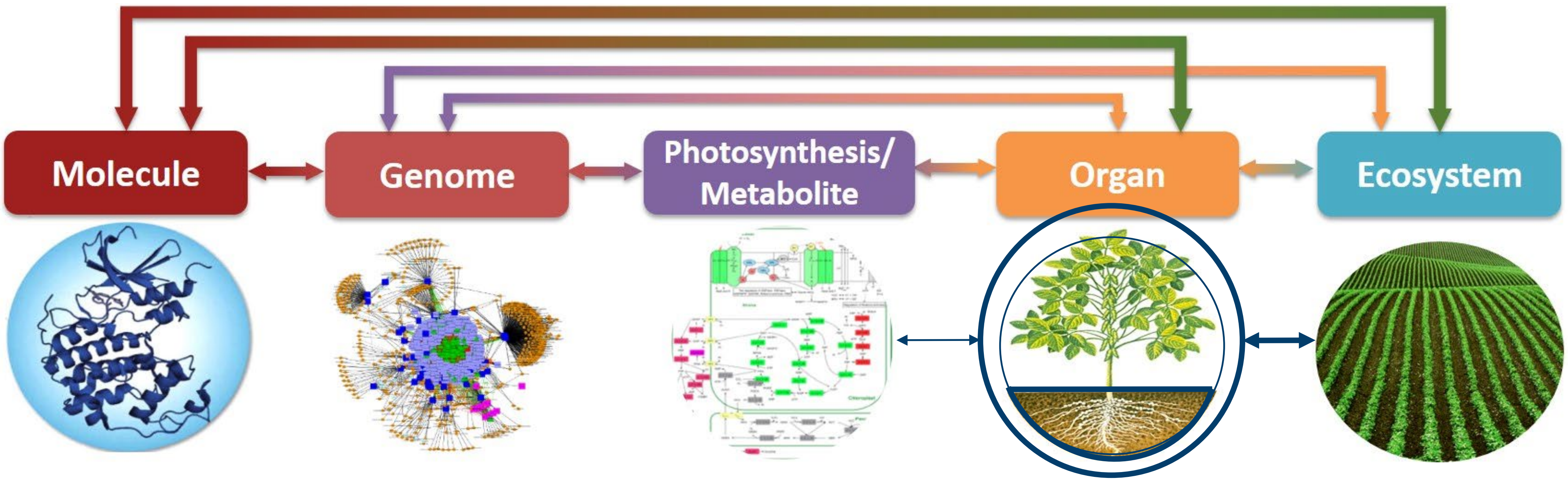
FUNCTIONAL-STRUCTURAL PLANT MODELING WITH CPLANTBOX

Local Processes and Emerging Patterns

JUNE 8th, 2021 I ANDREA SCHNEPF

INTRODUCTION

Subline



source: https://cropsinsilico.org, accessed 20.05.2021

CPLANTBOX - THE CODE

Dataset collection

for whole plant or root systems

core C++ code

https://plant-root-soil-interactions-modelling.github.io/CPlantBox

Python shared library

easier scripting
easier coupling with other models

Web applications

Shinyapp: only for root systems, basic model functions
export as VTK, RSML, CSV
https://bit/ly/crootbox

Binder: http://b.cplantbox.com

Examples

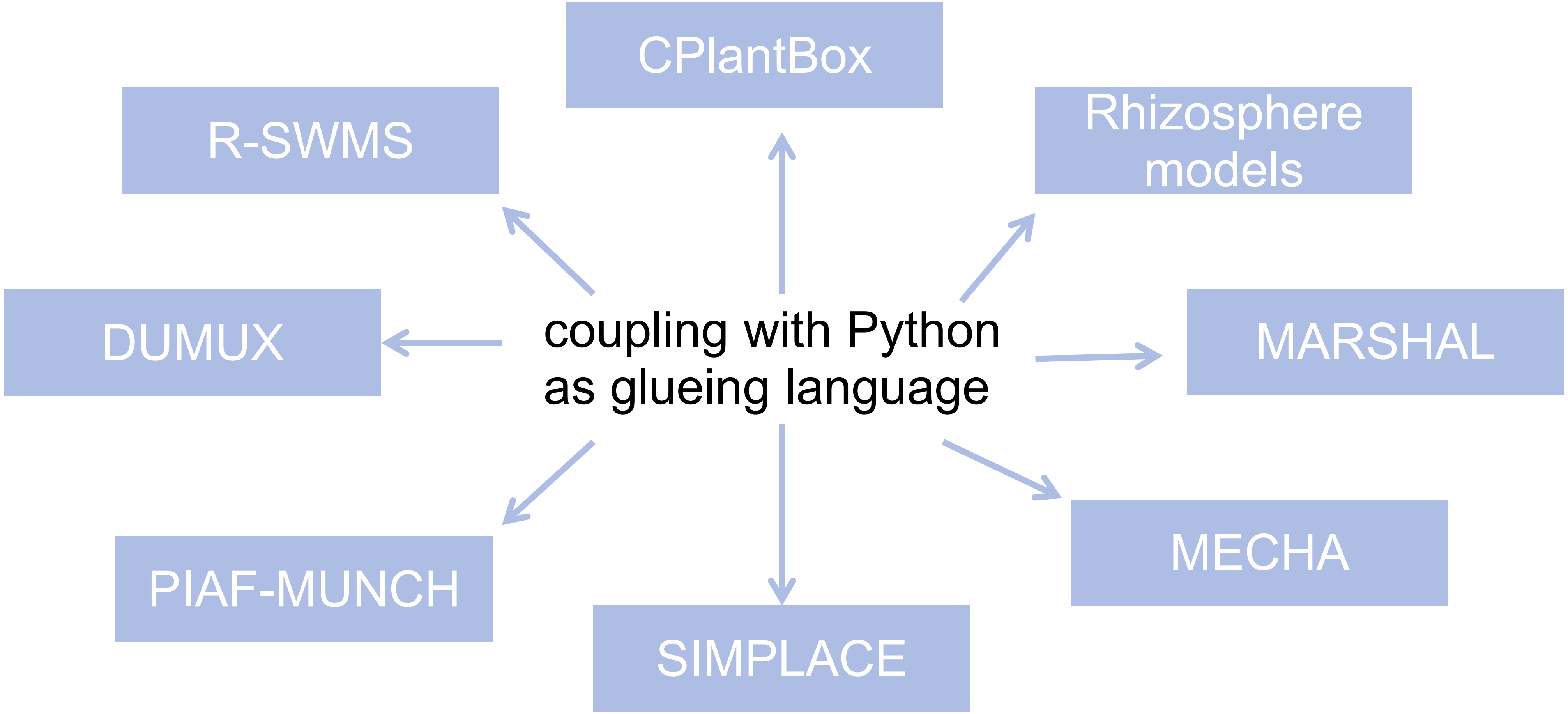
Plant/root architectures
Growth in containers
Multiple plants/root systems
Field scale growth
Tropisms
Carbon limitation of growth
Flow and transport in soil-root system

