MEAGAN LANG

CROPS IN SILICO HACKATHON 2021

BUT FIRST…

NOTEBOOK PREP

PREP CHECKLIST

1. SIGN-UP FOR GITHUB

We will be using GitHub Issues to debug

2. OPEN THE PROJECT MATERIALS

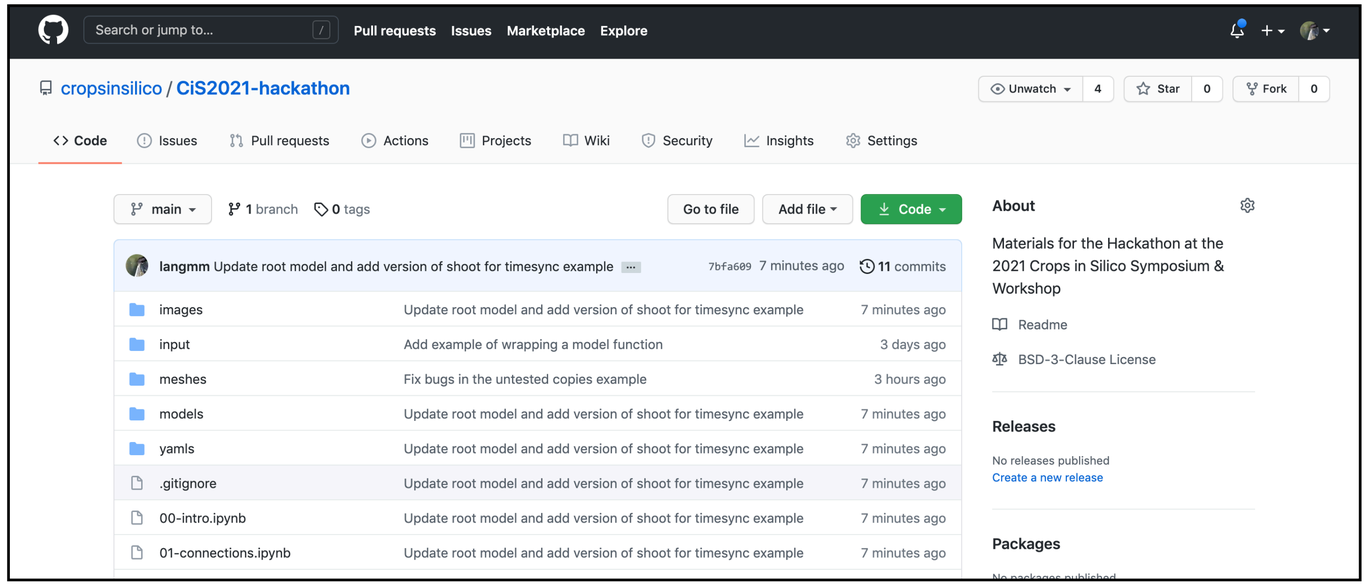
3. START A MYBINDER INSTANCE

We will be using Jupyter notebooks via MyBinder to avoid local installations (instructions for installing locally are found in the README)

Materials: https://github.com/cropsinsilico/CiS2021-hackathon

Launch binder in a **new** window/tab

Keep the materials repo open, we will need it later



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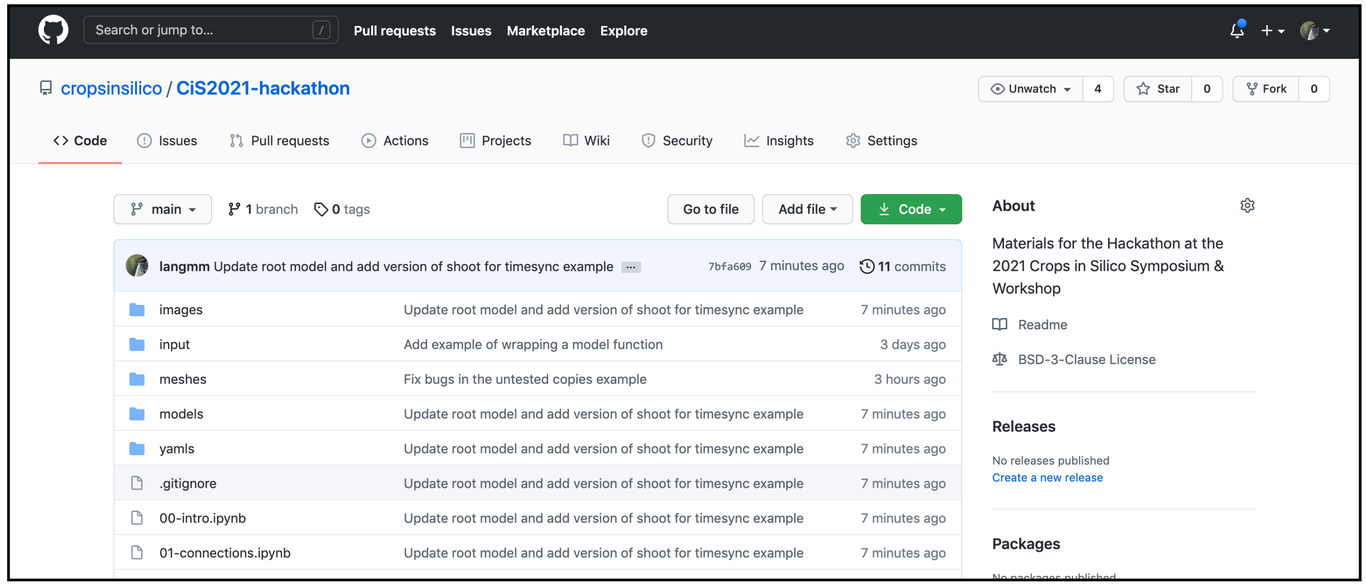
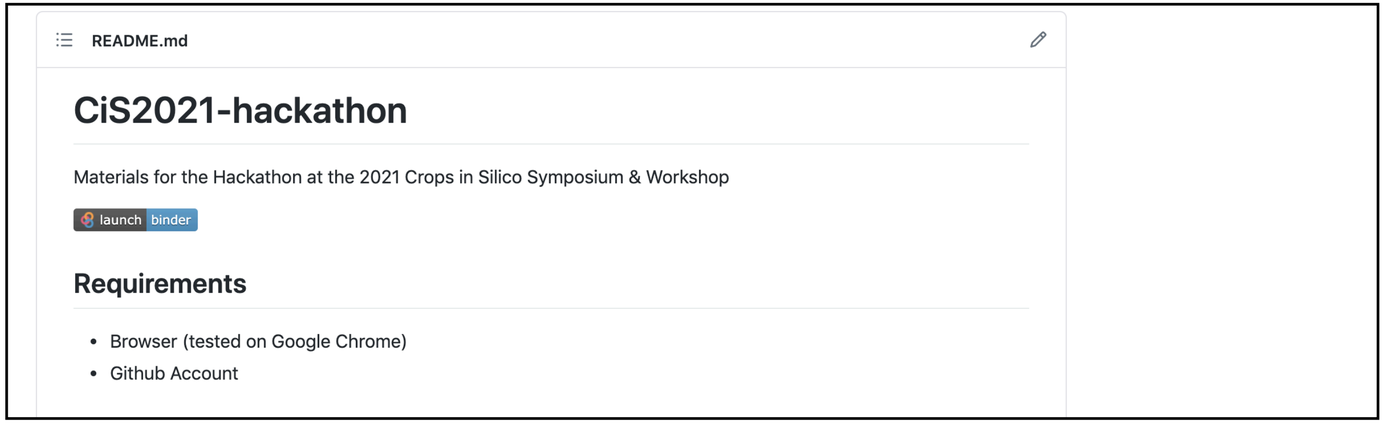


SCROLL



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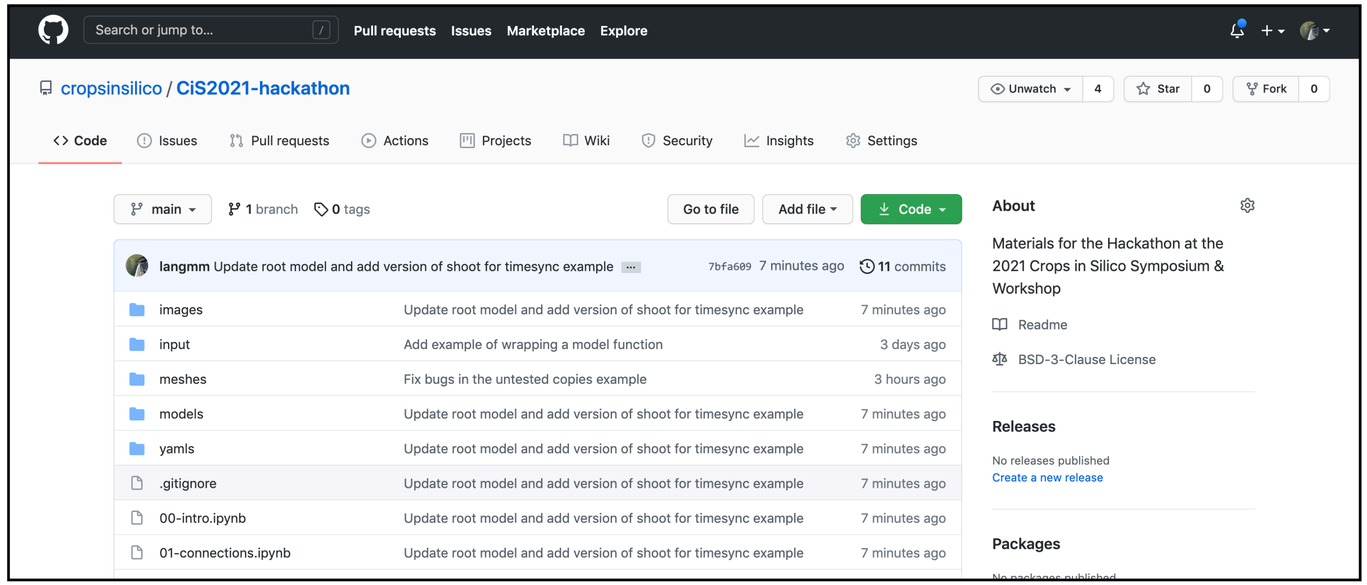

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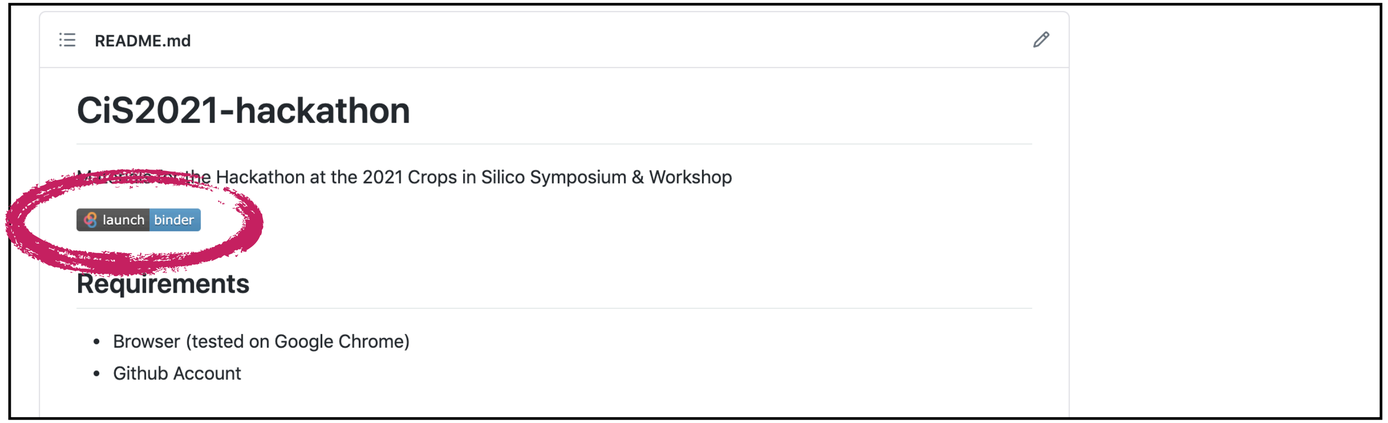

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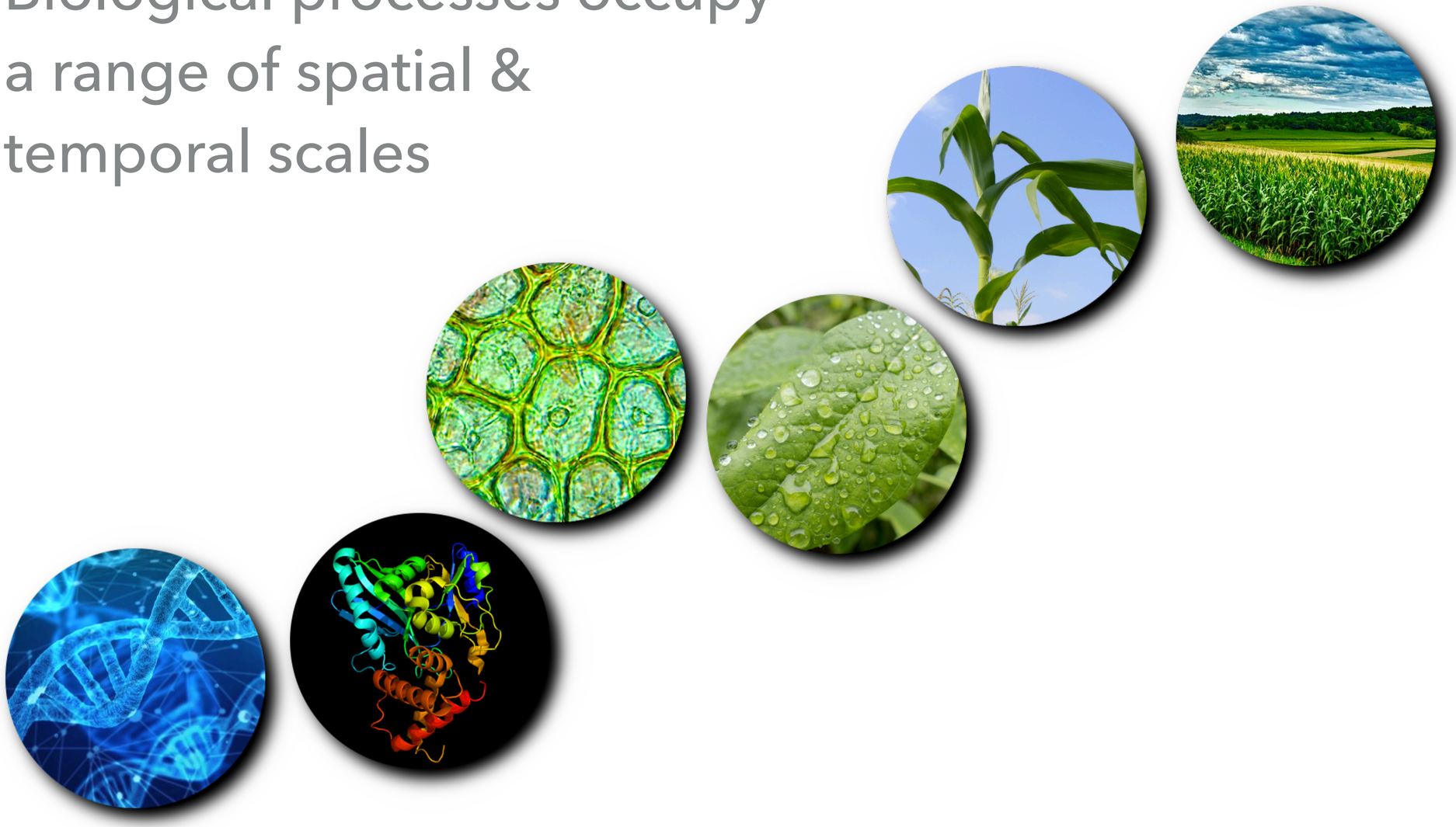
OK BACK TO THE…

INTRODUCTION

Biological processes occupy
a range of spatial &
temporal scales



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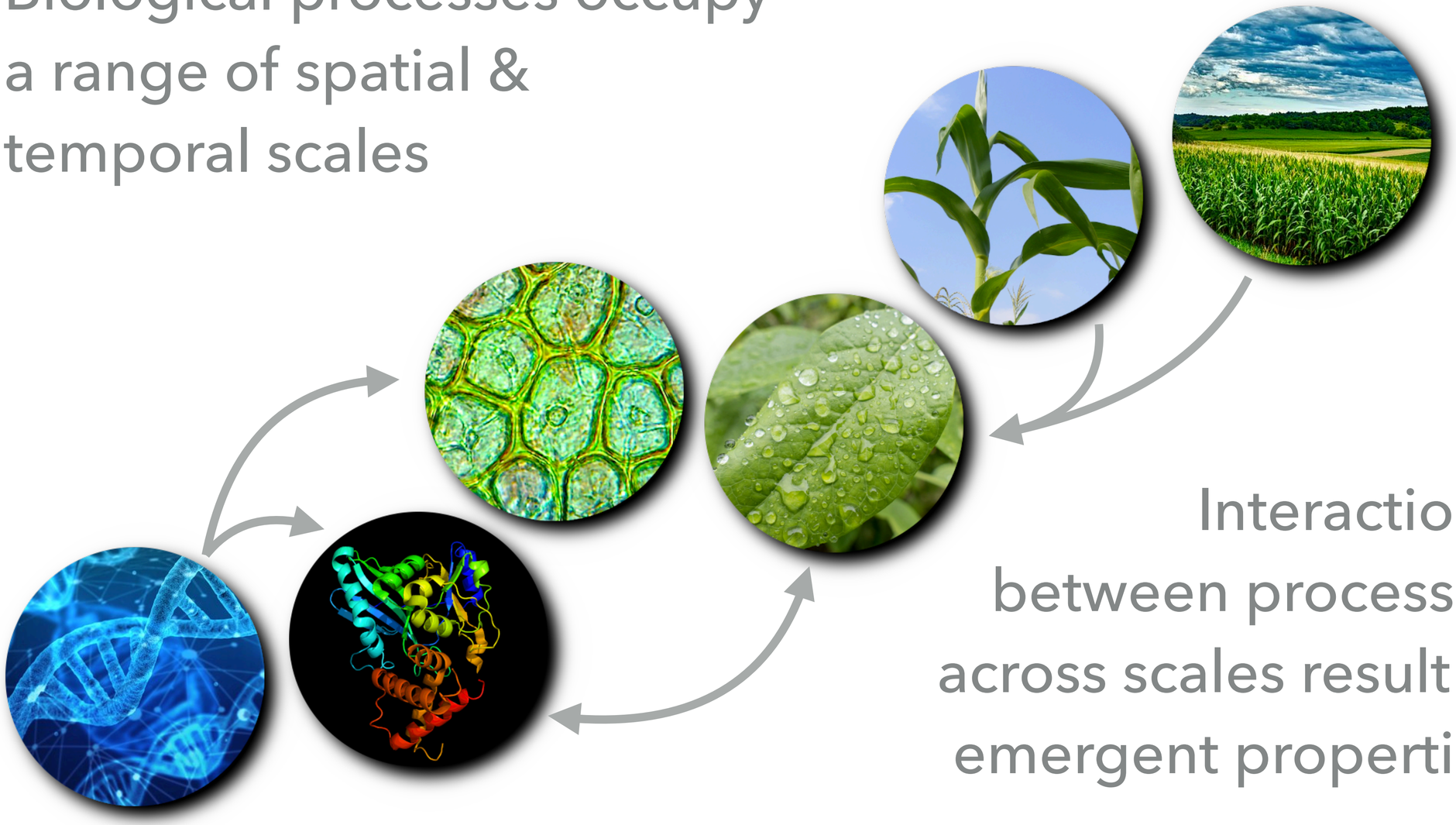
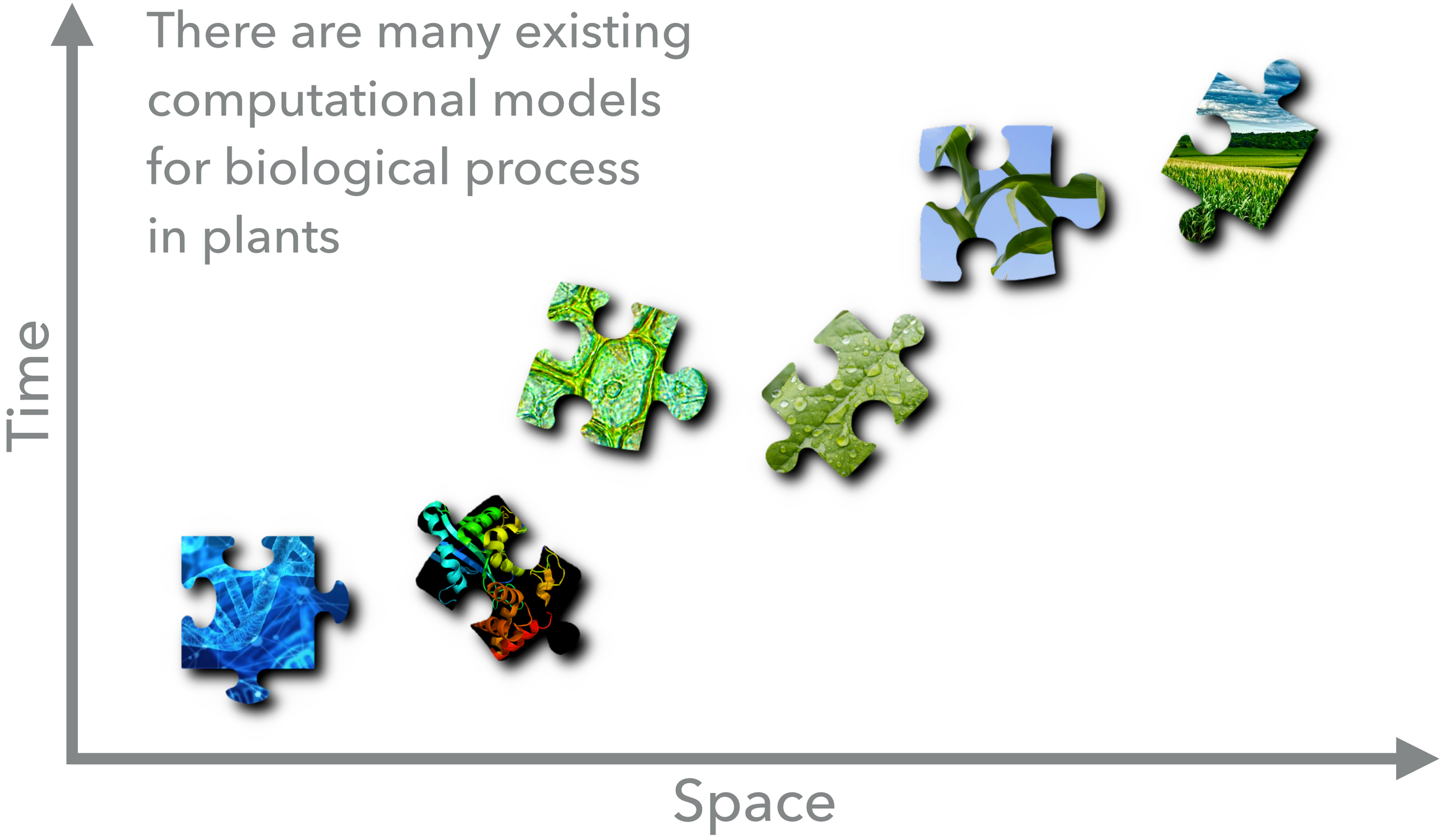


Interactions
between processes
across scales result in
emergent properties

There are many existing computational models for biological process in plants



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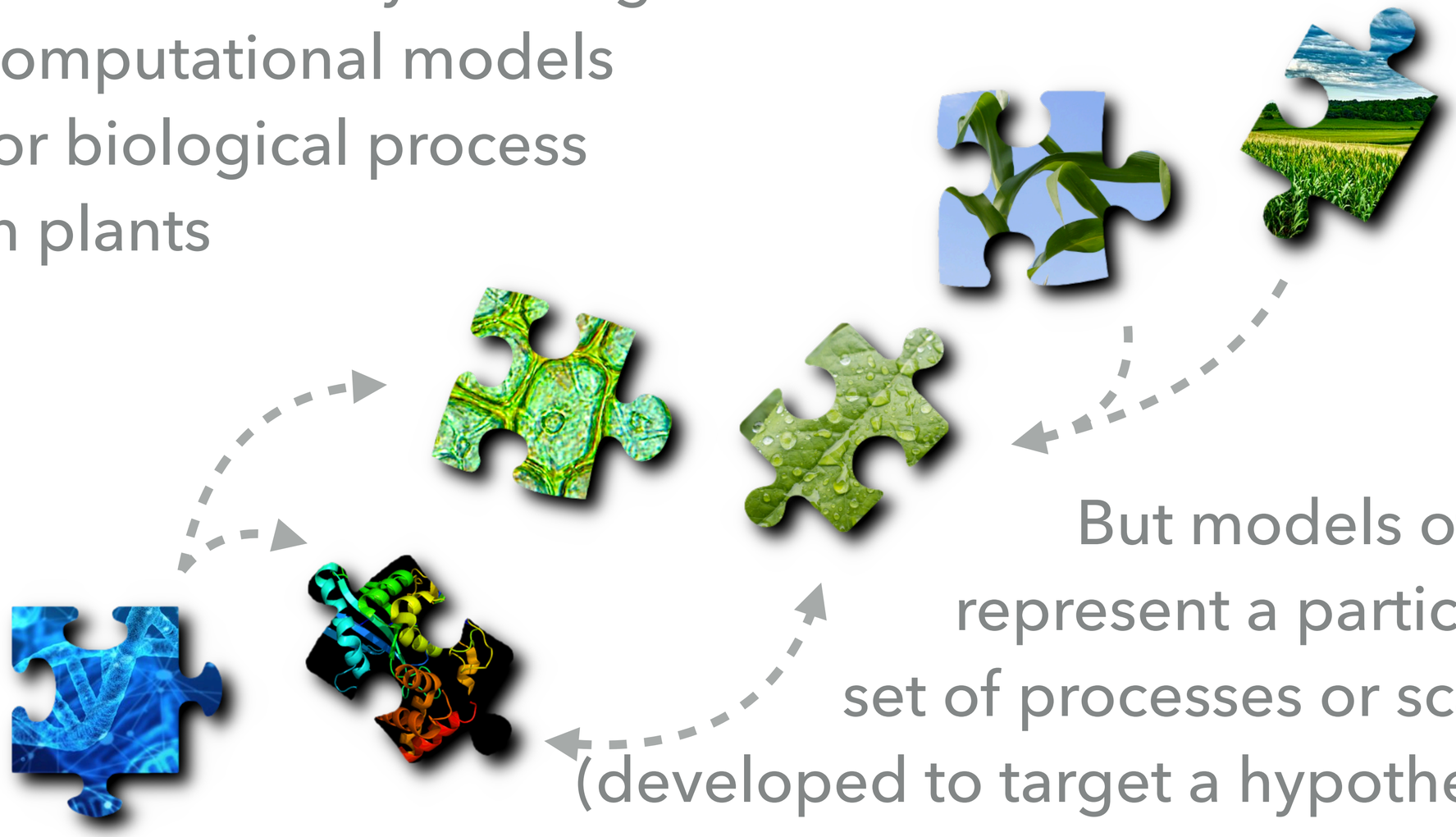


But models often represent a particular set of processes or scales (developed to target a hypothesis)

Time

Space

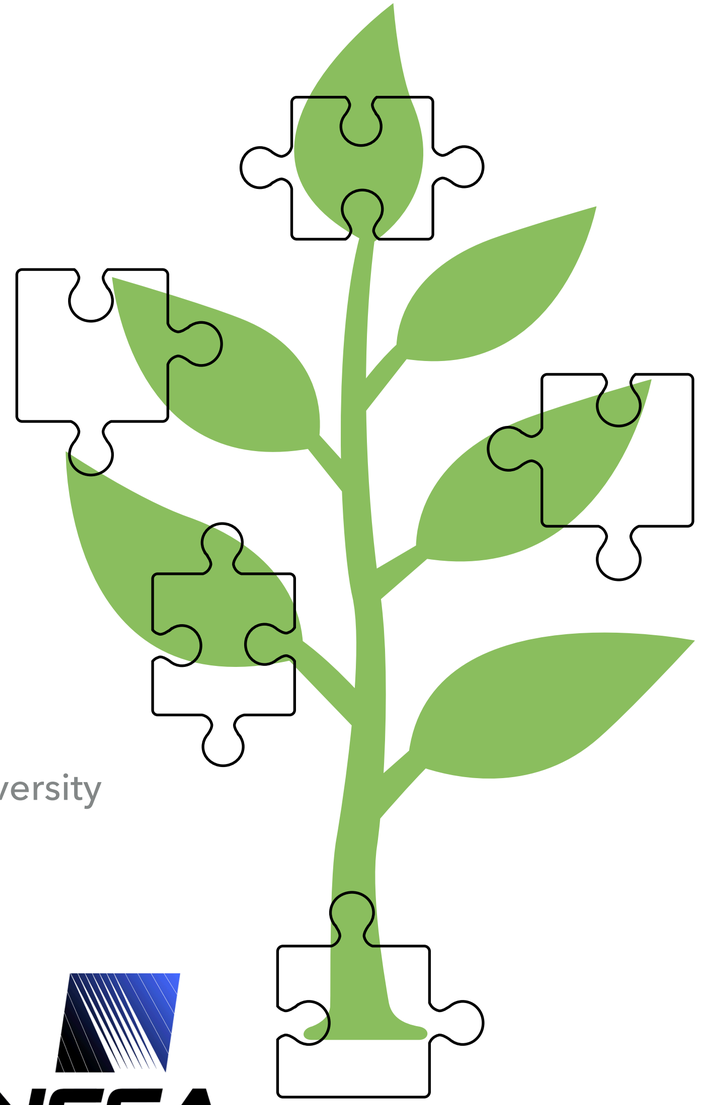
Crops[1] *in silico*

ILLINOIS

In partnership with
Oxford University
Pennsylvania State University
Purdue University
University of Nebraska

Funded by

FFAR ISEE NCSA



Models are pieces from different puzzles

We need an adapter

Crops[1] *in silico*

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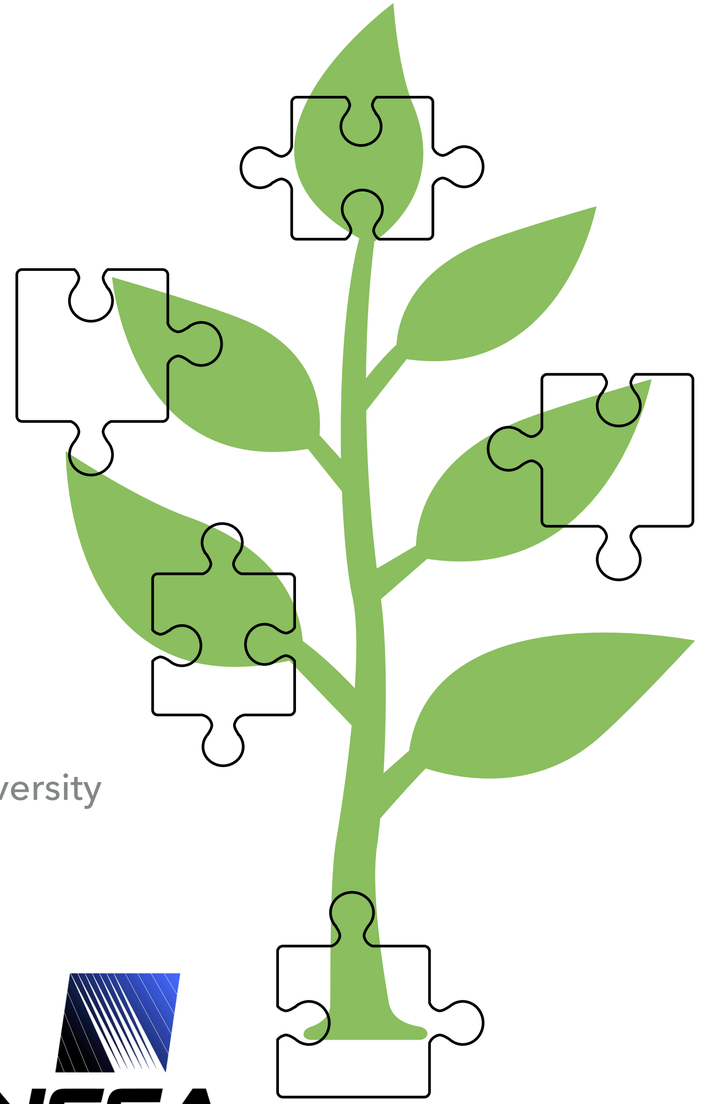
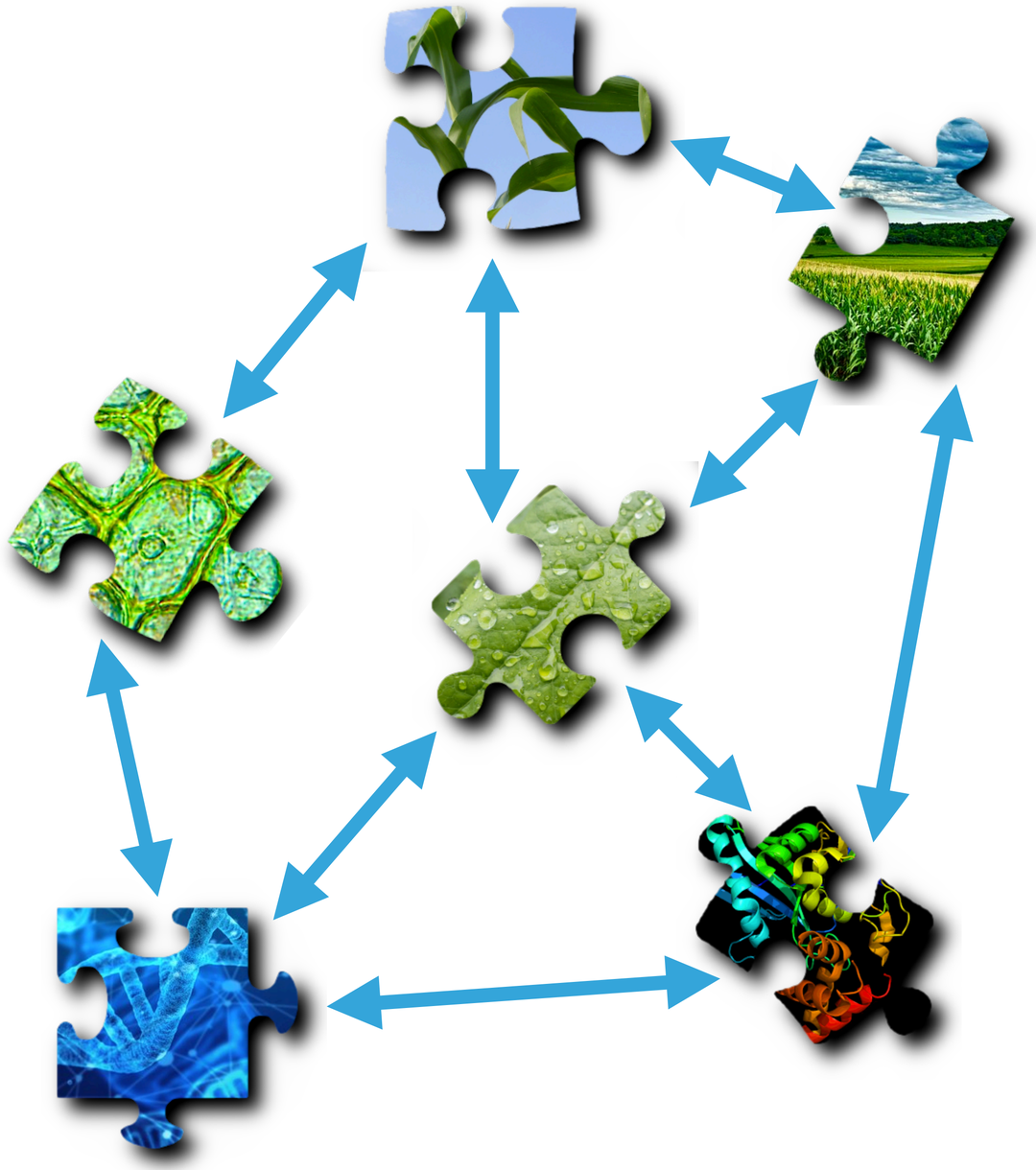
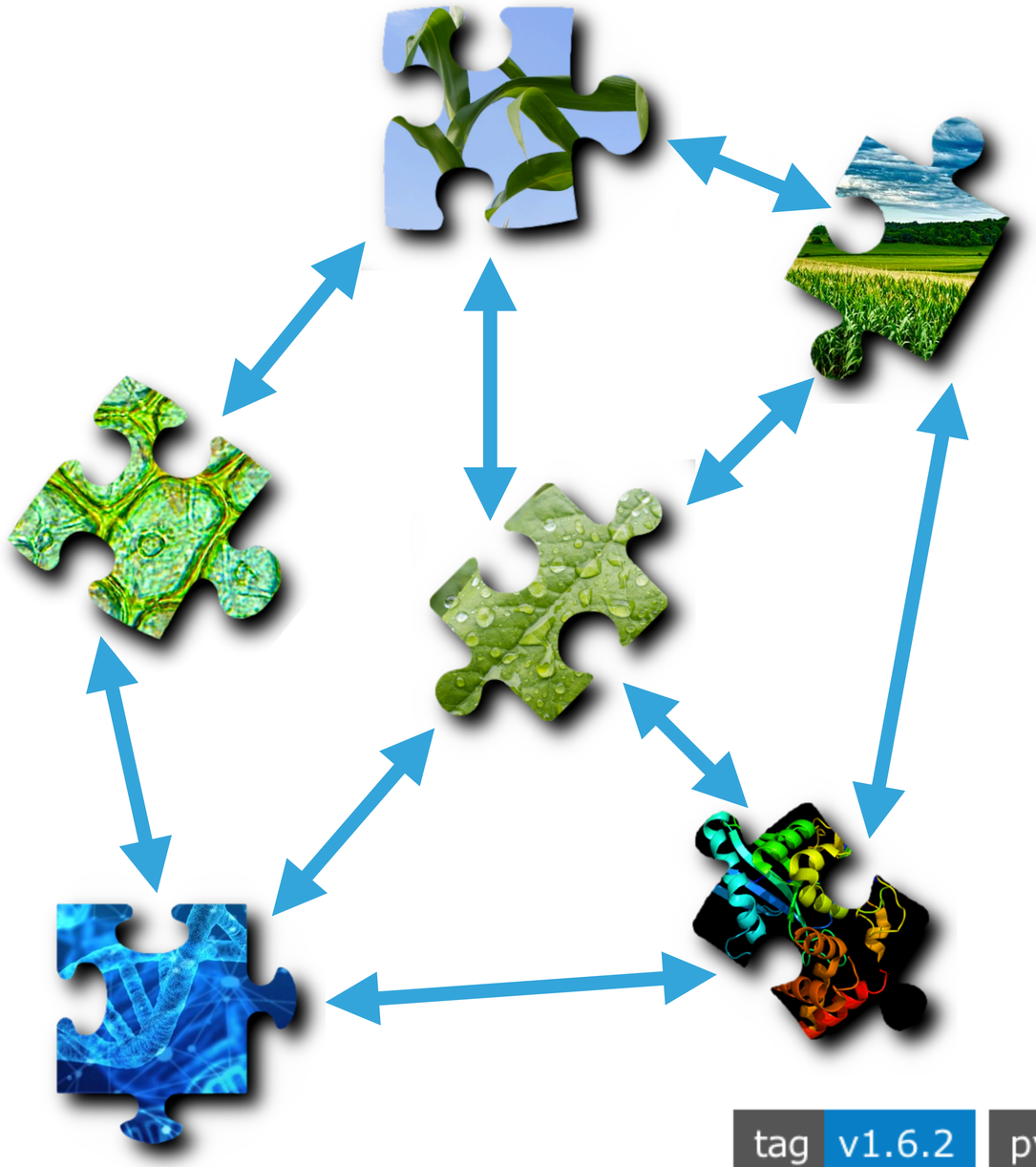




