3D rendering of a Copper Beech tree.

Figure 1: The Copper Beech at Portland State University. Very complex branch structure with a height exceeding 40m

SEE THE FOREST FOR THE POINT CLOUD

Tree Diameter Detection

An increasing number of ecologists and foresters are viewing LiDAR as an essential tool to expand their knowledge of ecological processes and to derive precise measurements of biomass. However, using LiDAR to model individual trees and entire forest stands presents interesting challenges.

The amount of biomass in a region, tree growth rate, and canopy structure are just a few examples of the information that can be obtained using LiDAR to analyze a forested area, but trees by their very nature tend to be extremely complex structures, and accurately modeling them is the subject of much research in the LiDAR world.

In the not so distant past, point returns from the upper canopy were discarded when aerial LiDAR was processed, as the value of the tree data was not fully appreciated. Simple metrics such as average tree height in an area can be derived from aerial LiDAR, and using the data to model basic branch structure and canopy density, it may be possible to remotely identify areas that are potential habitat for sensitive species such as red tree voles *(Arborimus longicaudus)* or northern flying squirrels *(Glaucomys sabrinus)*.

In the near future, ecologists and foresters may be flying remote controlled airplanes equipped with ultralight LiDAR systems over forest stands, or they may be hiking through the stands with LiDAR sensors strapped to their body generating point clouds

BY JONATHAN **BATCHELOR**

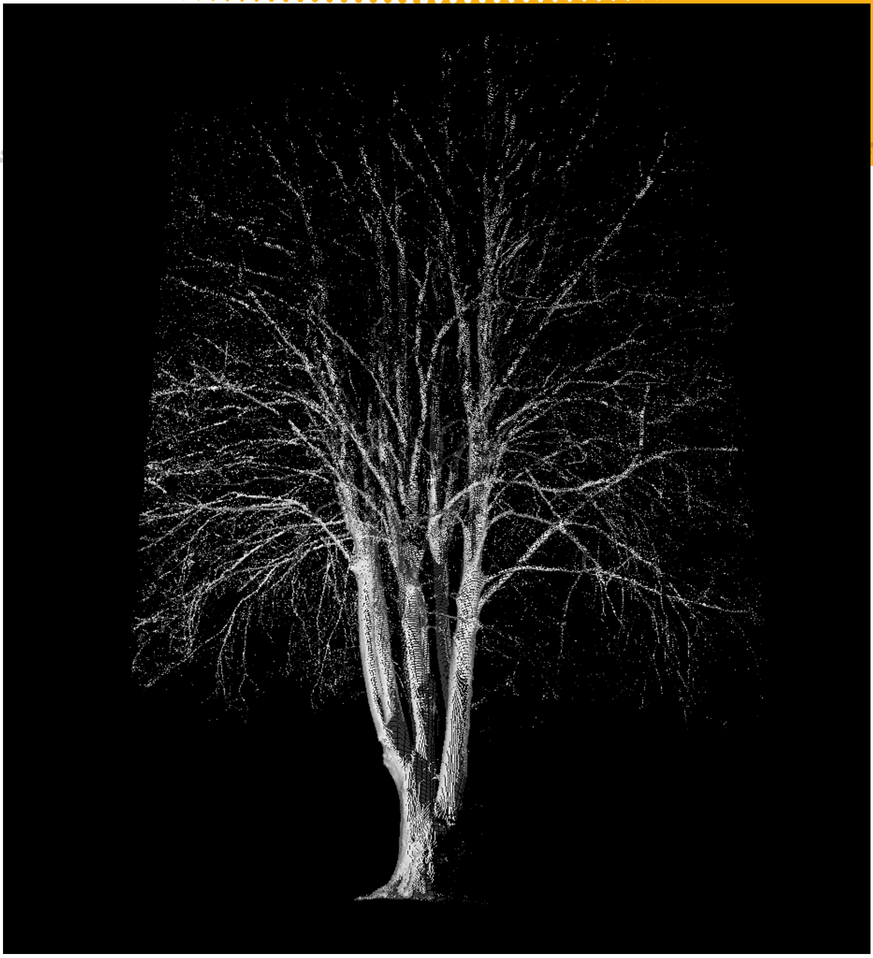

Figure 2: The composite image of the tree. There are sections in the upper main stem that are missing due to shadowing from lower branches and the finer branches are mixed in with a fair amount of noise

as they walk. The potential is nearly endless, but what are some of the issues that must first be addressed in order for accurate tree modeling to be possible?

To explore that question, we created a model of a copper beech *(Fagus sylvatica f. purpurea)* with an extremely complex branch structure. **Figure 1** is a photograph of the beech that is located on the campus of Portland State University in Portland, Oregon. Four scan positions were used to generate the point cloud of the tree.

Branch occlusion

You can't scan what you can't see. This may be obvious but this issue is the main hurdle for researchers interested in producing accurate models of trees. From a single scan position you are likely to miss at much as 70% of the branch structure of a tree, as not only are you unable to see the backside of the tree, you are also blocked from viewing the upper reaches of the tree by lower branches. With two scan positions you are able to acquire much more of the branch structure but even with four scan positions spaced evenly around the tree, your vision is still constrained by the lower branches. **Figure 2** is a composite image of all four scans we obtained and you can see the data drops out in the upper reaches of the tree as shadowing effects from the lower branches block much of the view.

The smaller diameter branches in the upper canopy often appear as noise as they are broken up into small segments with no connectivity back to the main stem due to the occlusion by lower branch structures. To get a fully accurate scan of a tree, many scan positions would be required, both in a radial pattern around a tree but also along a vertical axis moving up the height of the tree. This process would be extremely time consuming and functionally impossible if modeling larger areas.

