南京林業大學
NANJING FORESTRY UNIVERSITY

# Three Dimensional Tree Modeling Based on the Skeleton Path Optimization and Geometrical Cones

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目录 / CONTENTES

# 01 Introduction

# Introduction

## Background

With the appearance of various remote sensing data, such as satellite imagery and LiDAR (Light Detection and Ranging) point clouds, remote sensing technology has been widely utilized in the acquisition of forest information and land cover data, 3D geometric models of trees have become an indispensable and important part of vegetation study.

## Current Studies

- 3D modeling based on point cloud
  - Modeling by manual or with semi-automated ways
  - Modeling automatically
    - Verroust et al. introduced a method for extracting accurate skeletal curves from the collection of unorganized scattered points lying on a surface.
    - Xu et al. proposed an algorithm for reconstructing a network model from the original scanned point clouds of individual trees.
    - Livny et al. constructed and optimized the skeleton points based on the physiological structure of the tree.
    - Pfeifer et al. used a cylindrical fitting algorithm to obtain points of skeletons. The radius of branches is based on the achieved skeletons.

# Introduction

This paper takes ginkgo trees, cherry trees and phoenix trees as experimental data, and builds a three-dimensional model of those trees from handheld LiDAR point clouds.

Contributions

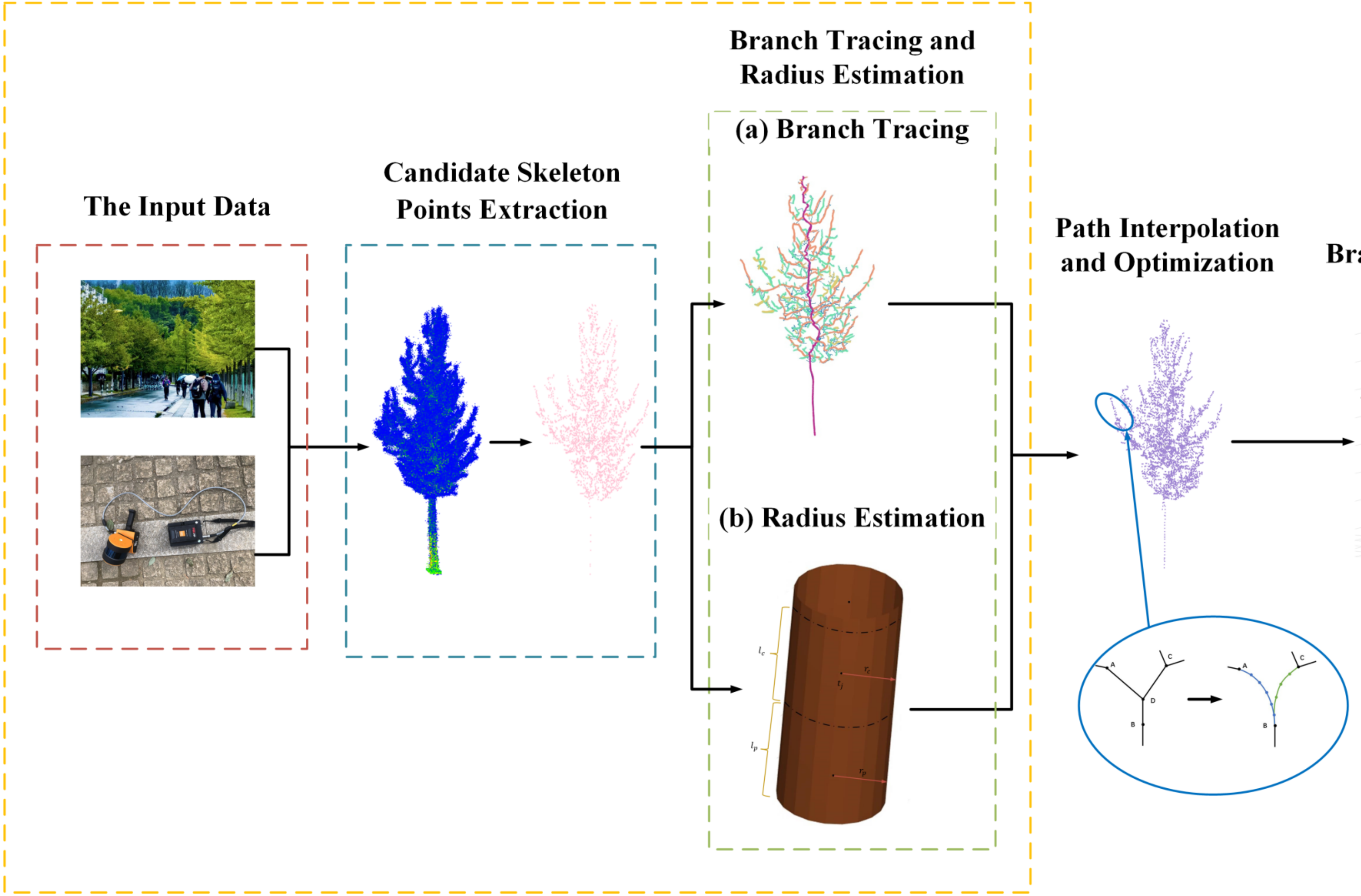
a) A clustering algorithm is proposed to obtain central points of clusters, and a slicing method is present to find the corresponding skeleton points from the directions of X axis, Y axis and Z axis.

