Pseudo-Genetic Algorithm Method for Space Farm Modelling

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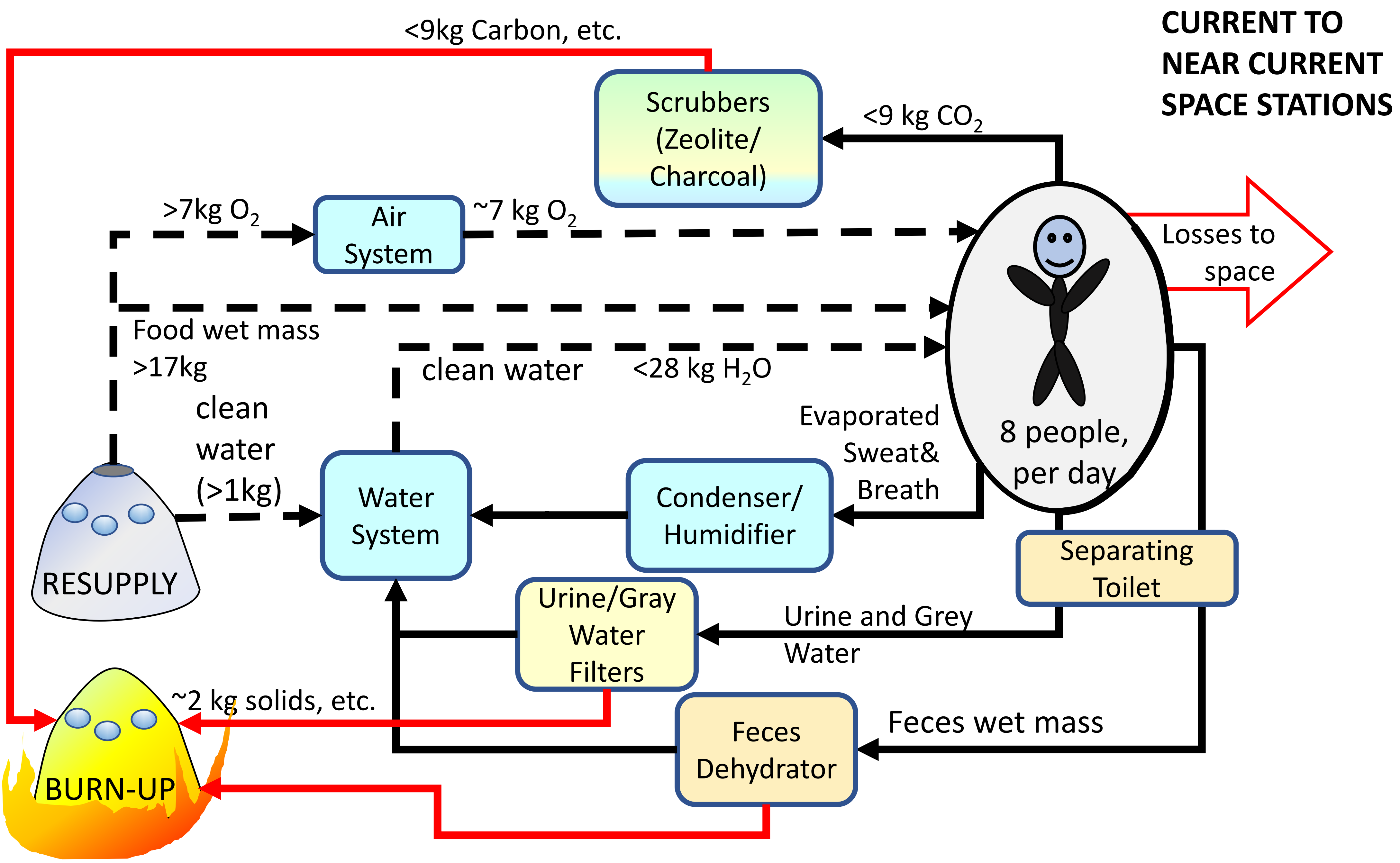
Outline

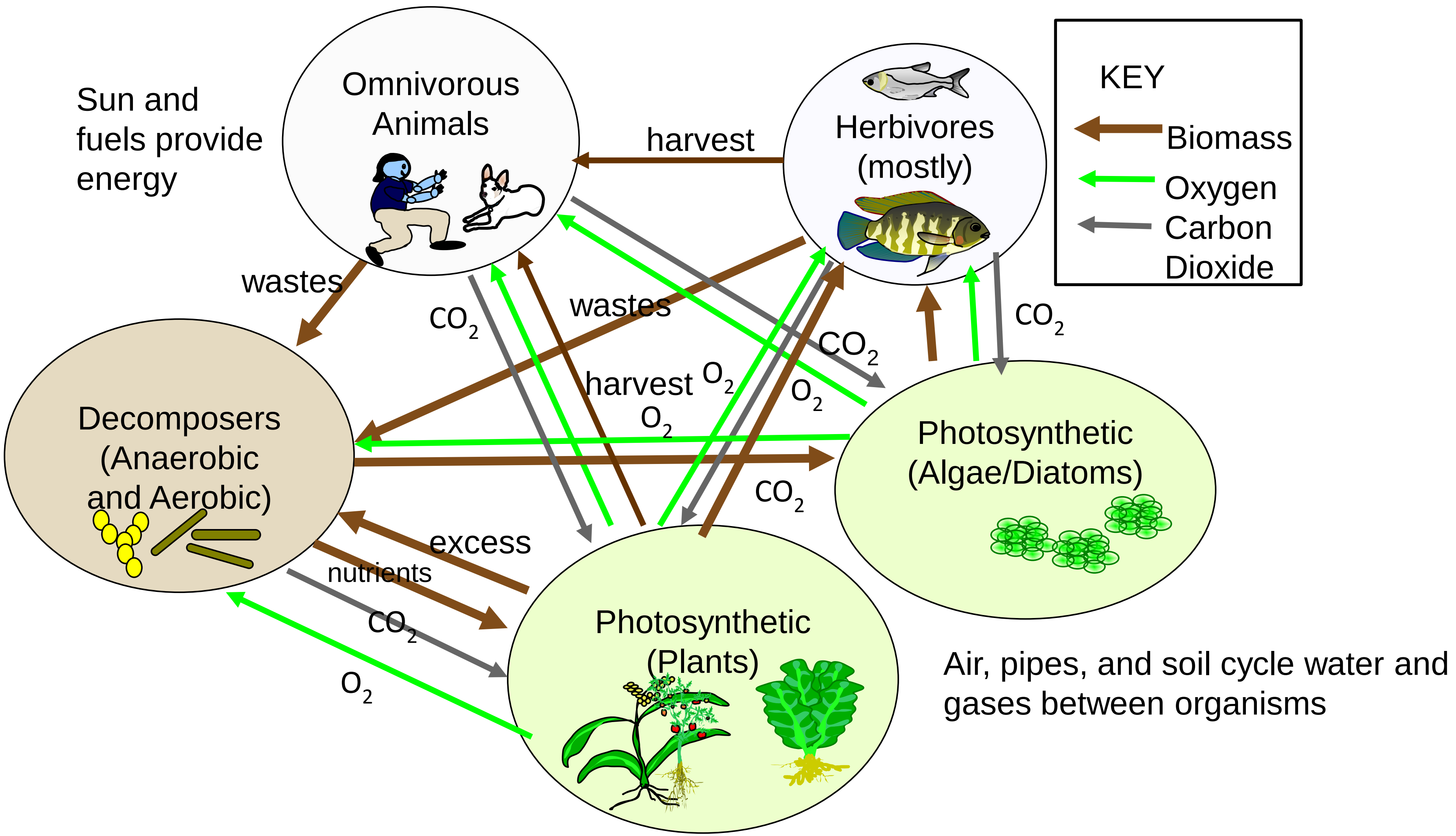
- Space Farm 101, and why I need analysis
  - Data and Processes
- Monte Carlo Analysis
- Genetic Algorithms
- Using a sort of Genetic Algorithm to balance a space farm