Stem Taper and Oblong stem shape

Modeling algorithms are being developed and tested to try and derive upper canopy measurements from ground based LiDAR systems but the complexity and differing growth patterns between individuals of the same species are proving to be problematic. Two basic issues that confront researchers are stem taper and oblong stem shape.

When looking at a tree, it is fairly obvious, that as the tree increases in height, the diameter of the trunk decreases, and that most tree trunks are, in fact, not circular but are rather oblong in shape. If standing in an open ponderosa pine *(Pinus ponderosa)* stand, obtaining extremely detailed scans of the base of the trees is relatively simple but these giant trees can regularly reach heights over 60m and much of that height may be obscured from the ground. In a Douglas fir *(Pseudotsuga menziesii)* forest recovering from a disturbance event, such as logging, trees can be densely packed and arrow straight, shooting up from the ground and competing with one another for the limited resource, sunlight.

In scanning either an open ponderosa pine stand or a dense Douglas fir stand, it is possible to estimate the upper

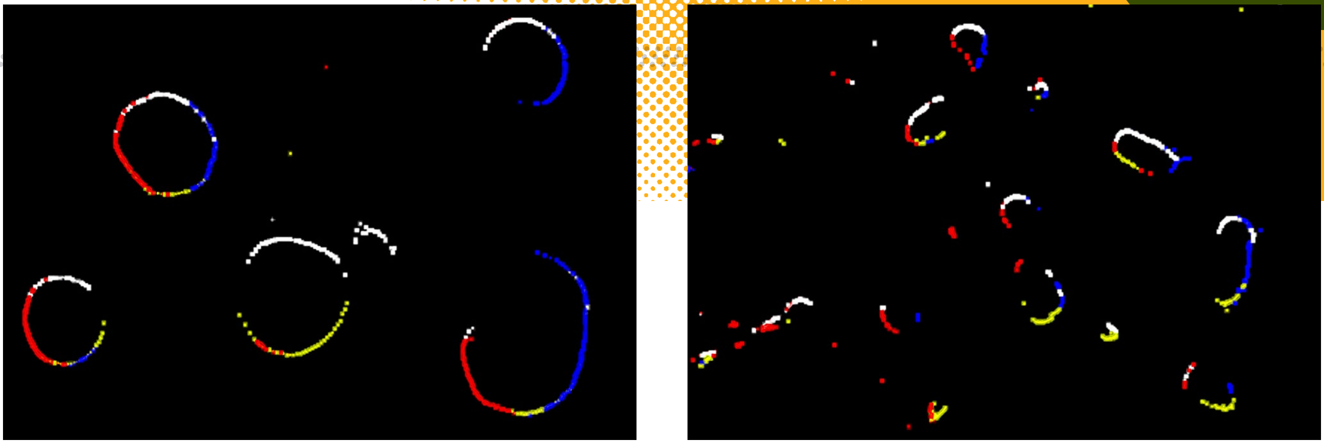

Figure 3: Cut planes colored by scan position of the beech tree at 3m and 8m to show the amount of stem taper, branching, occlusion, and oblong shape.

diameter of the tree trunk using the size, and rate of reduction in diameter of the trunk at lower levels of the tree. The accuracy of these estimates depends on the uniformity of growth of the trees that are being modeled, but how a tree grows is entirely dependent on where it is growing. A tree in an open area with plenty of water and nutrients will grow in an entirely different manner than a tree in a harsh and crowed environment. It is possible to fine tune an algorithm to estimate upper stem volume that works wonderfully in one situation but fails completely when trying to model the same tree species in a different environment.

Conifer trees, overall, do tend to be much more uniform in shape with a central stem. All the problems faced when trying to estimate upper stem volume in conifer trees, are greatly magnified when trying to estimate upper stem volume in deciduous trees. The classic archetype of the conifer tree is the tall, straight, central trunk with smaller branches radiating out from it. Deciduous trees often more closely resemble a fractal pattern in their branch structure, with trunk and branches more likely to have an exaggerated oblong shape.

> “LiDAR is an exciting new technology with amazing potential for helping us understand the biotic communities of this planet.”

Figure 3 shows two cut planes from the scan of the copper beech. One near the base of the tree and one further up the trunk. You can see that the main stems near the ground are more circular in nature, and that a larger percentage of each stem was captured by one of the four scan positions. Going up only a few meters, the stems become much more oblong, numerous (due to forking), and less of the circumference is captured by the four scan positions.

We attempted many auto detect functions, such as Leica Cyclone’s pipe fit tool, but we were unable to find any software that accurately and reliably derived a diameter of the stems. We compared auto detect tools using only one scan position and auto detect tools using a composite of all scans but the amount of the stem detected was seemingly less important than the shape of the stem in regards to how accurate we felt the results were. In the end, the most efficient manner we found to derive diameter was to manually trace the stem outlines and find the line length.

This paper is written from the perspective of a curious ecologist exploring the possibilities of LiDAR to model what I love most—trees. By no means am I an expert on LiDAR nor was this an attempt to present a study that underwent rigorous development or scrutiny. LiDAR is an exciting new technology with amazing potential for helping us understand the biotic communities of this planet. LiDAR will be an invaluable tool in helping us understand how these biotic communities are being effected in this time of changing climate.

Jonathan Batchelor is currently a graduate student in the Forest Ecosystems and Society Department at Oregon State University.