b) A new algorithm is proposed to branch and track the skeleton points, which aims to guarantee local integrity of trees.

c) A geometric cones method is present in the modeling of tree models.

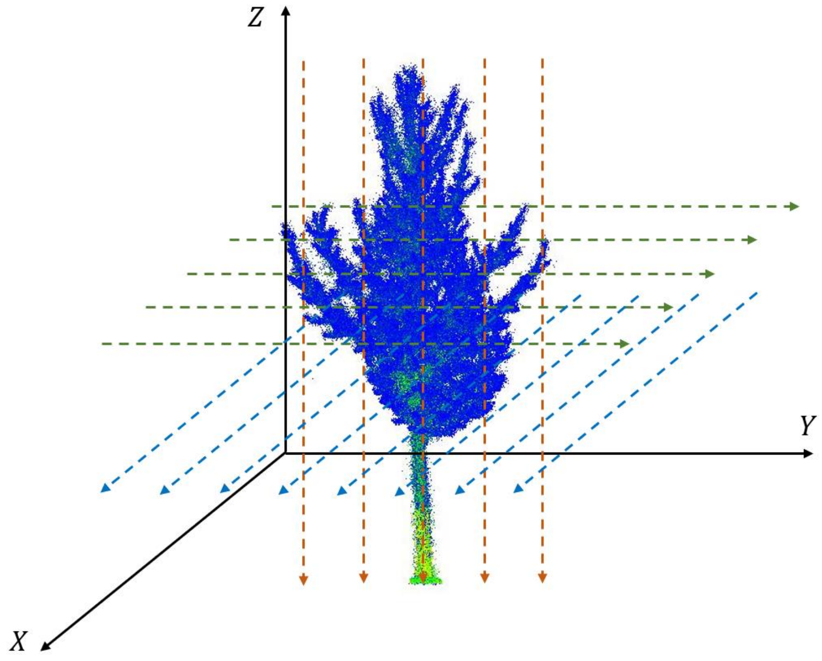
# 02 Method

# Overview of the proposed approach



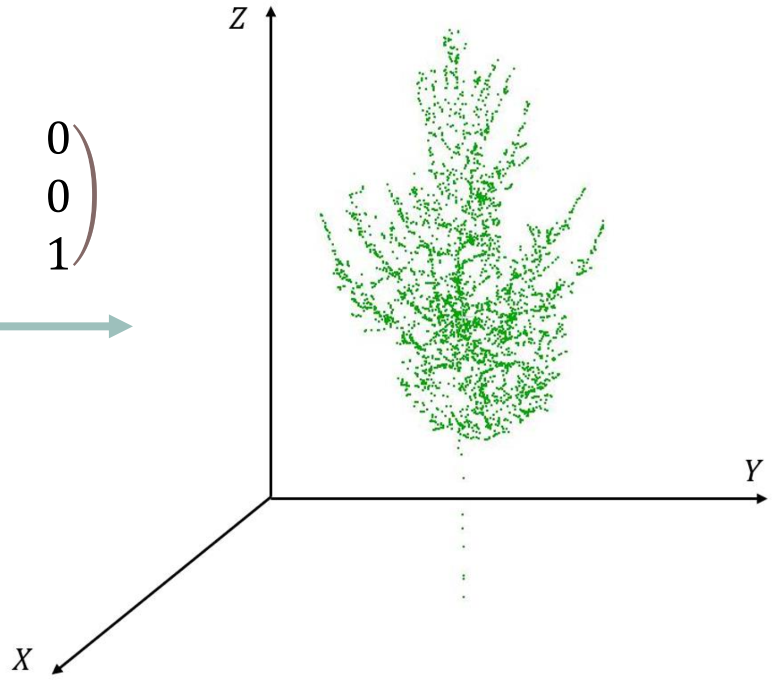
# Candidate Skeleton Points Extraction

- First, the candidate skeleton regions are obtained based on the Euclidean clustering
- Second, we sliced point in the direction of the X axis, Y axis and Z axis, respectively. The step size for slicing in each direction is 0.1.




$$T = \begin{pmatrix} cos\phi & -sin\phi & 0 \\ sin\phi & cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\phi = \frac{\Pi}{6}$$



