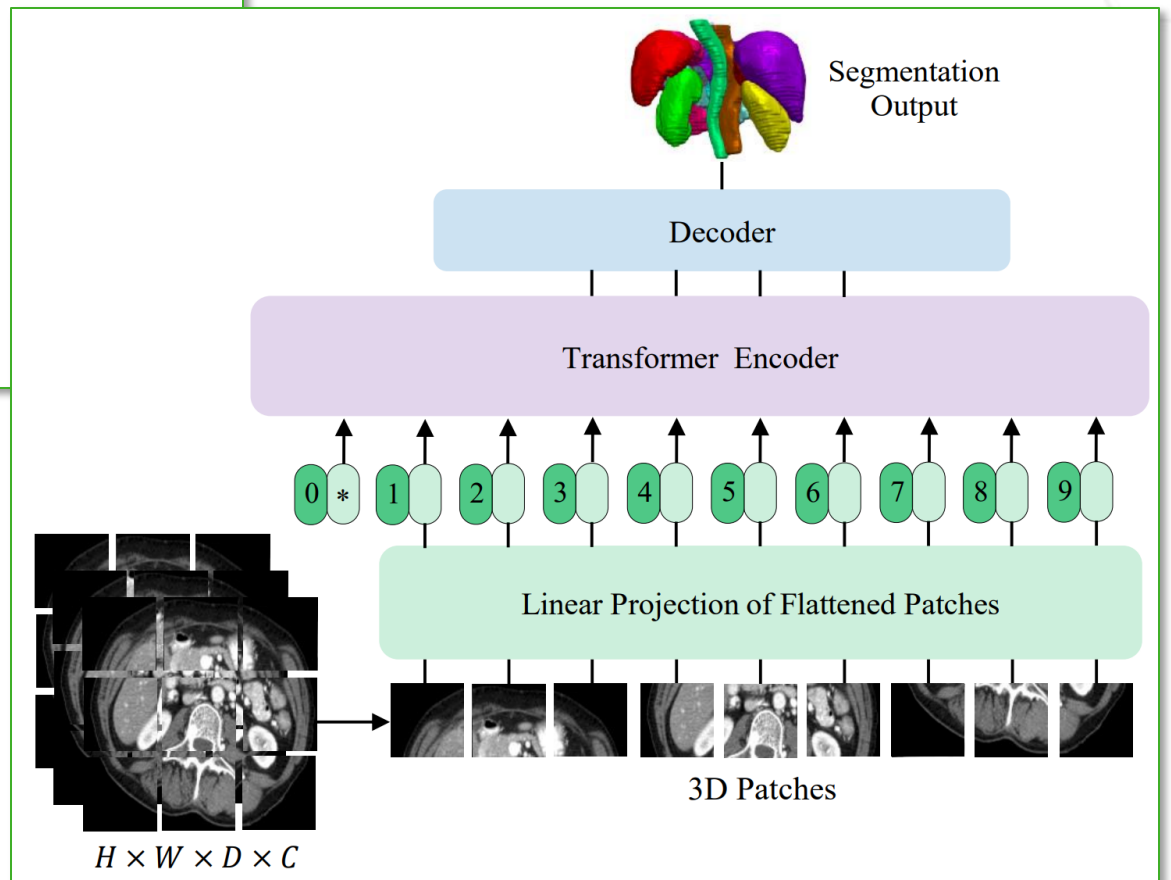
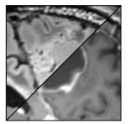


Figure 1. Overview of UNETR. Our proposed model consists of a transformer encoder that directly utilizes 3D patches and is connected to a CNN-based decoder via skip connection.