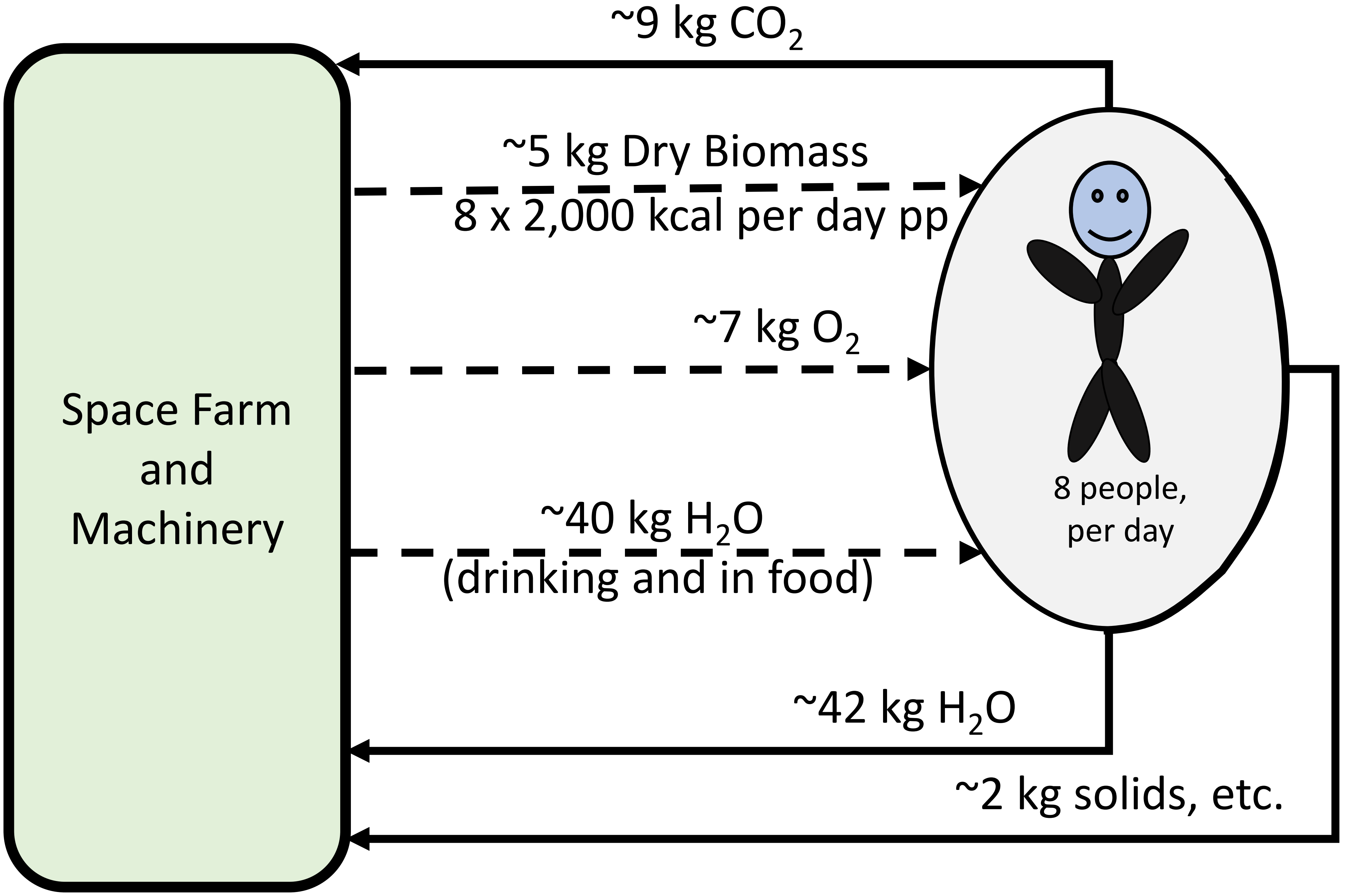
Space Farm 101

- In space, i.e. anything above 100 km or out, mass is expensive!
  - >$1,000/lb+ to LEO, $50,000/lb+ to Moon surface, and $1M+/lb to Mars.
  - Must close the mass loop: Goes into = Goes out of.
- Space Farm: Combination of machinery and organisms to take the outputs from humans, and convert them to the inputs to humans.
  - Related concept: Ecologically Closed Life Support System (ECLSS)
  - Midwestern Farmer terms: poop to plate.
- BIG NOTES:
  - Technologies for space farms, come from current ag, chemical factories, and indoor farms
  - Technologies to optimize space farms CAN OPTIMIZE Earth food production!


CURRENT TO NEAR CURRENT SPACE STATIONS
<9kg Carbon, etc.
Scrubbers (Zeolite/ Charcoal)
<9 kg CO_2
>7kg O_2
Air System
~7 kg O_2
Losses to space
Food wet mass >17kg
clean water
<28 kg H_2O
clean water (>1kg)
Evaporated Sweat& Breath
8 people, per day
Water System
Condenser/ Humidifier
RESUPPLY
Separating Toilet
Urine/Gray Water Filters
Urine and Grey Water
~2 kg solids, etc.
Feces wet mass
Feces Dehydrator
BURN-UP

