Open science: a path to success in academia and industry

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The professor…

…and his students

Bob graduates

I cannot find Bob's code.


Bob’s code won’t compile


I cannot replicate Bob's results


I emailed Bob a question, but he hasn’t responded

Open Science is the answer

Focus on publishing your research
so that other people can duplicate
and learn from it.

- Software
- Data

… sharing leads to success

Three Presentations

- Open Science
- Path to Success in Academia and Industry
- Research at Kitware

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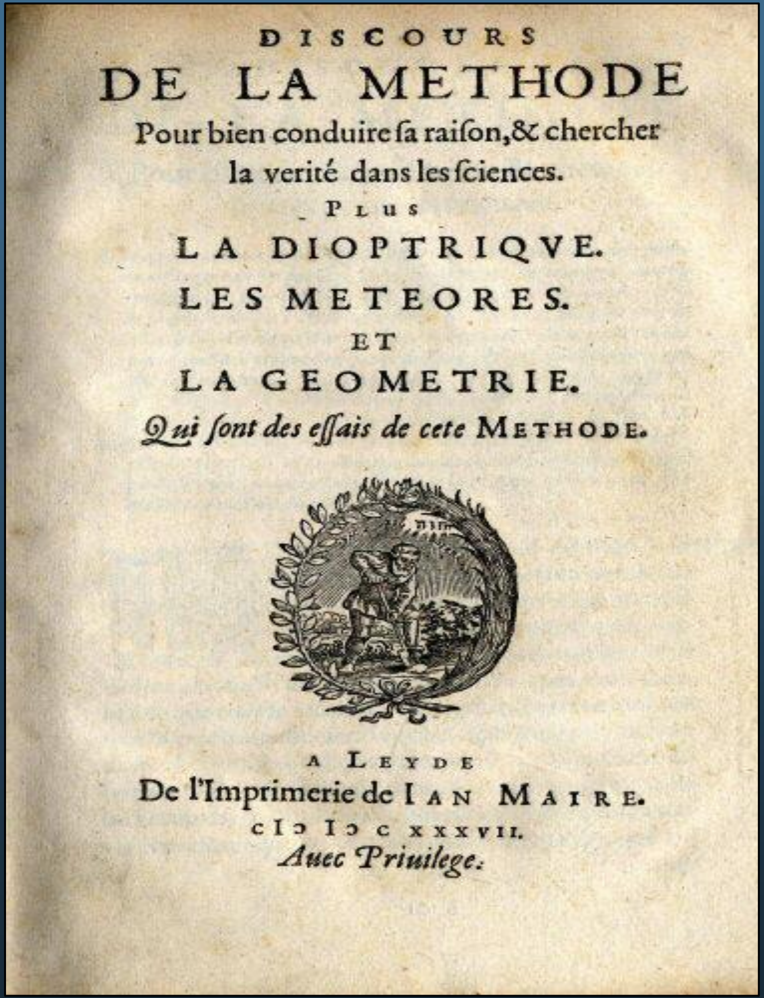

DISCOURS
DE LA METHODE
Pour bien conduire ſa raiſon, & chercher la verité dans les ſciences.
PLUS
LA DIOPTRIQVE.
LES METEORES.
ET
LA GEOMETRIE.
Qui ſont des eſſais de cete METHODE.

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

A Failure of Science (scientific publication)

Nature (March 2012)

-- Glenn Begley: Head of cancer research at Amgen (pharma giant)

-- Lee M. Ellis: Cancer researcher at the University of Texas

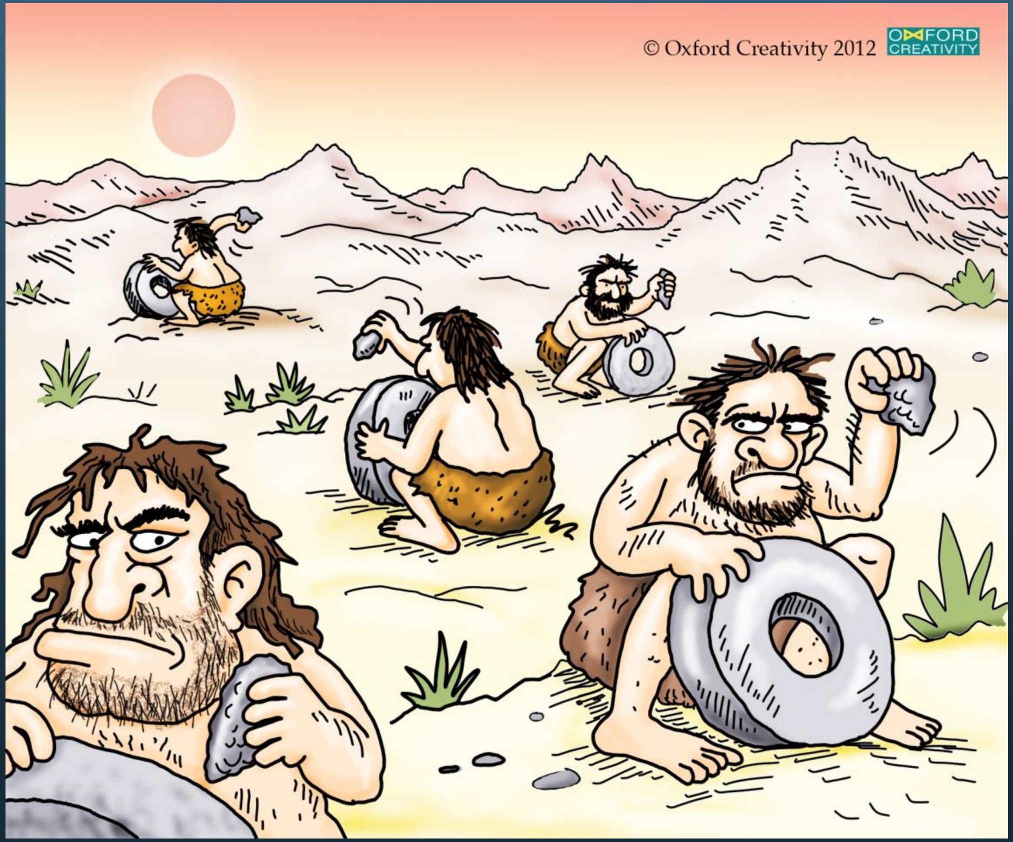
Identified 53 'landmark' publications.

Sought to double-check the findings before building on them for drug development.

Result: 47 of the 53 could not be replicated.

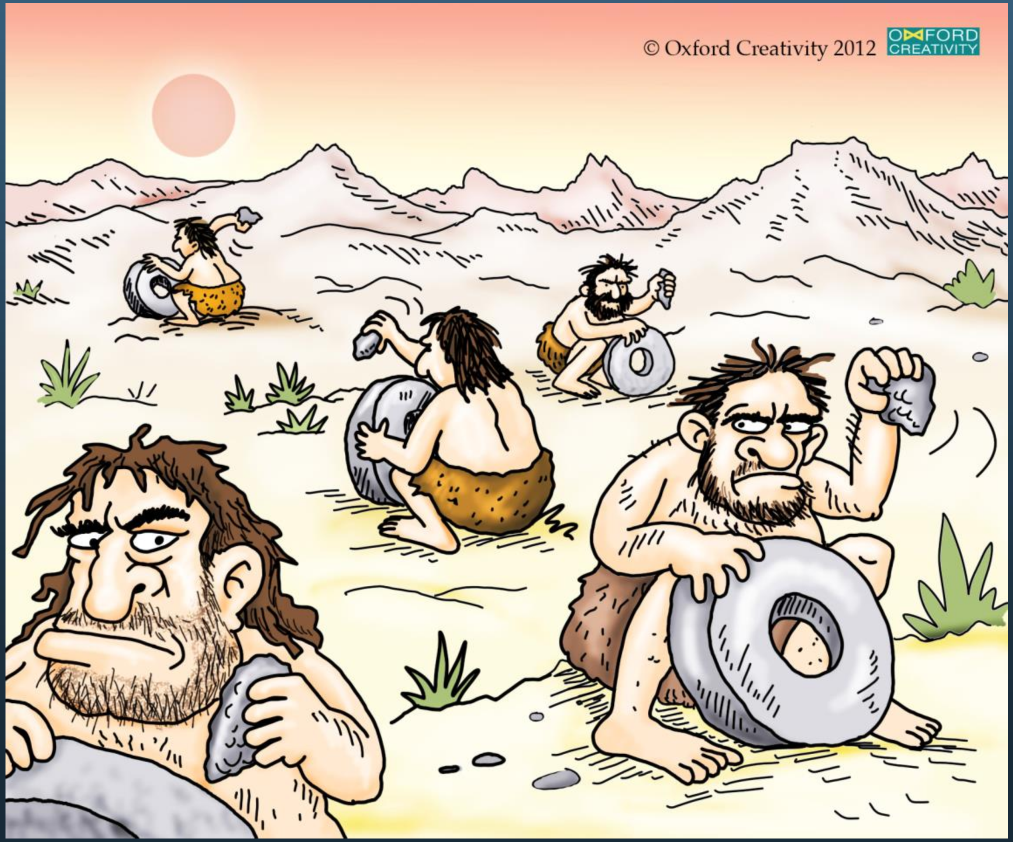
Three challenges to open science

1) Sense of competition



Three challenges to open science

1) Sense of competition



2) Inadequacy of journal articles

Intraoperative ultrasound for guidance and tissue shift correction in image-guided neurosurgery

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Department of Neurology and Neurosurgery, Montreal Neurological Institute, McGill University, Montreal, Quebec H3A 2B4, Canada

Aaron Fenster
Imaging Research Labs, The John P. Robarts Research Laboratories, University of Western Ontario, London, Ontario N6A 5K8, Canada

Terry M. Peters
Imaging Research Labs, The John P. Robarts Research Laboratories, University of Western Ontario, London, Ontario N6A 5K8, Canada and McConnell Brain Imaging Center, Montreal Neurological Institute, McGill University, Montreal, Quebec H3A 2B4, Canada

(Received 9 September 1999; accepted for publication 11 January 2000)

We present a surgical guidance system that incorporates pre-operative image information (e.g., MRI) with intraoperative ultrasound (US) imaging to detect and correct for brain tissue deformation during image-guided neurosurgery (IGNS). Many interactive IGNS implementations employ pre-operative images as a guide to the surgeons throughout the procedure. However, when a craniotomy is involved, tissue movement during a procedure can be a significant source of error in these systems. By incorporating intraoperative US imaging, the target volume can be scanned at any time, and two-dimensional US images may be compared directly to the corresponding slice from the pre-operative image. Homologous points may be mapped from the intraoperative to the pre-operative image space with an accuracy of better than 2 mm, enabling the surgeon to use this information to assess the accuracy of the guidance system along with the progress of the procedure (e.g., extent of lesion removal) at any time during the operation. Anatomical features may be identified on both the pre-operative and intraoperative images and used to generate a deformation map, which can be used to warp the pre-operative image to match the intraoperative US image. System validation is achieved using a deformable multi-modality imaging phantom, and preliminary clinical results are presented. [S0094-2405(00)01404-8]

Key words: image-guided surgery, ultrasound, tissue deformation, image warping, image registration, neurosurgery, intraoperative imaging

I. INTRODUCTION

A. Image-guided neurosurgery (IGNS)

Radiological images have been used as a guide in neurosurgery for decades. Soon after their introduction by Roentgen, surgeons took advantage of this new form of information to better plan and perform surgical procedures. In 1918, Aubrey Mussen[1] built a stereotactic frame designed for human use. However, it was not until 30 years later (after his death) that this device was re-discovered. Subsequently, Spiegel and Wycis in 1947 further developed this technique of stereotaxy, which involved the use of a three-dimensional Cartesian coordinate system for the human brain. These coordinates were defined with respect both to the brain and radiographic images that were acquired with a reference (or stereotactic) frame attached to the patient's head.