Coupled to

DuMu^x
Simplace
PiafMunch

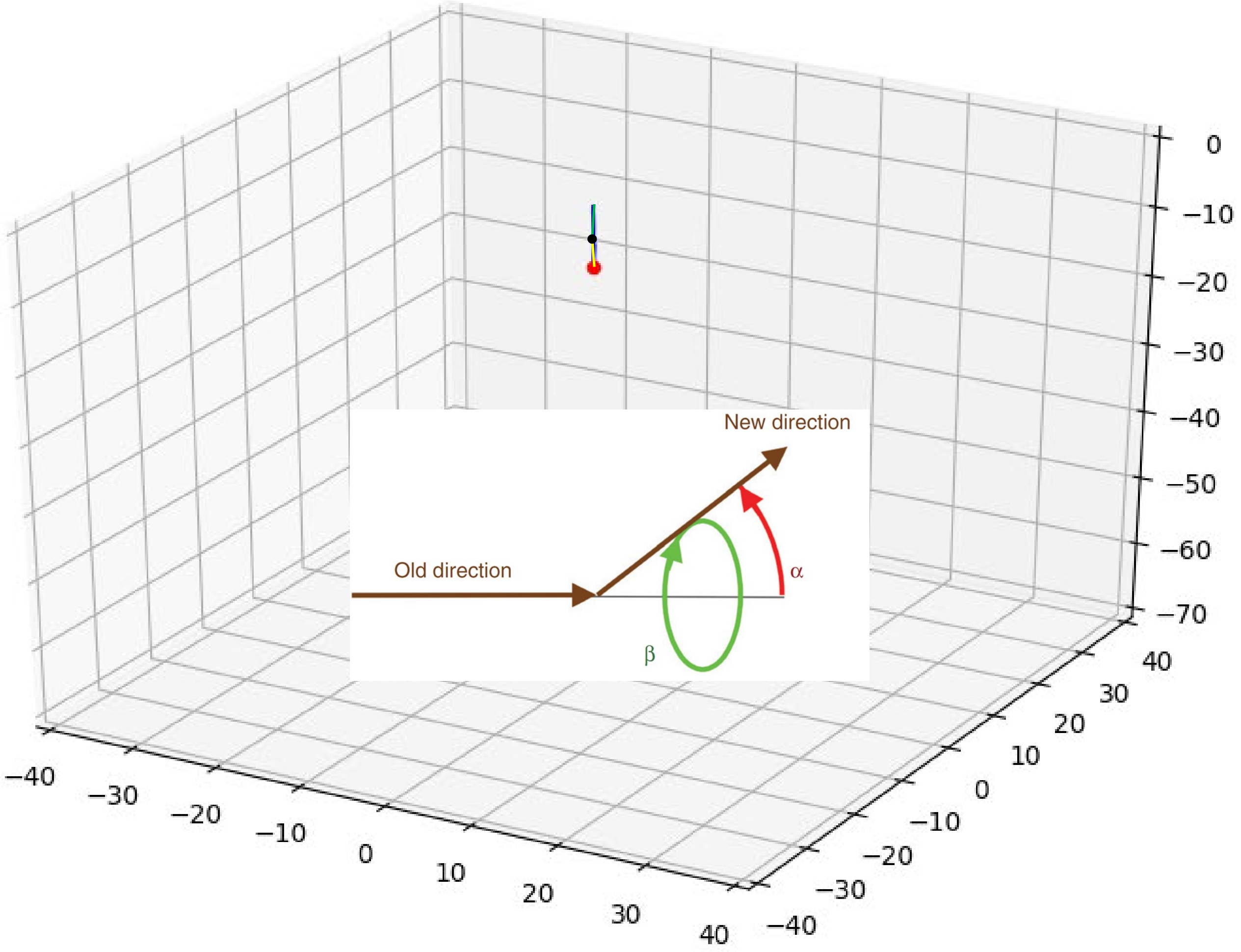
Zhou et al. 2020, in silico Plants

MODULARITY OFFERS FLEXIBILITY



CPLANTBOX

Growth rules for root architectures



Elongation

$$l_{\text{lin}}(t) = \min(l_{max}, r.t), \text{or } l_{\exp}(t) = l_{max}\left(1 - e^{-\frac{r}{l_{max}}t}\right)$$