YGGDRASIL:

OPEN SOURCE PYTHON PACKAGE FOR CONNECTING MODELS ACROSS SCALES AND LANGUAGES



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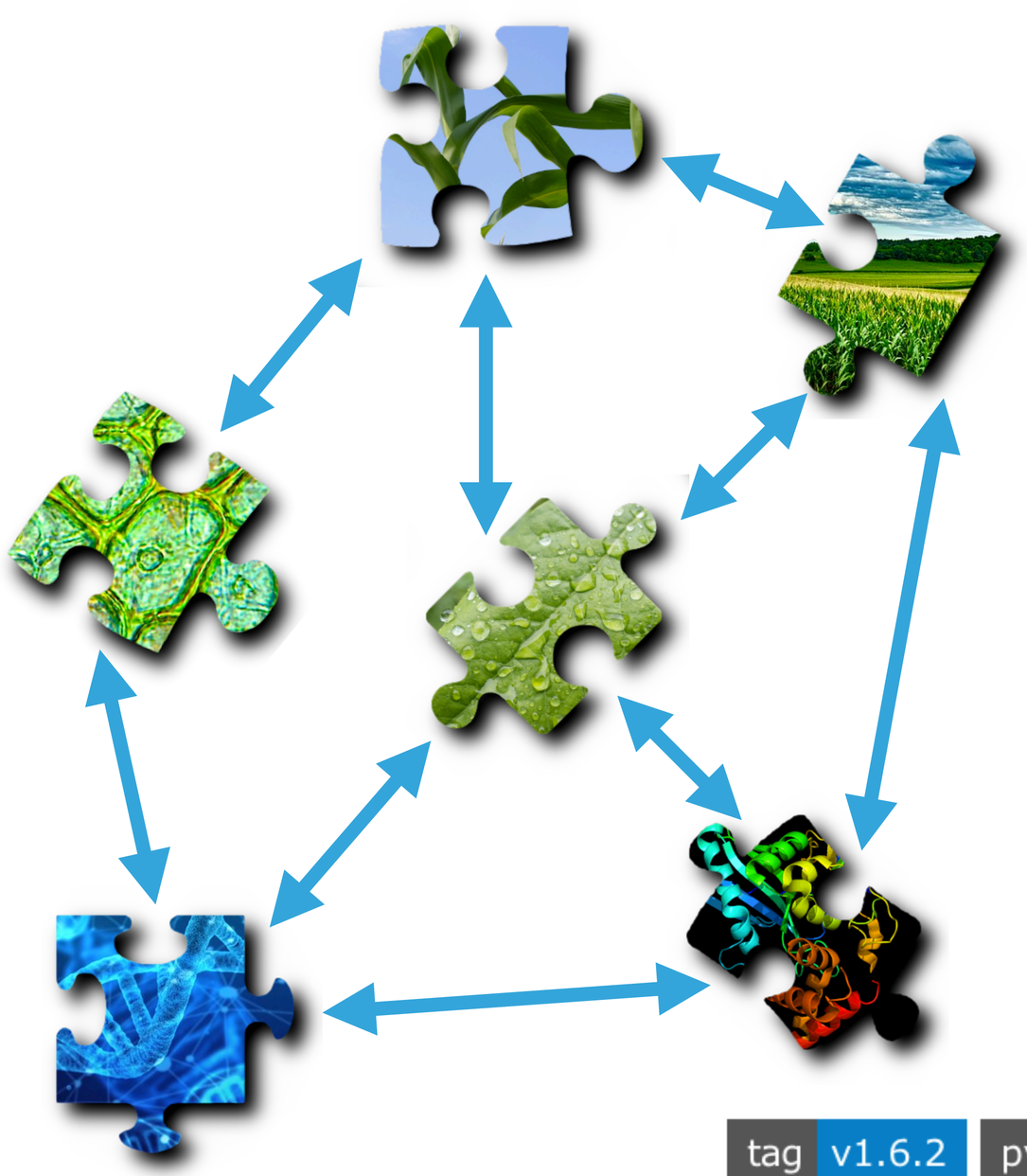

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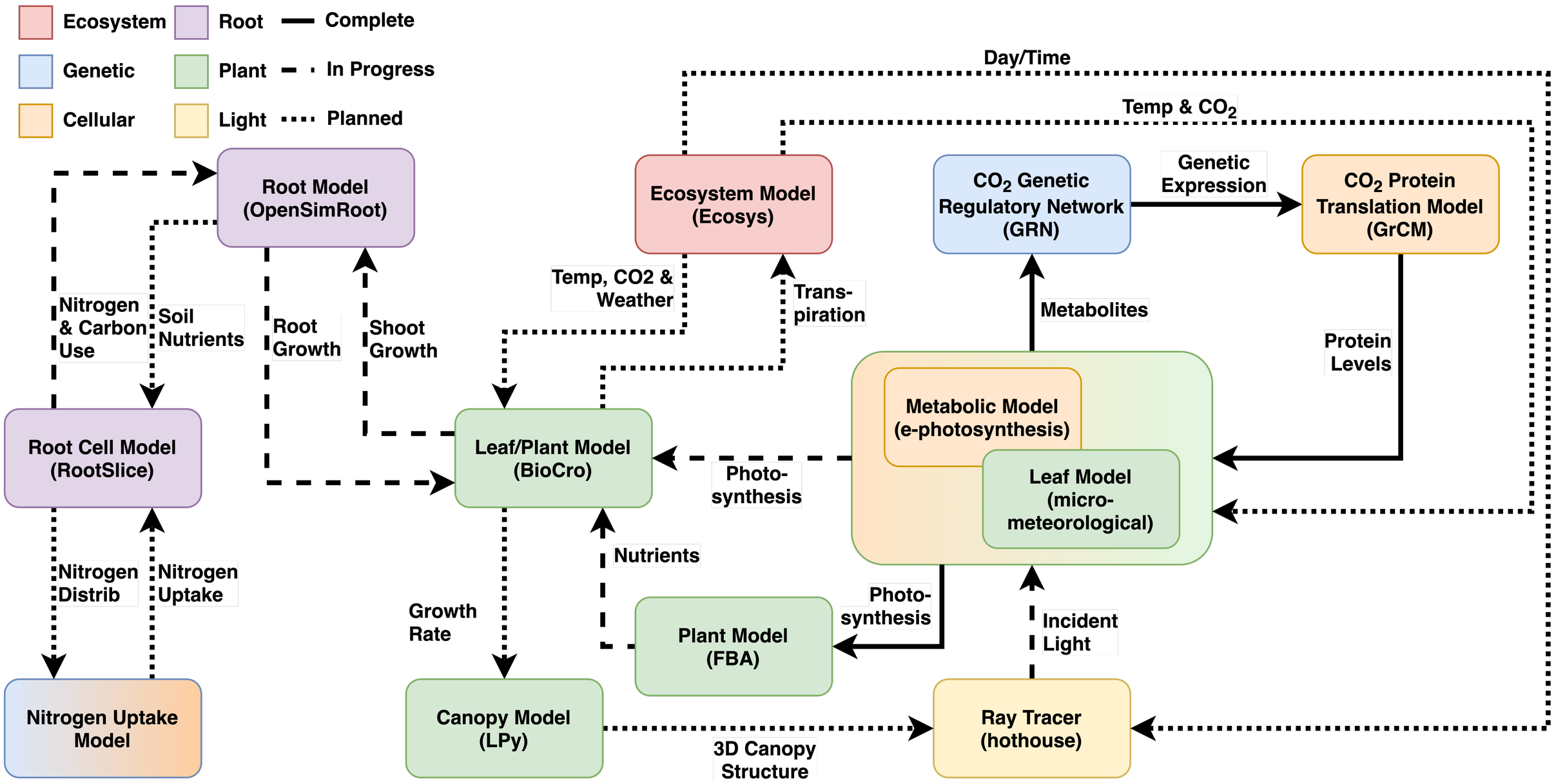
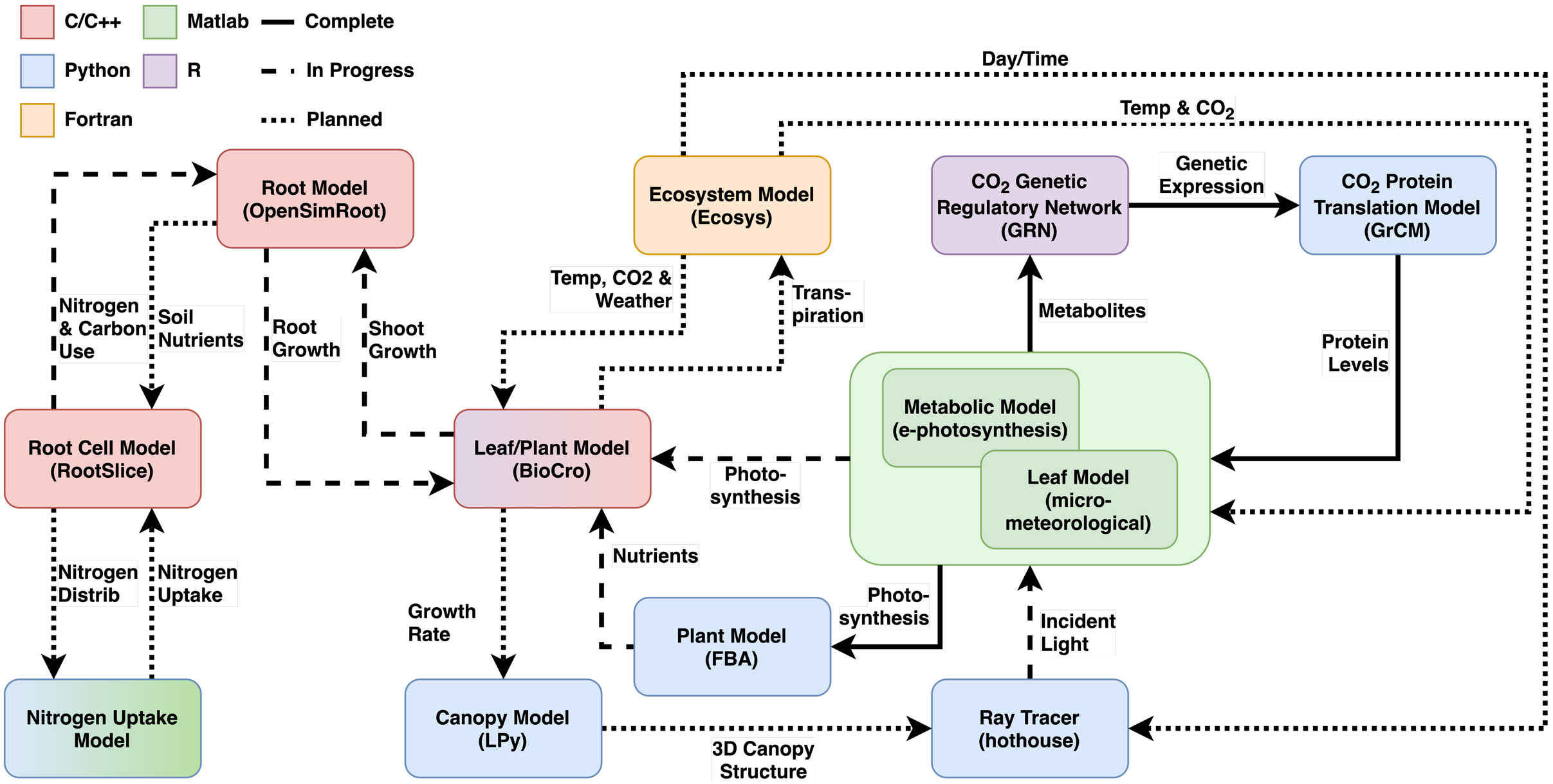

Ecosystem
Root
Complete
Genetic
Plant
In Progress
Cellular
Light
Planned
Day/Time
Temp & CO_2
Root Model (OpenSimRoot)
Ecosystem Model (Ecosys)
CO_2 Genetic Regulatory Network (GRN)
Genetic Expression
CO_2 Protein Translation Model (GrCM)
Nitrogen & Carbon Use
Soil Nutrients
Root Growth
Shoot Growth
Temp, CO2 & Weather
Trans-piration
Metabolites
Protein Levels
Root Cell Model (RootSlice)
Leaf/Plant Model (BioCro)
Metabolic Model (e-photosynthesis)
Leaf Model (micro-meteorological)
Photo-synthesis
Nutrients
Nitrogen Distrib
Nitrogen Uptake
Growth Rate
Plant Model (FBA)
Photo-synthesis
Incident Light
Nitrogen Uptake Model
Canopy Model (LPy)
Ray Tracer (hothouse)
3D Canopy Structure


C/C++
Matlab
Complete
Python
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In Progress
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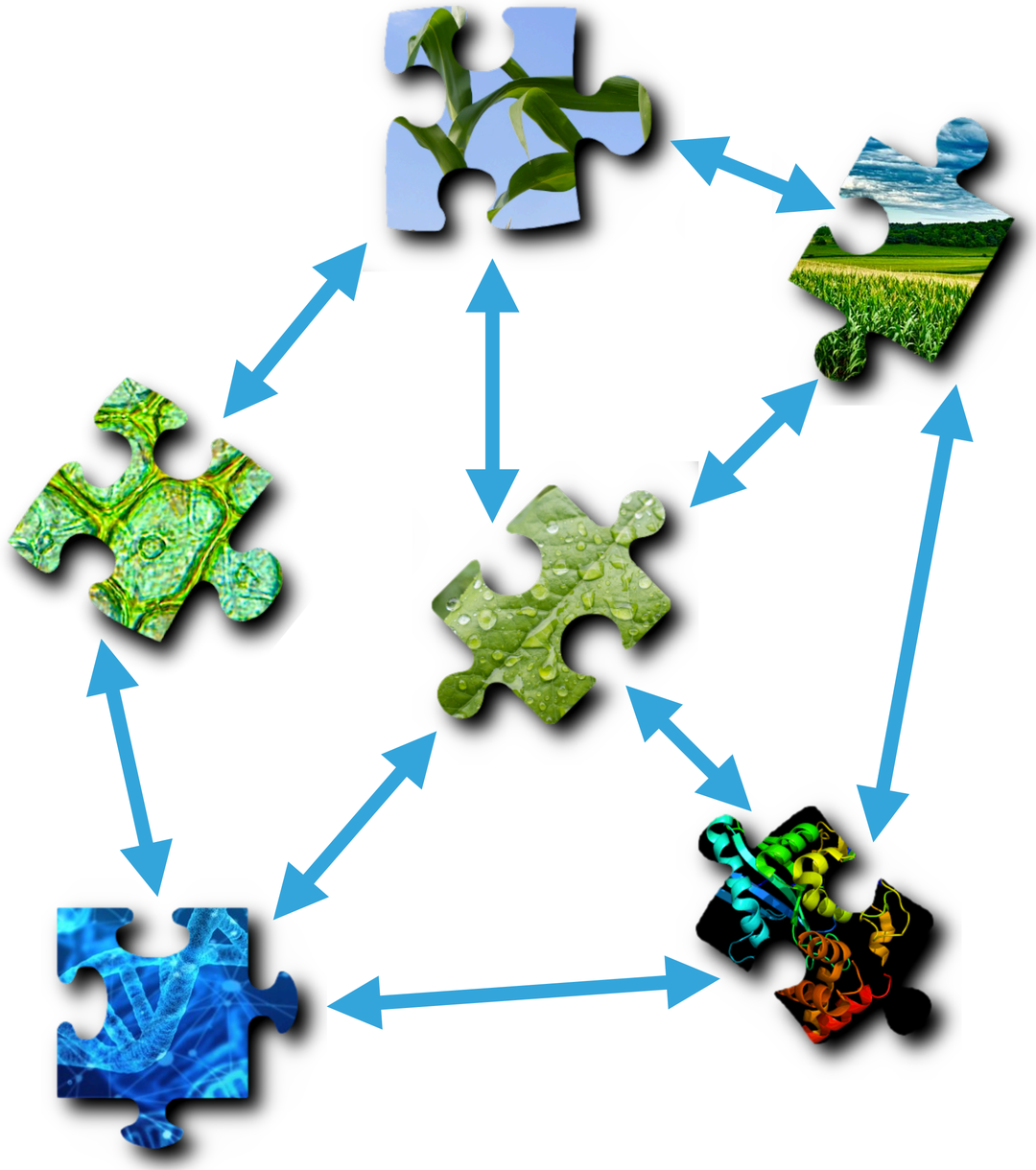


LANGUAGES

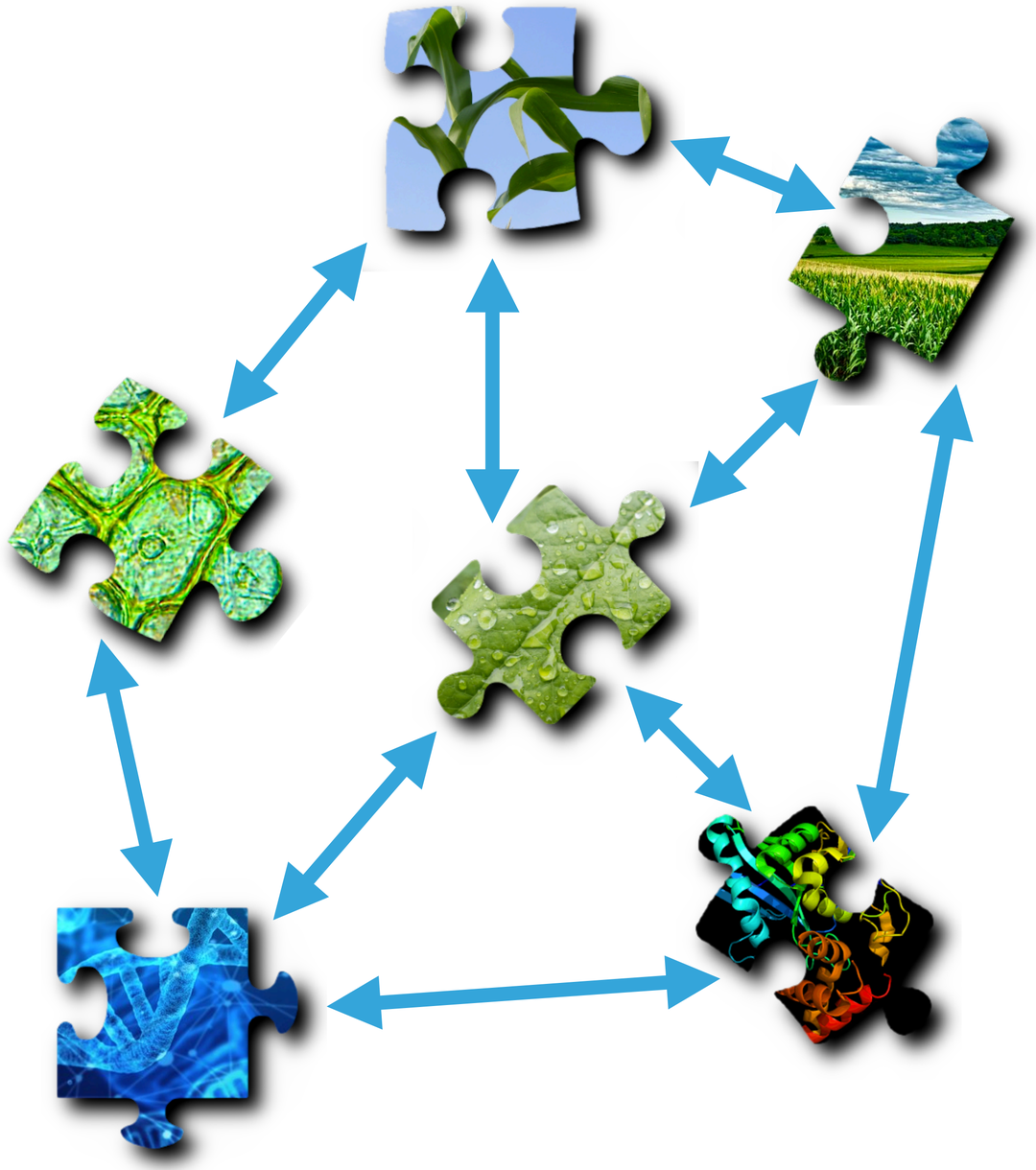
PYTHON

MATLAB

R

C/C++

FORTRAN ('03)



LANGUAGES

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DOMAIN SPECIFIC LANGUAGES

SBML

OPENSIMROOT XML

COMMUNICATION

PARALLEL EXECUTION

MODEL A

MODEL B

PARALLEL EXECUTION

MODEL A

MODEL B

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

MODEL B

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

SEND

MODEL B

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

SEND

MODEL B

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

SEND

MODEL B

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

SEND

MODEL B

RECEIVE

ASYNCHRONOUS COMMUNICATION

(SEND FIRST)

MODEL A

SEND

MODEL B

RECEIVE

ASYNCHRONOUS COMMUNICATION

(RECEIVE FIRST)

MODEL A

MODEL B

ASYNCHRONOUS COMMUNICATION

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MODEL A

MODEL B

RECEIVE

ASYNCHRONOUS COMMUNICATION

(RECEIVE FIRST)

MODEL A

SEND

MODEL B

RECEIVE

ASYNCHRONOUS COMMUNICATION

(RECEIVE FIRST)

MODEL A

SEND

MODEL B

RECEIVE

ASYNCHRONOUS COMMUNICATION

(RECEIVE FIRST)

MODEL A

SEND

MODEL B

RECEIVE

COMM:

COMMUNICATION OBJECT ALLOWING MODELS TO SEND/RECEIVE MESSAGES TO/FROM OTHER MODELS

COMM CLASSES

INPUT

Receive messages from another model

OUTPUT

Send messages to another model

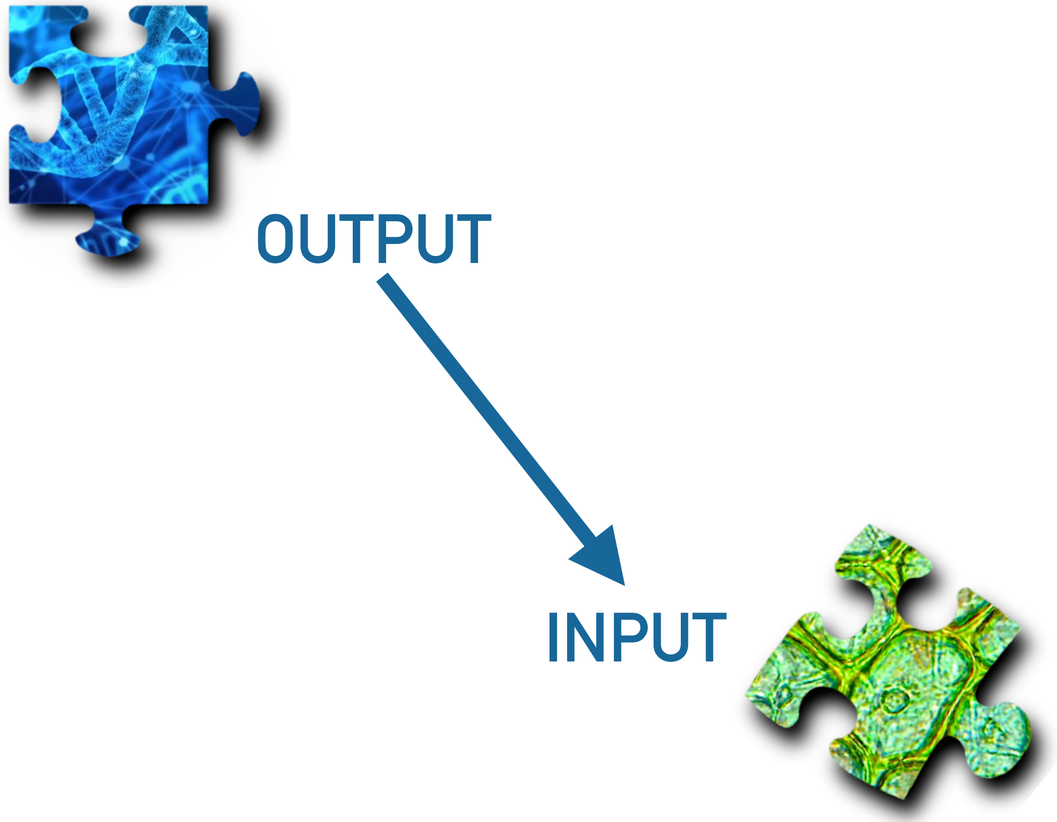
COMM CLASSES

INPUT

Receive messages from another model

OUTPUT

Send messages to another model



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INPUT

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OUTPUT

Send messages to another model

SERVER

Receive requests from client models and send responses

CLIENT

Send requests to a server model and receive messages (“call” a server model)

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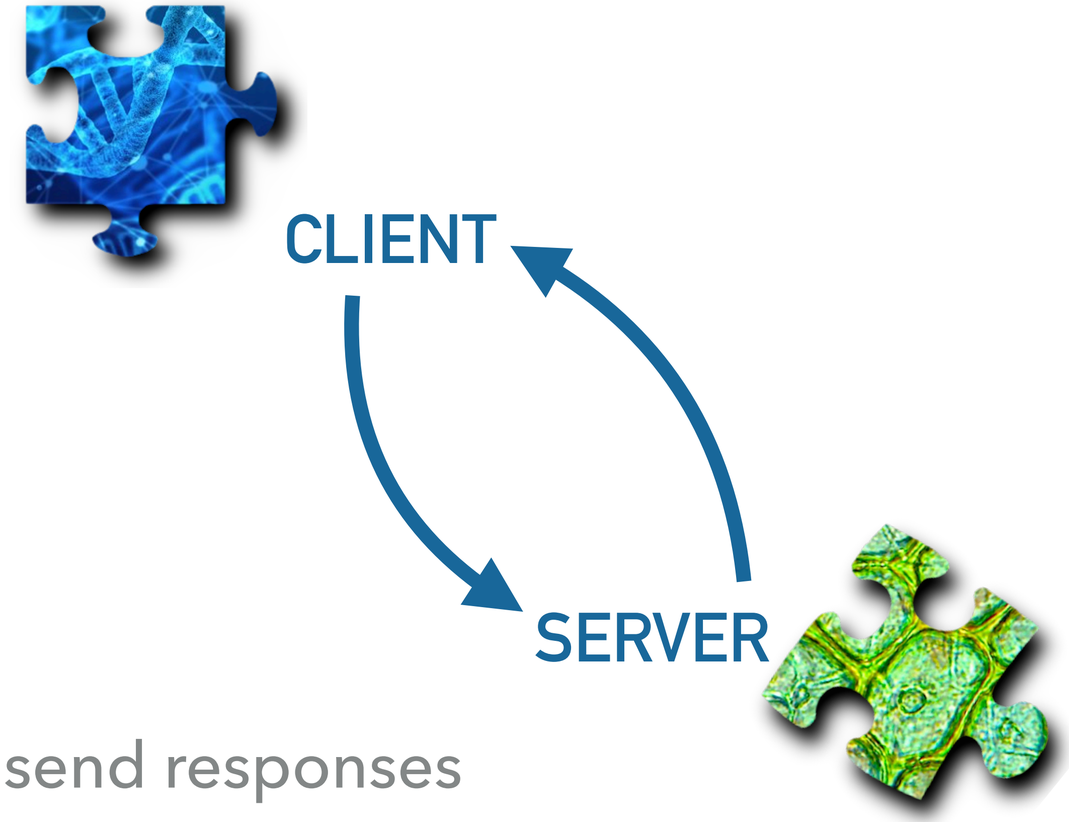

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TIMESYNC

Send requests to a set of time-dependent models and receive time-dependent variables (“call” a time step synchronization)

COMM CLASSES

TIMESYNC

INPUT

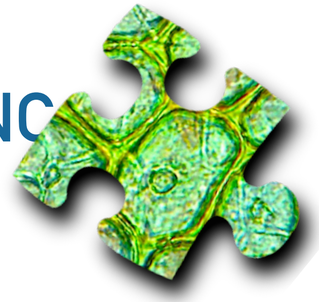
Receive messages from another model

SYNC

OUTPUT

Send messages to another model

TIMESYNC



SERVER

Receive requests from client models and send responses

CLIENT

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TIMESYNC

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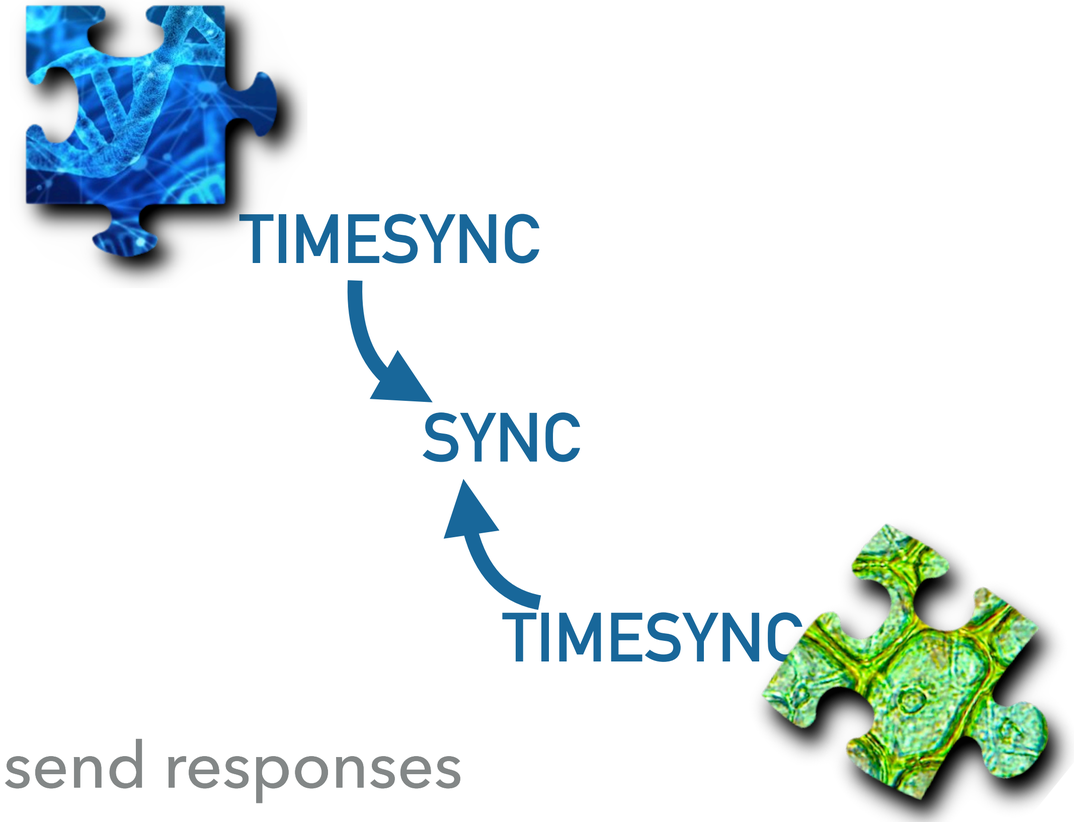

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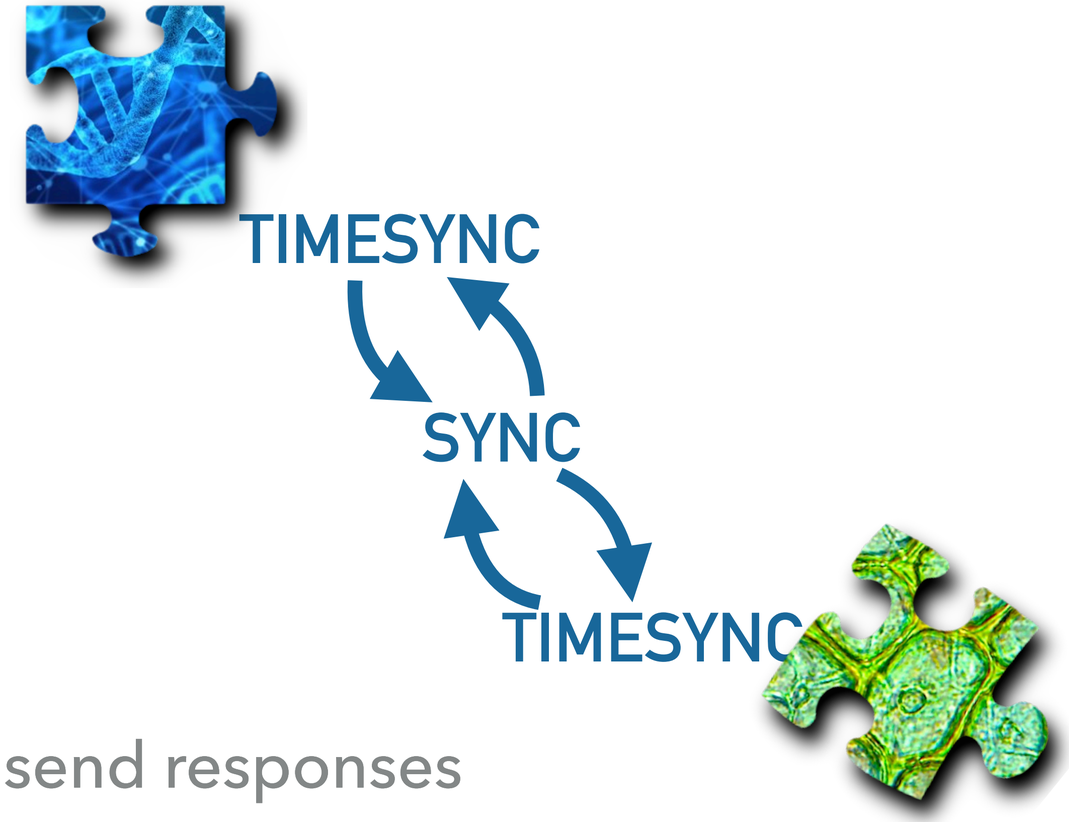

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COMM METHODS

IPC

Interprocess communication, only available on Unix (Linux & Mac)

ZEROMQ

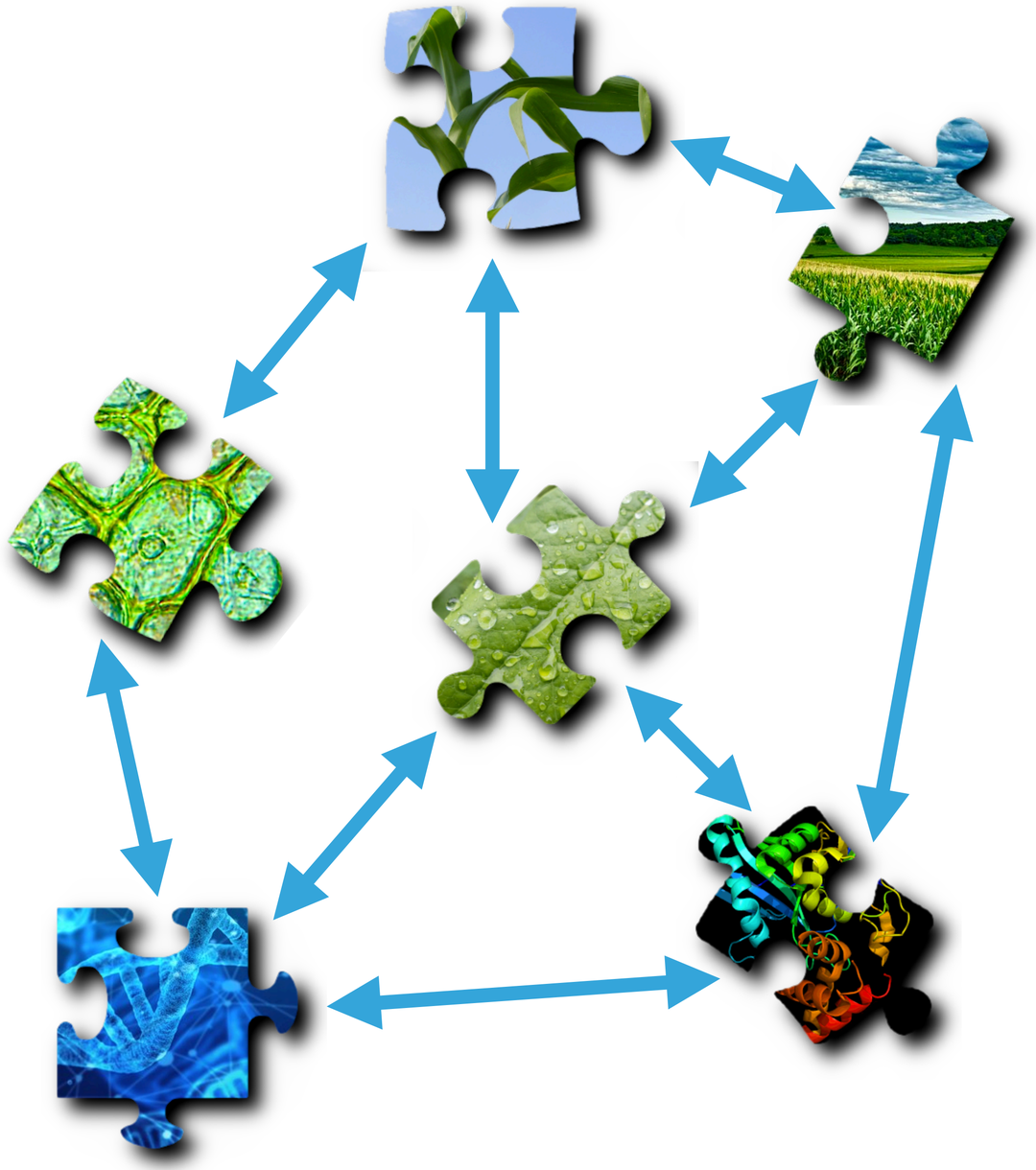
Broker-less communication sockets via TCP, IPC, UDP, inproc, etc.; available on all OSs

