Goal for each pre:

5 minutes information

2 minutes “treasure”

3 minutes Discussion

------

10 minutes for logistics, feedback

Week 5

Artificial Life
CSSE290

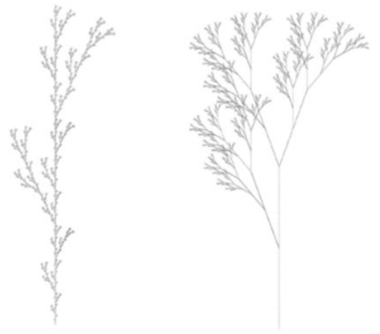
01

Steven Johnson

Steven Johnson

L(indenmeyer)-Systems

- All three of my resources
- Initial string of symbols
    - Axiom
- Production rules that evolve the axiom
    - Applied in parallel
    - Replace recursively all symbols in string
- Optional:
    - Turtle graphics
        - String -> Drawing
    - Stochastic element
        - Randomness



L-Systems are capable of generating many subtle tree-like structures. The 1990 text by Lindenmayer and Prusinkiewicz, *The Algorithmic Beauty of Plants*, is a classic not only in Artificial Life but in Computer Graphics modelling. It is available free online.

Figure 2.14: *A sophisticated plan (a mint) grown with L-systems.*

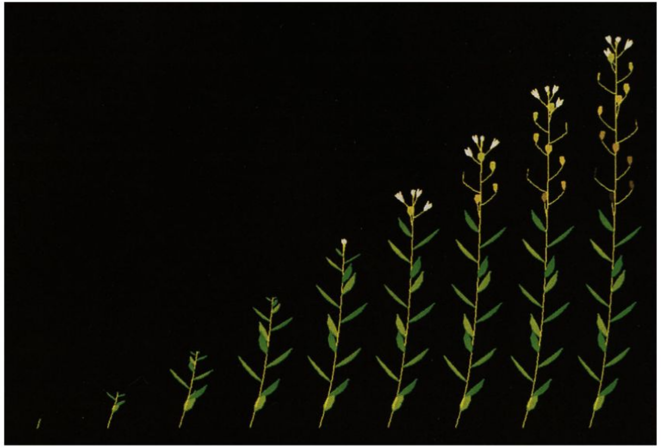


Figure 2.15: *Simulated development of Capsella bursapastoris.*

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Fractals

- Artificial Life
- “Self-similar on multiple scales” pg. 2.18
- “**nature’s answer to hard “optimization” problems**” pg. 2.19
    - Ex: blood vessels supplying blood to whole body while minimizing time & resources
- Four transformations: translation, scaling, reflection, rotation
- Fractal generation algorithms are always recursive and based on self-similarity and use those 4 transformations

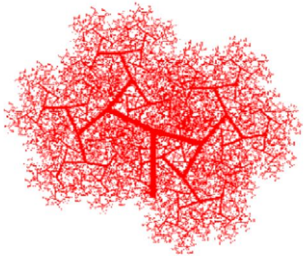

Figure 2.20: *A fractal model of the blood vessel system (from www.cs.ioc.ee/ioc/res98/fractal.html).*

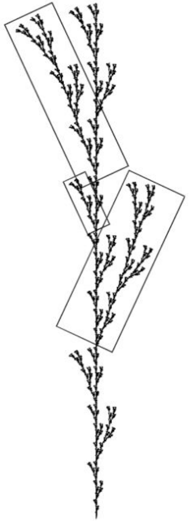

Figure 2.19: *A fractal fern*

Figure 2.18: *The fractal structure of L-system turtle graphics. Each branch in the boxes contains a rotated and re-scaled copy of the whole figure.*

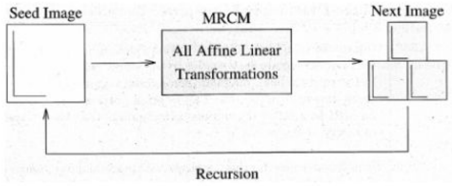

Figure 2.21: *A schematic of the MRCM algorithm. The input image is simultaneously transformed by translation and scaling.*

Multiple Reduction Copy Machine (MCRM)

Steven Johnson

Voxel automata

- Biological Bits
- Relies on
  - Voxels - diced up small cubes of the virtual space
    - Tiling process - filled
  - Parameters
- Ned Greene vines voxel automata accounts for
  - Phototrophic effects
  - Growth around obstacles
  - Self-intersection avoidance

Winter, generated using voxel automata grown over a model of a gazebo. © Ned Greene, 1989. Used with permission.

Vines generated using voxel automata. © Tobias Gleissenberger, 2006. Used with permission.

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Particle systems

- Biological Bits
- Everything is made up of particles
- Generation shape
  - Region that produces particles
  - Ex: single point for leaves drooping from a branch tip
  - Ex: rectangle for grass

Particle system simulation

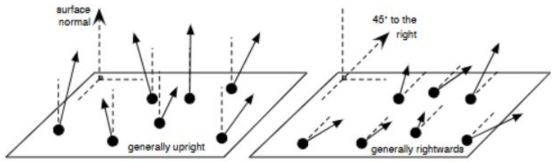
A simulation to generate paths from particles proceeds in discrete time steps. At each one of these steps three things happen:

(A) Active particles that have reached the end of their life span are "frozen" (they won't be updated further);

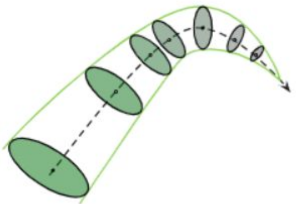
(B) New active particles are introduced from active generation shapes;

(C) Active particles are moved through space according to a physics simulation.

Repeated until no active particles and no active generation shapes



Each particle's initial velocity can be set individually. By varying initial speeds and directions the grass may be made more or less uniform.

