

# Project16

## **VR Guided Surgery SDF based guidance and safety**

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Mentors: Max Li, Adnan Munawar,  
Prof. Misha Kazhdan, Prof. Russ Taylor



# Background

- **Mastoidectomy Procedures**

Remove hollow bone behind the ear by drilling the temporal bone

- Require high precision

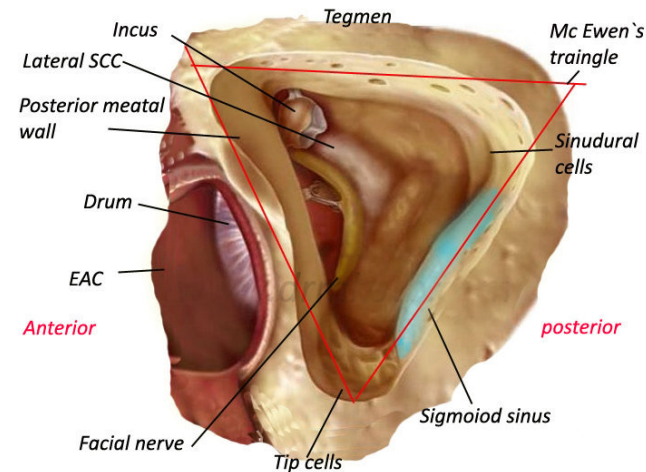
- Preserve important structures

e.g.) semicircular canals, sigmoid sinus, facial nerves etc.



Mastoid surgery animation

([https://www.youtube.com/watch?v=ZRxG\\_AmDaLI](https://www.youtube.com/watch?v=ZRxG_AmDaLI))

