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Models of evolving interlocking complexity in biology and economics

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Interlocking complexity (Inter-dependence)

Definition: **Multiple parts must be present and working properly** in order for the system to perform its function; if certain single parts are removed, the entire system is greatly impaired or fails to function at all.

Example: a clock

Self-organized
Interlocking Complexity

Definition: The parts are not put in place "by hand" by an external agent. Instead, from a simpler initial condition, **the complex arrangement self-assembles over time as the parts interact.**

Self-organized complexity is well suited to computer modeling. Interest is growing in physics, biology, and the social sciences.

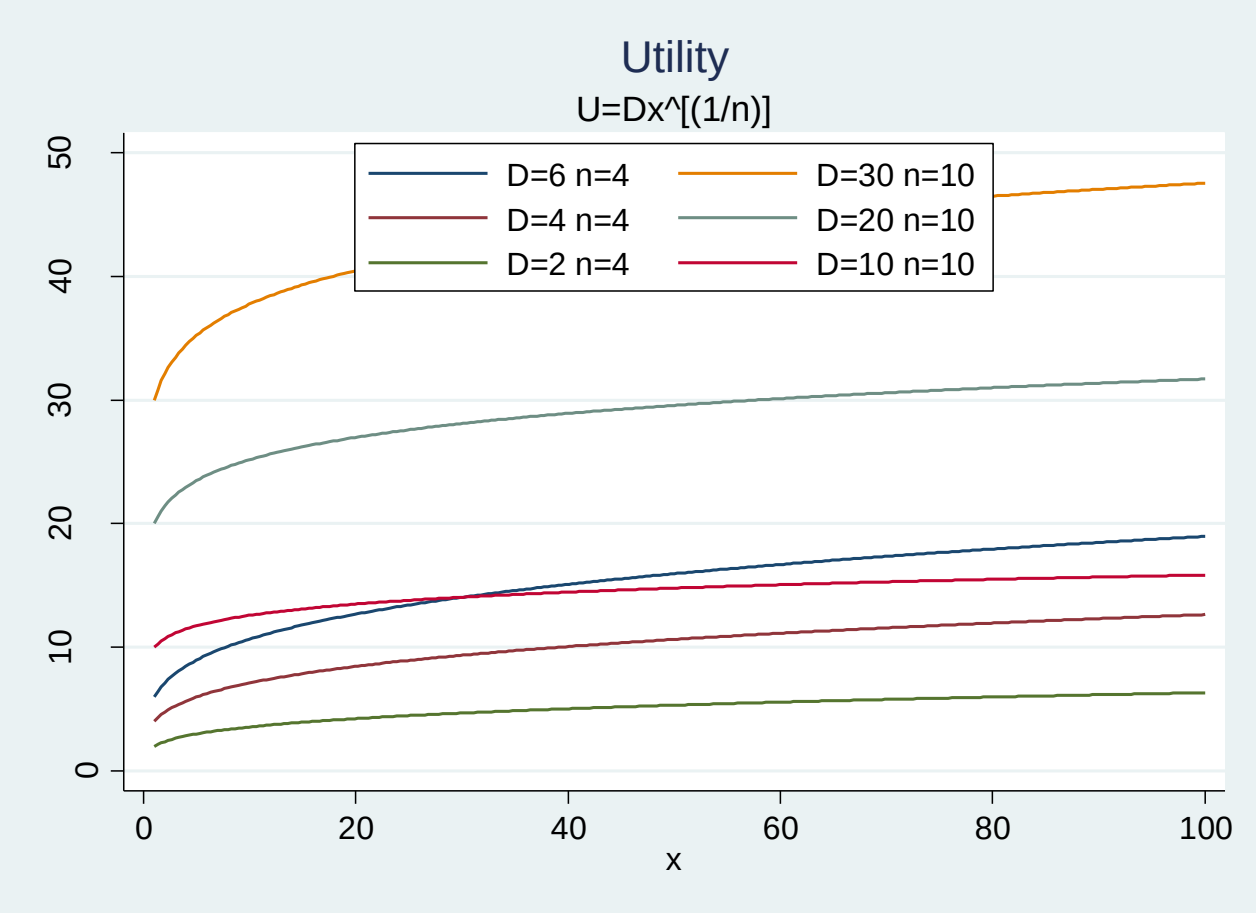
Overview of our economic model

Agents:

