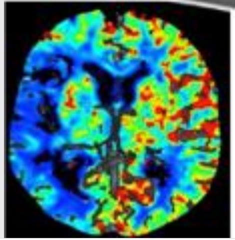


CBCT Brain Perfusion: Phantom and Digital Simulator

Computer Integrated Surgery II
Checkpoint Presentation

Karthik Chellamuthu and Michael Mow

Project Advisors: Jeff Siewerdsen Ph.D
Wojciech Zbijewski Ph.D
Alejandro Sisniega Ph.D

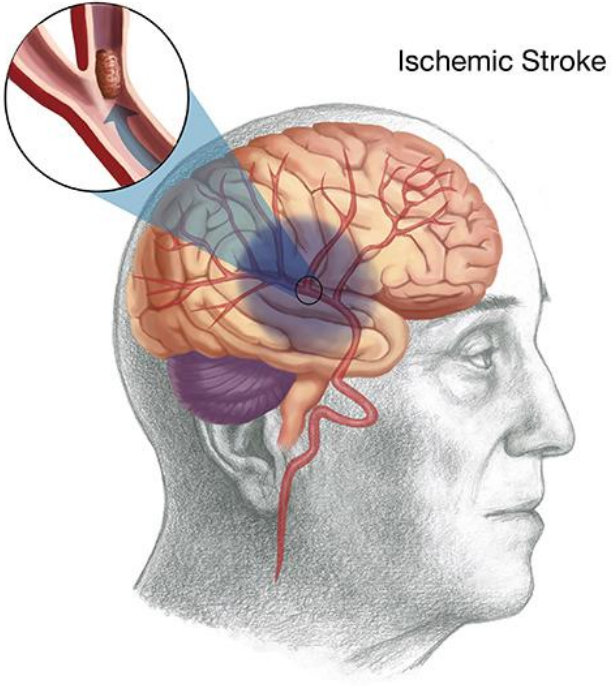
I-STAR

Overview

1. Project Background
2. Project Summary
3. Deliverables
4. Progress
   - Digital Phantom
   - Physical Phantom
5. Dependencies
6. Timeline
7. Milestones

Project Background

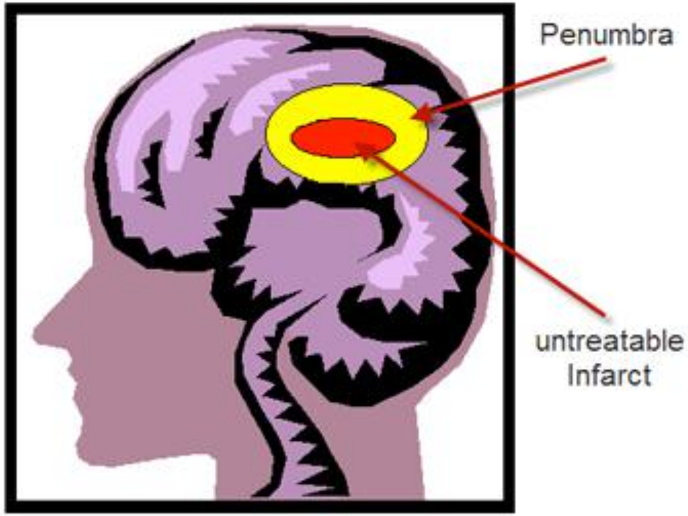
- A dedicated Cone-Beam Computed Tomography (CBCT) scanner for the detection and evaluation of intracranial hemorrhage (ICH) is being developed at JHMI
- 87% of stroke cases are diagnosed as ischemic rather than hemorrhagic
- One established method for the evaluation of ischemic stroke is brain perfusion imaging which describes the passage of blood flow through the brain's vasculature



(N&EA, 2015)

Project Summary

Develop a digital and physical brain perfusion imaging phantom to evaluate the feasibility and performance of a new CBCT scanner for characterization of perfusion parameters relevant to the detection of ischemic stroke



(StrokeCareNow, 2009)

Original Deliverables

Minimum

- Generate time attenuation curves for a wide range of stroke cases
- Complete a forward projection and reconstruction of a region of interest in the digital head phantom
- Perform validation by testing entire range of scan speeds and corresponding impact on accuracy

Expected

- Survey existing product landscape and literature
- Design CAD of phantom
- Order parts/equipment for phantom
- Fabricate phantom and begin initial testing

Maximum

- Thorough testing and measurements of time attenuation profiles and perfusion parameters in the phantom
- Submission to conference

