

# Plant Geometry from Fractals

Based on L-systems Theory

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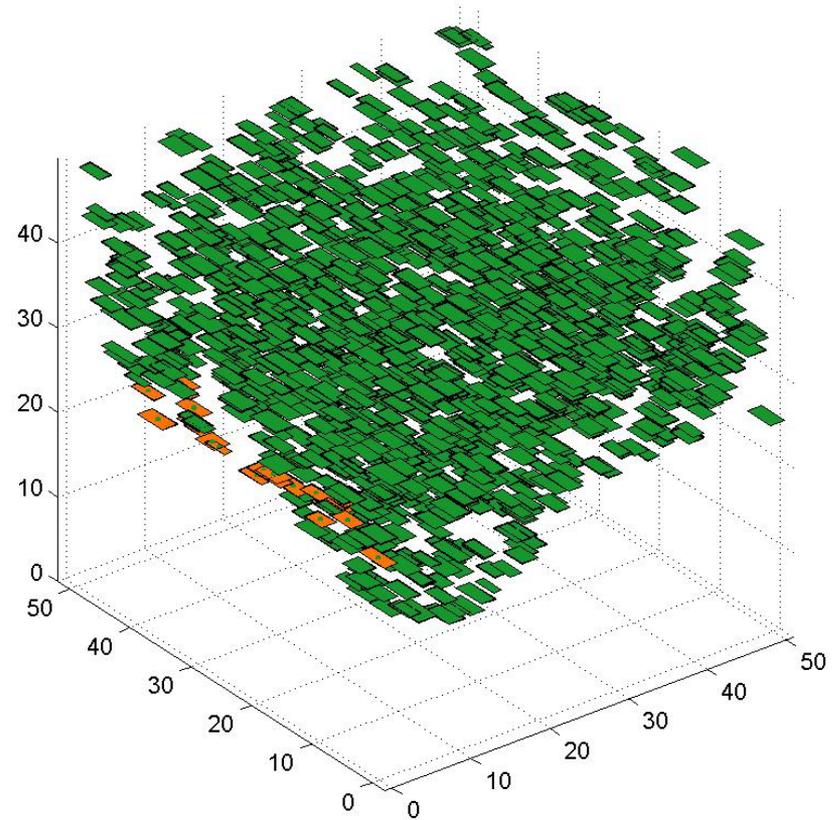


# Objective

- To generate plant geometries that place leaves in locations similar to the placement in chamise and Utah juniper

# Introduction to Bush Model

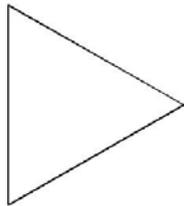
- Used for broadleaf species
- Leaves randomly placed in specified geometry (sphere, parabola, rectangle, etc.)



# Rewriting: from Simple to Complex

## Koch Snowflake

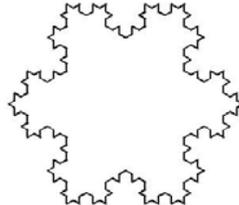
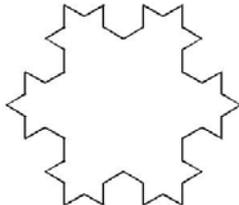
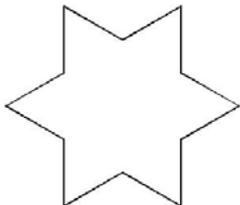
- Replaces each line of the initiator with the generator
- Increasingly complicated
- Self-similar design



Initiator

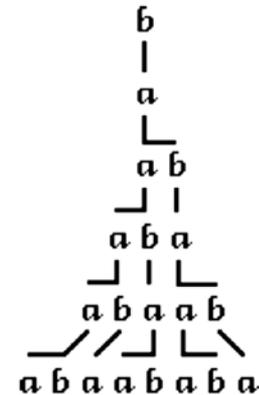


Generator



## DOL-systems

- Simplest class of L-systems
- Rewrites strings instead of shapes according to a specific set of rules
- Each time of rewriting is called a derivation



# Turtle Interpretation: Visually Representing L-systems Strings

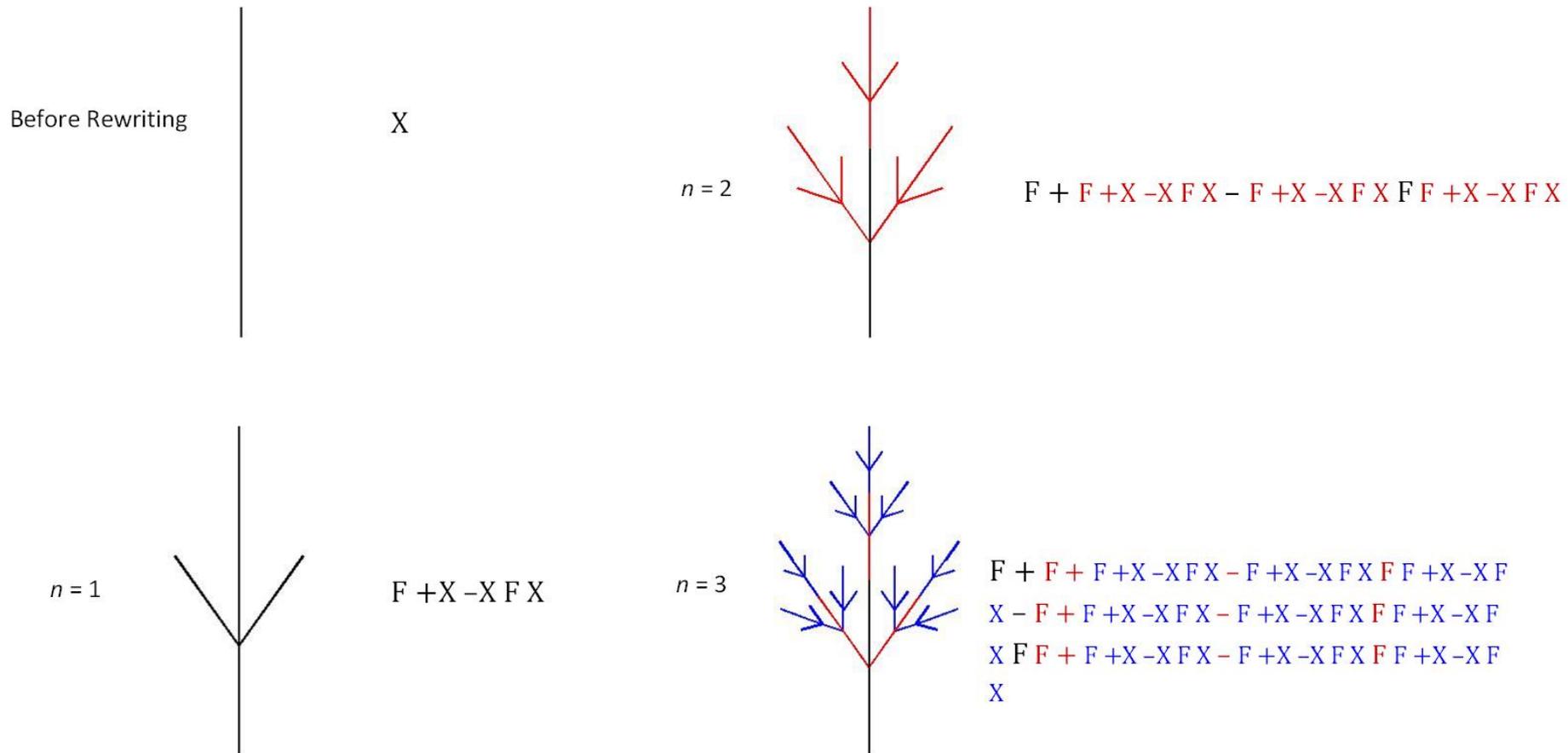
- Creates shape according to string with the following symbols:

F	forward one 'step' of length $d$
+	turn right in x-plane by angle $\delta$
-	turn left in x-plane by angle $\delta$
*	turn right in y-plane by angle $\delta$
!	turn left in y-plane by angle $\delta$
X	initial string to be replaced