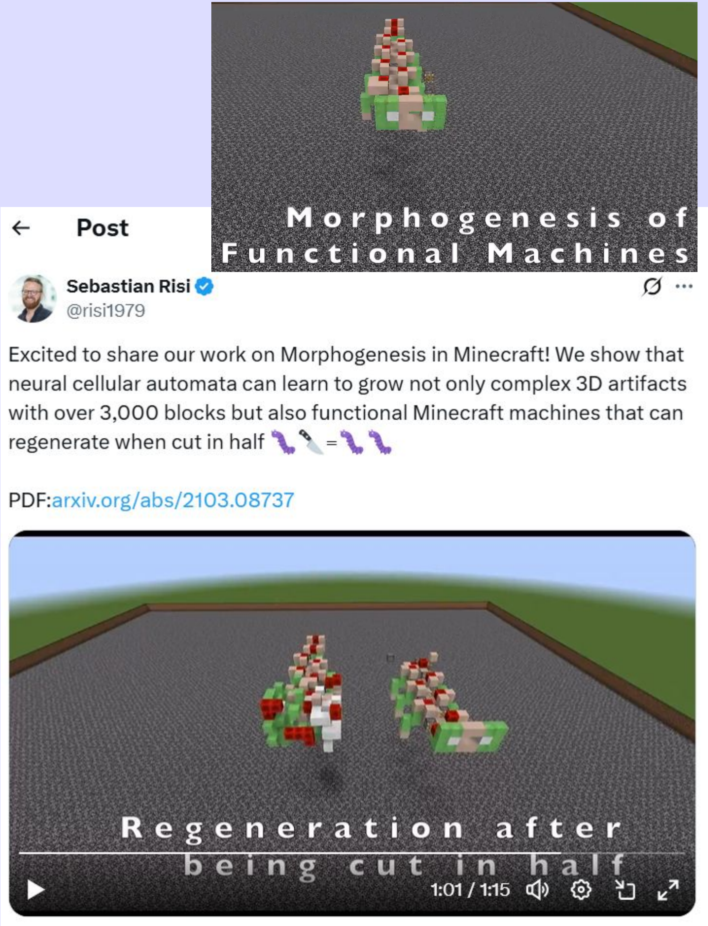


The diameter of the particle can be reduced over its life time. In this way, the path it sweeps out will taper towards the growing tip.

Steven Johnson

Treasure: **Minecraft** is great for ALife simulations

- Object-Oriented
  - Artificial Societies book
- Java
- Sandbox
- Physics
- Programmable
  - Command blocks
  - Plugins
  - Mods
- Marketable
- Ex: Neural cellular automata
  - Morphogenesis: the biological process by which a cell, tissue, or organism develops its shape and form
  - https://x.com/risi1979/status/1372158321256456198?s=20
  - Chosen because it "Allows for generation of static structures and moving machines"

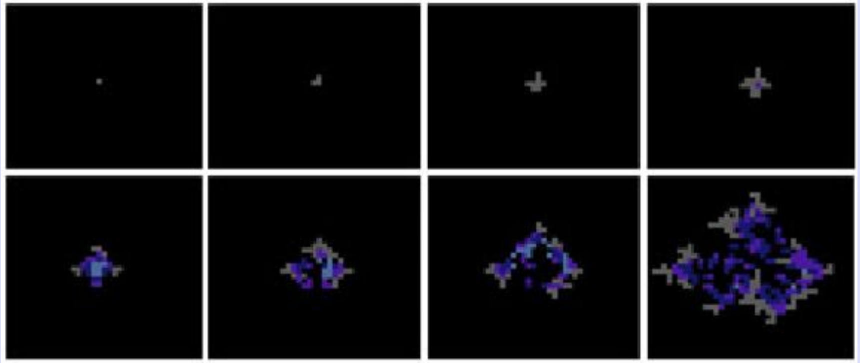


02

Will Greenlee

Will Greenlee

- Artificial Embriogeny
  - The creation of artificial systems that undergo a developmental phase based on a phenotype
  - Phenotypes
    - One-to-one
    - One-to-many
  - Limitations of traditional systems
    - Systems without a developmental phase lack a phenotype that has a one-to-many relationship to its expression
    - Development allows one gene to express a wide variety of different outcomes in the final organism
  - "An increasing number of AE systems are currently being developed, and a need has arisen for a principled approach to comparing and contrasting, and ultimately building, such systems."



Grammar Approaches

- Use a grammar to evolve a data structure or symbol set (starting from an axiom)
    - Context Free
    - Context Sensitive
- A Grammar (In CS)
    - Three Tuple:
        - Alphabet
        - Axiom
        - Propagation Rules
- Development ends when all symbols are terminals