Updated Deliverables

Minimum

- Survey existing product landscape and literature for physical phantom ✓
- Generate time attenuation curves for a wide range of stroke cases in digital phantom ✓
- Complete a forward projection of a region of interest in the digital head phantom ✓
- Design CAD of physical phantom ✓

Expected

- Account for various scan speeds, rotation methods, enhancement curves, regions of interest, and computational cost of digital phantom ✓
- Obtain parts/equipment for phantom
- Fabricate phantom and begin initial testing
- Complete a reconstruction method of the projection data

Maximum

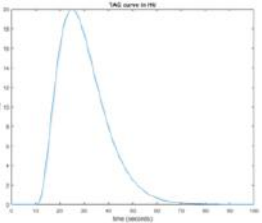
- Thorough testing and measurements of time attenuation profiles and perfusion parameters in the phantom
- Submission to conference

Technical Approach for Digital Phantom

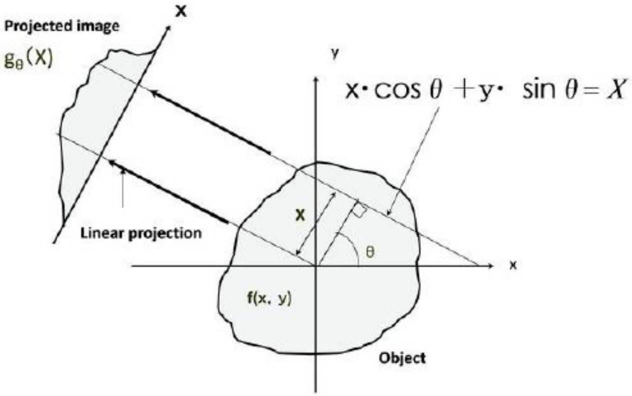
Time Attenuation Curve

+

Head Phantom

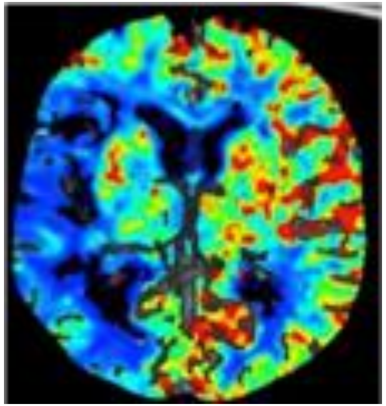


Forward Projection



(Hosimiya, 2013)

Reconstruction



(Mick, 2009)

Progress: Digital Phantom – Flow Chart

Head Phantom Voxel Image Input

Geometry Inputs
- Voxel size
- Detector size
- SAD & SDD
- Rotation method

Region of Interest Inputs
- Radii and centers
  or
- Specific voxels
- Optional smoothing

Time Attenuation Inputs
- Max enhancement
- Time delay
- Time at which max occurs
- Alpha parameter

Time Inputs
- Angle step (degrees)
- Frame rate (frames/sec)
- Acquisition time (sec)

Head Phantom Projection Data

Brute Force Forward Projection
- Enhancement addition in voxel image data
- For each time point, a 3D matrix is moved to GPU space and a separable footprint forward projection is completed using CudaTools

Faster Forward Projection
- Head phantom and ROI go through a static forward projection using CudaTools
- Enhancement addition in projection data based on scaling of the ROI