Learn2Reg: comprehensive multi-task medical image registration challenge, dataset and evaluation in the era of deep learning

Alessa Hering*, Lasse Hansen*†, Tony C. W. Mok, Albert C. S. Chung, Hanna Siebert, Stephanie Häger, Annkristin Lange, Sven Kuckertz, Stefan Heldmann, Wei Shao, Sulaiman Vesal, Mirabela Rusu, Geoffrey Sonn, Théo Estienne, Maria Vakalopoulou, Luyi Han, Yunzhi Huang, Mikael Brudfors, Yaël Balbastre, Samuel Joutard, Marc Modat, Gal Lifshitz, Dan Raviv, Jinxin Lv, Qiang Li, Vincent Jaouen, Dimitris Visvikis, Constance Fourcade, Mathieu Rubeaux, Wentao Pan, Zhe Xu, Bailiang Jian, Francesca De Benetti, Marek Wodzinski, Niklas Gunnarsson, Jens Sjölund, Huaqi Qiu, Zeju Li, Christoph Großbröhmer, Andrew Hoopes, Ingerid Reinertsen, Yiming Xiao, Bennett Landman, Yuankai Huo, Keelin Murphy, Nikolas Lessmann, Bram van Ginneken, Adrian V. Dalca, Mattias P. Heinrich

MONAI is… Longitudinal studies

	CuRIOUS		Hippocampus MR		Abdomen CT-CT	
	Fixed	Moving	Fixed	Moving	Fixed	Moving
						
Modalities	MR T1w & FLAIR/US		MR T1w/MR T1w		CT/CT	
Intra-/Inter-patient	Intra-patient		Inter-patient		Inter-patient	
Resolution	256×256×288		64×64×64		192×160×256	
Voxel size	∼0.5×0.5×0.5mm		1×1×1mm		2×2×2mm	
Cases (Train/Test)	32 (22/10)		394 (263/131)		50 (30/20)	
Preprocessing	resample		crop/pad/resample		canonical affine pre-align crop/pad/resample	
Annotations	9-18 landmarks/case		2 anatomical labels		13 anatomical labels	
Additional data						
Challenges	● ● ●		●		● ●	

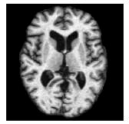
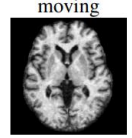
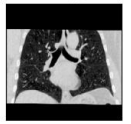
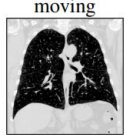
	Abdomen MR-CT		OASIS		Lung CT	
	fixed	moving	fixed	moving	fixed	moving
						
Modalities	MR T1w / CT		MR T1w / MR T1w		CT / CT	
Intra-/Inter-patient	Intra-patient		Inter-patient		Intra-patient	
Resolution	192×160×192		160×192×224		192×192×208	
Voxel size	2×2×2mm		1×1×1mm		1.75×1.25×1.75mm	
Cases (Train/Test)	16 (8/8)		455 (416/39)		30 (20/10)	
Preprocessing	canonical affine pre-align crop/pad/resample				affine pre-align crop/pad/resample	
Annotations	4-9 anatomical labels		35 anatomical labels		100 landmarks/case	
Additional data	90 unpaired MR/CT scans ROI masks				lung masks	
Challenges	● ● ● ●		●		● ● ● ●	

TABLE I: Overview of all six Learn2Reg tasks adressing the imminent challenges of medcial image registration: multi-modal scans ●, few/noisy annotations ●, partial visibility ●, small datasets ●, large deformations ●, small structures ●, unsupervised registration ● and missing correspondences ●.