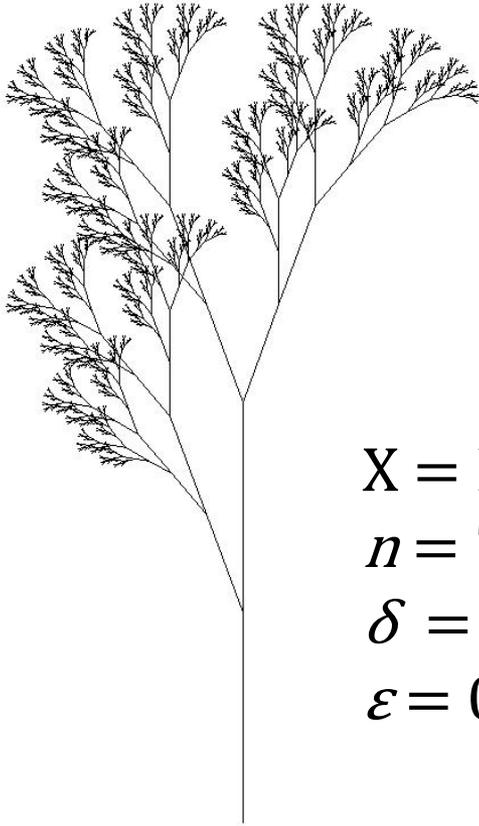
- Each symbol in string consecutively carried out
- X treated as F for last derivation to end rewriting
- Symbols to change angle in y-plane added to original L-systems symbols for three-dimensions

# Example of Turtle Interpretation

Rewriting rule: replace 'X' with 'F +X -X F X'



# L-systems in 2-D



$$X = F +X F +X -X$$

$$n = 7$$

$$\delta = 20^\circ$$

$$\varepsilon = 0.5$$

- Every F in string is one step forward of length,  $d$ , and angle,  $\delta$

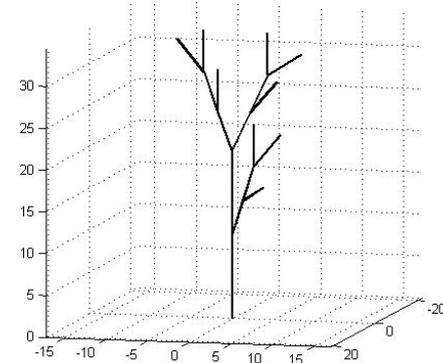
*(polar coordinates)*

- Number of derivations specified by the variable,  $n$
- Length of next derivation determined by a scaling factor,  $\varepsilon$ :

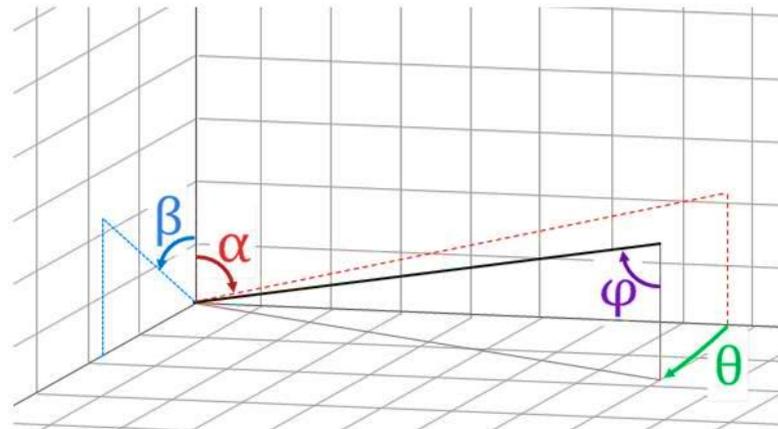
# Applying L-systems to 3-D

- Every F steps forward in spherical coordinates

$$X = F \text{ --!X } F \text{ +!X } *X$$

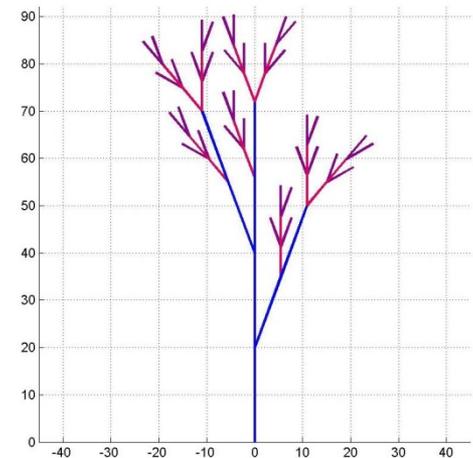
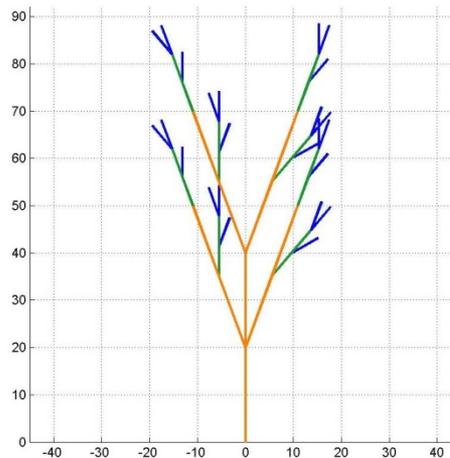
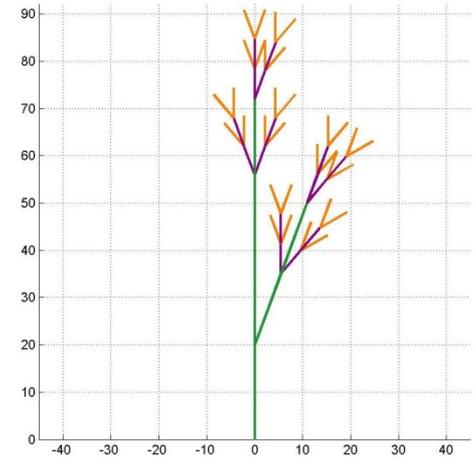
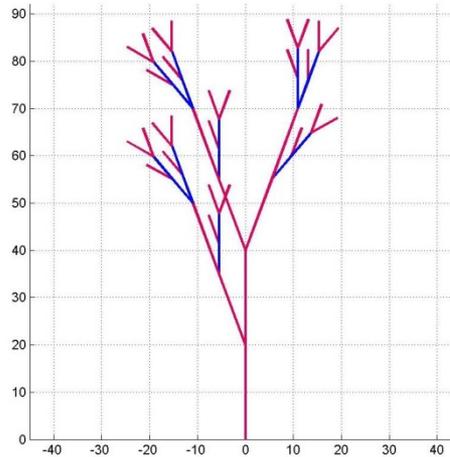
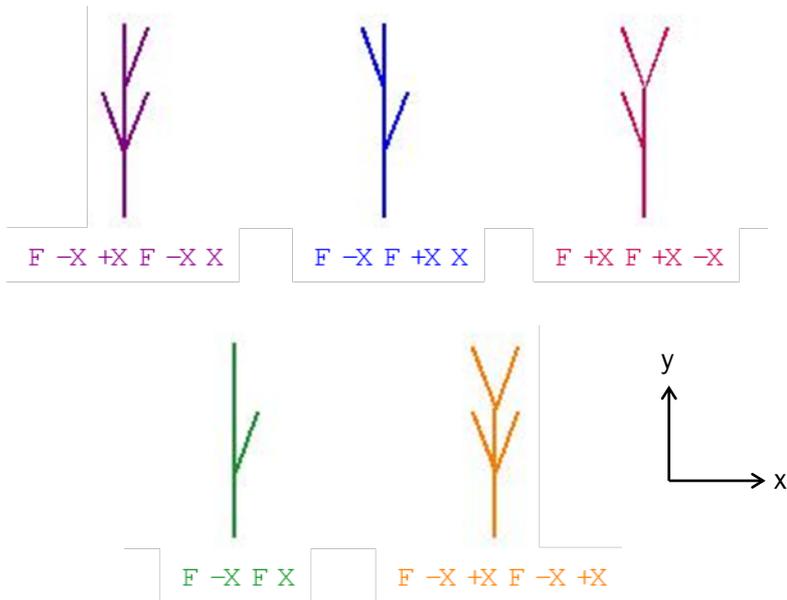