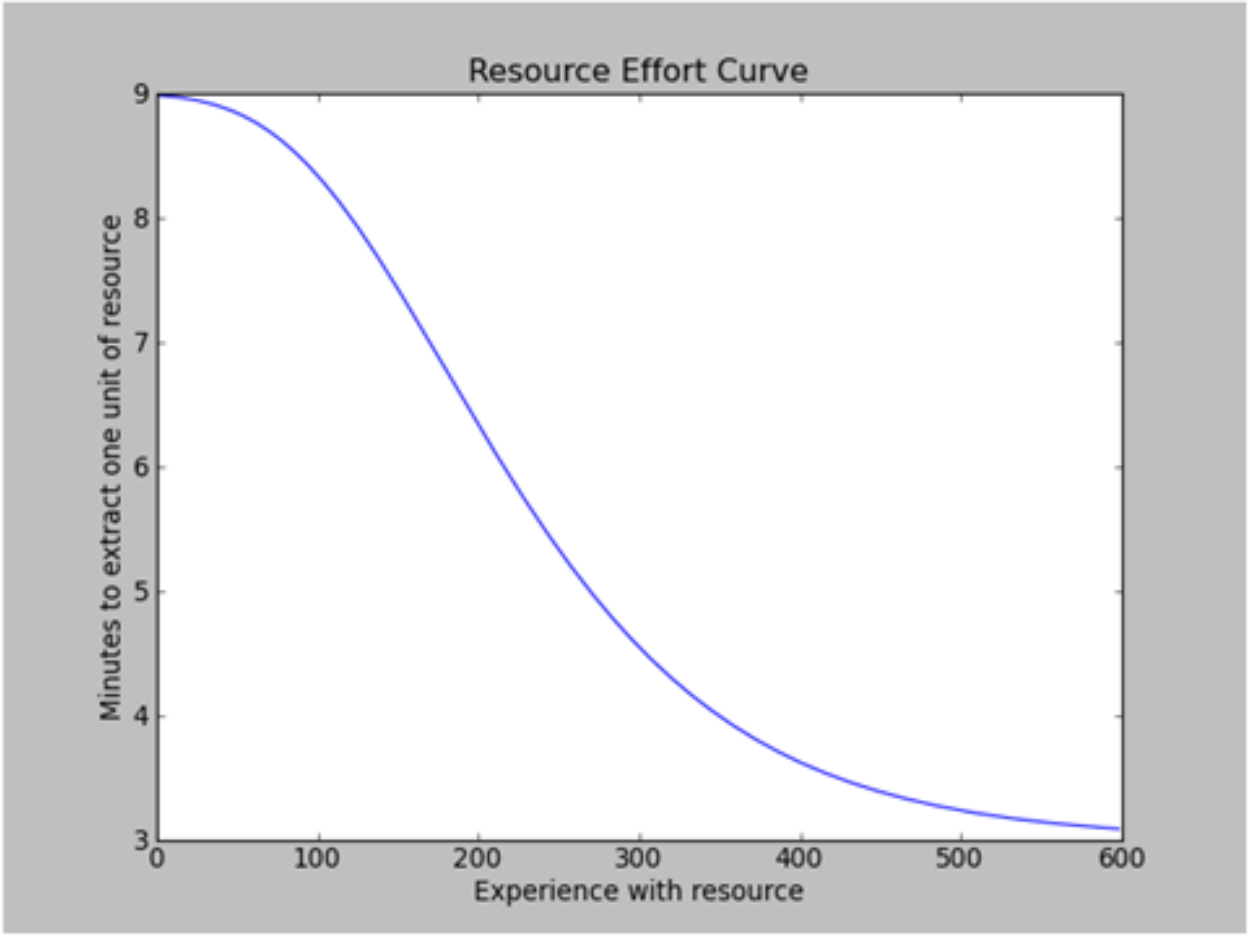
- gather various **resources** each **“day”** to meet needs & wants as measured by **utility**
- specialize to gain **efficiency**
- **trade** resources each day to increase utility
- combine resources to make **tools**, and combine lower-order **devices** into higher-order devices to further increase efficiency
- specialize in making devices
- trade devices

Phase 1: Resource gathering

Agents spend up to 600 minutes each “day” gathering resources, always gathering the resource which gives the most utility gain per minute.



- **With experience, gathering a unit of a resource takes less effort (fewer minutes).**
- This rewards specialization.
- Random choices can become locked in.

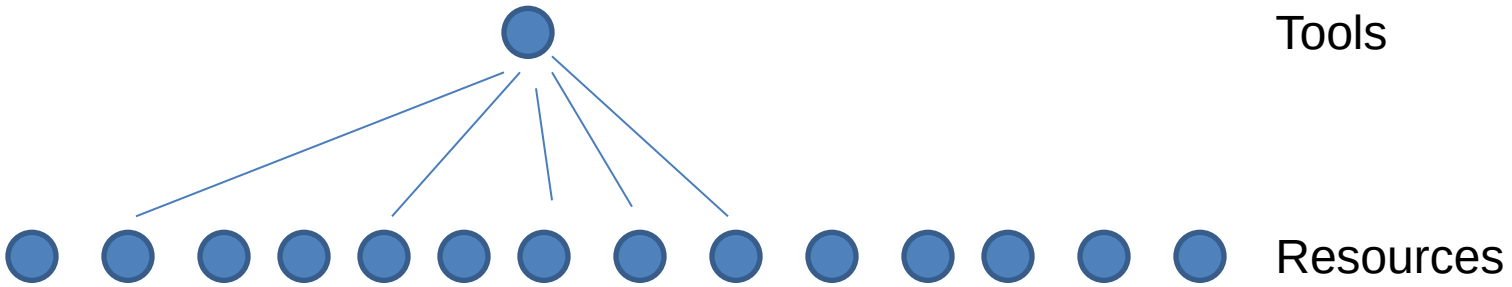


Phase 2: Resource trading

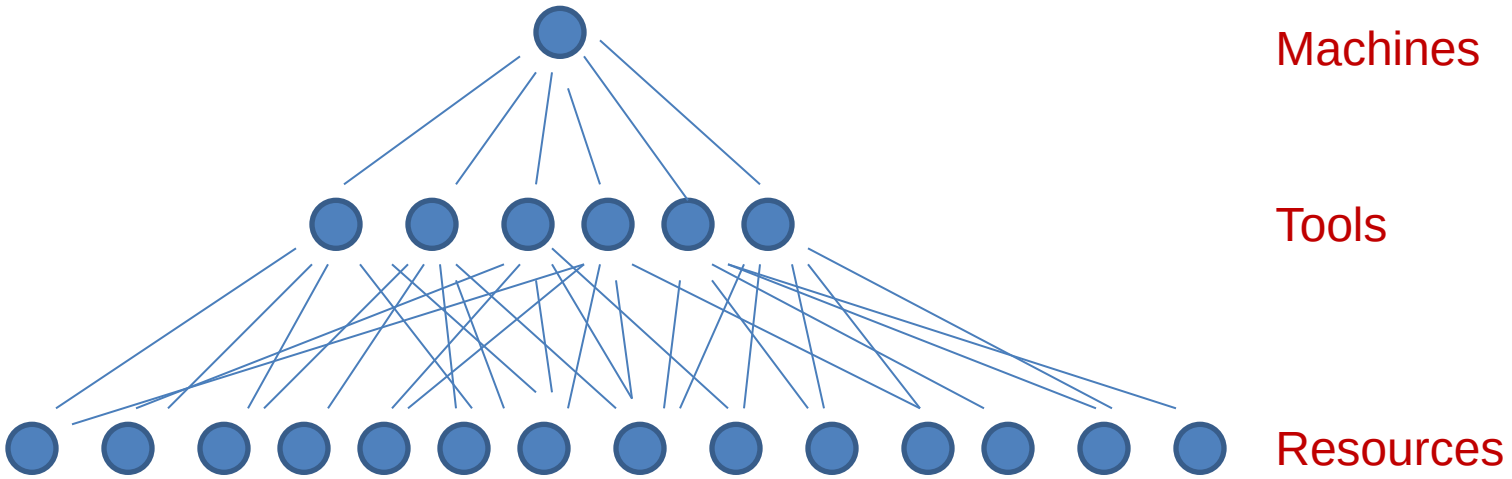
- Several rounds of agents meeting in randomized pairs, seeking to trade units of resources such that both agents increase utility
- This rewards specialization

Phase 3: Device invention

- Each agent gets one chance / day to invent a “tool”: a combination of 5 resources which speeds the gathering of a 6th resource by a factor of 3.
- Chance of successful invention proportional to experience.
- Tools have limited use (150 minutes).