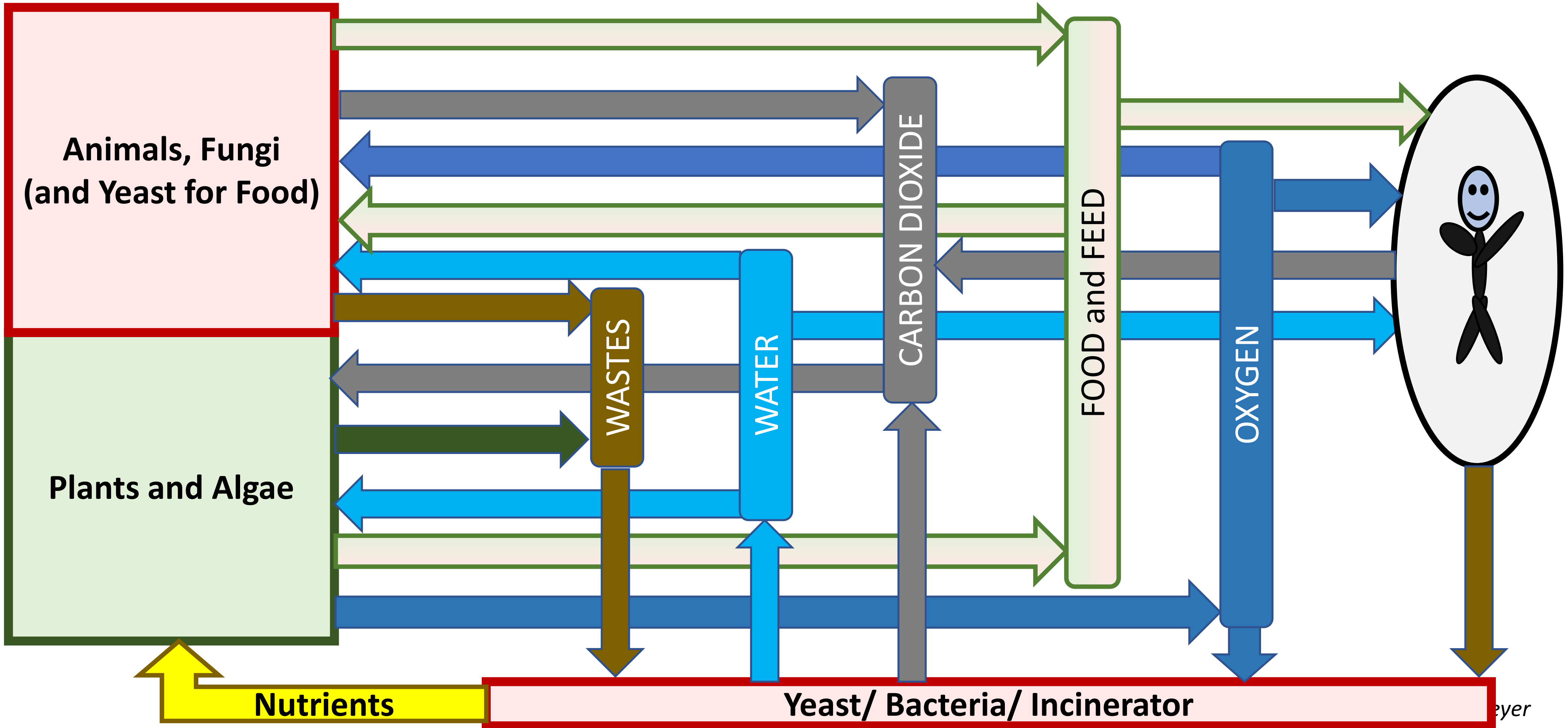
An Earth Farm Example Pseudo Ecosystem




~9 kg CO_2
~5 kg Dry Biomass
8 x 2,000 kcal per day pp
~7 kg O_2
~40 kg H_2O
(drinking and in food)
~42 kg H_2O
~2 kg solids, etc.
Space Farm
and
Machinery
8 people,
per day

Space Farm Crops and Parts

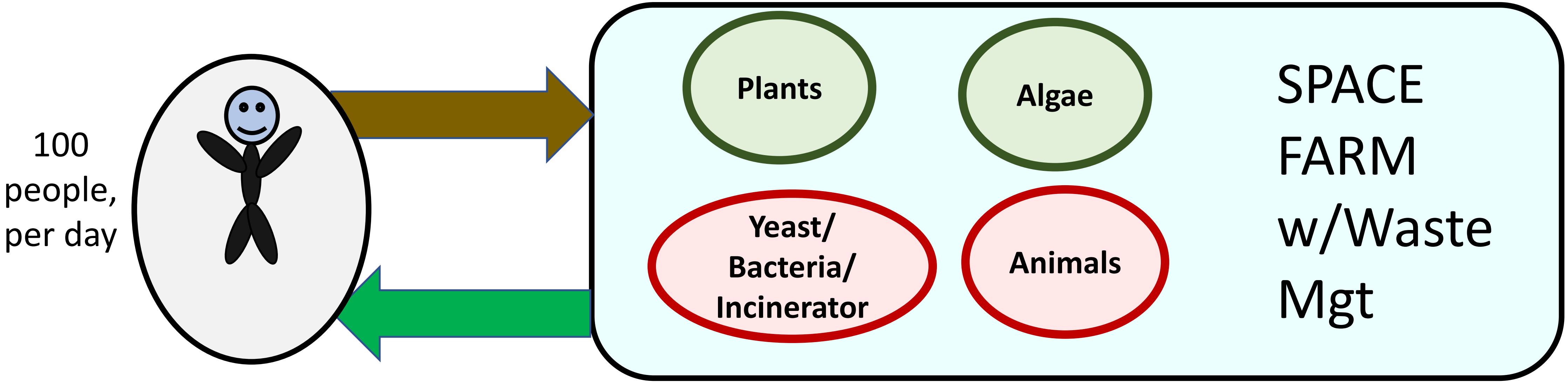
- ‘Green Crops’: Plants and Photobioreactors(i.e. algae): Take in carbon dioxide, nutrients (from wastes), and water, and use light energy, to produce more plant/algae and release oxygen.
- Humans and ‘Pink Crops’: Animals, Fungi inc. Yeast, and Bacteria: Take in oxygen, water, and food, and release carbon dioxide, wastes, and water, with heat.
- Key Trick: Green crops take in what humans and pink crops release!



So why is this a computer problem?

- Goal:
  1. Given a menu of raw foods that provide enough calories, nutritional needs like protein, carbs, fiber, fats
  2. Making sure there is enough oxygen and clean water for the humans
  3. Keeping all the crops alive, i.e. balance ins and outs for each crop too

  Can I get the sizes for a space farm where all the inputs from the humans meet all the outputs to humans, and balance all around?



Viewing the Space Farm as Data: Data Statements

Living Mass per Stage is dynamic when comparing possible farm solutions

- Space Farm has Stages and Habitat
  - Must Balance: Inputs and Output for mass types and elements.
  - Must: Meet Habitat minimum inputs, and nutrition needs.
  - Totals: Sizes, Energy, Initial Supply
- Each Stage has a **Living Mass** of one Crop.
  - Input Masses, Output Masses, Stage Size, Stage Energy Need, are all linear multiples of **Living Mass**
  - Must Balance: Inputs and Output for mass types and elements.
- Each Crop has per unit mass (per kg):
  - Input and Output Masses: Inputs are (-), Outputs are (+)
  - Size: Areas, Volumes, sizes for energy and initial set up.
  - Human nutrition: % edible, % water (1-% dry mass), kcal/kg, nutrition data (US RDA)
  - Must Balance: Inputs and Output for mass types and elements.
- Yeast-Bacteria-Incinerator Stage:
  - Stage can convert any set of waste, feed/food to nutrients for plants, carbon dioxide and water, given inputs of oxygen. HOWEVER, uses limiting variables to add reality!