Discretisation

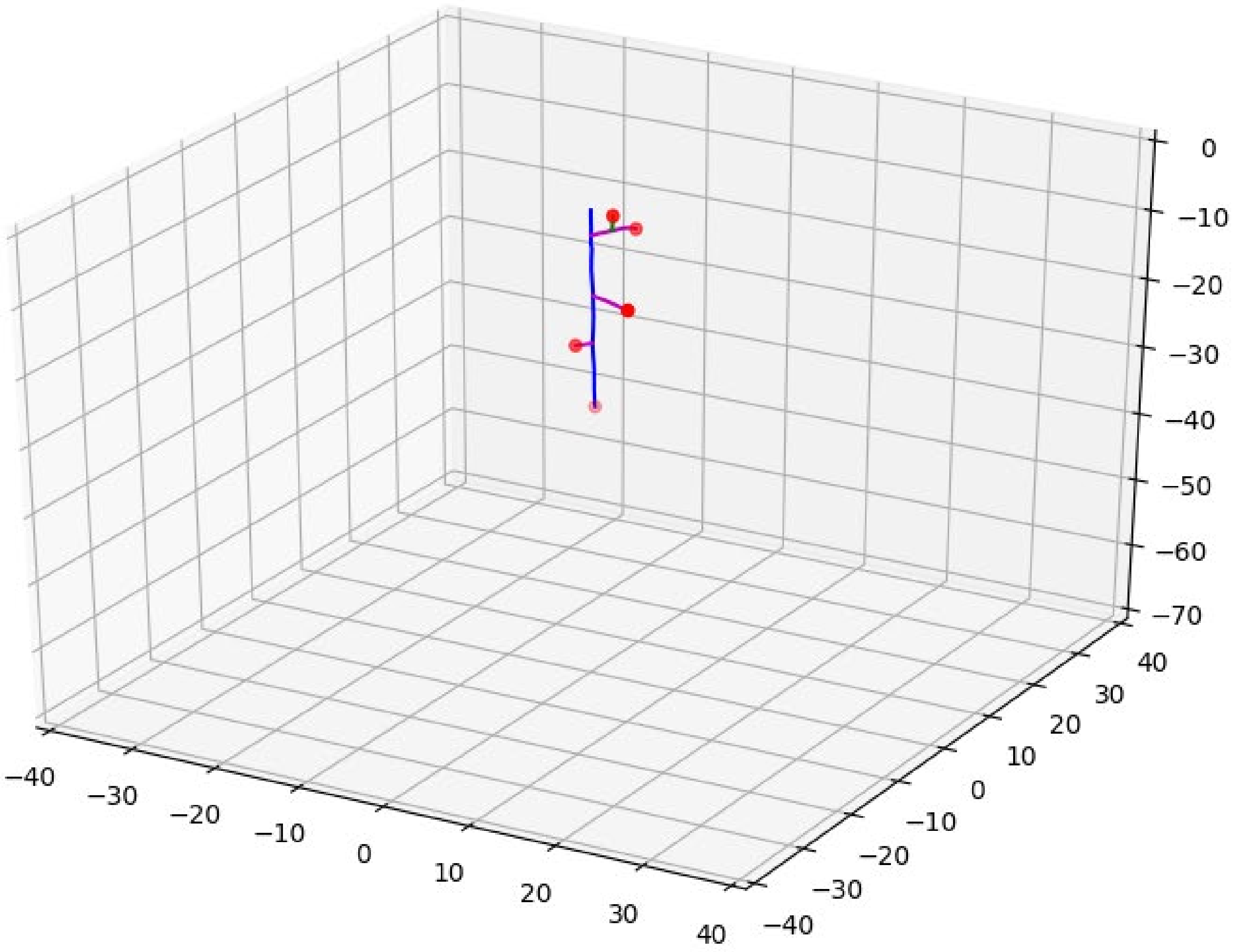
$$l = n \cdot dx$$

Growth direction

$$\sigma_{dx} = \sqrt{dx} \cdot \sigma$$

random or according to tropism

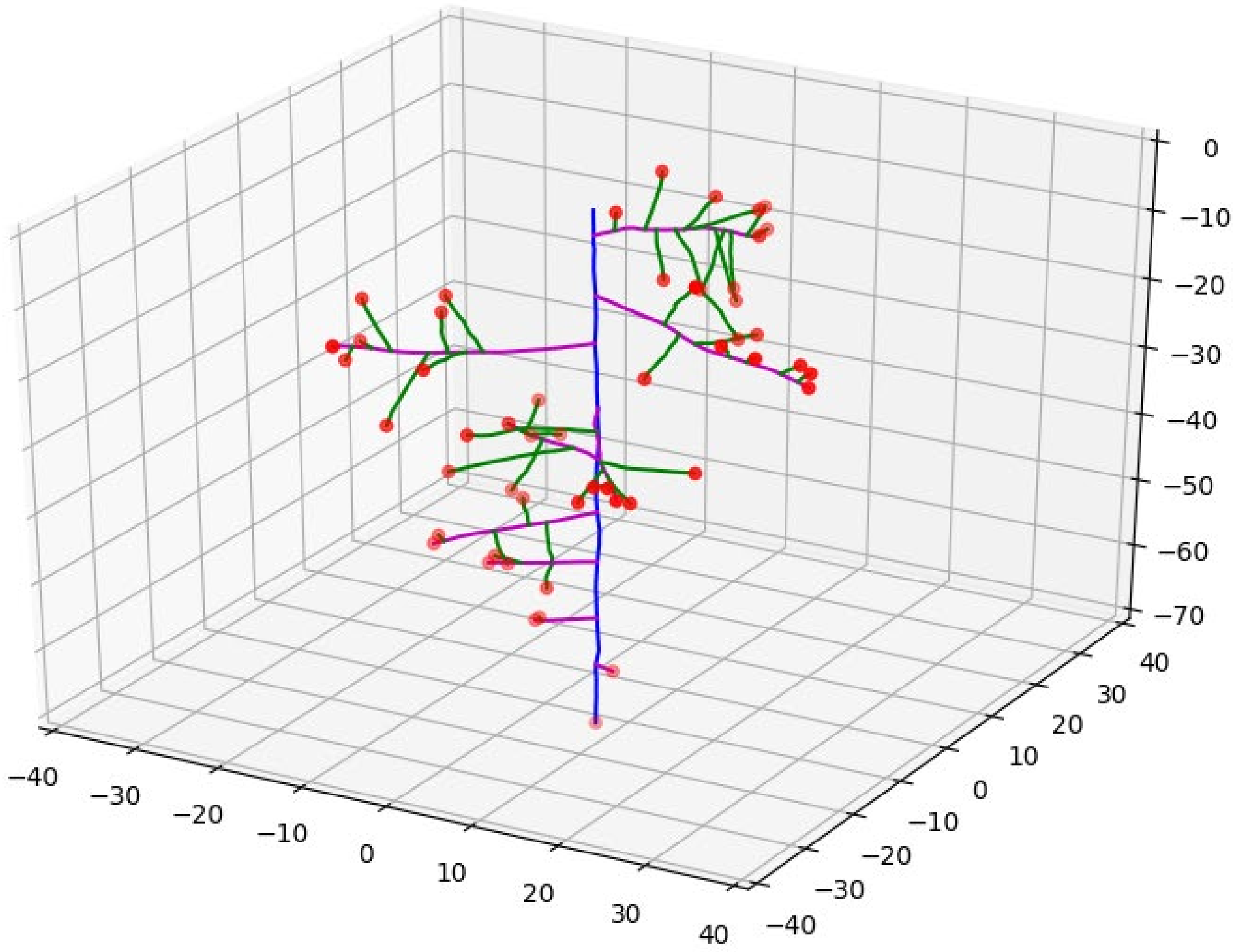
BRANCHING



Creation of new tips
Nonbranching basal zone
Interbranch distance

Emergence of root growth
After delay time

CPLANTBOX



Each root has a different age → different physiological properties

Each growing root tip experiences different local soil conditions → different elongation rates, branching angles, branching densities

Reacts to soil compaction, temperature, water or nutrient gradients

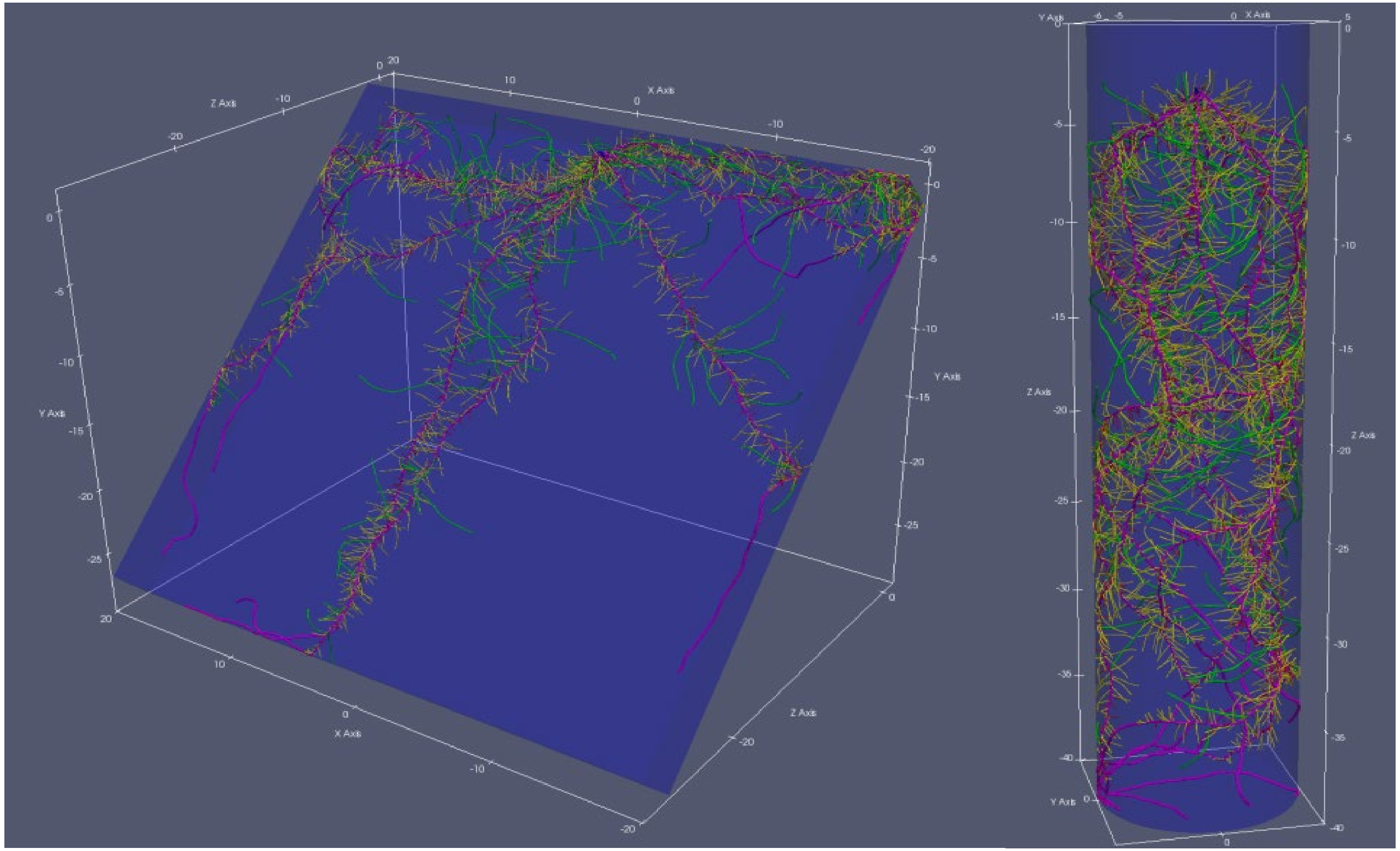
CPLANBOX MODEL PARAMETERS

Stochasticity

Parameter for each root type				Distribution (Landl et al. 2018, Plant Soil)
Root radius	a	cm	M,SD	
Initial elongation rate	r	$cm\ d^{-1}$	M,SD	
Insertion angle	θ	rad	M,SD	normal or uniform, < 90°
Length of basal zone	l_b	cm	M,SD	
Length of apical zone OR delay time	l_a OR d	cm OR d	M,SD	
Length between lateral branches	l_n	cm	M,SD	lognormal
Maximal root length	l_{max}	cm	M,SD	
Tropism type type	{0,1,2,3}	-		
Number of trials (tropism strength)	N	-		
Standard deviation of random angular change	σ	cm^{-1}		
Root successor types successor	[type, probability; …]	-		
Resolution along root axis	dx	cm		
Root life time	rlt	day	M,SD	
Type of root elongation	gf	Function		
Scale elongation	se	Function		
Scale branching probability	sbp	Function		
Scale branching angle	sa	Function		

