Microworld Rules

All updates happen per timestep = 1 month.

1. Biodiversity

Rule: Larger more mixed forests boast higher biodiversity b.

- IF no trees $THEN\ b = 0$.
- $FOR\ EACH$ coniferous tree for which there exists a deciduous tree ⇒ $b{+}{=}\ 3$.
- $FOR\ EACH$ remaining coniferous or deciduous tree for which there is another tree of the same type ⇒ $b{+}{=}\ 2$.
- $FOR\ EACH$ remaining coniferous or deciduous tree for which there is no other tree of any type ⇒ $b{+}{=}\ 1$.

Rule: Forests with more old growth and mature trees harbor greater biodiversity. Even dead trees (dead wood) contribute towards increased biodiversity (fungi, insects, etc.).

- $b{+}{=}\ 0.5 \times$ no. of seedlings.
- $b{+}{=}\ 0.8 \times$ no. of saplings.
- $b{+}{=}\ 2 \times$ no. of mature trees.
- $b{+}{=}\ 3 \times$ no. of old growth trees.
- $b{+}{=}\ 1 \times$ no. of dead trees (deadwood).

Rule: Ecosystems are more biodiverse than new forests or plantations.

- Biodiversity % $= b_{\%} = \frac{b}{b_{max} - b_{min}}$ where b_{max} = maximum biodiversity possible $= 3 \times$ no. of land positions and b_{min} = minimum biodiversity possible $= 0$.
- $IF\ 0 \leq b_{\%} < 0.25$ ⇒ unforested.
- $IF\ 0.25 \leq b_{\%} < 0.5$ ⇒ plantation.
- $IF\ 0.5 \leq b_{\%} < 0.75$ ⇒ forest.
- $IF\ 0.75 \leq b_{\%} < 1$ ⇒ ecosystem.

2. Carbon Dioxide

2.1. Emission

Rule: Each year, more CO_2 is released into the atmosphere than natural processes can remove, causing its amount in the atmosphere to increase. [1]

- Base CO_2 amount $= CO_2^{start}$.
- Current timestep CO_2 emission $= CO_2^{emit}$.

- CO_2 change percent per timestep = $CO_2^{ch\%}$.
- $CO_2^{emit} += CO_2^{ch\%}$
- $CO_2 = CO_2^{emit}$

Rule: Deadwood decays to slowly release CO_2 back into the environment over time.

- $FOR\ EACH$ dead naturally dead tree that remains on land $CO_2 -= 0.1 *$ decayed mass.

Rule: Felling of trees results in an increase in CO_2 in the environment depending on what the felled timber is used for. If it is used to produce energy, all the stored carbon within it is almost immediately released back into the environment. If it is used to make furniture, for construction etc. in the form of lumber, then only a fraction of stored carbon in that wood is released into the environment immediately.

- $FOR\ EACH$ felled tree $CO_2 += \left(1 * timberMass_{energy}\right) + (0.3 * timberMass_{lumber})$.

2.2. Absorption

Rule: Trees require CO_2 for growth. They absorb a certain portion of their mass' worth in CO_2.

- $FOR\ EACH$ live tree $\Rightarrow CO_2^{removed} = \frac{((0.2\times \text{Mass}) + (0.5\times \text{GR} \times \text{Mass}))}{12\times 30}$.
- $CO_2 -= CO_2^{removed}$.

3. Temperature

Rule: Local temperature fluctuates depending on the month of the year based on corresponding position of the earth around the sun.

- For each month change pair (e.g., "jan-feb", "feb-mar", etc.), a fixed value for change in temperature from one month to the other has been defined (e.g., -2°C, +3°C, etc.) = $\Delta T_{monthly}$.

Rule: Global temperature is directly proportional to global atmospheric levels of CO_2.

- Change in temperature due to changes in CO2 levels = $\Delta T_{co2} = \frac{CO_2 - CO_2^{start}}{CO_2^{start}} \times 0.01$.
- $T = T + \Delta T_{monthly} + \Delta T_{co2}$.

4. Tree Growth

- $FOR\ EACH$ tree IF the tree is alive $\Rightarrow live()$
- $ELSE \Rightarrow decay()$.