Accounting for the Farm: Mass Balance by day

Stage	Minimum living mass in stage (kg)	CO2 (kg)	O2 (kg)	H2O Clean (kg)*	H2O Waste (kg)	Waste Dry Mass (kg)	Feed Wet Biomass	Nutrient Dry Mass (kg)	Food Wet Mass (kg)	C	H	O	N	(…each tracked element)
HABITAT	100 People													
Stage/Crop 1	**(Living mass in stage 1)**													
Stage/Crop 2	**(Living mass in stage 2)**													
Stage/Crop n	**(Living mass in stage n)**													
Yeast-Bacteria-Incinerator	Mass processed: Calculated from mass total (CO2+O2+ H2O+ Dry masses													

***Total needs to be (near) zero for each column…a deficit means a need for in situ or resupply*.**

Dataview Diagram

Chemistry Data: CHON, etc. and Model

Farm

-Mass Balance
-by component
-by element
-Total Energy Need
-Total Size
-ID Data (date, time, run, etc.)
-List of Stages

Stage

-**Living Mass in Stage**
-Stage Type: Aquatic, Photobioreactor, Plant, etc.
-Mass Balance for all living mass in stage
-Energy, Sizes
-Other data

Crop

-Per kg Mass Balance
-% edible, % dry mass
- Per kg Nutrition Data
- Per kg Sizing
- Other data

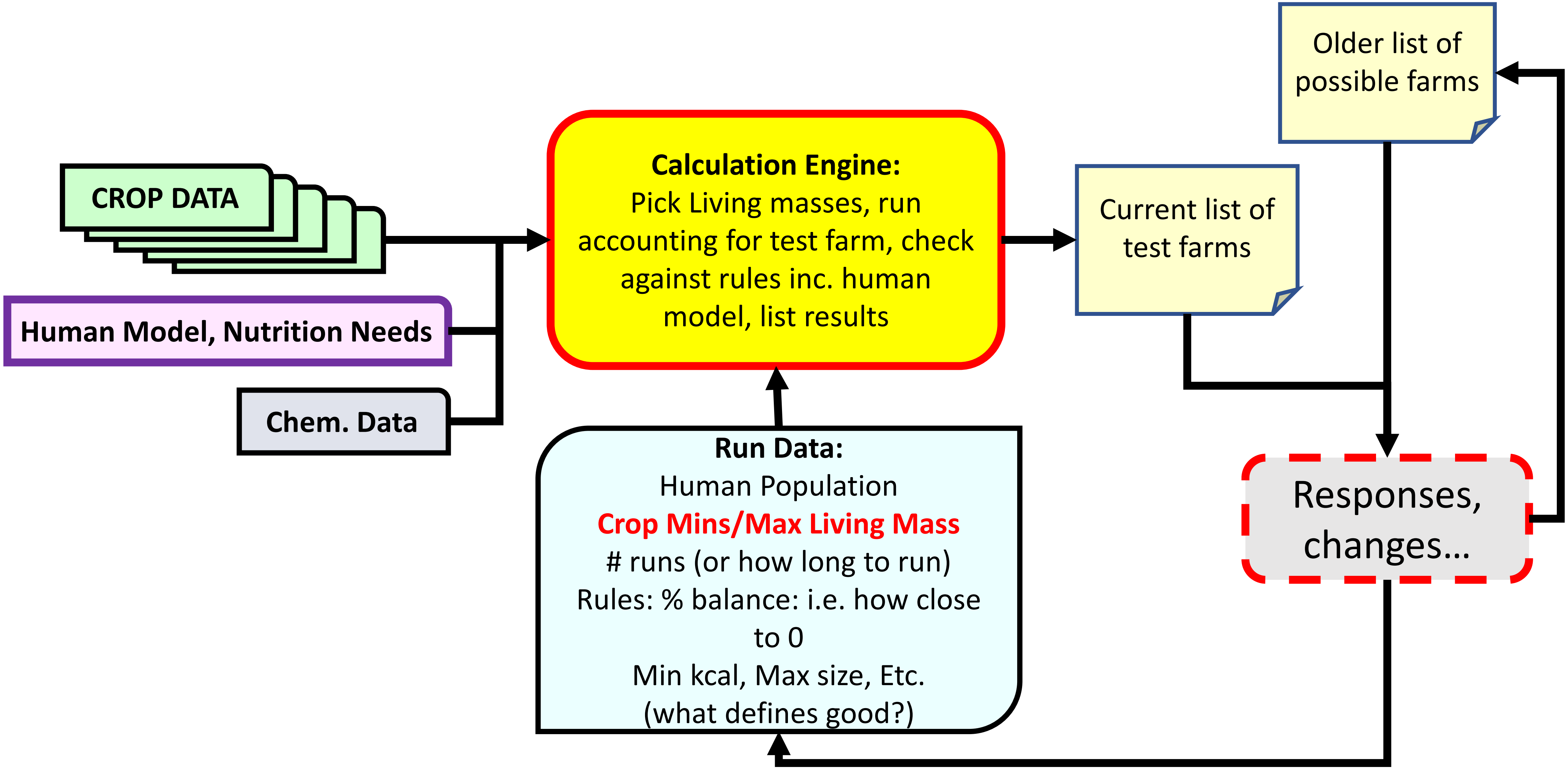
Stage: YBI

-Stage Type: YBI.
-Mass Balance to and from YBI
-Energy, Sizes based on ins and outs
-Other data

Habitat

-**People in stage**
-per capita Mass Balance (aka Human Mass Model)
-Per capita nutrition needs

Converging the Farm: Getting to a Stable Farm



Monte Carlo 101

1. Randomly pick values for the variables in question, in a range
2. Run analysis
3. Plot Results (virtually)→ select solution that is closest to desired result