ROOT SYSTEMS GROWING IN CONFINED GEOMETRY

Using signed-distance functions (d)



Example for a soil column with radius r

For any new position of the growing root tip (x,y,z),

$$d = \sqrt{x^2 + y^2} - r$$

d < 1: inside the column
d > 1: outside the column
d = 0: boundary point

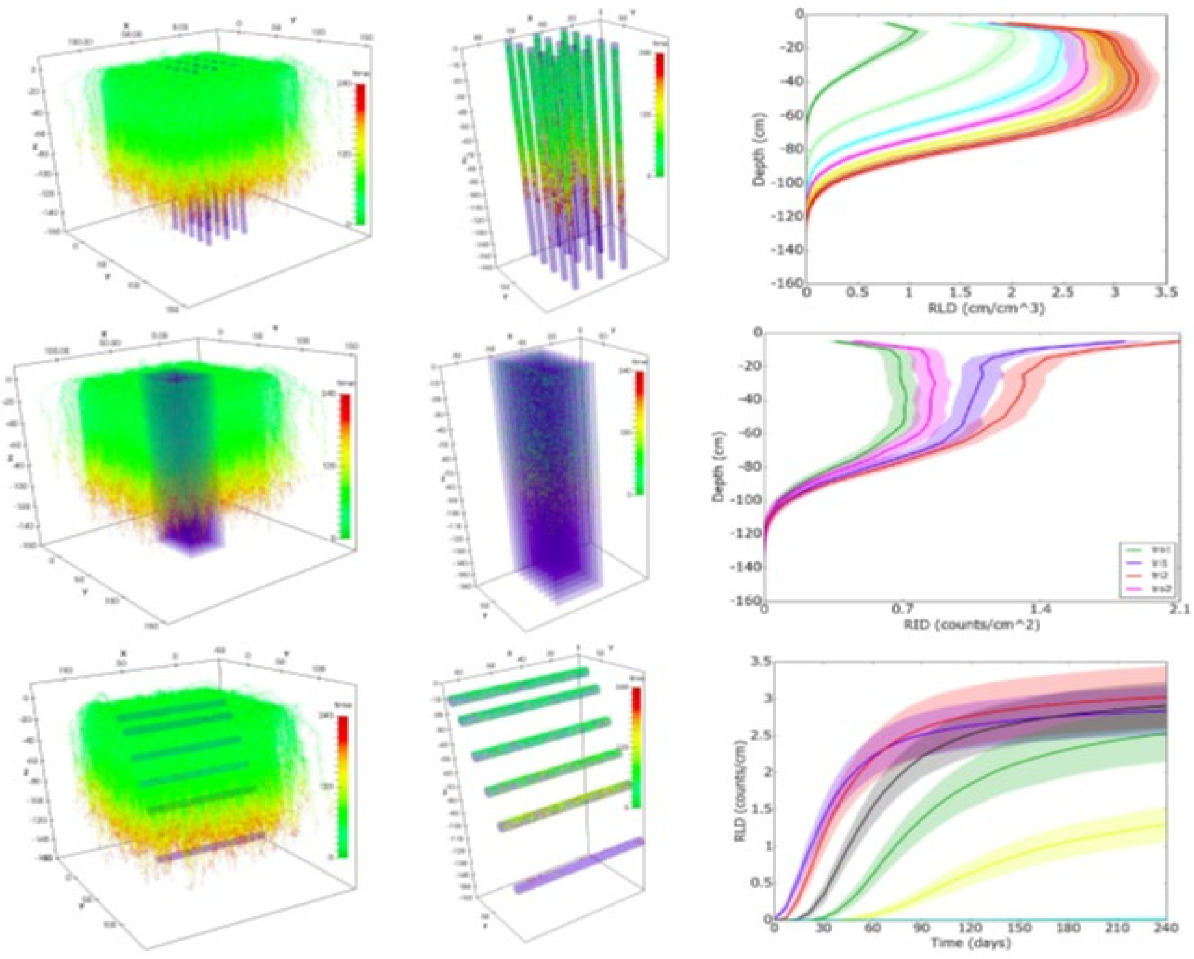
If d > 1 → a new position is computed by drawing a new value for σ.

→ thigmotropism

GROWTH OF MULTIPLE ROOT SYSTEMS

RSA PARAMETER ESTIMATION FROM FIELD DATA

Local growth processes with emerging pattern



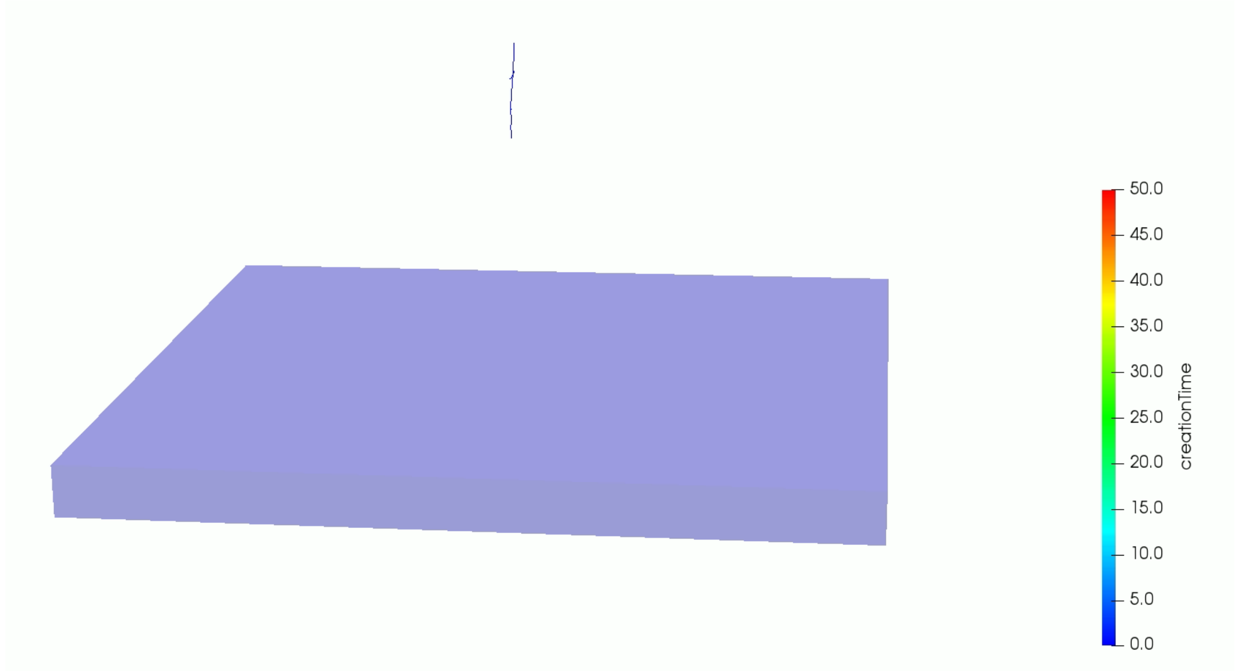
Root length density depth profies from virtual soil cores

Root counts from virtual trenches

Root arrival curves from virtual rhizotubes

ROOT GROWTH AFFECTED BY LOCAL SOIL CONDITIONS

Gravi-, Plagio-, Exo-, Chemo-, Hydrotropism determine the preferred growth direction