# Branch Tracing and Radius Estimation

$$Path = \sum_{i=0}^{n} \left\{ Min\{T'D(p_i, l)MD\left(p_i, t_j\right)\} \right\}$$

$$TD(p_i, l) = \min\{dis(p_i, l), k\}, l \in S(p_i)$$

$$MD\left(p_i, t_j\right) = \min\{dis\left(p_i, t_j\right), k\}$$

# Branch Tracing and Radius Estimation

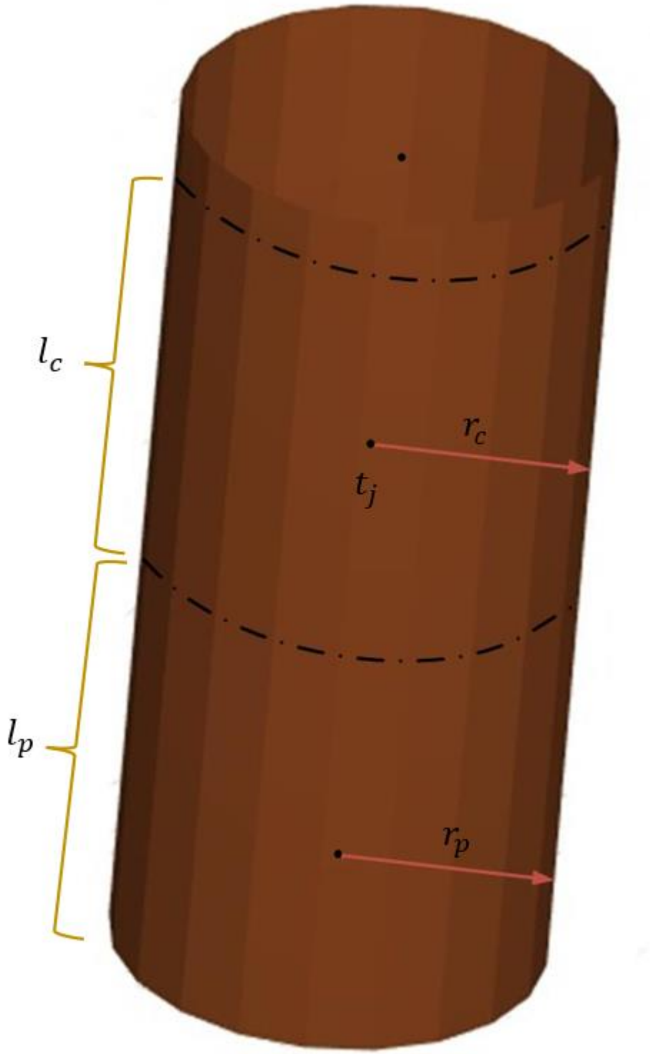
- We input the coordinates of the point cloud, calculated the Euclidean distance between points, and selected the spatially closest 10 points to each point to form the matrix ℕ.
- The sum of points in **tb** and **fb** are the total number of skeleton points of a tree. Every point in **fb** is taken as the current point, and the points in **tb** are traversed to determine whether they belong to the neighboring points of the current point in ℕ.