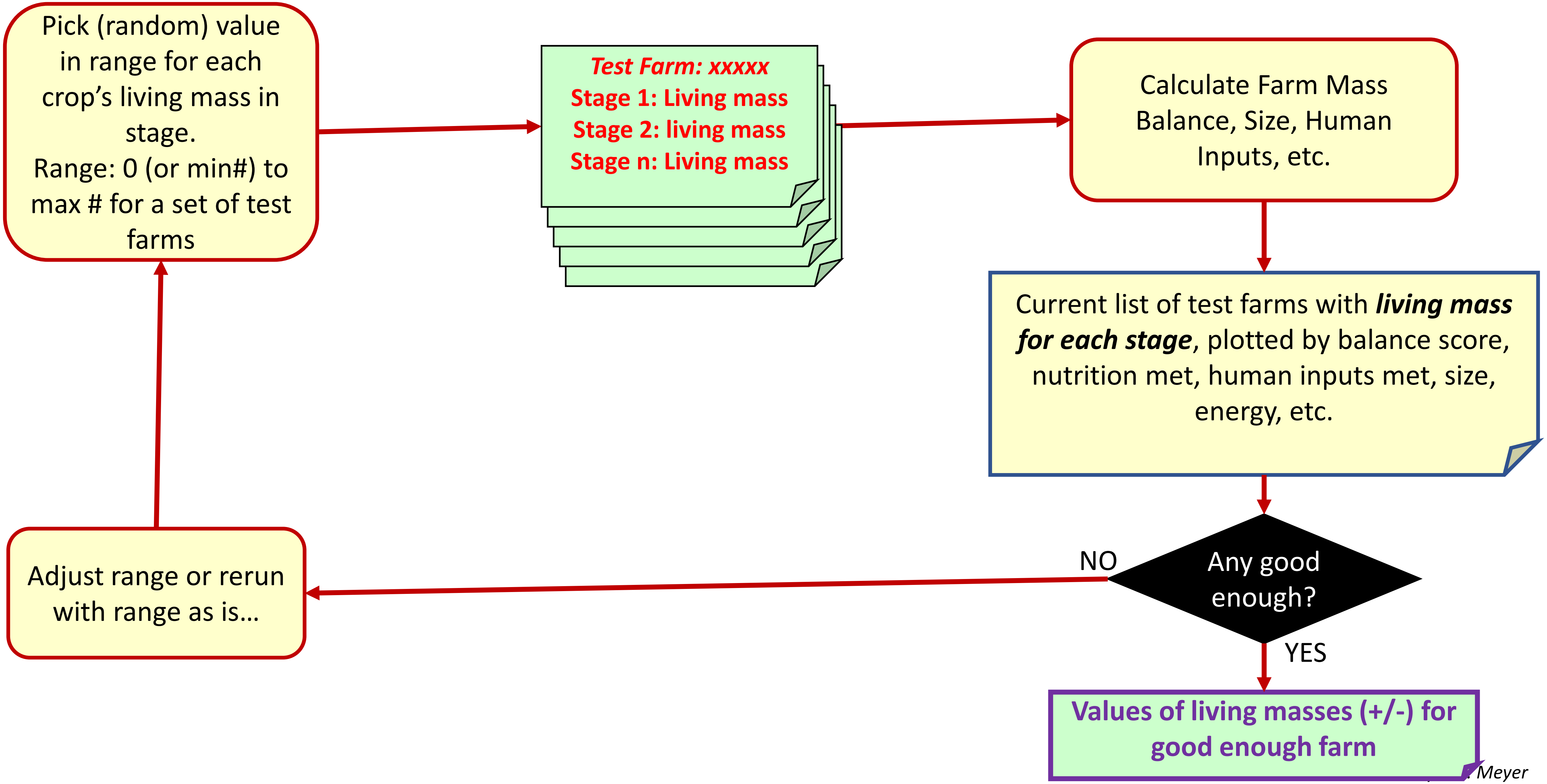
(Option A) Use statistical methods to seek a solution using data: ANOVA, Regression, tests, etc.

(Option B) Maybe (deterministic…this starts to look like a GA):

- Rank, zoom in range or lock values for some variables, re-run in new range

https://en.wikipedia.org/wiki/Monte_Carlo_method

Monte Carlo Method for Space Farm



Meyer

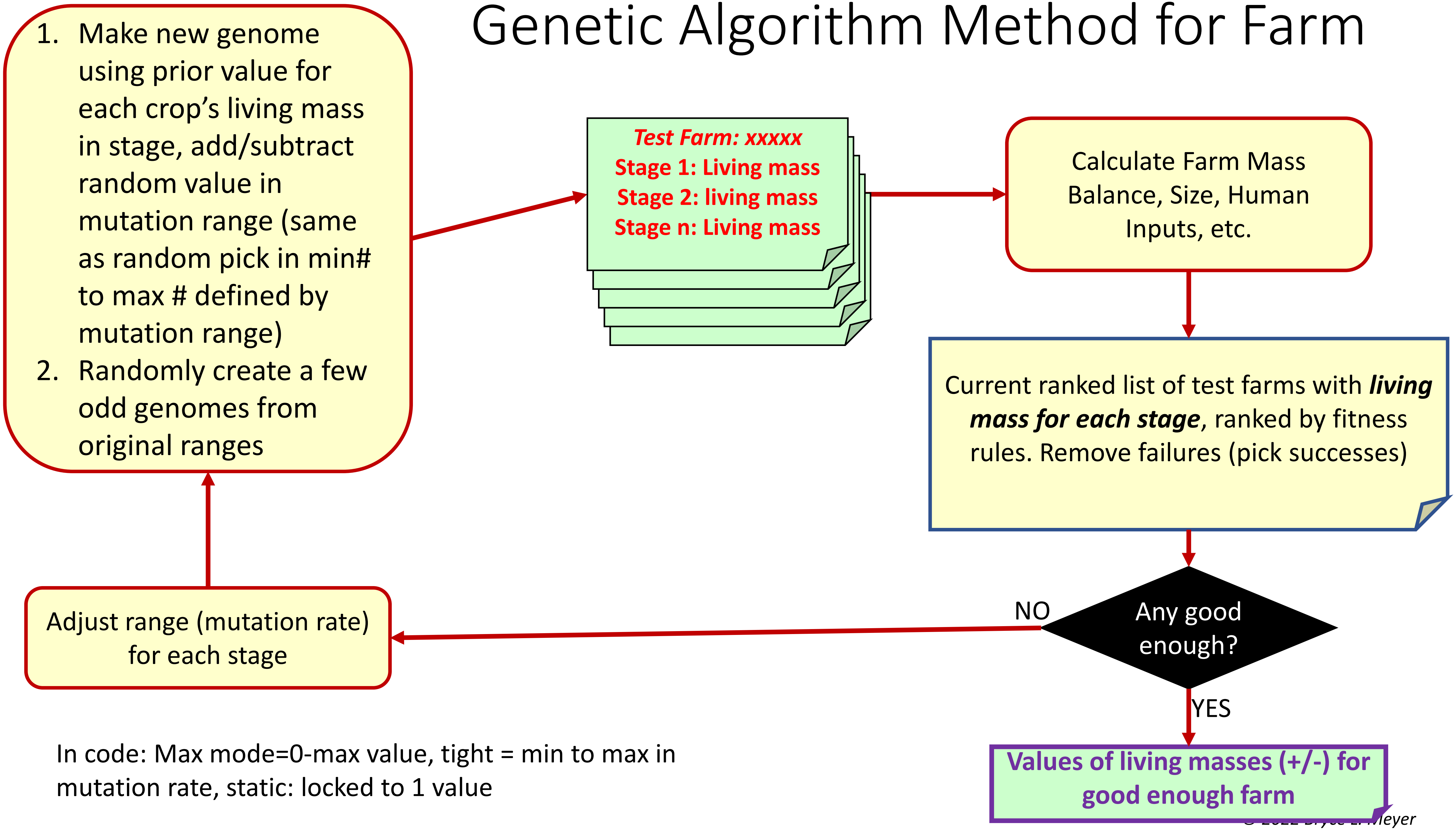
Genetic Algorithms 101 (my definition)

- Population→ Member with genome→ Genes in genome

1. Randomly pick values for the variables in question, in a range, for a possible set (population)
   a) Save string of chosen values = genome for each member of population
   b) Each variable value=gene
2. Run analysis for each genome
3. Use rules to assess fitness of genome (aka tournament/trial). Fit enough=keep genome
4. Use kept genomes to generate new gene values using a mutation rate
5. Repeat #2 to #4 until minimum fitness (good enough) is reached

Note: I add a few 'odd ducks' usually too: a random set of values in original range…see local minimum problem in next slides