Example Chemotropism

Layer with increased nutrient concentration, static, described using signed distance function

Preferred growth direction is determined by concentration gradients

Tropism strenght N

ROOT GROWTH AFFECTED BY LOCAL SOIL CONDITIONS

Scaling of elongation rate, branching angle or branching density

Reduced elongation rate in hard layer

Layer with increased penetration resistance, static, described using a soil grid

Elongation rate of root tips that are within the hard layer is reduced

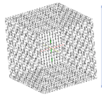
Empirical function or mechanistic model (signalling)

SOIL AFFECTED BY ROOT ACTIVITIES

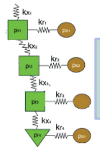
Dynamic soil and dynamic root – example: water flow in the soil-root system

Individual modules

Root architecture development



Water flow in soil



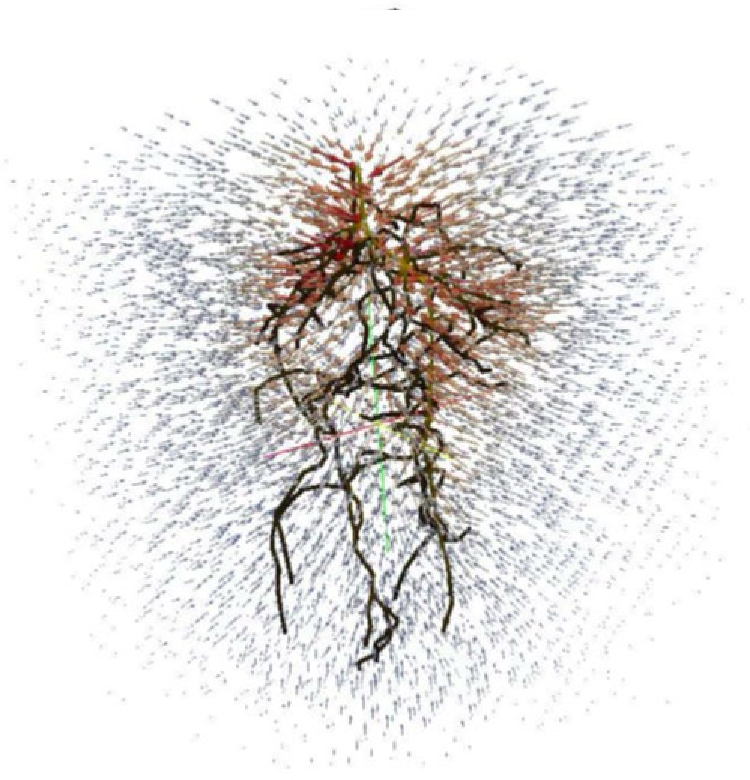
Water flow in roots

Coupled models

Water flow in soil-root system with a dynamic root architecture

Water flow in soil-root system with a static root architecture

monolytic versus sequential coupling



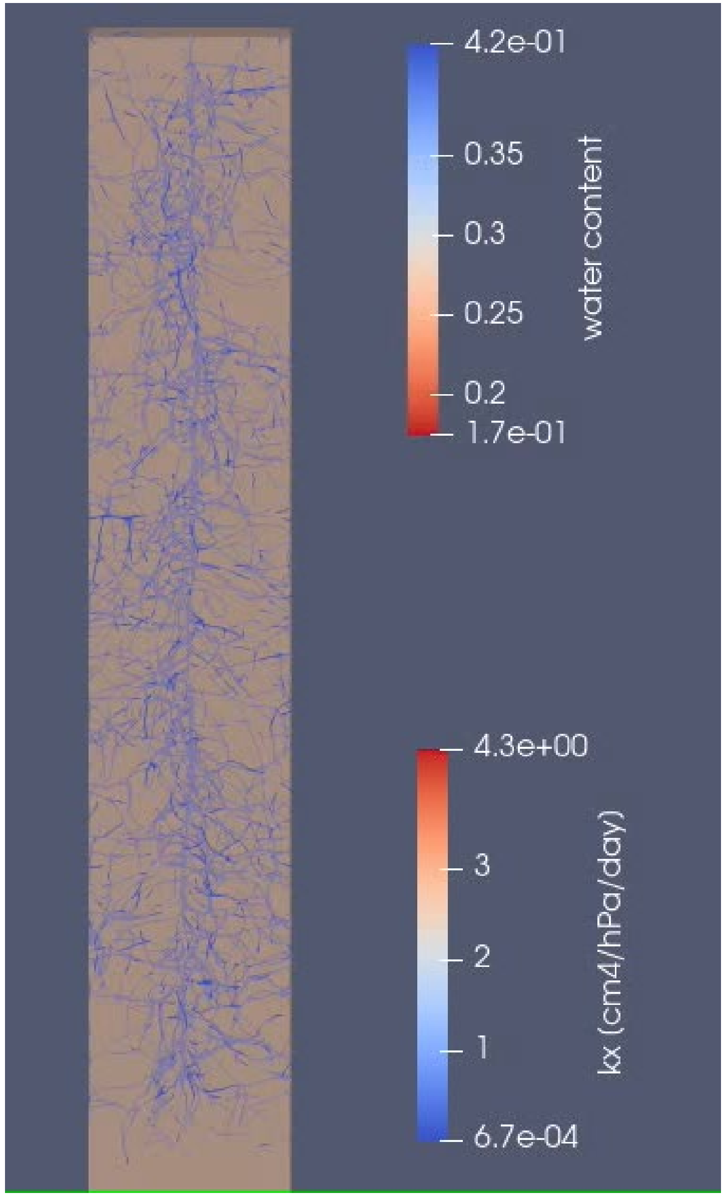
Schnepf et al. (2020, Front. Plant Sci.),
https://github.com/RSA-benchmarks/collaborative-comparison

ROOT WATER UPTAKE FROM DRYING SOIL

Local processes: root growth and water uptake at the segment level

3D water flow in soil as affected by climatic conditions and root water uptake

Water flow in roots as affected by potential transpiration b.c. and root water uptake