- Each +/- changes  $\alpha$  in x-plane and \*/! changes  $\beta$  in y-plane
- Spherical angles,  $\varphi$  and  $\theta$ , calculated from 2-d angles,  $\alpha$  and  $\beta$ , before each F



# Stochastic L-systems

- Equal probability of choosing one of five strings
- Each derivation uses a randomly chosen string



# Strings for Chamise and Juniper

- Studied smallest branch segment



Chamise



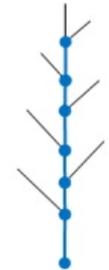
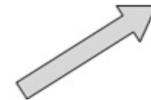
Juniper



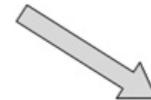
Fuel Sample



Simplified Shape



6 'F's



7 'X's

- Used measured average and standard deviation to decide number of 'F's and 'X's in strings

# Strings for Each Species

## Chamise

X1 = F -!X F +!X \*X F +!X

X2 = F +\*X F +!X F +\*X F +!X

X3 = F +!X -\*X F +!X \*X F -X

X4 = F +\*X F -\*X +\*X +!X !X

X5 = F -\*X F \*X +\*X F -\*X

## Utah juniper

X1 = F +\*X F +X -X !X

X2 = F -\*X F +\*X F -X !X

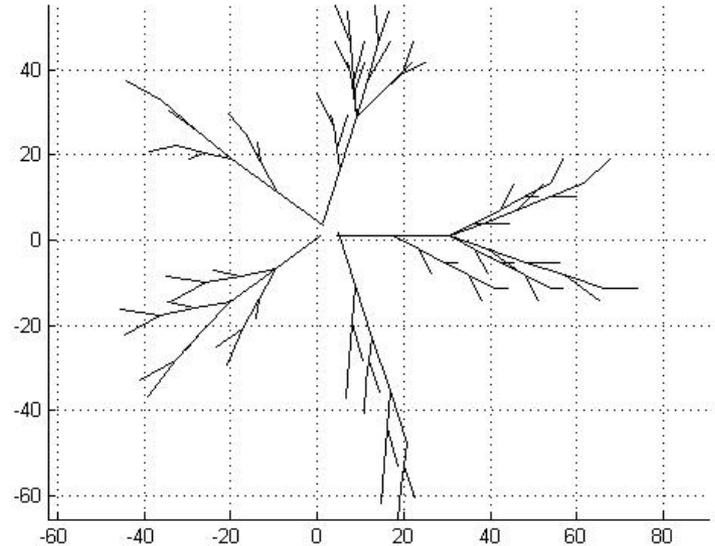
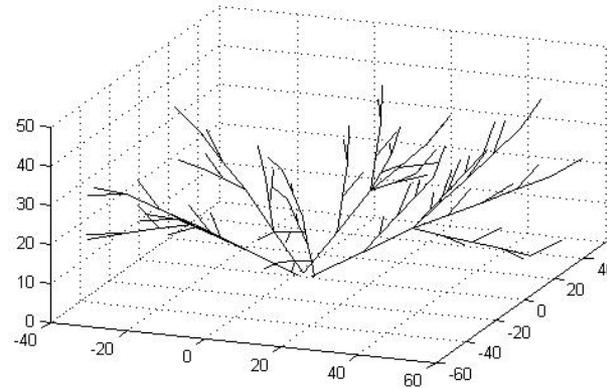
X3 = F +!X F -!X F +X F +\*X -\*X !X

X4 = F -!X F +\*X -\*X F -X F +X F \*+X !X

X5 = F +\*X F -\*X F +X F +!X F -X F +\*X -\*X X

# Modeling a Chamise Shrub using L-systems

- Equally divides 3-dimensional space between the number of branches
- Can specify an average distance from the origin so all branches do not come out of one central point

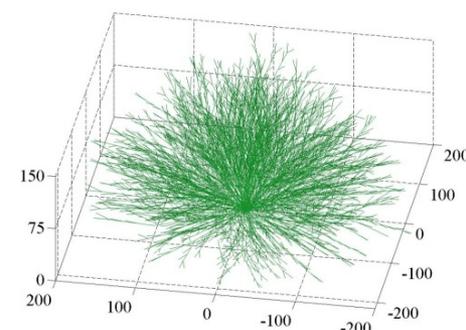
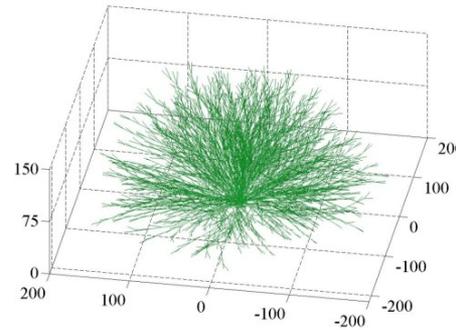
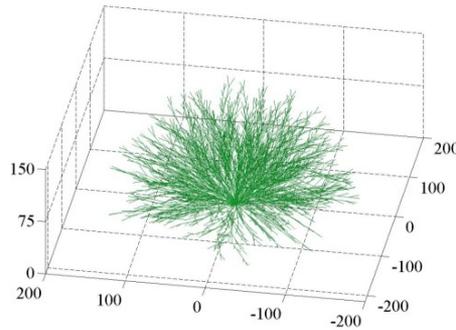
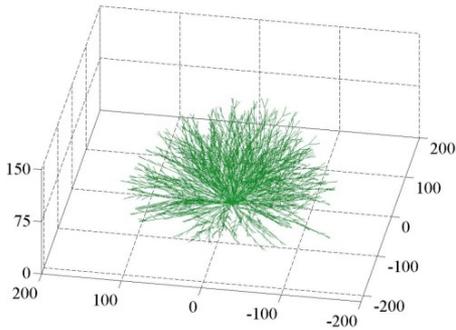
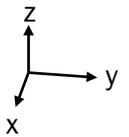


# Chamise Measurements

Variable Name	Description	*based on measurements made in lab
	Average primary branch angle (with 0° being vertical)	
	Angle between secondary and primary branches	*
	Length of secondary / length of primary	*
	Average distance of primary branches from the center of the shrub	

# Number of Branches for Chamise

- Number of branches determined by crown diameter
- Fuel split into four fuel classes