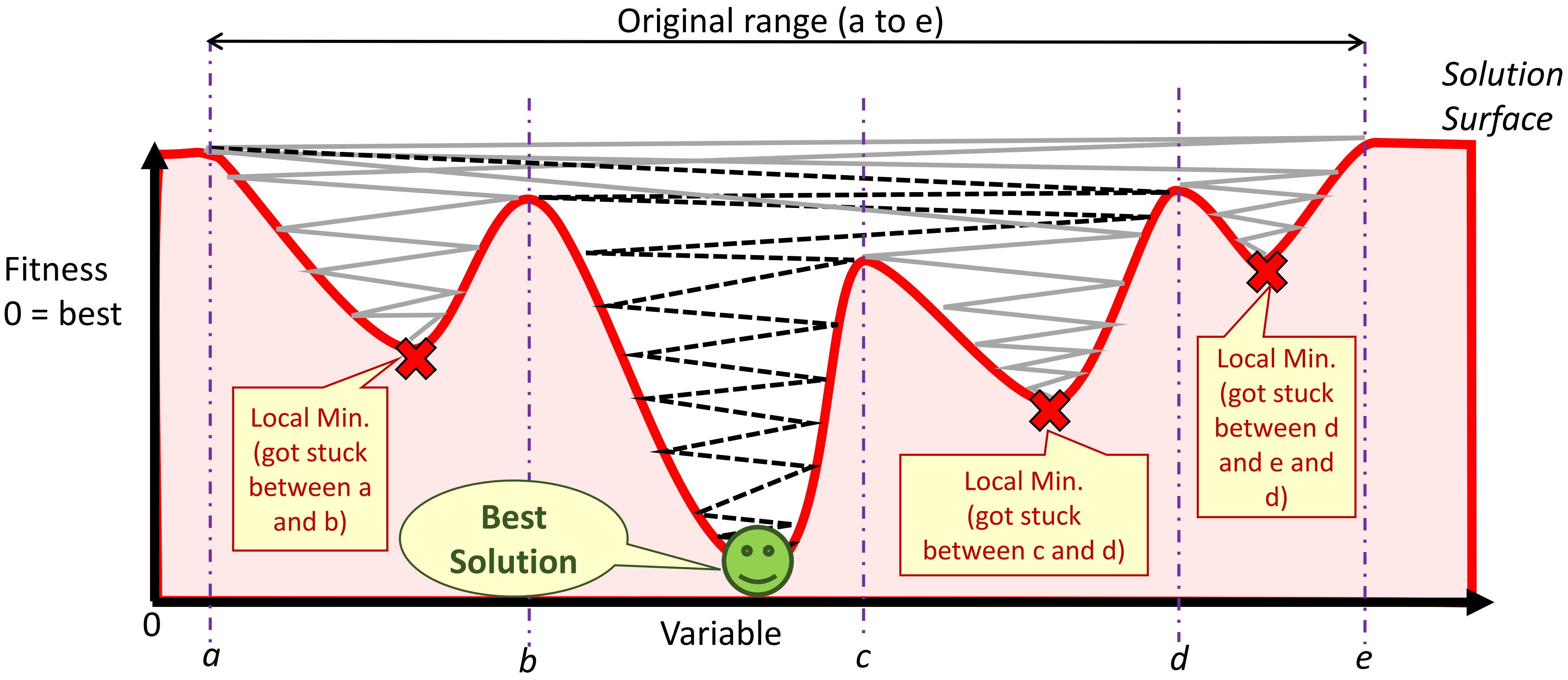
Genetic Algorithm Method for Farm



In code: Max mode=0-max value, tight = min to max in mutation rate, static: locked to 1 value

Avoiding the Local Minimum

- Any deterministic method can get stuck (converge) in a local solution that looks good, but isn't the best overall solution.
- Converge: Range between variable values decreases to a small difference.



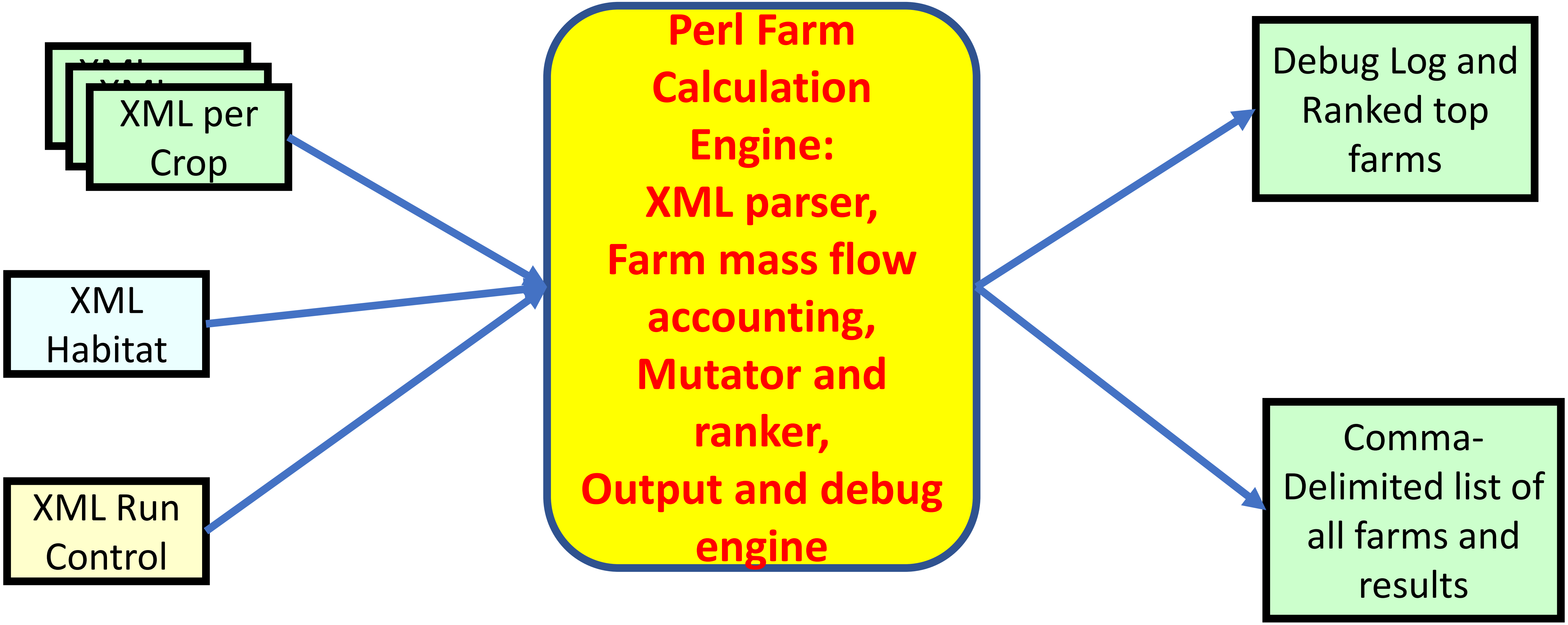
Trick: Seed Test Farms that are randomly picked from the original full range

