The slice-sector approximation of 3D models of tree crowns

Zachary J Robbins, *Dept. of Environmental Science and Mgmt, Portland State University*
Demetrios Gatziolis, *US Forest Service*
Nikolay Stirgul, *Dept. of Environmental Science and Mgmt, Washington State University Vancouver*
Kathryn Frankenhouser, *School of Public Health, Oregon Health and Science University*

Abstract

Increasing point cloud densities obtained by using evolving photogrammetry and laser scanning technologies facilitate the development of complex mathematical models of trees that not only account for traditional metrics such as crown radius and height, but also for multifaceted tree shape and form, parameters critical for quantifying tree competition, yield, and health. We have developed a novel method, named slice-sector approximation, conducive to determining shape and structure of trees at variable complexity, both vertically and radially, from dense point clouds. Using mean-shift algorithms structure of outlying shape is determined around a central point at each above-ground height class. Tree shape is approximated for a variable number of azimuth sectors radiating from this center. The number of vertical slices and azimuth sectors can vary from the simple, returning values for height and lower crown radius, to the more complex that approximate the upper crown shape and more detailed branch arrangements We have applied the slice-sector approximation to 3D reconstructions obtained by terrestrial and airborne LIDAR data and UAV-based photogrammetry. Our results suggest high method potential for improved allometric tree equations, crown morphological plasticity assessment, and quantification of active photosynthetic surface of tree crowns.

Background

Modern forest models relies on relationships between the largest measured crown diameter and the height, to determine metrics of canopy dynamics and light capture. These methods, originally derived from siliviculture do little to represent species specific vertical heterogeneity, spacing and phenotypic plasticity, which are crucial elements in understanding competition. Advances in computing technology allow for more complex forms of measurement, providing a vital opportunity to collect more complex data sets, and increase mathematical understanding of competition processes. Aerial remote sensing allows for greater quantification of the complexity of crown structure by providing comprehensive and gap-free reconstructions that can be used to derive algorithms for the recognition of individual tree structure. The confluence of aerial remote sensing and machine learning algorithms allows for researchers to now investigate and understand individual tree morphology in light based competition with neighbors and, ultimately, predict with future forest organization with higher accuracy..

Methods

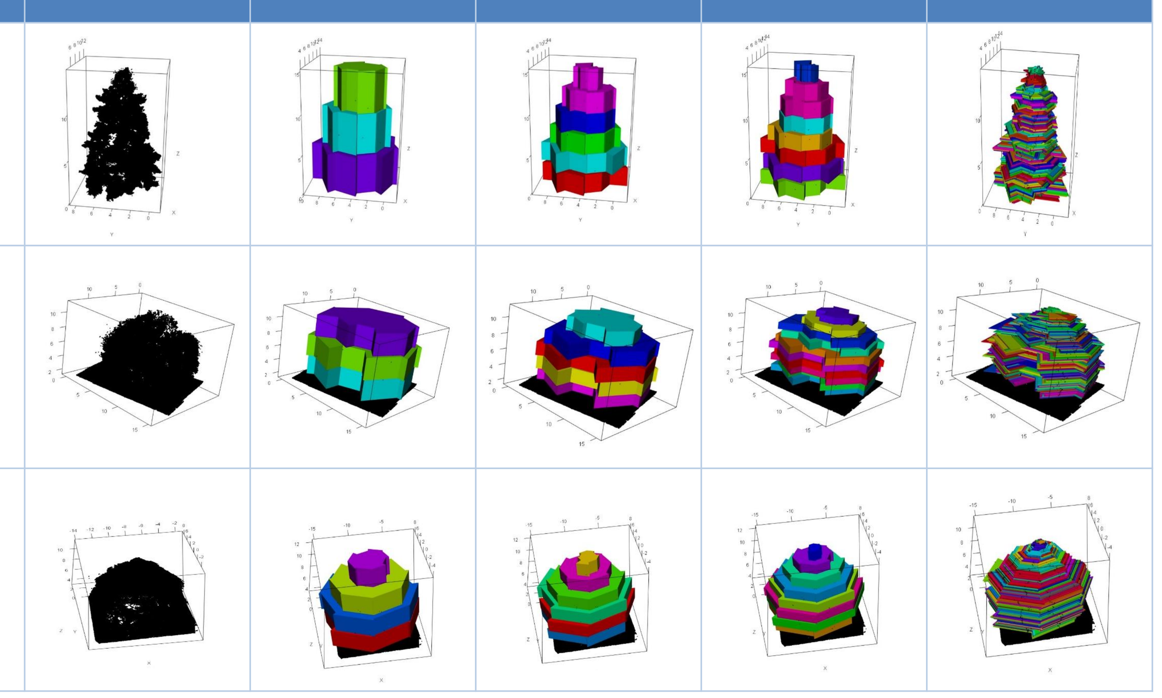
Initial processing reduces that point cloud density subsampling to create a min space of .0349 on average between points, lower the density of point clouds increases processing speeds without losing complexity of shape. Images are then post processed to determine the relative size and orientation of the image and the vertical location in which to begin vertical slices. While theoretically infinite, the optimal number of sectors is largely controlled by local point cloud density. Clustering computed using mean shift algorithm as present in the R package LPCM. Using the parameterization of h(bandwidth) the mean shift algorithm clusters points rated to be neighbors into likely groups these are then connected to the center points to for sectors. The distance between likely clustering groups in determined by the user provided bandwidth (h) of the Gaussian kernel

