Causal Loop Diagram

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Prepared for CSP320 System Modeling
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References:

1. Sterman, John D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hills. Chapter 3: The Modeling Processes.

Why Simulation is Essential

- Eliciting and mapping the participant’s mental models, while necessary, is far from sufficient. Simulation is the only practical way to test these models.
- Without simulation, conceptual models can only be tested and improved by relying on the learning feedback through the real world.
    - This feedback is very slow and often rendered ineffective by dynamic complexity, time delays, inadequate and ambiguous feedback, poor reasoning skills, defensive reactions, and the costs of experimentation.
- In this circumstances, simulation becomes the only reliable way to test hypotheses and evaluate the likely effects of policies.

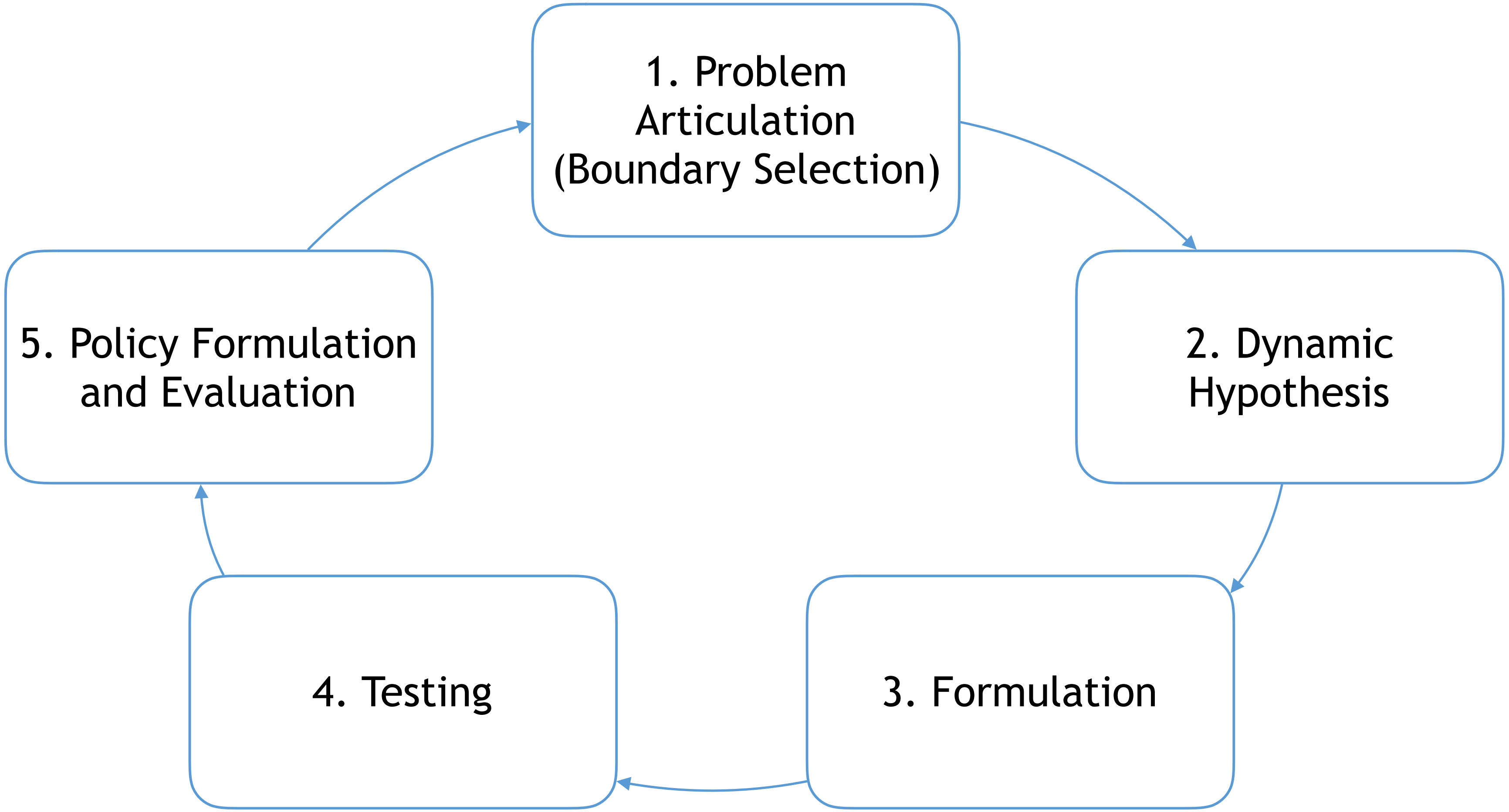
System Dynamics

- System Dynamics is an approach that should help in important top management problems.
- System Dynamics was born at MIT Sloan in the 1950s and developed by Prof. Emeritus Jay W. Forrester.
- System Dynamics helps us understand, design, and manage change.
- Using data and technology, System Dynamics models the relationships between all the parts of a system and how those relationships influence the behavior of the system over time.

