

CSC 163: Computing, Ethics, and Society

Chapter 5

Complex Systems Exercises Solution

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Exercise: Hallmarks of complexity

Name the hallmark of complex systems illustrated by each example: emergence, non-linearity and feedback, self-organization, criticality, distributed functionality, scalable structure and power laws, adaptive behavior.

Example	Hallmark
100 ants behave randomly, but tens of thousands behave as a colony	
The rich get richer: early funding attracts more funding	
Buyers and sellers settle on a price with no central planner	
One more grain of sand makes the whole pile collapse	
No single neuron or weight stores a concept; the knowledge is spread out	
Metabolic rate scales with body mass to a power (Kleiber's law)	
Developers take more risk once a system becomes more reliable (risk compensation)	

Exercise Solution: Hallmarks of complexity

Seven hallmarks: emergence, non-linearity and feedback, self-organization, criticality, distributed functionality, scalable structure and power laws, adaptive behavior (each used once).

Example	Hallmark
100 ants behave randomly, but tens of thousands behave as a colony	Emergence
The rich get richer: early funding attracts more funding	Non-linearity and feedback
Buyers and sellers settle on a price with no central planner	Self-organization
One more grain of sand makes the whole pile collapse	Criticality
No single neuron or weight stores a concept; the knowledge is spread out	Distributed functionality
Metabolic rate scales with body mass to a power (Kleiber's law)	Scalable structure / power laws
Developers take more risk once a system becomes more reliable (risk compensation)	Adaptive behavior

Exercise: Power-law scaling

Kleiber's law: metabolic rate $\propto$ (body mass)^{0.75}.

(a) Fill in the table: by what factor does the rate grow when the mass is multiplied by 2, 10, 100?

(b) An elephant (3000 kg) and a mouse (0.03 kg): how many times larger is the elephant's total rate? Its rate per kg is how many times the mouse's?

(c) A toy LLM law: loss $\propto$ (compute)^{-0.05}. By what factor does the loss change when compute grows $\times 10$? $\times 100$?

Mass factor	Rate factor
$\times 2$	
$\times 10$	
$\times 100$	

Exercise Solution: Power-law scaling

- (a) Rate factor = mass factor^{0.75}: $2^{0.75} \approx 1.68$; $10^{0.75} \approx 5.62$; $100^{0.75} \approx 31.6$.
- (b) Mass ratio = 100,000, so total rate ratio = $100,000^{0.75} \approx 5,600$; per kg: $5,623/100,000 \approx 0.056$ (about 1/18).
- (c) $10^{-0.05} \approx 0.89$ (−11 %); $100^{-0.05} \approx 0.79$ (−21 %).
- Properties scale non-linearly with size: a large system is not a sum of small ones.

Mass factor	Rate factor
× 2	1.68
× 10	5.62
× 100	31.6

Exercise: Puzzle, problem, or wicked?

Classify each task as a puzzle (one findable answer), a problem (several approaches, but it is clear when it is solved), or a wicked problem (social element, no flawless solution, unclear when solved).

Task	Type
Solve a sudoku	
Repair a car that will not start	
Reduce income inequality	
Assemble a piece of furniture from instructions	
Stop the spread of misinformation	
Make advanced AI safe	

Exercise Solution: Puzzle, problem, or wicked?

Wicked problems arise in complex systems and attempting to solve them is risky. AI safety is a wicked problem.

Task	Type
Solve a sudoku	Puzzle
Repair a car that will not start	Problem
Reduce income inequality	Wicked problem
Assemble a piece of furniture from instructions	Puzzle
Stop the spread of misinformation	Wicked problem
Make advanced AI safe	Wicked problem

Exercise: True or false

For each statement write T or F. If it is false, correct it with a few words.

Statement	T / F	Correction (if false)
Emergent features are present in each individual component of the system		
Positive feedback means the system down-regulates a change (homeostasis)		
A safe system is not necessarily still safe when scaled up		
We can build a large, safe AI system directly from scratch		
"Kill rats, present tails" reduced rat infestations		
Armchair analysis alone can anticipate all failure modes		

Exercise Solution: True or false

Each statement: 1 point for T/F, 1 point for the correction.

Statement	T / F	Correction (if false)
Emergent features are present in each individual component of the system	F	They cannot be found in any single component
Positive feedback means the system down-regulates a change (homeostasis)	F	That is negative feedback; positive feedback amplifies, e.g., the rich getting richer
A safe system is not necessarily still safe when scaled up	T	—
We can build a large, safe AI system directly from scratch	F	We are unlikely to; scale up gradually from small, safe systems (still no guarantee)
"Kill rats, present tails" reduced rat infestations	F	It led to rat farms: interventions can backfire
Armchair analysis alone can anticipate all failure modes	F	Trial and error is needed; theory cannot predict all emergent properties