**Algorithm 1** Find optimal branch

**Input:** The matrix **M** is used to store the coordinates of skeleton points.
**Output:** The optimal vector **Path**

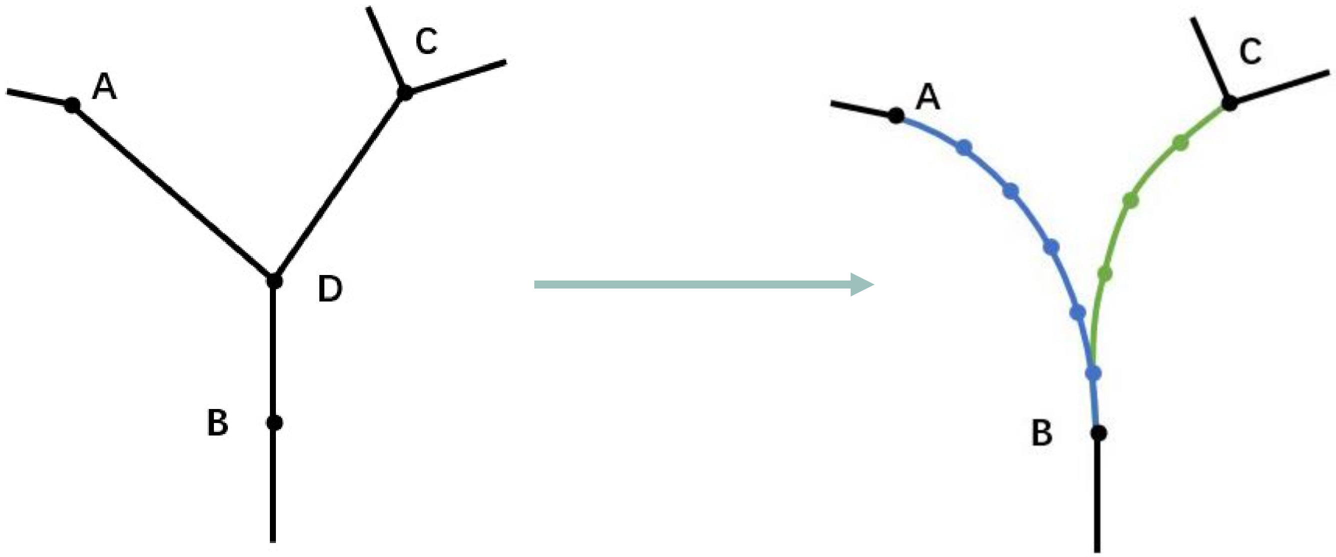
Initialize the value of a candidate branch from root for each point $p_i(x, y, z)$ as $dis_i = 0$;
**for** Each $i \in$ **M** **do**
  Calculate distance between two neighboring points in groups of the nearest 10 points;
  Formulate the index of neighboring points into the set ℕ;
**end for**
Create the set **fb** of all candidate points.
Create the set **tb** of all non- candidate points.
**while tb** is not NULL
  **for** Each $i \in$ **fb do**
    Consider $i$ as the leading point and formulate neighbors of $i$ into the set ℕ;
    **for** Each $j \in$ **tb do**
      **if** $j \in \mathbb{N}$ **then return** $Dis \leftarrow$ **Dis**(p, j)
      **end if**
      $Dis\_plus \leftarrow Dis + dis_i$
      **if** $MIN > Dis\_plus$ **then return** $MIN \leftarrow Dis\_plus, i^* \leftarrow i, j^* \leftarrow j$
      **end if**
    **end for**
  **end for**
  $dis_{j^*} \leftarrow MIN$
  Add $j^*$ into the set **fb**;
  Delete $j^*$ from the set **pb**;
  **Path**$(j^*) \leftarrow i^*$
**end while**