- Higher order devices can then be invented to speed resource gathering by factors of 9, 27, and 81.
- 6 tools → machine; 6 machines → factory; 6 factories → industry.
  - (also: device-making devices)
- **This produces interdependence!**

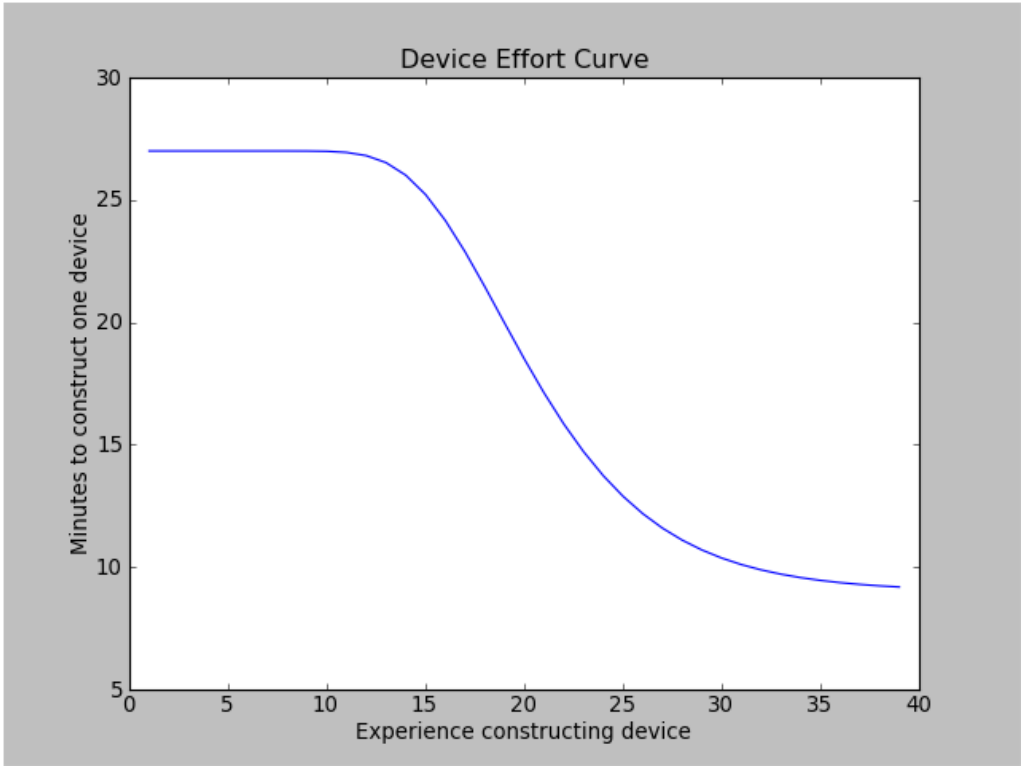


Phase 4: Device trading

- Several rounds of agents meeting in randomized pairs, seeking to trade units of resources for ***devices.***
  - Agents calculate **benefit** of a device = total extra utility it will gain by using device over its lifetime.
  - Agents calculate **cost** of making a device in terms of time and component pieces.
  - If Agent A gets more benefit than it costs Agent B to make, Agent B can make & sell device to A.

Phase 5: Device production

- Agents take resources and time (from the next day's gathering phase) to make devices they agreed or decided to make.
- Experience reduces effort, rewarding specialization.

