Phenocyte, Arabidopsis Segmentation Using SAM

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Intro

- Plants: Agriculture & Energy
- Human Selection
  - Phenotyping
  - Tedious Evaluation
- Arabidopsis Thaliana
  - Model Plant
  - Tiny
  - 4 Parts: Leaf, Stem, Seed, Root
- Automatic Segmentation
  - Predict Plant Part Masks
  - Minimize IoU Against Ground Truth

Existing Solutions

- RhizoVision[4] & RootPainter[5]
  - CNN-based
  - Herbaceous Plant Species (not Arabidopsis)
  - Root Finding Only
- Deep Learning-Based Approach for High-Throughput Hypocotyl Phenotyping[2]
  - CNN-based
  - Arabidopsis Functional
  - Stem/Other Finding Only
- RootNav 2.0[7]
  - CNN-based
  - Arabidopsis Functional
  - Root Finding Only
- RoAD: Robotic Assay for Drought[6]
  - Arabidopsis functional
  - Surface Only (no root finding)
  - Expensive

SAM

- Segment Anything 2[3]
  - Full or Partial Image Segmentation
- Point Prompting
- Negative Point Anti-Prompting

Solution 1: Raw SAM

- Full Image Segmentation
- Hyperparameter Search Space
  - Confidence Thresholds
  - Overlap Allowance
  - Segment Size Allowance
  - Precision
- Unsatisfactory Performance
  - Missing Parts
  - Obfuscating Lines

Solution 2: SAM Adapter

- SAM2 Adapter[1]
  - SAM2 Base
  - Adapter Insertion
- Not Implemented
  - Training Deemed Costly
  - Training Deemed Time Expensive

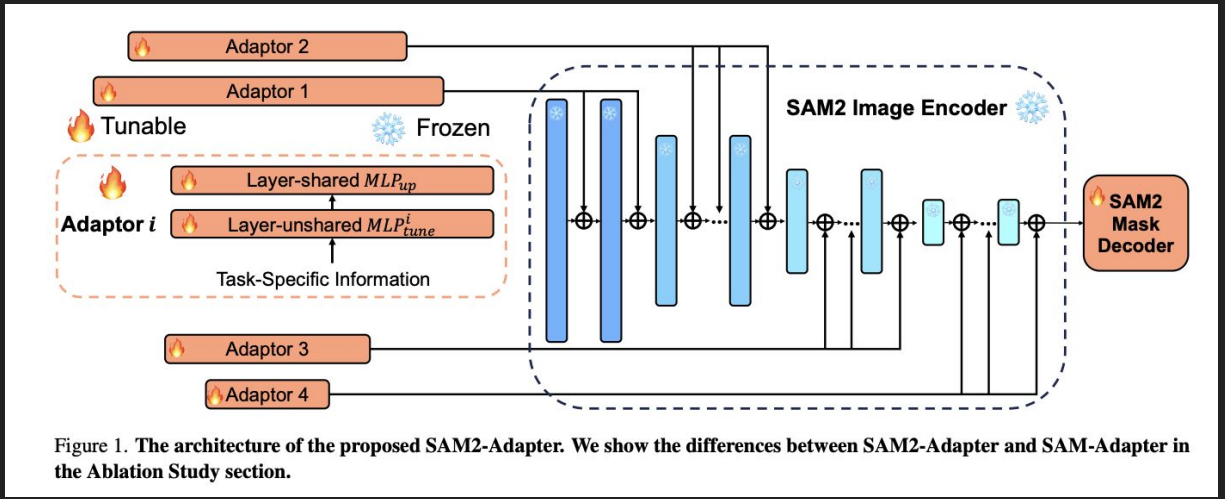
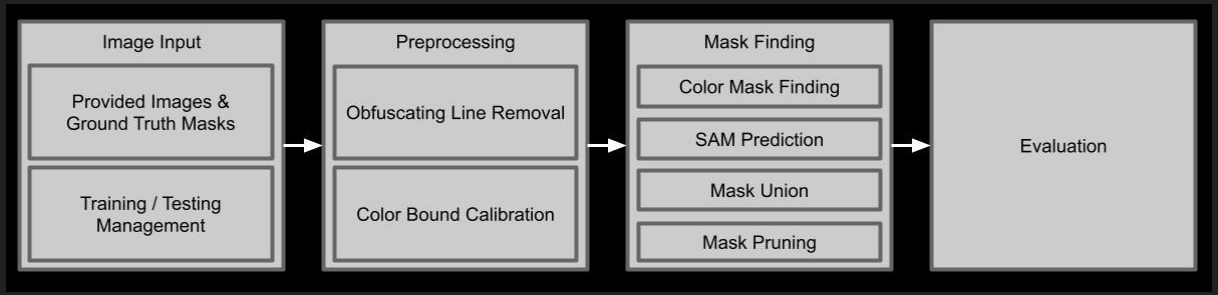