Projection Data with Enhancement

Progress: Digital Phantom – Flow Chart

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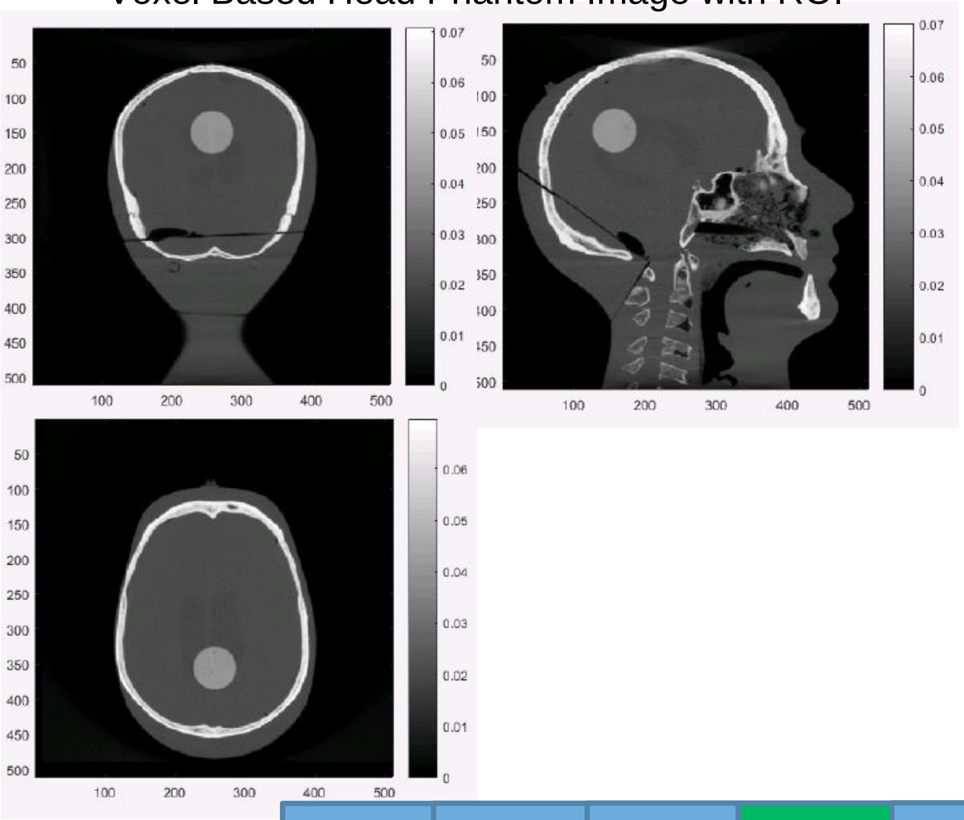
Projection Data with Enhancement

Progress: Digital Phantom – Head Image

Voxel Based Head Phantom Image with ROI



Head Phantom Projection Data with ROI

Progress: Digital Phantom – Flow Chart

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Projection Data with Enhancement

TAC: Gamma Variate Function

- Describes the dispersion of a bolus as it passes through a series of compartments

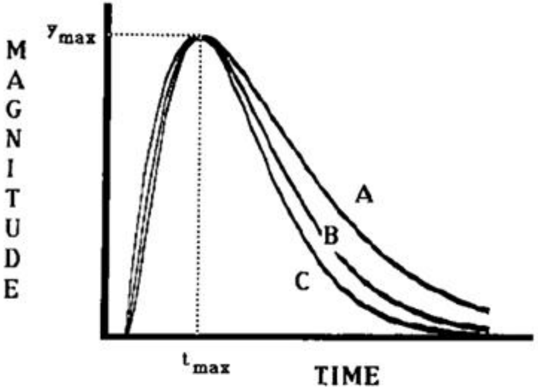
$$y(t') = y_{max}\ t'^{\alpha} \exp(\alpha(1 - t'))$$

$$t' = \frac{t - t_0}{t_{max} - t_0}$$

t_0 *is the delay time*

$y_{max} = y(t_{max})$

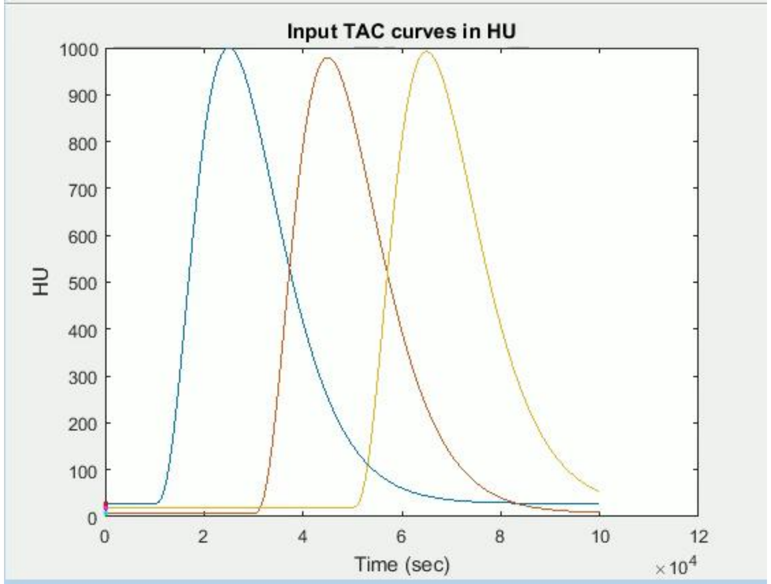
α *determines onset, decay*



(Madsen, 1992)

Figure 2. Three plots of equation (7) with α = 1.0 (curve A), α = 1.5 (curve B) and α = 2.0 (curve C). Note that both the location and the magnitude of the curves remain stable as α is increased.