Rule: Once a tree dies naturally, it **decays** and releases a portion of sequestered CO_2 back into the atmosphere slowly over time while the rest is assimilated into the soil.

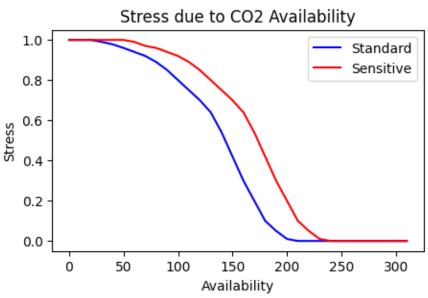
- Mass decayed is computed as volume decayed times wood density. $Decay_{mass} = Decay_{volume} \times WoodDensity$.

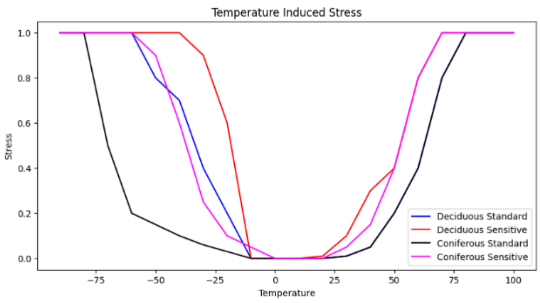
- Decay volume computation is based on volume of a cylinder which is the form that the tree mass is assumed to be in, here. $Decay_{volume} = 3.14 \times \left(\frac{Decay_{diameter}}{2}\right)^2 \times Decay_{height}$ where $Decay_{diameter} = TreeDiameter \times 0.01$ and $Decay_{height} = TreeHeight \times 0.05$.
- $Decay_{CO_2released} = Decay_{mass} \times 0.7$ (Release a portion of stored CO_2).
- $CO_2 = CO_2 + Decay_{CO_2released}$.
- Tree height and diameter are reduced as per decay. $TreeDiameter = TreeDiameter - Decay_{diameter}$ and $TreeHeight = TreeHeight - Decay_{height}$.
- $IF\ Decay_{volume} = 0 \Rightarrow$ tree has completely decayed, $THEN$ remove it from the land.

Rule: Living trees are under stress due to many environmental conditions of which atmospheric CO_2 levels and temperature are a part.

Rule: Young trees (seedlings and saplings) are more impacted by such stress.

- Only environmental stressors considered here are temperature T and CO_2 levels. Stress that the trees are under due to these factors are modelled using curves as below wherein $Sensitive \Rightarrow$ seedling or sapling and $Standard \Rightarrow$ trees in other life stages. These curves are captured by CO_2 or T stress functions such that given a value for level of CO_2 or temperature in the microworld, the function outputs a stress level for given tree.





- Environmental stressors at any given timestep are computed as $Stress_{env} = StressFun_{CO_2}(CO_2) + StressFun_T(T)$.
- $IF\ Stress_{env} > 0\ THEN\ Stress_{tree} = Stress_{tress} + Stress_{env}$.

Rule: When conditions are favorable, healthy plants slowly recover from past stresses.

- $IF\ Stress_{env} \leq 0 \wedge Stress_{tree} > 0 \Rightarrow Stress_{tree} = Max\big(0, Stress_{tree} - 0.1(1 - Stress_{tree})\big)$. That is, if environmental conditions are good and there is no environmental stress, recover from earlier stress depending on health of the tree.

Rule: Living trees also experience stress due to aging. Impact of stress on very old trees (senescent ones) increase as time passes.

- With every time step, IF the tree is in a life state that's equal to senescent or older, then $stress = stree + 0.01$.

Rule: Cutting down a tree immediately inflicts maximum stress on the tree.

- Felling a tree $\Rightarrow Stess_{tree} = 1.0$.

Rule: Trees die when stress is beyond tolerable.

- $IF\ Stess_{tree} \geq 1.0 \Rightarrow$ die.

Rule: Forests that harbor more biodiversity, grow faster and can better cope with stress.

- $IF\ BD_{\%} < 0.25\ THEN\ BD_{cat} =$ unforested.