Figure 1. **The architecture of the proposed SAM2-Adapter. We show the differences between SAM2-Adapter and SAM-Adapter in the Ablation Study section.**

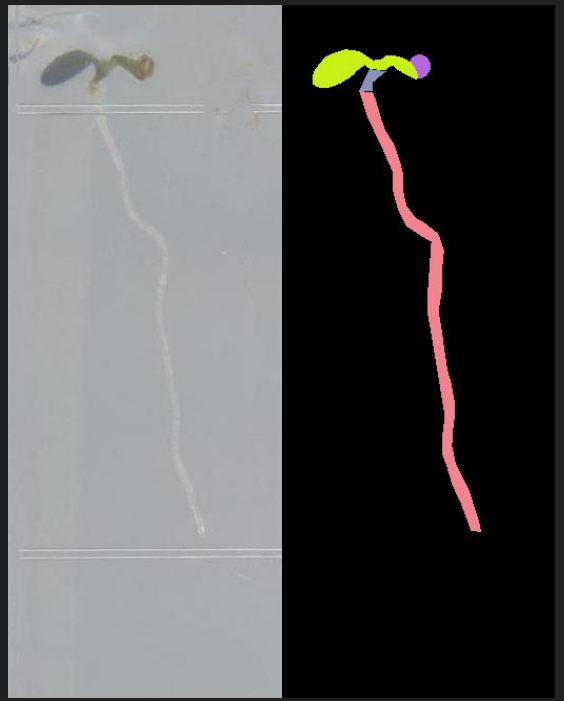
Solution 3: SAM Prompt

- Human-Trivial Prompt Point Selection
  - Algorithmic Prompt Point Selection
  - Strong Part Finding
  - Algorithm Can Tune Mistakes
- Color-Based Point Selection
  - Individually Powerful
  - Difficult on Large Dataset
- Contour-Based Point Selection
  - Background Artifacts



SAM Prompt Color Bound Calibration

- Coloration Consistency
  - Intra-Batch False Semblance of Consistency
- Manual Color Bound Tuning
  - Non-Scalable
- Automatic Color Bound Tuning
  - Requires Ground Truth Samples
  - Imperfect Ground Truth
  - Statistical Outlier Removal
- Algorithmic Core
  - Successful in Small Sample
  - Unsuccessful in Large Sample
    - Different Color Scheming
    - Scaling Marginal Differences

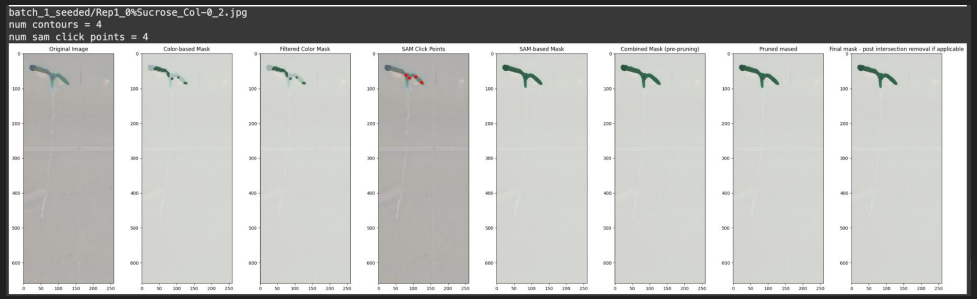


SAM Prompt Obfuscating Lines

- Obfuscating Lines
  - Straightness Detection
  - Natural-Looking Removal
- Attempted Removal Strategies
  - Nearby Pixel Color Averaging
  - Color Averaging with Noise
  - Lack of Sufficient Success
- Unimplemented Ideas
  - Out-to-in Noisy Color Averaging
  - Anti-Prompting

SAM Prompt Mask Finding

- Mask Finding: Per Image Per Part
- Color Mask: Color Bounds
  - Maximum Contour
  - Distance-Based Filtration (100 px)
- SAM Prompt Point Selection
  - Part Parameter: Largest x% of contours up to y
    - Single-part: Stem, Seed, Root (x = 100, y = 1)
    - Multi-part & Splotchy: Leaf (x = 50, y = 5)
- Union Mask
  - Exploit SAM Precision
  - Avoid SAM Loss
- Pruned Mask: Single Contour
- Post-Pruned Mask
  - Use Successful Masks