# Branch Tracing and Radius Estimation




$$r_c = r_p \times \left(\frac{l_c}{l_p}\right)^{\frac{3}{2}}$$

# Path Interpolation and Optimization




## 01 Matrix of Directions

$$A = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & -1 \end{bmatrix}$$

## 02 Radius Weight

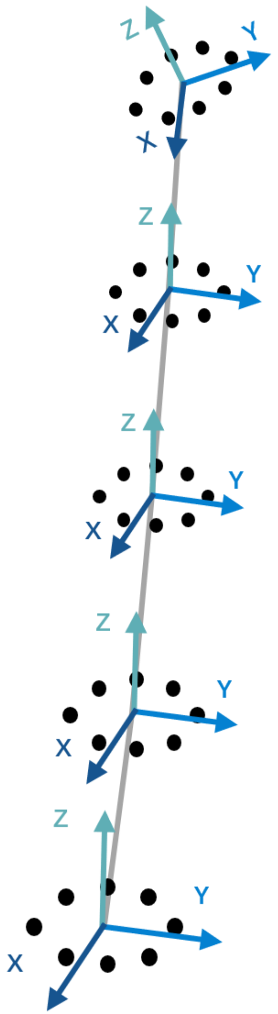
$$r_i = \frac{(r_c - r_p)}{n} \times i + r_c$$

# Branch Modeling

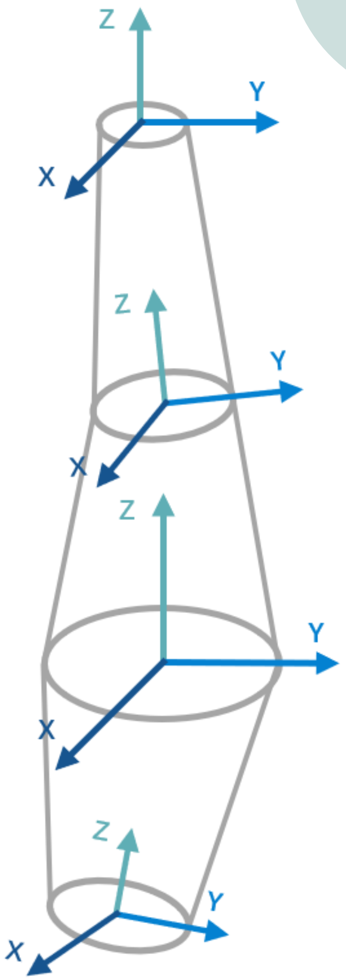
01

$$\begin{cases} x = R \cdot cos\theta \\ y = R \cdot sin\theta \\ z = 0 \end{cases}$$