Coding Choices

- Uses parsed naming standards for files and hashes….debug, tracking dtata trends, and the ability to parse strings that point to hashes.
- Static Input files: XML, pushed into delimited parsed hashes
- Output Files and Dynamic Files: comma delimited
- Engine: PERL
  - Hash Structures, linked using naming standards
  - (OPEN CODE FILE)

```
<xml>
<!-- AIAA SPACE 2017 version  OVERALL-->
<!-- growth model uses the pop inputs …-->
<!--growthmodel Yes -->
<!-- harvest model Yes if activated  -->
<!-- harvestmodel Yes -->
<!--pop in WET biomass kg -->
<!--initial mass feature added 20170728 -->
<initialmass>
<co2>0.0</co2>
(bunch of masses)
</initialmass>
<hydrolyzefiber>no</hydrolyzefiber>
<YBreactor name="YeastBacteria">
<type>BalanceReactor</type>
<file>YBReactor.xml</file>
</YBreactor>
<stage name="BarleyLx">
<file>BarleyLx.xml</file>
(used these for manual control or initial range)
<popmode>tight</popmode>
<minpop>72</minpop>
<maxpop>78</maxpop>
</stage>
<habitat>
<file>Habitat.xml</file>
</habitat>
</xml>
```

Coding Model Used



Coding Results

- Exponential Run Count with increased stages:
  - i.e. Algae+Yeast+Tomato take exponentially less time to converge then Algae+Yeast+Tomatoes+Beans+Rice…manually controlled some runs to get solutions
  - Results used in 2017 and 2018 papers:
  - https://space.nss.org/wp-content/uploads/NSS-JOURNAL-Space-Farm-Electrical-Requirements.pdf
  - https://space.nss.org/wp-content/uploads/NSS-JOURNAL-Multistage-Evolving-Space-Farms.pdf

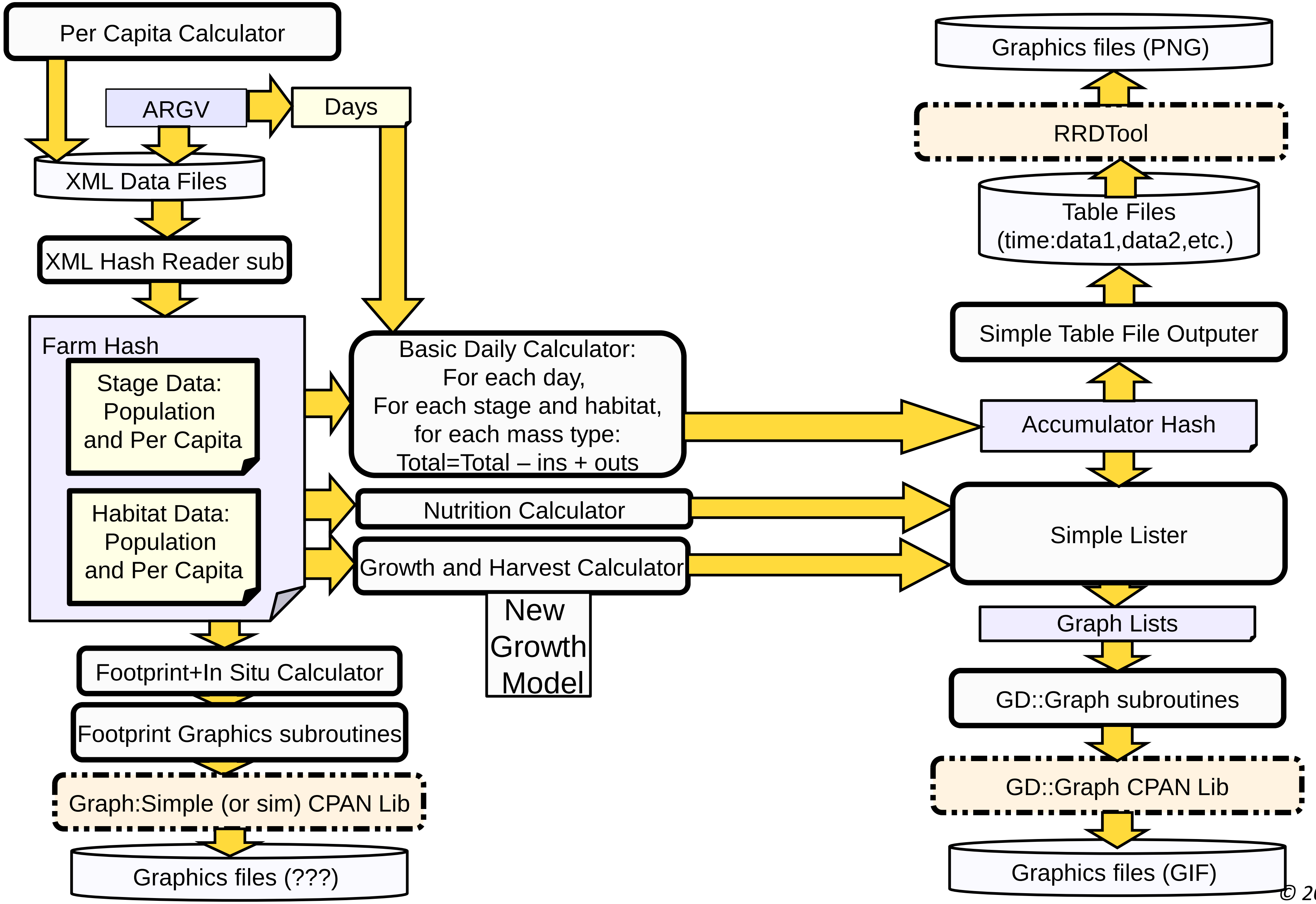
2017 Paper

Table 12. Species included in each scenario.

SPECIES	STAGE TYPE	SCENARIO 1A	1B	2A	2B	3+4
Barley	Hydroponic					X
Bell Peppers	Hydroponic			X	X	X
Chlorella	Algae Reactor	X	X	X	X	X
Pinto Beans	Hydroponic			X	X	X
Potatoes	Hydroponic			X	X	X
Rice	Hydroponic				X	X
Shrimp	Aquatic					X
Silver Carp	Aquatic					X
Soybeans	Hydroponic					X
Spirulina	Algae Reactor	X	X	X	X	X
Tilapia	Aquatic			X	X	X
Tomato	Hydroponic		X	X	X	X
Yeast-Bacteria Reactor	Yeast-Bacteria Reactor	X	X	X	X	X

25 MB comma delimited output files

FUTURE: Going Dynamic For the Farm itself



Conclusion

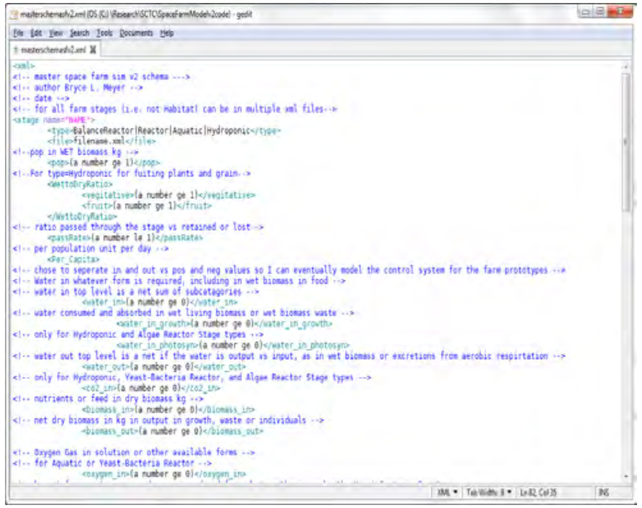
- Space Farms are farms for space settlement and space exploration that both use technologies from Earth ag, and improve ag for the future in space and on Earth.
- Monte Carlo and Genetic Algorithms are possible solution methods for space farms.