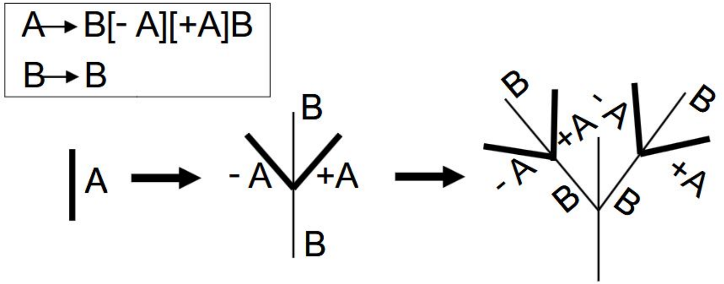
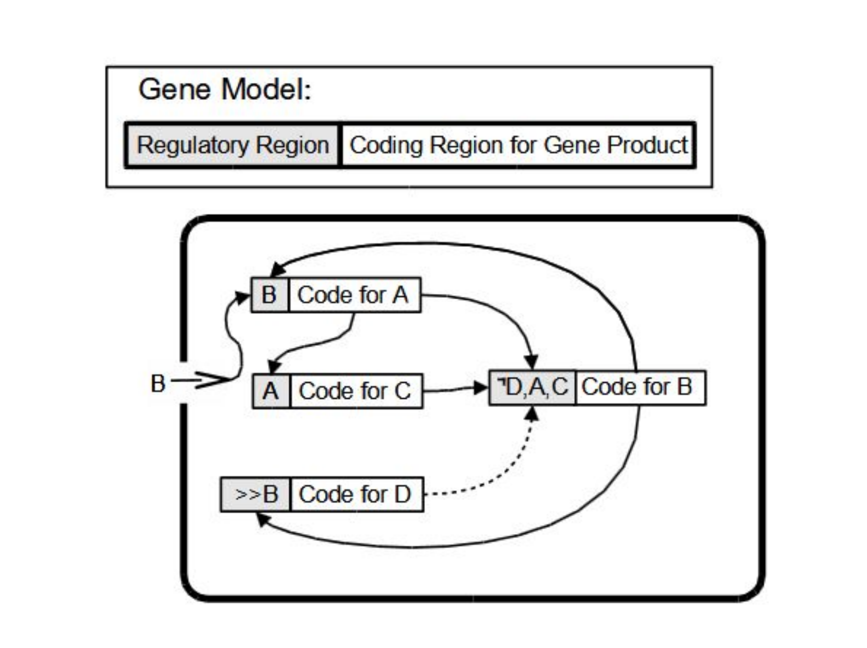


Figure 1: **Grammatical Approach Example (L-systems; Lindenmeyer 1968)..** The two rewrite rules (inset) describe the growth of a tree-like morphology. The symbol A, shown as a thick line in the tree, is the only symbol that is rewritten in this grammar. The symbol B, which does not expand, becomes a thin branch, and $-$ and $+$ determine relative angles of branches expanded from A symbols. This example illustrates how a few simple generative rules can encode a large structure with many components.

Cell-Chem Approaches

- "Cells are arranged in a physical space where simulated proteins can be sent as signals from one cell to another, as in nature. Growth processes such as axons and dendrites can form connections between cells through complex targeting mechanisms."
- Tries to mimic natural cell evolution and chemistry



Dimensions of AE Systems (Treasure)

1. **Cell Fate**
   a. The fate of a cell is the eventual role it will come to play during development.
2. **Targeting**
   a. The ability for cells to develop connections
   b. Enables interaction across the simulation (important for neural networks
3. **Heterochrony**
   a. Relates to flexibility across many generations (abstract)
4. **Canalization**
   a. Essentially, mutation tolerance. A system's ability to remain intact in the presence of mutation
5. **Complexification**
   a. Over many generations, new genes are added to increase natural complexity. This should be done organically.

It is claimed that maximizing these will produce highly complex developmental systems

Will Greenlee

Discussion on the Taxonomy:

1. **Cell Fate**
2. **Targeting**
3. **Heterochrony**
4. **Canalization**
5. **Complexification**

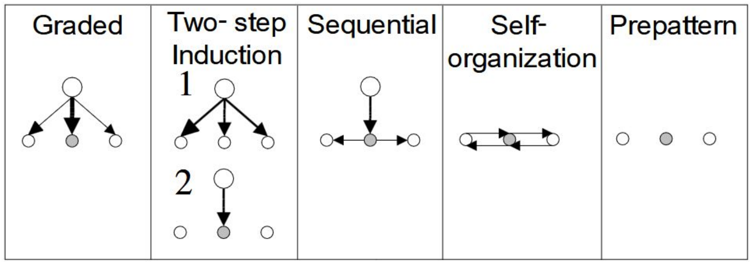


Figure 6: **Derivations of Cell Fates.** Five ways that cells can derive their roles are depicted. The large cell is an *organizer cell*, i.e. a cell that tells other cells what fates to assume. The smaller cells, which are initially undifferentiated, can become either cell type A (gray) or cell type B (white), through various mechanisms. A question for AE systems is which mechanisms lead to most efficient evolution? This figure is based on Wilkins (2002).

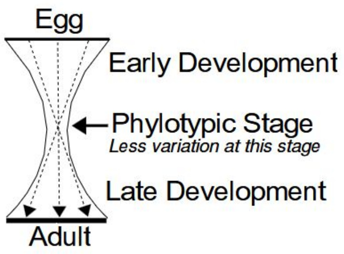


Figure 7: **The Developmental Hourglass (Raff 1996).** The hourglass represents the constraints on trajectories through developmental space. It illustrates that even in complex organisms, a great deal of change in developmental pathways is possible not only in late development, when established body parts are being refined, but also early in development, when the master body-plan is still being established. The phylotypic stage, where interactions between different developing components increase, is least amenable to change. Because global interaction between key components are critical to interconnecting the entire organism, timing changes during this stage could severely disrupt development. The three dotted lines depict different potential trajectories through the space, all of which cross identical phylotypic stages, even with different start and endpoints. This crossing illustrates that the phenotype at the phylotypic stage can remain constant even as early and late development vary in their timing and structure.