Although the stereotactic frame is still in use for many surgical procedures,[2,3] particularly where high accuracy and precision is required in the localization of targets, other techniques have recently been developed to provide more flexible and interactive means of relating structures within the brain to images obtained pre-operatively. This field has become known as interactive image guided neurosurgery (IGNS).[4–11] IGNS enables the surgeon to navigate within the patient's brain using pre-operative images as a guide, by using a handheld computer-tracked probe or other instruments during the procedure in the operating room (OR). Following a calibration procedure, three-dimensional position and orientation of such a probe may be relayed to a computer and displayed within the three-dimensional pre-operative image.

Many investigators have described IGNS systems that use pre-operative anatomical images, including magnetic resonance imaging (MRI), computed tomography (CT) and digital subtraction angiography (DSA), as a navigational guide.[12] In addition to anatomical information, others have described systems that incorporate functional information in the form of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) to improve the information content used for neuro-navigation.[13,14]

<<

3) Priorities: I have more important things to do…

publish

finish my dissertation

write a proposal

start my company

sell my company

Make $1,000,000

Benefits of Open Science

"…much of our intelligence and creativity results from interactions with tools and artifacts and from collaborating with other individuals."

-- Dr. Ben Shneiderman, 1986
Eight Golden Rules of Interface Design

Benefits of Open Science

“Whoever has the most ideas stolen, wins.”

-- Dr. Fred Brooks, UNC Comp Sci, 2001

Open Science is Easy

- Public databases
  - FITBIR: Database for TBI data
  - TCIA, GenBank, …

- Open-source software: R, Python, MATLAB
  - Standard for citing software (SPIE & Code Ocean DOI)

- Open-access journals, methods and data journals
  - Electronic notebooks

Impact: Publications, grants, tenure,…

1. An Object-Oriented Approach To 3D Graphics (Schroeder) Object-oriented modeling and design (Lorensen)
    - 13,000+ Citations

2. VTK Maintenance NIH R01 ($3.4M)

3. CMake, VTK, ParaView, 3D Slicer, ITK
    - 130,000 downloads per month

4. Image Segmentation Module (MATLAB)
    - 650+ downloads per month

5. Data smoothing with Splines (R Script)
    - 4,500+ downloads

6. 2D-3D Registration Module (ITK: Inight-Journal.org)
    - 30,000+ downloads

Three Presentations

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"Researchers typically act like a bunch of four-year-olds playing soccer…they crowd around and kick wildly at the ball. The ball eventually shoots out from the crowd, and they run to it and crowd around it again..."

-- Scott Senften, 1995

- *Goal?*
- *Teamwork?*

During meetings, do not discuss other companies. All decisions should be based on what is good for the customer. Avoid the “me too” business strategy. To get ahead of the market, you have to think for yourself.

-- Jeff Bezos (Amazon, CEO)

Academia and Industry: Success

Open science (share, collaborate) and….

focus on the goal (customer, patient)

Also…have as much fun as 4 year olds playing soccer…

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Kitware's customers & collaborators

Over **75 academic** institutions…

Harvard
Massachusetts Institute of Technology
University of California, Berkeley
Stanford University
California Institute of Technology
Imperial College London
Johns Hopkins University
Cornell University
Columbia University
Robarts Research Institute
University of Pennsylvania
Rensselaer Polytechnic Institute
University of Utah
University of North Carolina
Queen's University

Over **50 government** agencies and labs…

National Institutes of Health (NIH)
National Science Foundation (NSF)
National Library of Medicine (NLM)
Department of Defense (DOD)
Department of Energy (DOE)
Defense Advanced Research Projects Agency (DARPA)
Army Research Lab (ARL)
Air Force Research Lab (AFRL)
Sandia (SNL)
Los Alamos National Labs (LANL)
Argonne (ANL)
Oak Ridge (ORNL)
Lawrence Livermore (LLNL)

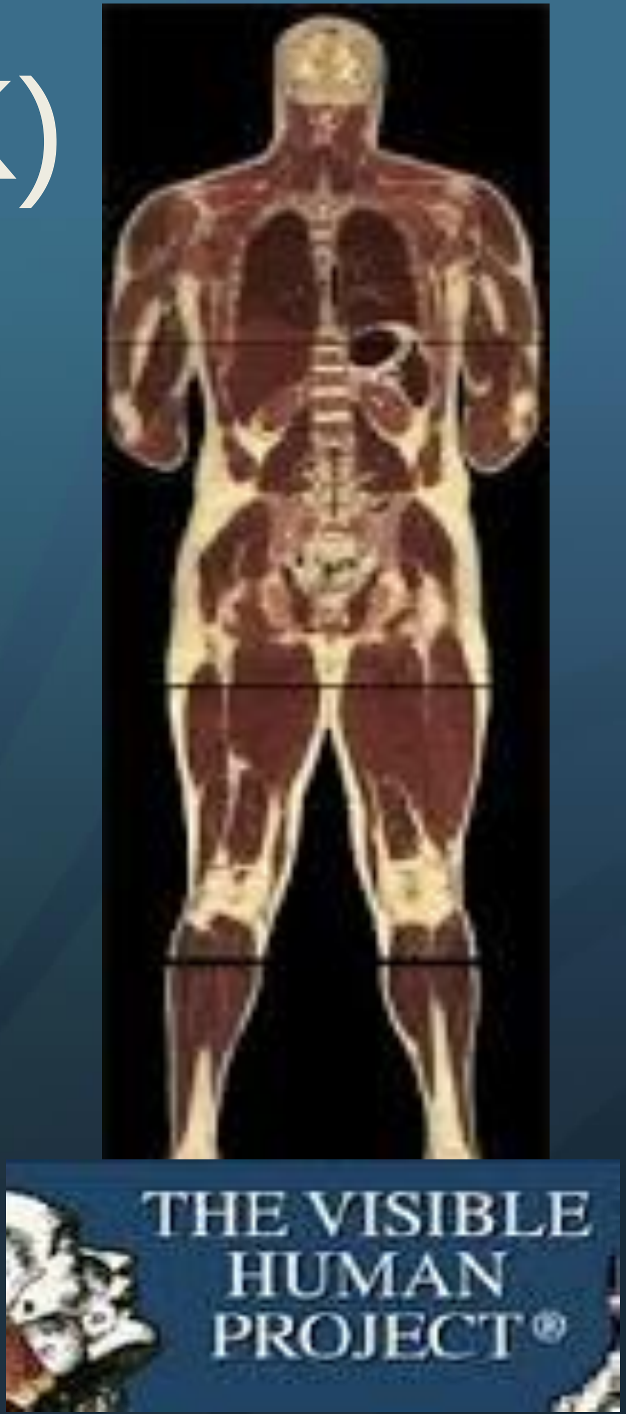
Over **100 commercial** companies…

Automotive
Aircraft
Defense
Energy technology
Environmental sciences
Finance
Industrial inspection
Oil & gas
Pharmaceuticals
Publishing
3D Mapping
Medical devices
Security
Simulation

The Insight Toolkit (ITK)

1999: NLM organized $13.5M for ITK

- GE Research / Harvard
- Kitware, Inc.
- Insightful / UPenn
- UNC / UPitt
- UPenn / Columbia
- University of Utah
- Mayo Clinic
- Harvard / Brigham and Women’s Hospital
- Cognita, Inc.
- Imperial and King’s College London
- University of Iowa
- Georgetown University
- Carnegie Mellon University