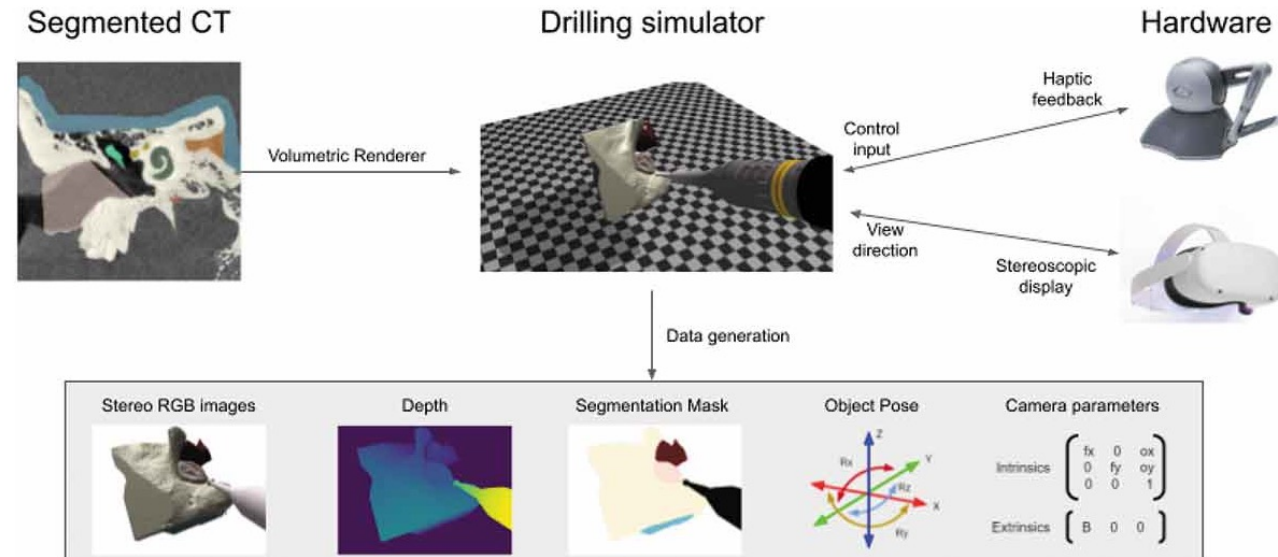


<http://entsurgeonkemptonpark.co.za/tympanoplasty-cortical-mastoidectomy-2/>



# Volumetric drilling virtual simulator

- **Asynchronous Multibody Framework (AMBF+)<sup>[1]</sup>**

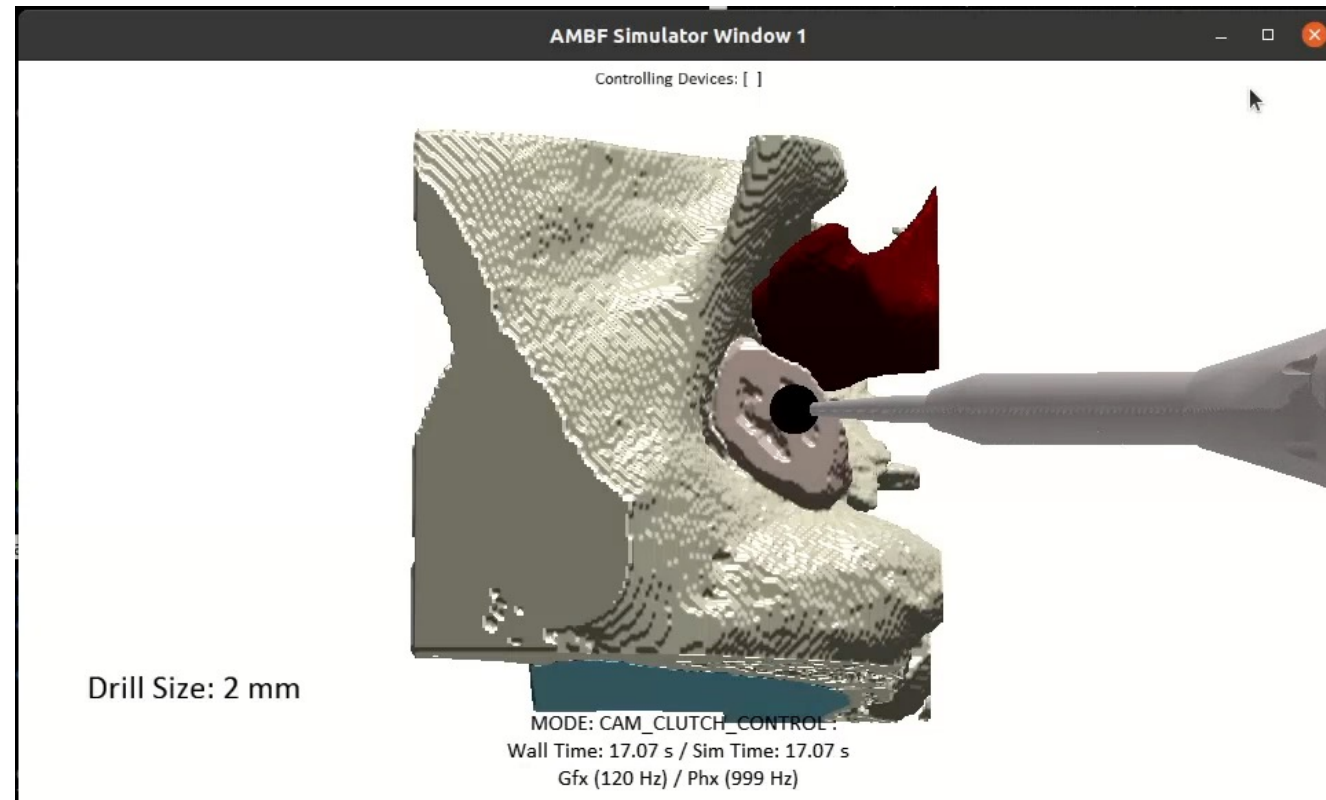


Allows users to practice surgical procedures

Generates relevant data in real-time for training of CV assistive system

[1] Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A.S., Kazanzides, P., Looi, T., Creighton, F.X., Taylor, R.H. and Unberath, M., 2021. Virtual reality for synergistic surgical training and data generation.