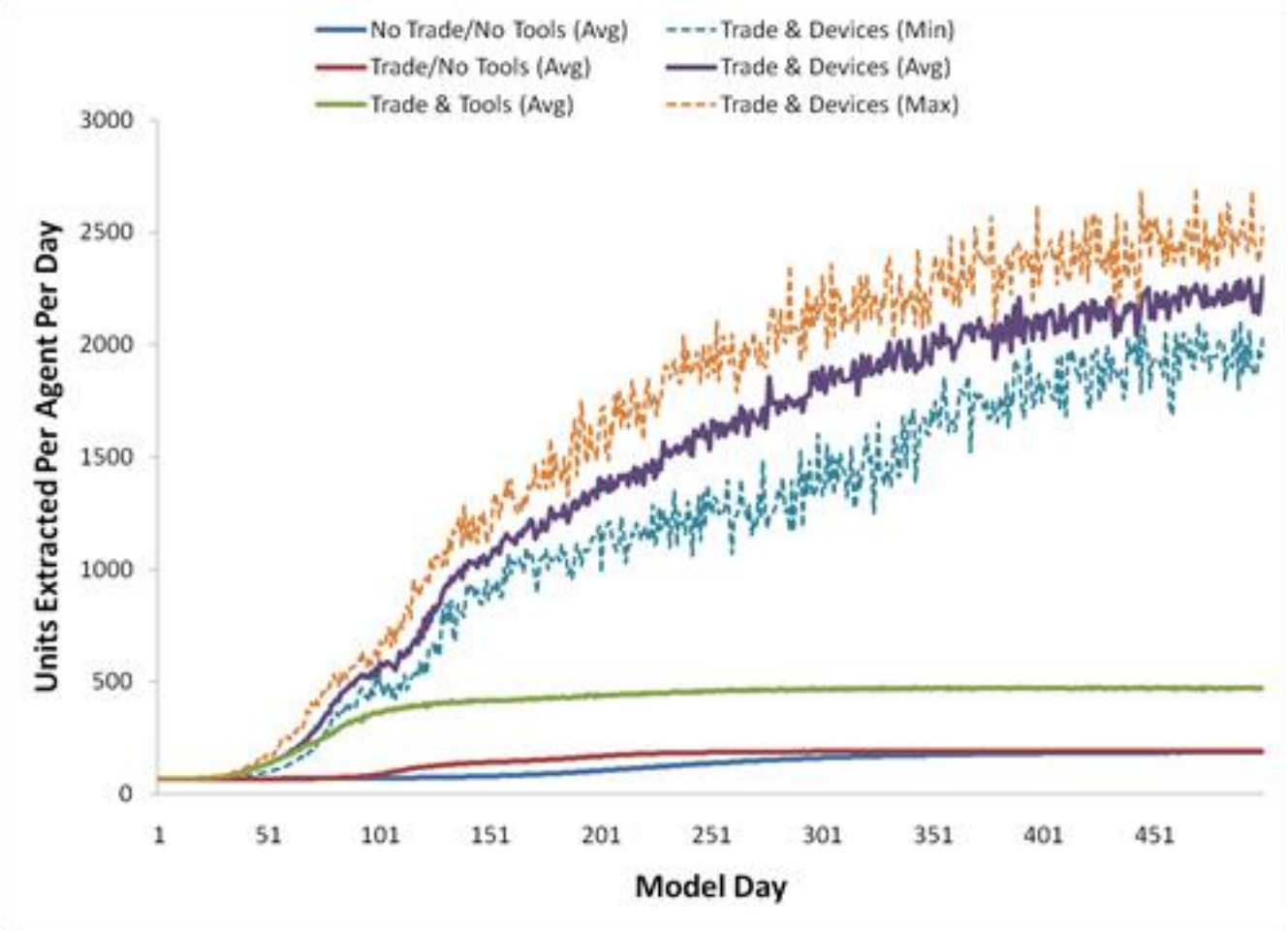


Phase 6: Resource use / depreciation

- End of day: a fixed percentage of all resources are used (or decays away).
- Devices depreciate (lose a little lifetime).
- Agents lose a little experience on any resource they didn’t gather or device they didn’t make.

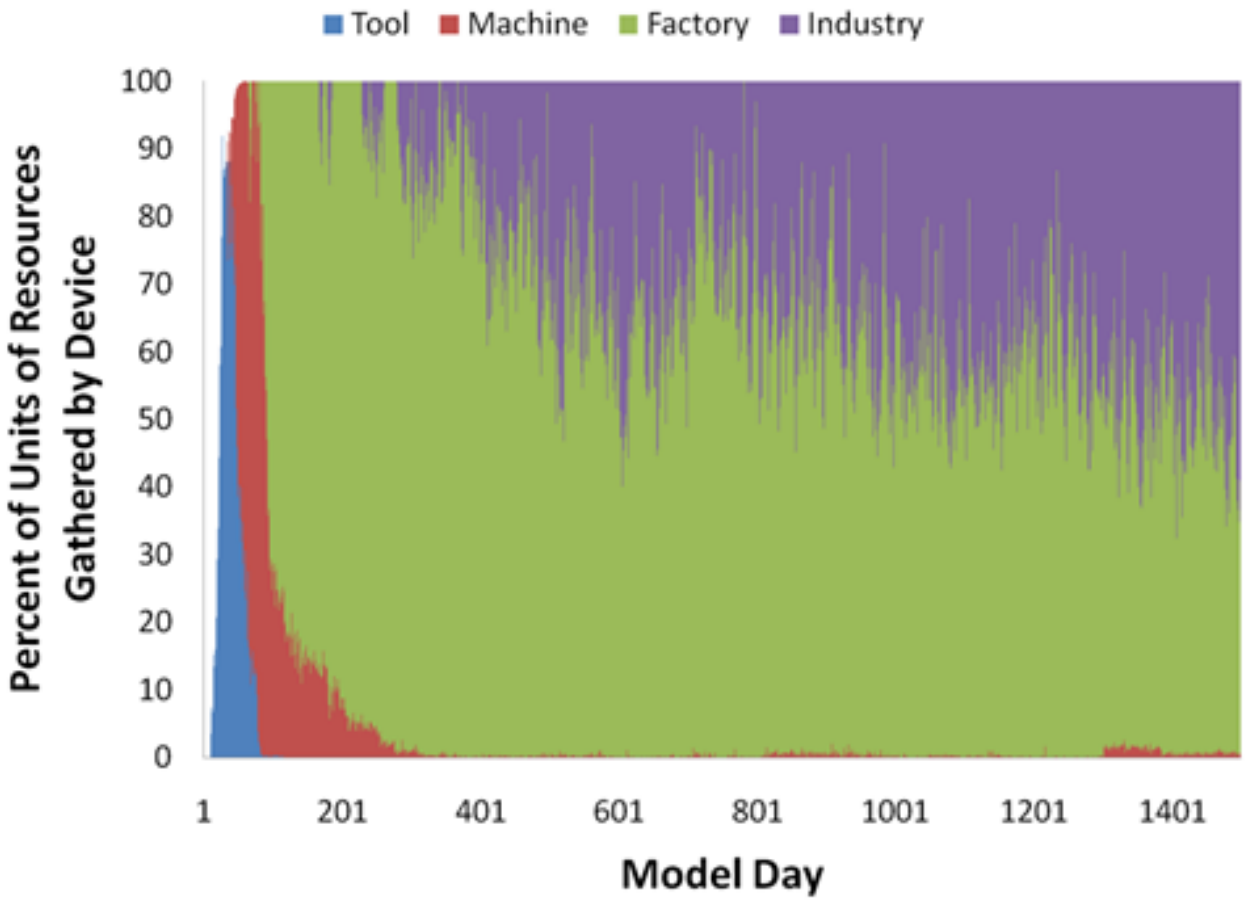
Results

Agent wealth grows over time, especially when devices are enabled.