SAM Prompt Results & Analysis

Leaf Results:

Mean IoU: 0.03%

Standard Deviation: 0.16%

Best IoU: 2.08%

Worst IoU: 0%

25th percentile (Q1): 0%

Median (Q2): 0%

75th percentile (Q3): 0%

Seed Results:

Mean IoU: 32.48%

Standard Deviation: 26.11%

Best IoU: 86.79%

Worst IoU: 0%

25th percentile (Q1): 7.11%

Median (Q2): 30.91%

75th percentile (Q3): 56.20%

SAM Prompt Results & Analysis

Root Results:

Mean IoU: 0.36%

Standard Deviation: 0.78%

Best IoU: 4.59%

Worst IoU: 0%

25th percentile (Q1): 0%

Median (Q2): 0%

75th percentile (Q3): 0.26%

Combo Results:

Mean IoU: 27.11%

Standard Deviation: 31.61%

Best IoU: 88.34%

Worst IoU: 0%

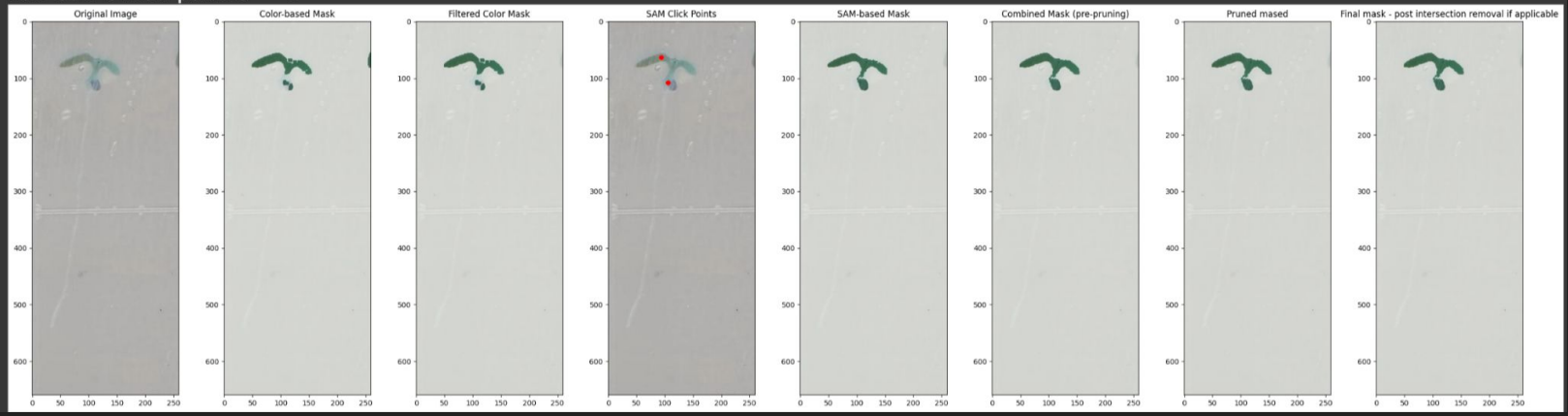
25th percentile (Q1): 2.65%

Median (Q2): 10.18%

75th percentile (Q3): 53.68%

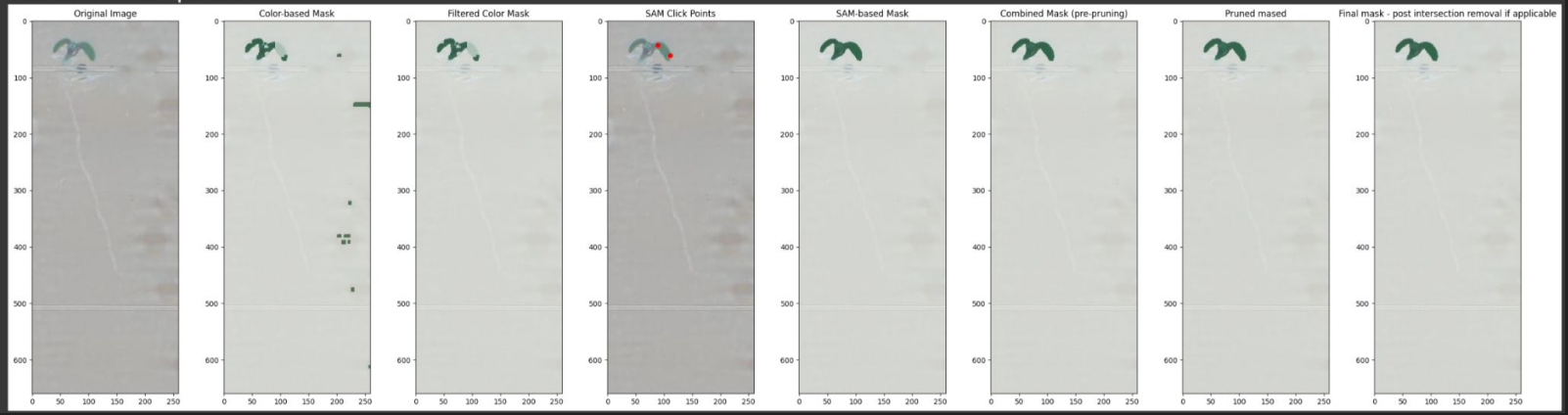
SAM Prompt Case Studies: Coloration Success

batch_1_seeded/Rep1_0%Sucrose_gaut10-3gaut11-3+_25.jpg
num contours = 3
num sam click points = 2



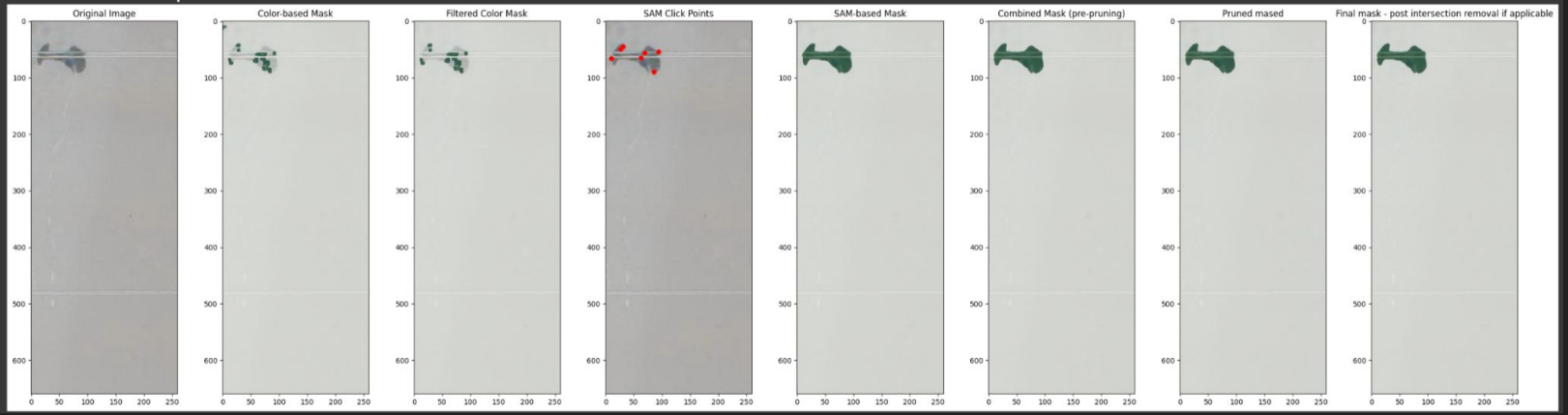
SAM Prompt Case Studies: Color Filtration Success

```
batch_1_seeded/Rep1_0.5%Sucrose_gaut10-3_6.jpg
num contours = 11
num sam click points = 2
```