Crown Diameter      300 cm

350 cm

400 cm

450 cm

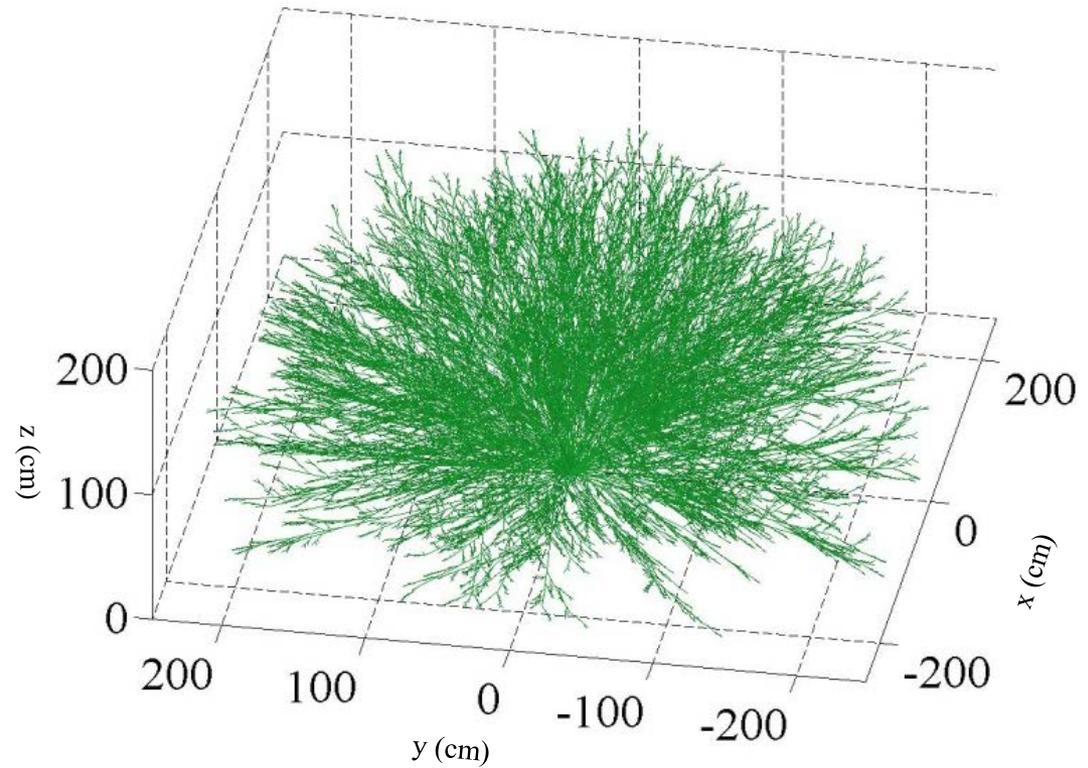
# Branches            98

117

139

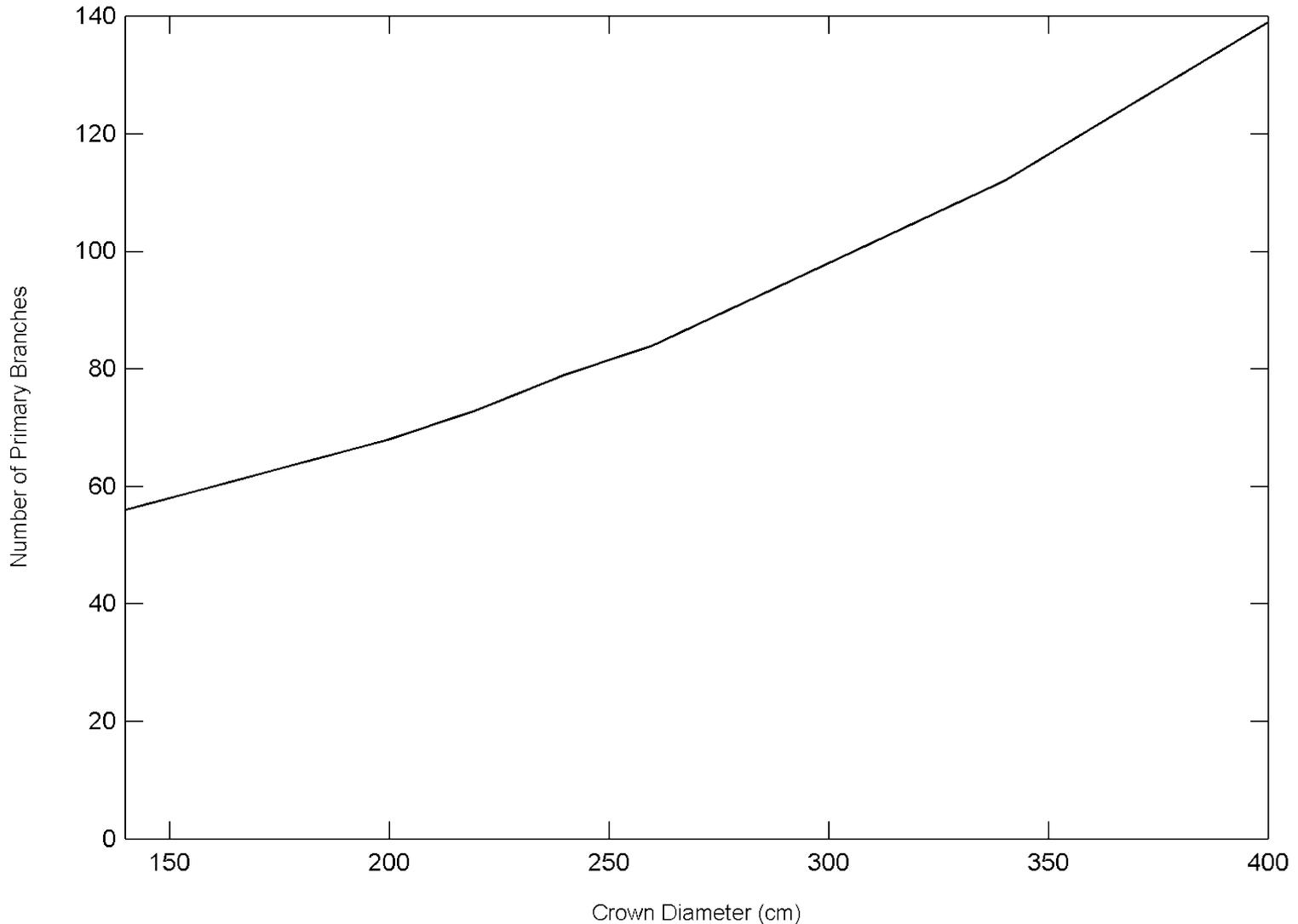
166

# Comparison of Chamise Geometry



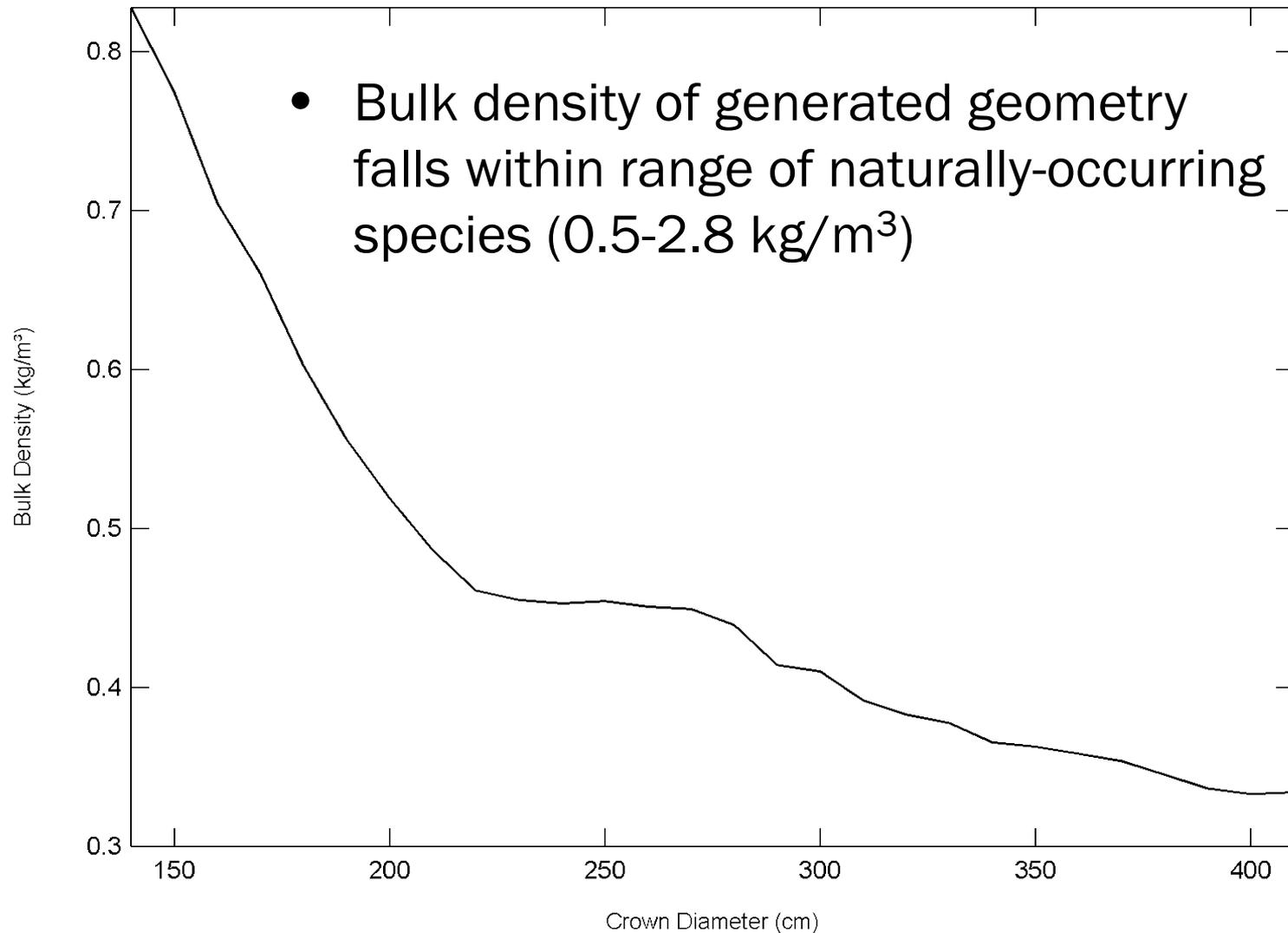