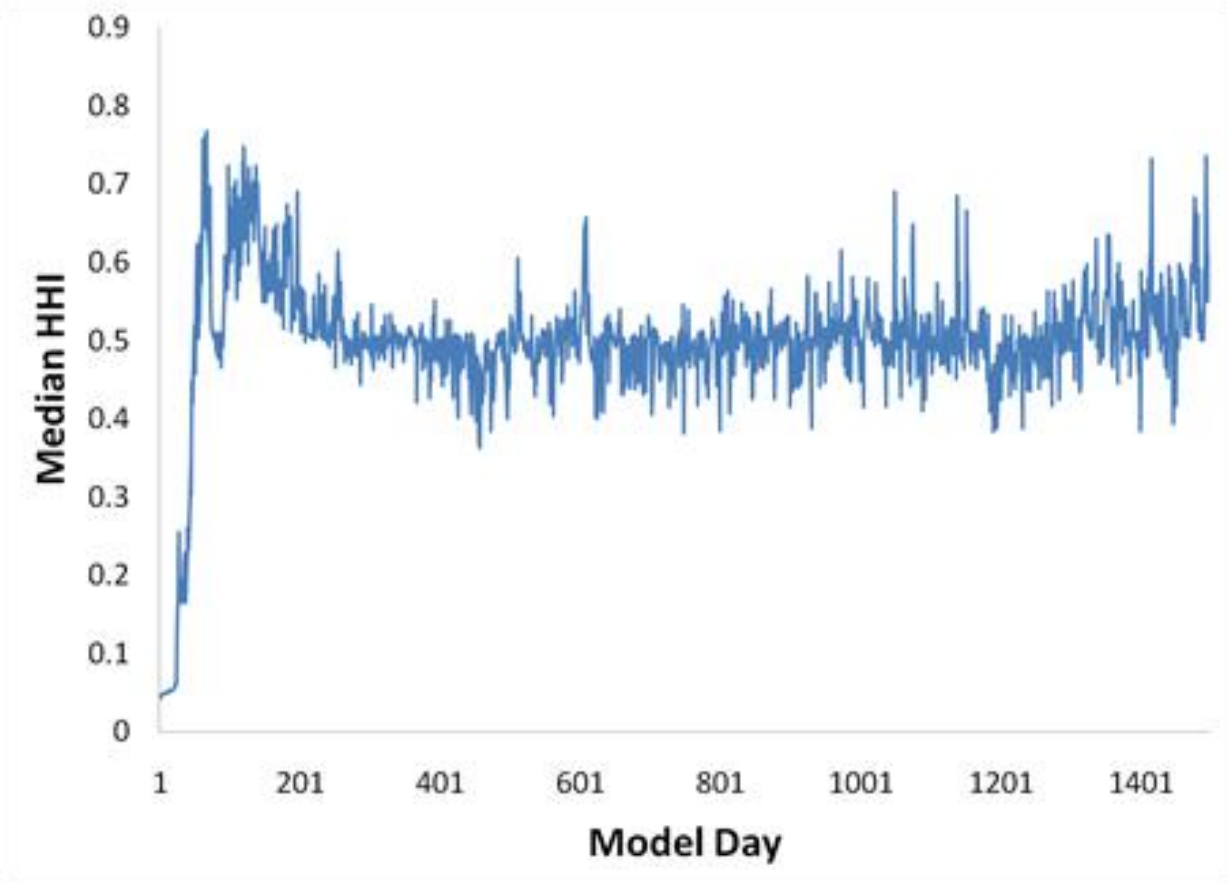
Results

Agents gather resources first “by hand”, then with tools, then machines, then factories and industries as they are invented.