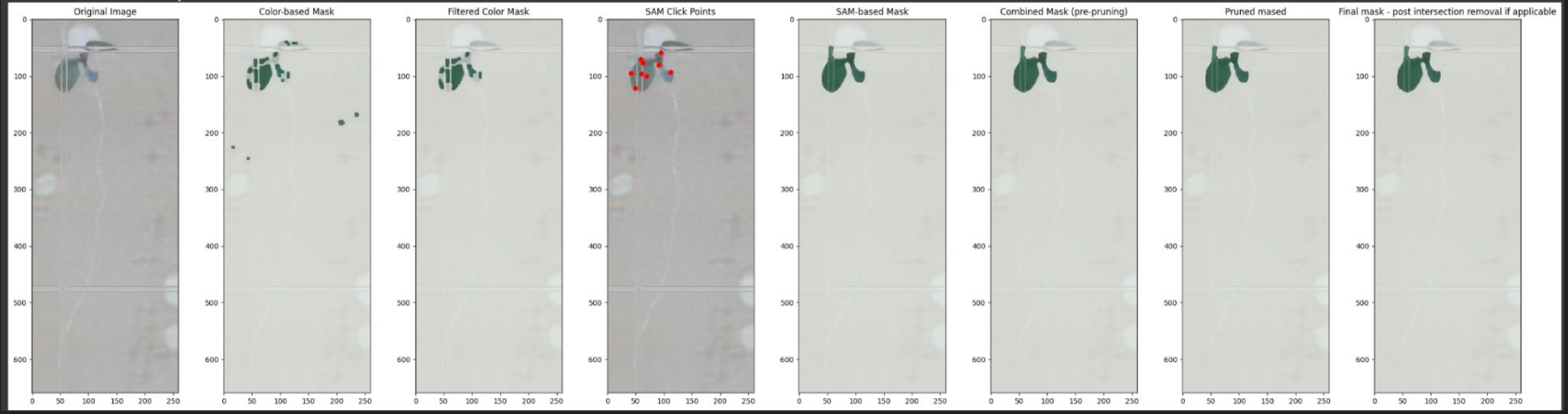
SAM Prompt Case Studies: SAM Success

batch_1_seeded/Rep1_0.5%Sucrose_gaut11-3_14.jpg
num contours = 8
num sam click points = 7



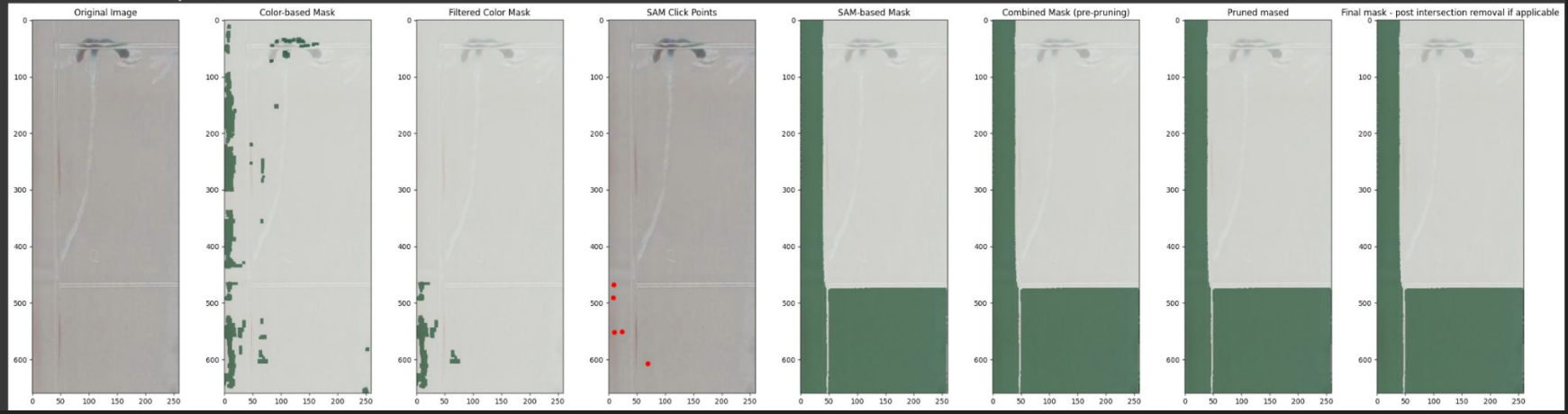
SAM Prompt Case Studies: Color Filtration Failure

```
batch_1_seeded/Rep1_0.5%Sucrose_gaut3-1gaut11-3_21.jpg
num contours = 16
num sam click points = 9
```