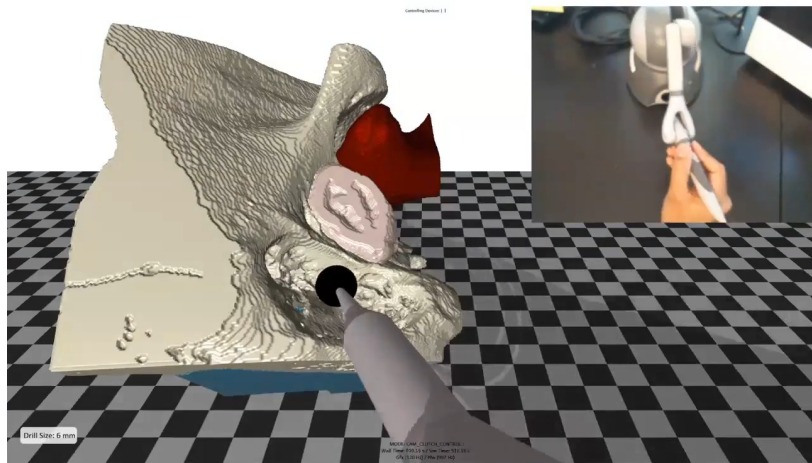
# Problem statement



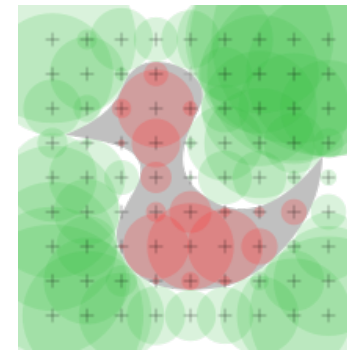
Warning comes out only after it actual collide with the important anatomy  
No haptic feedback or virtual fixture to secure important anatomy

# Method Overview

- Context situational awareness method using SDF
  - Visual feedback (“Warnings” when close to the important tissue)
  - Haptic feedback (Virtual fixture or haptic guidance)



Volumetric Drill Simulation [2]



Signed Distance Field [1]

4.9	4.4	4.0	3.7	3.5	3.5	3.7	4.0	4.1	4.0	4.0	4.1	4.4	4.8	5.2	5.8	
4.1	3.5	3.0	2.7	2.5	2.5	2.7	3.0	3.2	3.0	3.0	3.2	3.5	3.9	4.4	5.0	
3.4	2.7	2.1	1.7	1.5	1.5	1.7	2.1	2.2	2.0	2.0	2.2	2.5	3.0	3.6	4.3	
2.7	1.9	1.3	0.8	0.5	0.5	0.8	1.3	1.2	1.0	1.0	1.2	1.6	2.2	2.9	3.6	
2.1	1.3	0.5	-0.1	-0.5	-0.5	-0.1	0.5	0.3	0.0	0.0	0.3	0.8	1.4	2.2	3.0	
1.7	0.8	-0.1	-0.9	-1.4	-1.4	-0.9	-0.1	-0.6	-1.0	-1.0	-0.6	0.0	0.8	1.6	2.5	
1.5	0.5	-0.5	-1.4	-2.3	-2.3	-1.4	-0.6	-1.4	-1.9	-1.9	-1.4	-0.6	0.3	1.2	2.2	
1.5	0.5	-0.5	-1.4	-2.3	-2.3	-1.4	-1.0	-1.9	-2.8	-2.8	-1.9	-1.0	0.0	1.0	2.0	
1.7	0.8	-0.1	-0.9	-1.4	-1.4	-0.9	-1.0	-1.9	-2.8	-2.8	-1.9	-1.0	0.0	1.0	2.0	
2.1	1.3	0.5	-0.1	-0.5	-0.5	-0.1	-0.6	-1.4	-1.9	-1.9	-1.4	-0.6	0.3	1.2	2.2	
2.7	1.9	1.3	0.8	0.5	0.5	0.8	0.0	-0.6	-1.0	-1.0	-0.6	0.0	0.8	1.6	2.5	
3.4	2.7	2.1	1.7	1.5	1.5	1.7	2.1	2.2	2.0	2.0	2.2	2.5	3.0	3.6	4.3	
4.1	3.5	3.0	2.7	2.5	2.5	2.7	3.0	3.2	3.0	3.0	3.2	3.5	3.9	4.4	5.0	
4.9	4.4	4.0	3.7	3.5	3.5	3.7	4.0	4.1	4.0	4.0	4.1	4.4	4.8	5.2	5.8	
5.7	5.3	4.9	4.6	4.5	4.4	4.3	3.9	3.5	3.2	3.0	3.0	3.2	3.5	3.9	4.4	5.0
6.6	6.2	5.9	5.6	5.5	5.2	4.8	4.4	4.1	4.0	4.0	4.1	4.4	4.8	5.2	5.8	

[2] Munawar, A., Li, Z., Kunjam, P., Nagururu, N., Ding, A.S., Kazanzides, P., Looi, T., Creighton, F.X., Taylor, R.H. and Unberath, M., 2021. Virtual reality for synergistic surgical training and data generation. (<https://www.youtube.com/watch?v=inonLwxW2Cg>)



# Project phases

## 1. SDF for static volumes (Offline SDF calculation)

~Mar. 14

- a) Familiarize with methods to calculate the Euclidean Distance Transform. (<https://github.com/mkazhdan/EDT>)
- b) Integrate SDF functions with AMBF using plugins.