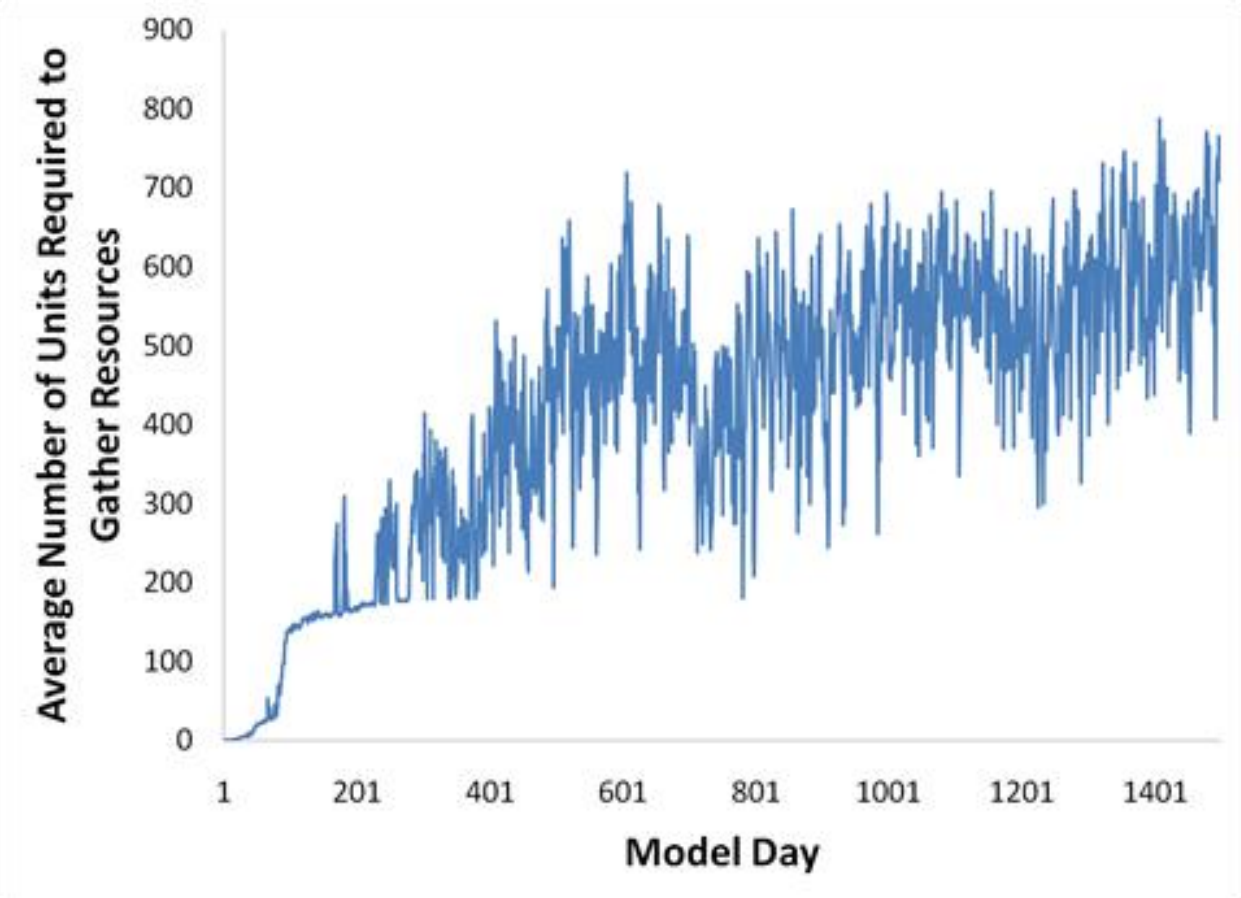
Results

Specialization of resource production. (In this case of 24 agents / 24 resources, each resource produced by ~2 agents on average.)



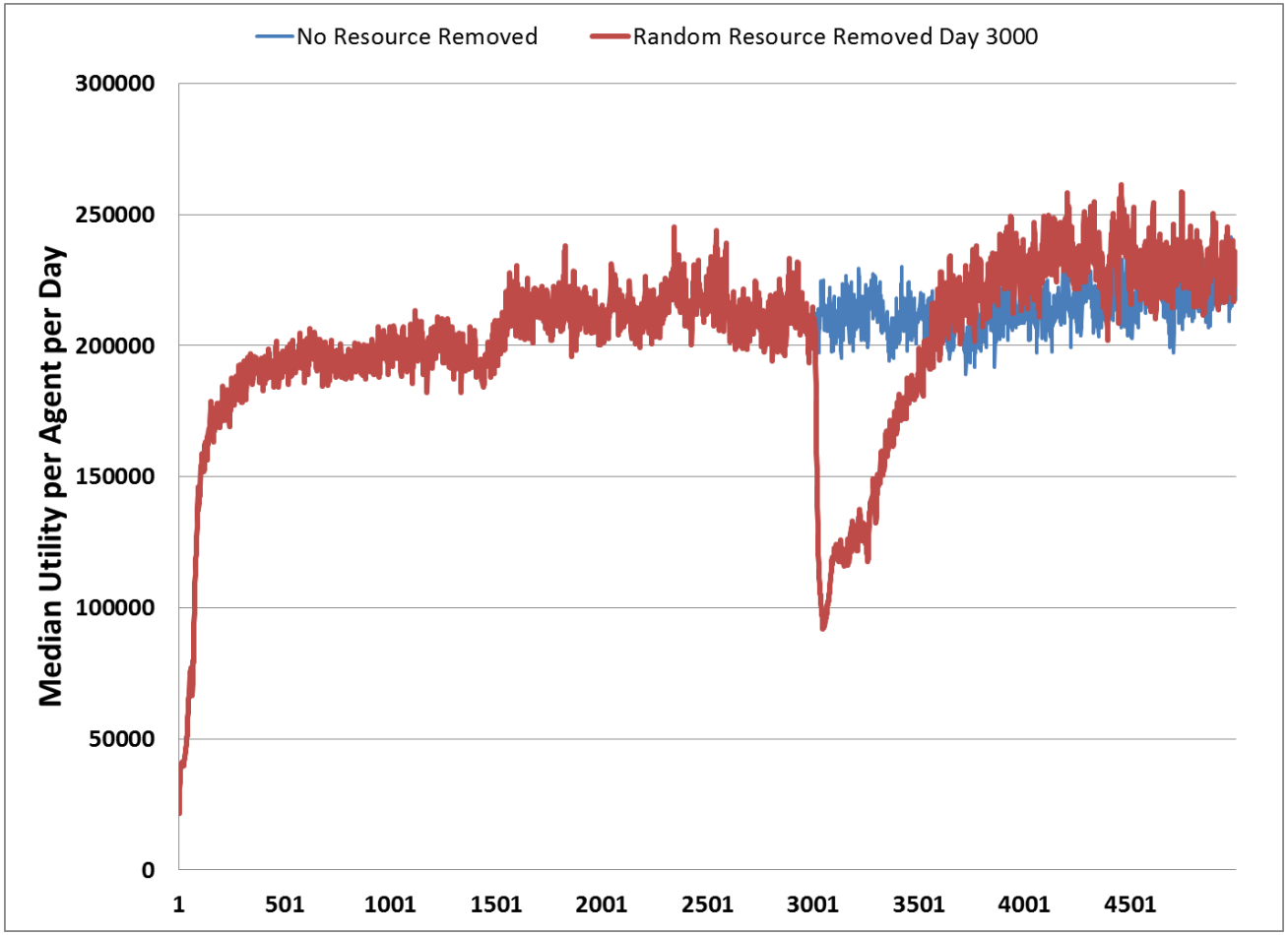
Interlocking complexity

Through devices, the gathering of each resource becomes dependent on every other resource.
(Numbers >24 indicate redundant dependence.)