RABBITMQ

Brokered communication; requires a RabbitMQ server, but allows for more reliable communication with remote machines

FILES

Slow due to interaction with the disk, but useful for input/output of parameters in a generic way that allows the same model to be used w/ files or other models

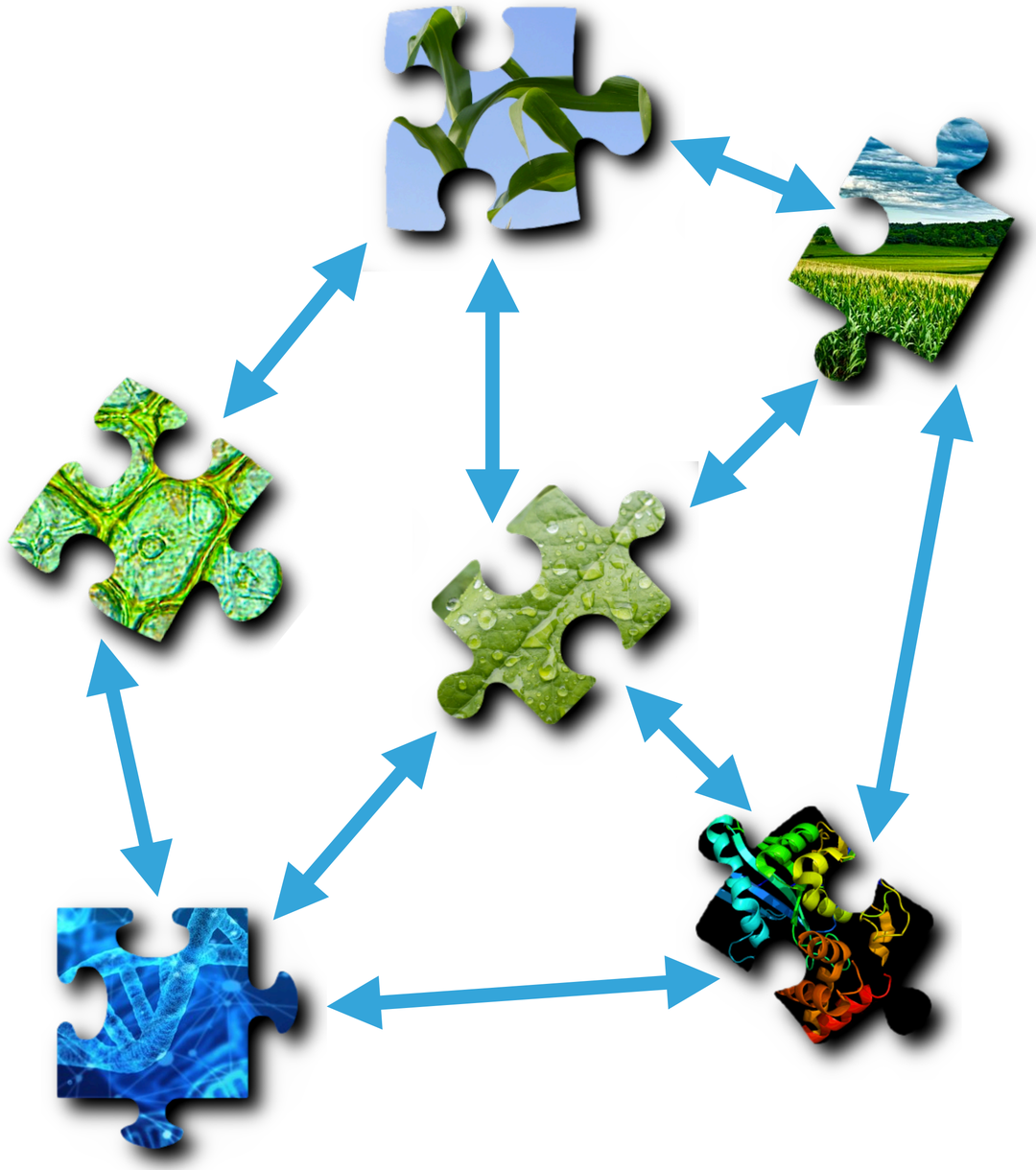


UNITS (AUTOMATED CONVERSION)

UNYT (PYTHON)

MATLAB SYMBOLIC UNITS

R UNITS



UNITS (AUTOMATED CONVERSION)

UNYT (PYTHON)

MATLAB SYMBOLIC UNITS

R UNITS

DATA FORMATS

SCALARS/ARRAYS

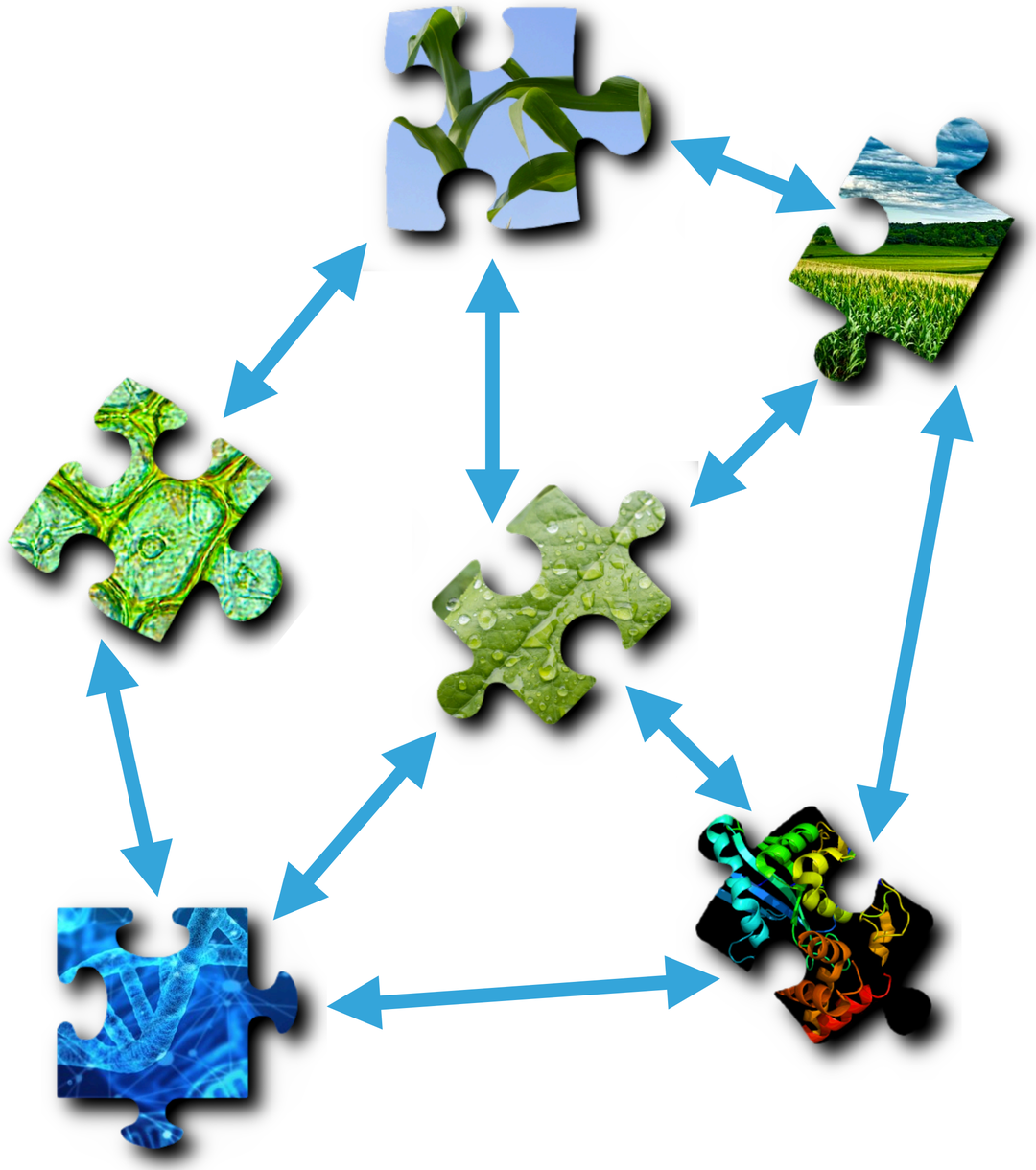
DELIMITED TABLES

PANDAS/R DATA FRAMES

PLY/OBJ

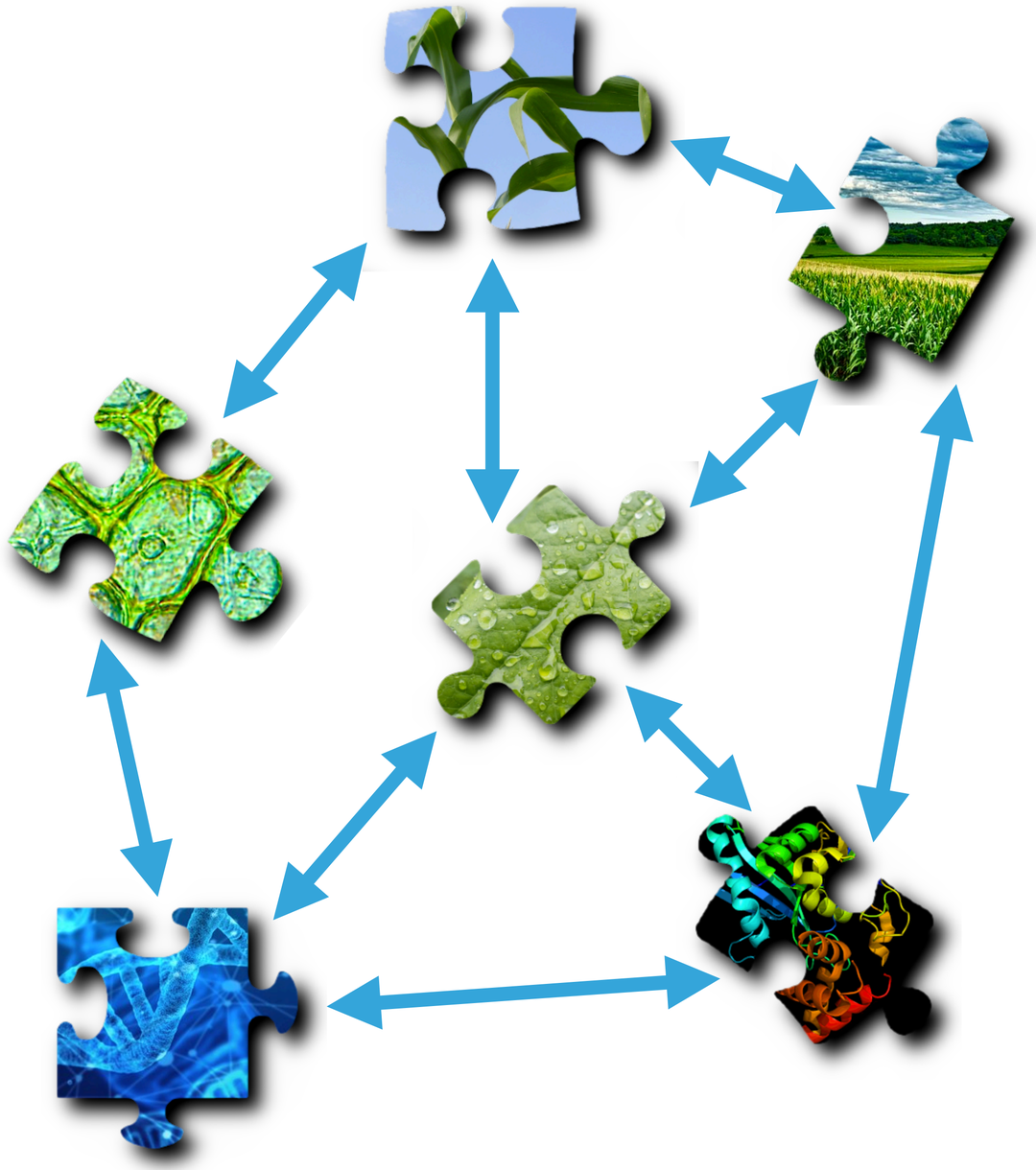
PYTHON PICKLES/
R .RDATA/MATLAB .MAT

EXECUTION



INTEGRATION:

NETWORK OF MODELS
RUN USING YGGDRASIL



YAML SPECIFICATION:

INPUT FILE(S) TO YGGDRASIL CONTAINING INFO ON MODELS & CONNECTIONS

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```yaml
model:
  name: GrowthModel
  language: python
  args: ./src/growth.py
  inputs:
    - light
  outputs:
    - growth_rate
```

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  name: GrowthModel
  language: python
  args: ./src/growth.py
  inputs:
    - light
  outputs:
    - growth_rate

connections:
  - input: LightModel:light
    output: GrowthModel:light
  - input: growth_rate
    output: ./Output/growth.txt
    filetype: table
    field_names: growth_rate
```

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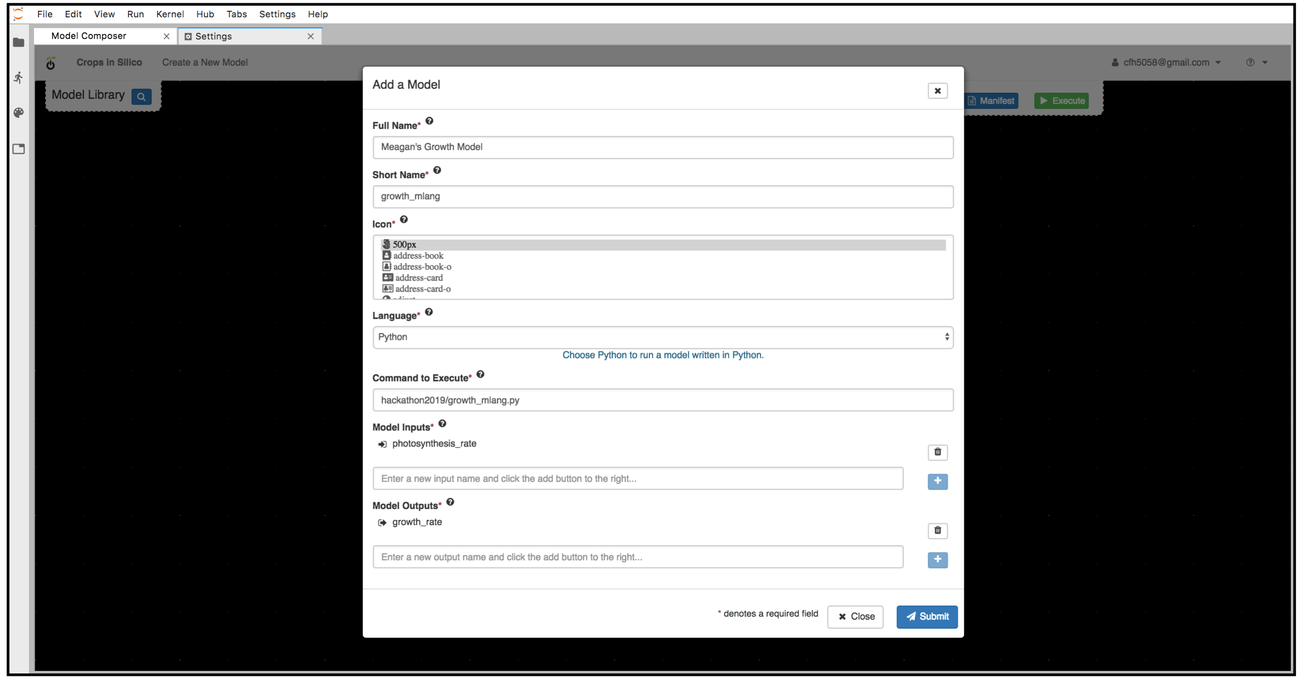
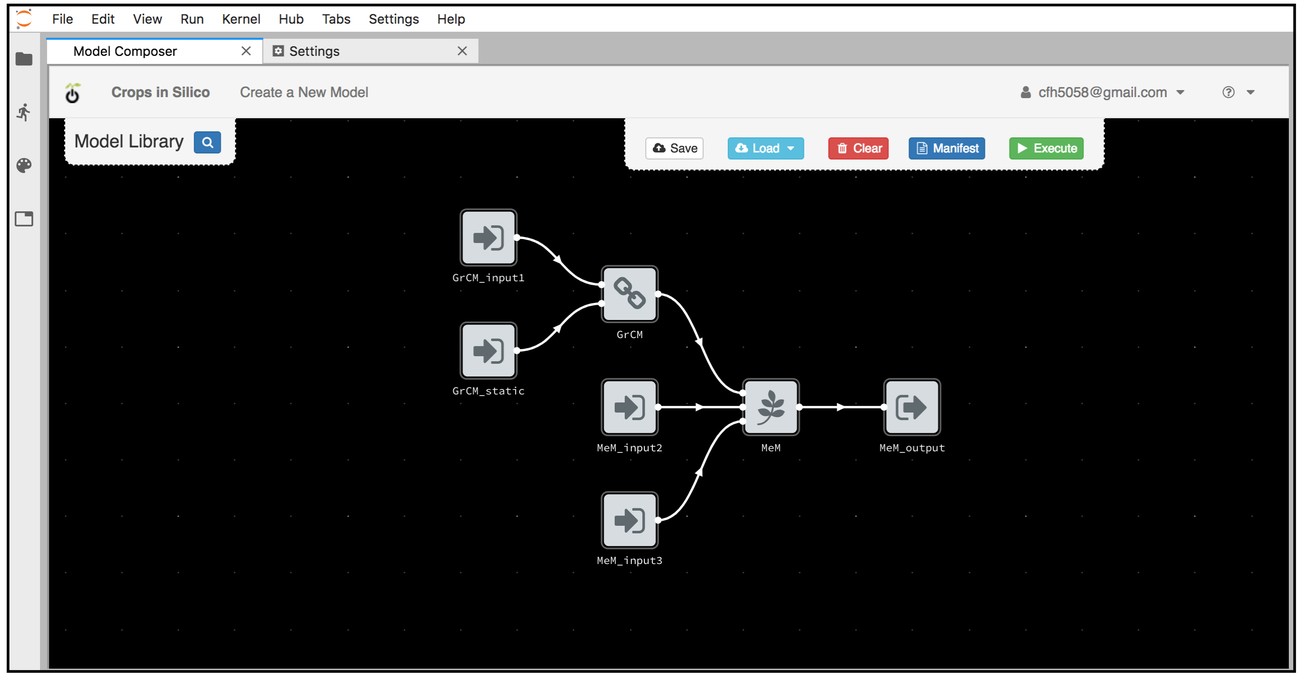
INPUT FILE(S) TO YGGDRASIL CONTAINING INFO ON MODELS & CONNECTIONS



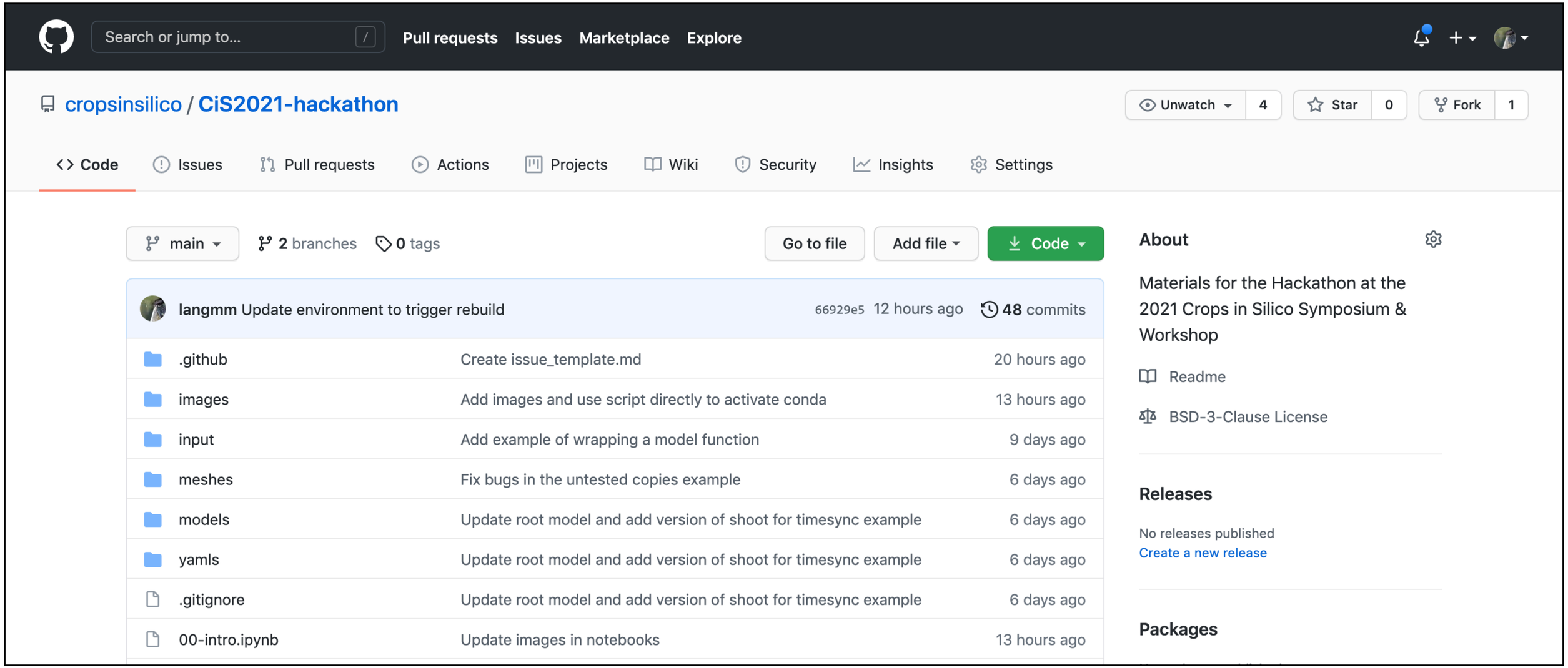


GUI:

GRAPHICAL USER INTERFACE IN DEVELOPMENT FOR YGGDRASIL CAN GENERATE THE YAML

DEBUGGING

GITHUB ISSUES



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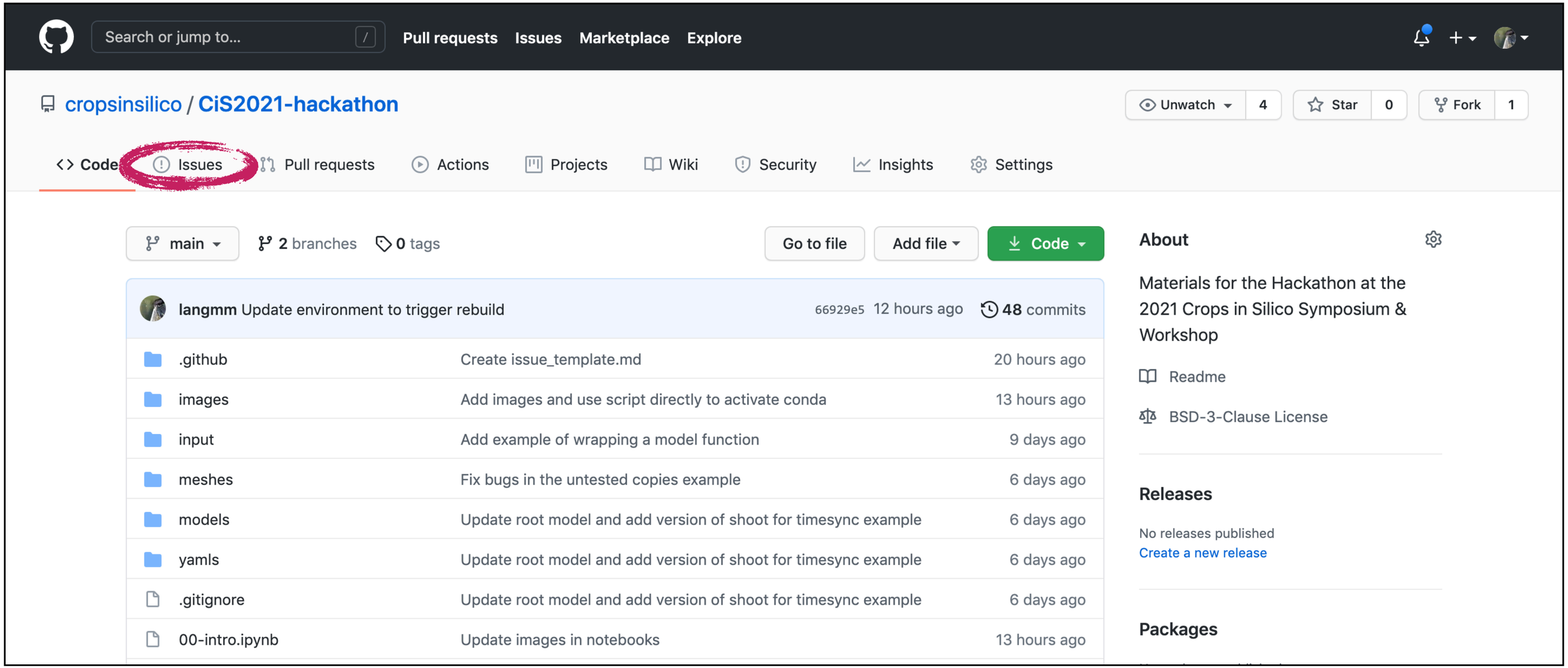

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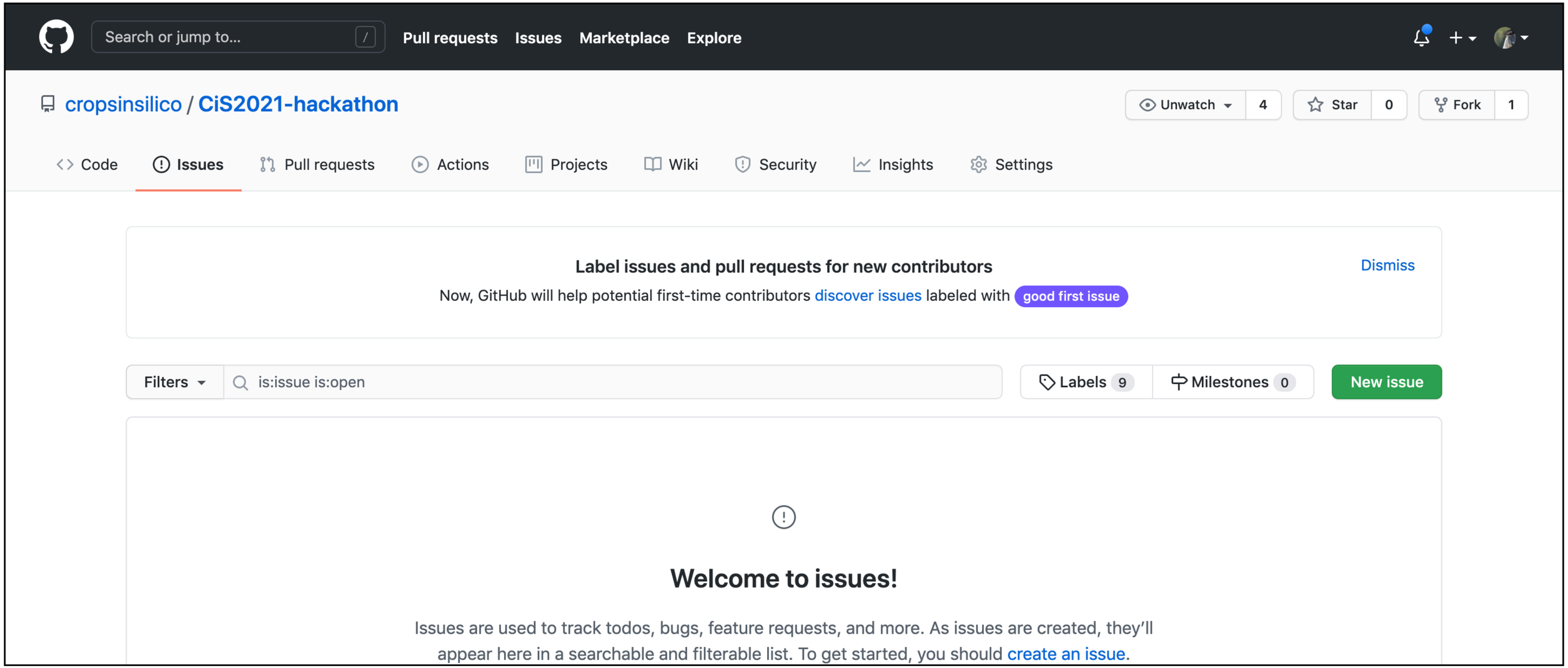

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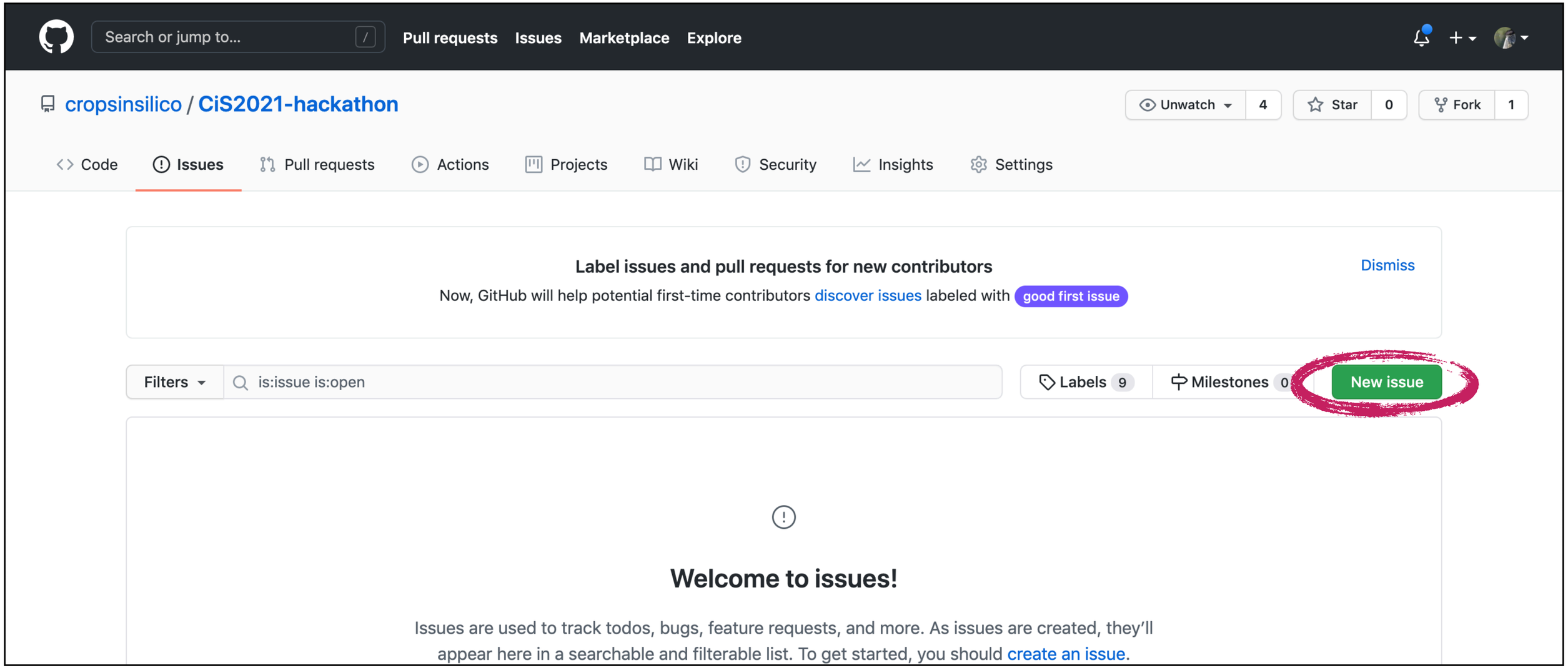

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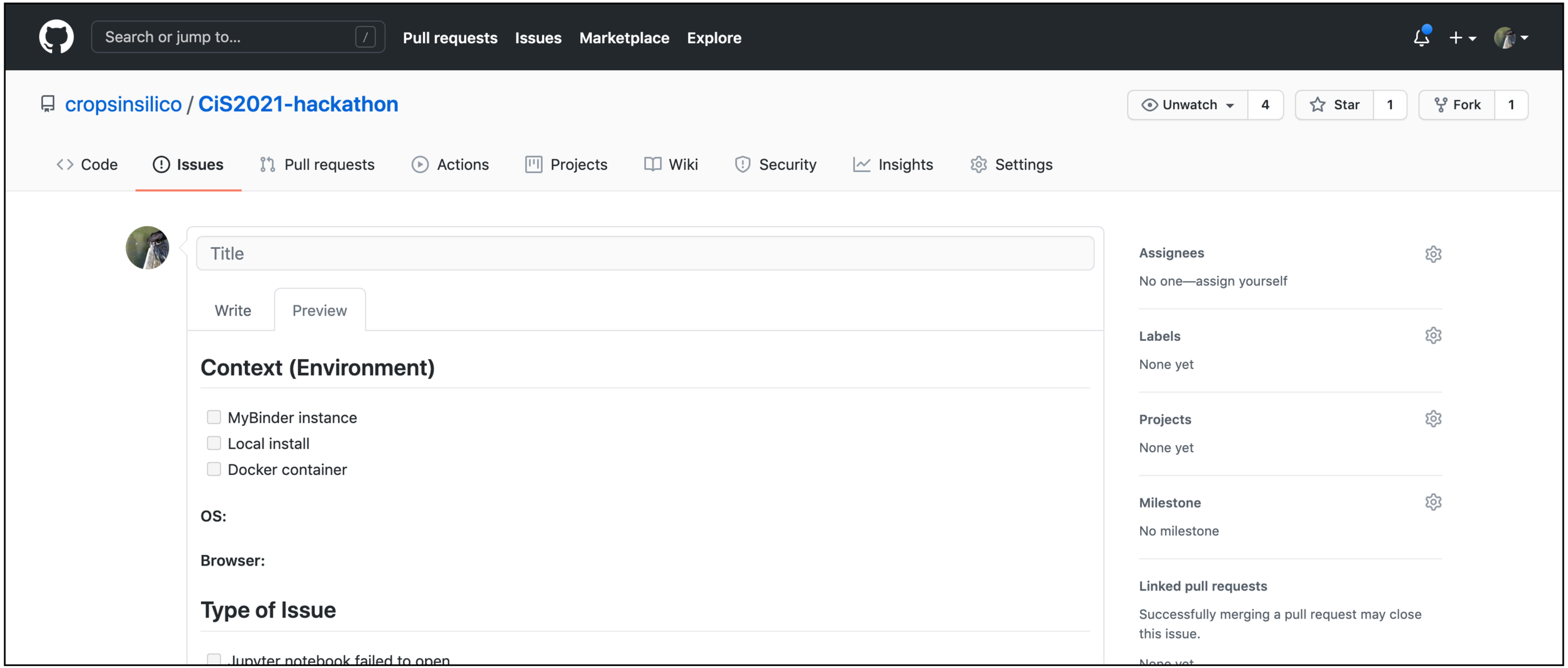
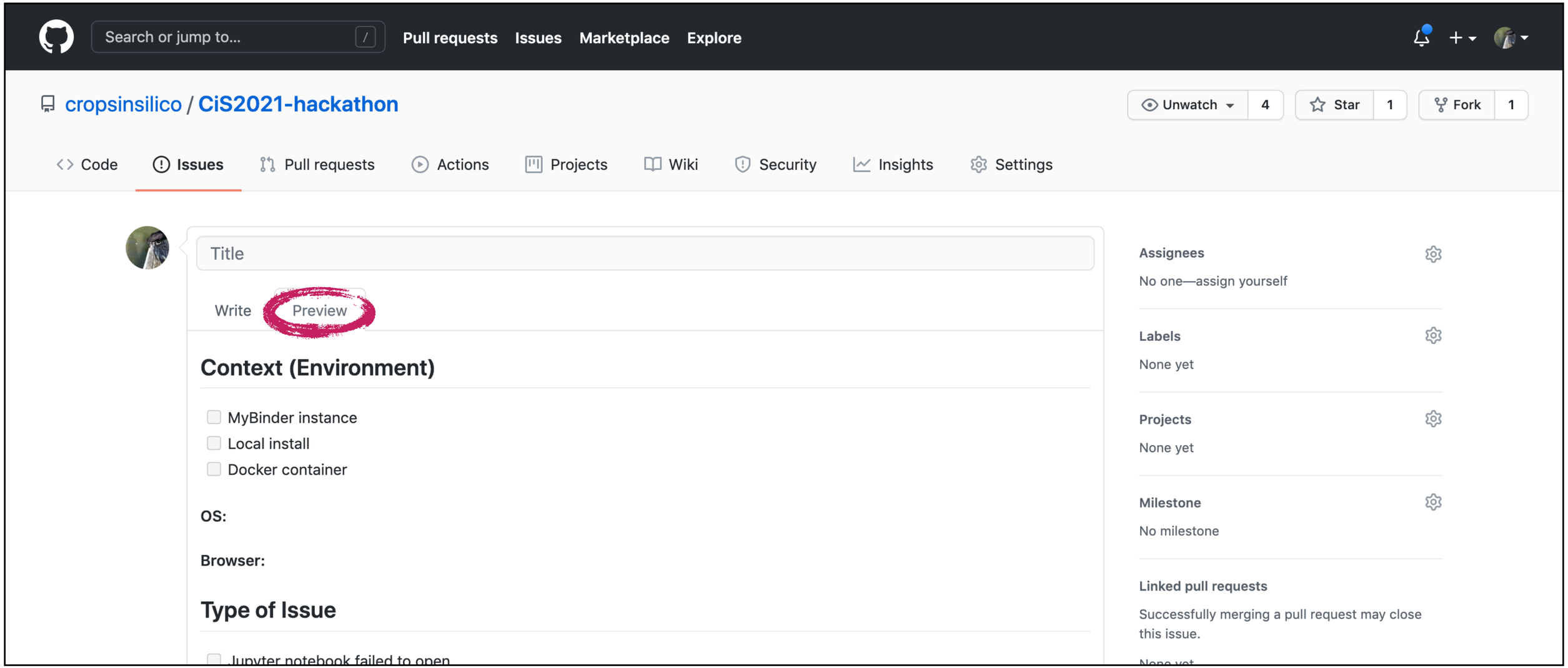


GITHUB ISSUES



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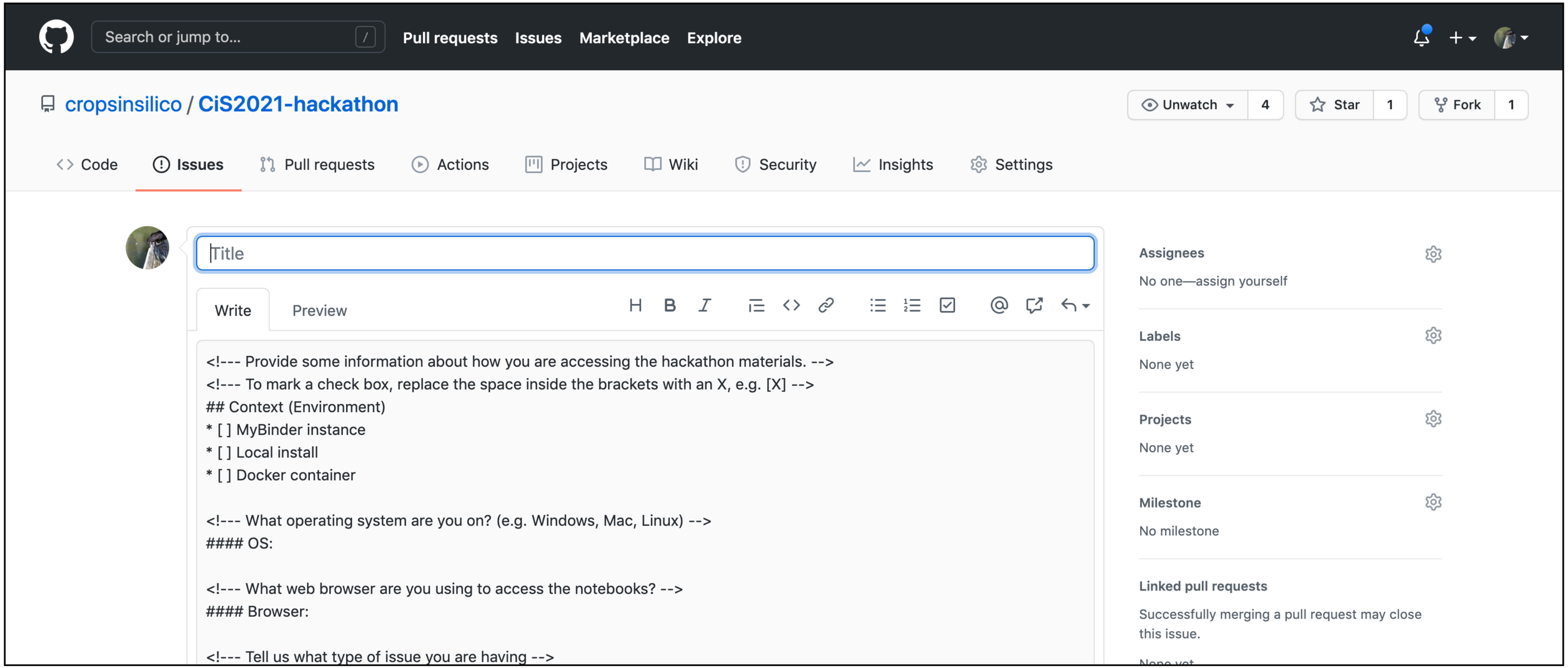

README.md

launch binder

Getting Started

All of the materials for the 2021 Crops in Silico Hackathon can be found in this repository.