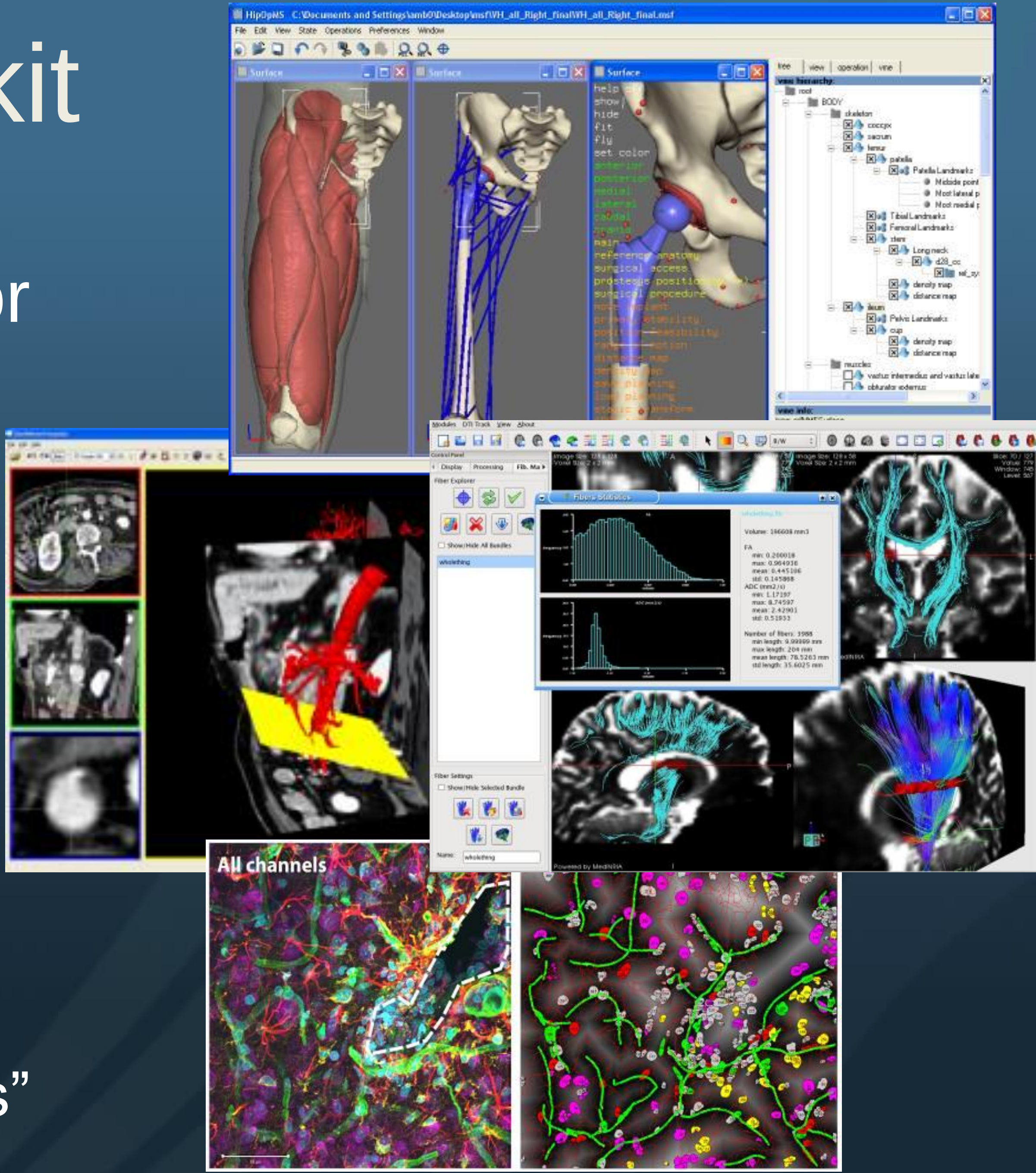
The Insight Toolkit

2017: ITK is the dominant toolkit for medical image segmentation and registration

- 1.5M lines of code
- Estimated at 452 years of effort

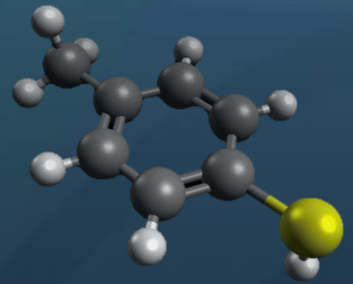
- C++, Python
- Mac, Linux, Windows

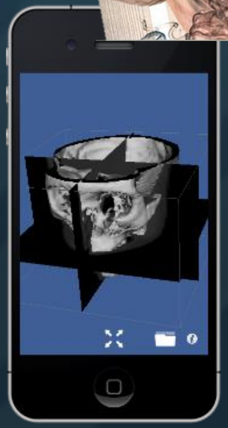
- 40% of the code contributed by “others”

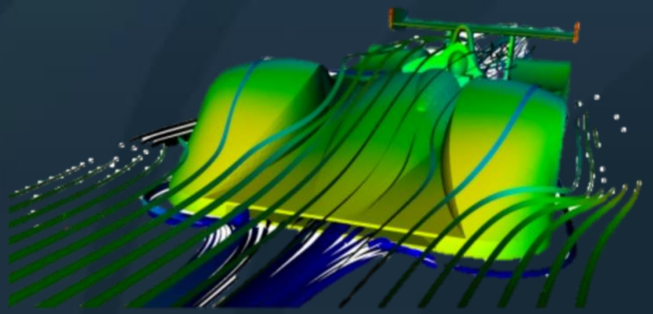


Open-source platforms

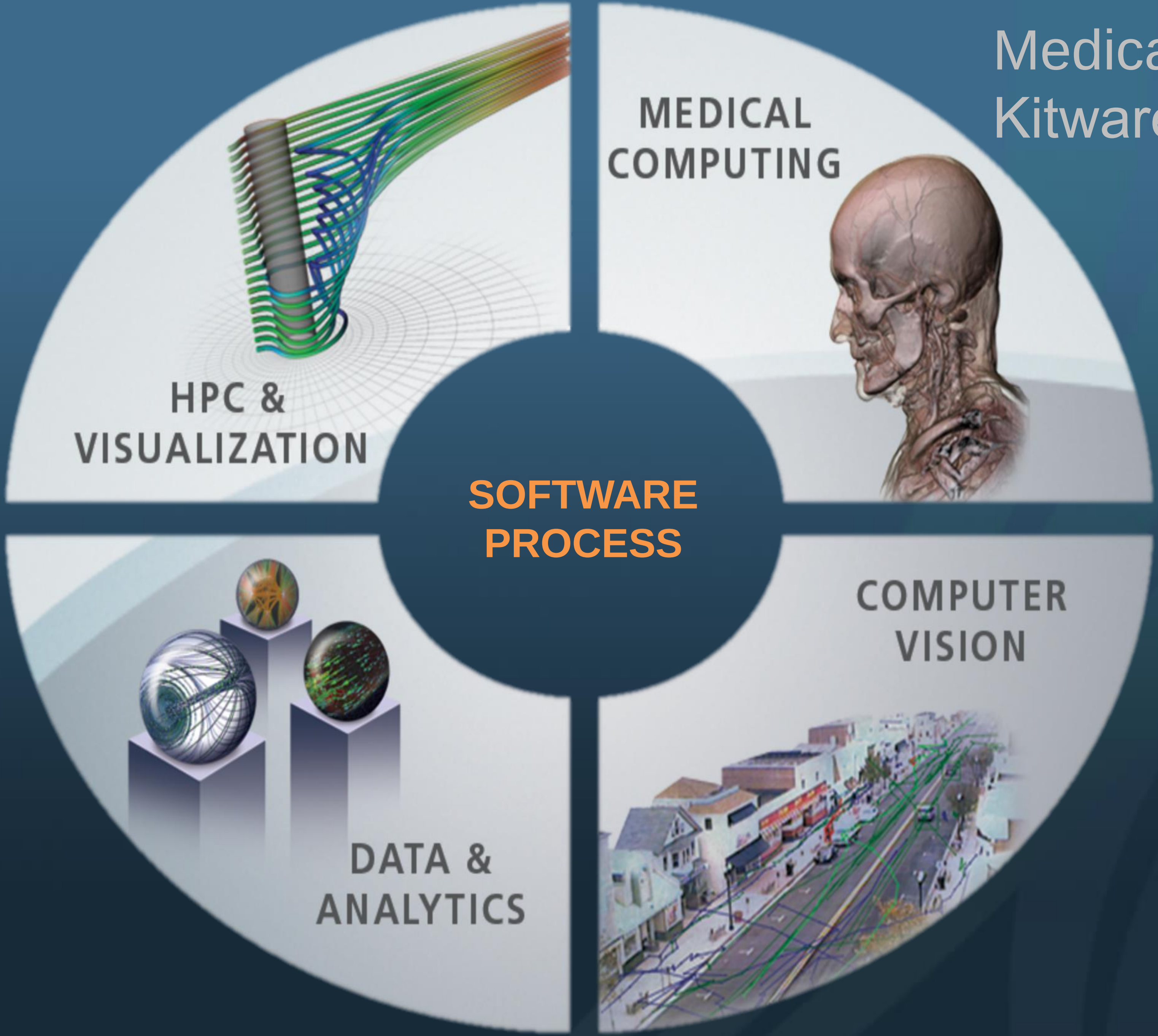
- **ITK & 3D Slicer** image analysis and personalized medicine research
- **VTK & ParaView** scientific data visualization and analysis
- **CMake** cross-platform build system
  - CDash, CTest, CPack, software process tools
- **Resonant** informatics and infovis
- **KWIVER** computer vision image and video analysis
- Simulation, ultrasound, physiology, information security, materials science, …