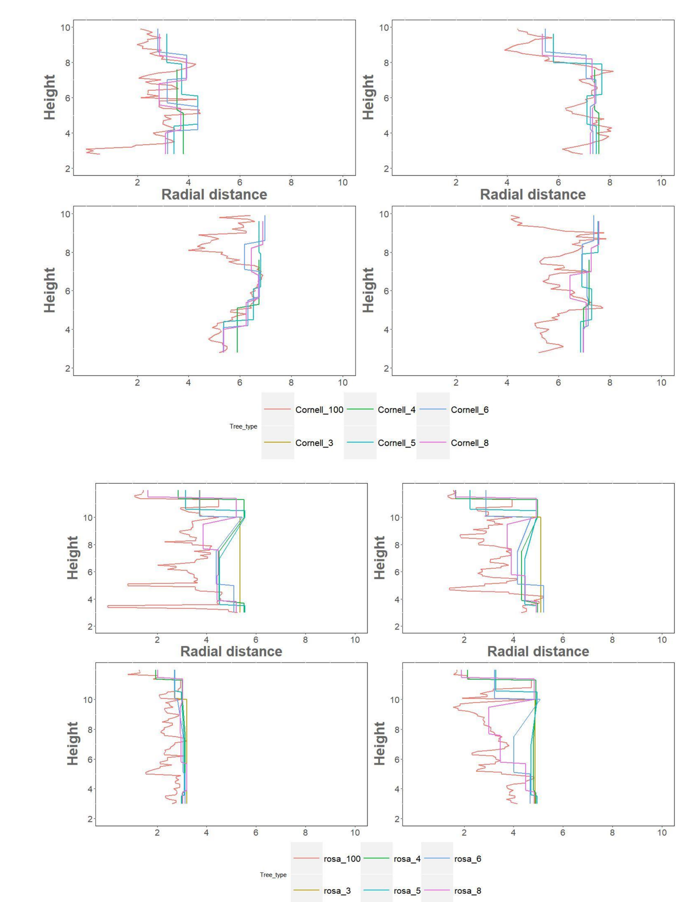
These sectors connected to a common center of these cluster then form the structure of the crown radius at a given height, the more optimal h bandwidths can be determined using an the bandwidth for which the most symmetrical sectors for given slices are returned. Radius for given trees can be reduced to means or kept as unique radius for each sector represented in azimuth direction around the center point.