02

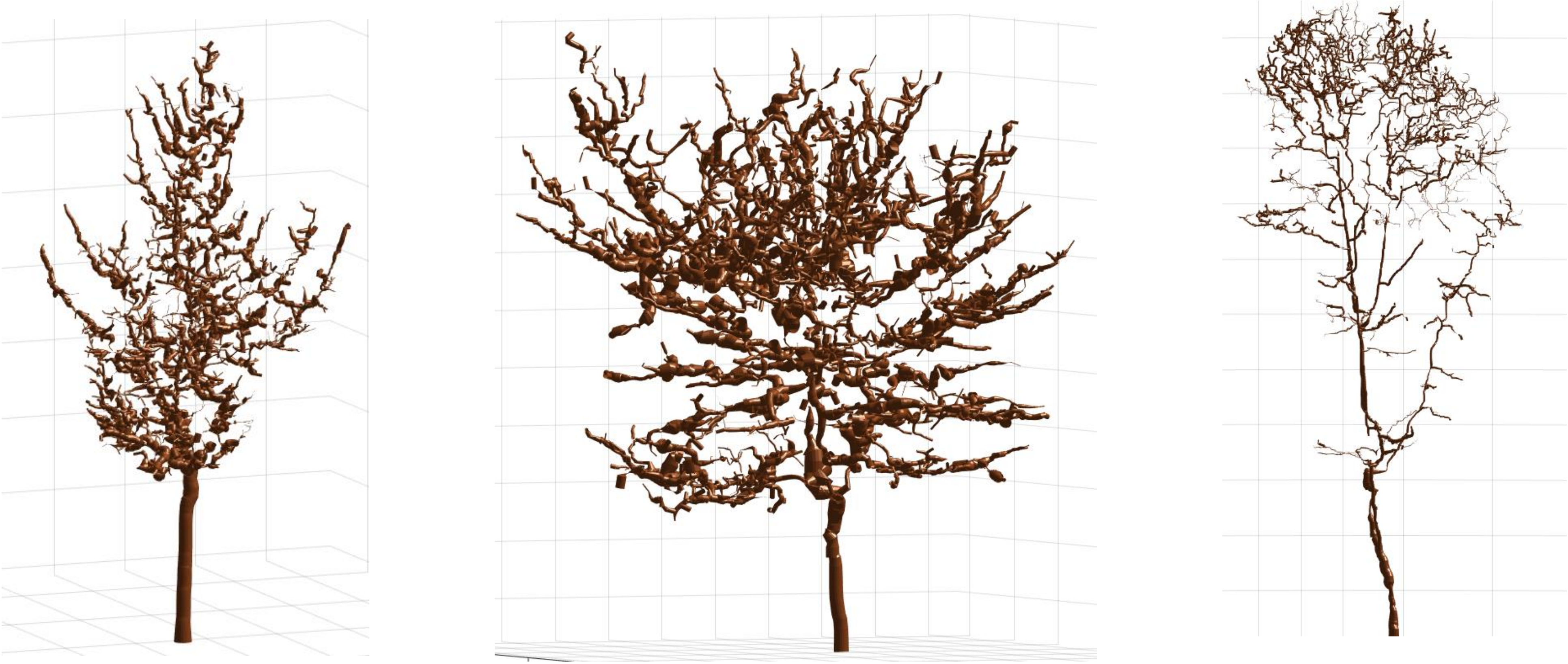



03



# 03 Experiments and Analysis

# Modeling Results



The above are the modeling results of ginkgo tree, cherry tree and phoenix tree respectively.