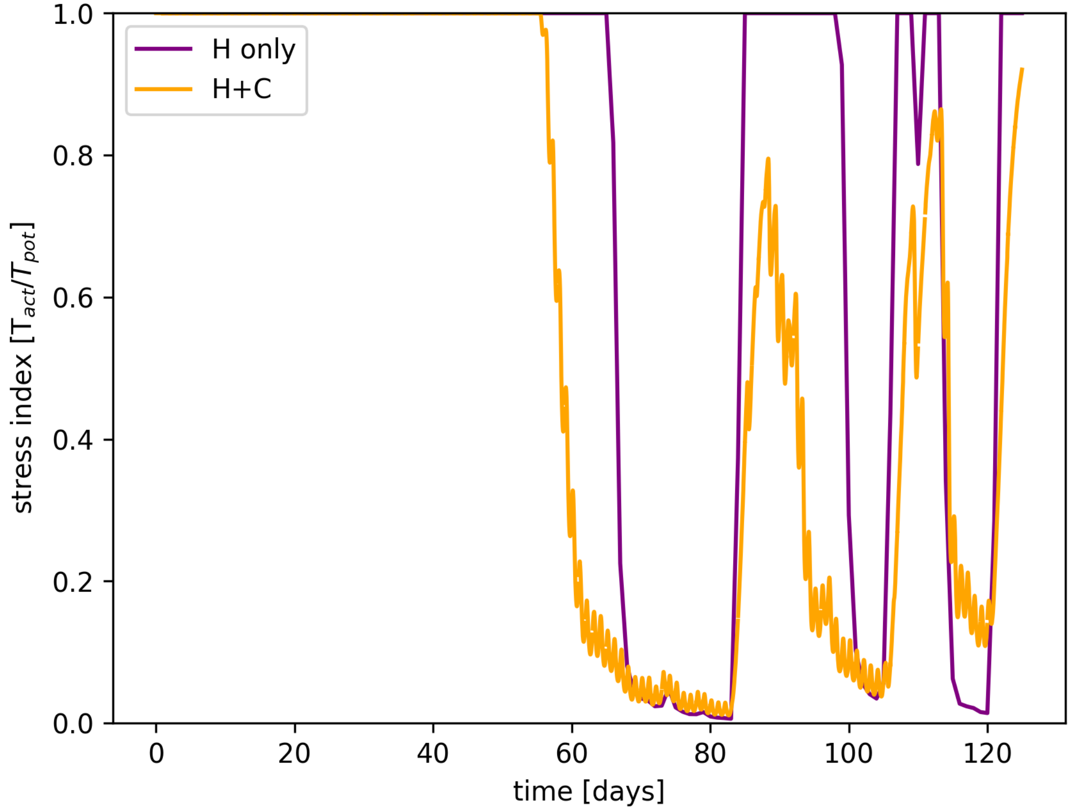
EMERGING PATTERN AT THE PLANT SCALE

Transpiration of same root architecture
- Hydraulic control > hydraulic plus chemical control

Hormonal production rate
- Reflects dry periods

Water potential at the root collar
- Hydraulic control < hydraulic plus chemical control

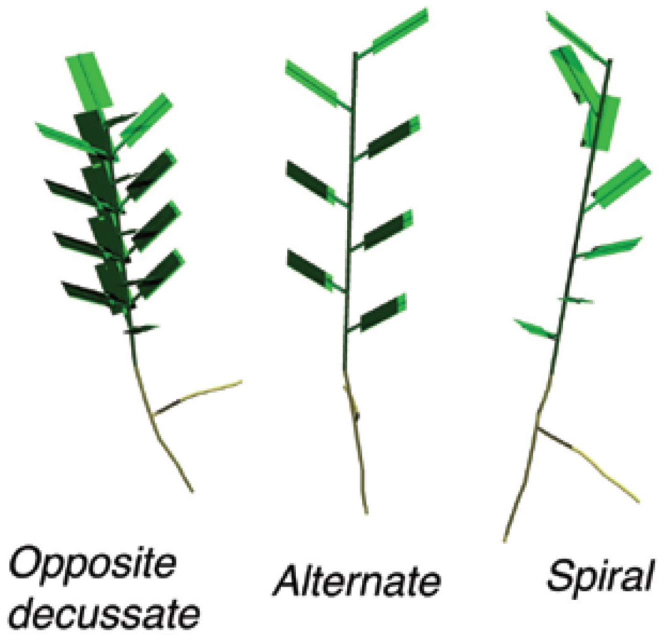
Stress index T_{act}/T_{pot}
- Chemical control causes transpiration reduction earlier



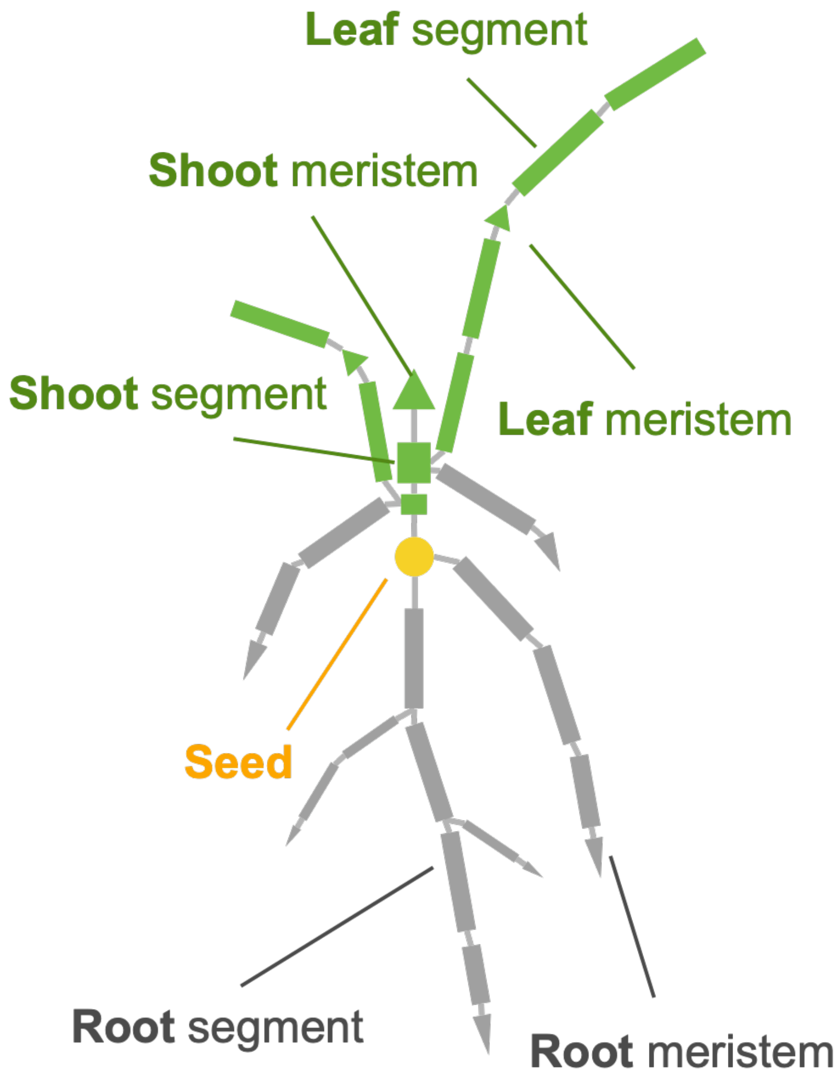
Khare, Bodner, Leitner, Schnepf et al., ongoing

