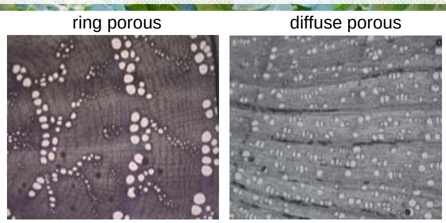
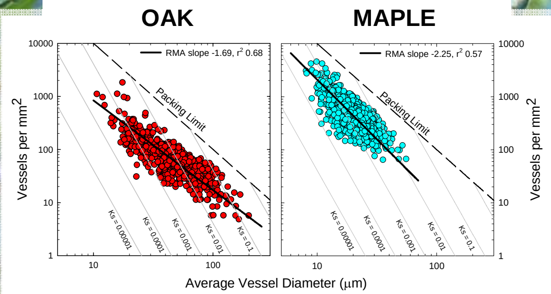
# Integrating vascular principles into a general model for the structure and function of plant networks.

John S. Sperry[1], Duncan D. Smith[1], Erica von Allmen[1], Brian J. Enquist[2], Van M. Savage[3] & Lisa Patrick[2]
[1]Department of Biology, University of Utah, 257 S 1400 E, Salt Lake City, UT 84112,
[2]Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ 85721
[3]Biomathematics Department, University of California, Los Angeles, CA



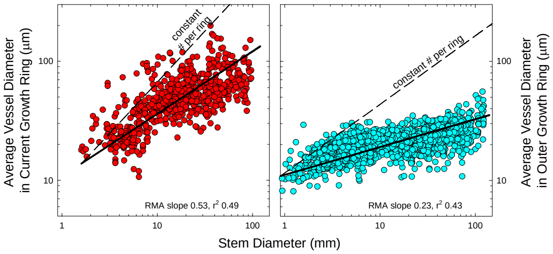

## INTRODUCTION

Trees grow according to several "rules" of vascular structure and branching that arise from a variety of constraints. In this collaborative project, we are using these rules to refine the influential plant architecture model of West, Brown, & Enquist (WBE[1]). The model is useful for interpreting the adaptive significance of tree form, and for predicting water use and metabolism as a function of plant size and functional type. Here we apply the revised model to the sharply contrasting anatomy of a ring- (*Quercus gambelii*, oak) vs. a diffuse-porous (*Acer grandidentatum,* maple) tree species, showing component rules, model structure, and some preliminary results. [1] West et al. 1997 Science 276: 122-126.



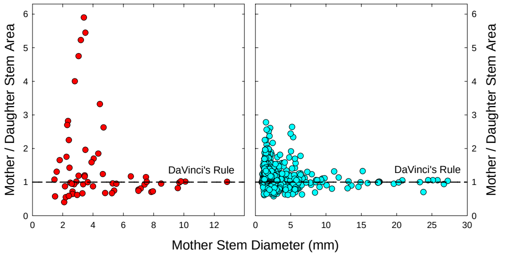

### Vessel-packing rule:

Space-filling and mechanical constraints lead to a log-linear relationship between vessel frequency and mean vessel diameter. Species' specific packing functions were substantially below the maximum space-filling limit (dashed line), and limited the theoretical hydraulic efficiency of the wood (grey conductivity contours).



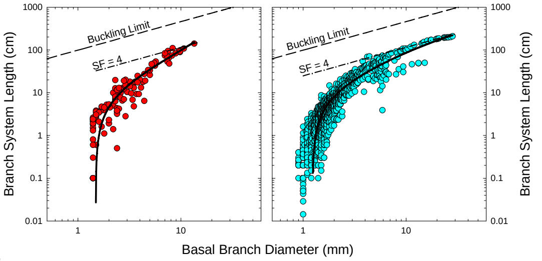

### Vessel-taper rule:

Vessels taper axially within a growth ring, and radially from inner-to-outer annual rings. Taper can be viewed as a constraint arising from the packing function and the need for a minimum number of vessels per growth ring (dashed curves). Taper diminished at a much larger vessel diameter in oak than maple.