MONAI is…
Survival Prediction

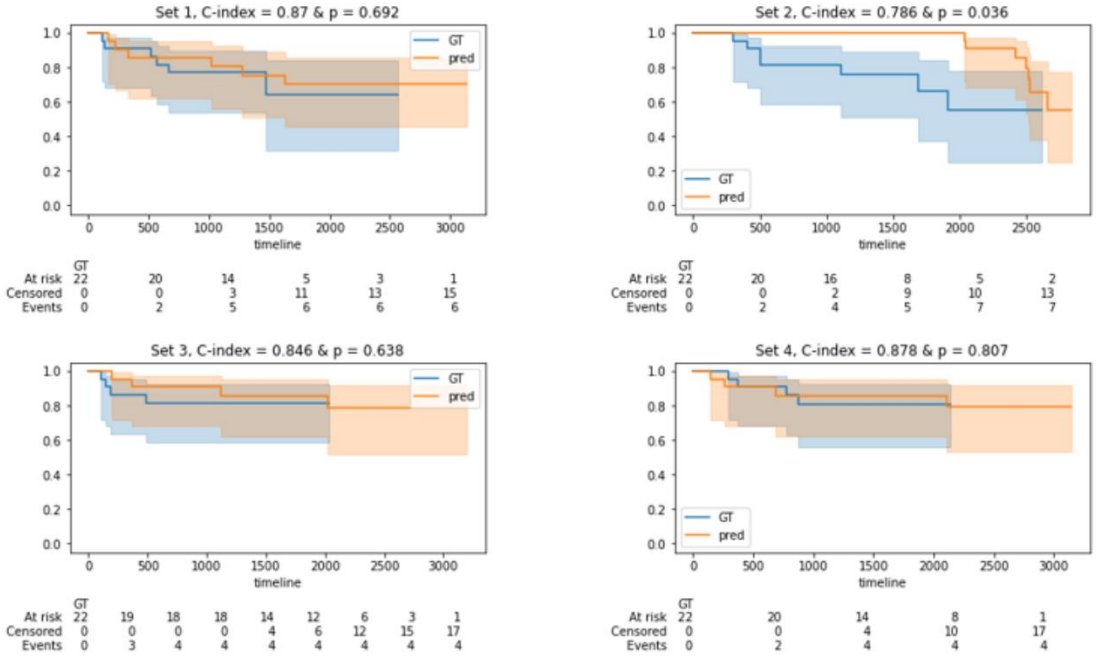
medRxiv
THE PREPRINT SERVER FOR HEALTH SCIENCES
Cold Spring Harbor Laboratory BMJ Yale

Progression Free Survival Prediction for Head and Neck Cancer using Deep Learning based on Clinical and PET-CT Imaging Data

Mohamed A. Naser, Kareem A. Wahid, Abdallah S.R. Mohamed, Moamen Abobakr Abdelaal, Renjie He, Cem Dede, Lisanne V. van Dijk, Clifton D. Fuller

doi: https://doi.org/10.1101/2021.10.14.21264955

Fig. 4. Kaplan Meier plots showing survival probabilities as a function of time in days for the ground truth (GT) PFS and the predicted PFS by the model using only imaging data (i.e., CT and PET) for each validation set of 22 patients. The C-index and the p-value of the logrank test for the GT and predicted PFS are shown above each subplot.



MONAI is...

1.1M+	Downloads
150+	Individual contributors
3,400+	Gihub stars
480+	Derived projects
600+	Google Scholar results from ‘ “MONAI” medical deep learning ’