Progress: Digital Phantom – Multiple ROI



Progress: Digital Phantom – Rotation Method

Full Sweep Rotation (Clinical CT)

Partial Sweep Rotation (C-arm)

Progress: Digital Phantom – Flow Chart

Head Phantom Voxel Image Input

Geometry Inputs
- Voxel size
- Detector size
- SAD & SDD
- Rotation method

Region of Interest Inputs
- Radii and centers
  or
- Specific voxels
- Optional smoothing

Time Attenuation Inputs
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- Enhancement addition in projection data based on scaling of the ROI

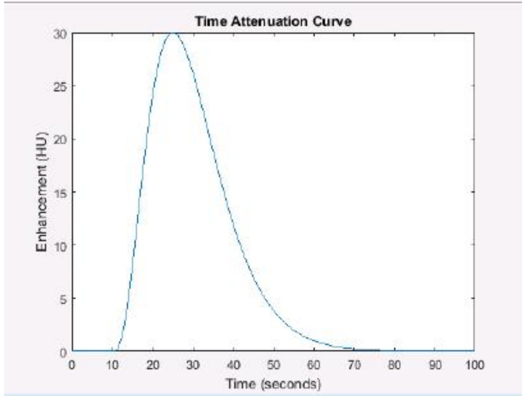
Projection Data with Enhancement

Progress: Digital Phantom – Forward Projection

Brute Force Forward Projection

- Load head phantom voxel based image
- For each frame, add enhancement value from TAC time point to head phantom image over the ROI
- Complete separable footprint forward projection for each frame

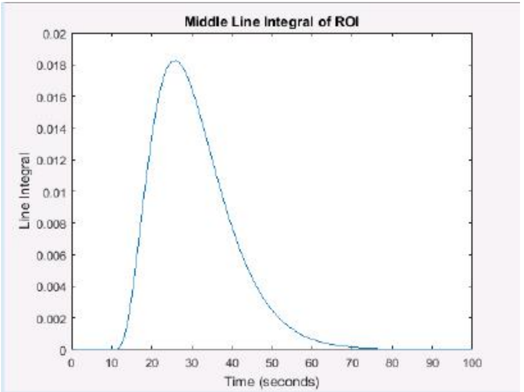
$$\int_{SDD} (\mu_{head\ phantom} + \mu_{enhancement})\, dL$$



Faster Scaling Forward Projection

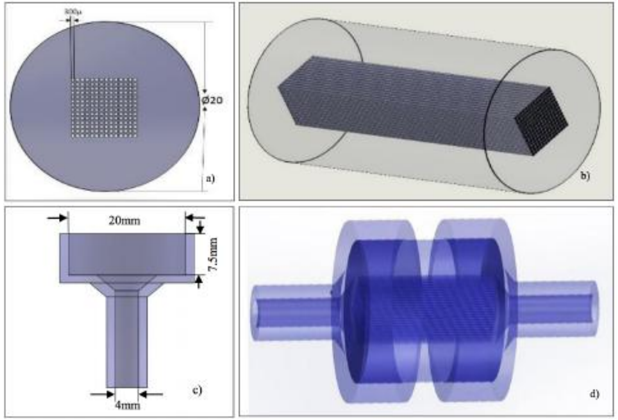
- Load head phantom projection image data
- Create projections of ROI mask
- For each frame, scale ROI projection mask by enhancement value from TAC time point and add to head phantom projection

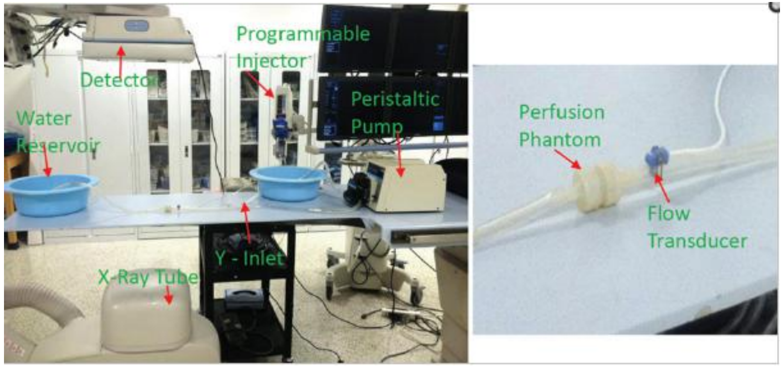
$$\int_{SDD} \mu_{head\ phantom}\, dL + \mu_{enhancement} \int_{ROI} dL$$