## 2. Use SDF to improve situational awareness of the user.

~Apr. 27

- a) Provide Visual feedback.
- b) Haptic Feedback.
- c) Perform a user study (optional).

## 3. SDF for changing volumes (Online SDF calculation)

~May. 17

- a) Optimizing algorithms to calculate SDF for volumes that change over time



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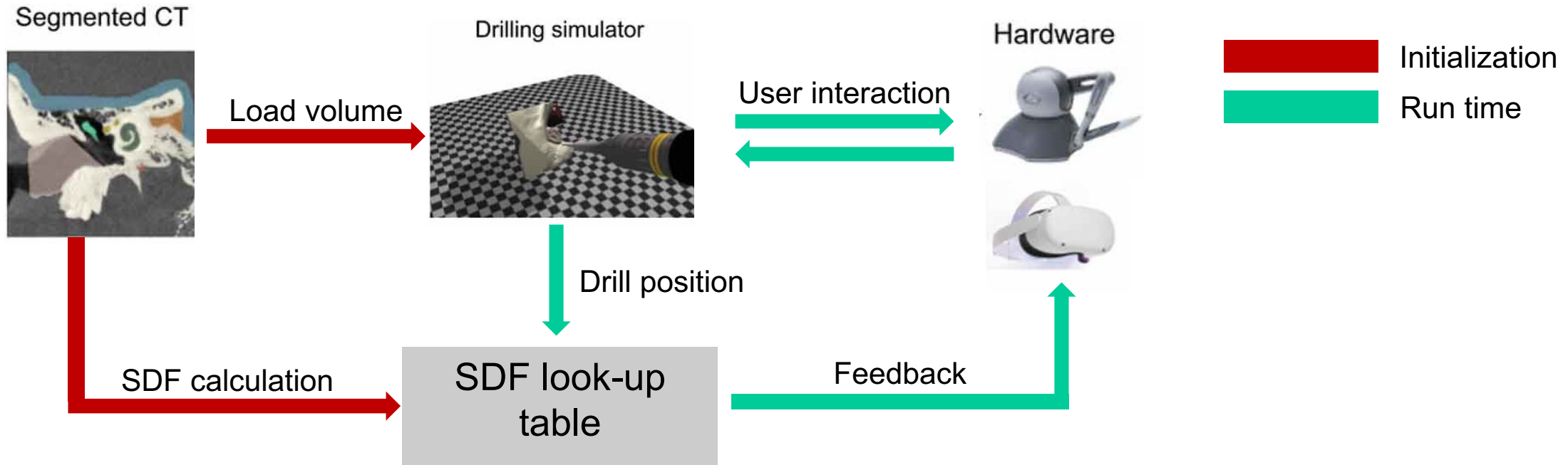
~May. 17

- a) Optimizing algorithms to calculate SDF for volumes that change over time



# Technical overview

- Phase 1: SDF calculation for static objects & software integration architecture.



- SDF calculation for volumes represented by a voxel grid based on [Saito and Toriwaki, 1994][2].
- SDF functions will be loaded as a shared library to AMBF.