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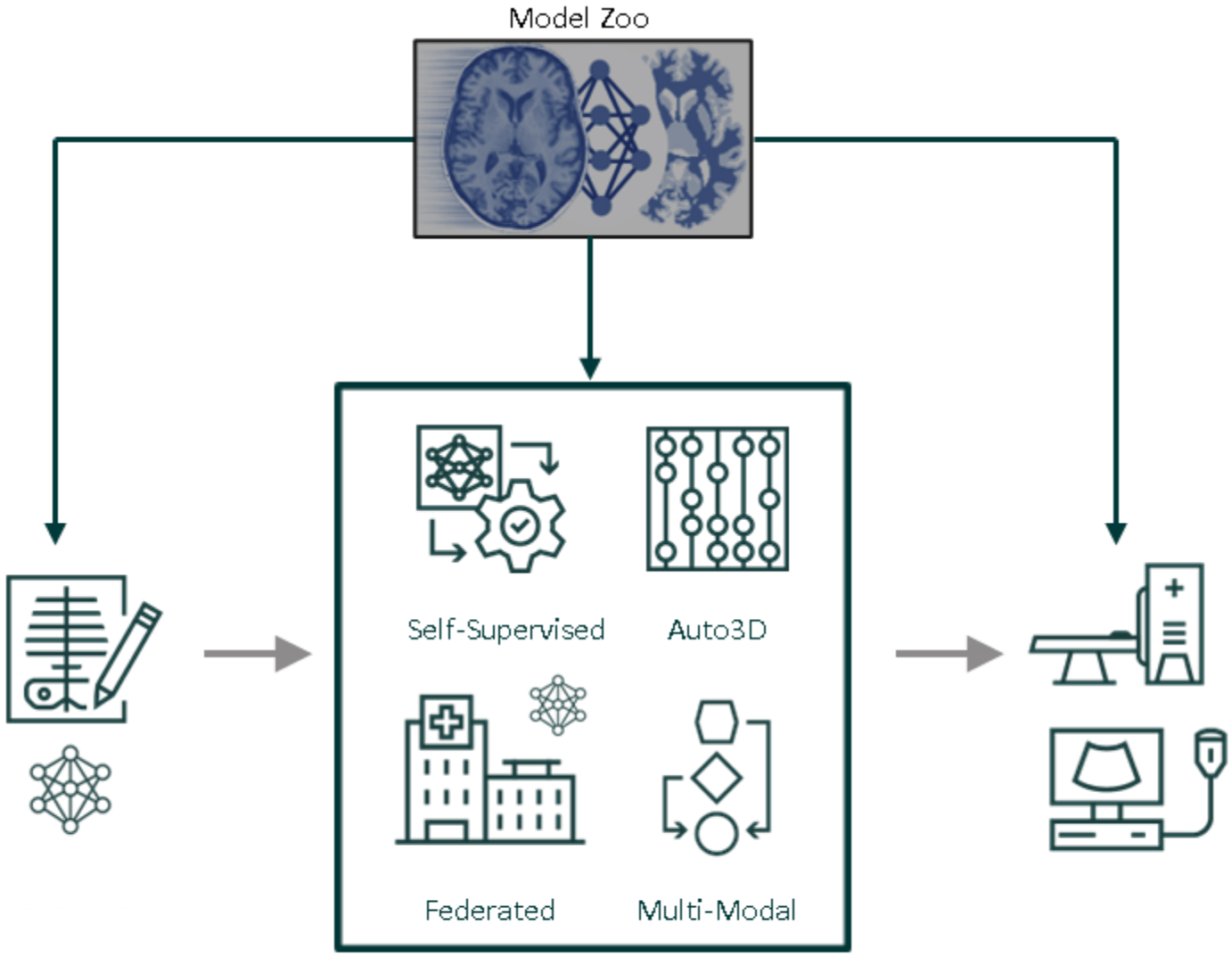
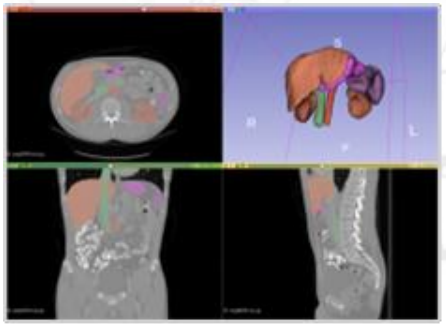
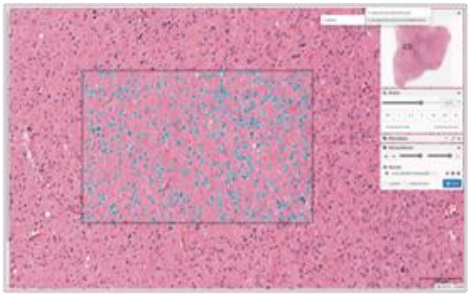
MONAI 1.0 (Sept. 2022)