Progress: Physical Phantom – Wood

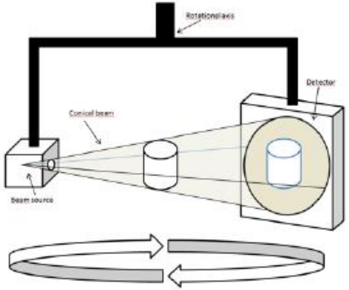
- "Initial testing of a 3D printed perfusion phantom using digital subtraction angiography" *(Wood, 2015)*
- Phantom was designed on SolidWorks and build with Objet Eden 260V Stratasys printer (200 micron resolution in XY-plane, 17 micron in Z-plane)
- Printed using Duraswhite material polypropylene like
- Dimensions:
  - Diameter: 20mm
  - Length: 20mm or 30mm
  - Capillaries: 196 300umx300um channels
- Flow rates: 250,300,350 mL/min





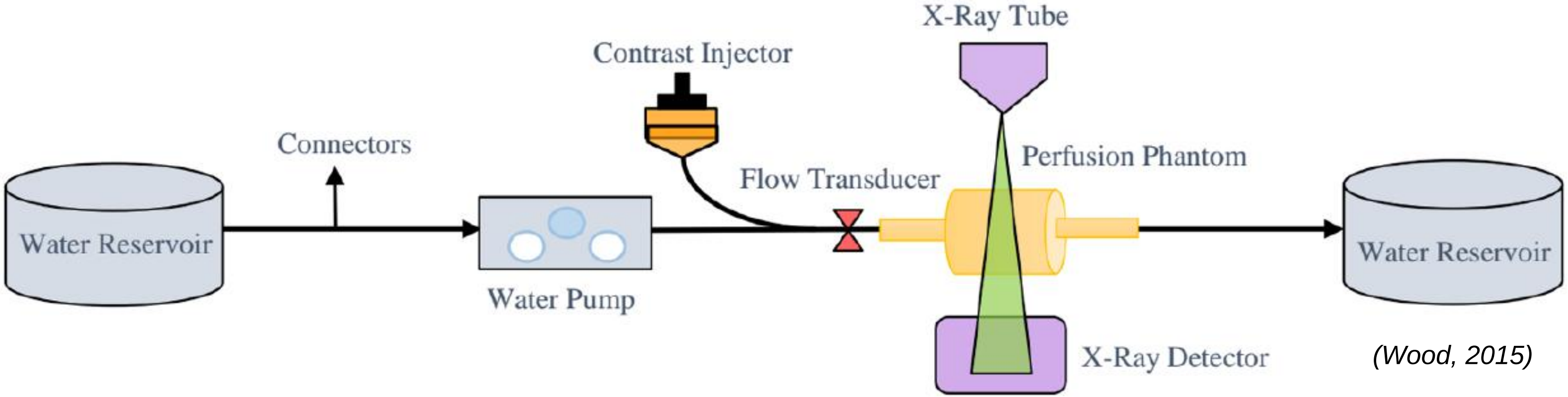
Progress: Physical Phantom - Diagram

Peristaltic Pump



CT Scanner

Contrast Injector



(Wood, 2015)

Progress: Physical Phantom - Budget

Peristaltic Pump	Cost	Condition	Flow rates	Flow types	Status	Hyperlink
Harvard Apparatus IPC pumps	5383-7485	New	0.002 to 44mL/min		Price depends on VAC/number of channels	https://www.harvardapparatus.com/webapp/wcs/stores/servlet/haisku4 10001 11051 43442 -1 HAI ProductDetail N 37295 37298 37299 37300
Harvard Apparatus IPC-N pumps	5383-7485	New	0.0004 to 11mL/min		Price depends on VAC/number of channels	https://www.harvardapparatus.com/webapp/wcs/stores/servlet/haisku4 10001 11051 43453 -1 HAI ProductDetail N 37295 37298 37299 37300
Harvard Apparatus pump heads	573-3000	New				https://www.harvardapparatus.com/webapp/wcs/stores/servlet/haicat4 10001 11051 37303 -1 HAI Categories N 37295 37298 37302
Harvard Appartus Infusion Only syringe pumps	2000-5000	New				https://www.harvardapparatus.com/webapp/wcs/stores/servlet/haicat3 10001 11051 37315 -1 HAI Categories N 37295 37313
LKB Bromma 2232 Microperspex S Pump Controller	229.99	Good	0.5-500 mL/hr	Constant/pulsatile	Working, need pump head	https://www.dotmed.com/listing/pump-controller/lkb-bromma/2232-microperpex-s-peristaltic-pump-2232-001/2099691
Flexiflo Petrol Feeding pump	55	Good	1 to 300 mL/hr	For enteral nutrition Use	7 day warranty	https://www.dotmed.com/listing/feeding-pump/flexiflo/petrol-peristaltic/1474629
Millipore XX8020000 drive with Masterflex 7013-21 pump head	199	Good	?	?	7 day warranty	https://www.dotmed.com/listing/pump-suction/millipore/7013-21-peristaltic/1249097