# Chamise

## Number of Branches

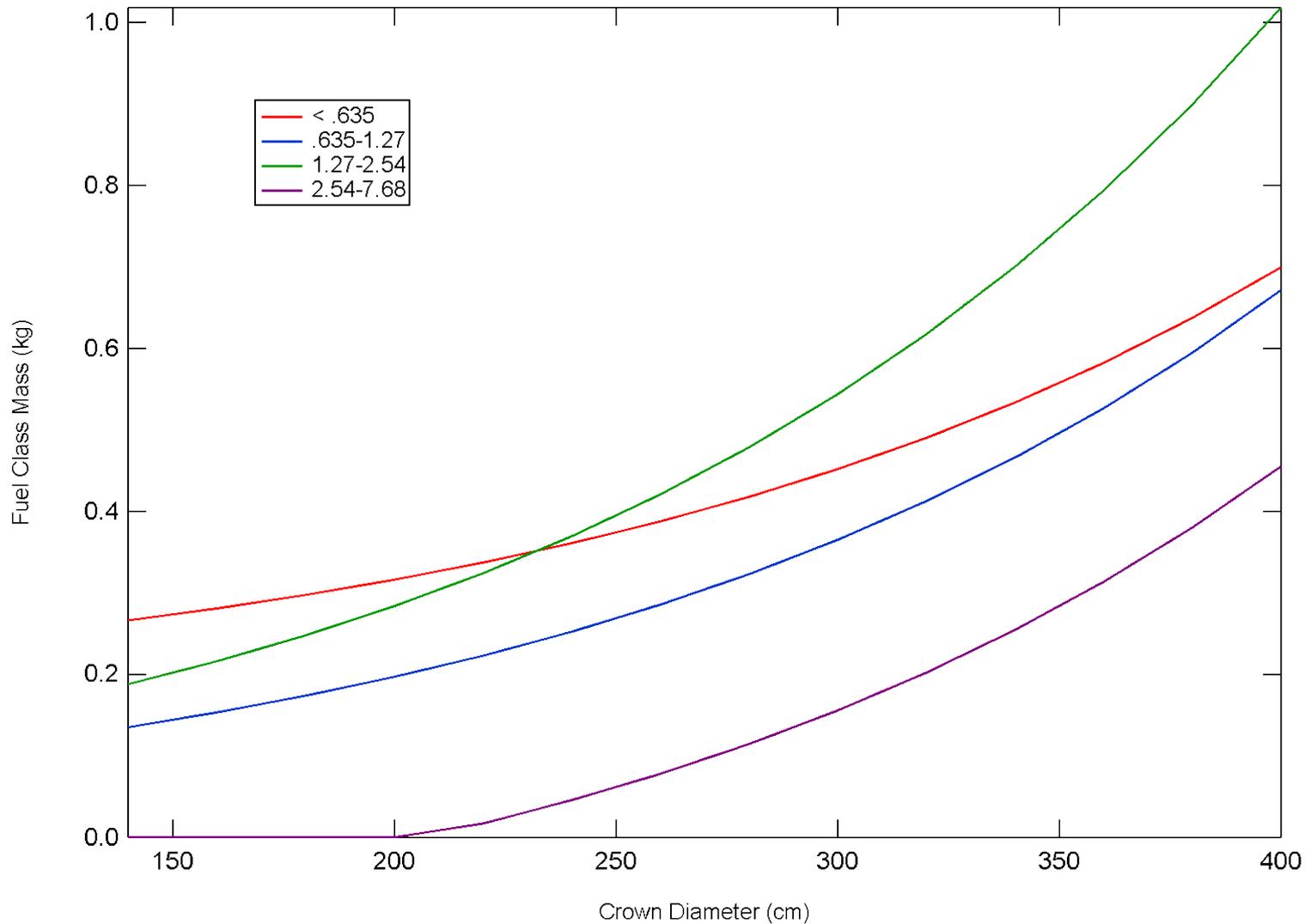


# Chamise

## Bulk Density

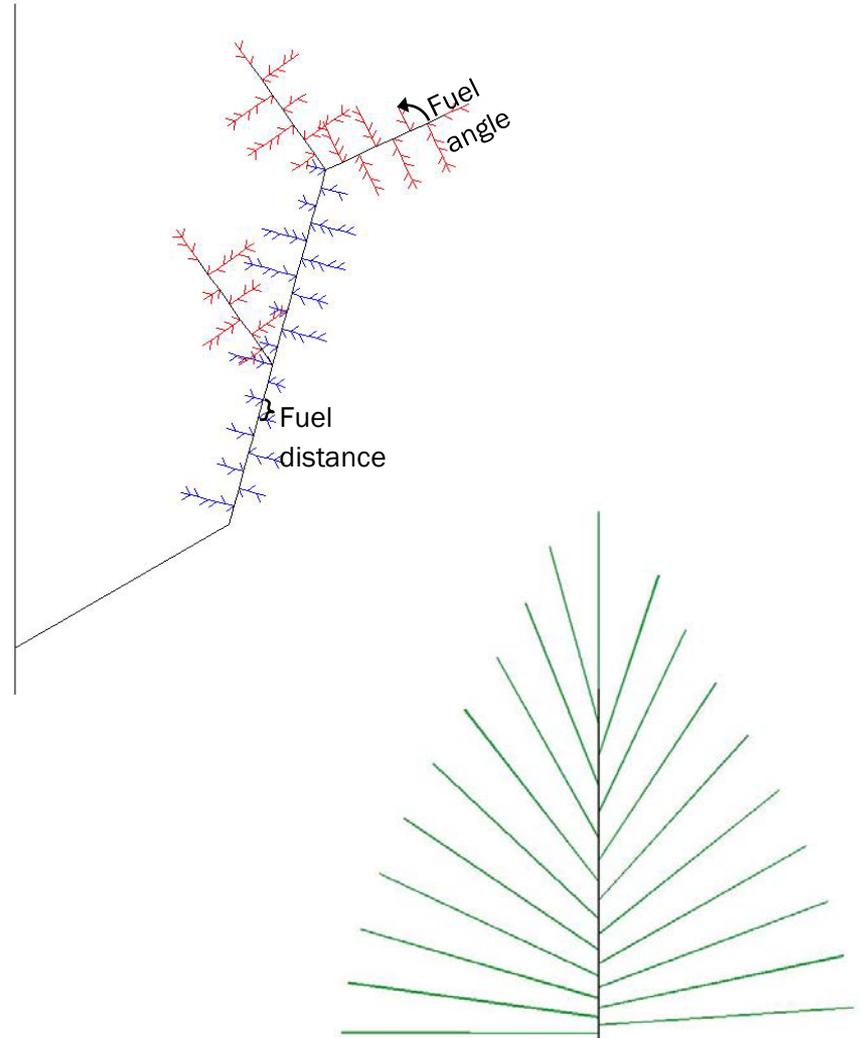
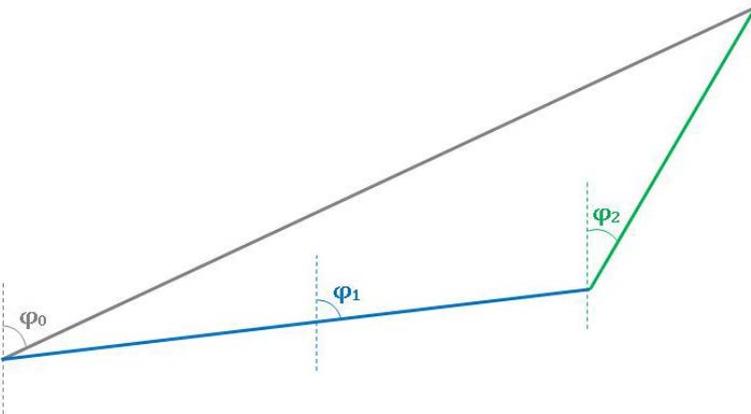