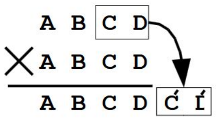


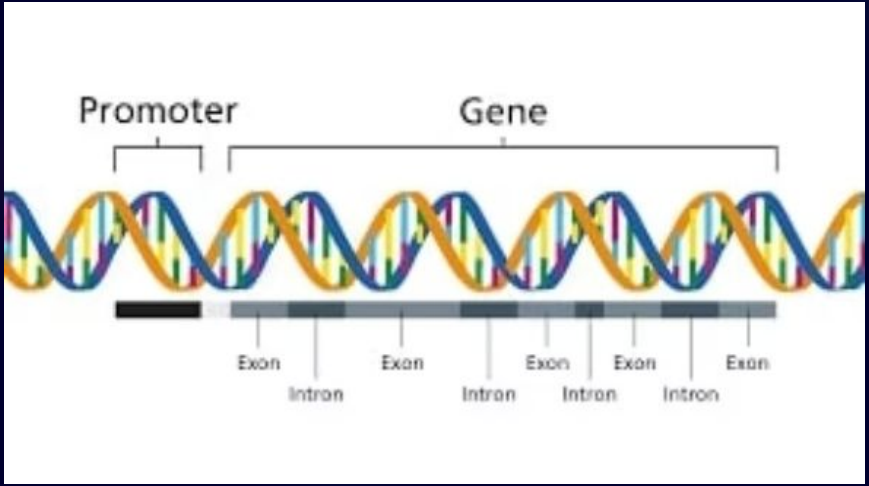
Figure 8: **Gene Duplication.** Two genomes of equal length are crossed over. The letters represent the trait expressed by each gene. The offspring has two additional redundant genes, resulting from the duplication of genes C and D from the first parent.

03

Presenter

Gene Regulatory Networks

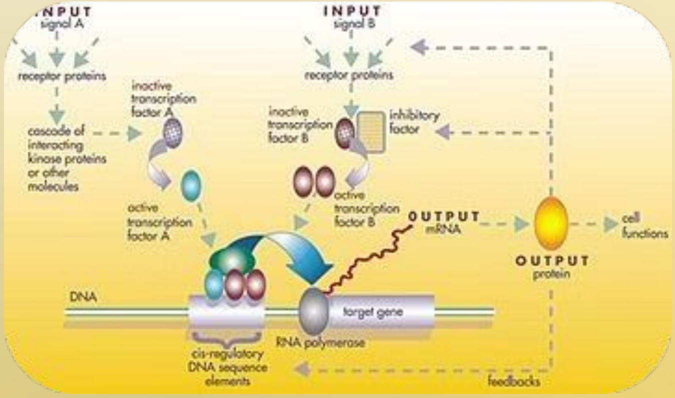
Dominic Reilly



Gene Regulation in Biology

Gene Regulatory Network (GRN)

- Set of DNA segments before or near a gene(s) that describe how it should be expressed
  - Produces proteins according to this description
- These sets can encode to promote, weaken, or silence the genes that follow
- This can effectively turn on or off a gene or set of genes



Artificial Gene Regulatory Networks (AGRN)

Computational Challenges

Simulating a gene network exactly is computationally intense

Compromise with an opaque thought experiment

Differential Equation Model

Describe continuous change in protein concentrations

Boolean Networks

Genes are on or off

Feedback Loops

Simple positive/negative feedback loops can lead to oscillators

Evolution

Indirect Genome Encoding

Can encode genomes indirectly

- Bit string 01011001

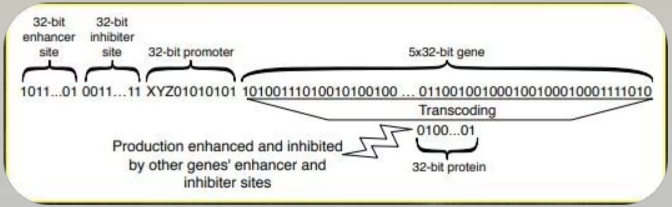
Target Function Reproduction

Attempt to reproduce some target function such as oscillatory, sigmoid, or exponential

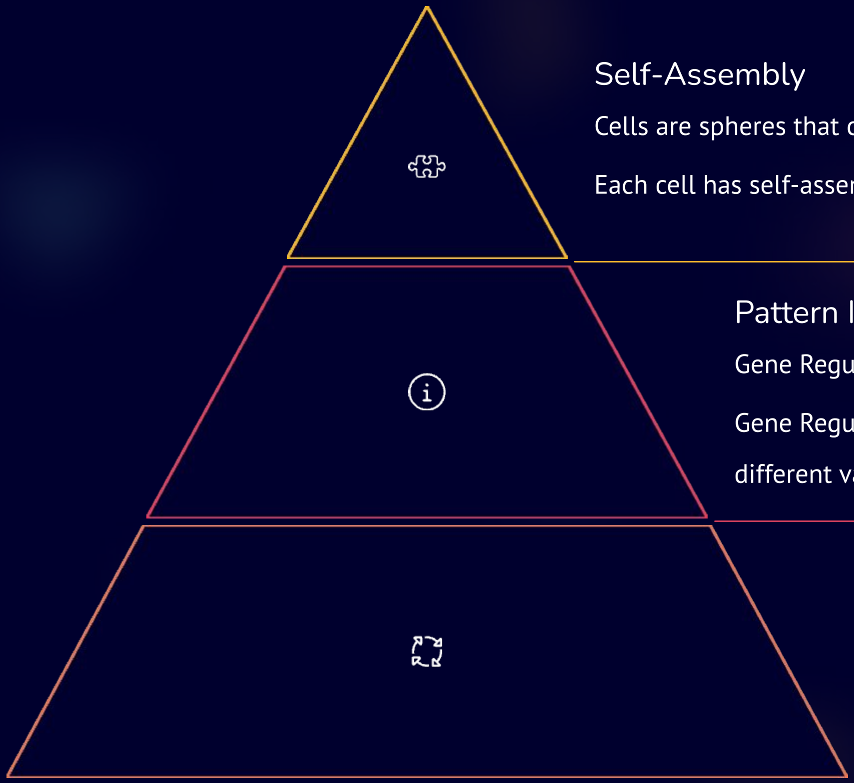
Robustness

Very robust

- Mutation will likely still produce a fit offspring
- Maintain functionality with gene duplication or crossover



MapDevo3D



Self-Assembly

Cells are spheres that can attract or repel other cells

Each cell has self-assembly genes to specific division rate, attractions, range, etc.