For this project we applied slice sector approximation to three different trees (labeled Rosa, Cornell, and Omega) and addressed applying increased complexity to tree models. We also addressed how to apply this methodology to stand level UAV data as well as LIDAR imaging.

Vertical Heterogeneity

	Original	3 Slices	5 Slices	10 slices	100 slices
Rosa					
Cornell					
Omega					

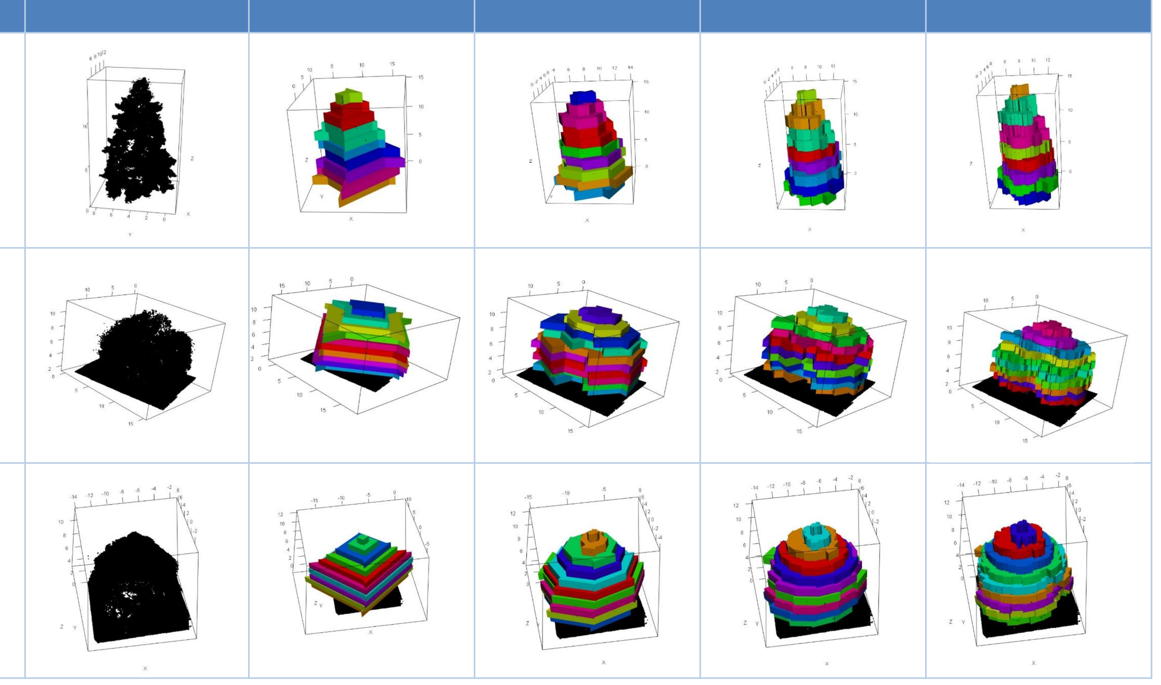


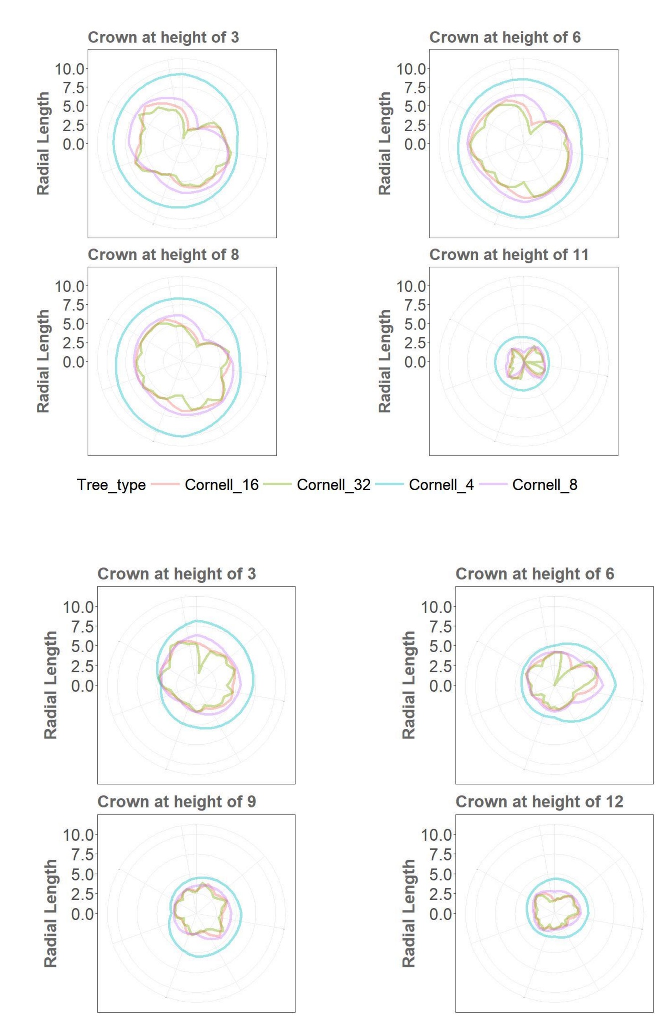