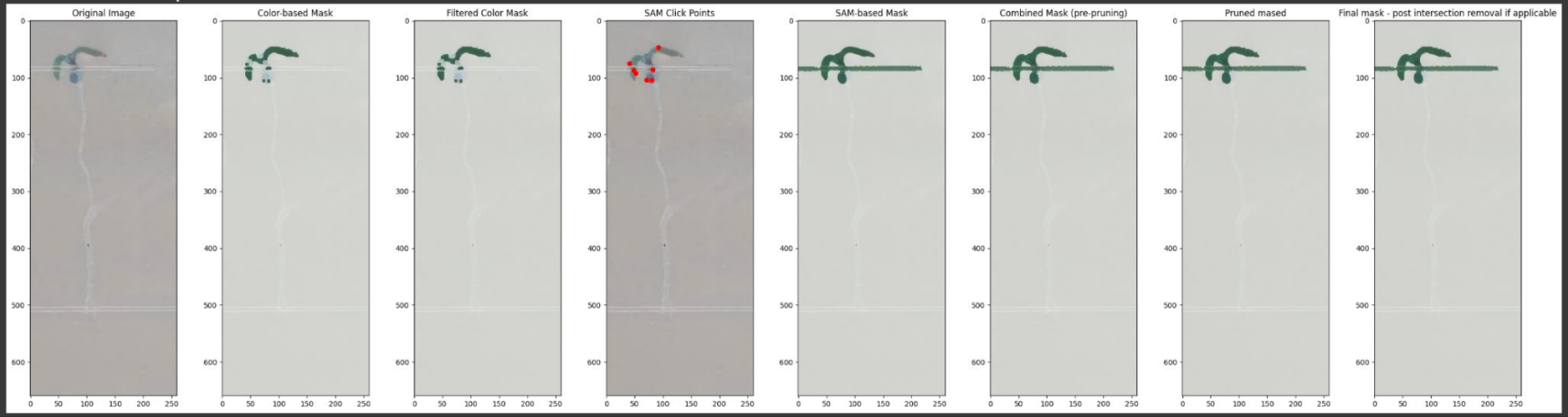
SAM Prompt Case Studies: Color Bound Failure

```
batch_1_seeded/Rep1_0.5%Sucrose_gaut10-3+gaut11-3_14.jpg
num contours = 30
num sam click points = 5
```



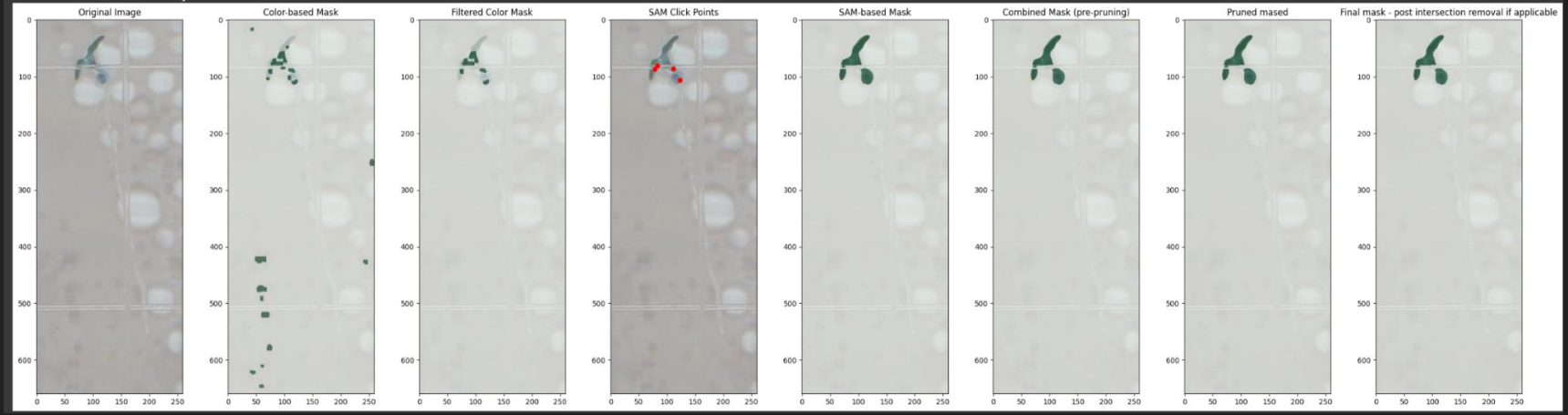
SAM Prompt Case Studies: Obfuscating Line Failure 1

```
batch_1_seeded/Rep1_0.5%Sucrose_Col-0_2.jpg
num contours = 7
num sam click points = 7
```



SAM Prompt Case Studies: Obfuscating Line Failure 2

```
batch_1_seeded/Rep1_0.5%Sucrose_gaut10-3+gaut11-3_10.jpg
num contours = 19
num sam click points = 4
```