Requirements

- Browser (tested on Google Chrome, Safari, Firefox)
- Github Account

Preparing for the hackathon

- Check that you can sign-in to Github, creating an account as necessary. We will be using Github Issues to track problems encountered during the hackathon.
- Try launching a mybinder instance by clicking on this launch binder icon (or the link below). It may take a few moments to initialize. If you encounter an error, open an issue and try with another browser. If you still cannot launch the binder, follow the instruction here for downloading and installing the materials locally.

https://mybinder.org/v2/gh/cropsinsilico/CiS2021-hackathon/HEAD

Useful links

- Hackathon Repository
- yggdrasil Repository
- yggdrasil Documentation
- Additional Examples
- Debugging Tips & Documented Errors

OTHER RESOURCES

README.md

launch binder

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yggdrasil
1.6.1

Search docs

CONTENTS:

- Overview
- Installation
- Getting started
- Formatted I/O
- Server/Client I/O
- Autowrapping Model Functions
- Notes on Autowrapping C/C++ Model Functions
- Conditional I/O
- Transformed I/O
- Timestep Synchronization
- YAML Files
- Configuration Files
- Units
- C-Style Format Strings
- Debugging
  - Tips for Debugging
  - Possible Errors
- OpenMP Threading in Models
- Examples

» Debugging View page source

Debugging

Tips for Debugging

1. *Look at the full output.* The final error raised by yggdrasil may not contain all of the informations provided by errors that were raised within a model due to limitations of error forwarding between the different languages. It is important to look at the full output from a failed run. Usually the first error encountered or the error raised within the model's language will be the most relevant and be the most useful for debugging.
2. *Check for known errors.* The list below includes several errors that have already been encountered by yggdrasil users and the method used to solve the issue.
3. *Turn on debugging log messages.* This will increase the number of log messages greatly and help you track down any issues. Debug messages can be enabled by setting the `ygg` and `client` debug options in your config file to `DEBUG` (see Configuration Options for details on the location of the user config file and additional logging options).
4. *Trace the flow of data.* Use the debug messages to trace the flow of data from one model to the next and determine where the failure is occuring.
5. *Check |yggdrasil| summary.* yggdrasil includes a command line utility, `ygginfo` that will print out relevent information about yggdrasil, the languages it supports, and the operating system. This information can be useful for running down conflicting dependencies or determining why yggdrasil thinks a language is or isn't install. Additional information about the system can be display by adding the `--verbose` flag, including the current conda environment information (if you are using a conda environment) and informaiton about the current R installation (if R is installed). This information should be included in any Github issues opened related to bugs in order to help us assist you.

DEMO TIME!

Thanks to Google Cloud, OVH, GESIS Notebooks and the Turing Institute for supporting us! 🎉

Starting repository: cropsinsilico/CiS2021-hackathon/HEAD

You can connect with the Binder community in the Jupyter community forum.

Build logs hide

```
libgfortran-ng-9.3.0 | 22 KB     | ########## | 100%
gitdb-4.0.7          | 46 KB     | ########## | 100%
r-jsonlite-1.7.2     | 462 KB    | ########## | 100%
smmap-3.0.5          | 22 KB     | ########## | 100%
czmq-4.2.1           | 540 KB    | ########## | 100%
networkx-2.5.1       | 1.2 MB    | ########## | 100%
gcc_linux-64-9.3.0   | 23 KB     | ########## | 100%
openjpeg-2.4.0       | 444 KB    | ########## | 100%
r-rappdirs-0.3.3     | 50 KB     | ########## | 100%
```

jupyter

Visit repo | Copy Binder link | Quit

Files | Running | Clusters | Nbextensions

Select items to perform actions on them.

Upload | New | ↻

0 / | Name ↓ | Last Modified | File size

images	33 minutes ago	
input	33 minutes ago	
meshes	33 minutes ago	
models	33 minutes ago	
yamls	33 minutes ago	
00-intro.ipynb	33 minutes ago	457 kB
01-connections.ipynb	33 minutes ago	470 kB
02-timesync.ipynb	33 minutes ago	298 kB
03-misc.ipynb	33 minutes ago	3.56 kB

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Introduction

(NOTE: This notebook is intended for use with the slides found here).

This is a Jupyter notebook. It allows us to run code (in this case Python) alongside text in different "cells". This cell is a markdown cell that can display text and html, the next cell is a code cell.

In the code cells (prefixed by `In [ ]:`), you can assign variables, perform calculations or call external functions/classes. You can run code cells by selecting the cell (so that a blue or green box appears around it) and then clicking the run button (located at the top of the page) or pressing `Shift+Enter` together. Then a number will appear inside the brackets indicating the order of when the cell was executed.

Output from the cell will be displayed below it with the `Out[#]:` prefix where the number in the brackets indicates the input cell that generated it.

In [ ]:
```
x = 1
y = 3
z = (x + y)**3
z
```

Any Python code can be used, and we can import external packages as well just like in Python scripts. Cells can also use any variables created in any previously executed cell. The cell below imports some tools that will be used in the rest of this notebook.

jupyter 00-intro Last Checkpoint: 8 minutes ago (autosaved)

Logout

File Edit View Insert Cell Kernel Help

Not Trusted

Python 3

Run

Markdown

TEXT CELL

Introduction

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CODE CELL

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NOTEBOOK INTRO

Code cells can contain any valid Python code

Run cells by holding shift and pressing enter

(shift + enter)

In [ ]:
```
x = 1
y = 3
z = (x + y)**3
z
```

Code cells can contain any valid Python code

Run cells by holding shift and pressing enter

(shift + enter)

In [1]:
```
x = 1
y = 3
z = (x + y)**3
z
```

Out[1]: 64

Code cells can contain any valid Python code

Run cells by holding shift and pressing enter

(shift + enter)

In [1]:
```
x = 1
y = 3
z = (x + y)**3
z
```

Out[1]: 64

Output appears below

Number in bracket is the order of execution

("*" indicates the cell is still running)

We need some tools!

trimesh - package for loading/displaying meshes in the notebook
yggdrasil - the method for running yggdrasil integration

In [2]:
```
from yggdrasil import tools  # Displaying syntax
from yggdrasil.runner import run  # Running integ
import trimesh  # Load & display 3D meshes
```

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```

No output, so nothing appears below

Lets load & display some 3D mesh data

In [ ]:
```
fname = 'meshes/plants-2.obj'
mesh = trimesh.load_mesh(fname)
mesh.show()
```

Lets load & display some 3D mesh data

In [3]:
```
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mesh = trimesh.load_mesh(fname)
mesh.show()
```
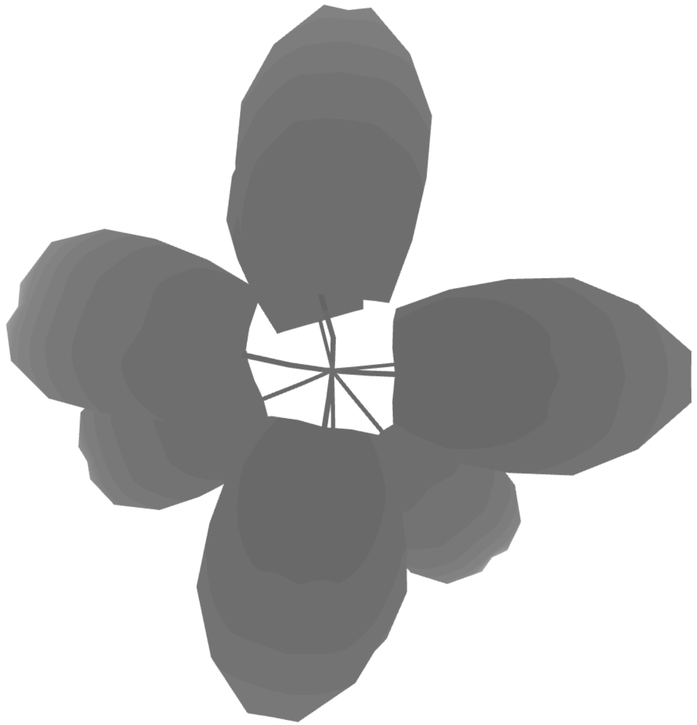
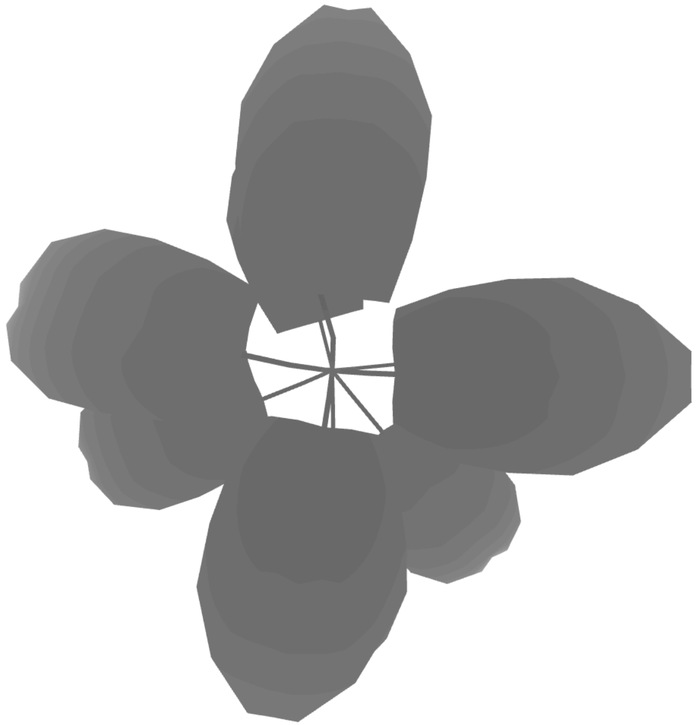

Out[3]:



Lets load & display some 3D mesh data

In [3]:
```
fname = 'meshes/plants-2.obj'
mesh = trimesh.load_mesh(fname)
mesh.show()
```

Out[3]:



Click and drag
to move mesh

INTEGRATING MODELS AS FUNCTIONS

In [4]:
```
tools.display_source('models/light_v0.py', number_lines=True)
```

```
file: models/light_v0.py
========================
 1: import numpy as np
 2: from yggdrasil import units
 3:
 4:
 5: def light(doy, height):
 6:     r"""Compute the intensity of light.
 7:
 8:     Args:
 9:         doy (float): Day of year.
10:         height (float): Distance from ground in cm.
11:
12:     Returns:
13:         float: Intensity of light in ergs cm^-2 s^-1.
14:
15:     """
16:     # Define parameters that are static across a run
17:     amplitude = units.add_units(80.0, 'ergs cm^-3 s^-1')
18:     doy_offset = units.add_units(0.0, 'days')
19:
20:     # Calculate intensity
21:     intensity = (
22:         amplitude * height *
23:         (1.0 + np.sin(2.0 * np.pi * (doy - doy_offset) /
24:                       units.add_units(365.0, 'days'))))
25:
26:     return intensity
```

In [5]:
```
tools.display_source('yamls/light_v0_python.yml', number_lines=True)
```

```
file: yamls/light_v0_python.yml
================================
 1: model:
 2:    name: light
 3:    language: python
 4:    args: ../models/light_v0.py
 5:    function: light
```

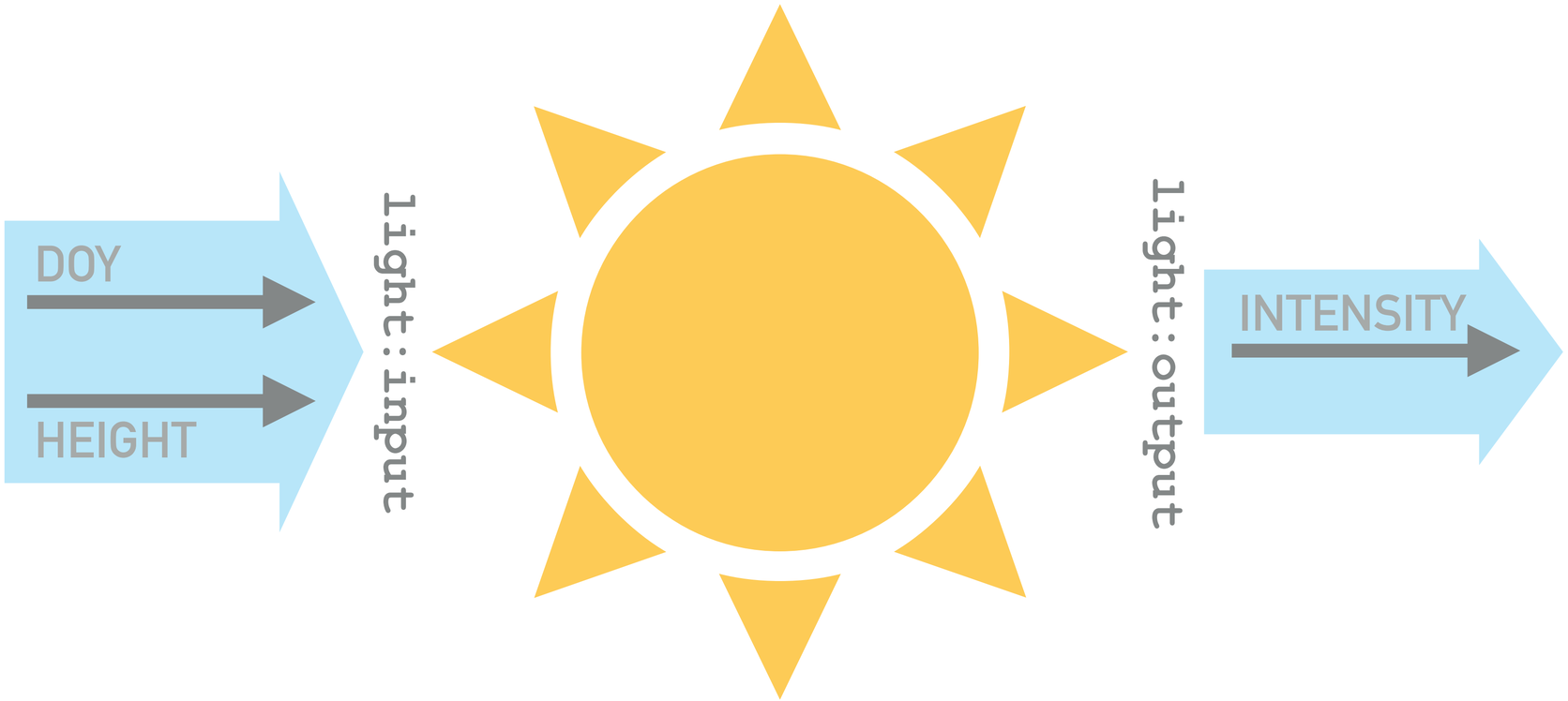
```
In [5]: tools.display_source('yamls/light_v0_python.yml', number_lines=True)
```

```
file: yamls/light_v0_python.yml
================================
 1: model:
 2:    name: light
 3:    language: python
 4:    args: ../models/light_v0.py
 5:    function: light
```

YAMLs provide info needed to run model

function - name of the function that yggdrasil should wrap

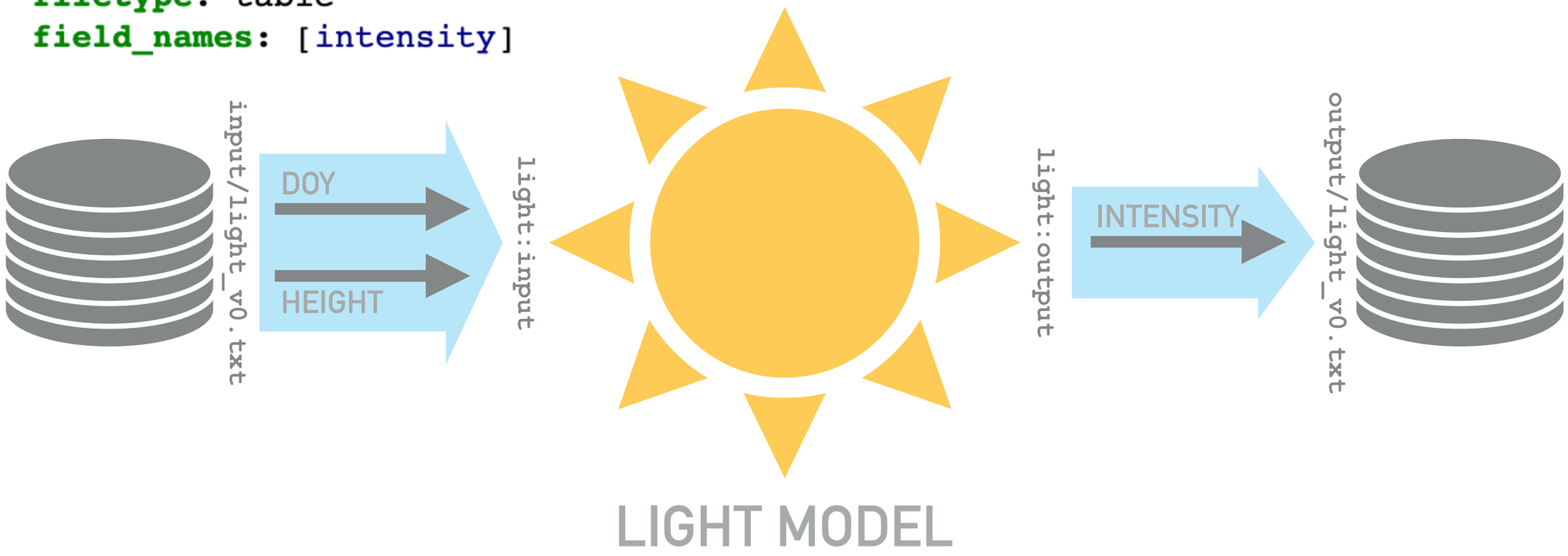

DOY
HEIGHT
INTENSITY
LIGHT MODEL


DOY
HEIGHT
light:input
light:output
INTENSITY
LIGHT MODEL


output/light_v0.txt
INTENSITY
light:output
light:input
DOY
HEIGHT
input/light_v0.txt
LIGHT MODEL

In [6]:
```
tools.display_source('yamls/connections_v0.yml', number_lines=True)
```

```
file: yamls/connections_v0.yml
==============================
 1: connections:
 2:   - input:
 3:       name: ../input/light_v0.txt
 4:       filetype: table
 5:     output: light:input
 6:   - input: light:output
 7:     output:
 8:       name: ../output/light_v0.txt
 9:       filetype: table
10:       field_names: [intensity]
```



In [7]:
```
run(['yamls/light_v0_python.yml', 'yamls/connections_v0.yml'], production_run=True)
```

```
INFO:88383:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
End of input from temp_doy.
INFO:88383:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:88383:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:88383:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:88383:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:88383:runner.run[374]:YggRunner(runner):          load drivers      0.309536
INFO:88383:runner.run[374]:YggRunner(runner):         start drivers      0.091199
INFO:88383:runner.run[374]:YggRunner(runner):            run models      5.400952
INFO:88383:runner.run[374]:YggRunner(runner):               at exit      0.023104
INFO:88383:runner.run[376]:YggRunner(runner): ========================================
INFO:88383:runner.run[377]:YggRunner(runner):                 Total      5.824792
```

In [7]:
```
run(['yamls/light_v0_python.yml', 'yamls/connections_v0.yml'], production_run=True)
```

```
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INFO:88383:runner.run[376]:YggRunner(runner): ========================================
INFO:88383:runner.run[377]:YggRunner(runner):                 Total      5.824792
```

In [8]:
```
tools.display_source('output/light_v0.txt', number_lines=True)
```

```
file: output/light_v0.txt
=========================
 1: # intensity
 2: # erg/(cm**2*s)
 3: # %g
 4: 0
 5: 40.6885
 6: 82.7537
 7: 168.259
 8: 342.017
 9: 434.386
10: 617.737
11: 896.166
```

In [9]:
```
tools.display_source('models/light_v0.cpp', number_lines=True)
tools.display_source('yamls/light_v0_cpp.yml', number_lines=True)
run(['yamls/light_v0_cpp.yml', 'yamls/connections_v0.yml'], production_run=True)
tools.display_source('output/light_v0.txt', number_lines=True)
```

```
file: models/light_v0.cpp
=========================
 1: #define _USE_MATH_DEFINES  // Required to use M_PI with MSVC
 2: #include <math.h>
 3:
 4: /*!
 5:   @brief Compute the intensity of light.
 6:
 7:   @param[in] doy Day of year.
 8:   @param[in] height Distance from ground in cm.
 9:
10:   @returns intensity Intensity of light in ergs cm^-2 s^-1.
11:  */
12: double light(double doy, double height) {
13:   // Define parameters that are static across a run
14:   double amplitude = 80.0;
15:   double doy_offset = 0.0;
16:
17:   // Calculate intensity
18:   double intensity = amplitude * height * (1.0 + sin(2.0 * M_PI * (doy - doy_offset) / 365));
19:
20:   return intensity;
21: }
```

In [9]:
```
tools.display_source('models/light_v0.cpp', number_lines=True)
tools.display_source('yamls/light_v0_cpp.yml', number_lines=True)
run(['yamls/light_v0_cpp.yml', 'yamls/connections_v0.yml'], production_run=True)
tools.display_source('output/light_v0.txt', number_lines=True)
```

```
file: yamls/light_v0_cpp.yml
============================
 1: model:
 2:   name: light
 3:   language: c++
 4:   args: ../models/light_v0.cpp
 5:   function: light
 6:   inputs:
 7:     - name: input
 8:       vars: [doy, height]
 9:       datatype:
10:         type: array
11:         items:
12:           - type: float
13:             units: day
14:           - type: float
15:             units: cm
16:   output:
17:     - name: output
18:       datatype:
19:         type: float
20:         units: ergs/(cm**2*s)
```

In [9]:
```
tools.display_source('models/light_v0.cpp', number_lines=True)
tools.display_source('yamls/light_v0_cpp.yml', number_lines=True)
run(['yamls/light_v0_cpp.yml', 'yamls/connections_v0.yml'], production_run=True)
tools.display_source('output/light_v0.txt', number_lines=True)
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INFO:91854:runner.run[374]:YggRunner(runner):         start drivers      0.148603
INFO:91854:runner.run[374]:YggRunner(runner):            run models      0.533877
INFO:91854:runner.run[374]:YggRunner(runner):               at exit      0.075296
INFO:91854:runner.run[376]:YggRunner(runner): ========================================
INFO:91854:runner.run[377]:YggRunner(runner):                 Total      4.614775

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 5: 40.6885
 6: 82.7537
 7: 168.259
 8: 342.017
 9: 434.386
10: 617.737
11: 896.166
```
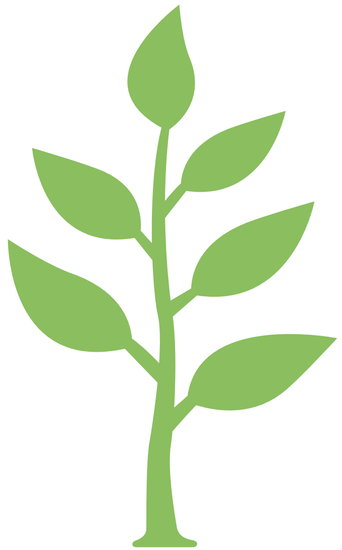

INTEGRATING MODELS VIA INTERFACE

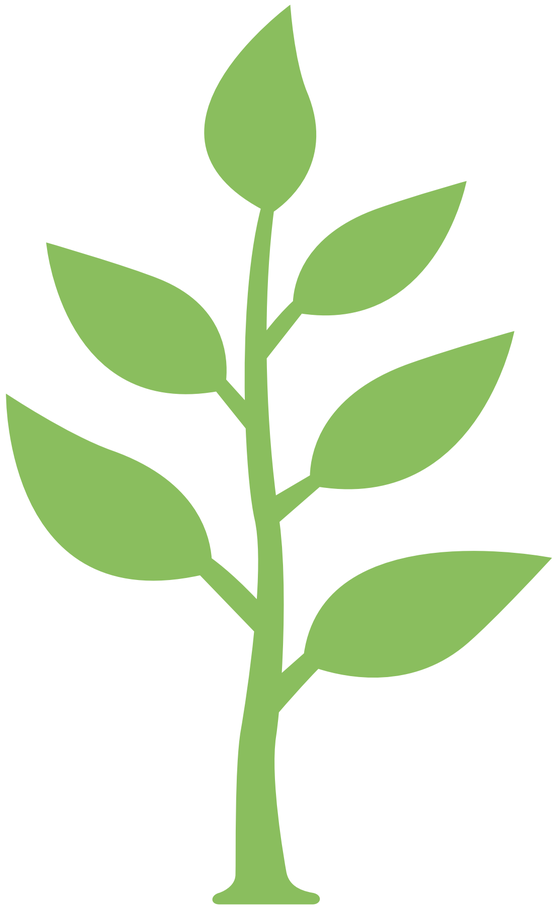
```
In [12]: tools.display_source('models/shoot_v0.py', number_lines=True)
```

file: models/shoot_v0.py

```
 1: import os
 2: import trimesh
 3: import argparse
 4:
 5: _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7: # Parse command-line arguments
 8: parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9: parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10: parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11: parser.add_argument('tstep', help='Time step (in hours)', type=float)
12: parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                     default='../meshes/plants-2.obj')
14: args = parser.parse_args()
15: tmin = args.tmin
16: tmax = args.tmax
17: tstep = args.tstep
18: mesh = trimesh.load_mesh(args.meshfile)
19:
20: # Set initial conditions
21: mass = 2000.0
22: t = tmin
23: i = 0
24:
25: # Continue simulation until time limit is reached
26: while t <= tmax:
27:
28:     # Compute the scale factor
29:     # (pretend this is a biologically complex calculation)
30:     scale = mass / 4.5e4
31:
32:     # Grow the shoot
33:     # (pretend this is a biologically complex calculation)
34:     mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
35:     mass += mass * scale
36:
37:     # Save mesh for this timestep
38:     filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
39:     with open(filename_mesh, 'w') as fd:
40:         mesh.export(fd, 'obj')
41:
42:     # Advance time step
43:     t += tstep
44:     i += 1
```



SHOOT
MODEL



SHOOT
MODEL

In [13]:
```
tools.display_source('yamls/shoot_v0.yml', number_lines=True)
run('yamls/shoot_v0.yml', production_run=True)
```

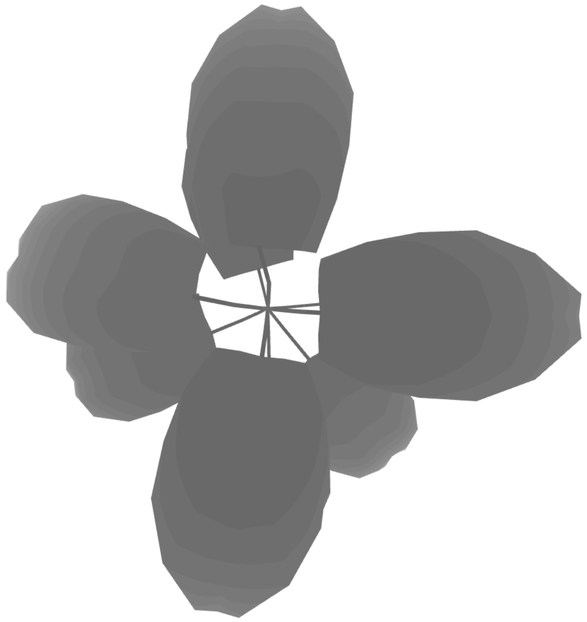
```
file: yamls/shoot_v0.yml
========================
 1: model:
 2:   name: shoot
 3:   language: python
 4:   args: [../models/shoot_v0.py, 0.0, 48.0, 6.0]

INFO:91854:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v0.py 0.0 48.0 6.0
INFO:91854:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:91854:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:91854:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:91854:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:91854:runner.run[374]:YggRunner(runner):          load drivers      0.000918
INFO:91854:runner.run[374]:YggRunner(runner):         start drivers      0.042213
INFO:91854:runner.run[374]:YggRunner(runner):            run models      0.856992
INFO:91854:runner.run[374]:YggRunner(runner):               at exit      0.000524
INFO:91854:runner.run[376]:YggRunner(runner): ========================================
INFO:91854:runner.run[377]:YggRunner(runner):                 Total      0.900648
```

In [13]:
```
tools.display_source('yamls/shoot_v0.yml', number_lines=True)
run('yamls/shoot_v0.yml', production_run=True)
```

```
file: yamls/shoot_v0.yml
========================
 1: model:
 2:   name: shoot
 3:   language: python
 4:   args: [../models/shoot_v0.py, 0.0, 48.0, 6.0]

INFO:91854:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v0.py 0.0 48.0 6.0
INFO:91854:runner.waitModels[553]:Y
INFO:91854:runner.waitModels[559]:Y
INFO:91854:runner.waitModels[573]:Y
INFO:91854:runner.run[374]:YggRunne
INFO:91854:runner.run[374]:YggRunne
INFO:91854:runner.run[374]:YggRunne
INFO:91854:runner.run[374]:YggRunne
INFO:91854:runner.run[374]:YggRunne
INFO:91854:runner.run[376]:YggRunne
INFO:91854:runner.run[377]:YggRunne
```

In [14]:
```
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

Out[14]:



```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil

```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

Import yggdrasil functions and connect to the channel that will be listed in the YAML.

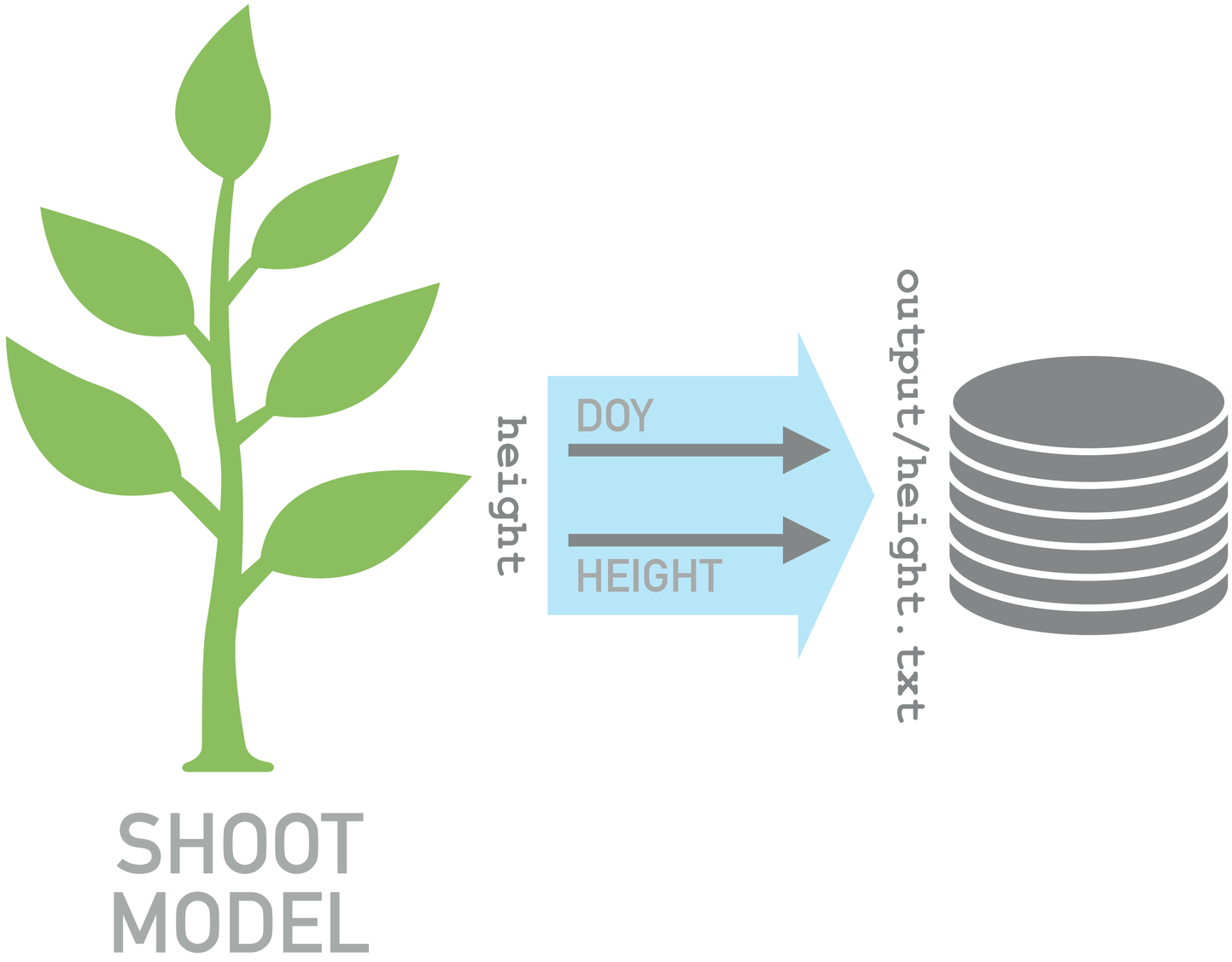
Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil

```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
==========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