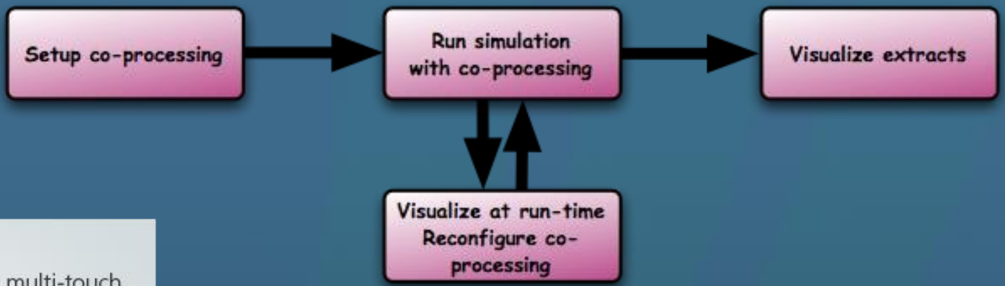


Medical = 20% of Kitware's business

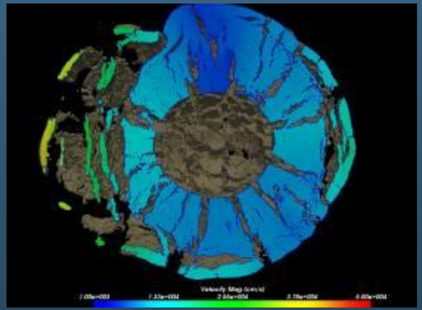


HPC & Visualization

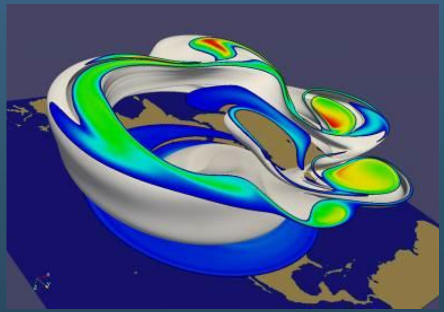
Co-processing



Massive data visualization

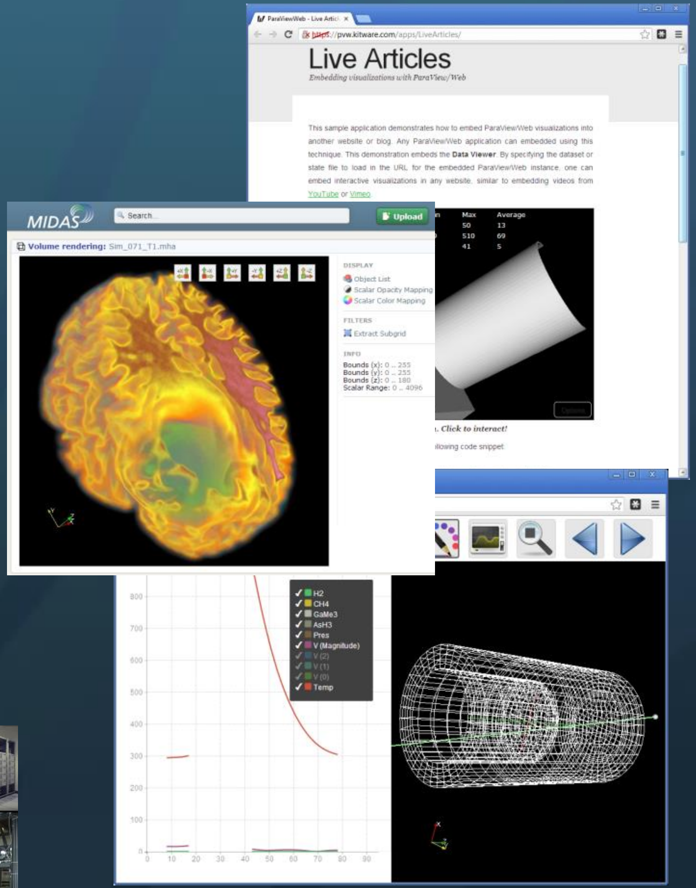


1 billion cell asteroid simulation

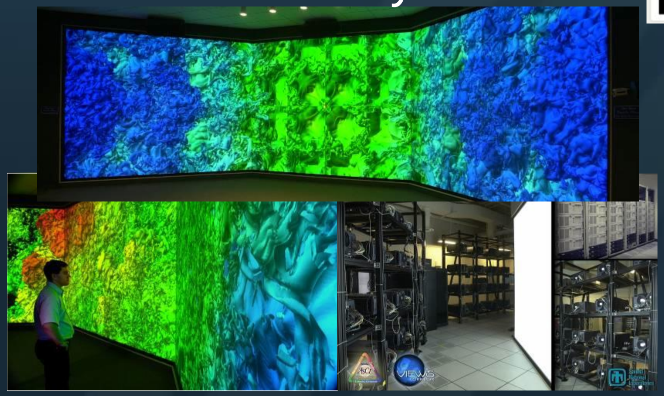


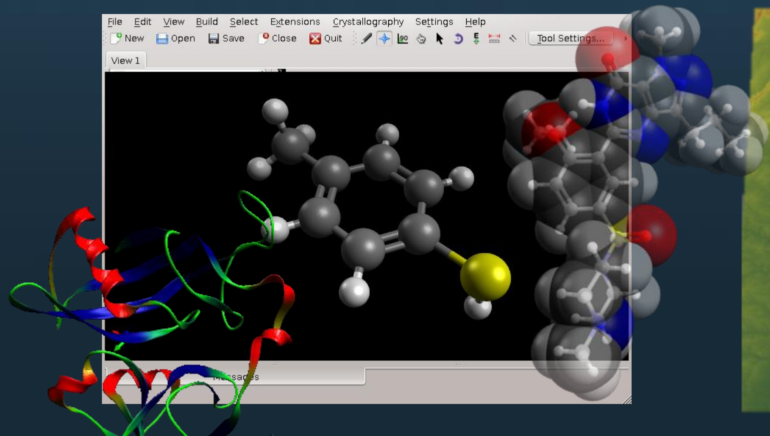
½ billion cell weather simulation

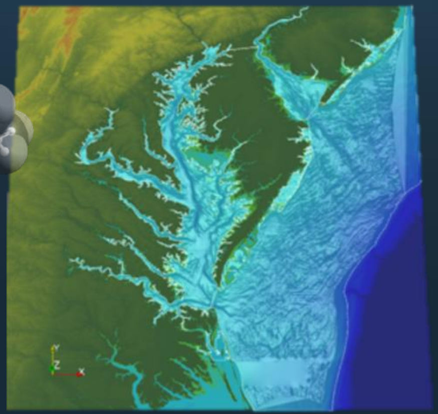
Mobile visualization



Large displays and virtual reality





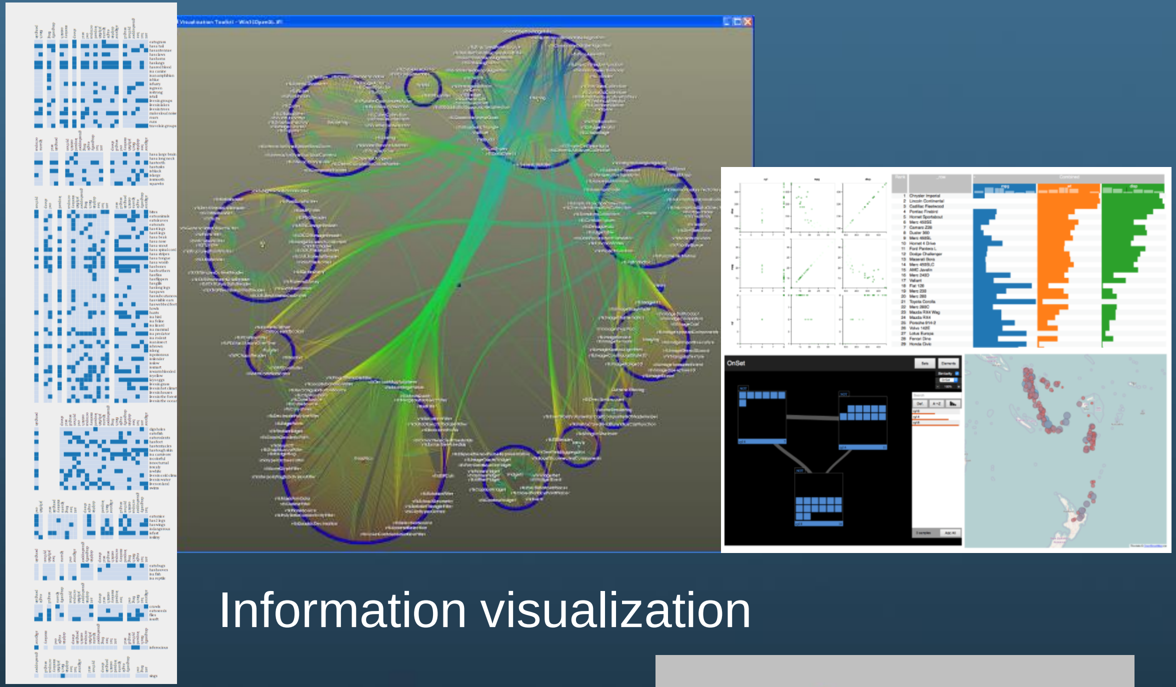


Computational Chemistry

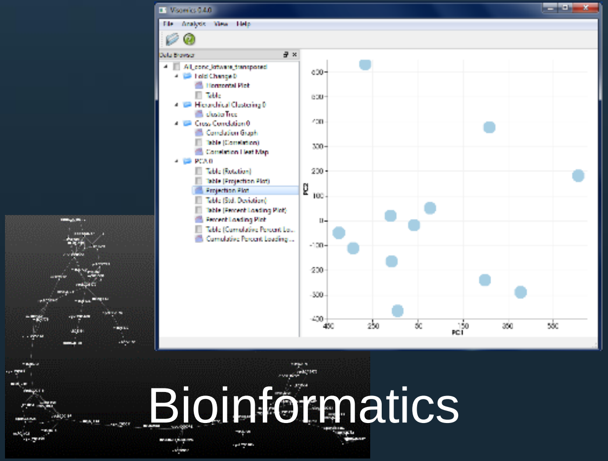
Simulation

Web visualization

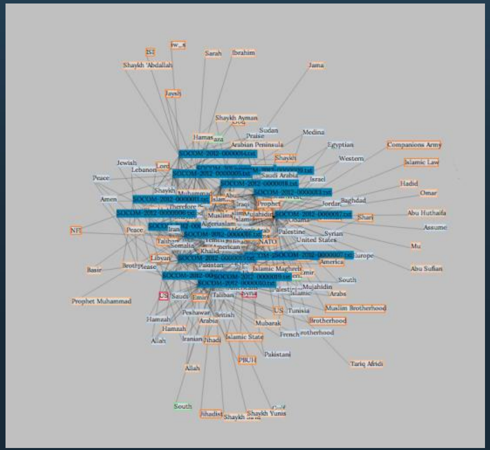
Data & Analytics



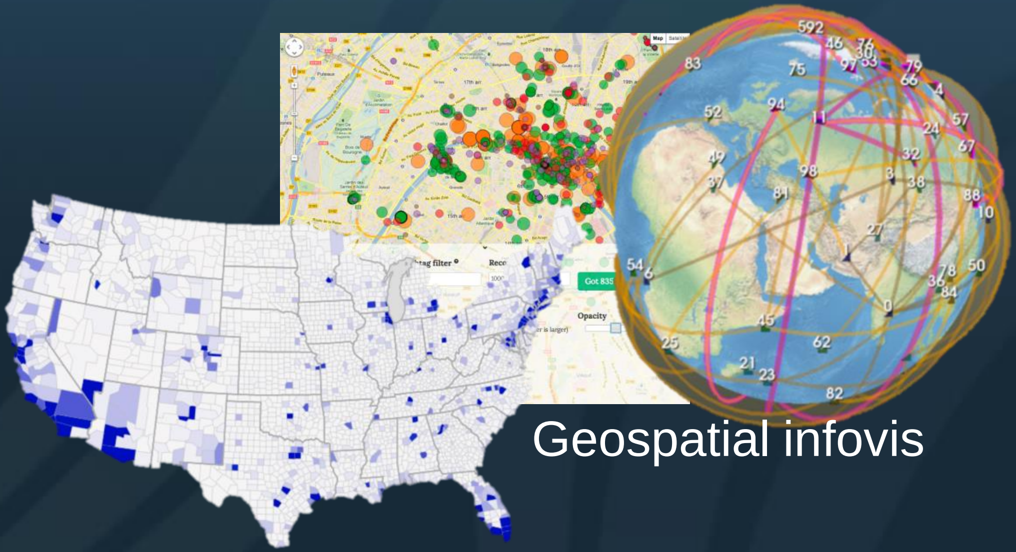
Information visualization



Bioinformatics

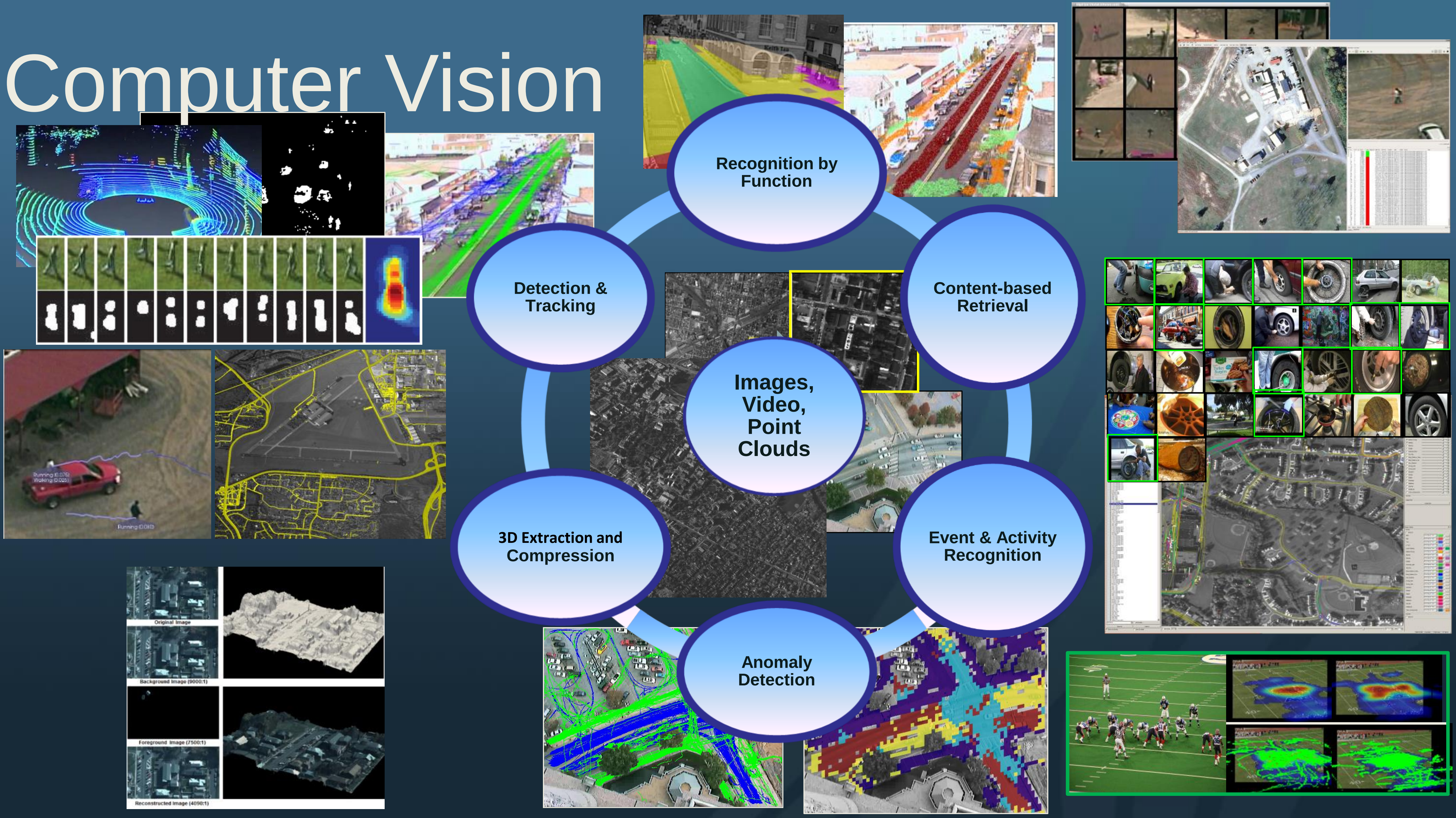


Text analysis

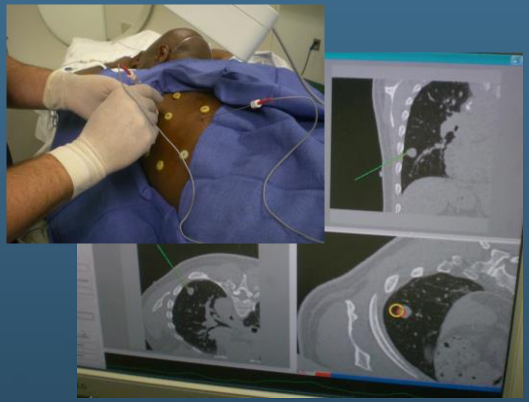


Geospatial infovis

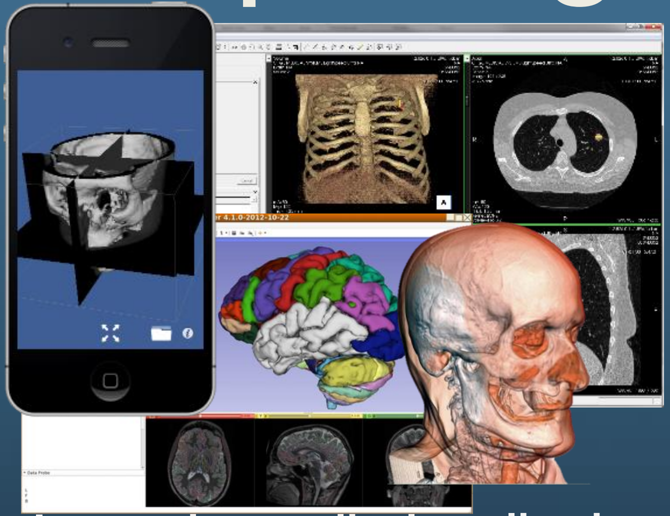
Computer Vision



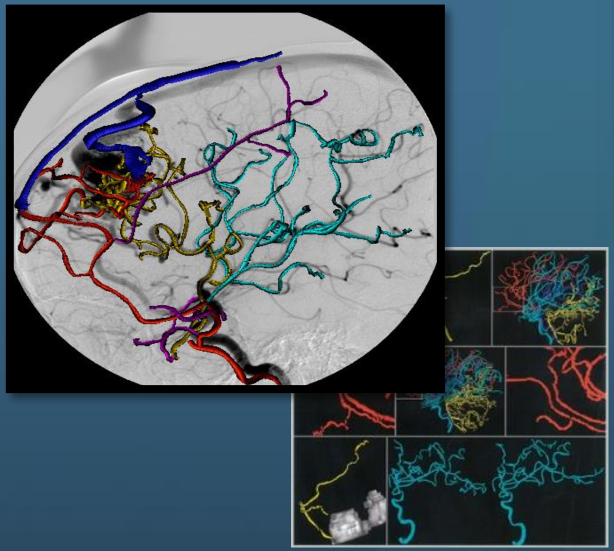
Medical Computing



Surgical guidance
And simulation

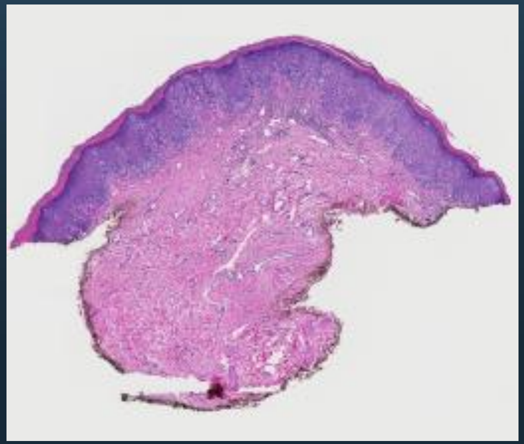