Pattern Information

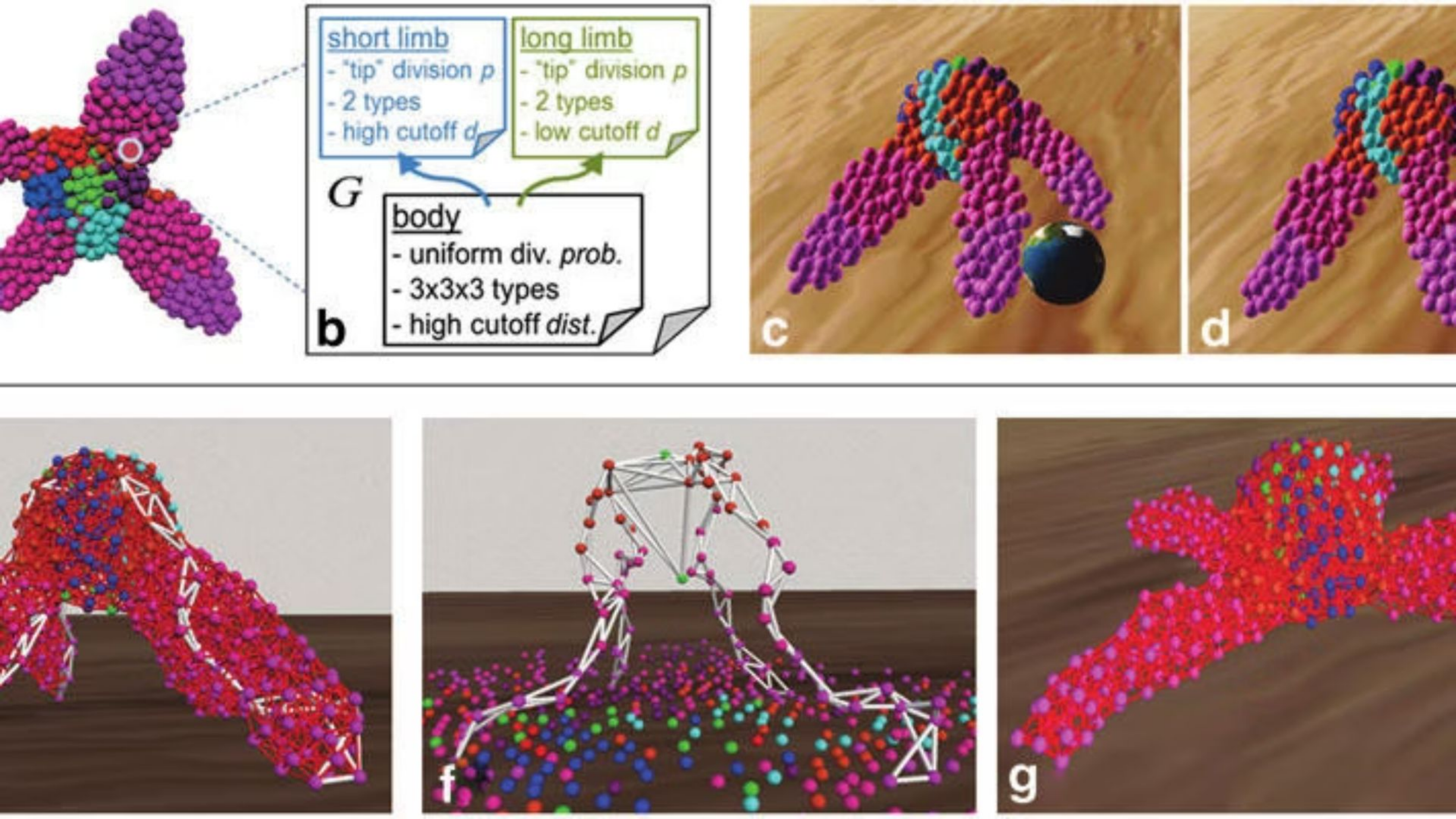
Gene Regulatory Networks in each cell take nearby gradients as inputs

Gene Regulatory Networks output a cells identity and differentiate cells into different varieties (body vs limb)

Recursive Gene Regulation

Each region of same-identity cells can trigger its own GRN

These cells now adjust their division rates and adhesion to divide into subdomains (muscle vs bone)


short limb
- "tip" division p
- 2 types
- high cutoff d
long limb
- "tip" division p
- 2 types
- low cutoff d
G
body
- uniform div. prob.
- 3x3x3 types
- high cutoff dist.
b
c
d
f
g

Functionality

Virtual Environment

After development, the organism is placed in a virtual world with gravity, collision, drag, etc.

Local Rules

There is no local controller to control the body

- Behaves through local rules on a schedule
- Muscles contract and stretch according to some simple signal pattern

Evolution!

Fitness function is ability to walk, jump, etc.

Genome is starting seed and parameters of starting GRN (adhesion, division, etc.)

Combine With Other Techniques

Could be combined with evolutionary search for full evo-devo

Could add a neural network controller for more efficient bodily control

04

Presenter

Person Name

Talking Points

Wrapping Up

Connection to prior weeks?