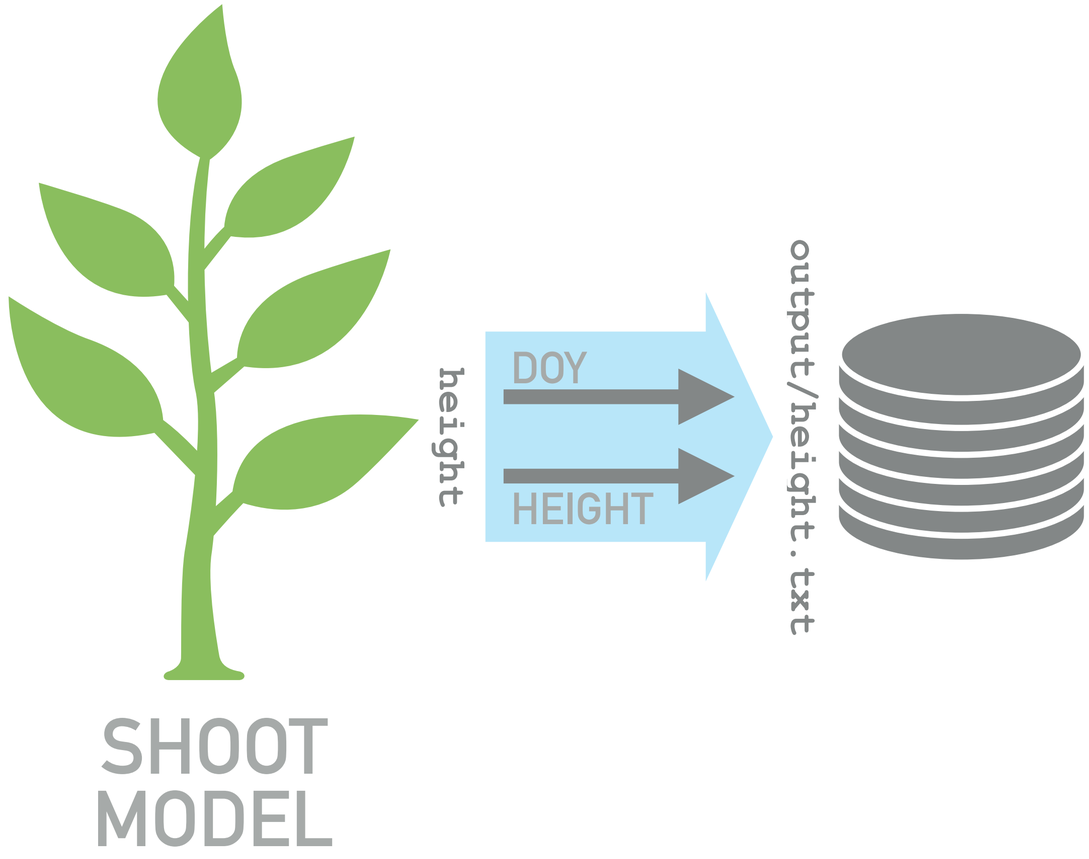
Send height to output channel

Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil


SHOOT
MODEL
height
DOY
HEIGHT
output/height.txt

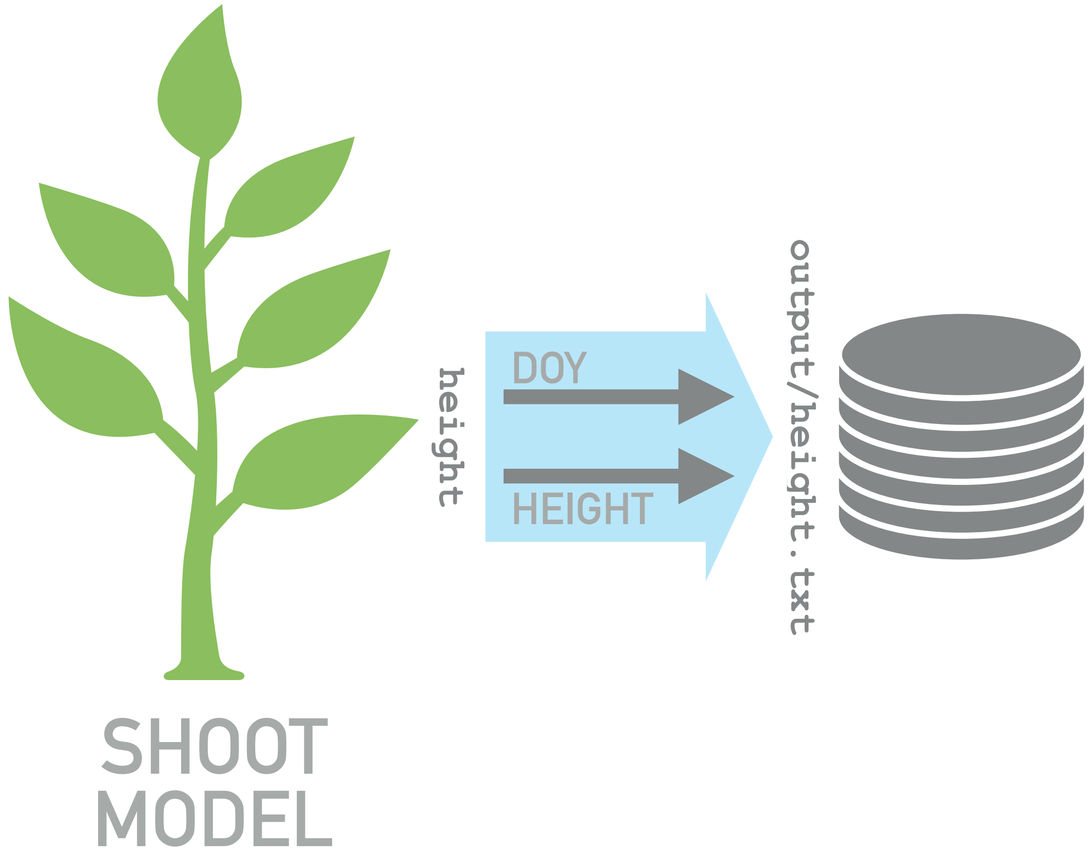
In [16]:
```
tools.display_source_diff('yamls/shoot_v0.yml', 'yamls/shoot_v1.yml', number_lines=True)
```

```
file1: yamls/shoot_v0.yml
file2: yamls/shoot_v1.yml
=========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v0.py, 0.0, 48.0, 6.0]
    ?
 4: +   args: [../models/shoot_v1.py, 0.0, 48.0, 6.0]
    ?
 5: +   outputs:
 6: +     - name: height
 7: +       default_file:
 8: +         name: ../output/height.txt
 9: +         filetype: table
```



```
In [16]: tools.display_source_diff('yamls/shoot_v0.yml', 'yamls/shoot_v1.yml', number_lines=True)
```

```
file1: yamls/shoot_v0.yml
file2: yamls/shoot_v1.yml
=========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v0.py, 0.0, 48.0, 6.0]
    ?

 4: +   args: [../models/shoot_v1.py, 0.0, 48.0, 6.0]
    ?

 5: +   outputs:
 6: +     - name: height
 7: +       default_file:
 8: +         name: ../output/height.txt
 9: +         filetype: table
```



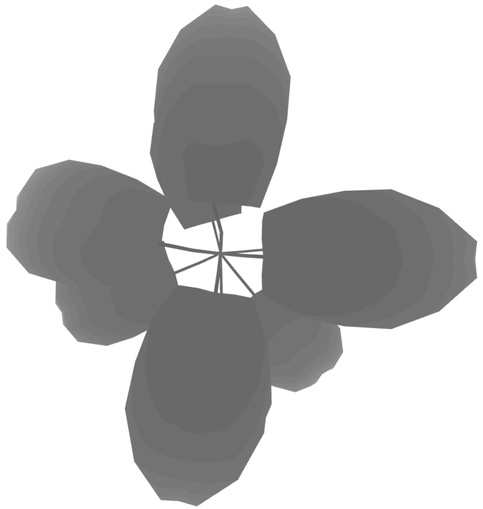
Declare one output with a default file that is only used if no other connection connects to it.

In [17]:
```
run(['yamls/shoot_v1.yml'], production_run=True)
```

```
INFO:91854:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v1.py 0.0 48.0 6.0
INFO:91854:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:91854:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:91854:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:91854:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:91854:runner.run[374]:YggRunner(runner):          load drivers      0.006655
INFO:91854:runner.run[374]:YggRunner(runner):         start drivers      0.060119
INFO:91854:runner.run[374]:YggRunner(runner):             run models      5.849015
INFO:91854:runner.run[374]:YggRunner(runner):                at exit      0.003885
INFO:91854:runner.run[376]:YggRunner(runner): ========================================
INFO:91854:runner.run[377]:YggRunner(runner):                  Total      5.919675
```

In [18]:
```
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

Out[18]:



In [19]:
```
tools.display_source('output/height.txt')
```

```
file: output/height.txt
=======================
# hr     m
# %g     %g
0        77.2603
6        80.6941
12       84.4399
18       88.5415
24       93.0513
30       98.0321
36       103.561
42       109.73
48       116.656
```

NEW NOTEBOOK!
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models	33 minutes ago	
yamls	33 minutes ago	
00-intro.ipynb	33 minutes ago	457 kB
01-connections.ipynb	33 minutes ago	470 kB
02-timesync.ipynb	33 minutes ago	298 kB
03-misc.ipynb	33 minutes ago	3.56 kB

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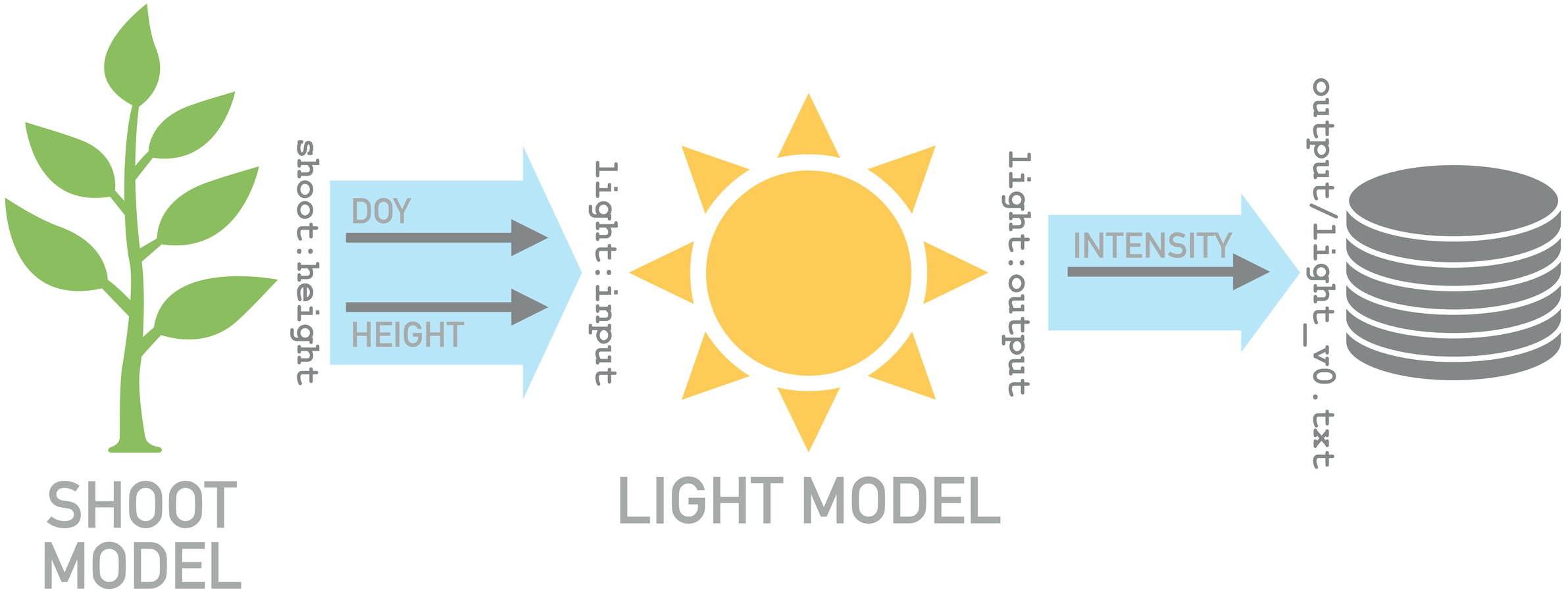
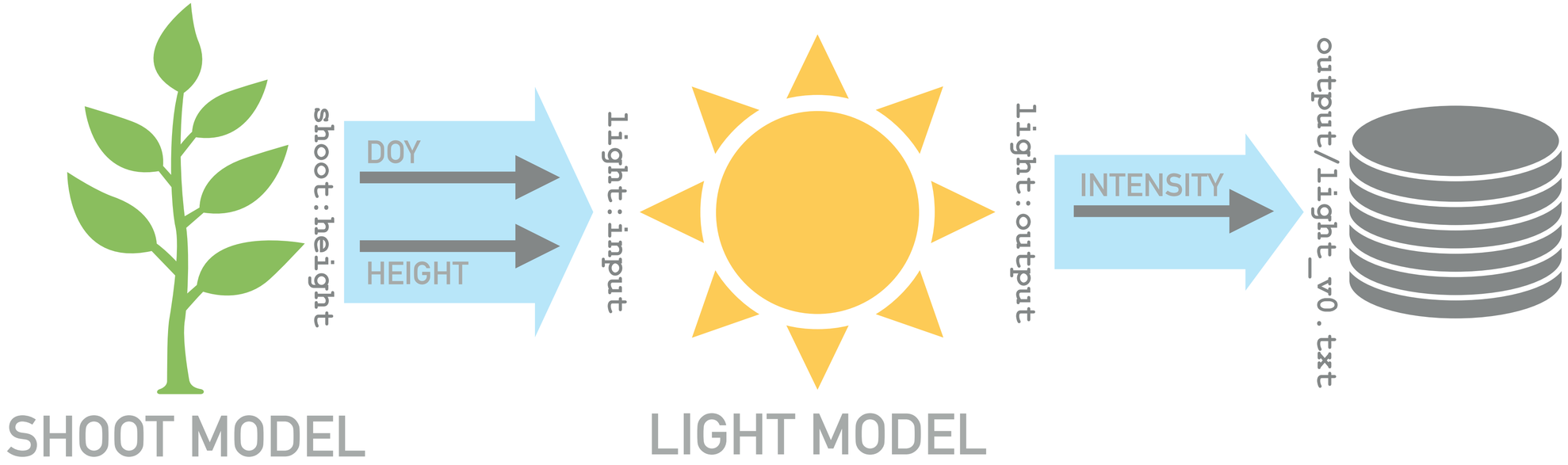
images		33 minutes ago	
input		33 minutes ago	
meshes		33 minutes ago	
models		33 minutes ago	
yamls		33 minutes ago	
00-intro.ipynb		33 minutes ago	457 kB
01-connections.ipynb		33 minutes ago	470 kB
02-timesync.ipynb		33 minutes ago	298 kB
03-misc.ipynb		33 minutes ago	3.56 kB

ONE WAY MODEL-TO-MODEL CONNECTION


shoot:height
DOY
HEIGHT
light:input
light:output
INTENSITY
output/light_v0.txt
SHOOT MODEL
LIGHT MODEL

In [2]:
```
tools.display_source_diff('yamls/connections_v0.yml', 'yamls/connections_v1.yml', number_lines=True)
```

```
file1: yamls/connections_v0.yml
file2: yamls/connections_v1.yml
==============================
 1:   connections:
    -   - input:
 2: +   - input: shoot:height
    ?                                 ++++++++++++

    -       name: ../input/light_v0.txt
    -       filetype: table
 3:       output: light:input
 4:     - input: light:output
 5:       output:
 6:         name: ../output/light_v0.txt
 7:         filetype: table
 8:         field_names: [intensity]
```

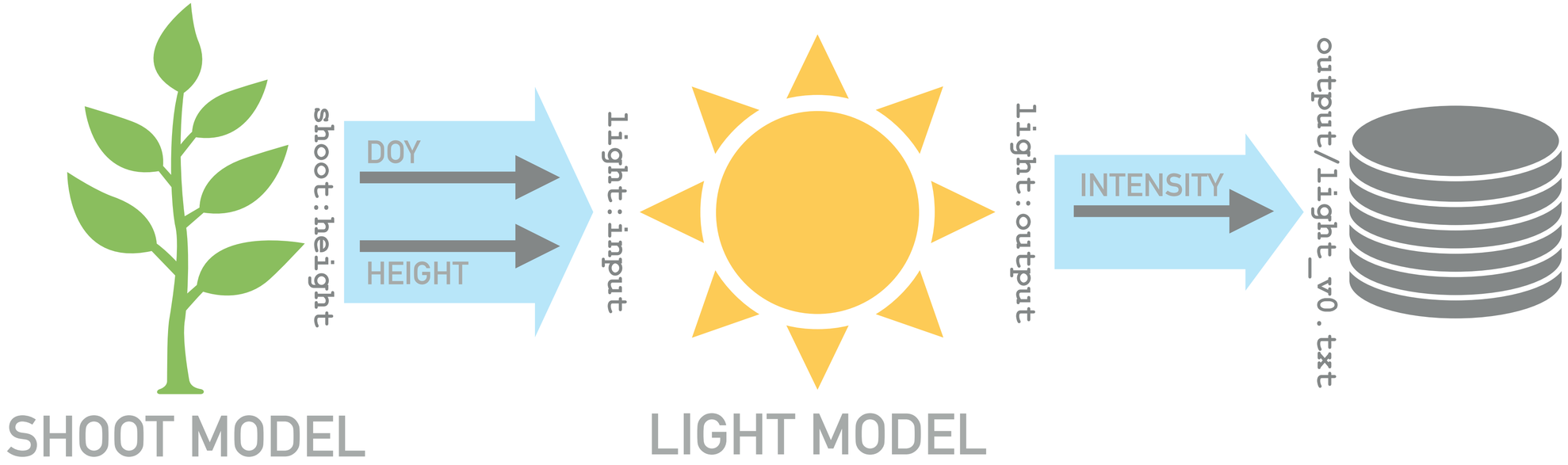


```
In [2]: tools.display_source_diff('yamls/connections_v0.yml', 'yamls/connections_v1.yml', number_lines=True)
```

```
file1: yamls/connections_v0.yml
file2: yamls/connections_v1.yml
==============================
 1:   connections:
    -   - input:
 2: +   - input: shoot:height
    ?                          ++++++++++++

    -       name: ../input/light_v0.txt
    -       filetype: table
 3:       output: light:input
 4:     - input: light:output
 5:       output:
 6:         name: ../output/light_v0.txt
 7:         filetype: table
 8:         field_names: [intensity]
```

Connect light input with shoot output channel "`height`"

The prefix "`shoot:`" indicates the height channel for the shoot model

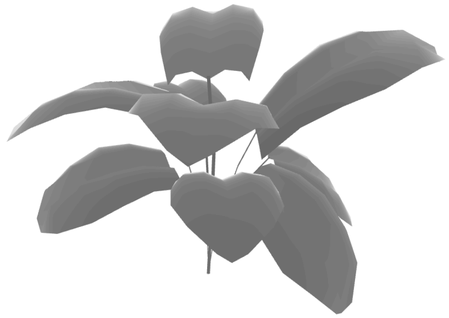


In [3]:
```
run(['yamls/light_v0_python.yml', 'yamls/shoot_v1.yml', 'yamls/connections_v1.yml'], production_run=True)
```

```
INFO:93696:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v1.py 0.0 48.0 6.0
End of input from temp_doy.
INFO:93696:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:93696:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:93696:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:93696:runner.run[374]:YggRunner(runner):                  init      0.000000
INFO:93696:runner.run[374]:YggRunner(runner):          load drivers      0.282206
INFO:93696:runner.run[374]:YggRunner(runner):         start drivers      0.090545
INFO:93696:runner.run[374]:YggRunner(runner):            run models      6.751301
INFO:93696:runner.run[374]:YggRunner(runner):               at exit      0.021096
INFO:93696:runner.run[376]:YggRunner(runner): ========================================
INFO:93696:runner.run[377]:YggRunner(runner):                 Total      7.145148
```

In [4]:
```
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

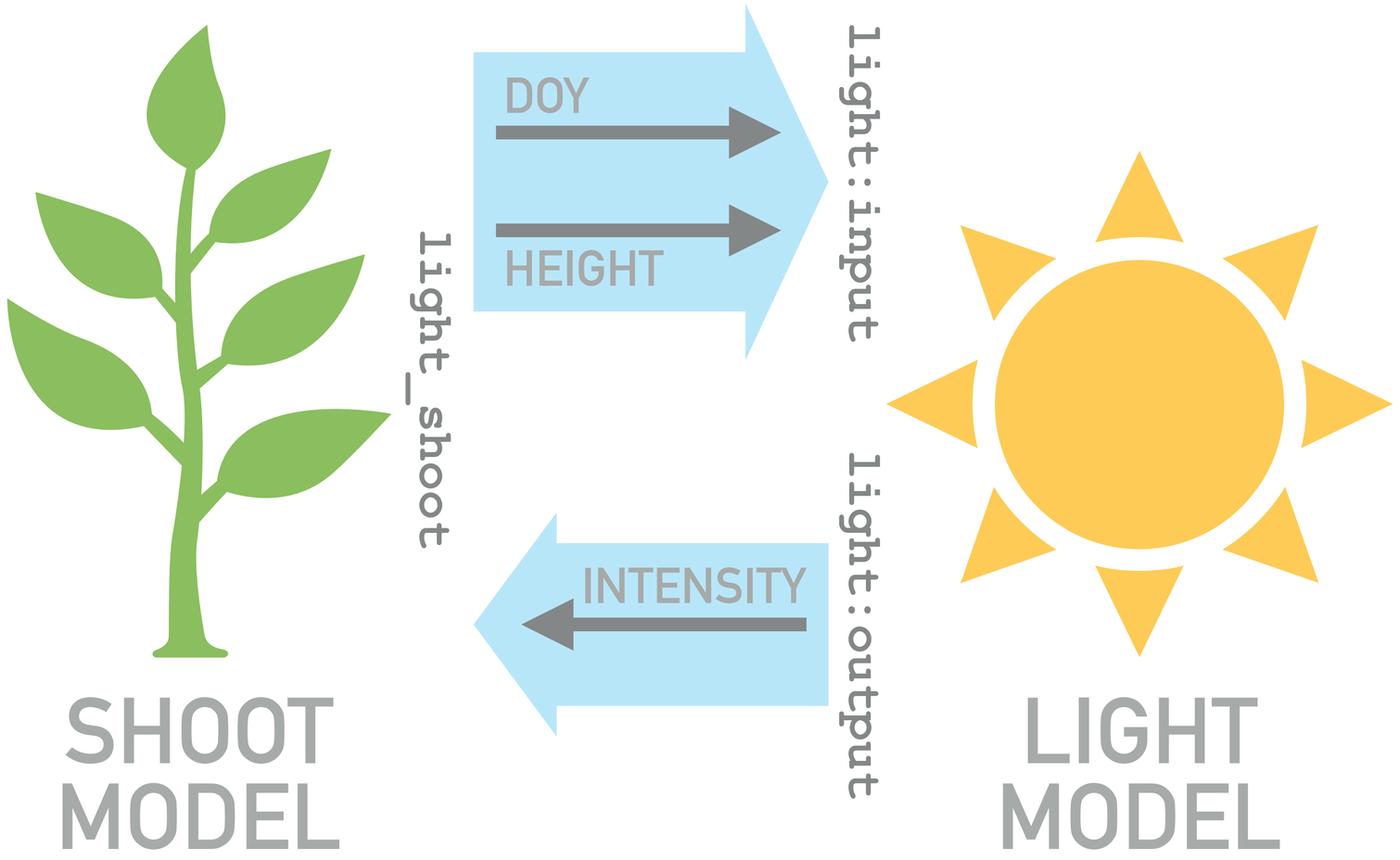
Out[4]:



In [5]:
```
tools.display_source('output/light_v0.txt')
```

```
file: output/light_v0.txt
=========================
# intensity
# erg/(cm**2*s)
# %g
618082
648331
681333
717477
757224
801131
849874
904281
965376
```

REMOTE PROCEDURE CALL (RPC)


DOY
HEIGHT
light::input
light_shoot
INTENSITY
light::output
SHOOT MODEL
LIGHT MODEL

In [6]:
```
tools.display_source_diff('models/shoot_v1.py', 'models/shoot_v2.py', number_lines=True)
```

```
file1: models/shoot_v1.py
file2: models/shoot_v2.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse

...


28:   # If the model is running as part of an yggdrasil integration, import
29:   # the relevant yggdrasil routines and use the interface routine to
30:   # complete the connection defined in the YAML
31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggOutput
    ?
^^ ---

33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient
    ?
^^^^^^^^

    -     height_out = YggOutput('height')
    ?     ^^     ^^^                        ^^^ ^                              ^^

34: +     light_rpc = YggRpcClient('light_shoot')
    ?     ^     ^^^                        ^ ^^^^^^                           ^   ++++++

35:
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
    -         flag = height_out.send(
    ?                              ^^     ^^^                 ^^^^

42: +         flag, intensity = light_rpc.call(
    ?             ++++++++++++                   ^     ^^^                 ^^^^
43:               [units.add_units(t, 'hrs'),
44:                units.add_units(max(mesh.vertices[:, 2]), 'm')])


...
```

```
    -     # Compute the scale factor
47: +
48: +         # Compute the scale factor using intensity, stripping units
49: +         # of the result to allow use with trimesh
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++

51: +         scale = units.get_data(
52: +             units.add_units(mass, 'g') * intensity /
53: +             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
54: +
55: +     else:
56: +         # Compute the scale factor
57: +         # (pretend this is a biologically complex calculation)
    -     scale = mass / 4.5e4
58: +         scale = mass / 4.5e4
    ? ++++
```

```
In [6]: tools.display_source_diff('models/shoot_v1.py', 'models/shoot_v2.py', number_lines=True)
```

```
file1: models/shoot_v1.py
file2: models/shoot_v2.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse

...


28:   # If the model is running as part of an yggdrasil integration, import
29:   # the relevant yggdrasil routines and use the interface routine to
30:   # complete the connection defined in the YAML
31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggOutput
    ?
^^ ---

33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient
    ?
^^^^^^^^

    -     height_out = YggOutput('height')
    ?     ^^     ^^^                        ^^^ ^                          ^^

34: +     light_rpc = YggRpcClient('light_shoot')
    ?     ^     ^^^                        ^ ^^^^^^                         ^   ++++++

35:
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
    -         flag = height_out.send(
    ?                              ^^     ^^^                  ^^^^

42: +         flag, intensity = light_rpc.call(
    ?             ++++++++++                   ^     ^^^                  ^^^^
43:               [units.add_units(t, 'hrs'),
44:                units.add_units(max(mesh.vertices[:, 2]), 'm')])

...
```

```
    -     # Compute the scale factor
47: +
48: +         # Compute the scale factor using intensity, stripping units
49: +         # of the result to allow use with trimesh
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++

51: +         scale = units.get_data(
52: +             units.add_units(mass, 'g') * intensity /
53: +             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
54: +
55: +     else:
56: +         # Compute the scale factor
57: +         # (pretend this is a biologically complex calculation)
    -     scale = mass / 4.5e4
58: +         scale = mass / 4.5e4
    ? ++++
```

Replace the interface function

```
In [6]: tools.display_source_diff('models/shoot_v1.py', 'models/shoot_v2.py', number_lines=True)
```

```
file1: models/shoot_v1.py
file2: models/shoot_v2.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse

...


28:   # If the model is running as part of an yggdrasil integration, import
29:   # the relevant yggdrasil routines and use the interface routine to
30:   # complete the connection defined in the YAML
31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggOutput
    ?
^^ ---

33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient
    ?
^^^^^^^^

    -     height_out = YggOutput('height')
    ?     ^^     ^^^                        ^^^ ^                          ^^

34: +     light_rpc = YggRpcClient('light_shoot')
    ?     ^     ^^^                        ^ ^^^^^^                       ^   ++++++

35:
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
    -         flag = height_out.send(
    ?                              ^^     ^^^                ^^^^

42: +         flag, intensity = light_rpc.call(
    ?             ++++++++++                  ^     ^^^                ^^^^
43:               [units.add_units(t, 'hrs'),
44:                units.add_units(max(mesh.vertices[:, 2]), 'm')])

...
```

```
    -     # Compute the scale factor
47: +
48: +         # Compute the scale factor using intensity, stripping units
49: +         # of the result to allow use with trimesh
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++

51: +         scale = units.get_data(
52: +             units.add_units(mass, 'g') * intensity /
53: +             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
54: +
55: +     else:
56: +         # Compute the scale factor
57: +         # (pretend this is a biologically complex calculation)
    -     scale = mass / 4.5e4
58: +         scale = mass / 4.5e4
    ? ++++
```

Replace the send with a call

```
In [6]: tools.display_source_diff('models/shoot_v1.py', 'models/shoot_v2.py', number_lines=True)
```

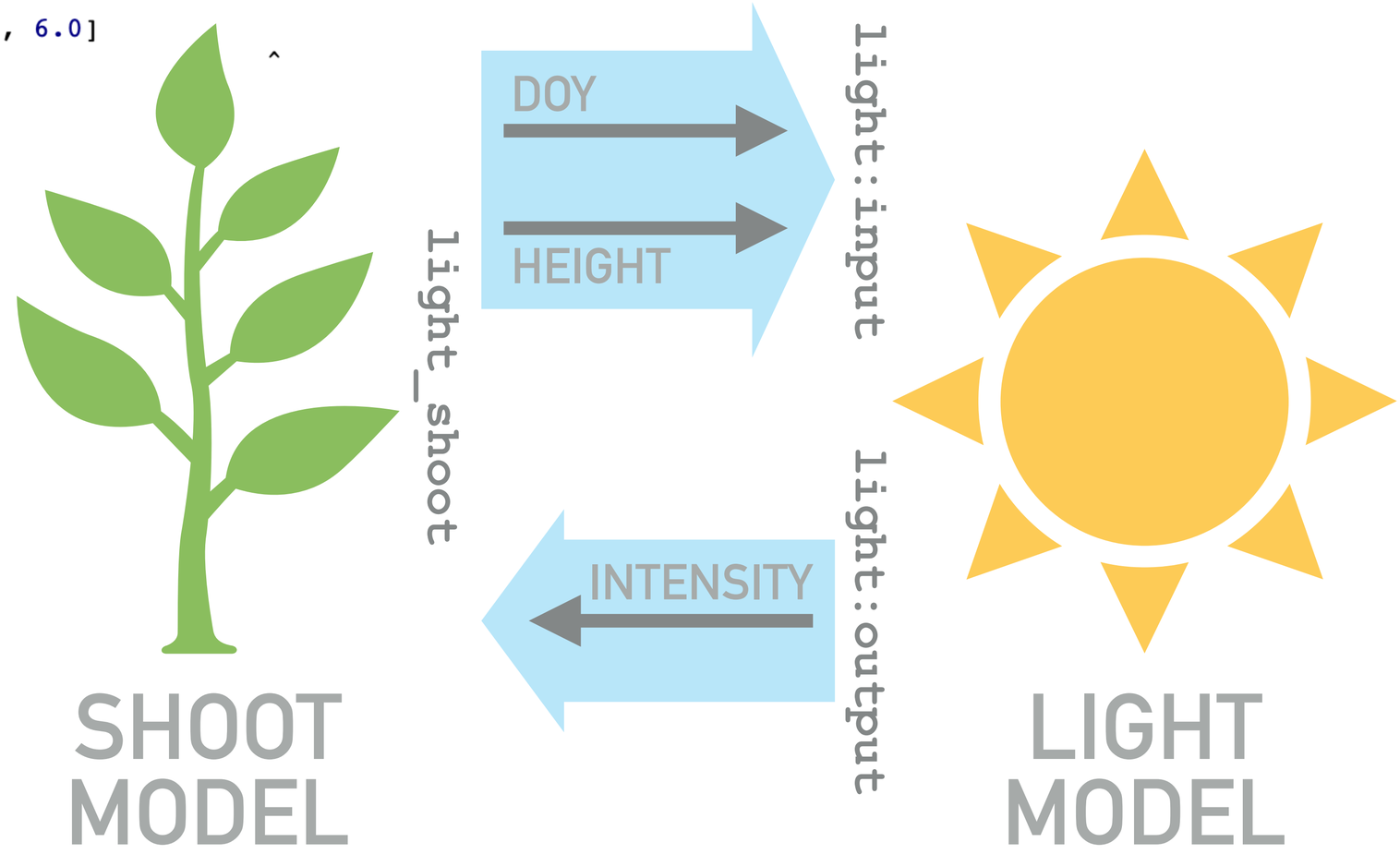
```
file1: models/shoot_v1.py
file2: models/shoot_v2.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse

...


28:   # If the model is running as part of an yggdrasil integration, import
29:   # the relevant yggdrasil routines and use the interface routine to
30:   # complete the connection defined in the YAML
31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggOutput
    ?
^^ ---

33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient
    ?
^^^^^^^^

    -     height_out = YggOutput('height')
    ?     ^^     ^^^                        ^^^ ^                              ^^

34: +     light_rpc = YggRpcClient('light_shoot')
    ?     ^     ^^^                        ^ ^^^^^^                           ^   ++++++

35:
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
    -         flag = height_out.send(
    ?                                ^^     ^^^                 ^^^^

42: +         flag, intensity = light_rpc.call(
    ?             ++++++++++++                  ^     ^^^                 ^^^^
43:               [units.add_units(t, 'hrs'),
44:                units.add_units(max(mesh.vertices[:, 2]), 'm')])


...
```

```
    -     # Compute the scale factor
47: +
48: +         # Compute the scale factor using intensity, stripping units
49: +         # of the result to allow use with trimesh
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++

51: +         scale = units.get_data(
52: +             units.add_units(mass, 'g') * intensity /
53: +             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
54: +
55: +     else:
56: +         # Compute the scale factor
57: +         # (pretend this is a biologically complex calculation)
    -     scale = mass / 4.5e4
58: +         scale = mass / 4.5e4
    ? ++++
```

Change how scale is computed when yggdrasil used

In [7]:
```
tools.display_source_diff('yamls/shoot_v1.yml', 'yamls/shoot_v2.yml', number_lines=True)
tools.display_source_diff('yamls/light_v0_python.yml', 'yamls/light_v1_python.yml', number_lines=True)
```

```
file1: yamls/shoot_v1.yml
file2: yamls/shoot_v2.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v1.py, 0.0, 48.0, 6.0]
    ?                                                ^

 4: +   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?                                                ^

    -   outputs:
    -     - name: height
    ?   ----               ^^^          ^^

 5: +   client_of: light
    ?                ++++ ^^^^          ^

    -       default_file:
    -         name: ../output/height.txt
    -         filetype: table

file1: yamls/light_v0_python.yml
file2: yamls/light_v1_python.yml
================================
 1:   model:
 2:     name: light
 3:     language: python
 4:     args: ../models/light_v0.py
 5:     function: light
 6: +   is_server: true
```

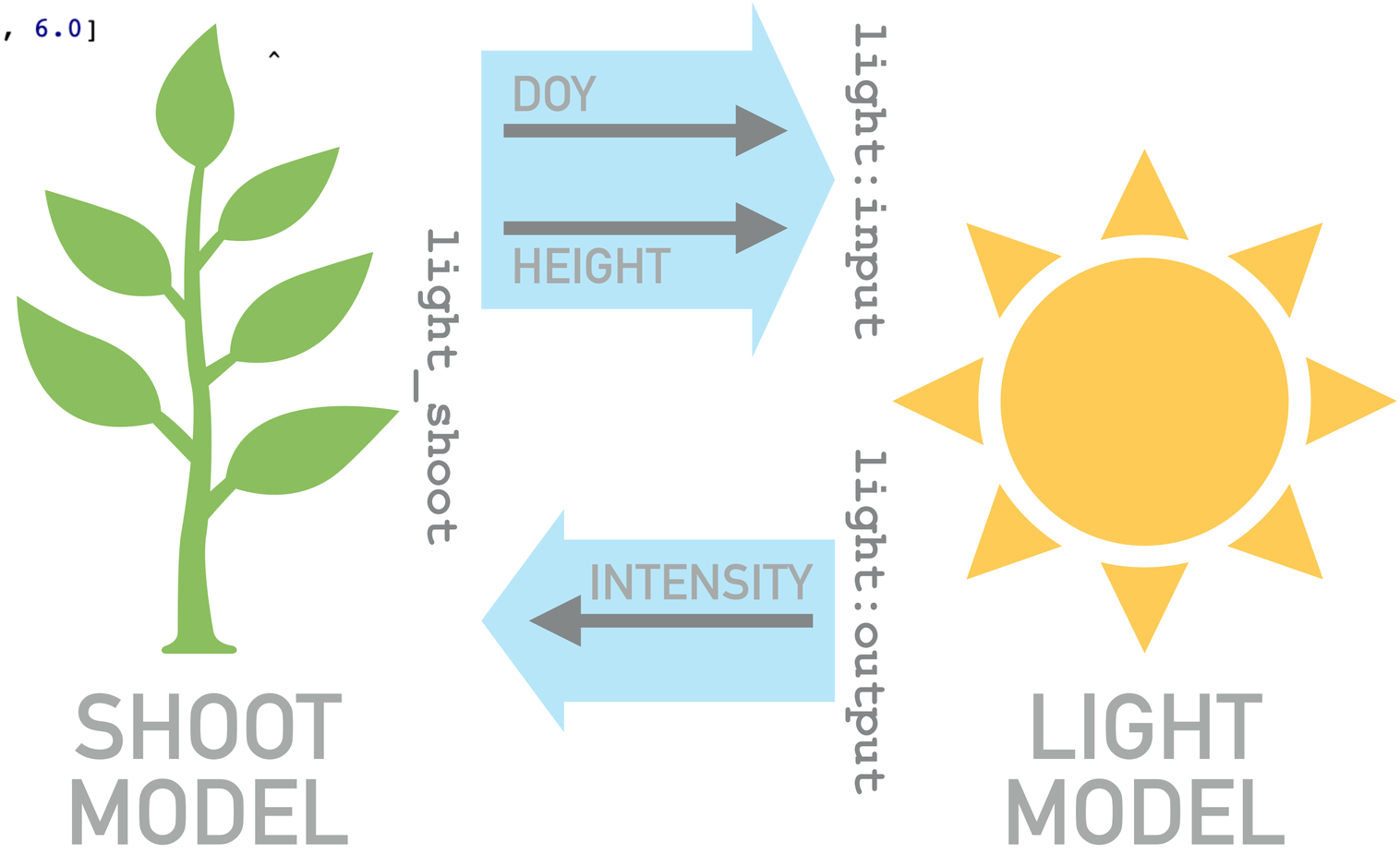


In [7]:
```
tools.display_source_diff('yamls/shoot_v1.yml', 'yamls/shoot_v2.yml', number_lines=True)
tools.display_source_diff('yamls/light_v0_python.yml', 'yamls/light_v1_python.yml', number_lines=True)
```

```
file1: yamls/shoot_v1.yml
file2: yamls/shoot_v2.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v1.py, 0.0, 48.0, 6.0]
    ?

 4: +   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?

    -   outputs:
    -     - name: height
    ?   ----               ^^^          ^^

 5: +   client_of: light
    ?                +++ ^^^^           ^

    -       default_file:
    -         name: ../output/height.txt
    -         filetype: table
```

```
file1: yamls/light_v0_python.yml
file2: yamls/light_v1_python.yml
================================
 1:   model:
 2:     name: light
 3:     language: python
 4:     args: ../models/light_v0.py
 5:     function: light
 6: +   is_server: true
```

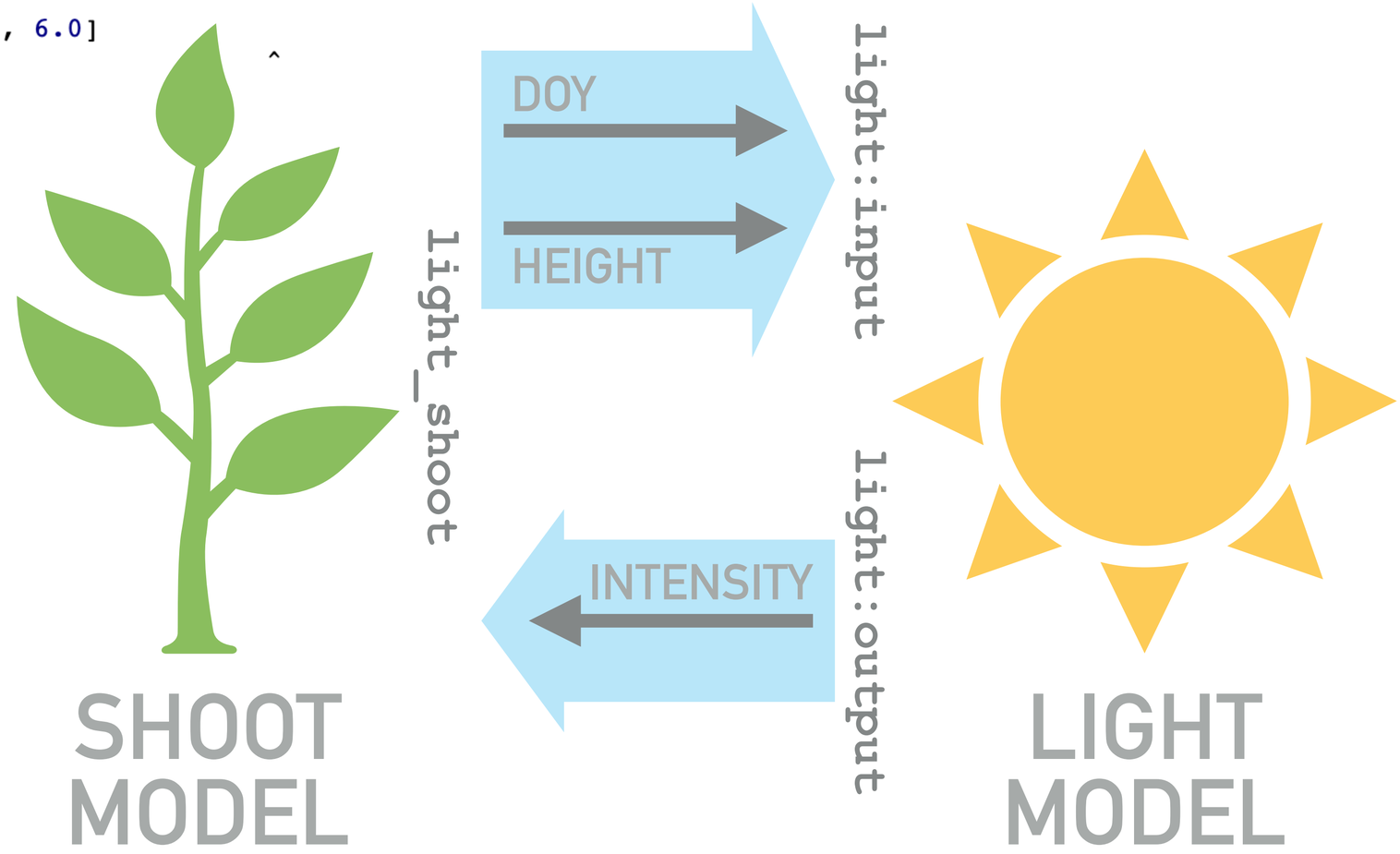
Remove output & add "client_of" to shoot model



In [7]:
```
tools.display_source_diff('yamls/shoot_v1.yml', 'yamls/shoot_v2.yml', number_lines=True)
tools.display_source_diff('yamls/light_v0_python.yml', 'yamls/light_v1_python.yml', number_lines=True)
```

```
file1: yamls/shoot_v1.yml
file2: yamls/shoot_v2.yml
=========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v1.py, 0.0, 48.0, 6.0]
    ?                                              ^

 4: +   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?                                              ^

    -   outputs:
    -     - name: height
    ?   ----               ^^^          ^^

 5: +   client_of: light
    ?                +++ ^^^^           ^

    -       default_file:
    -         name: ../output/height.txt
    -         filetype: table

file1: yamls/light_v0_python.yml
file2: yamls/light_v1_python.yml
================================
 1:   model:
 2:     name: light
 3:     language: python
 4:     args: ../models/light_v0.py
 5:     function: light
 6: +   is_server: true
```

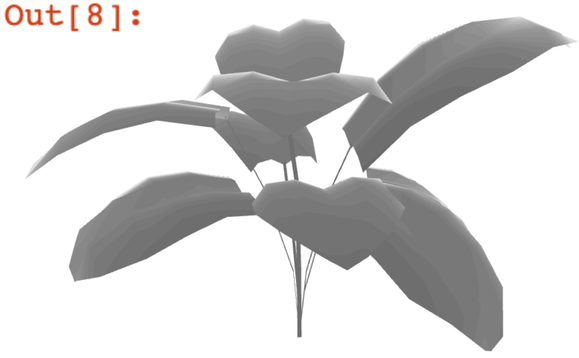
Add "`is_server`" to light model



In [8]:
```
run(['yamls/light_v1_python.yml', 'yamls/shoot_v2.yml'], production_run=True)
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

```
INFO:93696:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v2.py 0.0 48.0 6.0
End of input from temp_doy.
INFO:93696:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:93696:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:93696:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:93696:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:93696:runner.run[374]:YggRunner(runner):          load drivers      0.010089
INFO:93696:runner.run[374]:YggRunner(runner):         start drivers      0.090419
INFO:93696:runner.run[374]:YggRunner(runner):             run models      7.769536
INFO:93696:runner.run[374]:YggRunner(runner):                at exit      0.044337
INFO:93696:runner.run[376]:YggRunner(runner): ========================================
INFO:93696:runner.run[377]:YggRunner(runner):                  Total      7.914382
```

Out[8]:



SPLITTING RPC CALLS

In [9]:
```
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v2_split.py', number_lines=True)
```

```
file1: models/shoot_v2.py
file2: models/shoot_v2_split.py
================================

...