Interactive medical applications
and visualizations

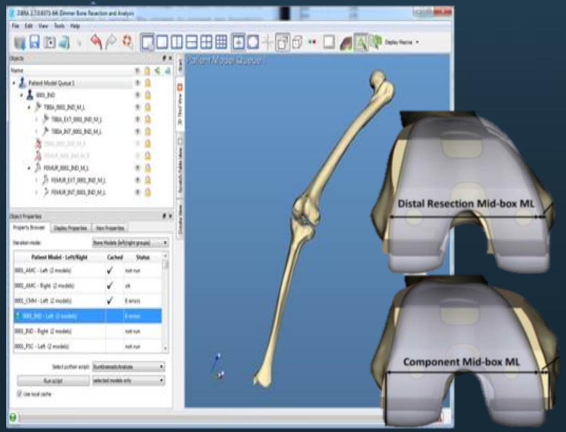


Vascular analysis

Longitudinal and
population shape
analysis

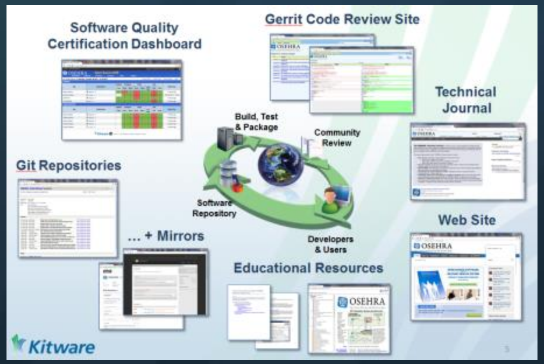


Digital pathology



Orthopedic analysis

Quantitative imaging



Electronic health records

Example: Point-of-care Ultrasound

- Far-forward, medical and EMS personnel lack portable, easy-to-use diagnostic devices to detect:
  - Intra-abdominal bleeding (IAB)
  - Pneumothorax (PTX)
  - Traumatic brain injury (TBI).

- When in-field ultrasound is conducted by experts, patient management is altered in 37% of cases. [Walcher 2002]
- Even after hours of training, pre-hospital personnel are not sufficiently proficient in FAST for over 48% of trauma patients. [Melanson 2001]

Computer-Augmented Point-of-Care Ultrasound

- ✓ Rugged, compact, portable hardware
- ✓ Multiple diagnostic capabilities
- Intuitive
  - Task-specific interfaces
    - Support targeted acquisition of high-quality data
  - Automated image analysis
    - Display diagnostic results (red light / green light), not B-Mode images.