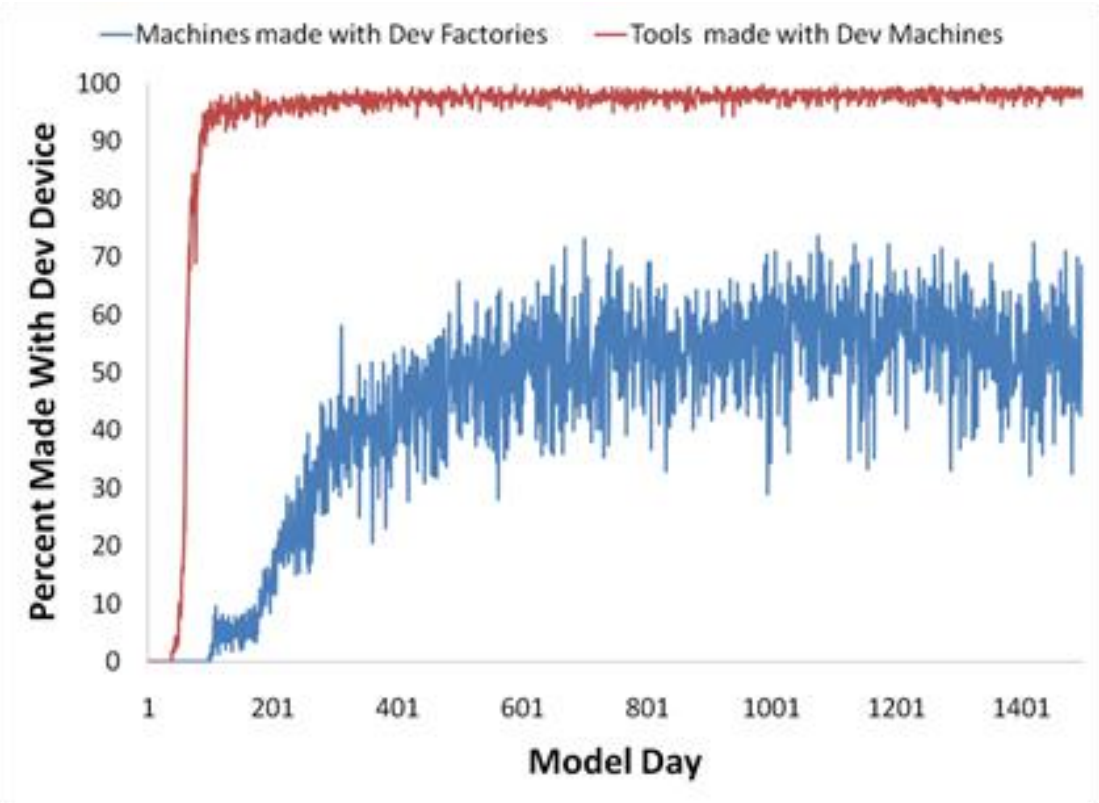
Interlocking complexity

Removing a resource from the model causes an economic collapse.



Interlocking complexity and exaptation

- Tools and machines become re-purposed.
- Economy becomes dependent on production of tools and tool-making-machines (and each depends on the other), although neither are used in resource gathering.



Overview of our biological model

Pykaryotes: digital organisms

- Gather **chemicals** from the **environment.**
- Have **genomes** which are strings of **codons.**
- Make **proteins** from strings of gathered chemicals.
- Proteins sometimes combine into **complexes**.
- After a certain number of genome reading steps, its **fitness** is calculated based on amounts of chemicals gathered.
- Fitness determines **reproductive probability**.
- **Mutations** happen during reproduction.

Genomes and codons

Codon #	Meaning
1,2,3,…	Do “mode” action on chemical # 1, 2, 3…
0	Switch to “gather mode.” Gather 0.1% of that codon chemical in this location.
-1	Switch to “move mode” for 5 codons. Move towards higher concentration of codon chemicial.
-2	Switch to “protein build mode” for 5 codons. Make a protein out of the next 5 chemicals.

Proteins

- Most proteins have no function.
- Some, once made, are **functional**. It increases the organism's ability to gather one chemical.
- The first time a protein is made by any organism, its function (or lack thereof) is randomly determined.
  - If a new protein is only a few point mutations from an existing one, it is typically (not always) assigned to that protein **family** and given a similar function (or lack thereof).

Complexes

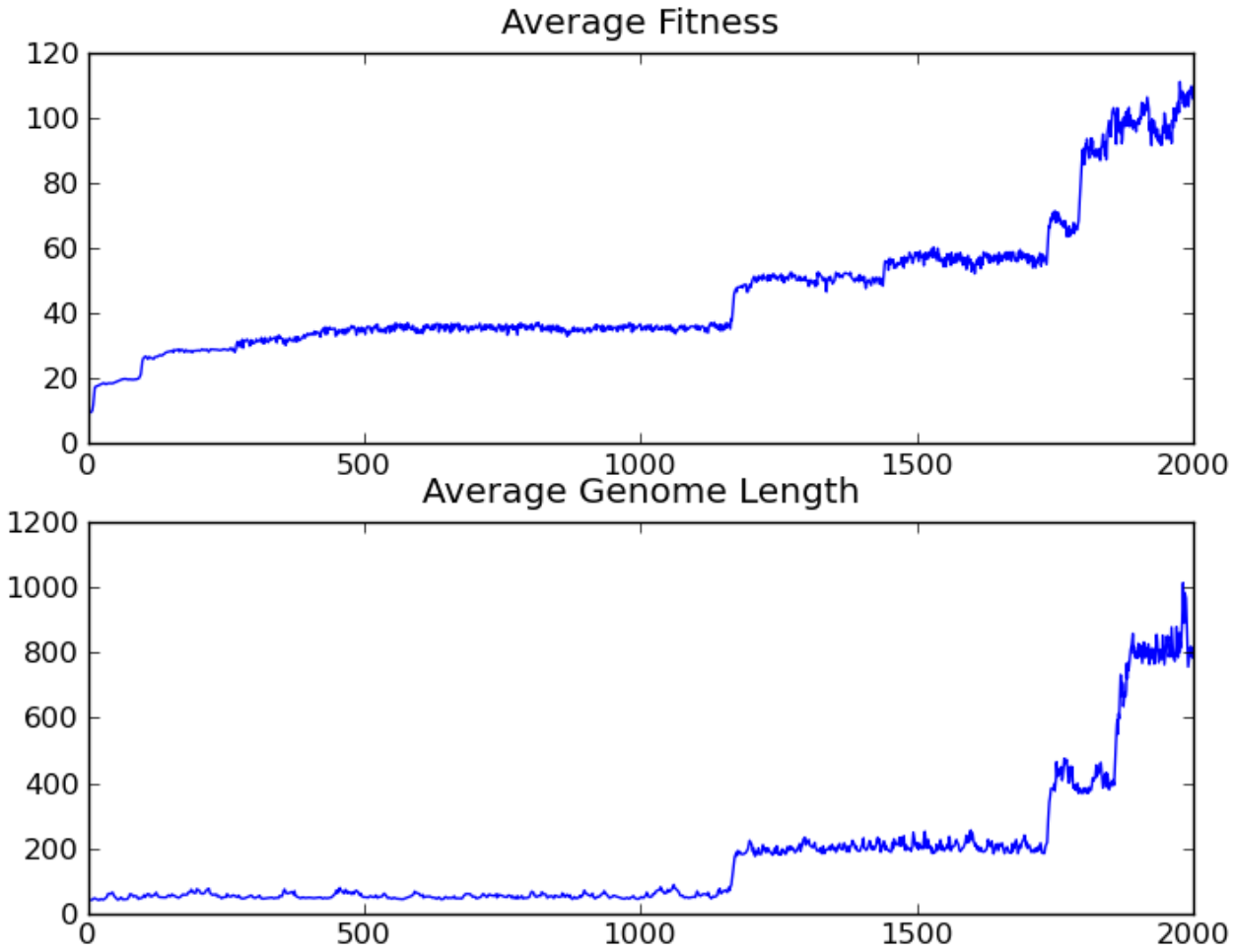
- Proteins sometimes bind to other proteins to make **complexes** of size 2, 3, 4, 5 or 6.
- A complex's **function** is independent from its proteins' functions.
  - A functional complex of length 3 might have 0, 1, 2 or 3 non-functional proteins.
- Most are non-functional. Functional complexes have effect of (protein function)^(complex size).
- Complex's function (or lack) is randomly determined. (Complex **families** are composed of proteins from the same families.)

