# 1 Paper Outline

- Abstract
  - Flatbed scanner alternative with improved resolution to digitizing tree cookies and cores
  - Digital twins of samples is important for building data repositories and promoting replicable science
  - Digitizing wood samples has limits to sample dimensions or lacks affordable implementations
  - Current alternatives are very expensive ($70,000USD), lack a high level of detail (printer scanners), or cannot scan cookies (CaptuRING)
  - Tina is open source and able to be assembled with 3D printed parts, OpenBuilds parts kits, and hand tools
- Introduction
  - Tree ring science overview
    - **Lizzie add here**
    - tree rings can help reconstruct past climates
    - understanding tree growth mechanisms
  - Development of scanning alternatives
    - beginning with ATRICS
    - expensive Gigapixel
    - DIY CaptuRING
  - Main reasons to build this
    - further develop the affordable / open source alternatives for scientific equipment
    - reduce the need for proprietary software such as PTGUI for image stitching
    - allow a method to digitize cookies to have higher quality data than cores alone
    - avoid size limitations to digitize tree cookies and cores
    - Digitizing wood samples for better data pooling / archiving
  - Software can be used to help record annual growth
    - Coorecorder
    - Various ML based methods that Sandy has researched
- Materials and Methods
  - Hardware Design
    - Cartesian gantry robot kit from OpenBuilds (ACRO system)
    - Camera
      - chose Raspberry Pi HQ Camera for C-mount lens options, ability to stream, cost effectiveness, and clear obscelescence statement
    - computer
      - NVIDIA Jetson Orin Nano for processing power in a light package, can connect to Raspberry Pi camera. Powerful enough to power a GUI and monitor display as well
      - NVMM Hardware accelerated video streaming reduces CPU load
    - 3D printed components
      - 3D printed parts from a Bambu X1C were designed to mount the lens and computer to the ACRO system
      - other parts such as a drag chain for cable management were also 3D printed
      - levelling tables were designed to allow for the cookie samples to be arranged orthogonally to the lens. Imperative to capturing in focus images across the entire cookie

  - Software Design
    - image focusing
      - sample levelling is not perfect. At different points on the cookie, the Z-height of the gantry must vary to capture the in focus image. A routine was made to take multiple images at varied Z-heights. The image with the highest normalized variance score was chosen as the in focus image and is kept.
      - automatic PID control was implemented to adjust the initial Z-coordinate for each set of images to increase the probability of having an in focus image at each image set
    - grid traverse
      - The software traverses the entire surface area of the sample. Each row and column is overlapping with its adjacent row and column. Allowing for feature based image stiching.
    - feature based image stitching
      - An implementation, Stitch2D, of feature based OpenCV image stitching was used. Edits to the code were made to allow for more memory efficient methods of stitching with the use of NumPy memory maps
    - user interface
      - A GUI was made to navigate the machine to samples, set the size of the sample and its center. After samples are set up the operation is passive.

- Results
  - scans of cookies / cores
    - ultra high resolution scans (DPI 15,000 +)
    - downscaled versions as high resolution is not necessary for all applications
    - Digitization time as a function of surface area. Large cookies can scan only a portion of the cookie including the center and half of the rings.
    - large surface areas can produce files that are inconveniently large
  - File-size results in functional limits
    - max filesize for TIFF files is 2.5 GB
    - other lossless filetypes for larger images are not compatible with standard image viewers
    - workaround with NumPy memory maps and cropped viewing

- Discussion (for MEE Only)
  - strengths and opportunities
    - Ability to capture multiple cores / cookies simultaneously
    - cost effective
    - potential for automatic tree ring identification with iamge processing / ML
    - potential for vessel counts for an entire ring

      although final quality is only as good as the sample preparation
  - opportunities for improvements
  - Lenses
    - troubles with fixed aperature / non autofocusing / poorly manufactured lens
      - lack of control to increase sharpness
      - autofocusing with Z-axis movement is time consuming to do without image blur
      - poor lens manufacturing can lead to drastically different quality / lighting between the edges and center of an image
    - good lens can increase sharpness and therefore stitching accuracy and ML inference
    - obtain similar quality between the corner and center of the image

      poor lens quality seemed to be the culprit of producing visible seams when stitching with larger field of view images

  - focus stacking

    when a sample is microtomed, the vessels are hollow. The autofocusing algorithm can be confused from this

  - Difficulty stitching with lower detail images, can't increase digitizing speed, must downscale high resolution images
  - Autofocusing with hardware would significantly decrease the time to capture a cookie (using a professional camera)

- Conclusions (optional for MEE)

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