Further Reading

- My Presos on Space Farms: http://www.spacefarms.info
- St. Louis UNIX Users Group: https://www.sluug.org/

BACKUPS

Overall XML Scheme so far



```xml
<xml>
<!-- master space farm sim v2 schema --->
<!-- author Bryce L. Meyer -->
<!-- date -->
<!-- for all farm stages (i.e. not Habitat) can be in multiple xml files-->
<stage name="NAME">
	<type>BalanceReactor|Reactor|Aquatic|Hydroponic</type>
	<file>filename.xml</file>
<!--pop in WET biomass kg -->
	<pop>(a number ge 1)</pop>
<!--For type=Hydroponic for fuiting plants and grain-->
	<WettoDryRatio>
		<vegitative>(a number ge 1)</vegitative>
		<fruit>(a number ge 1)</fruit>
	</WettoDryRatio>
<!-- ratio passed through the stage vs retained or lost -->
	<passRate>(a number le 1)</passRate>
<!-- per population unit per day -->
	<Per_Capita>
<!-- chose to seperate in and out vs pos and neg values so I can eventually model the control system for the farm prototypes -->
<!-- Water in whatever form is required, including in wet biomass in food -->
<!-- water in top level is a net sum of subcatagories -->
		<water_in>(a number ge 0)</water_in>
<!-- water consumed and absorbed in wet living biomass or wet biomass waste -->
			<water_in_growth>(a number ge 0)</water_in_growth>
<!-- only for Hydroponic and Algae Reactor Stage types -->
			<water_in_photosyn>(a number ge 0)</water_in_photosyn>
<!-- water out top level is a net if the water is output vs input, as in wet biomass or excretions from aerobic respirtation -->
		<water_out>(a number ge 0)</water_out>
<!-- only for Hydroponic, Yeast-Bacteria Reactor, and Algae Reactor Stage types -->
		<co2_in>(a number ge 0)</co2_in>
<!-- nutrients or feed in dry biomass kg -->
		<biomass_in>(a number ge 0)</biomass_in>
<!-- net dry biomass in kg in output in growth, waste or individuals -->
		<biomass_out>(a number ge 0)</biomass_out>

<!-- Oxygen Gas in solution or other available forms -->
<!-- for Aquatic or Yeast-Bacteria Reactor -->
		<oxygen_in>(a number ge 0)</oxygen_in>
```

(XML which is for the whole farm): Farm

Stage

Name (used many places)
Type (eventually to do growth)
File (location of stage data file)
Pop(ulation) in mass-equivelent wet biomass kg
Wet to Dry Biomass

Per Capita: Biomass, Water, Oxygen, CO2, and CHON, Ash

Crop: nutrition data

Nutrition: Fat, Carbo, Moisture, Protein, etc.

Footprint:
Volume and Mass Ratios:
How big is the farm,
how much mass total,
initial resources
Launches to LEO

Habitat: Habitat level Data, Population

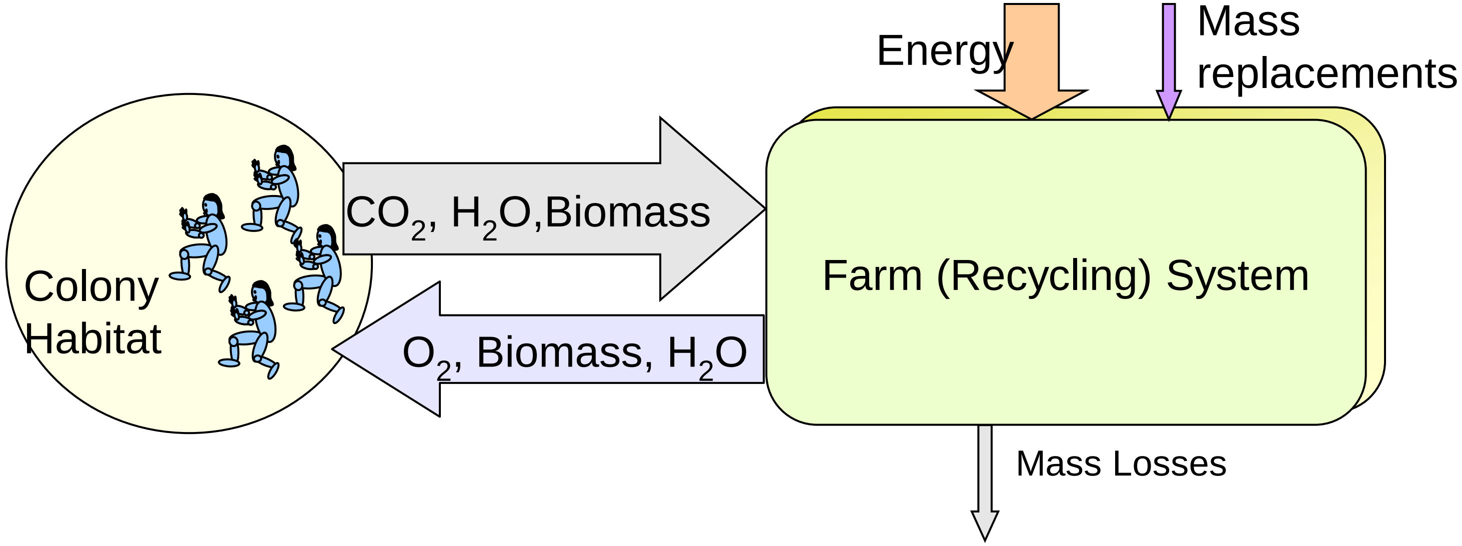
Per Capita: Biomass, Water, Oxygen, CO2

Diet: Fat, Carbo, Moisture, Protein, etc.

Likely flesh out growth model as multi-factor and footprint calculator ratios next

Space Farm as a Black Box

- Habitat exchanges mass in carbon dioxide, water, and biological wastes for oxygen, water, and biological foods
- Once stable, the farm takes in energy, then exchanges any losses due to inefficiency or other losses for resupplied mass additions.



Biomass

- Food, growth, and wastes are all called <u>**biomass**</u> in this presentation. Biomass includes sugars, proteins/amino acids, fats, other organic compounds, ammonia, urea, nitrates, etc. i.e. anything that isn't water, oxygen, or carbon dioxide.
- Biomass is either dry or wet.
- Biomass, as in living or formerly living tissue, or in biological waste, is usually wet biomass.
- Dry biomass is the fraction of wet biomass if all the water is removed.
- The ratio of wet biomass to dry biomass by mass is important.
- Animals (inc. People) eat wet biomass, and excrete wet biomass.