BladderScan


Philips Lumify

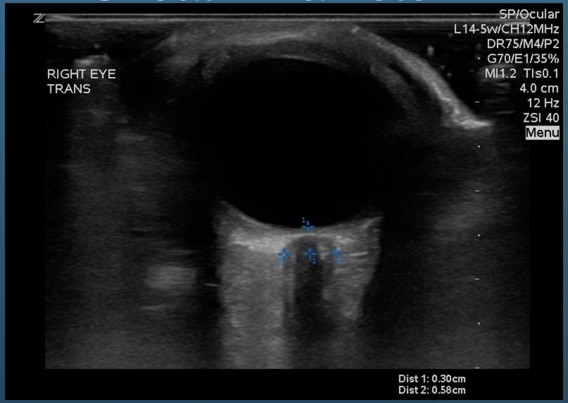
Equipment and Applications

- TBI (Intracranial pressure: ICP)
- FAST
- Pneumothorax
- Hemothorax
- Renal dysfunction

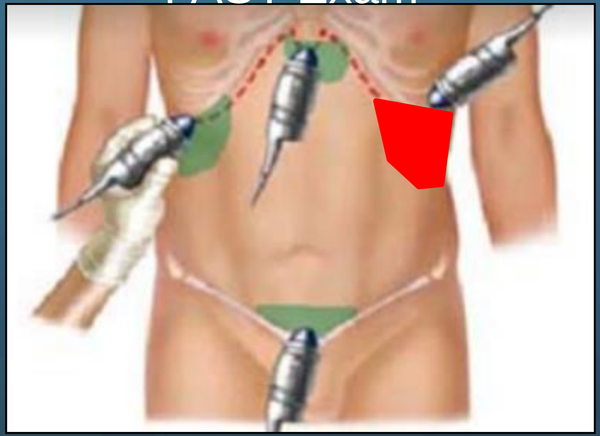
- Guidance: paracentesis, peripheral vascular access

- General medicine: Scoliosis

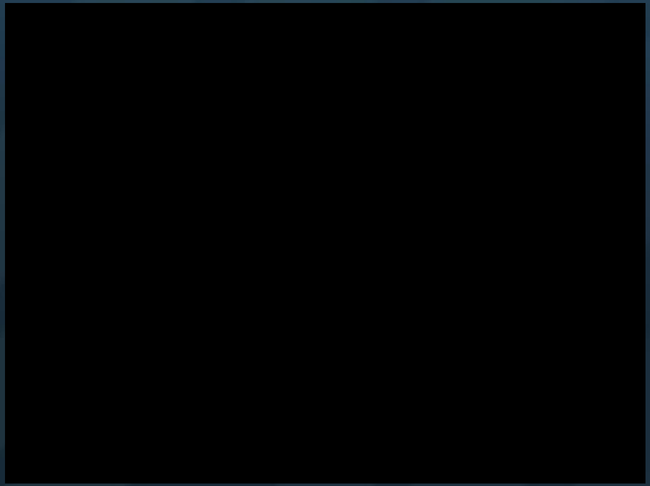
ICP: Optic Nerve Sheath Diameter



FAST Exam



PTX



(A) Intel® STK2mv64CC

- Powerful, actively cooled 1 GHz Intel m5-6Y57 CPU
- Integrated graphics
- 4 GB RAM
- Windows operating system supports ultrasound device drivers
- USB 3.0, for rapid communication with ultrasound probe
- Runs off 5v USB power
- Very small: 38 x 12 x 114 mm

(B) Waveshare LCD Screen

- 5v, 400 mA
- 4 inch form factor
- 800x480 Resolution
- HDMI interface
- IPS for wide viewing angle

(C) Jackery Mini 5V 3350mAh Battery

B-Mode ultrasound and tissue characterization

- B-Mode Image = power envelope of returned RF signal
  - Single (centered) pulse power and frequency
  - Envelope computation and scan conversion = massive data reduction

B-Mode Image

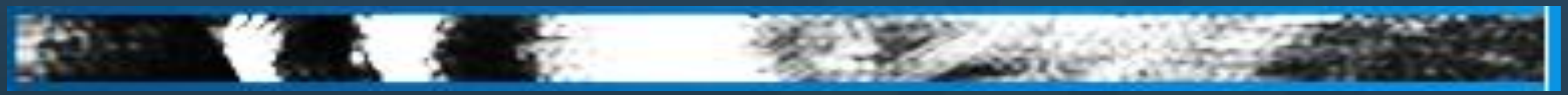
512

512

127 (Elements)

RF Data

4096 (Time)



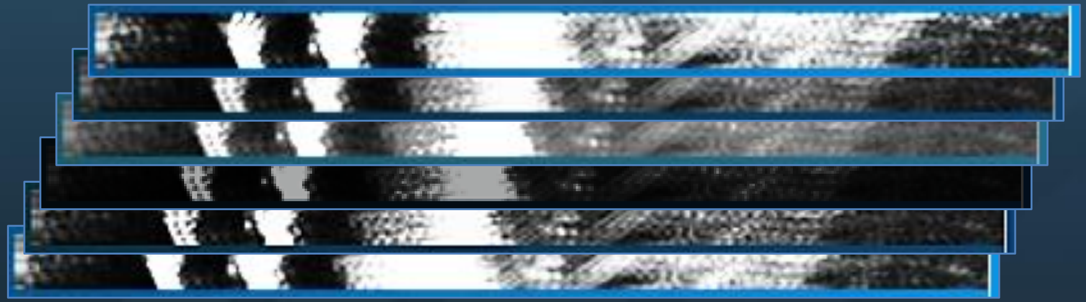
- RF-based tissue characterization has existed for over 30 years

[Lizzi 1983]

Ultrasound Spectroscopy

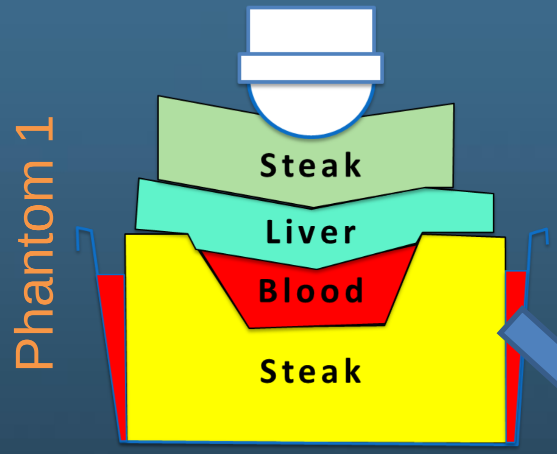
Analyze RF returns from
multiple powers and multiple frequencies

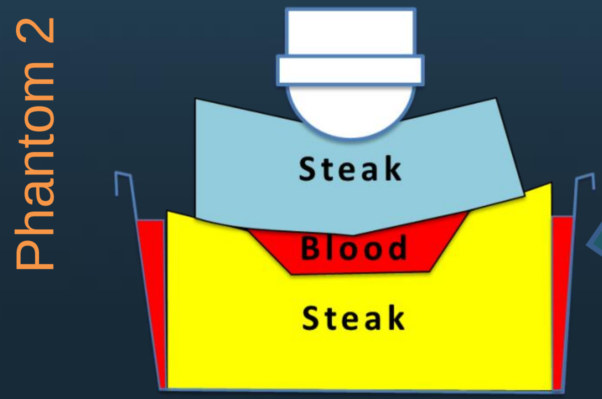
	Power	Freq.
1	15%	2.5
2	15%	3.5
3	15%	5.0
4	30%	2.5
5	30%	3.5
6	30%	5.0

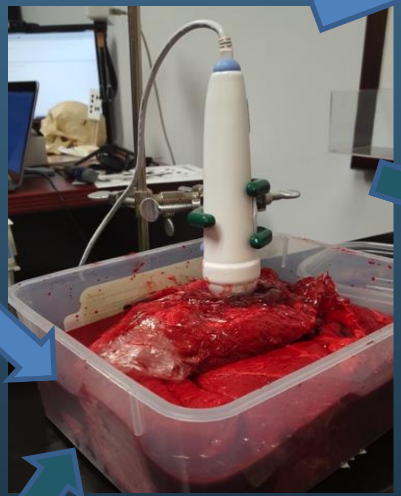


- Pre-processing
  - "Quantitative Ultrasound" [Lavarello 2011]
- RF Characterization
  - Chebyshev Polynomial Coefficients
  - Legendre Polynomial Coefficients
  - Linear Fit (Slope, Intercept)
  - Backscatter Coefficient Estimation
- Classification = Neural Network

Preliminary Ex Vivo Tissue Experiment







Phantom 1 training data

Phantom 2 testing data

Random Forest Classifier
(Blood –vs- Not Blood)

Blood detection accuracy

Pwr	Freq	Features	TPR	FPR	%Err
All	All	B-Mode Only	0.565	0.057	13.46
All	All	All (102 features)	0.948	0.005	1.51

Factor Analysis

Best-First greedy feature selection chose these 14 for blood-vs-not-blood classification.

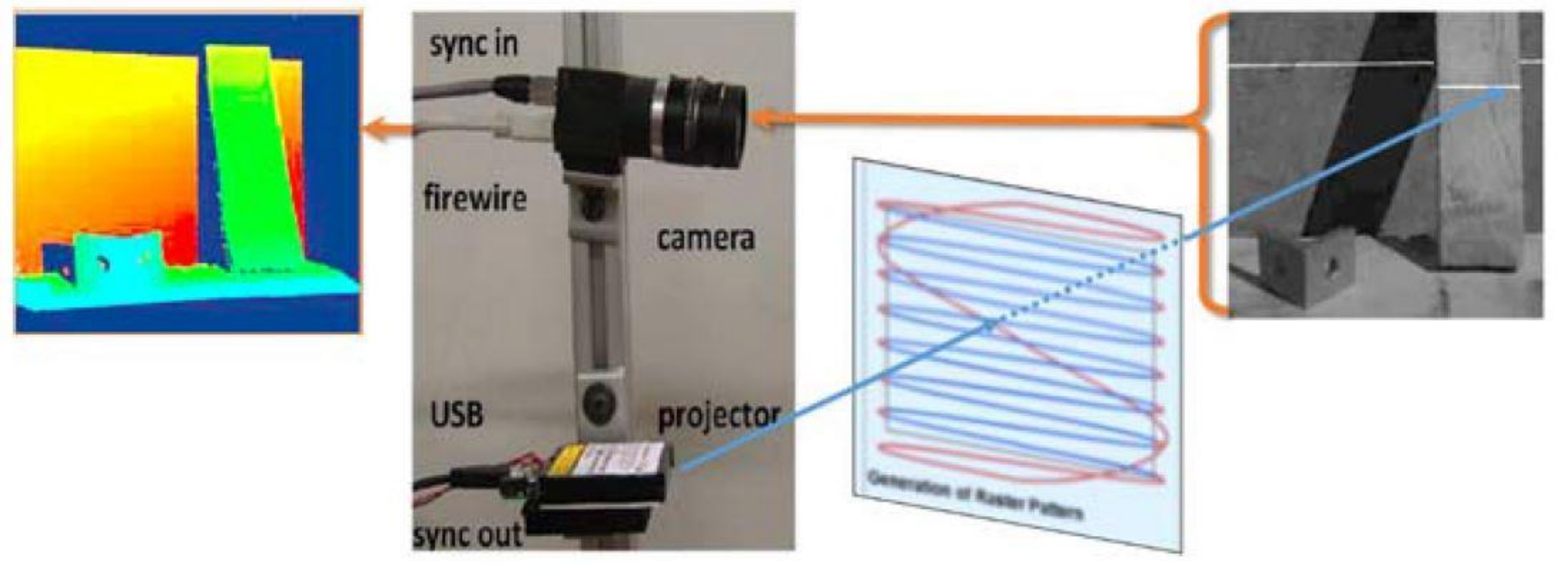
Pwr	Freq	Feature	
15	25	Chebyshev	Coef 3
15	35	Chebyshev	Coef 4
15	35	Legendre	Coef 2
15	35	Legendre	Coef 6
15	50	Chebyshev	Coef 3
15	50	Chebyshev	Coef 5
15	50	Legendre	Coef 3
30	25	Chebyshev	Coef 4
30	25	Legendre	Coef 0
30	25	Legendre	Coef 3
30	35	Chebyshev	Coef 4
30	35	Legendre	Coef 2
30	50	Chebyshev	Coef 3
30	50	Legendre	Coef 4