WHOLE PLANT MODELLING

Conceptually the same but with multiple organ types



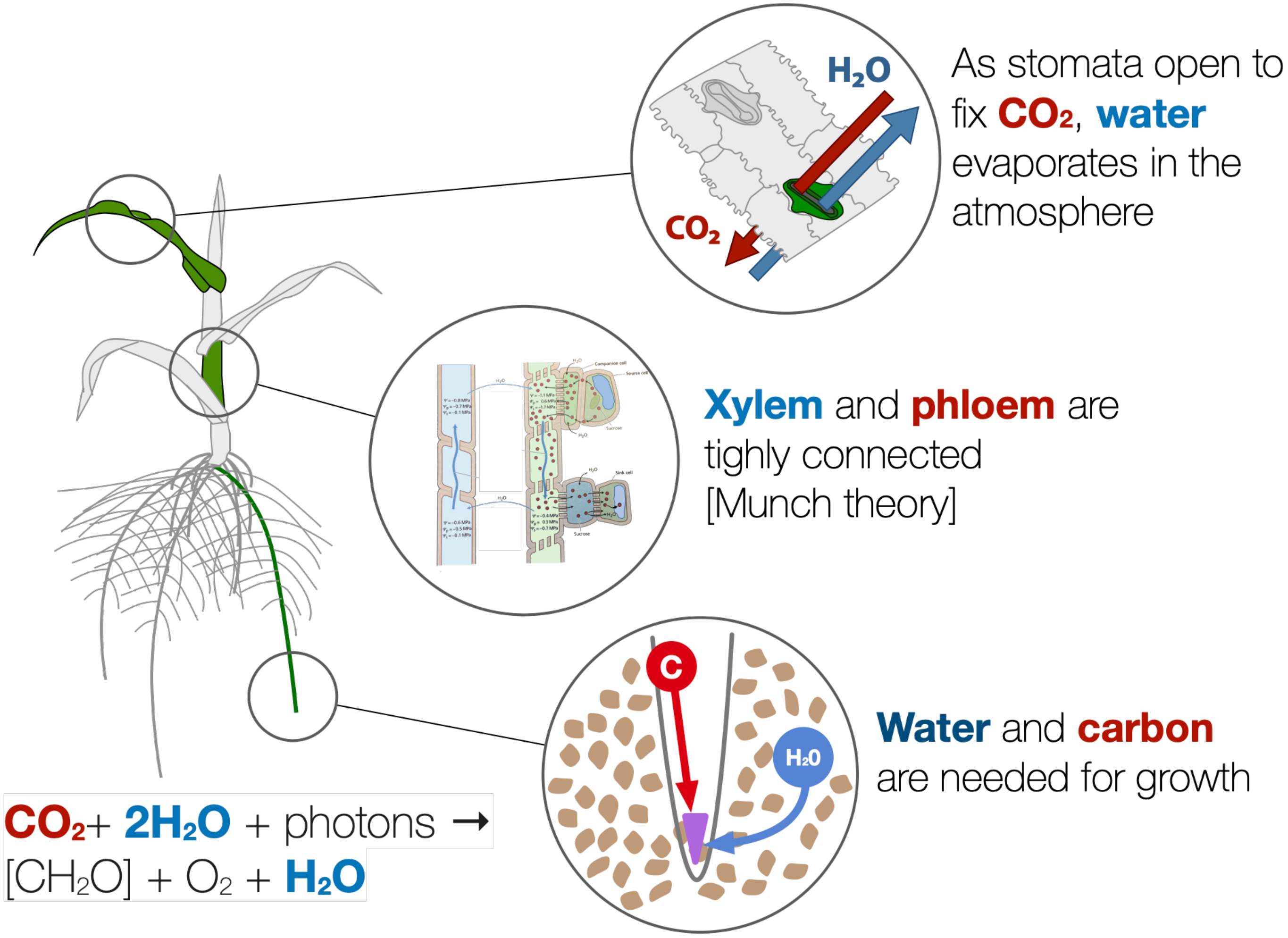
Leaf arrangements



CARBON AND WATER, THE PLANT'S DAILY TRADE

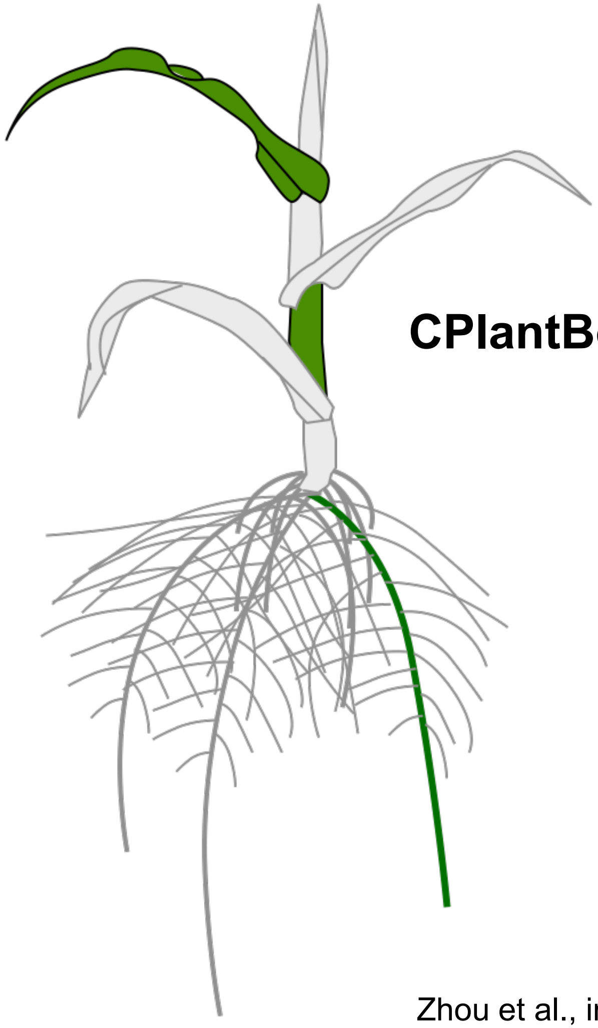
Emerging pattern: Tact, organ growth, root exudation

- Carbon and water flow are tighly interconnected and influence each other
- Shoot growth and development is needed to have a better prediction of photsynthesis and carbohydrate production
- Shoot growth is influenced by the water flow in the plant