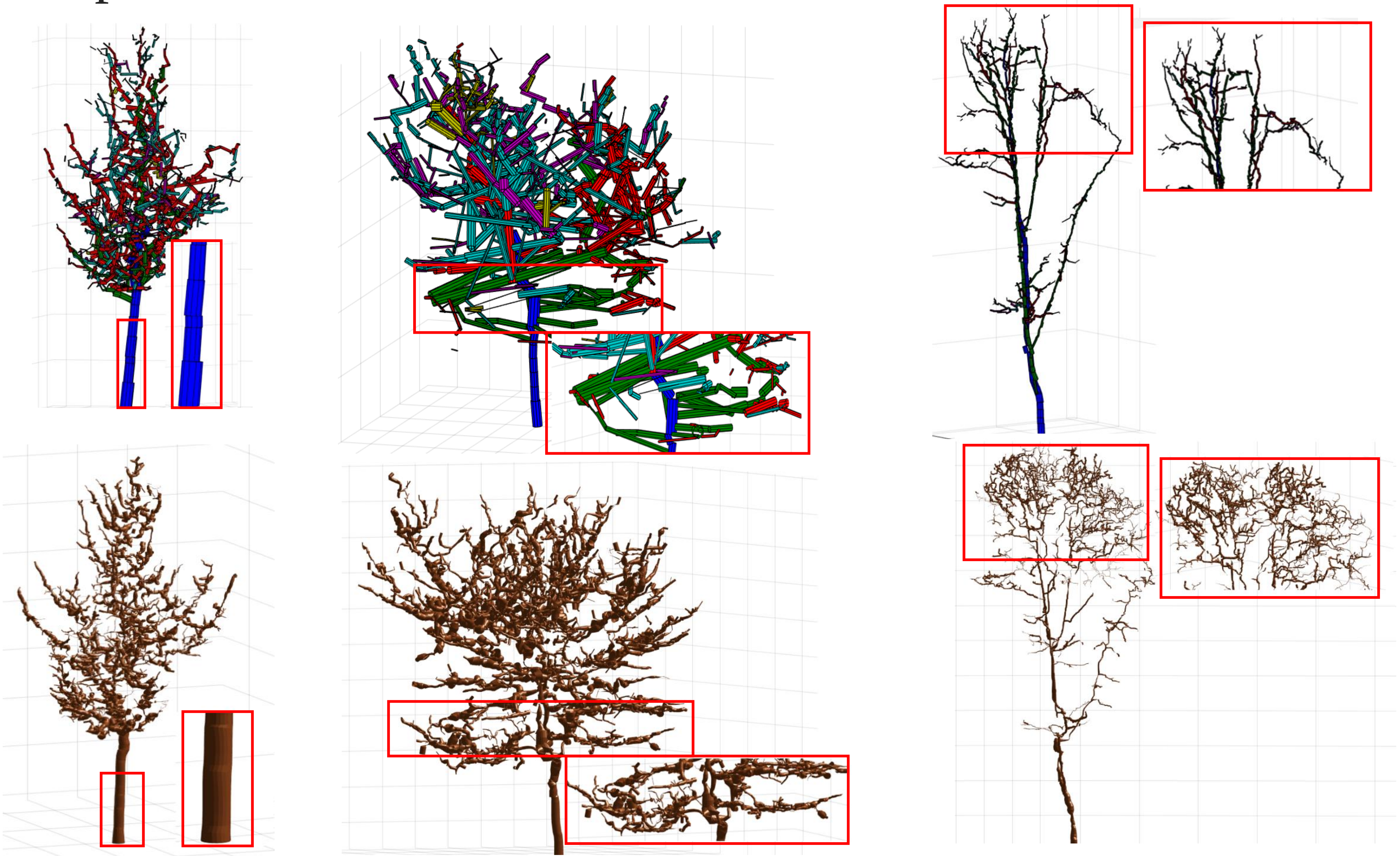
# Ablation Experiments

## 01 Comparison of results before and after optimization

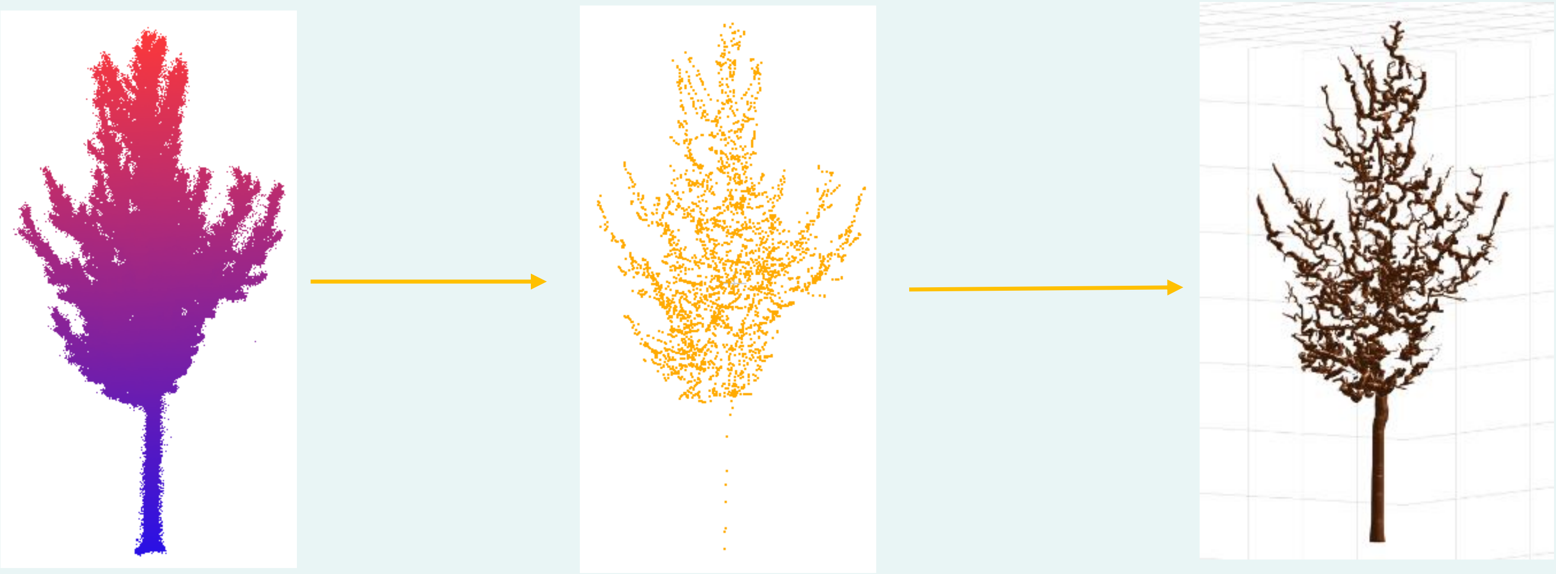
# Ablation Experiments

02 **The modeling results with different geometric**

# Comparisons



# Quantitative Analysis

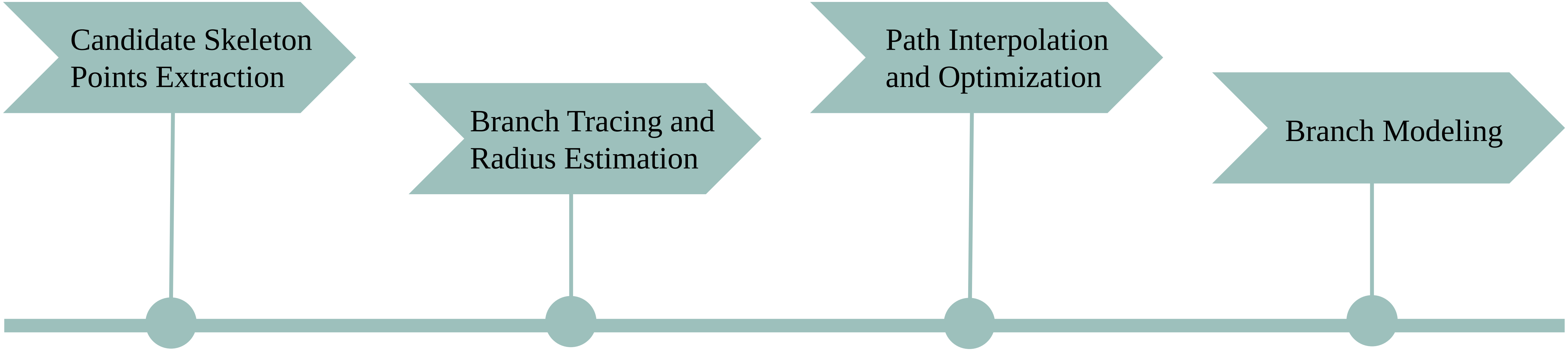


$$Accuracy = \frac{1}{m} \cdot \sum \delta(p_i, p_j)$$

| ID | Our_ginkgo tree | TreeQSM_ginkgo tree | Our_cherry tree | TreeQSM_cherry tree | Our_phoenix tree | TreeQSM_phoenix tree |
|---|---|---|---|---|---|---|
| **Points** | 945333 | 945333 | 1972532 | 1972532 | 93768 | 93768 |
| **S** | 1 | 1 | 2 | 2 | 3 | 3 |
| **Complexity** | M | M | D | D | D | D |
| **Accuracy** | 97.69% | 92.39% | 97.64.% | 81.19% | 92.53% | 39.43% |

# 04 Conclusion

# Conclusion




We propose a method to obtain skeleton branches and then reconstruct 3D tree models. The experimental results show that the average accuracy of individual tree data is up to 95.53% based on the proposed geometrical cones method, which providing a promising approach for 3D tree modeling.

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# 谢 谢 观 看

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