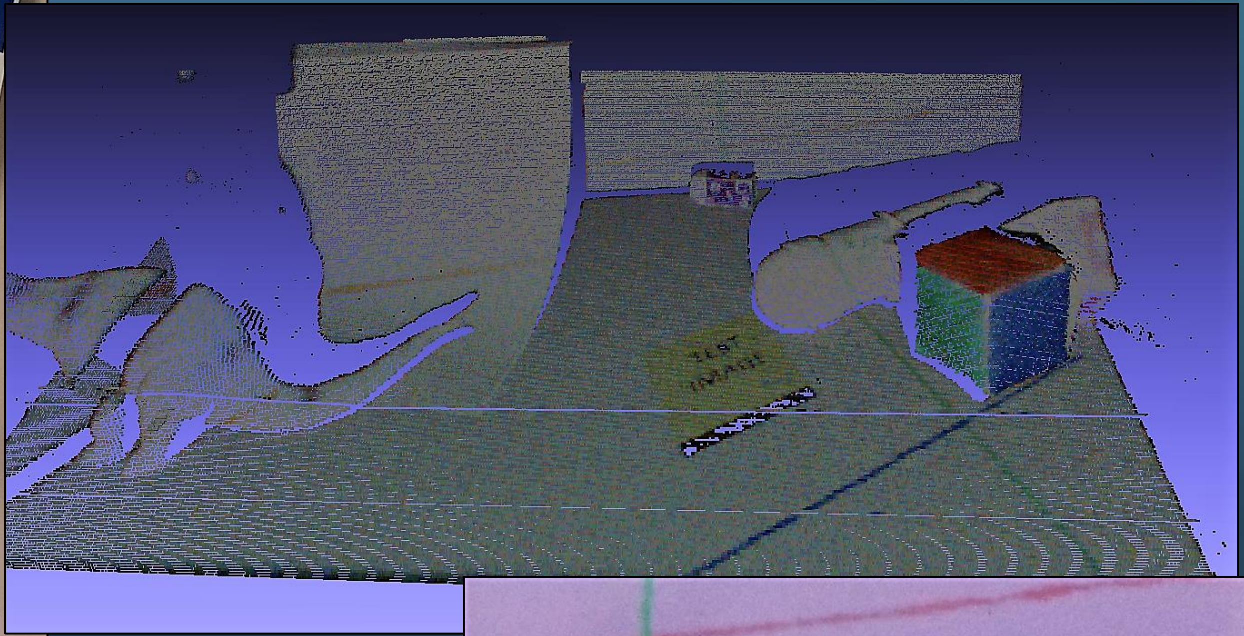
(1) every power and frequency is represented

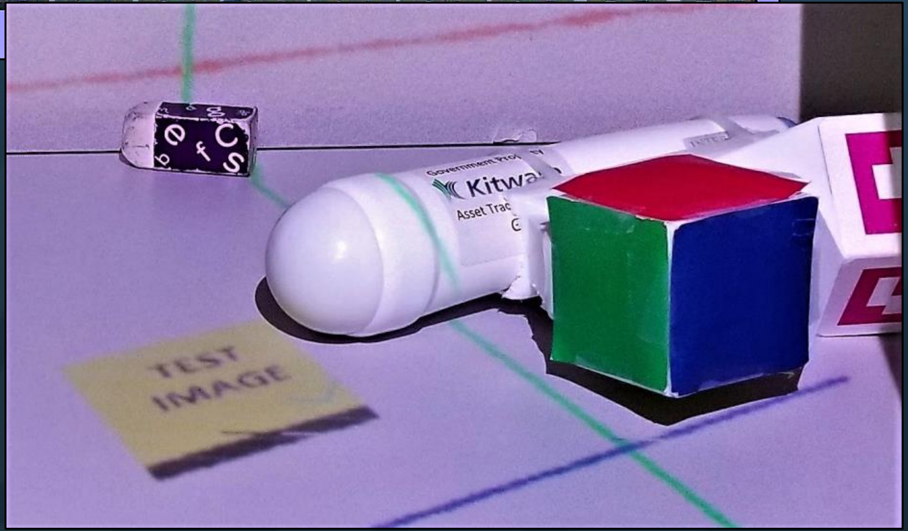
(2) nearly every Chebyshev and Legrende coefficient degree is used, from different powers and frequencies

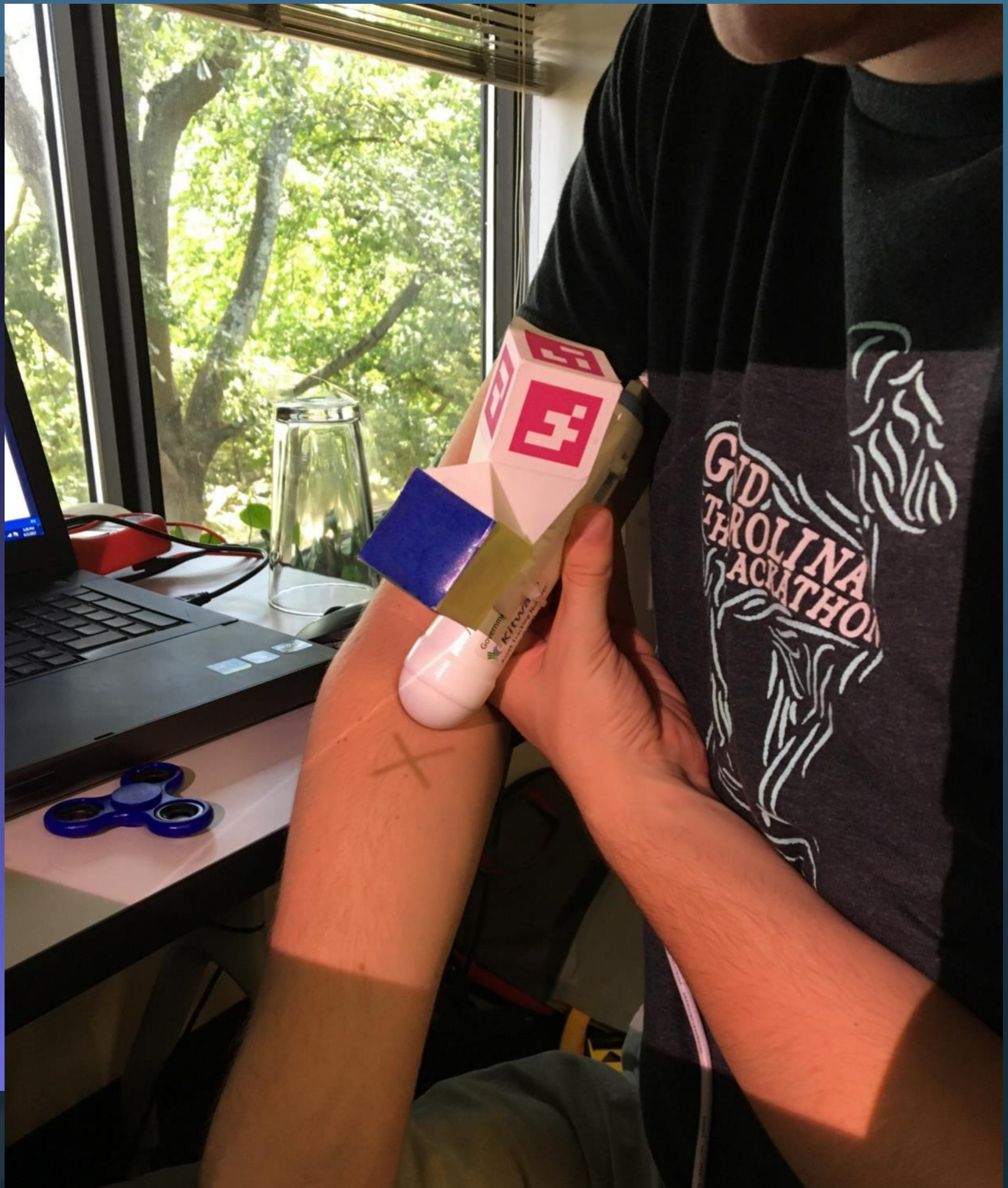
(3) none of the traditional features of slope, intercept, and backscatter are ranked among the top fourteen most informative features, for any power or frequency setting.