Provide Peer Evaluation (including Self)

Portfolio Reflection Entry

Midterm Evaluation

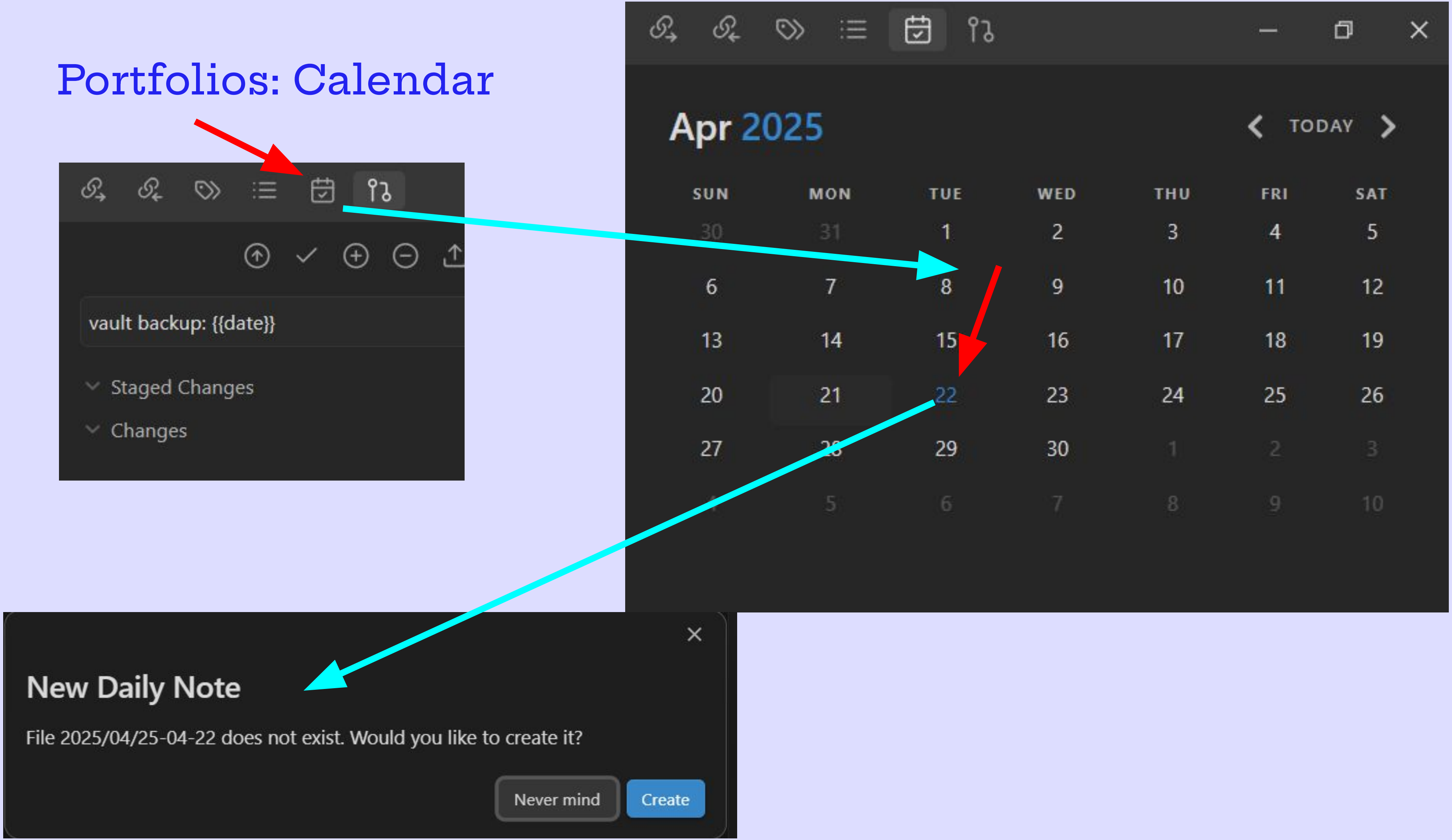
Essays

- Overall good and unique perspectives

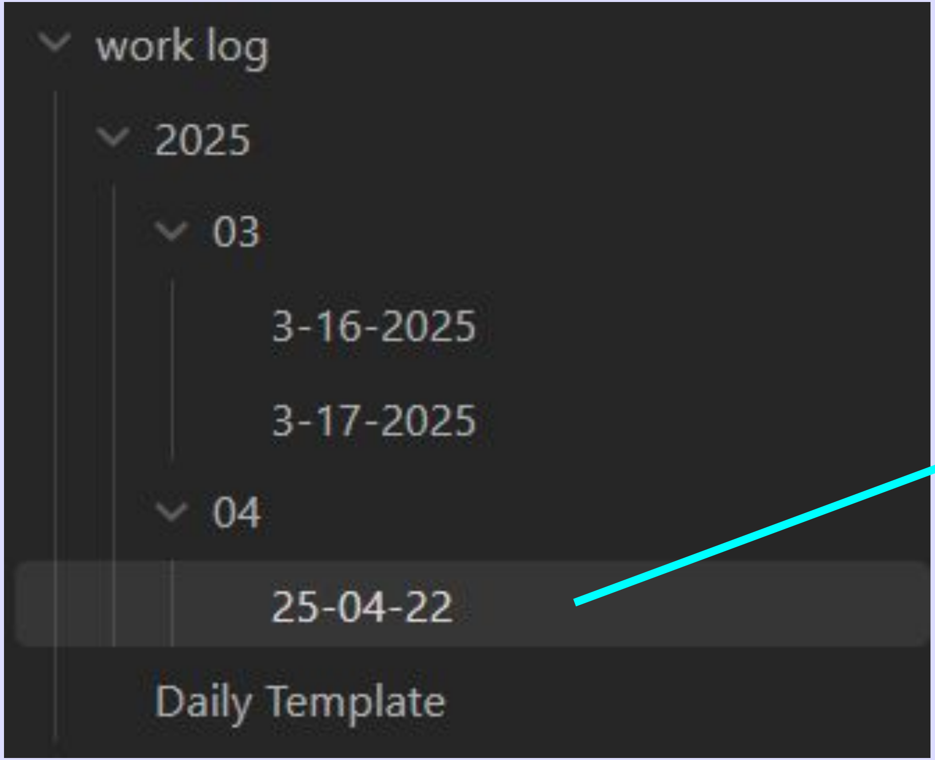
Portfolios

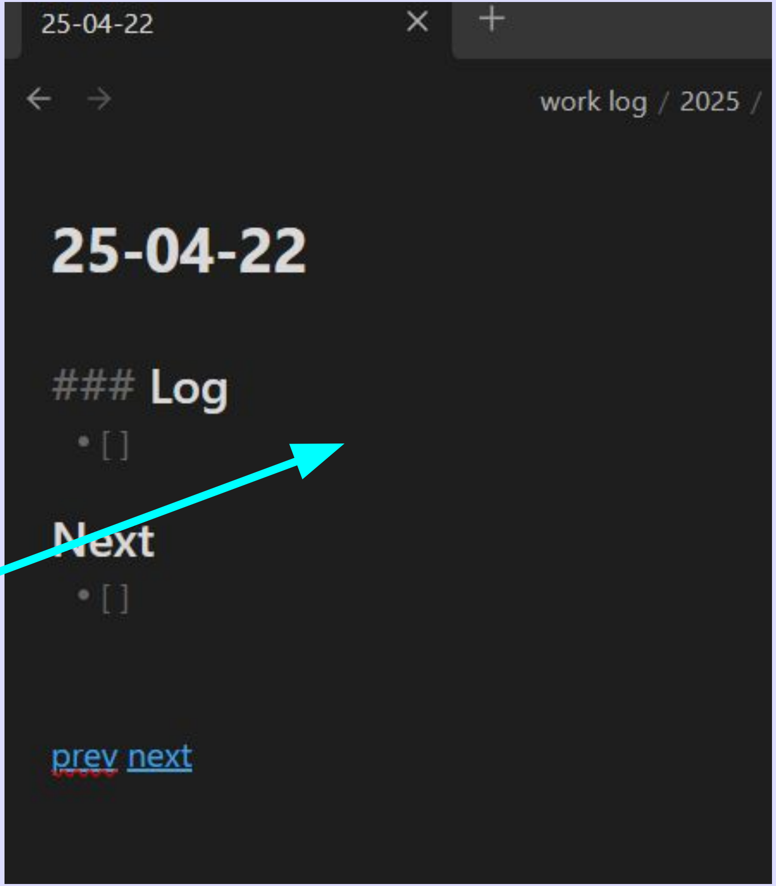
- Had some issues with people syncing
- Hard for me to easily find things
    - Perhaps always use notes and then link outside
- Realized Calendar/Work Log not being used
- Realized many folders not used

Portfolios: Calendar



Portfolios: Calendar and Work Log