The increase in complexity at a given height is greatly increased as the number of sector increases. in complexity is observed in having 32 azimuth directions as opposed to 16. As for vertical heterogeneity, increasing the number of slices seemed to increase complexity up at every tested level.

Radial Heterogeneity

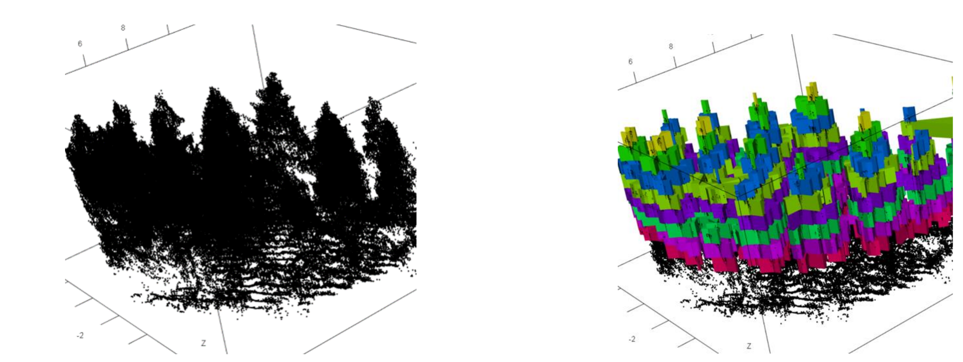
	Original	4 Sectors	8 Sectors	16 Sectors	32 Sectors
Rosa					
Cornell					
Omega					