- $IF\ BD_{\%} < 0.5\ THEN\ BD_{cat}$ = plantation.
- $IF\ BD_{\%} < 0.25\ THEN\ BD_{cat}$ = forest.
- $IF\ BD_{\%} < 0.25\ THEN\ BD_{cat}$ = ecosystem.
- IF BD_{cat} = unforested $THEN\ BD^{-} = 0$.
- IF BD_{cat} = plantation $THEN\ BD^{-} = 0.01$.
- IF BD_{cat} = forest $THEN\ BD^{-} = 0.1$.
- IF BD_{cat} = ecosystem $THEN\ BD^{-} = 0.3$.
- $GR_{tree} = (1 - Max\big(0, Stress_{tree} - BD^{-}(Quadrant_{tree})\big) \times GR_{max}$
- $IF\ TreeDiameter < TreeDiameter_{max}\ THEN\ TreeDiameter = Min(TreeDiameter_{max}, TreeDiameter + (GR_{tree} \times TreeDiameter)$.
- $IF\ TreeHeight < TreeHeight_{max}\ THEN\ TreeHeight = Min(TreeHeight_{max}, TreeHeight + (10 \times GR_{tree} \times TreeDiameter)$.
- Absorb CO_2 like in section 2.2.
- Trees may reproduce only once every x no. of years.
- If there is a free space adjacent to the tree and the tree is mature and $Stress \leq\ 0.5$ then the tree reproduces, resulting in a new seedling at the adjacent empty land spot.

5. Actions

Rule: Planting a tree cost less than felling a tree.

- $Cost_{plant} = x \qquad Cost_{fell} = y \qquad x < y$.

Rule: Plant action adds a new seedling of given tree type to the given quadrant if possible.

Rule: Planting a tree immediately leads to reduction in funds to emulate related expenses.

- $IF\ \exists\ free\ space\ in\ desired\ quadrant\ at\ desired\ time\ THEN\ new\ seedling\ in\ random\ spot$.
- $Funds = Funds - Cost_{plant}$.

Rule: Felling action removes a given type of tree of given age from the given quadrant if such a tree did exist in that quadrant.

Rule: Felling a tree immediately leads to reduction in funds to emulate related expenses.

Rule: Felling a tree immediately increases stress of the tree to 1. This triggers death of the tree.

Rule: Felled tree mass is used to meet timber demand either for lumber or energy.

- $IF\ \exists\ desired\ tree\ type\ of\ esired\ age\ in\ desired\ quadrant\ at\ desired\ time\ THEN\ remove\ this\ tree$.
- $Action_{fell} \Rightarrow Stress_{tree} = 1$.
- $Action_{fell} \Rightarrow Funds = Funds - Cost_{fell}$.
- $Mass_{tree} \Rightarrow Volume_{tree} \times WoodDensity_{tree}$.
- $Volume_{tree} \Rightarrow \pi \left(\frac{Diameter_{tree}}{2}\right)^2 Height_{tree}$.

Rule: Wood density of deciduous trees is generally greater than that of coniferous trees.

6. Timber Demand

Rule: Timber demand increases by a constant % every time step.

- With each time step, $Demand_{timber} = Demand_{timber} + (Demand_{timber}^{base} \times Time_{year} \times ConstantChange\%_{demand}^{timber})$.

- $Change\%_{demand}^{timber} = \frac{(Demand_{timber}^{t-1} - Demand_{timber}^{t})}{Demand_{timber}^{t-1}}$.

Rule: Timber prices increase and decrease per time step based on demand.

- $Demand_{timber}^{base\ adjusted} = Price_{timber}^{base} + \left(Price_{timber}^{base} \times (Demand_{timber} \times 0.03)\right)$
- $Price_{timber} = Price_{timber}^{base} \times \left((1 + Change\%_{demand}^{timber})^{\pm Change\%_{demand}^{timber}}\right)$

Note: Prices here ⇒ price per unit.

Rule: Timber is burned to produce energy, or it may also be used in construction/carpentry. Thus here, there are two types of timber usage, being energy and lumber. There is more demand for the former, compared to the latter and the former amounts to instant release of more CO2 than the latter.

7. Funds

7.1. Increase

Rule: Felling trees leads to an increase in funds as timber demand is met.

- $Funds = Funds + (Price_{timber} \times Mass_{tree} \times 0.01)$

7.2. Decrease

Rule: Felling or planting trees leads to a decrease in funds as given in section 5 above.