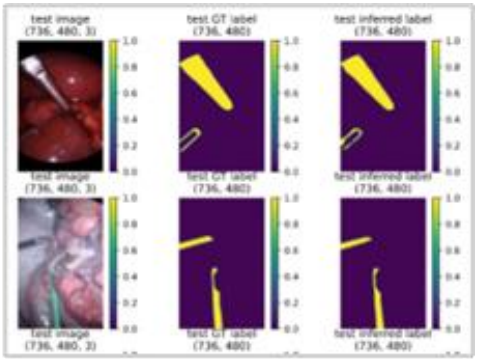




Radiology



Pathology



Endoscopy

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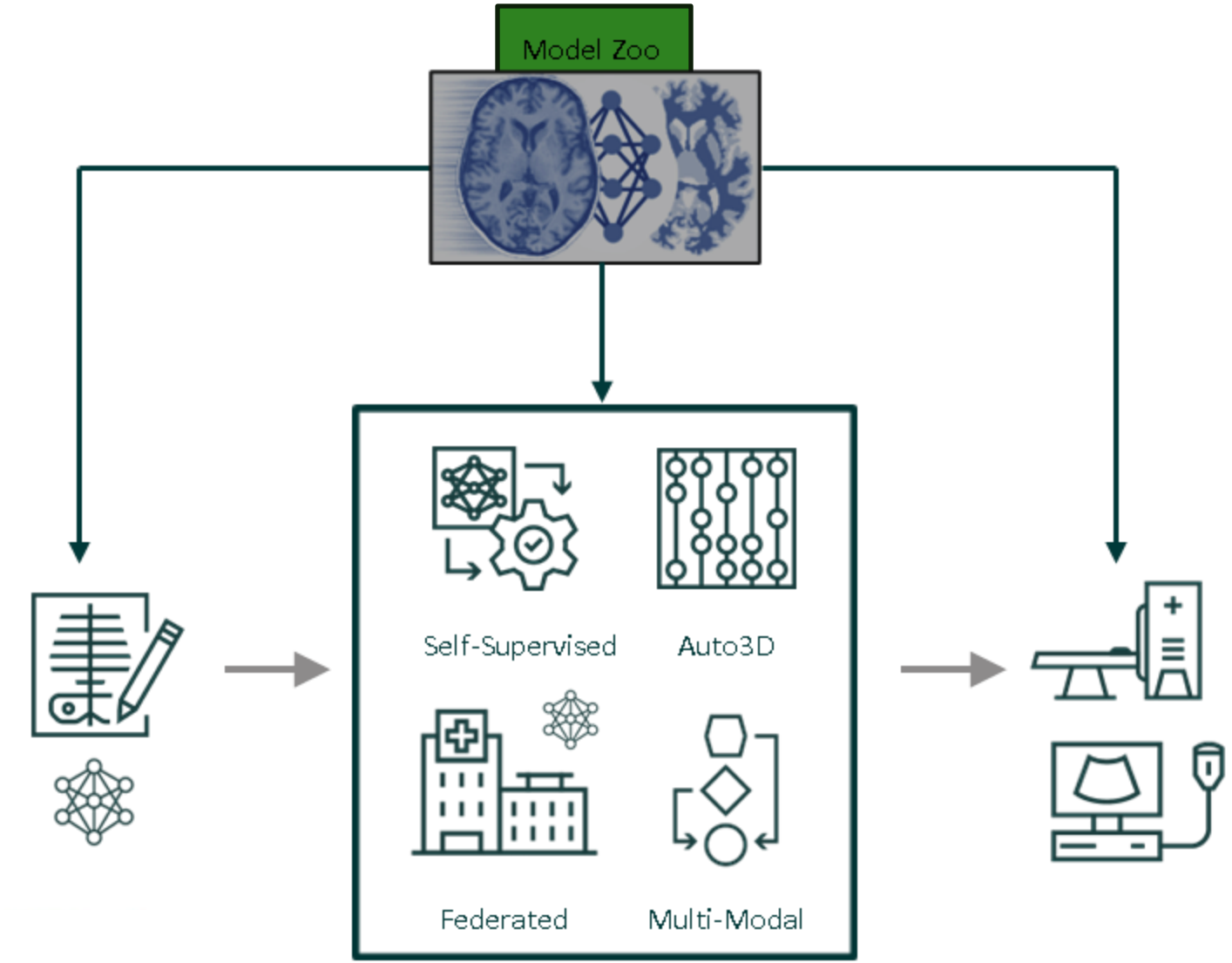
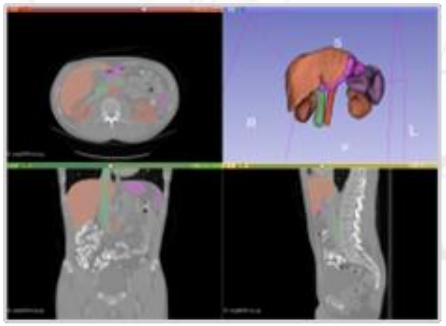
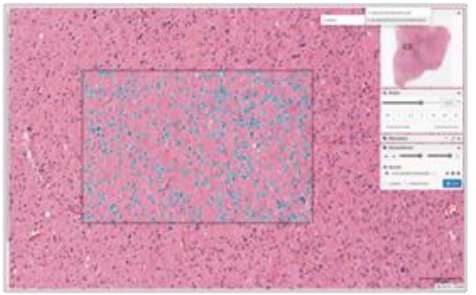
MONAI 1.0 (Sept. 2022)