39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
42: +         # Send request to the light model
    -         flag, intensity = light_rpc.call(
    ?             -----------                                                ^^^^

43: +         flag = light_rpc.send(
    ?                                                                        ^^^^

44:               [units.add_units(t, 'hrs'),
45:                units.add_units(max(mesh.vertices[:, 2]), 'm')])
46:           if not flag:
    -             raise Exception("Error calling the light model.")
    ?

47: +             raise Exception("Error sending request to the light model.")
    ?
++++++++++

48: +
49: +         # Calculations that don't rely on the output from the light model
50: +         # can be run here in parallel with the light model calculations
51: +
52: +         # Receive response from the light model
53: +         flag, intensity = light_rpc.recv()
54: +         if not flag:
55: +             raise Exception("Error receiving response from the light model.")

...
```

In [9]:
```
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v2_split.py', number_lines=True)
```

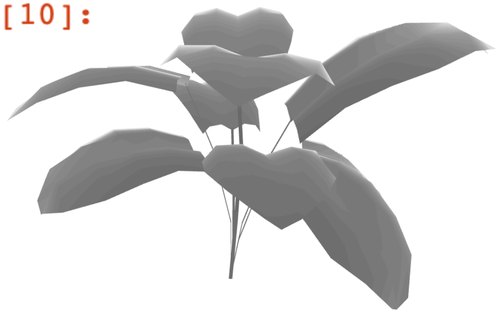
```
file1: models/shoot_v2.py
file2: models/shoot_v2_split.py
================================

...

39:       # If running as part an yggdrasil integration, send the time and
40:       # maximum height of the mesh to the height channel with units
41:       if with_yggdrasil:
42: +         # Send request to the light model
    -         flag, intensity = light_rpc.call(
    ?             -----------                                          ^^^^

43: +         flag = light_rpc.send(
    ?                                                    ^^^^

44:               [units.add_units(t, 'hrs'),
45:                units.add_units(max(mesh.vertices[:, 2]), 'm')])
46:           if not flag:
    -             raise Exception("Error calling the light model.")
    ?

47: +             raise Exception("Error sending request to the light model.")
    ?
++++++++++

48: +
49: +         # Calculations that don't rely on the output from the light model
50: +         # can be run here in parallel with the light model calculations
51: +
52: +         # Receive response from the light model
53: +         flag, intensity = light_rpc.recv()
54: +         if not flag:
55: +             raise Exception("Error receiving response from the light model.")

...
```

Calls can be split into send & recv to enhance parallelism

In [10]:
```
run(['yamls/light_v1_python.yml', 'yamls/shoot_v2_split.yml'], production_run=True)
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

```
INFO:93696:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v2_split.py 0.0 48.0 6.0
End of input from temp_doy.
INFO:93696:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:93696:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:93696:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:93696:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:93696:runner.run[374]:YggRunner(runner):          load drivers      0.009048
INFO:93696:runner.run[374]:YggRunner(runner):         start drivers      0.087974
INFO:93696:runner.run[374]:YggRunner(runner):             run models      7.865753
INFO:93696:runner.run[374]:YggRunner(runner):                at exit      0.044422
INFO:93696:runner.run[376]:YggRunner(runner): ========================================
INFO:93696:runner.run[377]:YggRunner(runner):                  Total      8.007198
```

Out[10]:



DUPLICATING MODELS

In [11]:
```
tools.display_source_diff('models/shoot_v2_split.py', 'models/shoot_v2_copies.py', number_lines=True)
```

```
file1: models/shoot_v2_split.py
file2: models/shoot_v2_copies.py
================================

...

41:         # If running as part an yggdrasil integration, send the time and
42:         # maximum height of the mesh to the height channel with units
43:         if with_yggdrasil:
    -           # Send request to the light model
44: +           # Send requests to the light model for each mesh vertex
    ?                                 +                    ++++++++++++++++++++

45: +           for v in mesh.vertices[:, 2]:
    -           flag = light_rpc.send(
46: +               flag = light_rpc.send(
    ? ++++

    -               [units.add_units(t, 'hrs'),
47: +                   [units.add_units(t, 'hrs'),
    ? ++++

    -                units.add_units(max(mesh.vertices[:, 2]), 'm')])
48: +                   units.add_units(v, 'm')])
    -           if not flag:
49: +               if not flag:
    ? ++++

...
```

```
In [11]: tools.display_source_diff('models/shoot_v2_split.py', 'models/shoot_v2_copies.py', number_lines=True)
```

```
file1: models/shoot_v2_split.py
file2: models/shoot_v2_copies.py
================================

...

41:         # If running as part an yggdrasil integration, send the time and
42:         # maximum height of the mesh to the height channel with units
43:         if with_yggdrasil:
    -           # Send request to the light model
44: +           # Send requests to the light model for each mesh vertex
    ?                                 +                    ++++++++++++++++++++

45: +           for v in mesh.vertices[:, 2]:
    -           flag = light_rpc.send(
46: +               flag = light_rpc.send(
    ? ++++

    -               [units.add_units(t, 'hrs'),
47: +                   [units.add_units(t, 'hrs'),
    ? ++++

    -                units.add_units(max(mesh.vertices[:, 2]), 'm')])
48: +                   units.add_units(v, 'm')])
    -           if not flag:
49: +               if not flag:
    ? ++++

...
```

Send heights for each vertex to the light model

In [11]:
```
tools.display_source_diff('models/shoot_v2_split.py', 'models/shoot_v2_copies.py', number_lines=True)
```

```
file1: models/shoot_v2_split.py
file2: models/shoot_v2_copies.py
================================

...

56: +          nvert = mesh.vertices.shape[0]
57: +          intensity = np.zeros(nvert, 'f8')
58: +          for iv in range(nvert):
    -          flag, intensity = light_rpc.recv()
59: +              flag, v_intensity = light_rpc.recv()
    ? ++++               ++

    -          if not flag:
60: +              if not flag:
    ? ++++

    -              raise Exception("Error receiving response from the light model.")
61: +                  raise Exception("Error receiving response from the light model.")
    ? ++++

62: +              if not units.has_units(intensity):
63: +                  intensity = units.add_units(intensity,
64: +                                              units.get_units(v_intensity))
65: +              intensity[iv] = v_intensity
66: +          filename_light = os.path.join(_dir, f'../output/light_{i:03d}.pkl')
67: +          with open(filename_light, 'wb') as fd:
68: +              pickle.dump(intensity, fd)

...
```

```
In [11]: tools.display_source_diff('models/shoot_v2_split.py', 'models/shoot_v2_copies.py', number_lines=True)
```

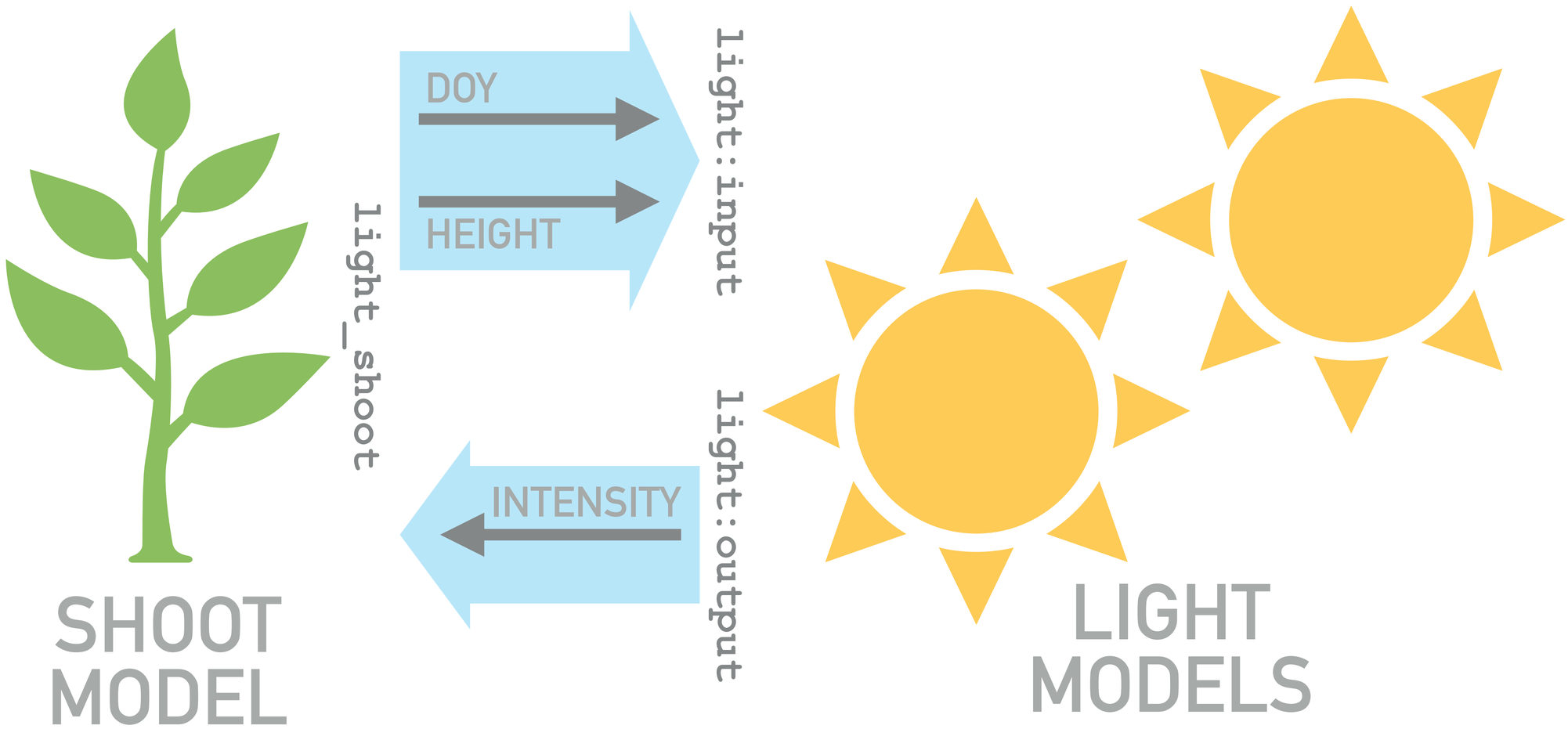
```
file1: models/shoot_v2_split.py
file2: models/shoot_v2_copies.py
================================
...
56: +          nvert = mesh.vertices.shape[0]
57: +          intensity = np.zeros(nvert, 'f8')
58: +          for iv in range(nvert):
    -          flag, intensity = light_rpc.recv()
59: +              flag, v_intensity = light_rpc.recv()
    ? ++++               ++

    -          if not flag:
60: +              if not flag:
    ? ++++

    -              raise Exception("Error receiving response from the light model.")
61: +                  raise Exception("Error receiving response from the light model.")
    ? ++++

62: +              if not units.has_units(intensity):
63: +                  intensity = units.add_units(intensity,
64: +                                              units.get_units(v_intensity))
65: +              intensity[iv] = v_intensity
66: +          filename_light = os.path.join(_dir, f'../output/light_{i:03d}.pkl')
67: +          with open(filename_light, 'wb') as fd:
68: +              pickle.dump(intensity, fd)

...
```

Receive intensities for each vertex

```
In [11]: tools.display_source_diff('models/shoot_v2_split.py', 'models/shoot_v2_copies.py', number_lines=True)
```

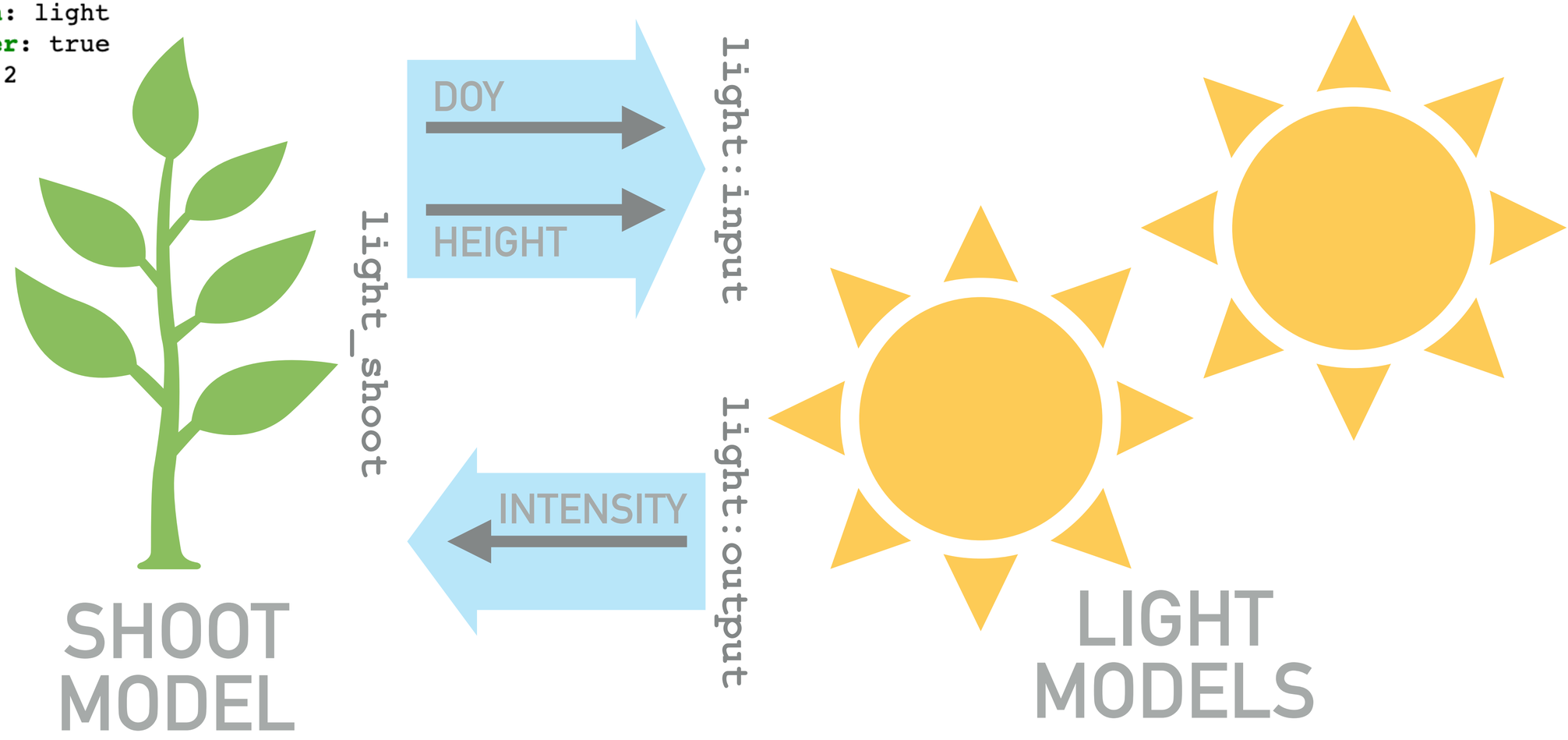
```
file1: models/shoot_v2_split.py
file2: models/shoot_v2_copies.py
================================

...

56: +          nvert = mesh.vertices.shape[0]
57: +          intensity = np.zeros(nvert, 'f8')
58: +          for iv in range(nvert):
    -          flag, intensity = light_rpc.recv()
59: +              flag, v_intensity = light_rpc.recv()
    ? ++++               ++

    -          if not flag:
60: +              if not flag:
    ? ++++

    -              raise Exception("Error receiving response from the light model.")
61: +                  raise Exception("Error receiving response from the light model.")
    ? ++++

62: +              if not units.has_units(intensity):
63: +                  intensity = units.add_units(intensity,
64: +                                              units.get_units(v_intensity))
65: +              intensity[iv] = v_intensity
66: +          filename_light = os.path.join(_dir, f'../output/light_{i:03d}.pkl')
67: +          with open(filename_light, 'wb') as fd:
68: +              pickle.dump(intensity, fd)

...
```

Save intensities for each vertex to a file


DOY
HEIGHT
light_shoot
light:input
light:output
INTENSITY
SHOOT
MODEL
LIGHT
MODELS

In [12]:
```
tools.display_source_diff('yamls/light_v1_python.yml', 'yamls/light_v2_python.yml', number_lines=True)
```

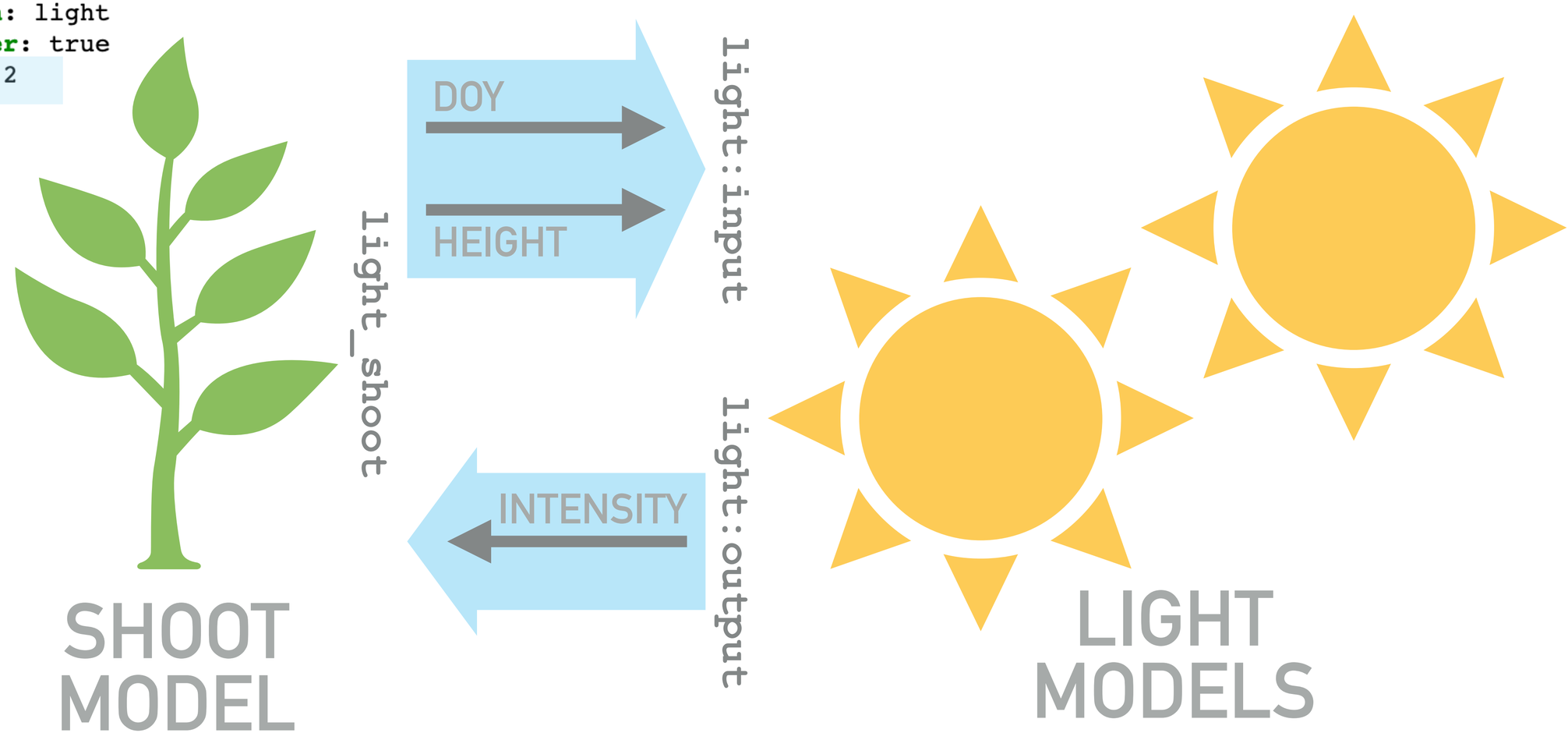
```
file1: yamls/light_v1_python.yml
file2: yamls/light_v2_python.yml
================================
 1:   model:
 2:     name: light
 3:     language: python
 4:     args: ../models/light_v0.py
 5:     function: light
 6:     is_server: true
 7: +   copies: 2
```



In [12]:
```
tools.display_source_diff('yamls/light_v1_python.yml', 'yamls/light_v2_python.yml', number_lines=True)
```

```
file1: yamls/light_v1_python.yml
file2: yamls/light_v2_python.yml
================================
 1:   model:
 2:     name: light
 3:     language: python
 4:     args: ../models/light_v0.py
 5:     function: light
 6:     is_server: true
 7: +   copies: 2
```

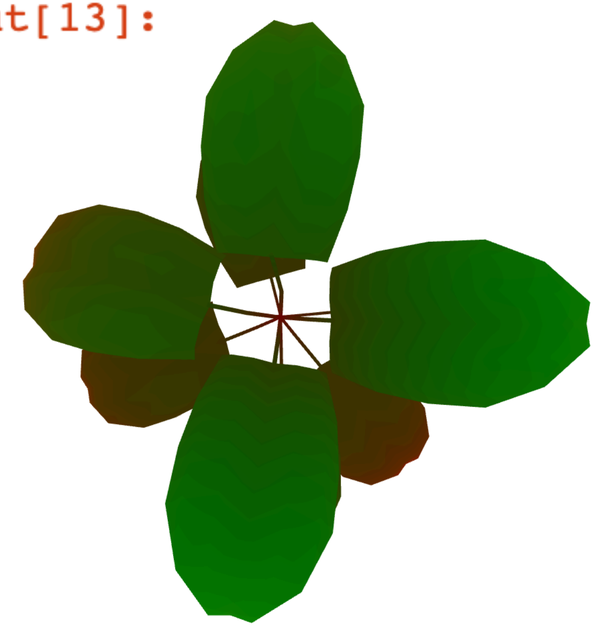
Add “copies” to indicate multiple instances of a model should be run



In [13]:
```
run(['yamls/light_v1_python.yml', 'yamls/shoot_v2_copies.yml'], production_run=True)

# Plot results w/ light intensity mapped to color
import pickle
with open('output/light_008.pkl', 'rb') as fd:
    light = pickle.load(fd)
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.visual.vertex_colors = trimesh.visual.interpolate(light/max(light))
mesh.show()
```

```
INFO:93696:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v2_copies.py 0.0 48.0 6.0
End of input from temp_doy.
INFO:93696:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:93696:runner.waitModels[553]:YggRunner(runner): shoot finished running.
INFO:93696:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:93696:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:93696:runner.run[374]:YggRunner(runner):                  init      0.000000
INFO:93696:runner.run[374]:YggRunner(runner):          load drivers      0.009468
INFO:93696:runner.run[374]:YggRunner(runner):         start drivers      0.086156
INFO:93696:runner.run[374]:YggRunner(runner):            run models      107.365030
INFO:93696:runner.run[374]:YggRunner(runner):               at exit      0.028054
INFO:93696:runner.run[376]:YggRunner(runner): ========================================
INFO:93696:runner.run[377]:YggRunner(runner):                 Total      107.488708
```

Out[13]:



PARALLELISM ON MYBINDER

MyBinder instances only have access to 1 core (models run in serial)

MODEL A

MODEL B

PARALLELISM ON MYBINDER

MyBinder instances only have access to 1 core (models run in serial)

MODEL A

MODEL B

NEW NOTEBOOK!
(BREAK TIME)

jupyter

Visit repo | Copy Binder link | Quit

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Select items to perform actions on them.

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00-intro.ipynb	33 minutes ago	457 kB
01-connections.ipynb	33 minutes ago	470 kB
02-timesync.ipynb	33 minutes ago	298 kB
03-misc.ipynb	33 minutes ago	3.56 kB

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images	33 minutes ago	
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00-intro.ipynb	33 minutes ago	457 kB
01-connections.ipynb	33 minutes ago	470 kB
02-timesync.ipynb	33 minutes ago	298 kB
03-misc.ipynb	33 minutes ago	3.56 kB

TIME STEP SYNCHRONIZATION

In [2]:
```
tools.display_source('models/roots_v0.py', number_lines=True)
```

file: models/roots_v0.py

```
 1: import os
 2: import argparse
 3: import pickle
 4:
 5: _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7: # Parse command-line arguments
 8: parser = argparse.ArgumentParser("Simulate root growth over time.")
 9: parser.add_argument('tmin', help='Starting time (in days)', type=float)
10: parser.add_argument('tmax', help='Ending time (in days)', type=float)
11: parser.add_argument('tstep', help='Time step (in days)', type=float)
12: args = parser.parse_args()
13: tmin = args.tmin
14: tmax = args.tmax
15: tstep = args.tstep
16:
17: # Set initial conditions
18: mass = 0.0
19: t = tmin
20: times = []
21: masses = []
22:
23: # Continue simulation until time limit is reached
24: while t <= tmax:
25:
26:     # Compute the scale factor
27:     # (pretend this is a biologically complex calculation)
28:     scale = 0.2
29:
30:     # Calculate mass for the time step
31:     # (pretend this is a biologically complex calculation)
32:     mass += t * scale
33:

...

...

34:     # Add mass & time to array
35:     times.append(t)
36:     masses.append(mass)
37:
38:     # Advance time step
39:     t += tstep
40:
41: # Write the total mass array to output
42: filename_masses = os.path.join(_dir, '../output/masses.pkl')
43: with open(filename_masses, 'wb') as fd:
44:     pickle.dump({'times': times, 'masses': masses}, fd)
```

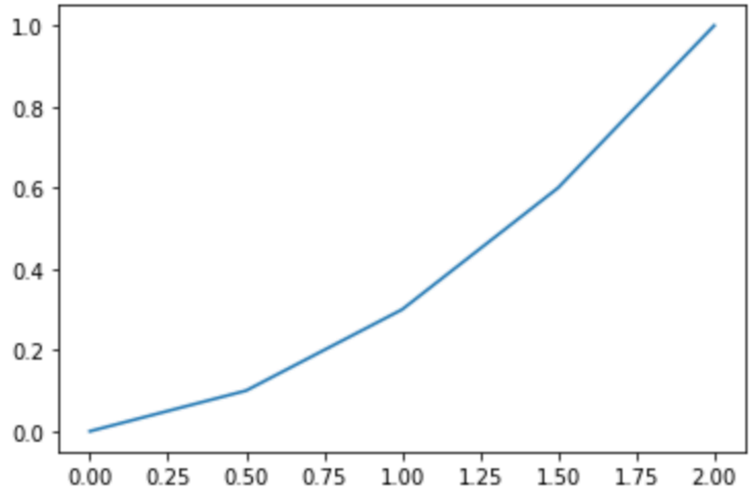
In [3]:
```
tools.display_source('yamls/roots_v0.yml', number_lines=True)
run(['yamls/roots_v0.yml'], production_run=True)
```

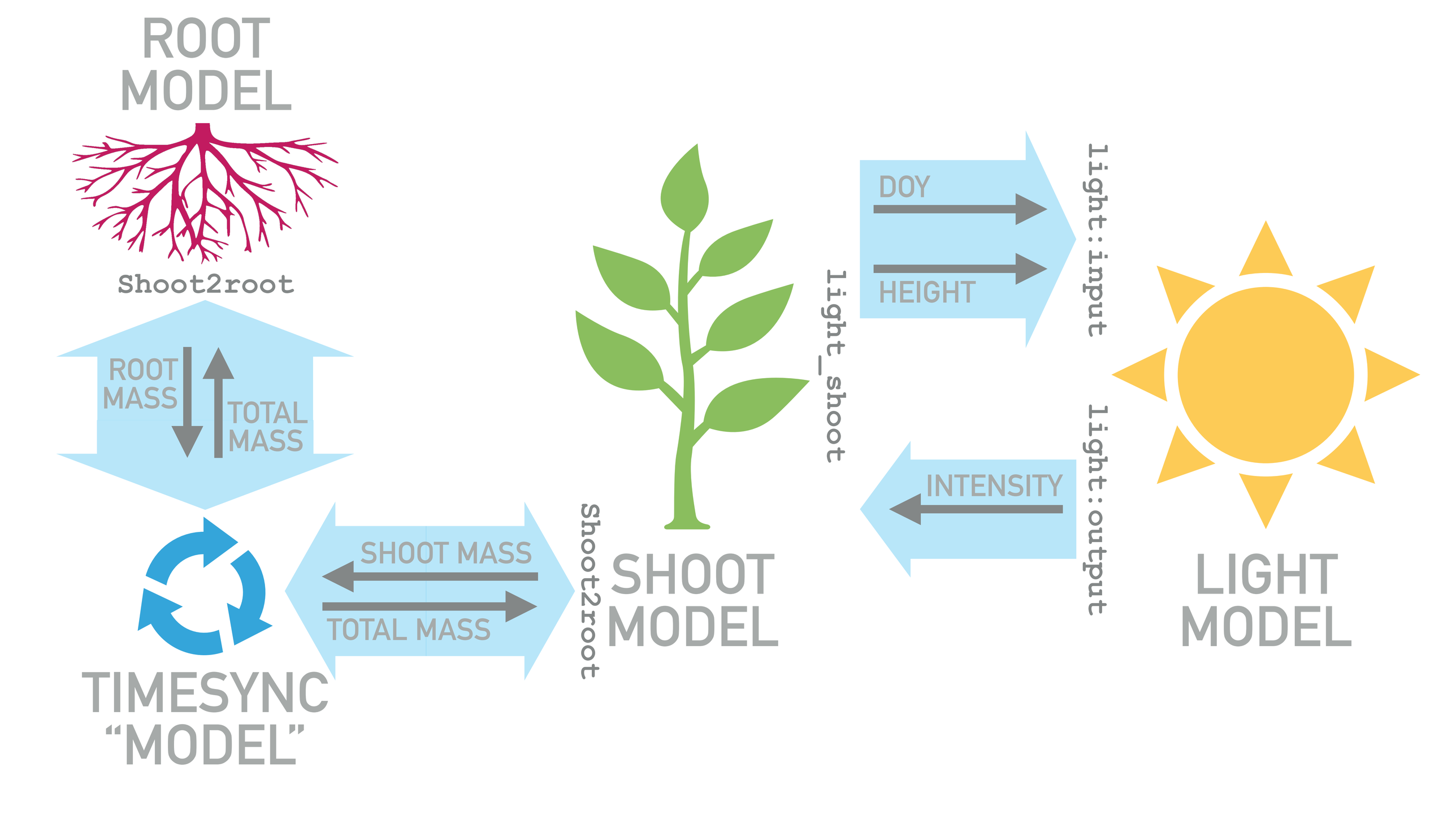
```
file: yamls/roots_v0.yml
========================
 1: model:
 2:   name: roots
 3:   language: python
 4:   args: [../models/roots_v0.py, 0.0, 2.0, 0.5]

INFO:96257:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/roo
ts_v0.py 0.0 2.0 0.5
INFO:96257:runner.waitModels[553]:YggRunner(runner): roots finished running.
INFO:96257:runner.waitModels[559]:YggRunner(runner): roots finished exiting.
INFO:96257:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:96257:runner.run[374]:YggRunner(runner):                 init      0.000000
INFO:96257:runner.run[374]:YggRunner(runner):         load drivers      0.279398
INFO:96257:runner.run[374]:YggRunner(runner):        start drivers      0.039544
INFO:96257:runner.run[374]:YggRunner(runner):           run models      0.103028
INFO:96257:runner.run[374]:YggRunner(runner):              at exit      0.000614
INFO:96257:runner.run[376]:YggRunner(runner): ======================================
INFO:96257:runner.run[377]:YggRunner(runner):                Total      0.422584
```

In [4]:
```
import matplotlib.pyplot as plt
filename_masses = 'output/masses.pkl'
with open(filename_masses, 'rb') as fd:
    masses = pickle.load(fd)
plt.plot(masses['times'], masses['masses'])
```