Unet Model & Augmentation

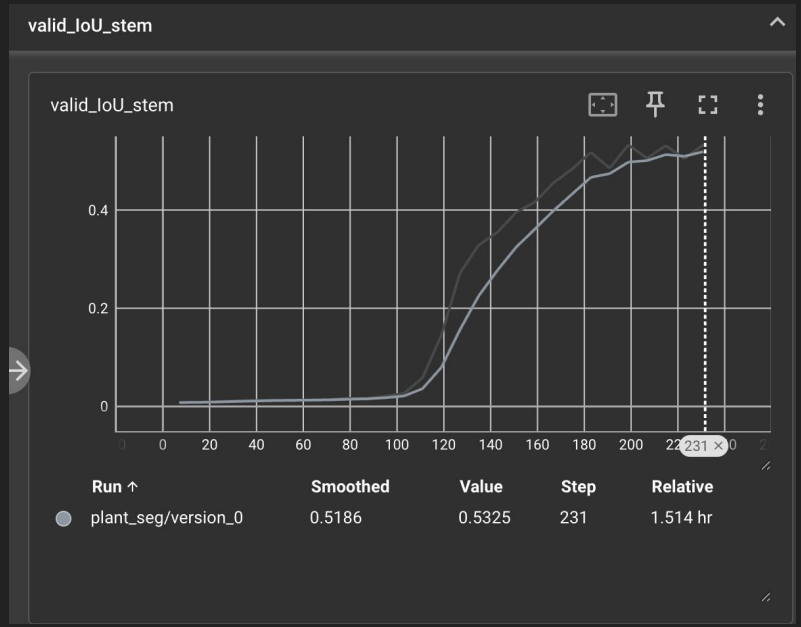
- Intuition
  - Complex image pattern finding: CNN
  - State of the art
    - Unet architecture
    - Resnet34 encoder
- Training/Validation/Testing
  - 70/15/15
  - Batch Size = 8
- Augmentation

```
A.HorizontalFlip(p=0.5),

A.ShiftScaleRotate(
    scale_limit=0.1,
    rotate_limit=10,
    shift_limit=0.05,
    p=1,
    border_mode=0,
),

A.PadIfNeeded(min_height=672, min_width=288, always_apply=True),
A.RandomCrop(height=672, width=288, always_apply=True),

A.GaussNoise(p=0.1, std_range=(0.01, 0.05)),

A.Perspective(p=0.3, scale=(0.005, 0.01)),

A.OneOf(
    [
        A.CLAHE(p=1),
        A.RandomBrightnessContrast(p=1),
        A.RandomGamma(p=1),
    ],
    p=0.9,
),

A.OneOf(
    [
        A.Sharpen(p=1),
        A.Blur(blur_limit=2, p=1),
        A.MotionBlur(blur_limit=3, p=1),
    ],
    p=0.9,
),

A.OneOf(
    [
        A.RandomBrightnessContrast(p=1),
        A.HueSaturationValue(p=1),
    ],
    p=0.9,
),

A.ElasticTransform(p=0.2, alpha=1, sigma=10),
```