# Chamise Fuel Classes



# Modeling a Utah Juniper Shrub using L-systems

- Primary branches distributed along bush height
- Secondary branches determined by L-systems string
- Fuel spaced along secondary branches by certain distance
- Primary branches bent (“curved”)

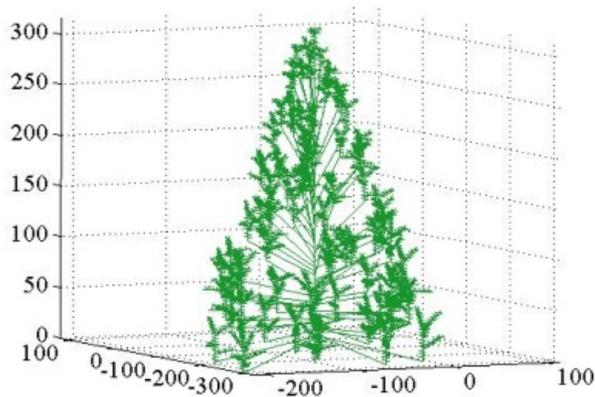


# Utah Juniper Measurements

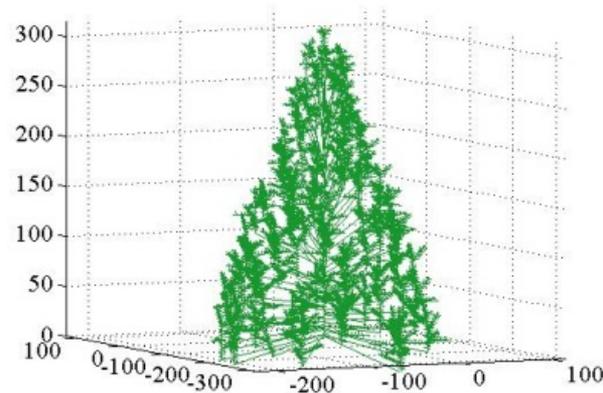
Variable Name	Description
	Maximum primary branch angle
	Secondary branch angle
	Length of secondary / length of primary
	Length of highest primary branch / length of lowest primary branch
	Angle of highest primary branch / angle of lowest primary branch
	Distance between highest two primary branches / distance between lowest primary branches
	Distance between fuel elements
	Angle between fuel and primary/secondary branch

# Number of Branches for Juniper

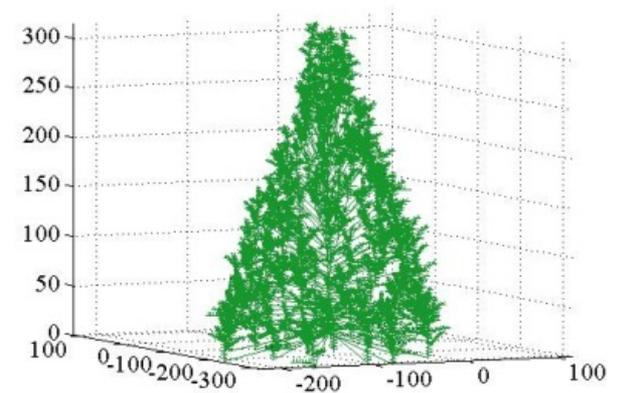
- Data from Mason, L.R., Hutchings, S.S., 1967
- Three fuel denseness classes – sparse, medium, or dense
- Number of branches determined by crown density



Sparse  
76 branches



Medium  
106 branches

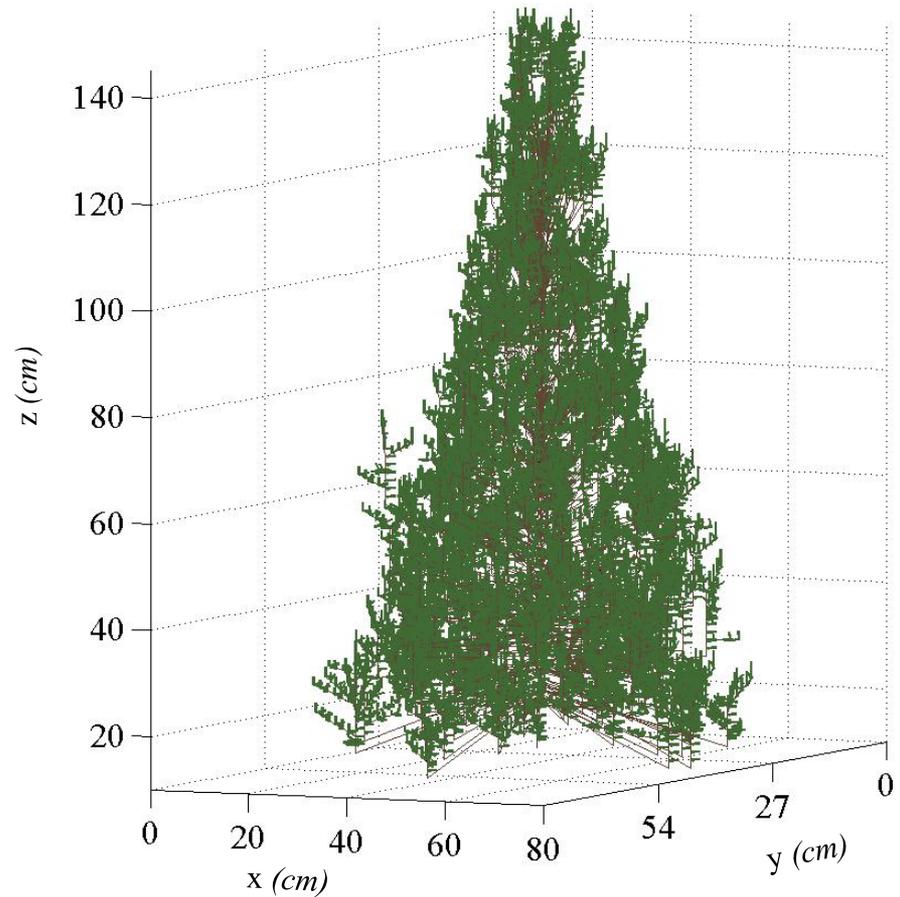


Dense  
152 branches

# Number of Branches for Juniper

- Additional correlation made using data collected
- Predicts the number of branches to give the correct fuel weight for the specified crown diameter
  