Out[4]:
```
[<matplotlib.lines.Line2D at 0x147647e48>]
```

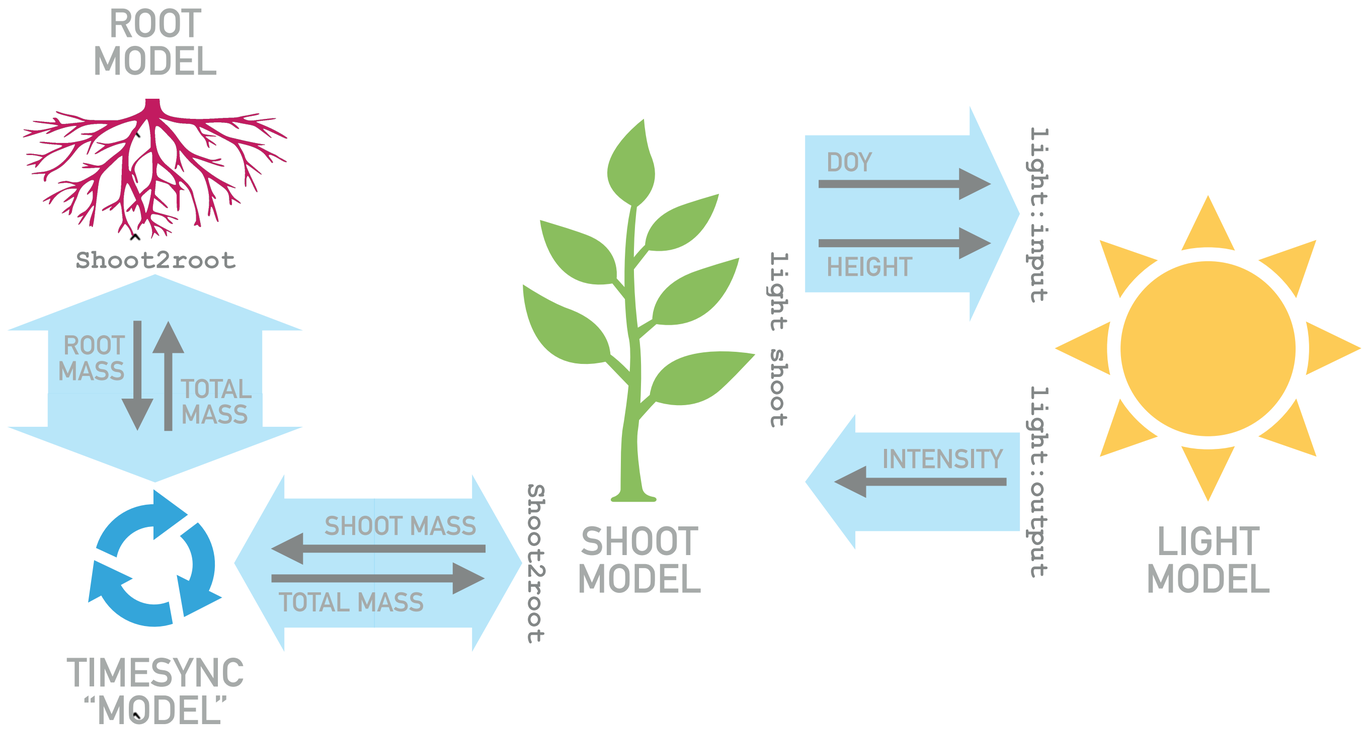



ROOT
MODEL
Shoot2root
ROOT
MASS
TOTAL
MASS
TIMESYNC
"MODEL"
SHOOT MASS
TOTAL MASS
Shoot2root
SHOOT
MODEL
light_shoot
DOY
HEIGHT
light:input
INTENSITY
light:output
LIGHT
MODEL

In [5]:
```
tools.display_source_diff('yamls/roots_v0.yml', 'yamls/roots_v1.yml', number_lines=True)
tools.display_source_diff('yamls/shoot_v2.yml', 'yamls/shoot_v3.yml', number_lines=True)
```

```
file1: yamls/roots_v0.yml
file2: yamls/roots_v1.yml
==========================
 1:   model:
 2:     name: roots
 3:     language: python
    -   args: [../models/roots_v0.py, 0.0, 2.0, 0.5]
    ?
 4: +   args: [../models/roots_v1.py, 0.0, 2.0, 0.5]
    ?
 5: +   timesync: shoot2root

file1: yamls/shoot_v2.yml
file2: yamls/shoot_v3.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?
 4: +   args: [../models/shoot_v3.py, 0.0, 48.0, 6.0]
    ?
 5:     client_of: light
 6: +   timesync: shoot2root
```



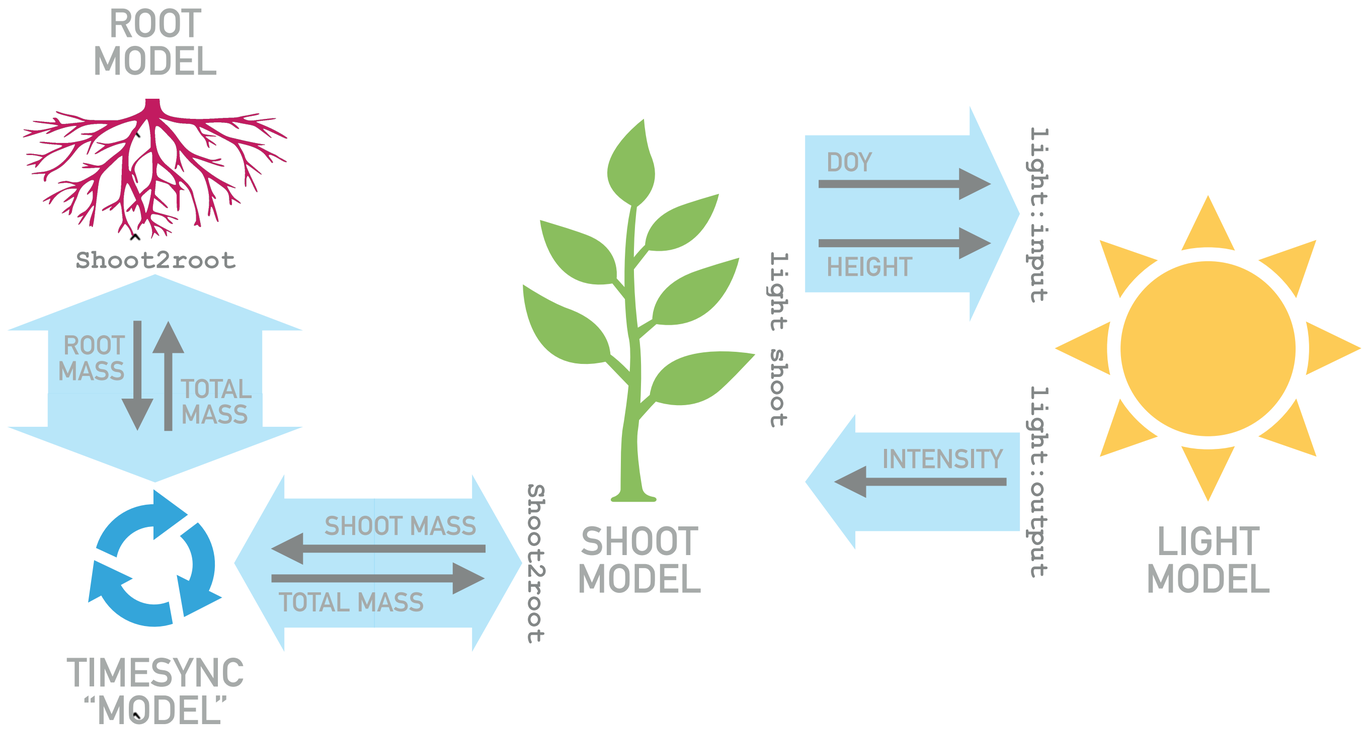
In [6]:
```
tools.display_source('yamls/timesync.yml', number_lines=True)
```

```
file: yamls/timesync.yml
========================
 1: model:
 2:   name: shoot2root
 3:   language: timesync
 4:   aggregation: sum
```

In [5]:
```
tools.display_source_diff('yamls/roots_v0.yml', 'yamls/roots_v1.yml', number_lines=True)
tools.display_source_diff('yamls/shoot_v2.yml', 'yamls/shoot_v3.yml', number_lines=True)
```

```
file1: yamls/roots_v0.yml
file2: yamls/roots_v1.yml
==========================
 1:   model:
 2:     name: roots
 3:     language: python
    -   args: [../models/roots_v0.py, 0.0, 2.0, 0.5]
    ?
 4: +   args: [../models/roots_v1.py, 0.0, 2.0, 0.5]
    ?
 5: +   timesync: shoot2root

file1: yamls/shoot_v2.yml
file2: yamls/shoot_v3.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?
 4: +   args: [../models/shoot_v3.py, 0.0, 48.0, 6.0]
    ?
 5:     client_of: light
 6: +   timesync: shoot2root
```



In [6]:
```
tools.display_source('yamls/timesync.yml', number_lines=True)
```

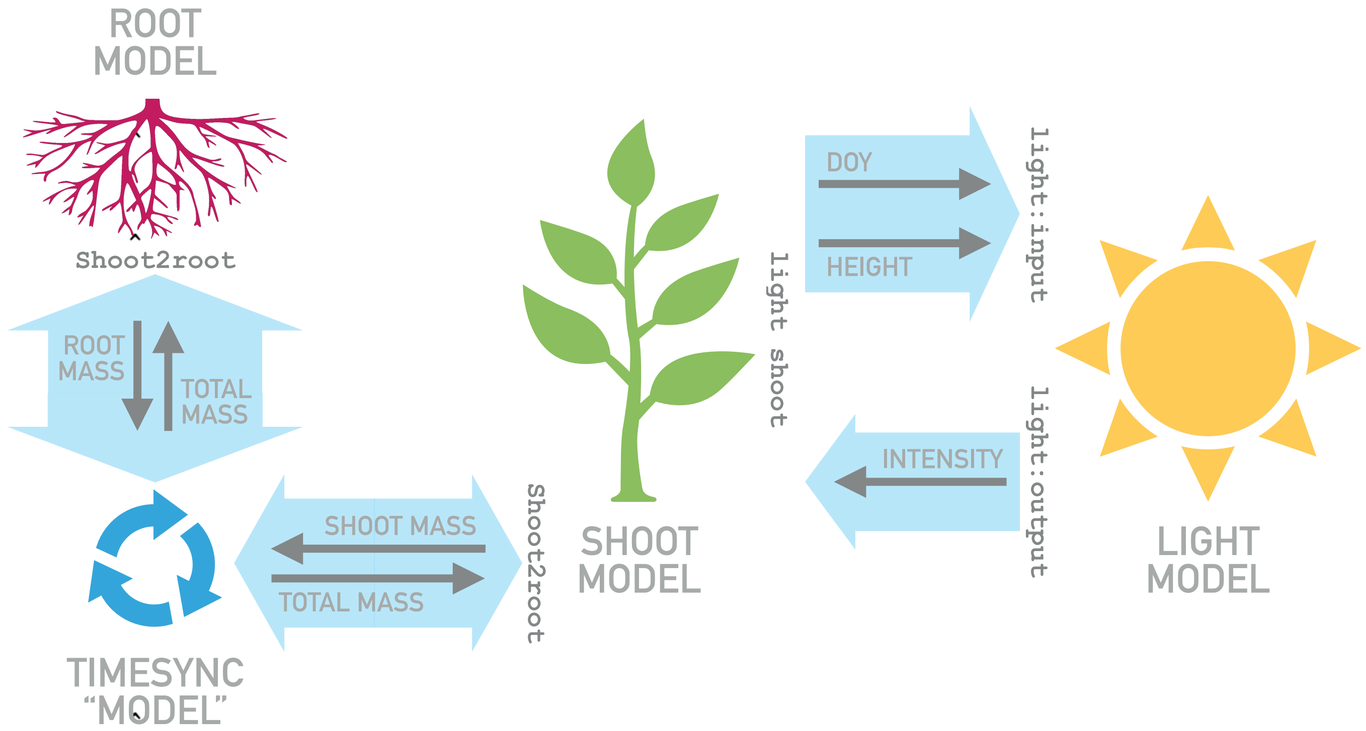
```
file: yamls/timesync.yml
========================
 1: model:
 2:   name: shoot2root
 3:   language: timesync
 4:   aggregation: sum
```

Match name of time sync model "shoot2root"

In [5]:
```
tools.display_source_diff('yamls/roots_v0.yml', 'yamls/roots_v1.yml', number_lines=True)
tools.display_source_diff('yamls/shoot_v2.yml', 'yamls/shoot_v3.yml', number_lines=True)
```

```
file1: yamls/roots_v0.yml
file2: yamls/roots_v1.yml
==========================
 1:   model:
 2:     name: roots
 3:     language: python
    -   args: [../models/roots_v0.py, 0.0, 2.0, 0.5]
    ?
 4: +   args: [../models/roots_v1.py, 0.0, 2.0, 0.5]
    ?
 5: +   timesync: shoot2root

file1: yamls/shoot_v2.yml
file2: yamls/shoot_v3.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?
 4: +   args: [../models/shoot_v3.py, 0.0, 48.0, 6.0]
    ?
 5:     client_of: light
 6: +   timesync: shoot2root
```



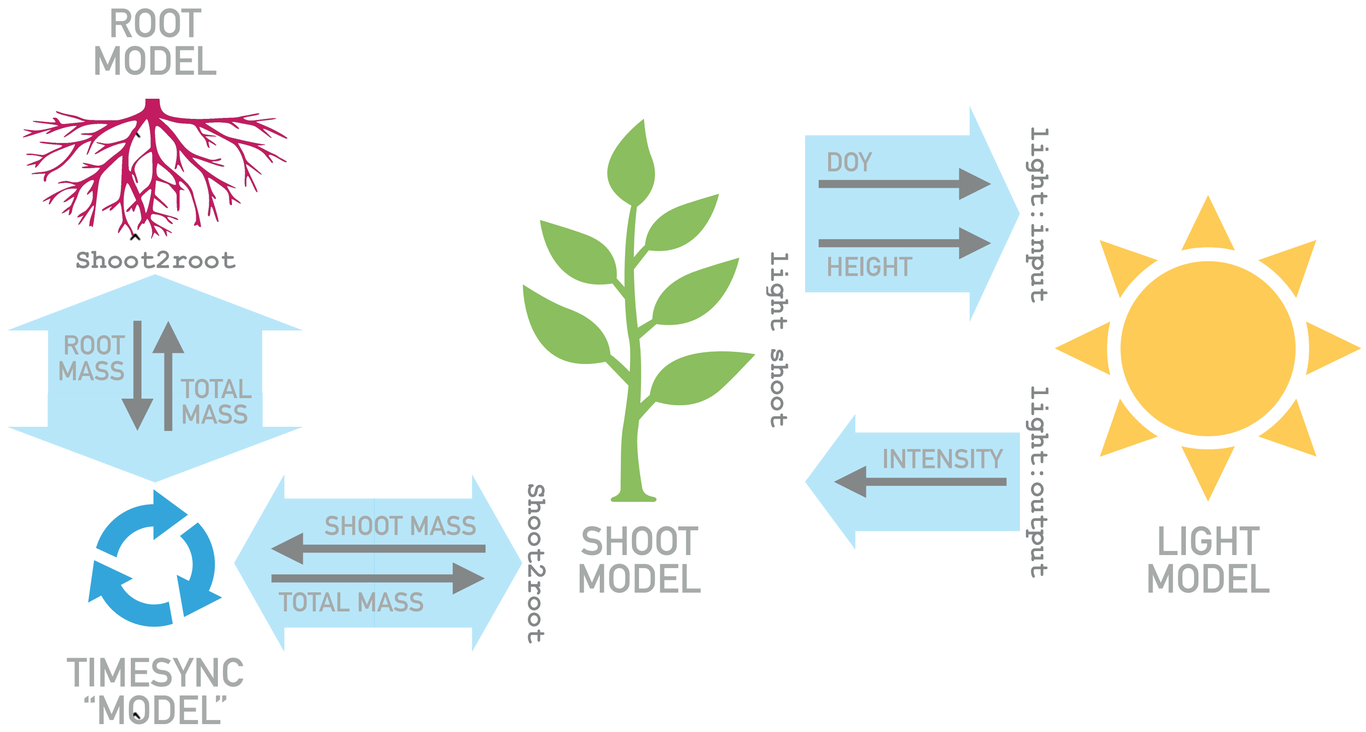
In [6]:
```
tools.display_source('yamls/timesync.yml', number_lines=True)
```

```
file: yamls/timesync.yml
========================
 1: model:
 2:   name: shoot2root
 3:   language: timesync
 4:   aggregation: sum
```

In [5]:
```
tools.display_source_diff('yamls/roots_v0.yml', 'yamls/roots_v1.yml', number_lines=True)
tools.display_source_diff('yamls/shoot_v2.yml', 'yamls/shoot_v3.yml', number_lines=True)
```

```
file1: yamls/roots_v0.yml
file2: yamls/roots_v1.yml
==========================
 1:   model:
 2:     name: roots
 3:     language: python
    -   args: [../models/roots_v0.py, 0.0, 2.0, 0.5]
    ?
 4: +   args: [../models/roots_v1.py, 0.0, 2.0, 0.5]
    ?
 5: +   timesync: shoot2root

file1: yamls/shoot_v2.yml
file2: yamls/shoot_v3.yml
==========================
 1:   model:
 2:     name: shoot
 3:     language: python
    -   args: [../models/shoot_v2.py, 0.0, 48.0, 6.0]
    ?
 4: +   args: [../models/shoot_v3.py, 0.0, 48.0, 6.0]
    ?
 5:     client_of: light
 6: +   timesync: shoot2root
```



In [6]:
```
tools.display_source('yamls/timesync.yml', number_lines=True)
```

```
file: yamls/timesync.yml
========================
 1: model:
 2:   name: shoot2root
 3:   language: timesync
 4:   aggregation: sum
```

"aggregation"

determines how values should be combined

```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil

```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
=========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

Import yggdrasil functions and connect to the channel that will be listed in the YAML.

Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil

```
In [15]: tools.display_source_diff('models/shoot_v0.py', 'models/shoot_v1.py', number_lines=True)
```

```
file1: models/shoot_v0.py
file2: models/shoot_v1.py
==========================
 1:   import os
 2:   import trimesh
 3:   import argparse
 4:
 5:   _dir = os.path.dirname(os.path.realpath(__file__))
 6:
 7:   # Parse command-line arguments
 8:   parser = argparse.ArgumentParser("Simulate a shoot's growth over time.")
 9:   parser.add_argument('tmin', help='Starting time (in hours)', type=float)
10:   parser.add_argument('tmax', help='Ending time (in hours)', type=float)
11:   parser.add_argument('tstep', help='Time step (in hours)', type=float)
12:   parser.add_argument('--meshfile', help='Path to file where mesh is stored.',
13:                       default='../meshes/plants-2.obj')
14:   args = parser.parse_args()
15:   tmin = args.tmin
16:   tmax = args.tmax
17:   tstep = args.tstep
18:   mesh = trimesh.load_mesh(args.meshfile)
19:
20:   # Set initial conditions
21:   mass = 2000.0
22:   t = tmin
23:   i = 0
24:
25: + # Check if model is running as a part of an yggdrasil integration
26: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
27: +
28: + # If the model is running as part of an yggdrasil integration, import
29: + # the relevant yggdrasil routines and use the interface routine to
30: + # complete the connection defined in the YAML
31: + if with_yggdrasil:
32: +     from yggdrasil import units
33: +     from yggdrasil.languages.Python.YggInterface import YggOutput
34: +     height_out = YggOutput('height')
35: +
36:   # Continue simulation until time limit is reached
37:   while t <= tmax:
38:
39: +     # If running as part an yggdrasil integration, send the time and
40: +     # maximum height of the mesh to the height channel with units
41: +     if with_yggdrasil:
42: +         flag = height_out.send(
43: +             [units.add_units(t, 'hrs'),
44: +              units.add_units(max(mesh.vertices[:, 2]), 'm')])
45: +         if not flag:
46: +             raise Exception("Error sending height to output")
47: +
48:       # Compute the scale factor
49:       # (pretend this is a biologically complex calculation)
50:       scale = mass / 4.5e4
51:
52:       # Grow the shoot
53:       # (pretend this is a biologically complex calculation)
54:       mesh.vertices[:, 2] += mesh.vertices[:, 2] * scale
55:       mass += mass * scale
56:
57:       # Save mesh for this timestep
58:       filename_mesh = os.path.join(_dir, f'../output/mesh_{i:03d}.obj')
59:       with open(filename_mesh, 'w') as fd:
60:           mesh.export(fd, 'obj')
61:
62:       # Advance time step
63:       t += tstep
64:       i += 1
```

Send height to output channel

Code to call yggdrasil inside “if blocks” so that model runs exactly the same without yggdrasil

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/roots_v0.py
file2: models/roots_v1.py
==========================
23: + # Check if model is running as a part of an yggdrasil integration
24: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
25: +
26: + # If the model is running as part of an yggdrasil integration, import
27: + # the relevant yggdrasil routines and use the interface routine to
28: + # complete the connection defined in the YAML
29: + if with_yggdrasil:
30: +     from yggdrasil import units
31: +     from yggdrasil.languages.Python.YggInterface import YggTimesync
32: +     shoot2root = YggTimesync('shoot2root')
33: +
34:   # Continue simulation until time limit is reached
35:   while t <= tmax:
36:
    -     # Compute the scale factor
37: +     # If running as part an yggdrasil integration, send the time and
38: +     # mass to the timesync channel and then updated the mass based on
39: +     # the returned state
40: +     if with_yggdrasil:
41: +         root_state = {'mass': units.add_units(mass, 'kg')}
42: +         flag, total_state = shoot2root.call(units.add_units(t, 'days'),
43: +                                             root_state)
44: +         if not flag:
45: +             raise Exception("Error performing time-step synchronization "
46: +                             "with shoot model.")
47: +
48: +         # Compute the scale factor using total mass, stripping units
49: +         # of the result to allow use with original code
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++
51: +         scale = units.get_data(
52: +             units.convert_to(
53: +                 units.add_units(0.05, 'days-1') * total_state['mass'],
54: +                 'kg/day'))
55: +
56: +     else:
57: +         # Compute the scale factor
58: +         # (pretend this is a biologically complex calculation)
    -     scale = 0.2
59: +         scale = 0.2
    ? ++++
```

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/roots_v0.py
file2: models/roots_v1.py
==========================
23: + # Check if model is running as a part of an yggdrasil integration
24: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
25: +
26: + # If the model is running as part of an yggdrasil integration, import
27: + # the relevant yggdrasil routines and use the interface routine to
28: + # complete the connection defined in the YAML
29: + if with_yggdrasil:
30: +     from yggdrasil import units
31: +     from yggdrasil.languages.Python.YggInterface import YggTimesync
32: +     shoot2root = YggTimesync('shoot2root')
33: +
34:   # Continue simulation until time limit is reached
35:   while t <= tmax:
36:
    -     # Compute the scale factor
37: +     # If running as part an yggdrasil integration, send the time and
38: +     # mass to the timesync channel and then updated the mass based on
39: +     # the returned state
40: +     if with_yggdrasil:
41: +         root_state = {'mass': units.add_units(mass, 'kg')}
42: +         flag, total_state = shoot2root.call(units.add_units(t, 'days'),
43: +                                             root_state)
44: +         if not flag:
45: +             raise Exception("Error performing time-step synchronization "
46: +                             "with shoot model.")
47: +
48: +         # Compute the scale factor using total mass, stripping units
49: +         # of the result to allow use with original code
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++
51: +         scale = units.get_data(
52: +             units.convert_to(
53: +                 units.add_units(0.05, 'days-1') * total_state['mass'],
54: +                 'kg/day'))
55: +
56: +     else:
57: +         # Compute the scale factor
58: +         # (pretend this is a biologically complex calculation)
    -     scale = 0.2
59: +         scale = 0.2
    ? ++++
```

Import yggdrasil functions and connect to the time sync channel listed in the YAML.

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/roots_v0.py
file2: models/roots_v1.py
==========================
23: + # Check if model is running as a part of an yggdrasil integration
24: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
25: +
26: + # If the model is running as part of an yggdrasil integration, import
27: + # the relevant yggdrasil routines and use the interface routine to
28: + # complete the connection defined in the YAML
29: + if with_yggdrasil:
30: +     from yggdrasil import units
31: +     from yggdrasil.languages.Python.YggInterface import YggTimesync
32: +     shoot2root = YggTimesync('shoot2root')
33: +
34:   # Continue simulation until time limit is reached
35:   while t <= tmax:
36:
    -     # Compute the scale factor
37: +     # If running as part an yggdrasil integration, send the time and
38: +     # mass to the timesync channel and then updated the mass based on
39: +     # the returned state
40: +     if with_yggdrasil:
41: +         root_state = {'mass': units.add_units(mass, 'kg')}
42: +         flag, total_state = shoot2root.call(units.add_units(t, 'days'),
43: +                                             root_state)
44: +         if not flag:
45: +             raise Exception("Error performing time-step synchronization "
46: +                             "with shoot model.")
47: +
48: +         # Compute the scale factor using total mass, stripping units
49: +         # of the result to allow use with original code
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++
51: +         scale = units.get_data(
52: +             units.convert_to(
53: +                 units.add_units(0.05, 'days-1') * total_state['mass'],
54: +                 'kg/day'))
55: +
56: +     else:
57: +         # Compute the scale factor
58: +         # (pretend this is a biologically complex calculation)
    -     scale = 0.2
59: +         scale = 0.2
    ? ++++
```

Send root state to the time sync model and receive the total state back

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/roots_v0.py
file2: models/roots_v1.py
==========================
23: + # Check if model is running as a part of an yggdrasil integration
24: + with_yggdrasil = os.environ.get('YGG_SUBPROCESS', False)
25: +
26: + # If the model is running as part of an yggdrasil integration, import
27: + # the relevant yggdrasil routines and use the interface routine to
28: + # complete the connection defined in the YAML
29: + if with_yggdrasil:
30: +     from yggdrasil import units
31: +     from yggdrasil.languages.Python.YggInterface import YggTimesync
32: +     shoot2root = YggTimesync('shoot2root')
33: +
34:   # Continue simulation until time limit is reached
35:   while t <= tmax:
36:
    -     # Compute the scale factor
37: +     # If running as part an yggdrasil integration, send the time and
38: +     # mass to the timesync channel and then updated the mass based on
39: +     # the returned state
40: +     if with_yggdrasil:
41: +         root_state = {'mass': units.add_units(mass, 'kg')}
42: +         flag, total_state = shoot2root.call(units.add_units(t, 'days'),
43: +                                             root_state)
44: +         if not flag:
45: +             raise Exception("Error performing time-step synchronization "
46: +                             "with shoot model.")
47: +
48: +         # Compute the scale factor using total mass, stripping units
49: +         # of the result to allow use with original code
    -     # (pretend this is a biologically complex calculation)
50: +         # (pretend this is a biologically complex calculation)
    ? ++++
51: +         scale = units.get_data(
52: +             units.convert_to(
53: +                 units.add_units(0.05, 'days-1') * total_state['mass'],
54: +                 'kg/day'))
55: +
56: +     else:
57: +         # Compute the scale factor
58: +         # (pretend this is a biologically complex calculation)
    -     scale = 0.2
59: +         scale = 0.2
    ? ++++
```

Compute the scale using the total state when run with yggdrasil

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/shoot_v2.py
file2: models/shoot_v3.py
==========================
...

31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggRpcClient
33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient, YggTimesync
    ?
++++++++++++

34:       light_rpc = YggRpcClient('light_shoot')
35: +     shoot2root = YggTimesync('shoot2root')
36:
37:   # Continue simulation until time limit is reached
38:   while t <= tmax:
39:
40:       # If running as part an yggdrasil integration, send the time and
    -     # maximum height of the mesh to the height channel with units
41: +     # maximum height of the mesh to the height channel with units and
    ?                                                                  ++++

42: +     # send the current mass and tiem to the timesync channel
43:       if with_yggdrasil:
44: +         shoot_state = {'mass': units.add_units(mass, 'g')}
45: +         flag, total_state = shoot2root.call(units.add_units(t, 'hrs'),
46: +                                             shoot_state)
47: +         if not flag:
48: +             raise Exception("Error performing time-step synchronization "
49: +                             "with root model.")
50: +

...

60:           scale = units.get_data(
    -             units.add_units(mass, 'g') * intensity /
    ?             ^^^  ^ ------------------------------                        ^

61: +                 total_state['mass'] * intensity /
    ?             ^^^^ +++++ ^^^^                              ^^^^

    -             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
62: +                 units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
    ? ++++


...
```

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/shoot_v2.py
file2: models/shoot_v3.py
==========================
...

31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggRpcClient
33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient, YggTimesync
    ?
++++++++++++

34:       light_rpc = YggRpcClient('light_shoot')
35: +     shoot2root = YggTimesync('shoot2root')
36:
37:   # Continue simulation until time limit is reached
38:   while t <= tmax:
39:
40:       # If running as part an yggdrasil integration, send the time and
    -     # maximum height of the mesh to the height channel with units
41: +     # maximum height of the mesh to the height channel with units and
    ?                                                                  ++++

42: +     # send the current mass and tiem to the timesync channel
43:       if with_yggdrasil:
44: +         shoot_state = {'mass': units.add_units(mass, 'g')}
45: +         flag, total_state = shoot2root.call(units.add_units(t, 'hrs'),
46: +                                             shoot_state)
47: +         if not flag:
48: +             raise Exception("Error performing time-step synchronization "
49: +                             "with root model.")
50: +

...

60:           scale = units.get_data(
    -             units.add_units(mass, 'g') * intensity /
    ?             ^^^  ^ ------------------------------                    ^
61: +                 total_state['mass'] * intensity /
    ?             ^^^^ +++++ ^^^^                          ^^^^
    -             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
62: +                 units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
    ? ++++

...
```

Import the time sync interface & connect to the "`shoot2root`" channel

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/shoot_v2.py
file2: models/shoot_v3.py
==========================
...

31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggRpcClient
33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient, YggTimesync
    ?
++++++++++++

34:       light_rpc = YggRpcClient('light_shoot')
35: +     shoot2root = YggTimesync('shoot2root')
36:
37:   # Continue simulation until time limit is reached
38:   while t <= tmax:
39:
40:       # If running as part an yggdrasil integration, send the time and
    -     # maximum height of the mesh to the height channel with units
41: +     # maximum height of the mesh to the height channel with units and
    ?                                                                  ++++

42: +     # send the current mass and tiem to the timesync channel
43:       if with_yggdrasil:
44: +         shoot_state = {'mass': units.add_units(mass, 'g')}
45: +         flag, total_state = shoot2root.call(units.add_units(t, 'hrs'),
46: +                                             shoot_state)
47: +         if not flag:
48: +             raise Exception("Error performing time-step synchronization "
49: +                             "with root model.")
50: +

...

60:           scale = units.get_data(
    -             units.add_units(mass, 'g') * intensity /
    ?             ^^^  ^ ------------------------------                ^
61: +                 total_state['mass'] * intensity /
    ?             ^^^^ +++++ ^^^^                    ^^^^
    -             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
62: +                 units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
    ? ++++

...
```

Send the shoot state to the time sync model & receive back the total state

In [7]:
```
tools.display_source_diff('models/roots_v0.py', 'models/roots_v1.py', number_lines=True)
tools.display_source_diff('models/shoot_v2.py', 'models/shoot_v3.py', number_lines=True)
```

```
file1: models/shoot_v2.py
file2: models/shoot_v3.py
==========================
...

31:   if with_yggdrasil:
32:       from yggdrasil import units
    -     from yggdrasil.languages.Python.YggInterface import YggRpcClient
33: +     from yggdrasil.languages.Python.YggInterface import YggRpcClient, YggTimesync
    ?
++++++++++++

34:       light_rpc = YggRpcClient('light_shoot')
35: +     shoot2root = YggTimesync('shoot2root')
36:
37:   # Continue simulation until time limit is reached
38:   while t <= tmax:
39:
40:       # If running as part an yggdrasil integration, send the time and
    -     # maximum height of the mesh to the height channel with units
41: +     # maximum height of the mesh to the height channel with units and
    ?                                                                  ++++

42: +     # send the current mass and tiem to the timesync channel
43:       if with_yggdrasil:
44: +         shoot_state = {'mass': units.add_units(mass, 'g')}
45: +         flag, total_state = shoot2root.call(units.add_units(t, 'hrs'),
46: +                                             shoot_state)
47: +         if not flag:
48: +             raise Exception("Error performing time-step synchronization "
49: +                             "with root model.")
50: +

...

60:           scale = units.get_data(
    -             units.add_units(mass, 'g') * intensity /
    ?             ^^^  ^ ------------------------------                    ^

61: +                 total_state['mass'] * intensity /
    ?             ^^^^ +++++ ^^^^                              ^^^^

    -             units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
62: +                 units.add_units(4.0e10, 'g*erg/(cm**2*s)'))
    ? ++++

...
```

Change the scale calculation to use the total state

In [8]:
```
run(['yamls/shoot_v3.yml', 'yamls/roots_v1.yml', 'yamls/light_v1_python.yml', 'yamls/timesync.yml'], production_run=Tru
```

```
INFO:96257:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
_light_v0.py
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v3.py 0.0 48.0 6.0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/roo
ts_v1.py 0.0 2.0 0.5
End of input from temp_doy.
INFO:96257:runner.waitModels[553]:YggRunner(runner): shoot finished running.
No more messages from model process.
INFO:96257:DSLModelDriver.after_loop[131]:TimeSyncModelDriver(shoot2root): returncode = 0
INFO:96257:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:96257:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:96257:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:96257:runner.waitModels[553]:YggRunner(runner): roots finished running.
INFO:96257:runner.waitModels[559]:YggRunner(runner): roots finished exiting.
INFO:96257:runner.waitModels[553]:YggRunner(runner): shoot2root finished running.
INFO:96257:runner.waitModels[559]:YggRunner(runner): shoot2root finished exiting.
INFO:96257:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:96257:runner.run[374]:YggRunner(runner):                 init      0.000001
INFO:96257:runner.run[374]:YggRunner(runner):         load drivers      0.051068
INFO:96257:runner.run[374]:YggRunner(runner):        start drivers      0.303378
INFO:96257:runner.run[374]:YggRunner(runner):           run models      19.234870
INFO:96257:runner.run[374]:YggRunner(runner):              at exit      0.117888
INFO:96257:runner.run[376]:YggRunner(runner): ========================================
INFO:96257:runner.run[377]:YggRunner(runner):                Total      19.707205
```

```
In [8]: run(['yamls/shoot_v3.yml', 'yamls/roots_v1.yml', 'yamls/light_v1_python.yml', 'yamls/timesync.yml'], production_run=Tru
```

```
INFO:96257:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system Meagans-MacBook-Air.
local in namespace yggdrasil with rank 0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg
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/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/sho
ot_v3.py 0.0 48.0 6.0
/Users/langmm/miniconda3/envs/conda36/bin/python /Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/roo
ts_v1.py 0.0 2.0 0.5
End of input from temp_doy.
INFO:96257:runner.waitModels[553]:YggRunner(runner): sho
No more messages from model process.
INFO:96257:DSLModelDriver.after_loop[131]:TimeSyncModelD
INFO:96257:runner.waitModels[559]:YggRunner(runner): sho
INFO:96257:runner.waitModels[553]:YggRunner(runner): lig
INFO:96257:runner.waitModels[559]:YggRunner(runner): lig
INFO:96257:runner.waitModels[553]:YggRunner(runner): roo
INFO:96257:runner.waitModels[559]:YggRunner(runner): roo
INFO:96257:runner.waitModels[553]:YggRunner(runner): sho
INFO:96257:runner.waitModels[559]:YggRunner(runner): sho
INFO:96257:runner.waitModels[573]:YggRunner(runner): All
INFO:96257:runner.run[374]:YggRunner(runner):
INFO:96257:runner.run[374]:YggRunner(runner):          lo
INFO:96257:runner.run[374]:YggRunner(runner):         sta
INFO:96257:runner.run[374]:YggRunner(runner):
INFO:96257:runner.run[374]:YggRunner(runner):
INFO:96257:runner.run[376]:YggRunner(runner): ==========
INFO:96257:runner.run[377]:YggRunner(runner):
```
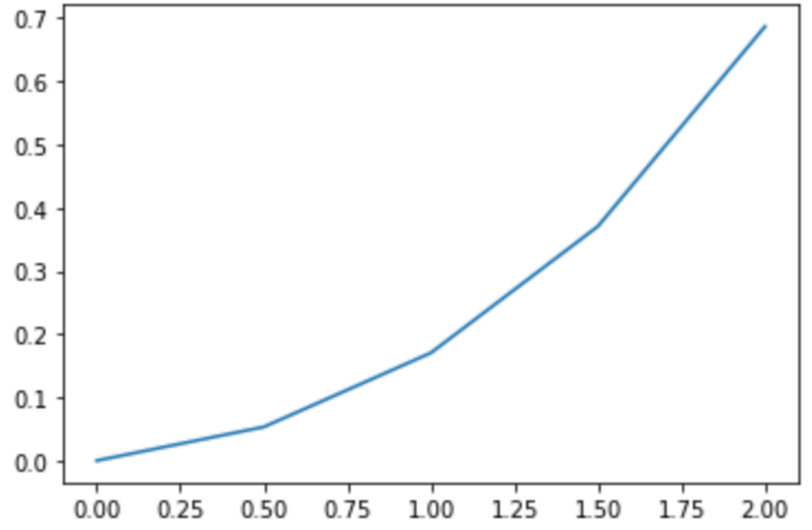
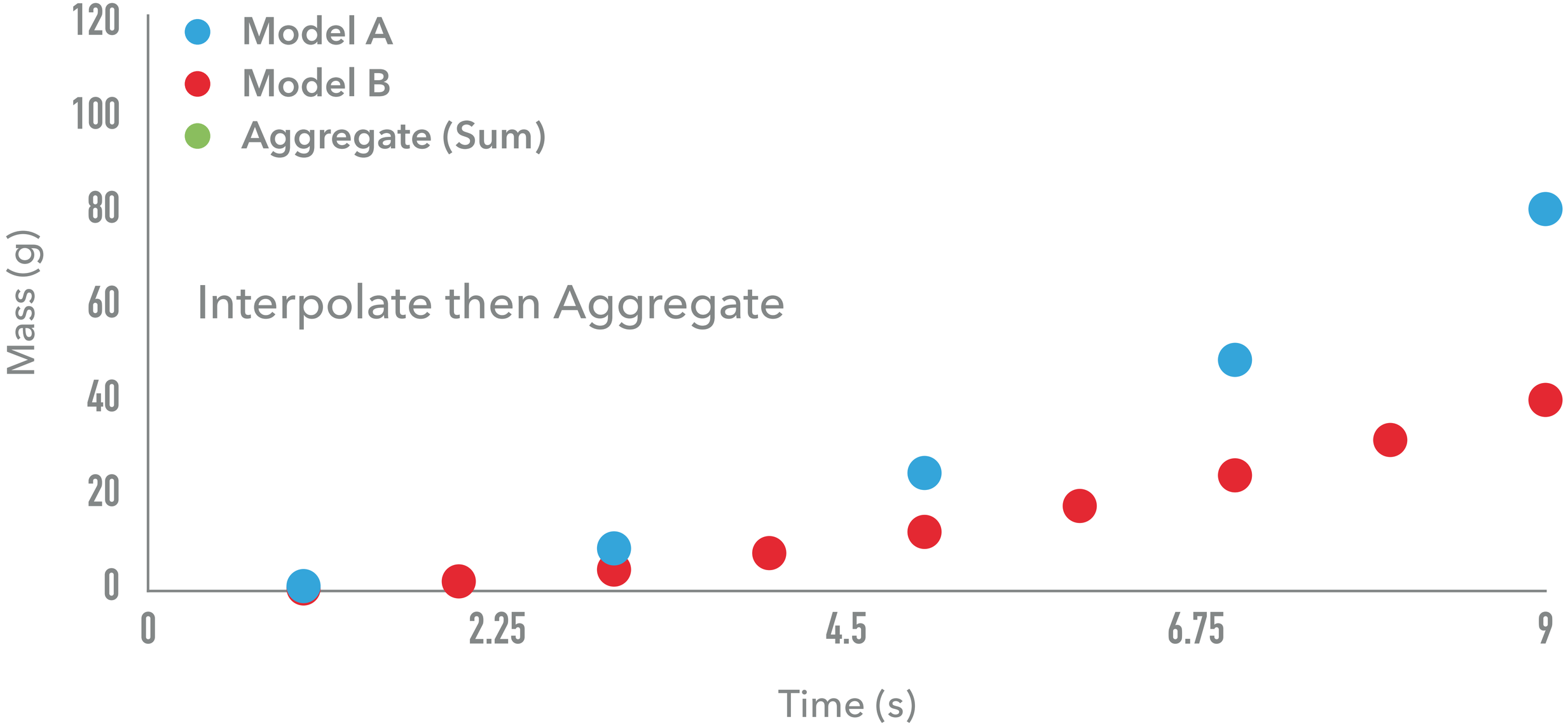