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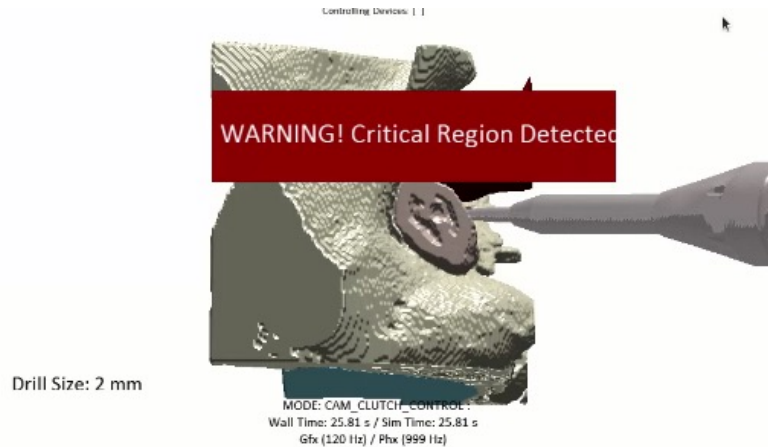
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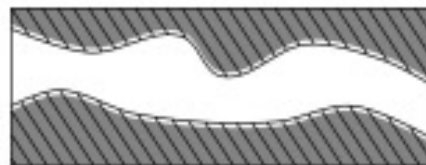
# Technical approach

- Development of Feedback modalities
  - Visual Feedback



- Overlay warning message
- Provide warning when the drill gets closer to anatomy than the threshold

- Haptic Feedback



Forbidden VF



Guidance VF

- Forbidden virtual fixture  
Avoid collision with the anatomy  
Use the gradient field of the SDF

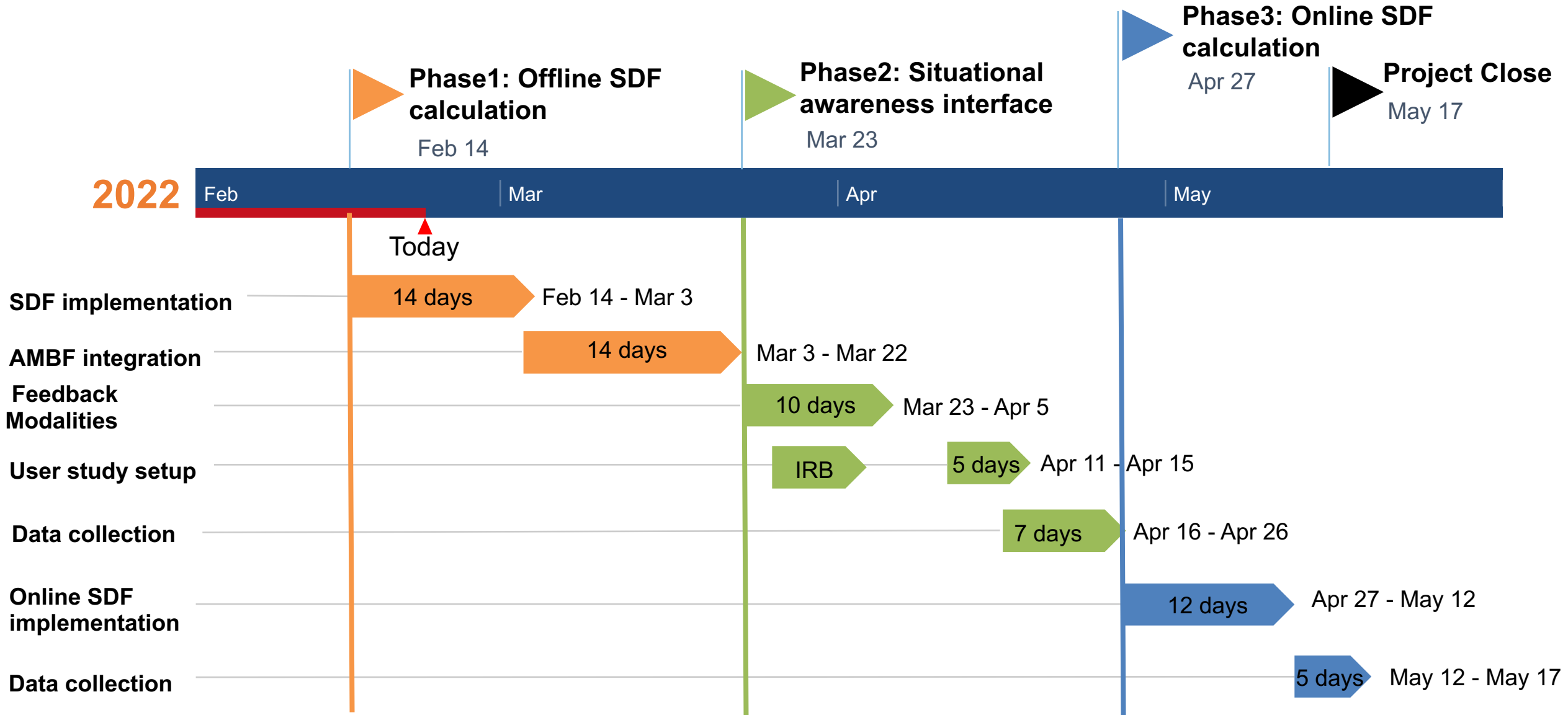
S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in *IEEE Transactions on Robotics*, vol. 30, no. 1, pp. 138-157, Feb. 2014, doi: 10.1109/TRO.2013.2283410.