- Measured bulk density higher than data from literature

# Comparison of Utah Juniper Geometry



# Comparison of Utah Juniper Geometry

## Shrub Measurements

Height: 140 cm

Crown Diameter: 84 cm

Dry Mass: 663.9 g

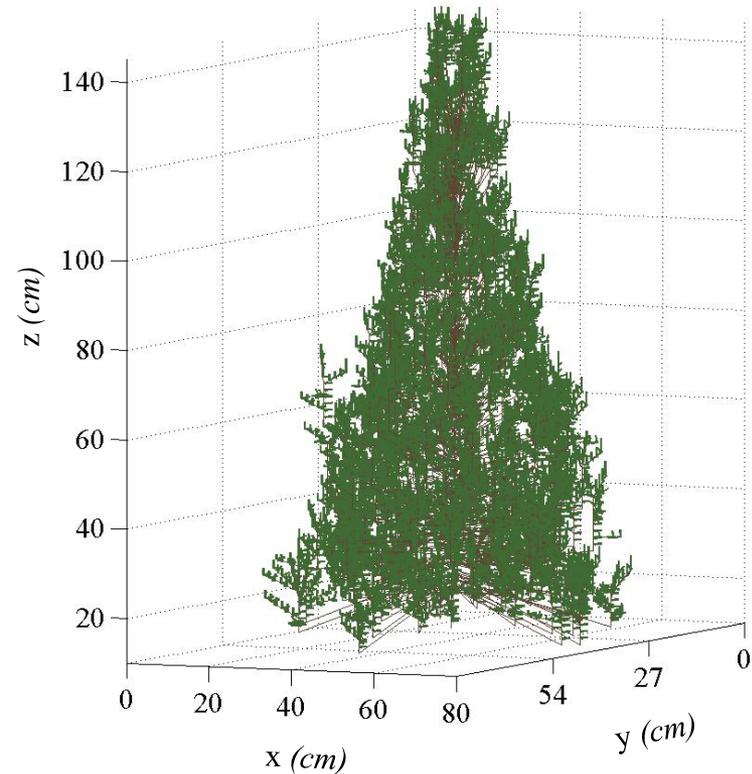


## Model Measurements

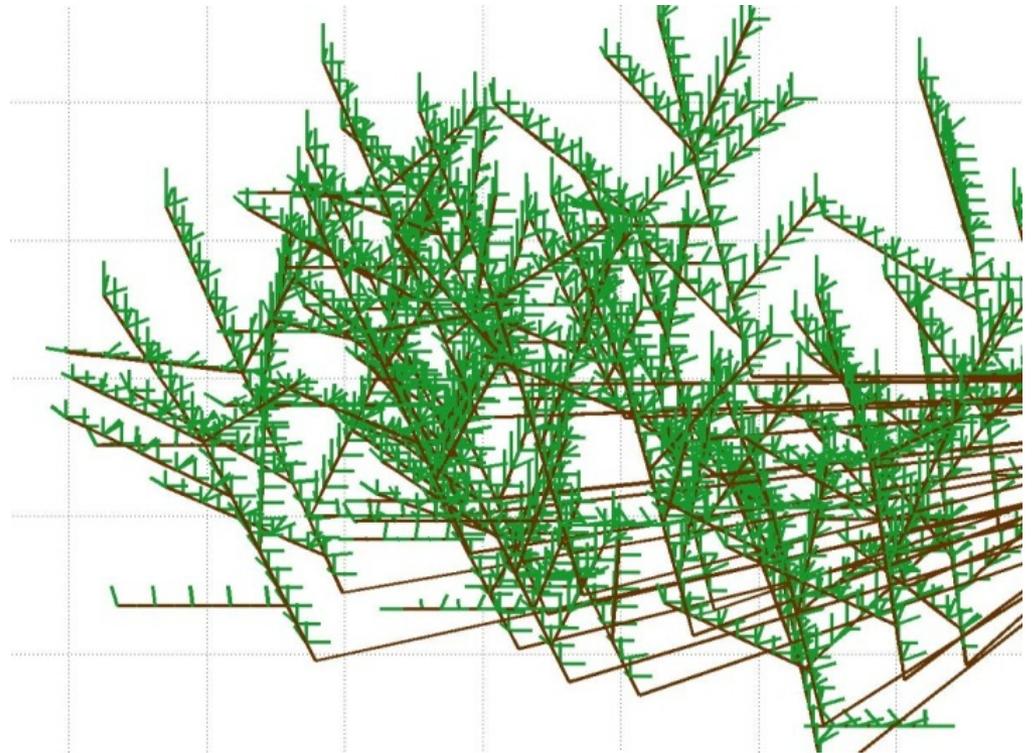
Height: 140 cm

Crown Diameter: 78 cm

Dry Mass: 855.6 g

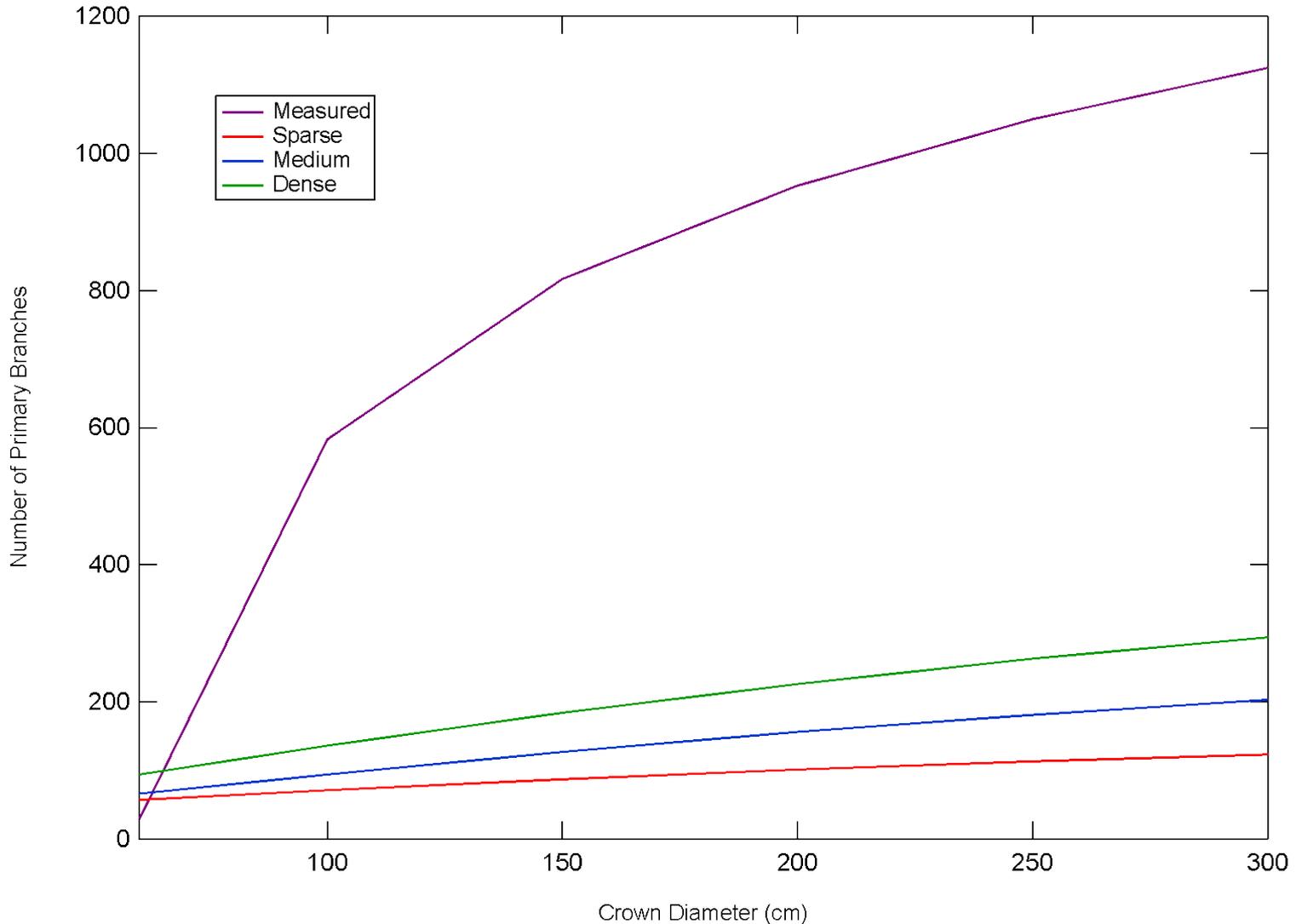


# Close-up Comparison

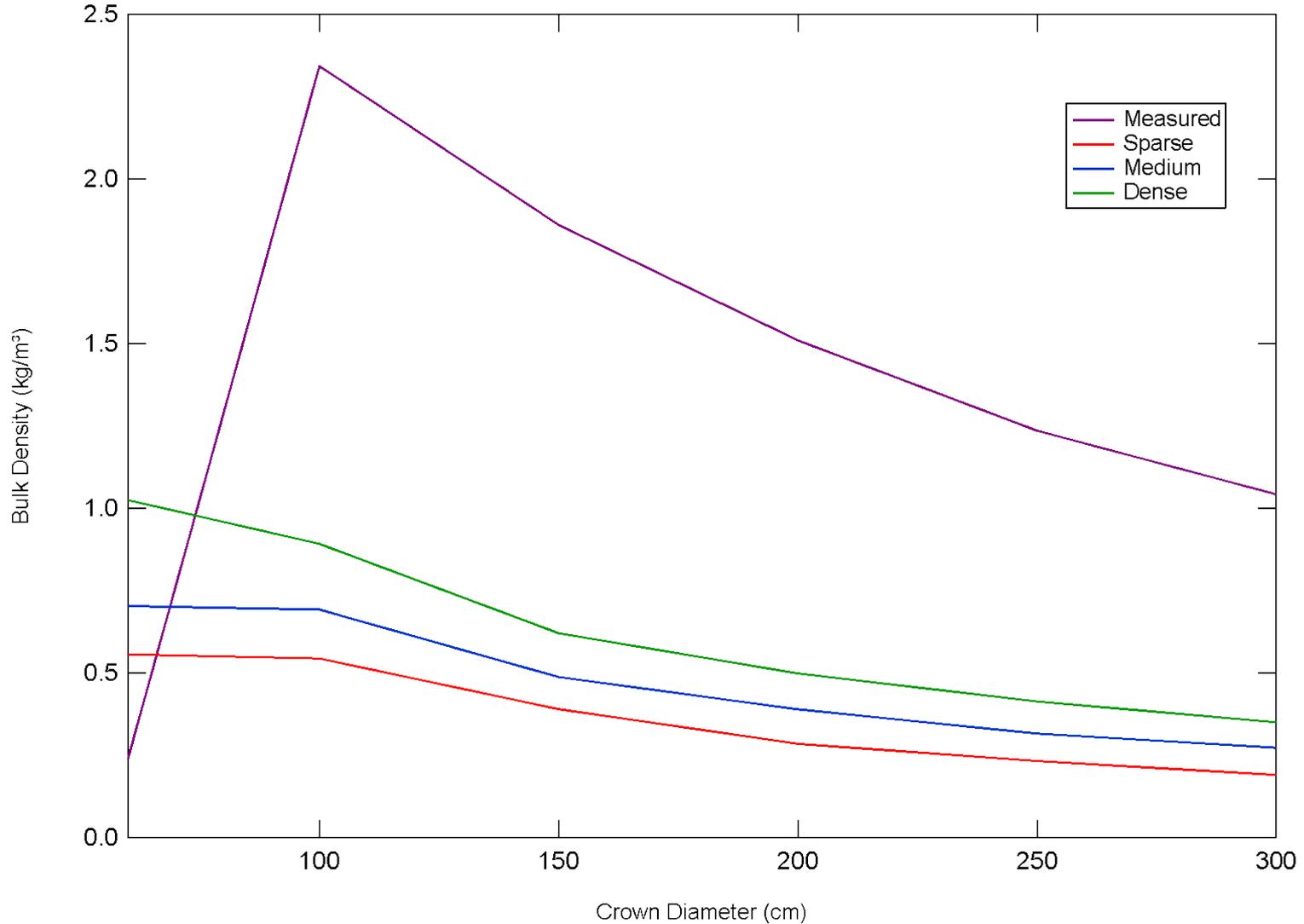