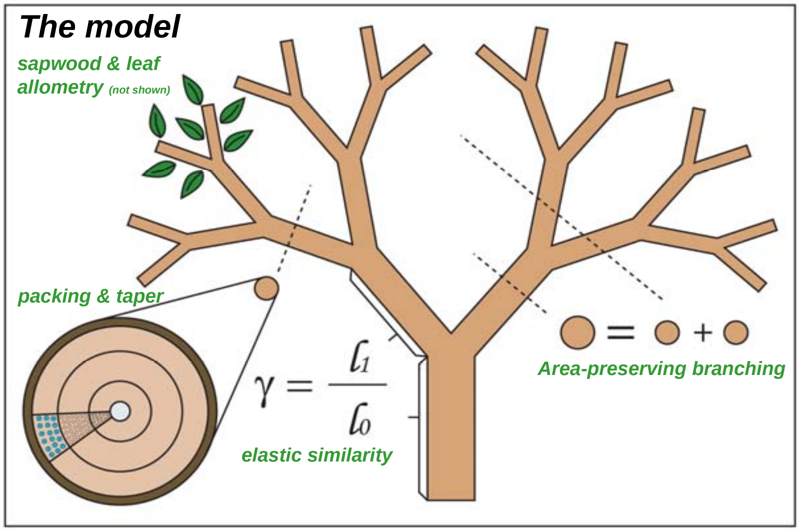

### Area-preserving rule:

Tree branching in both species preserved a nearly constant cross sectional area, conforming to Da Vinci's analysis and the original WBE model. "Da Vinci's rule" may reflect a compromise between mechanical stability, which must avoid a top-heavy tree, and hydraulic efficiency, which would be improved by area-increasing branching.




### Elastic similarity:

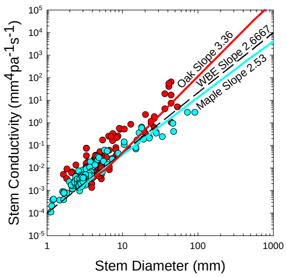
Scaling of branch length with basal stem diameter in both species converged on a log-linear trend required for a constant safety factor (SF) from Euler buckling in larger branches (elastic similarity). This mechanical constraint limits the stem length achieved for a given investment in stem thickness.




## MODEL

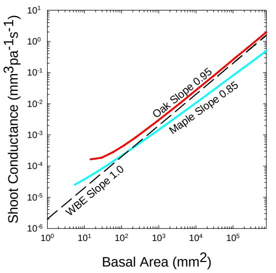
Packing, Taper, Area-Preservation, and Elastic Similarity functions were combined to dictate the piping and branch dimensions of trees. At present, branching structure is strictly self-similar as in the original WBE model. Species' specific sapwood-heartwood functions, leaf area per twig size relationships ("Corner's Rules") and petiole conductance functions (not shown) were also incorporated. Whole leaf conductance relationships will be added in the near future.

## MODEL RESULTS




### Stem Conductivities:

Modeled stem conductivity matched values calculated from twig anatomy, and scaled with stem diameter. Scaling exponents ranged from 3.36 in oak to 2.53 in maple, bracketing the predicted 2.67 for the original WBE model.




### Whole Shoot Conductances:

Modeled shoot conductance in oak exceeded maple. Shoot conductance scaled with basal area to the 0.95 power in oak, close to the isometric scaling of the original WBE model (dashed line). A lower scaling exponent of 0.85 was predicted for maple, suggesting that tree productivity does not invariably scale with shoot mass to the 0.75 power as originally proposed.

## FUTURE DIRECTION

Model predictions are being tested by sap flow and growth measurements of oak and maple stands of varying sizes. More functional types are being modeled, including conifers. The model is currently being extended to represent actual tree branching structures which are often not strictly self-similar.