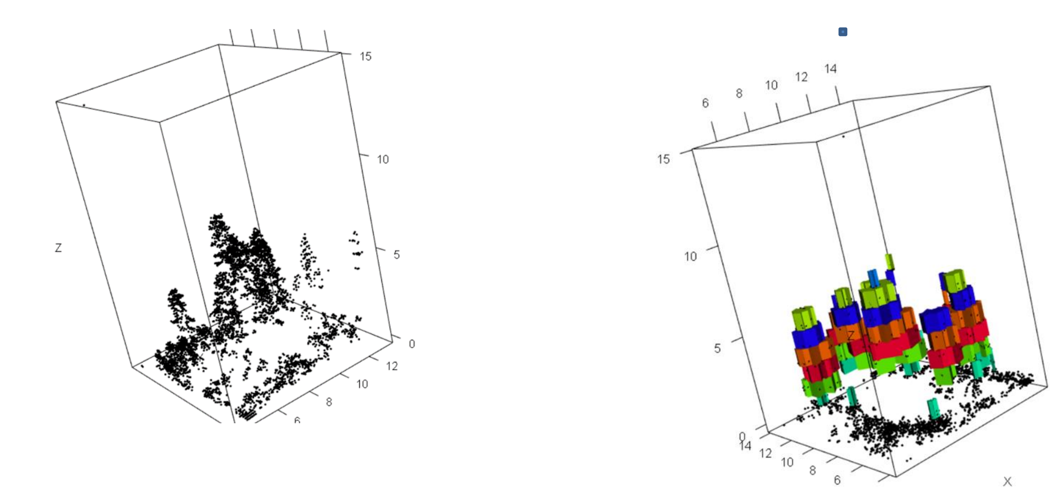
Increasing complexity is seen in increasing the number of sectors from 4 to 8 to 16 but little increase in complexity is observed in having 32 azimuth directions as opposed to 16. It is important to point out that increasing recognition of complexity also increases the likelihood of incorrectly quantifying shadows and relics such as those seen in the Rosa Tree example. At the lower height levels we found that a shadow relic, which left sparse cloud formation on one side, could be smoothed over with a smaller number of sectors, and would show up with an increased number of sectors. This shows that the accuracy of the method is dependent on usage and data fed into the algorithm.

Stand Application (UAV)



The application to stands allows for center point approximation, and crown dynamics with correct parameterization of the Gaussian bandwidths. This determination is crucially important to ensure that groups do not span multiple trees, or split individual trees into multiple radials. These bandwidths have been determined for several point density and scenarios.

Stand Application (Sparse LIDAR)



Sparse point clouds such as those found in LIDAR are only able to create less complex models with higher ranges of variability. However using the height of the highest given point and the largest mean crown radius at a given height for each location it is possible to reconstruct basic tree mapping of centerpoint and mean radius with no prior data of stem location or density.

Conclusion

The complexity added to tree modeling greatly increases as you move from a traditional radius representation to a slice-sector approximation. This has strong implications for light based vegetative growth models, as complexity in canopy structure, allows for far more light penetration than traditional conical model. We can recreate complex canopy structure, with no apriori knowledge, further work needs to be conducted to calibrate these classification. As with all reconstructions, effort need to be taken to ensure. We are also planning to employ this method for parameterization of spatially-explicit individual tree-based forest simulator. This method of structural modeling allows for branch structuring to be incorporated in individual growth models for the first time. Work is also being conducted to more accurately recognize optimal bandwidths for the mean-shift kernel and recognition he application to stands allows for center point approximation, and crown dynamics with correct parameterization of the Gaussian bandwidths

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- As point cloud density and acquisition methods improve there is increasing room to build more complex mathematical models of trees, ones that do not account just for traditional metrics like crown radius and height, but that can accurately account for the many facets of tree shape and form. These increasing mathematical understandings open the door to not just more efficiently quantify what has been used for years, but to further gain knowledge as to how tree shape can be a marker of competition, yield and even health. We have developed a novel method, called the slice-sector approximation, which allows us to determine shape and structure of trees at variable complexity both vertically and radial from dense point clouds. Using mean-shift algorithms, that require no knowledge of number of trees or clusters present, structure of outlying shape is determined around a central point at each height. The tree shape is then approximated in a variable number of round azimuth sectors radiating from this center. The number of vertical slices and azimuth sectors can be varied from simple, returning values for height and lower crown radius to more complex, giving approximation of upper crown shape and more Intricate branch structuring. This can be used to determine crown radius for 2n sectors with any integer n. Balance however must be made between data present in the point cloud to determine slice sectors and discretization error. We have applied the slice-sector approximation to 3D reconstructions obtained by terrestrial, and airborne LIDARs and UAV-based photogrammetry. These results allow us for increased understanding tree allometry and crown morphological plasticity, new recognition of photosynthetic surface of the crown. We are also planning to employ this method for parameterization of spatially-explicit individual based forest simulators.
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