Pharmacia P1 Liquid Chromatography Pump	175	Good	0.6-500mL/hr		working order	https://www.dotmed.com/listing/liquid-chromatograph-hplc/pharmacia/p-1-peristaltic-pump/1282547
Watson Marlow 505S pump controller	480	Good	0.6uL to 42mL/min		guaranteed working, needs pump head	https://www.dotmed.com/listing/pump-controller/watson-marlow/505s-peristaltic/2091961
Masterflex I/P Drive 77420-00 and 77601-60 Head	1695	Good	10-26000mL/min		fully functional	https://www.dotmed.com/listing/lab-general/thermo/masterflex-i-p/thermo-masterflex-i-p-peristaltic-pump-77420-00-%26-77601-60-predes.-hv-77420-10/2101163
Masterflex B/T pump head, controller, and drive	2695	Good	0.17 to 18.9 GPM		new, never used	https://www.dotmed.com/listing/lab-general/cole-parmer/masterflex-b-t/peristaltic-pump/2095503
Watson Marlow 720UN/R pump	2695	Good	0.0005-8.8 GPM		working properly	https://www.dotmed.com/listing/lab-general/watson/720un-r/peristaltic-pump/2097035
Masterflex 77600-62 Head and I/P 07592-40 Drive with L/S 07592-90 Controller	1095	Good	0.12 to 13 L/min		Good working order, tested	https://www.dotmed.com/listing/lab-general/cole-parmer/masterflex-77600-62/peristaltic-pump-head/1962489
Masterflex Micr 7524 controller only	395	Good	0.6-3400 mL/min		none	https://www.dotmed.com/listing/pump-controller/cole-parmer/masterflex-micr-7524/1437603
Waston Marlow	3250	Good	0.005		excellent	https://www.dotmed.com/listing/lab-

Progress: Physical Phantom - Pump

L/S Economy Pump System with Easy-Load 3 Pump Head

Cole-Palmer Masterflex

- Min Flow Rate: 16 mL/min
- Max Flow Rate: 480 mL/min
- Speed control: 20 to 600 rpm
- Cost: $916.20
- ±5% speed regulation