Portfolios: Work log Example

Example

3-16-2025

Log

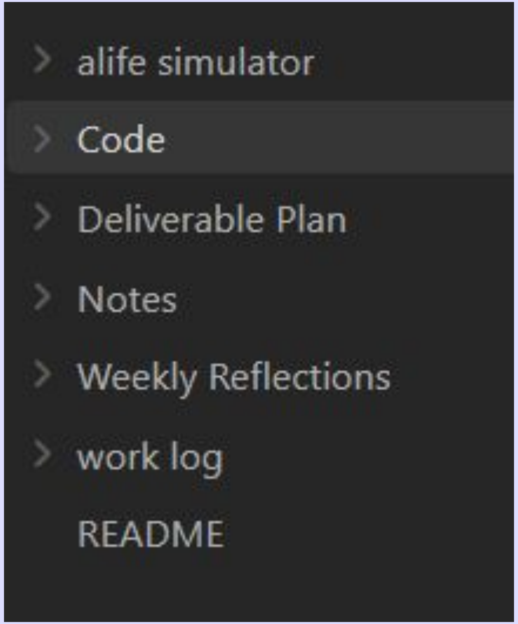
- Read Art and Artificial Life – a Primer
- Watched this video https://www.youtube.com/watch?v=kMKm1o1bEL8
- Found these art demos
    - https://neuralzoo.com/
    - https://sofiacrespo.com/

Next

- Create presentation

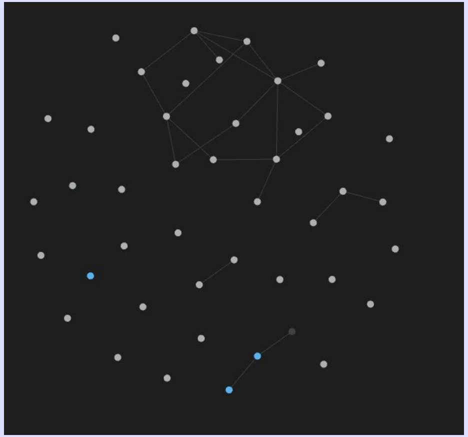
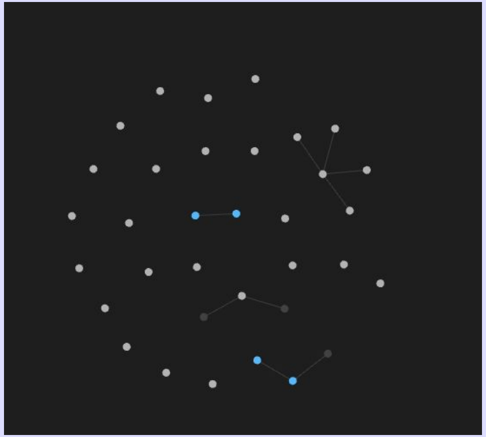
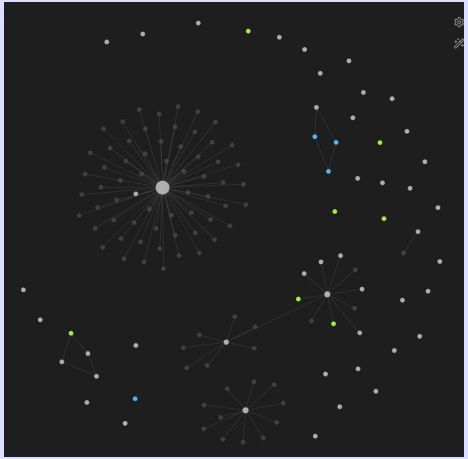
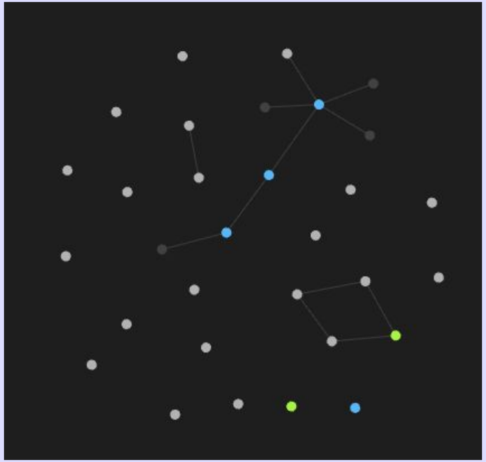
Portfolio Clean Up Tasks