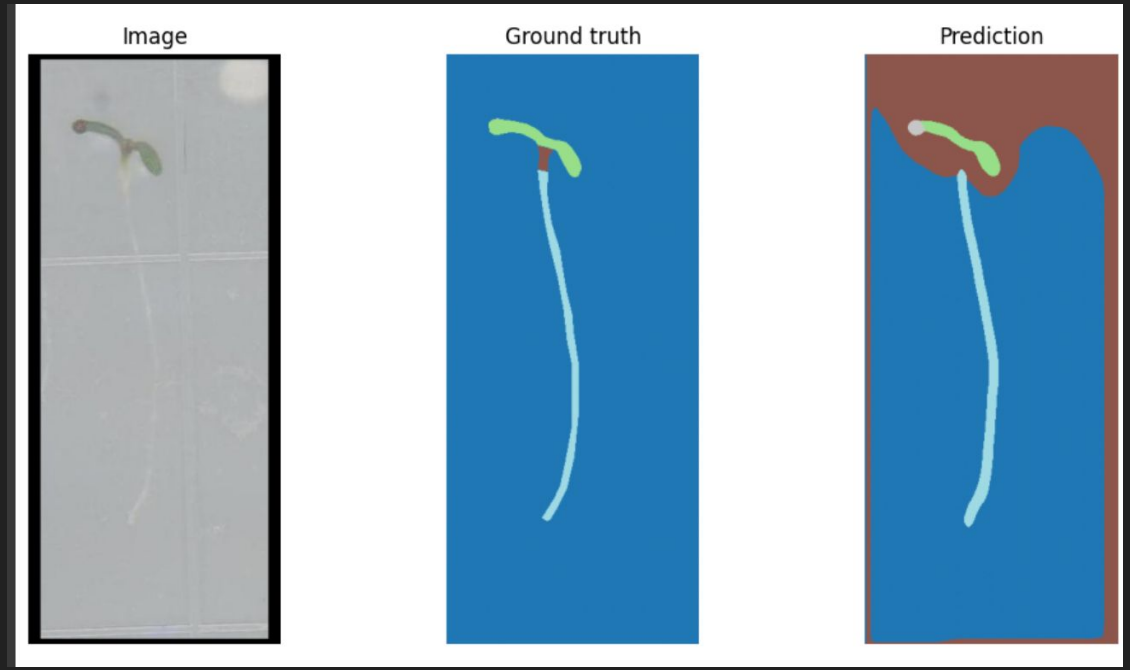
Unet Model Results

- 105 Epochs
  - Overall: 98.42% IOU
  - Background: 99.25% IOU
  - Root: 73.77% IOU
  - Leaf: 80.55% IOU
  - Stem: 53.25% IOU
  - Seed: 67.39% IOU
- Expected Results from Further Training
  - Stem++
  - 70-80% cap

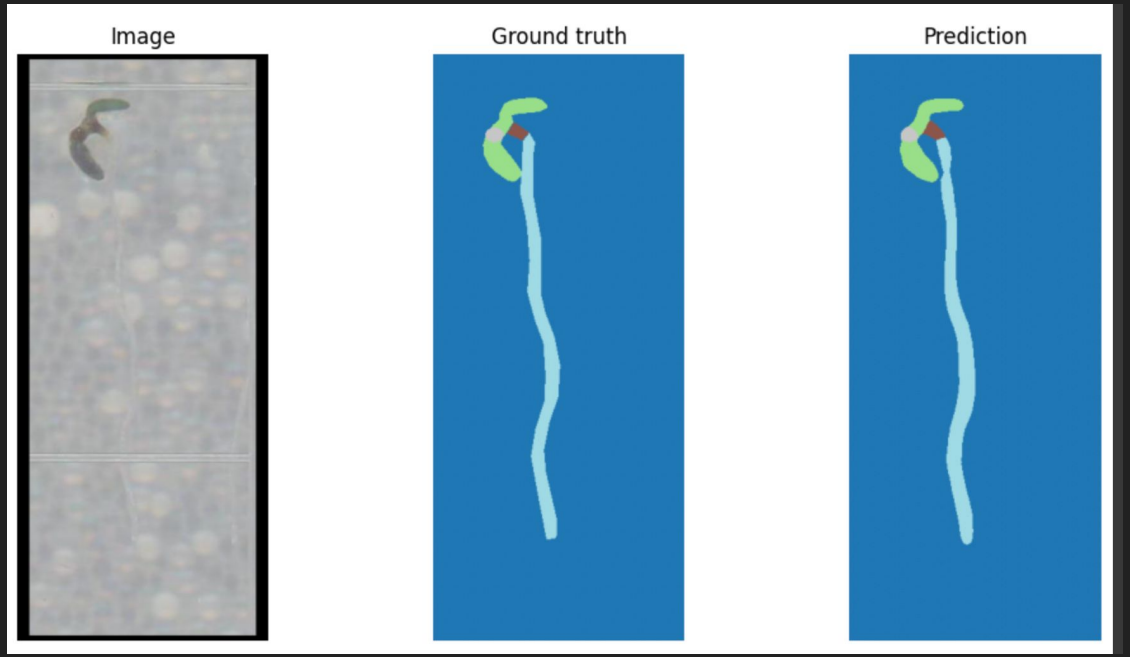
Epochs 78 - 105



Unet Model Result Case Study - 50 Epochs



Unet Model Result Case Study - 105 Epochs



Conclusion

- SAM
  - High fine precision
  - Misses big segments
  - Training is Necessary
- Unet Model
  - Leaf/Root: satisfactory
  - Seed/Stem: more epochs likely satisfactory
- Superhuman Performance
  - SAM Precision + Trained Consistency
  - SAM Adapter
  - HPC Cluster Resources

Works Cited

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[7] Yasrab, R., Atkinson, J. A., Wells, D. M., French, A. P., Pridmore, T. P., & Pound, M. P. (n.d.). Rootnav 2.0: Deep Learning for automatic navigation of Complex Plant Root Architectures | gigascience | oxford academic. https://academic.oup.com/gigascience/article/8/11/giz123/5614712