Status: Obtained quote and ready to be purchased

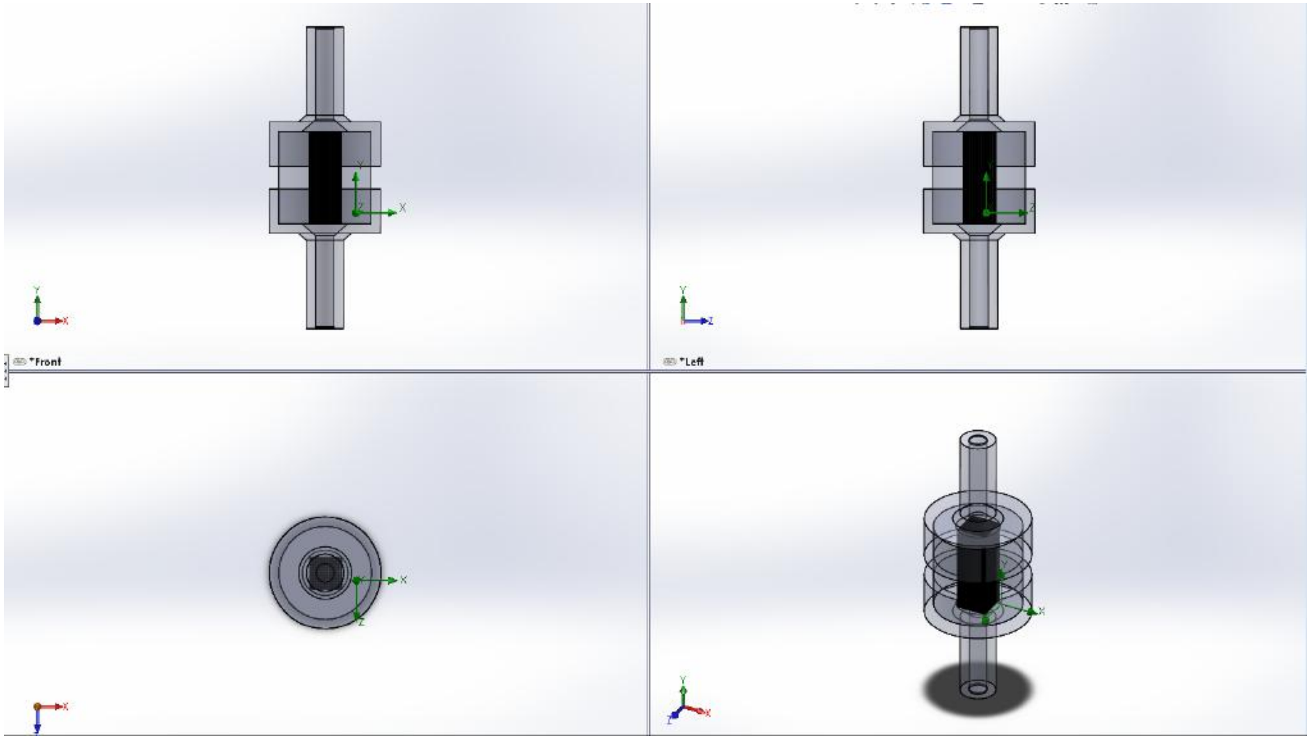
Progress: Physical Phantom - Injector

Medrad Mark V Plus Contrast Injector

- Min Flow Rate: 0.005 mL/min
- Max Flow Rate: 3000 mL/min
- Syringe Volume sizes: 60mL, 150mL, 200mL

Status: Obtained from Dr. Nafi Aygun (JHMI) for use on our project along with compatible syringes and Omnipaque contrast agent

Progress: Physical Phantom - CAD



Dependencies

Dependencies for Digital Phantom

- Access to a GPU Workstation (Met)
  - If Workstation fails, access to various other GPU workstations in I-STAR lab through remote desktop (Met)
- Access to CUDA Tools (Met)
- Digital Brain Phantom (Met)