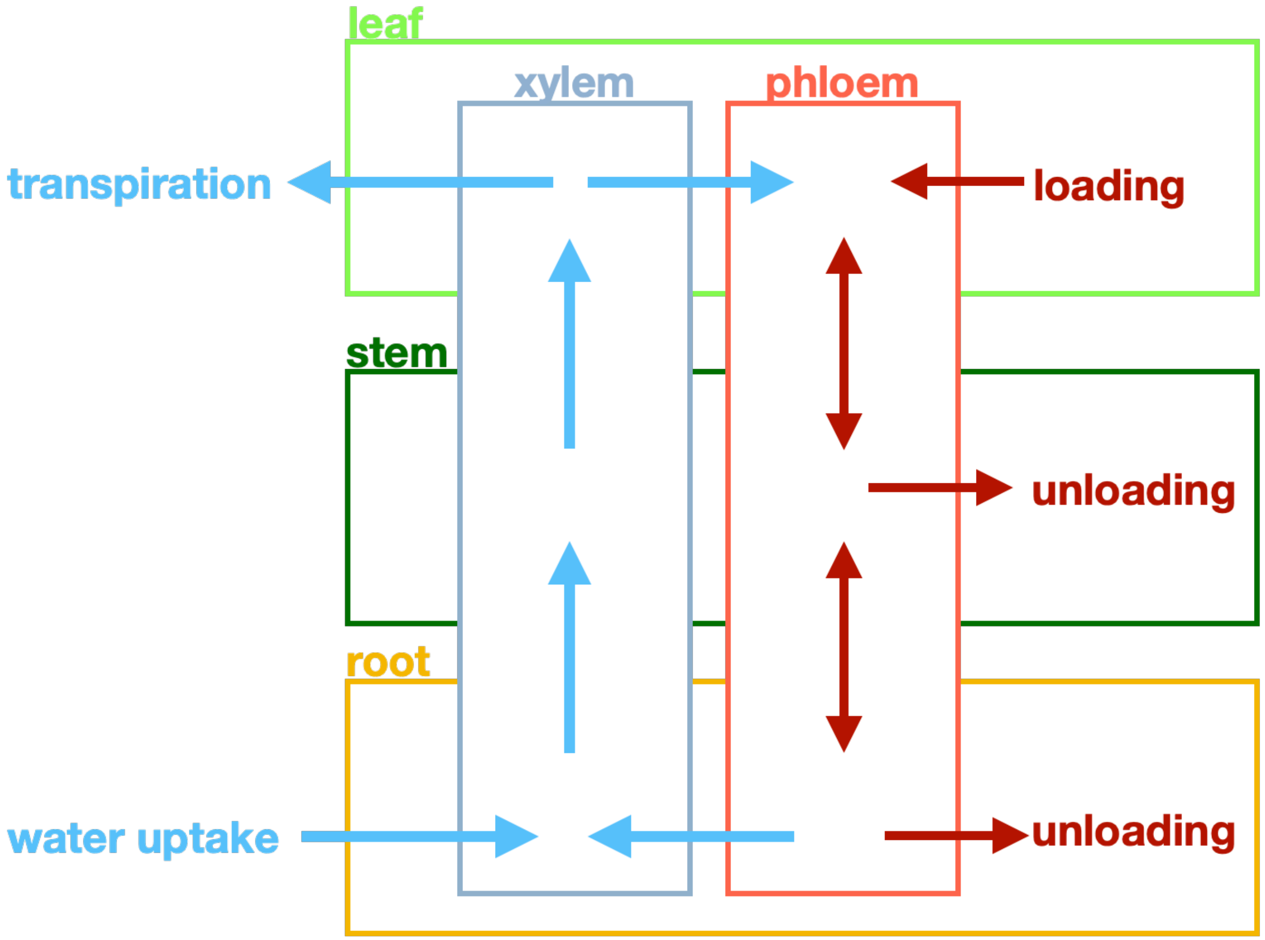


$CO_2 + 2H_2O$ + photons → $[CH_2O] + O_2 + H_2O$

SIMULATION OF LOCAL PROCESSES



CPlantBox

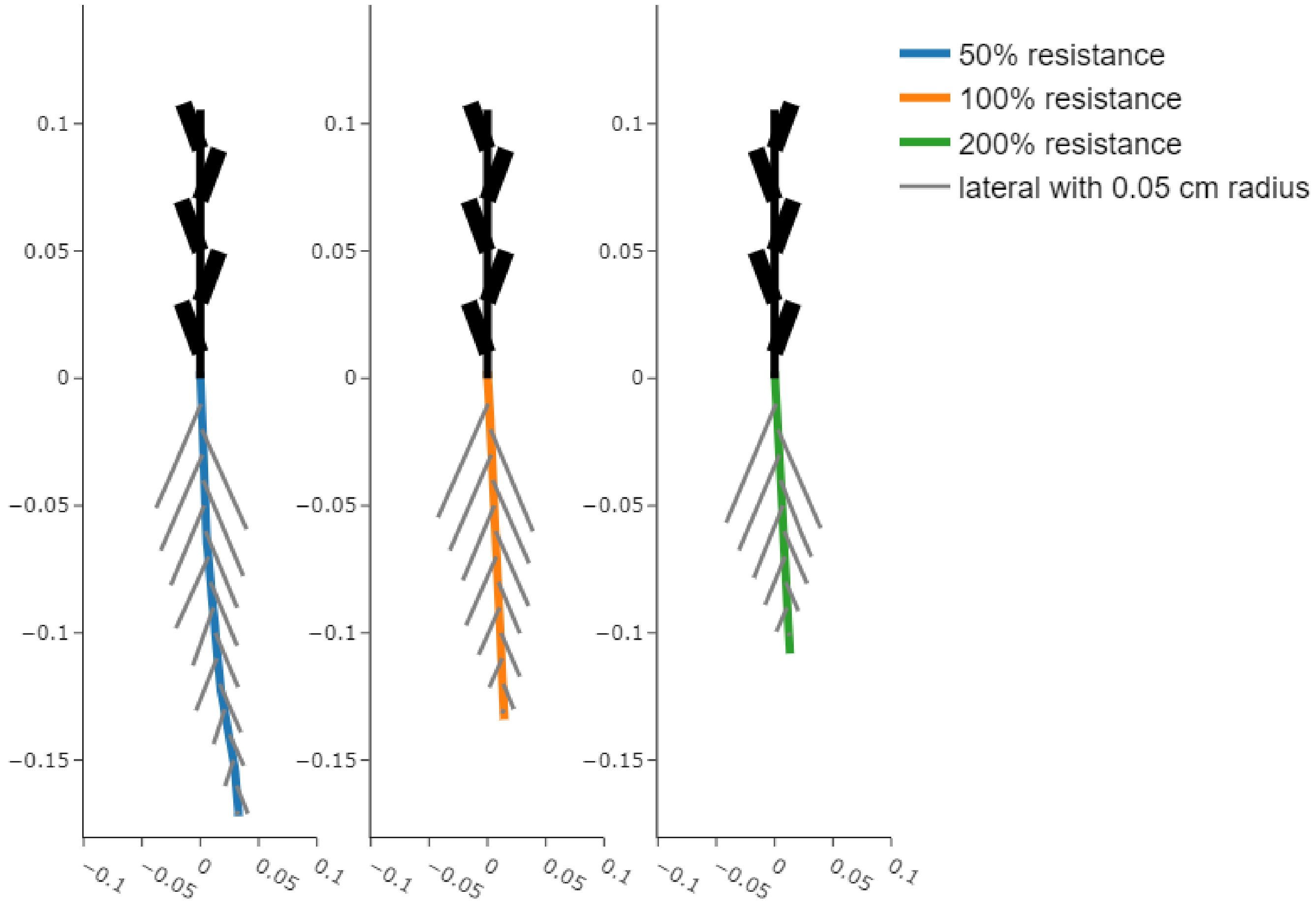


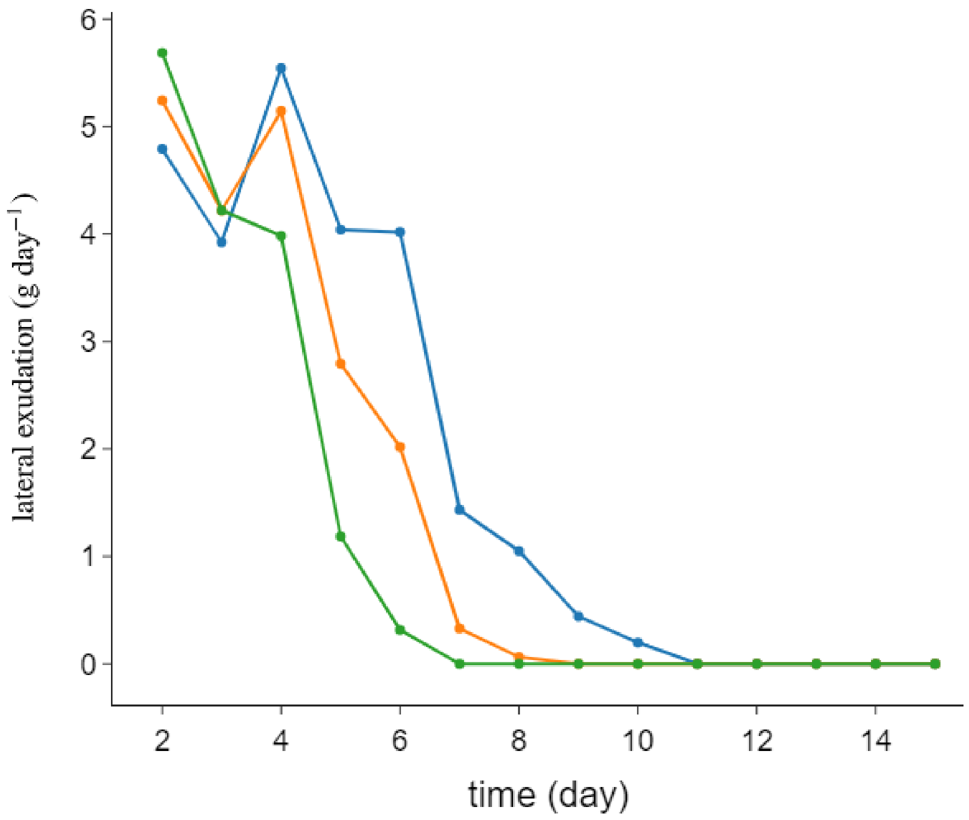
PiafMunch

Zhou et al., in silico Plants 2020

EMERGING PATTERN

Plant growth, exudation rates





Zhou et al., unpublished

SUMMARY

- Overview about CPlantBox and functional-structural root/plant modelling
  - Plants are represented as connected line segments
  - Additional information per segment: creation time, organ type, branch order, radius, hydraulic properties, …
  - They define the interaction with the surrounding environment
- Emergent pattern on plant/ecosystem scale are a result of multiple local processes
  - Plant growth, exudation, transpiration, …
  - They are of interest for applications, e.g. agronomic, environmental, ecosystem services

ROOT-SOIL INTERACTIONS GROUP

Landl Leitner Selzner Khare Lärm Zhuang Giraud

Ullah Bauer Feron Jorda Lobet Javaux Vereecken Vanderborght

ROSI

www.rosi.science

THANK YOU FOR YOUR ATTENTION!

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