Ultrasound Augmentation

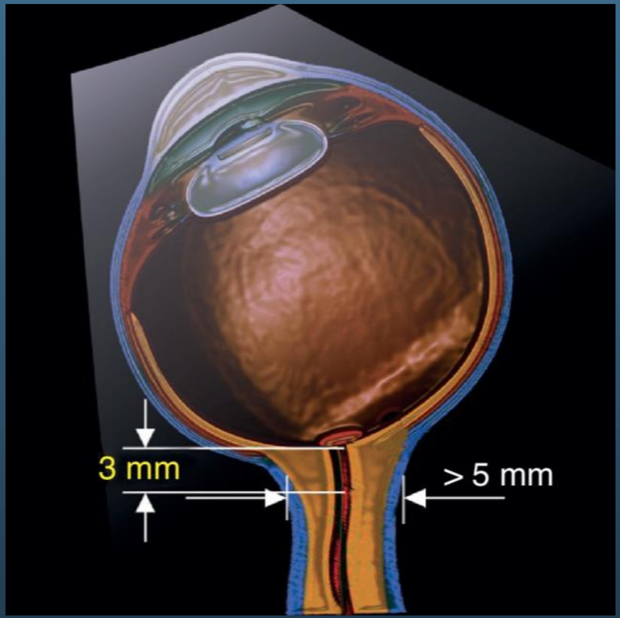





TEST IMAGE

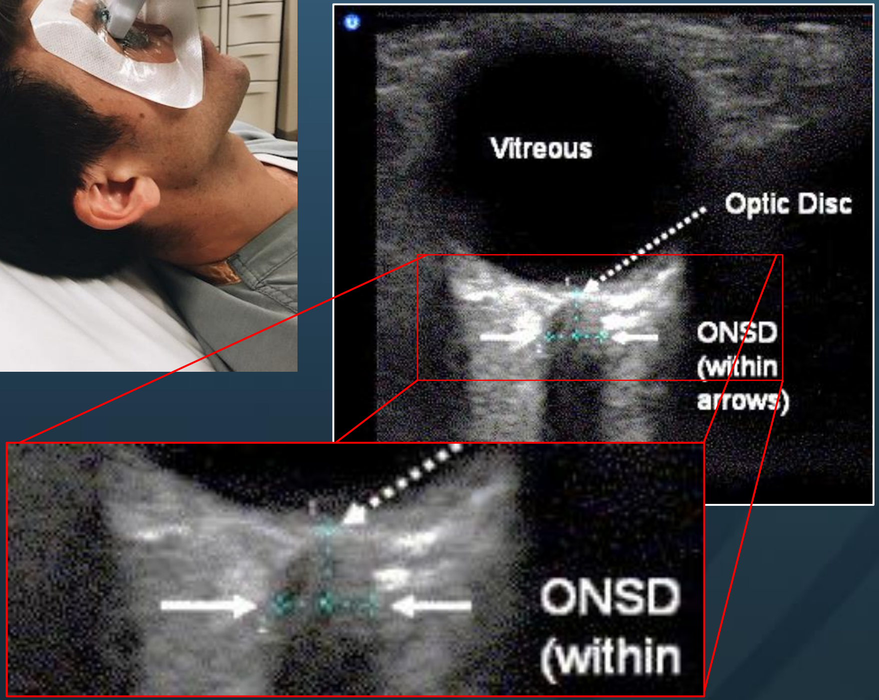


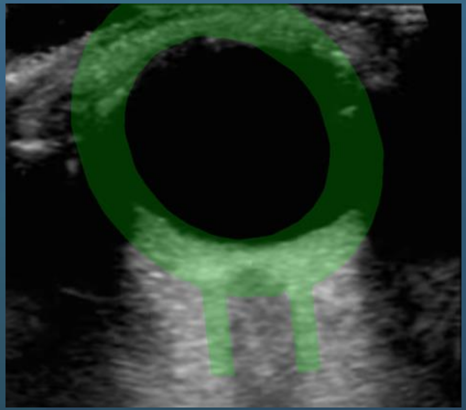
Traumatic Brain Injury: Increased ICP

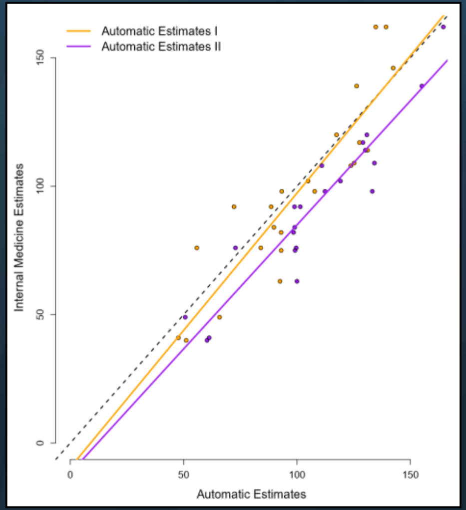


Mild increase in ICP

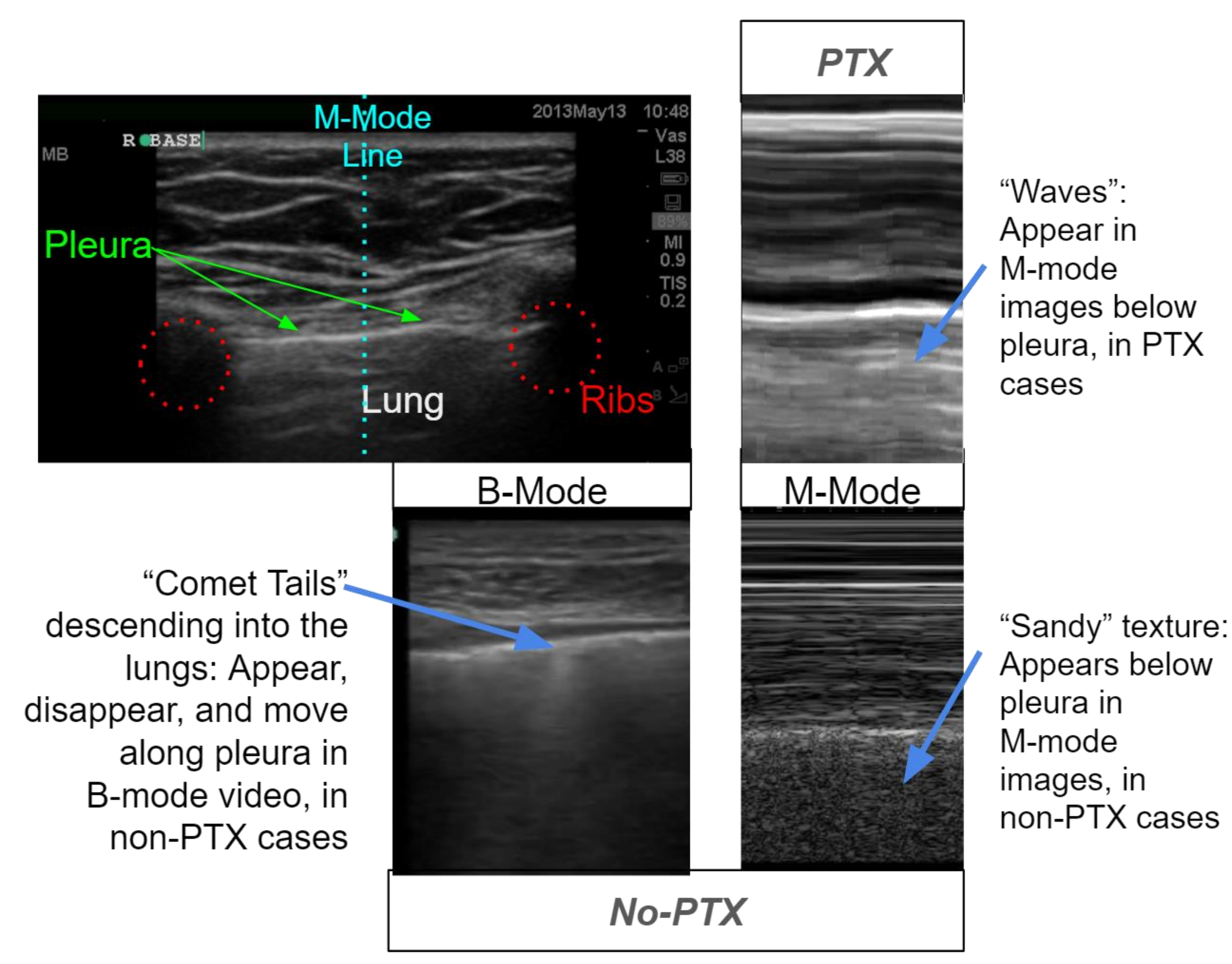
>5mm ONSD



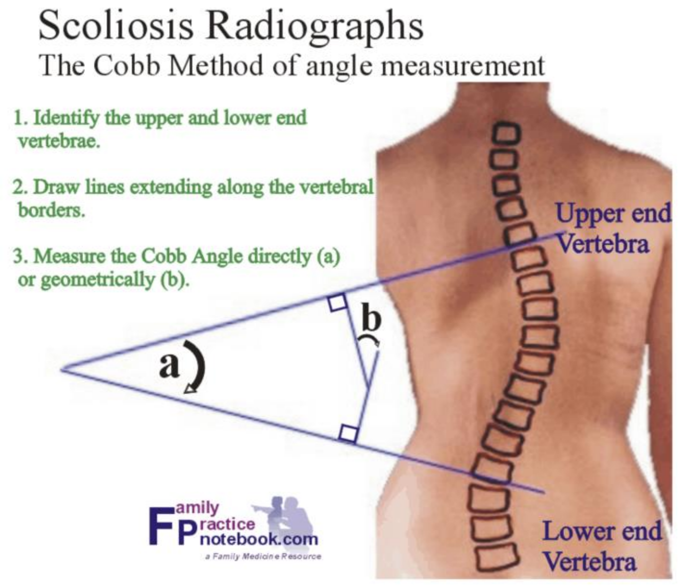


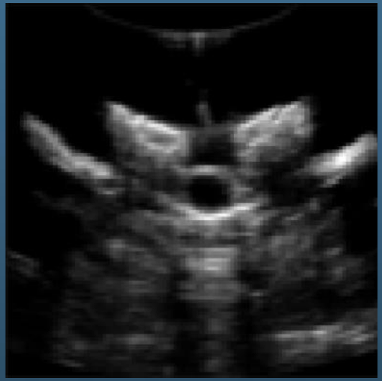


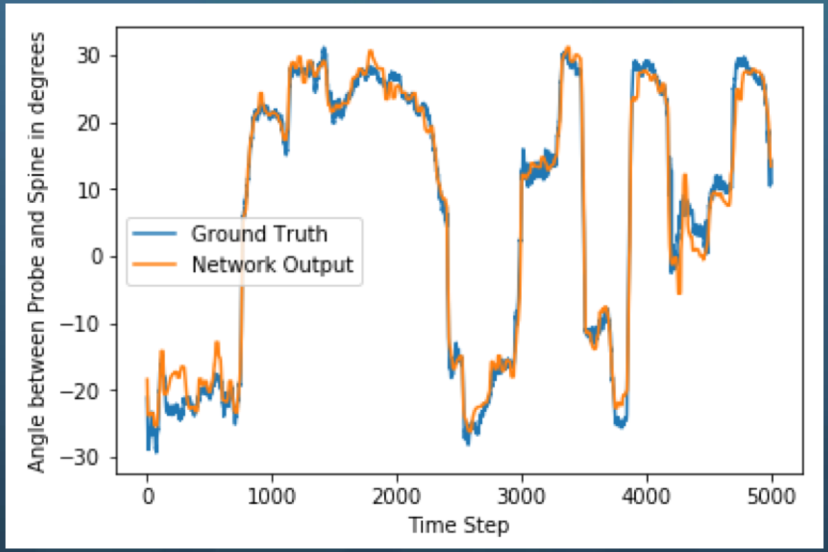
Pneumothorax



Scoliosis detection and monitoring







- Neural network estimates the angle of the probe to the spine based on b-mode images
- IMU estimates angle between the probe and vertical
- Combining those angles, you can track the angle between vertebrae and vertical

Other Applications

- Swelling assessment
- Respiratory gating + temporal super-resolution
- Longitudinal registration
- 3D reconstruction without tracking
- Trackers
- Augmented reality display

Open-Science: a path to success in academia and industry

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