# Key Deliverables

	<b>Deliverable</b>
Minimum	Creating an AMBF plugin to calculate SDFs for static objects in the volumetric drilling simulation.
Expected	Using the calculated SDFs to improve the user situational awareness via haptic feedback and/or visual cues.
Maximum 1	Internal user study and/or conference paper.
Maximum 2	Optimizing algorithms to calculate SDFs of objects changing overtime in real-time, e.g., the drilling volume.



# Gantt chart



# Dependencies

Dependency	Status	Fallback/Prevention	Needed by	Effect
Access to a Linux workstation	Obtained	N/A	02/18/2022	Delay in all milestones.
Access to haptic device	In progress	Focus only on visual feedback mechanisms.	03/23/2022	Delay in haptic feedback development.
IRB approval	In progress	N/A	03/31/2022	Delay in internal user study.
VR device	Obtained	Using 2D screen	03/31/2022	Delay in internal user study.



# Management plan

- Weekly meeting with mentors:
  - Max Li
  - Adnan Munawar
- Weekly lab meeting
- Weekly team meeting
- Technical advisory meeting(on demand)
  - Prof. Kazhdan
  - Prof. Taylor
- Communication through Slack
- Code management with Github
- Additional file management with OneDrive



# Reading list

- [1] A. Munawar *et al.*, “Virtual reality for synergistic surgical training and data generation,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–9, Nov. 2021, doi: [10.1080/21681163.2021.1999331](https://doi.org/10.1080/21681163.2021.1999331).
- [2] T. Saito and J.-I. Toriwaki, “New algorithms for euclidean distance transformation of an n-dimensional digitized picture with applications,” *Pattern Recognition*, vol. 27, no. 11, pp. 1551–1565, Nov. 1994, doi: [10.1016/0031-3203\(94\)90133-3](https://doi.org/10.1016/0031-3203(94)90133-3).
- [3] S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in *IEEE Transactions on Robotics*, vol. 30, no. 1, pp. 138-157, Feb. 2014, doi: [10.1109/TRO.2013.2283410](https://doi.org/10.1109/TRO.2013.2283410).
- [4] Li, Z., Gordon, A., Looi, T., Drake, J., Forrest, C., & Taylor, R. H. (2020, October). Anatomical mesh-based virtual fixtures for surgical robots. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 3267-3273). IEEE.



# References

- [1] A. Munawar et al., “Virtual reality for synergistic surgical training and data generation,” *Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization*, vol. 0, no. 0, pp. 1–9, Nov. 2021, doi: 10.1080/21681163.2021.1999331.
- [2] T. Saito and J.-I. Toriwaki, “New algorithms for euclidean distance transformation of an n-dimensional digitized picture with applications,” *Pattern Recognition*, vol. 27, no. 11, pp. 1551–1565, Nov. 1994, doi: 10.1016/0031-3203(94)90133-3.
- [3] S. A. Bowyer, B. L. Davies and F. Rodriguez y Baena, "Active Constraints/Virtual Fixtures: A Survey," in *IEEE Transactions on Robotics*, vol. 30, no. 1, pp. 138-157, Feb. 2014, doi: 10.1109/TRO.2013.2283410.
- [4] <https://shaderfun.com/2018/03/25/signed-distance-fields-part-2-solid-geometry/>
- [5] [https://www.youtube.com/watch?v=ZRxG\\_AmDaLI](https://www.youtube.com/watch?v=ZRxG_AmDaLI)
- [6] <http://entsurgeonkemptonpark.co.za/tympanoplasty-cortical-mastoidectomy-2/>