- Let's try to get everything in sync
- Let's use Calendar/Work Log
  - Each time you work on something from class
    - Add entry
    - Add approximate time
    - Add next goal (to pick up next time)
- Delete all starter/non-used items



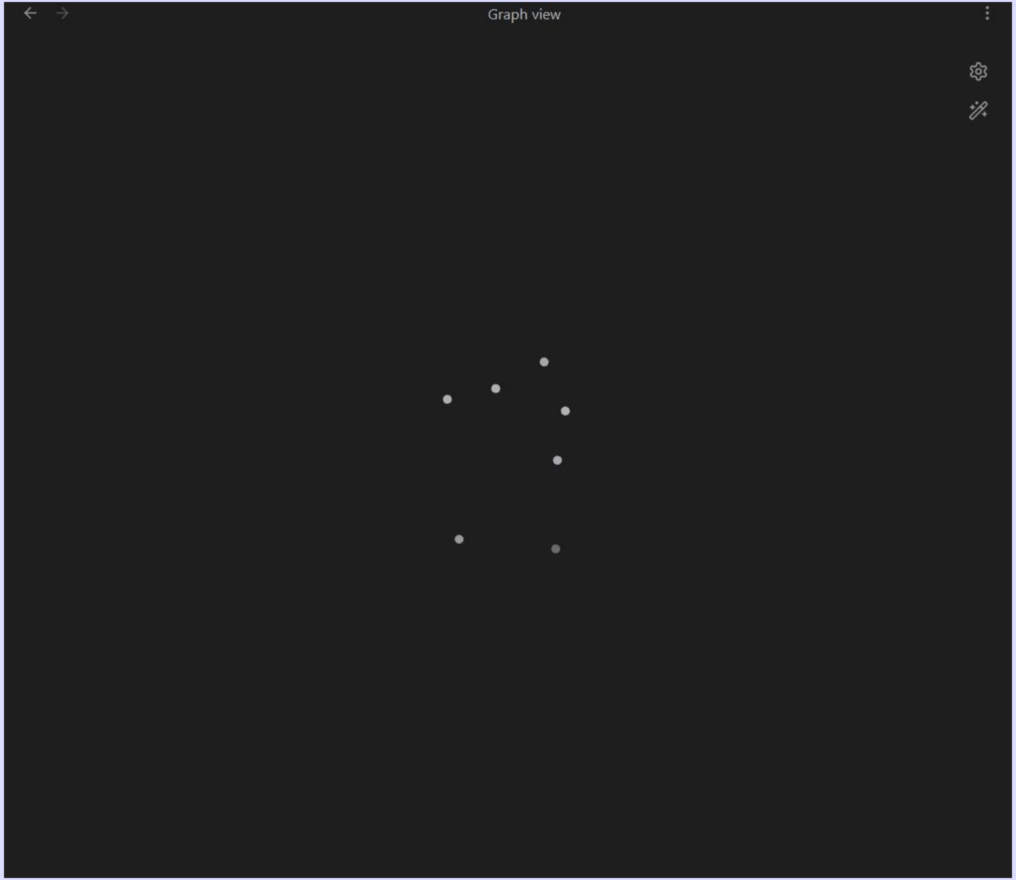
Graph Viewer

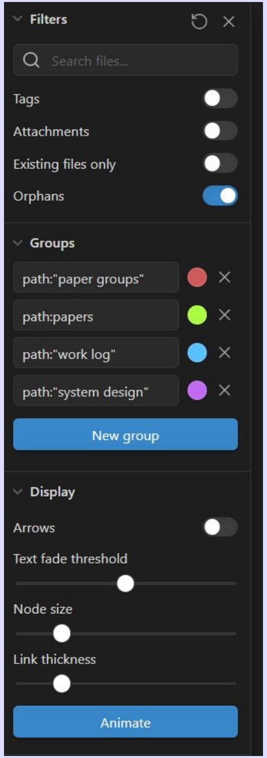
- Not reflective of work alone
  - Some notes are much larger than others
- Network of connections
  - This is something I'd like to encourage you all to do
  - Perhaps in the weekly reflections to link weeks
- This is new for me
  - Opportunity to assess integration of knowledge

Graph Viewer: Time Lapse

- Exploring this
- Not sure if it is really chronological or not, but it may be!
- If we delete old entries not sure how it will look...
- Lots of setting I have not explored yet...





Week 7 (next week)

Can we all do 4pm **instead** of 5pm on Tuesday?

Week 8

Would you all be interested in an **EXTRA** guest appearance at 4pm (following regular class, an extra hour of your time for that week)

- Tuesday vs. Thursday?