```
In [9]: import matplotlib.pyplot as plt
filename_masses = 'output/masses.pkl'
with open(filename_masses, 'rb') as fd:
    masses = pickle.load(fd)
plt.plot(masses['times'], masses['masses'])
```

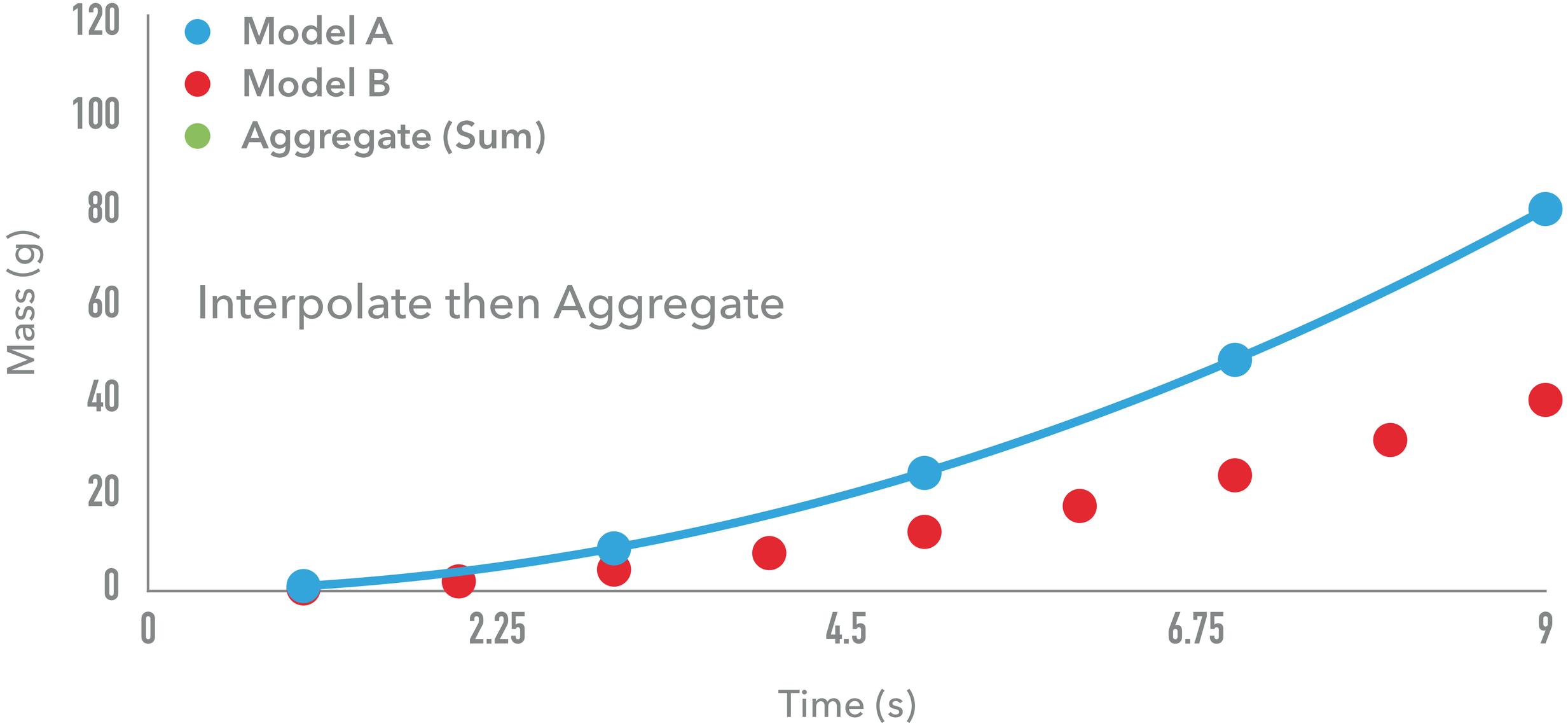
```
Out[9]: [<matplotlib.lines.Line2D at 0x147d40048>]
```



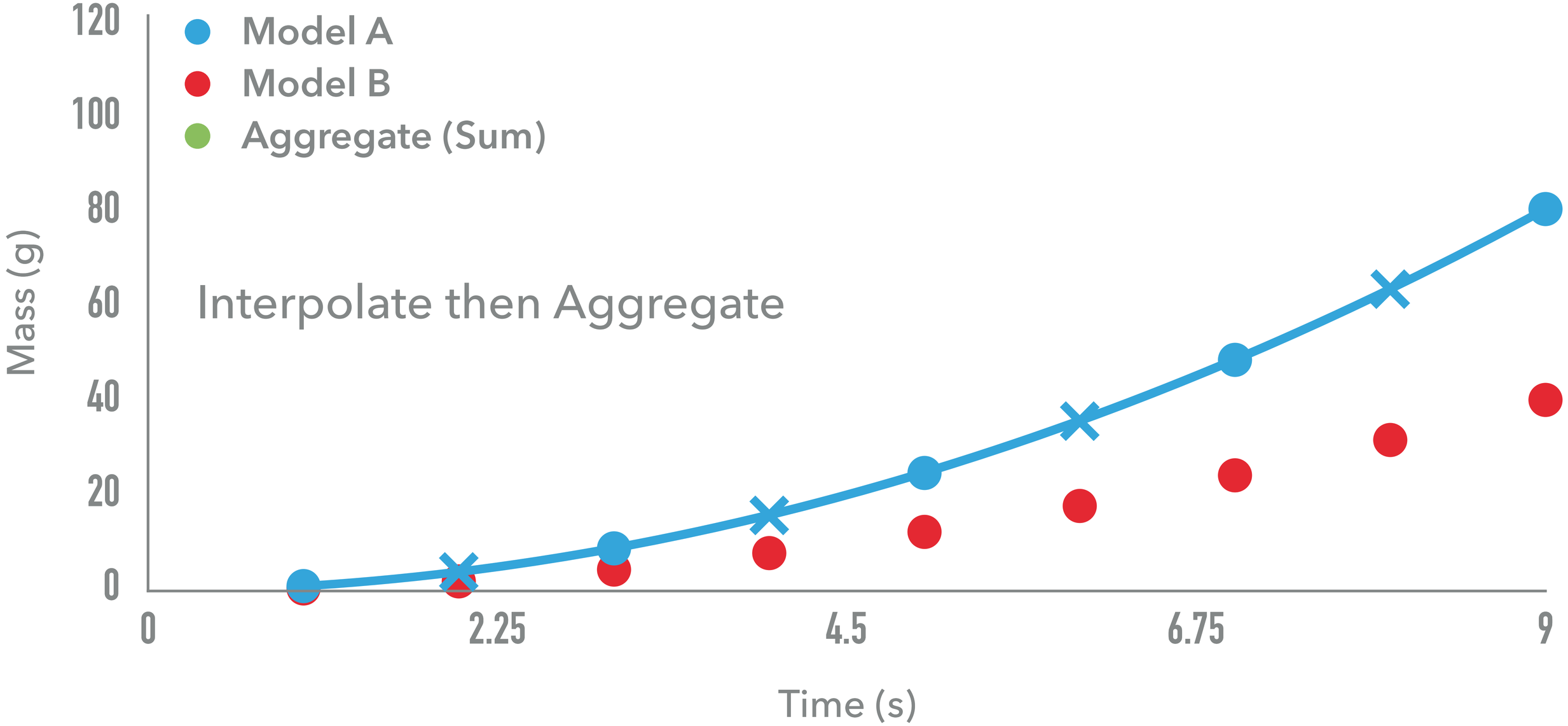
AGGREGATION OF TIME STEPS



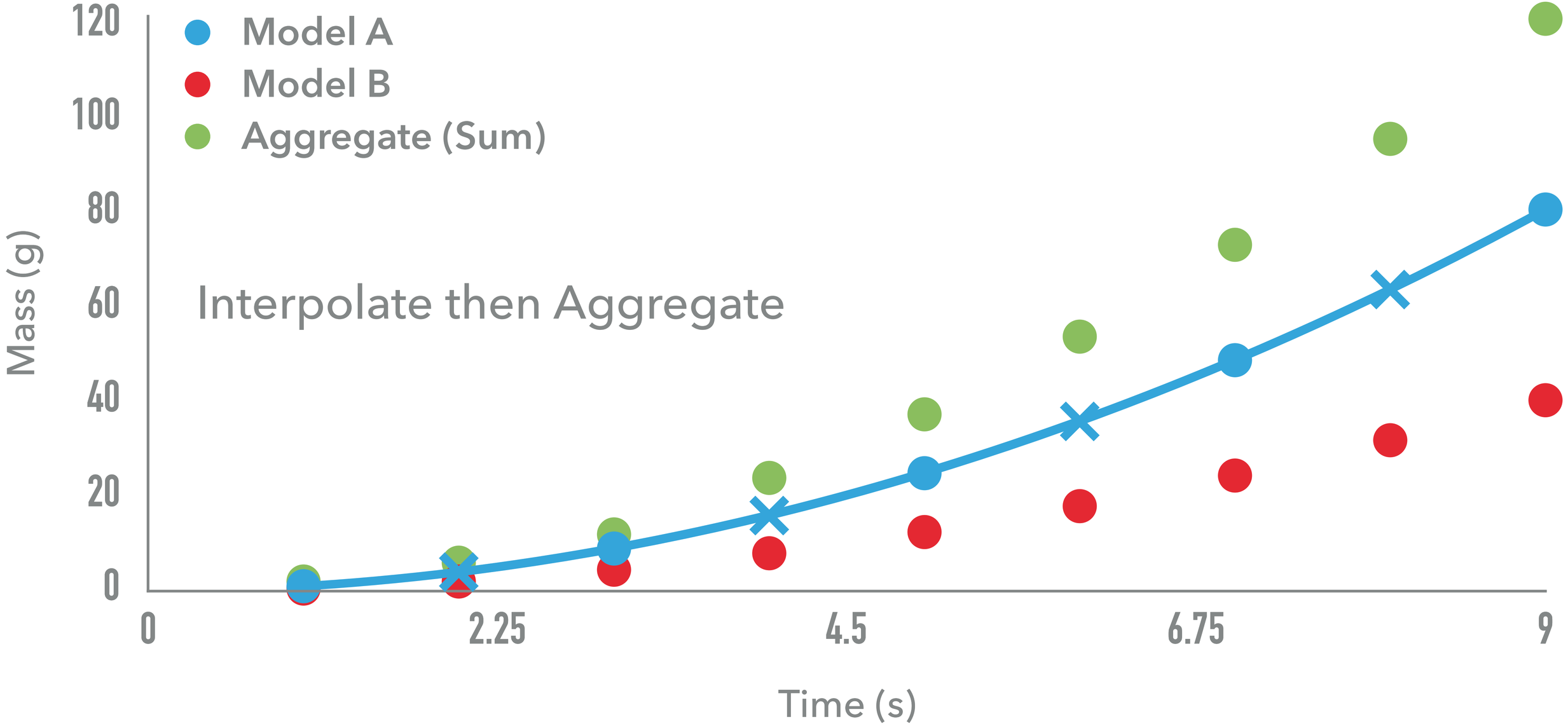
AGGREGATION OF TIME STEPS



AGGREGATION OF TIME STEPS



AGGREGATION OF TIME STEPS



NEW NOTEBOOK!
(BREAK TIME)

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02-timesync.ipynb		33 minutes ago	298 kB
03-misc.ipynb		33 minutes ago	3.56 kB

IMPORTING MODELS AS PYTHON FUNCTIONS

In [1]:
```
from yggdrasil import tools
tools.display_source('models/light_v0.f90', number_lines=True)
tools.display_source('yamls/light_v0_fortran.yml', number_lines=True)
```

file: models/light_v0.f90
```
 1: !-----------------------------------------------------------------------
 2: !> @brief Compute the intensity of light.
 3: !
 4: !> @param[in] doy: Day of year.
 5: !> @param[in] height: Distance from ground in cm.
 6: !
 7: !> @return intensity: Intensity of light in ergs cm^-2 s^-1.
 8: !-----------------------------------------------------------------------
 9: function light(doy, height) result(intensity)
10:   real(kind=8) :: doy
11:   real(kind=8) :: height
12:   real(kind=8) :: intensity
13:   real, parameter :: Pi = 3.1415927
14:
15:   ! Define parameters that are static across a run
16:   real, parameter :: amplitude = 80.0
17:   real, parameter :: doy_offset = 0.0
18:
19:   ! Calculate intensity
20:   intensity = amplitude * height * (1.0 + SIN(2.0 * Pi * (doy - doy_offset) / 365))
21: end function light
```

file: yamls/light_v0_fortran.yml
```
 1: model:
 2:   name: light
 3:   language: fortran
 4:   args: ../models/light_v0.f90
 5:   function: light
 6:   inputs:
 7:     - name: input
 8:       vars: [doy, height]
 9:       datatype:
10:         type: array
11:         items:
12:           - type: float
13:             units: day
14:           - type: float
15:             units: cm
16:   output:
17:     - name: output
18:       datatype:
19:         type: float
20:         units: ergs/(cm**2*s)
```

In [2]:
```
from yggdrasil import import_as_function
light = import_as_function('yamls/light_v0_fortran.yml')
```

```
INFO:97475:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system None in namespace yg
gdrasil with rank 0
/Users/langmm/yggdrasil/yggdrasil/demos/CiS2021-hackathon/models/ygg_light_v0_f90_gfortranx_gfortranx.out
INFO:97475:runner.run[374]:YggRunner(runner):                  init      0.000001
INFO:97475:runner.run[374]:YggRunner(runner):          load drivers      0.828631
INFO:97475:runner.run[374]:YggRunner(runner):         start drivers      0.061332
INFO:97475:runner.run[376]:YggRunner(runner): ========================================
INFO:97475:runner.run[377]:YggRunner(runner):                 Total      0.889964
```

In [3]:
```
light.model_info()
```

```
Models: light
Inputs:
        light:input_to_light:input (vars=['doy', 'height'])
Outputs:
        light:output (vars=['intensity'])
```

Model can be called from Python regardless of the language

In [4]:
```
import numpy as np
print(light(100.0, 100.0))
print(light(1.0, 2.9))
print(light(2.0, 3.0))
```

```
{'intensity': unyt_quantity(15909.42066435, 'erg/(cm**2*s)')}
{'intensity': unyt_quantity(235.99349874, 'erg/(cm**2*s)')}
{'intensity': unyt_quantity(248.26118702, 'erg/(cm**2*s)')}
```

Model units are assumed if not provided

In [4]:
```
import numpy as np
print(light(100.0, 100.0))
print(light(1.0, 2.9))
print(light(2.0, 3.0))
```

```
{'intensity': unyt_quantity(15909.42066435, 'erg/(cm**2*s)')}
{'intensity': unyt_quantity(235.99349874, 'erg/(cm**2*s)')}
{'intensity': unyt_quantity(248.26118702, 'erg/(cm**2*s)')}
```

Model units are assumed if not provided

In [5]:
```
from yggdrasil import units
print(light(units.add_units(24.0, 'hrs'), units.add_units(2.9, 'cm')))
print(light(units.add_units(1.0, 'days'), units.add_units(0.029, 'm')))
```

```
{'intensity': unyt_quantity(235.99349874, 'erg/(cm**2*s)')}
{'intensity': unyt_quantity(235.99349874, 'erg/(cm**2*s)')}
```

If units are provided, yggdrasil can handle transformations to/from the model's units

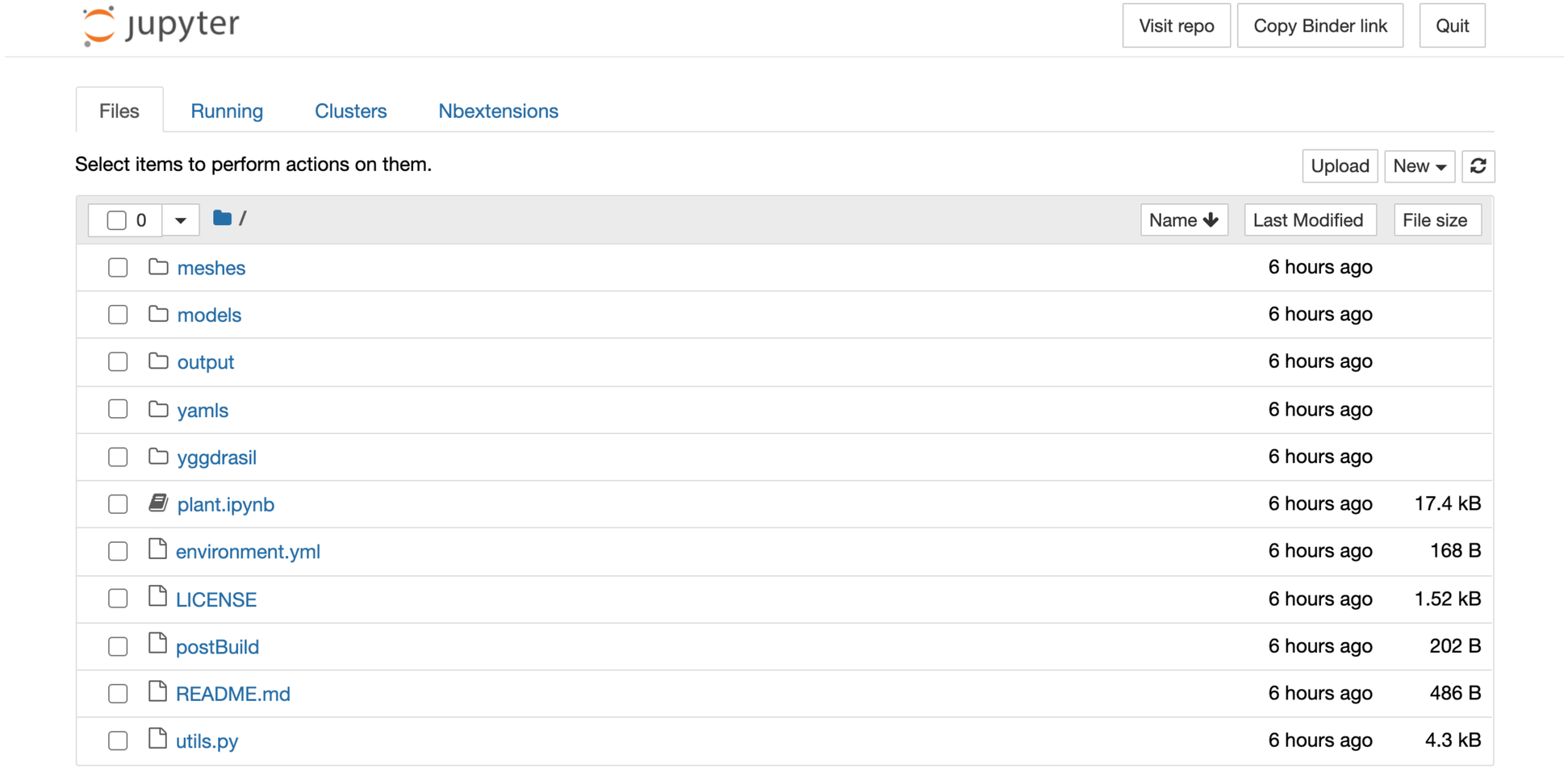
COMMAND LINE INTERFACE (CLI)

COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python

COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python



COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python

COMMAND LINE INTERFACE (CLI)

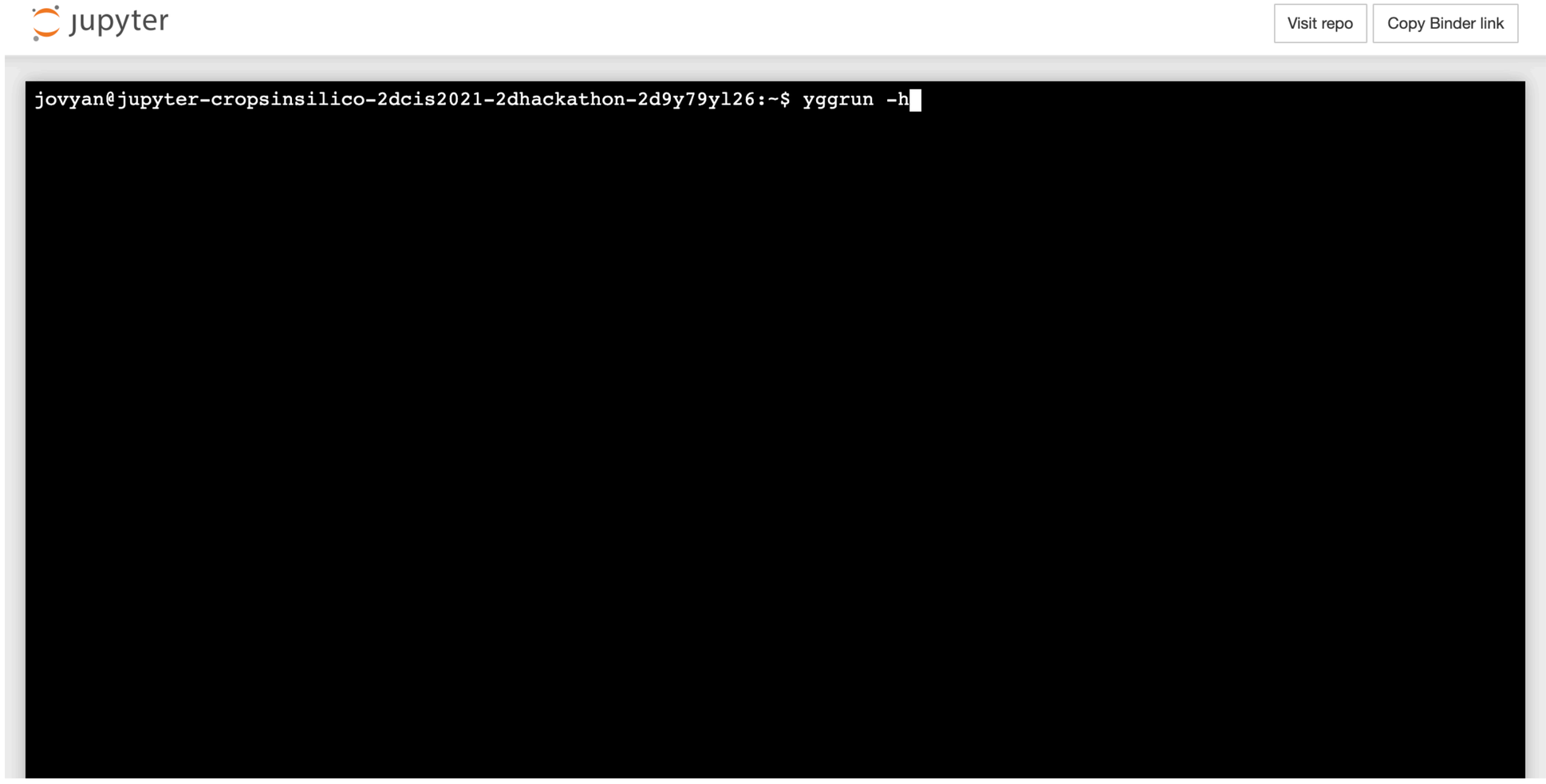
Run yggdrasil integration from the command line w/o opening Python

COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python

COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python



COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python

jupyter

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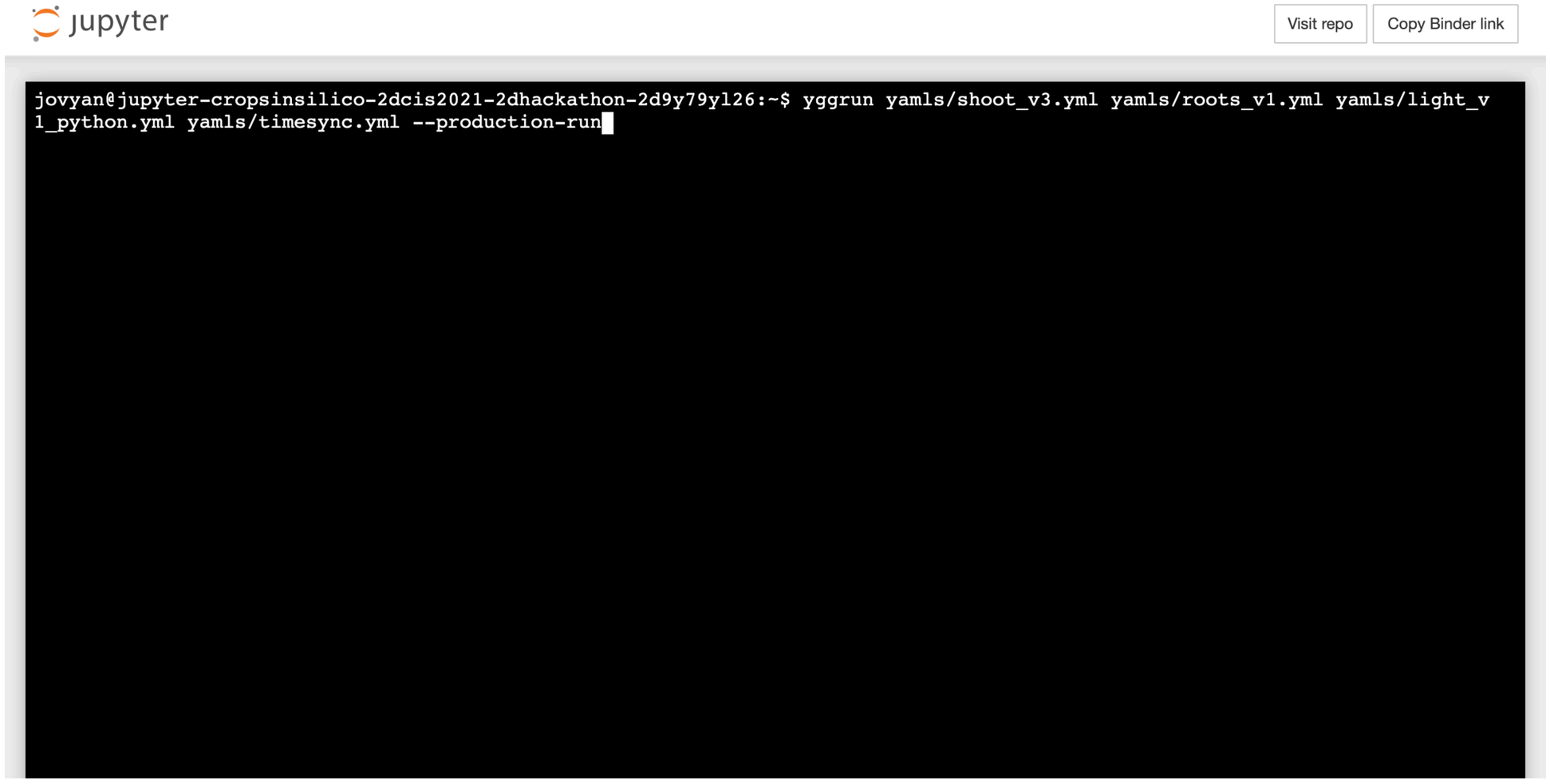
```
jovyan@jupyter-cropsinsilico-2dcis2021-2dhackathon-2d9y79yl26:~$ yggrun -h
usage: Run an integration. [-h] [--loglevel LOGLEVEL] [--rmq-loglevel RMQ_LOGLEVEL] [--client-loglevel CLIENT_LOGLEVEL]
                           [--validate-components] [--validate-messages {False,True,First}] [--namespace NAMESPACE]
                           [--host HOST] [--vhost VHOST] [--user USER] [--password PASSWORD] [--cluster CLUSTER]
                           [--default-comm DEFAULT_COMM] [--production-run] [--debug]
                           yamlfile [yamlfile ...]

positional arguments:
  yamlfile              One or more yaml specification files.

optional arguments:
  -h, --help            show this help message and exit
  --loglevel LOGLEVEL   Logging level for yggdrasil operations.
  --rmq-loglevel RMQ_LOGLEVEL, --rmqloglevel RMQ_LOGLEVEL
                        Logging level for RabbitMQ operations.
  --client-loglevel CLIENT_LOGLEVEL, --clientloglevel CLIENT_LOGLEVEL
                        Logging level for yggdrasil operations on model processes.
  --validate-components, --validatecomponents
                        Validate components on creation using their JSON schema (Decreases performance).
  --validate-messages {False,True,First}, --validatemessages {False,True,First}
                        Which messages should be validated during communication. 'True': all messages (decreases
                        performance), 'False': no messages, or 'First': only the first message a comm sends/receives.
  --namespace NAMESPACE
                        RabbitMQ namespace.
  --host HOST           RabbitMQ host address.
  --vhost VHOST         RabbitMQ virtual host address.
  --user USER           RabbitMQ username.
  --password PASSWORD   RabbitMQ password.
  --cluster CLUSTER     Cluster that should be used.
  --default-comm DEFAULT_COMM, --defaultcomm DEFAULT_COMM
                        Comm type that should be used by default.
```

COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python



COMMAND LINE INTERFACE (CLI)

Run yggdrasil integration from the command line w/o opening Python

jupyter

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```
jovyan@jupyter-cropsinsilico-2dcis2021-2dhackathon-2d9y79yl26:~$ yggrun yamls/shoot_v3.yml yamls/roots_v1.yml yamls/light_v
1_python.yml yamls/timesync.yml --production-run
INFO:1423:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system jupyter-cropsinsilico-2dcis
2021-2dhackathon-2d9y79yl26 in namespace yggdrasil with rank 0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/ygg_light_v0.py
/srv/conda/envs/notebook/bin/python /home/jovyan/models/shoot_v3.py 0.0 48.0 6.0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/roots_v1.py 0.0 2.0 0.5
End of input from temp_doy.
timesync server: End of input.
INFO:1423:runner.waitModels[553]:YggRunner(runner): shoot finished running.
No more messages from model process.
INFO:1423:DSLModelDriver.after_loop[131]:TimeSyncModelDriver(shoot2root): returncode = 0
INFO:1423:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:1423:runner.waitModels[553]:YggRunner(runner): light finished running.
INFO:1423:runner.waitModels[559]:YggRunner(runner): light finished exiting.
INFO:1423:runner.waitModels[553]:YggRunner(runner): roots finished running.
INFO:1423:runner.waitModels[559]:YggRunner(runner): roots finished exiting.
INFO:1423:runner.waitModels[553]:YggRunner(runner): shoot2root finished running.
INFO:1423:runner.waitModels[559]:YggRunner(runner): shoot2root finished exiting.
INFO:1423:runner.waitModels[573]:YggRunner(runner): All models completed
INFO:1423:runner.run[374]:YggRunner(runner):                 init       0.000001
INFO:1423:runner.run[374]:YggRunner(runner):         load drivers       0.164377
INFO:1423:runner.run[374]:YggRunner(runner):        start drivers       0.372987
INFO:1423:runner.run[374]:YggRunner(runner):           run models       23.552745
INFO:1423:runner.run[374]:YggRunner(runner):              at exit       0.054842
INFO:1423:runner.run[376]:YggRunner(runner): ======================================
INFO:1423:runner.run[377]:YggRunner(runner):                Total       24.144952

jovyan@jupyter-cropsinsilico-2dcis2021-2dhackathon-2d9y79yl26:~$
```

"PRODUCTION RUN" FLAG

Speeds up execution by skipping type checking and input validation
(only used once integration has been debugged)

In [10]:
```
run(['yamls/light_v1_python.yml', 'yamls/shoot_v2_split.yml'], production_run=True)
mesh = trimesh.load_mesh('output/mesh_008.obj')
mesh.show()
```

jupyter

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```
jovyan@jupyter-cropsinsilico-2dcis2021-2dhackathon-2d9y79yl26:~$ yggrun yamls/            yamls/roots_v1.yml yamls/light_v
1_python.yml yamls/timesync.yml --production-run
INFO:1423:runner.startDrivers[499]:YggRunner(runner): Starting I/O drivers and models on system jupyter-cropsinsilico-2dcis
2021-2dhackathon-2d9y79yl26 in namespace yggdrasil with rank 0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/ygg_light_v0.py
/srv/conda/envs/notebook/bin/python /home/jovyan/models/shoot_v3.py 0.0 48.0 6.0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/roots_v1.py 0.0 2.0 0.5
End of input from temp_doy.
timesync server: End of input.
INFO:1423:runner.waitModels[553]:YggRunner(runner): shoot finished running.
No more messages from model process.
INFO:1423:DSLModelDriver.after_loop[131]:TimeSyncModelDriver(shoot2root): returncode = 0
INFO:1423:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:1423:runner.waitModels[553]:YggRunner(runner): light finished running.
```

"PRODUCTION RUN" FLAG

Speeds up execution by skipping type checking and input validation
(only used once integration has been debugged)

```
In [10]: run(['yamls/light_v1_python.yml', 'yamls/shoot_v2_split.yml', production_run=True)
         mesh = trimesh.load_mesh('output/mesh_008.obj')
         mesh.show()
```

jupyter

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```
jovyan@jupyter-cropsinsilico-2dcis2021-2dhackathon-2d9y79yl26:~$ yggrun yamls/                yamls/roots_v1.yml yamls/light_v
1_python.yml yamls/timesync.yml --production-run
INFO:1423:runner.startDrivers[4[illegible]runner): Starting I/O drivers and models on system jupyter-cropsinsilico-2dcis
2021-2dhackathon-2d9y79yl26 in namespace yggdrasil with rank 0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/ygg_light_v0.py
/srv/conda/envs/notebook/bin/python /home/jovyan/models/shoot_v3.py 0.0 48.0 6.0
/srv/conda/envs/notebook/bin/python /home/jovyan/models/roots_v1.py 0.0 2.0 0.5
End of input from temp_doy.
timesync server: End of input.
INFO:1423:runner.waitModels[553]:YggRunner(runner): shoot finished running.
No more messages from model process.
INFO:1423:DSLModelDriver.after_loop[131]:TimeSyncModelDriver(shoot2root): returncode = 0
INFO:1423:runner.waitModels[559]:YggRunner(runner): shoot finished exiting.
INFO:1423:runner.waitModels[553]:YggRunner(runner): light finished running.
```

ADDITIONAL EXAMPLES

README.md

launch binder

Getting Started

All of the materials for the 2021 Crops in Silico Hackathon can be found in this repository.

Requirements

- Browser (tested on Google Chrome, Safari, Firefox)
- Github Account

Preparing for the hackathon

- Check that you can sign-in to Github, creating an account as necessary. We will be using Github Issues to track problems encountered during the hackathon.
- Try launching a mybinder instance by clicking on this launch binder icon (or the link below). It may take a few moments to initialize. If you encounter an error, open an issue and try with another browser. If you still cannot launch the binder, follow the instruction here for downloading and installing the materials locally.

https://mybinder.org/v2/gh/cropsinsilico/CiS2021-hackathon/HEAD

Useful links

- Hackathon Repository
- yggdrasil Repository
- yggdrasil Documentation
- Additional Examples
- Debugging Tips & Documented Errors

40+ EXAMPLES IN SUPPORTED LANGUAGES

README.md

launch binder

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- Check that you can sign-in to Github, creating an account as necessary. We will be using Github Issues to track problems encountered during the hackathon.
- Try launching a mybinder instance by clicking on this launch binder icon (or the link below). It may take a few moments to initialize. If you encounter an error, open an issue and try with another browser. If you still cannot launch the binder, follow the instruction here for downloading and installing the materials locally.

https://mybinder.org/v2/gh/cropsinsilico/CiS2021-hackathon/HEAD

Useful links

- Hackathon Repository
- yggdrasil Repository
- yggdrasil Documentation
- Additional Examples
- Debugging Tips & Documented Errors

40+ EXAMPLES IN SUPPORTED LANGUAGES

README.md

launch binder

Getting Started

All of the materials for the 2021 Crops in Silico Hackathon can be found in this repository.

Requirements

- Browser (tested on Google Chrome, Safari, Firefox)
- Github Account

Preparing for the hackathon

- Check that you can sign-in to Github, creating an account as necessar
  problems encountered during the hackathon.
- Try launching a mybinder instance by clicking on this launch binder ic
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yggdrasil
v1.6.3

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CONTENTS:

Examples

Name	Description
SaM	One model that receives input from two files and sends output to one file in the temporary directory. The YAML uses the deprecated driver-based method to represent connections.
ascii_io	A single model that receives data from three input files and sends received messages to three output files. The first file is an unstructure ASCII text file, the second file is a table delimited ASCII table that is read row by row, and the third file is a table identical to the second that is read all at once.
backwards	A single model using the deprecated “Cis” versions of the interface.
conditional_io	Three models, A, B1, & B2, that conditionally pass messages. Model A receives input from a tab delimited table and sends output to both models B1 & B2. The outputs to models B1 & B2 only succeed if the data satisfies conditions described in the YAML. Output from both models B1 & B2 are sent to a tab delimited table.
fakeplant	Four models that can be run in isolation or as an integration. Each model approximates a simplified model of a process governing plant growth. When run in isolation each model receives input from a file and sends output to a file. In the larger integration, the canopy model receives input from three files (initial structure, time steps, and some growth parameters. For each time step received, the canopy model also receives a growth rate from the growth model, computes the new structure. and send the structure to the light model. The light model receives the ambient light level from a file, calculates the intensity for each element of the structure, and sends the output to the photosynthesis model. The photosynthesis model receives temperature and CO2 from files, calculates the photosynthesis rate, and sends the result to the growth model. The growth model calculates the growth rate and sends the output to the canopy model.
formatted_io1	Two models, A & B, that send/receive ASCII data (strings). Model A receives input from a file and then sends it’s output to model B. Model B receives input from model A and sends it’s output to a file.
formatted_io2	Two models, A & B, that send/receive rows of table data. Model A receives input from a file and then sends it’s output to model B. Model B receives input from

QUESTIONS?

Github: https://github.com/cropsinsilico/yggdrasil

Docs: https://cropsinsilico.github.io/yggdrasil/

Paper: https://doi.org/10.1093/insilicoplants/diz001

Project Website: http://cropsinsilico.org/