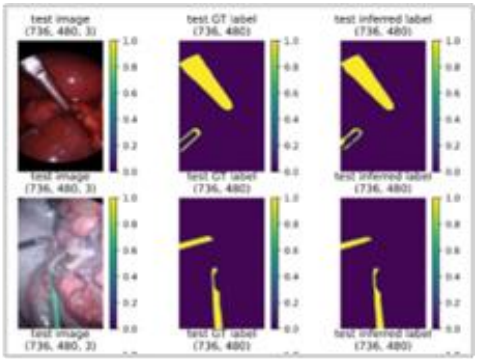




Radiology



Pathology



Endoscopy

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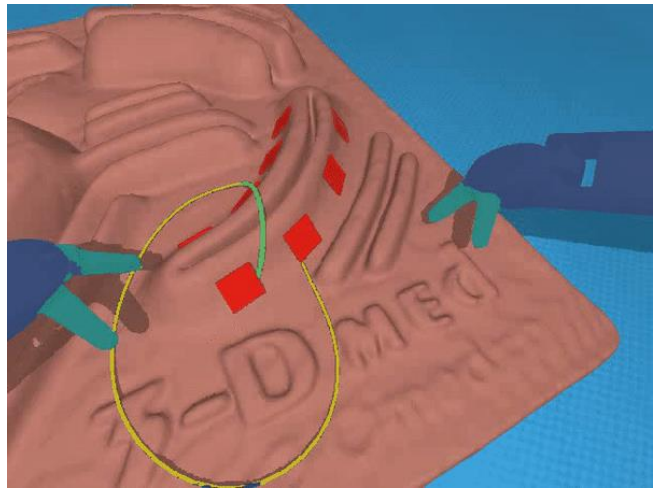
MONAI: Beyond Open Science (MONAI Stream)

- Open Science 2.0: Publications, Data, Software…and Hardware
- Holoscan SDK
  - Open-source interface with hardware
  - Low latency
  - Parallel inference (multiple AI models running simultaneously)
  - Ultrasound devices, ROS, DaVinci (DVRK), Frame grabbers, GPUs, AR/VR, …

Jetson, Nano, AGX, …



What's needed for even broader impact for open science?

- Regulatory approval that confirms the safety of community-supported, open-source software, without commercial sales or individual (developer) liability.
  - Transparent process
  - Continuous testing
  - World-wide use

Thank you!

ITK, 3D Slicer, and MONAI:

Creating and sustaining impact with open-science

Stephen R. Aylward, Ph.D.
Chair of MONAI Advisory Board
Senior Director of Strategic Initiatives, Kitware

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