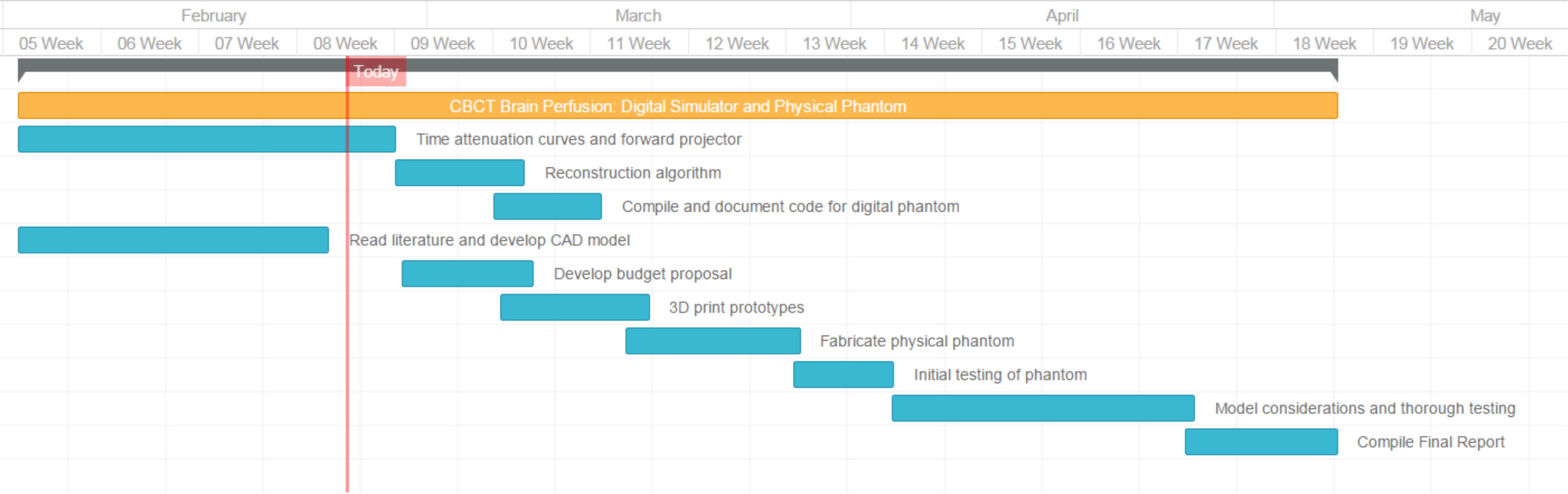
Dependencies for Physical Phantom

- Access and training for 3D Printer in Carnegie at JHMI (Met)
  - If 3D printer breaks or becomes unavailable, other options include fabrication at the JHU BME Design Studio, the JHU Digital Media Center, or outsource to other makerspace
- Obtain a contrast injector and peristaltic pump (Unmet, currently in budget proposal stage)
- Access to a CT scanner for testing (Met)
  - If new head scanner in I-STAR lab breaks or becomes unavailable, we will consult our advisors about finding a substitute facility such as a clinical CT scanner

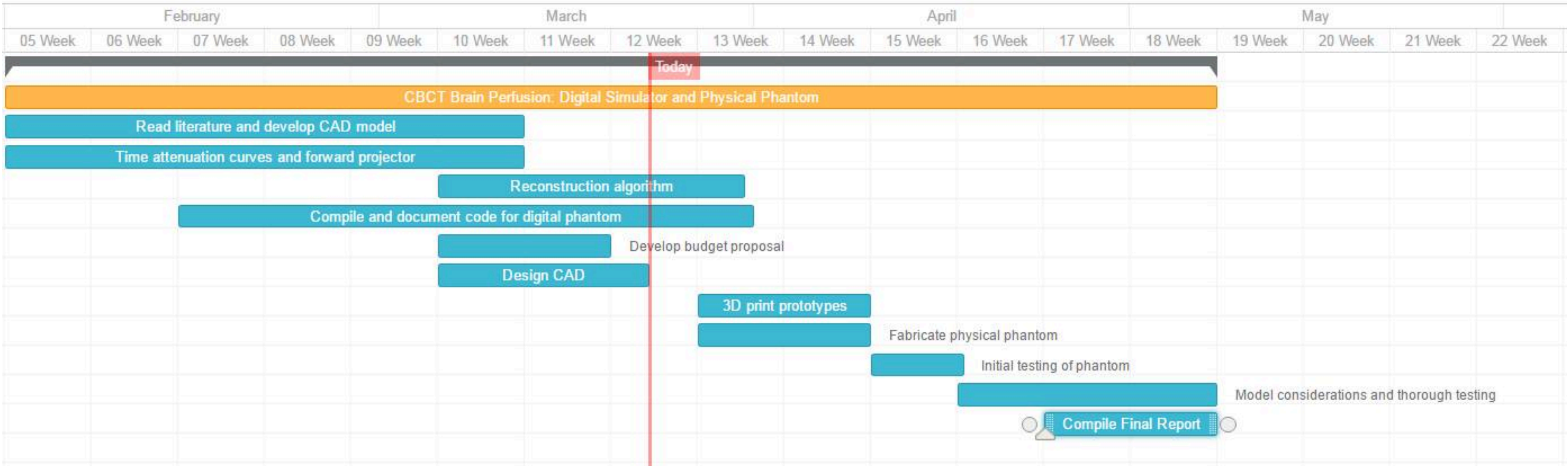
Advising Dependencies

- Funding for physical phantom component (Met)
  - We have obtained verbal agreement for funding from our advisors
- Availability of collaborators (Met)
  - We have arranged weekly meetings on Monday mornings with our advisors to obtain feedback and advice towards completing our project.

Original Timeline



Updated Timeline



Updated Milestones

February 25: Submit proposal documents ✓
March 7: Complete forward projection for digital phantom ✓
March 12: Propose budget and begin ordering parts ✓
March 20: Finish CAD design ✓ (**Minimum Deliverable Completed**)
April 1: Complete reconstruction algorithm for digital phantom and finalize digital phantom
April 7: Complete initial prototype of physical phantom and begin testing (**Expected Deliverable**)
April 4: Finalize design of physical phantom
April 25: Complete testing and standardization of the physical phantom (**Maximum Deliverable**)
May 06: Final report Presentation