# Utah Juniper

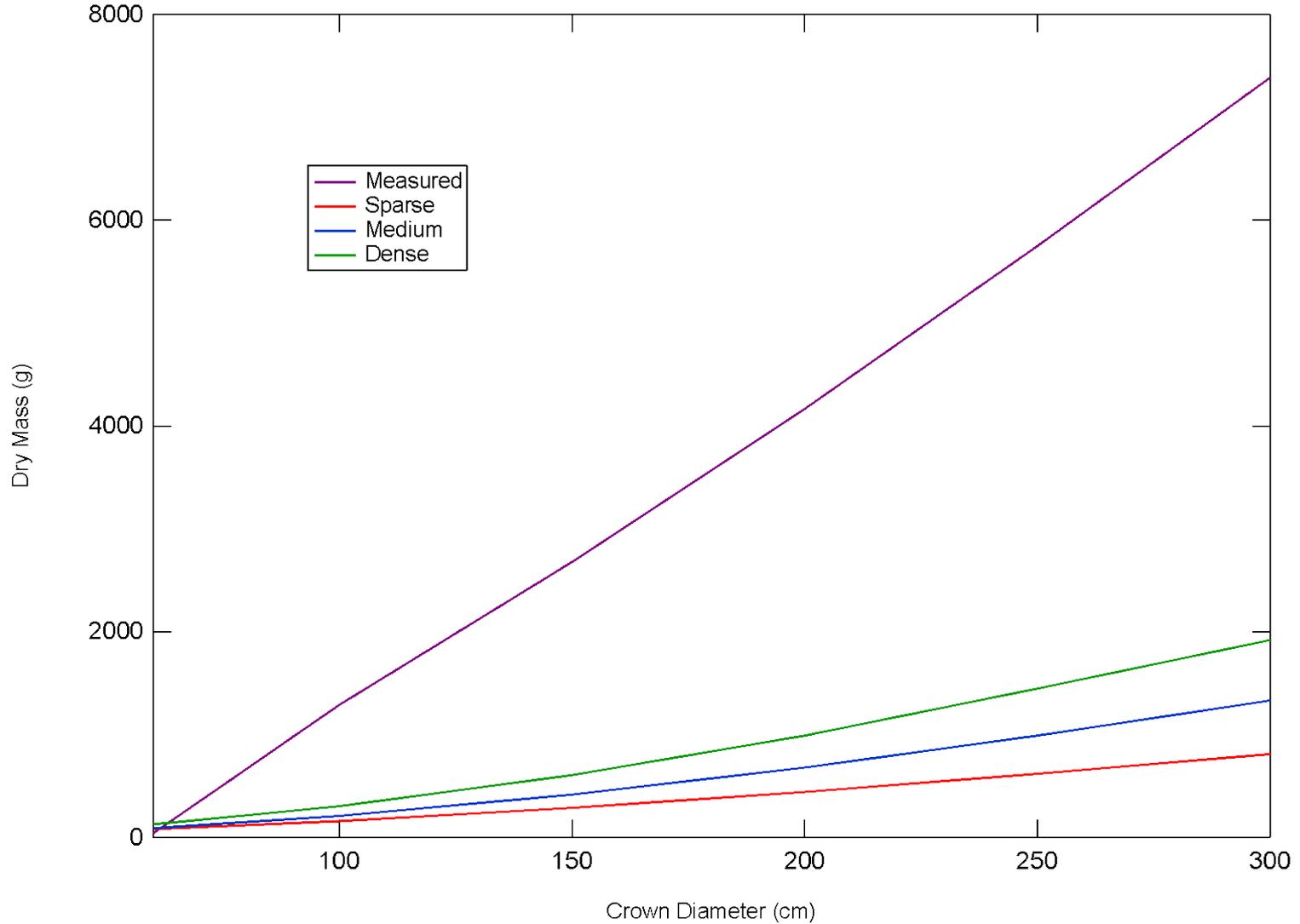
## Number of Branches



# Utah Juniper Bulk Density



# Utah Juniper Dry Mass



# Conclusions

- L-Systems used to portray shrub geometry based on fuel elements
- Chamise geometry has bulk density within range
- Juniper geometry has dry mass within range of naturally-occurring species

# Shrub Combustion Model for Broadleaf Species

- Leaves randomly placed in specified shape (e.g. box, sphere, hollow box or sphere, parabolic)