Reproduction and mutations

- After 10,000 codon reads, organism's fitness calculated based on chemicals gathered (with a cost associated with genome size).
- Organism reproduce 0, 1, 2 or more times with probability depending on fitness.
- Mutations are possible with various probabilities:
  - Point mutations
  - Genome doubling
  - Gene copying
  - Gene deletion
  - Horizontal gene transfer

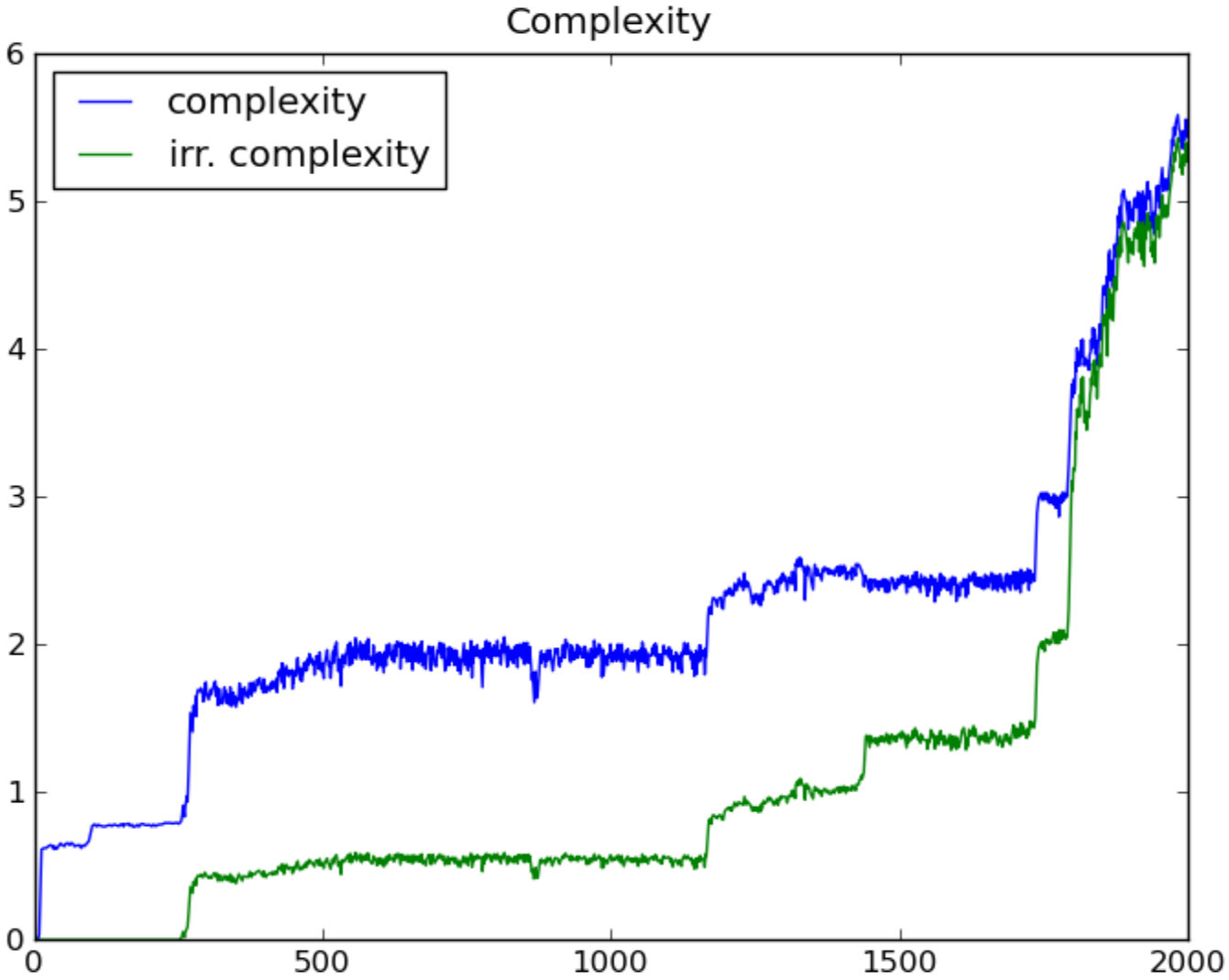
Results

Average fitness and genome length increase with generation number.



Results

Complexity and irreducible complexity evolve!



Theological reflection

- **Self-assembly to produce complexes which have capabilities far beyond component pieces seems built into creation at multiple levels.**
  - particles → atoms → molecules
  - atoms → stars and planets with oceans & air
  - molecules → autocatalytic cycles → life
  - single cell → multicellular organisms
  - organisms → ecosystems
  - Sensing cells → information processing brains
  - Individuals → social groups
  - Parental care → reciprocity → altruism
- **This suggests teleology, tells us something of God's character and purpose.**

Questions?

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