What is System Dynamics?

- Computer simulation modeling for studying and managing complex feedback systems, such as business and other social systems
- System:
  - In general, a collection of interacting elements that function together for some purpose
  - Here, **feedback** is the differentiating descriptor
- Properties of dynamic problems
  - Contain quantities that vary over time
  - Variability can be described causally
  - Important causal influences can be contained within a closed system of feedback loops

The Modeling Process



System Dynamics Modeling

- Identify a problem
- Develop a dynamic hypothesis explaining the cause of the problem
- **Create a basic structure of a causal graph**
- **Augment the causal graph with more information**
- Convert the augmented causal graph to a System Dynamics flow graph
- Translate a System Dynamics flow graph into DYNAMO programs or equations

Critical Aspects

- Thinking in terms of cause-and-effect relationships
- Focusing on the feedback linkages among components of a system
- Determining the appropriate boundaries for defining what is to be included within a system

Understand Cause and Effect

- Causal thinking is the key to organizing ideas in a system dynamics study
- Instead of 'cause', 'affect' or 'influence' can be used to describe the related components in the system
- Some are logical (e.g. physics)
  - Food intake→ weight
  - Money → happiness
  - Fire → smoke
- Some are not (e.g. sociology, economics)
  - Use of seatbelts → reduced highway fatalities
  - Shortened daylight hours → increased suicide rates

Feedback

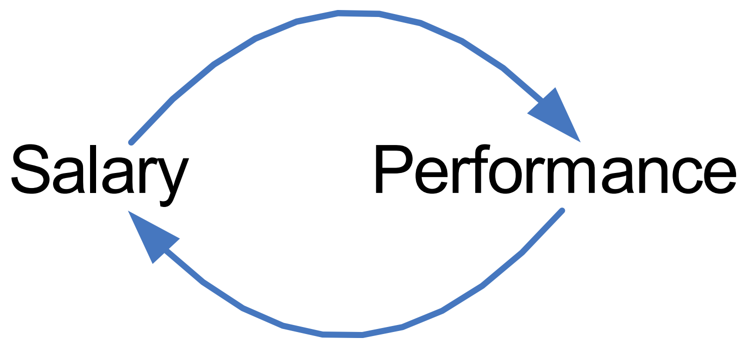
- Thinking in terms of "cause and effect" is not enough
  - ocean → evaporation → cloud → rain → ocean → …
- Feedback: an initial cause ripples through a chain of causation ultimately to re-affect itself
- Search to identify closed, causal feedback loops is one key element of System Dynamics
- The most important causal influences will be exactly those that are enclosed within feedback loop

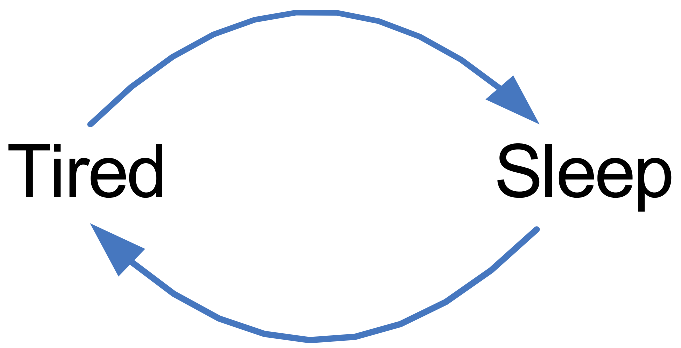
Causal Loop Diagram (CLD)

- Represent the feedback structure of systems
- Capture
  - The hypotheses about the causes of dynamics
  - The important feedbacks

CLD Examples

- Salary VS Performance
  - Salary → Performance
  - Performance → Salary
- Tired VS Sleep
  - Tired → sleep
  - Sleep → tired

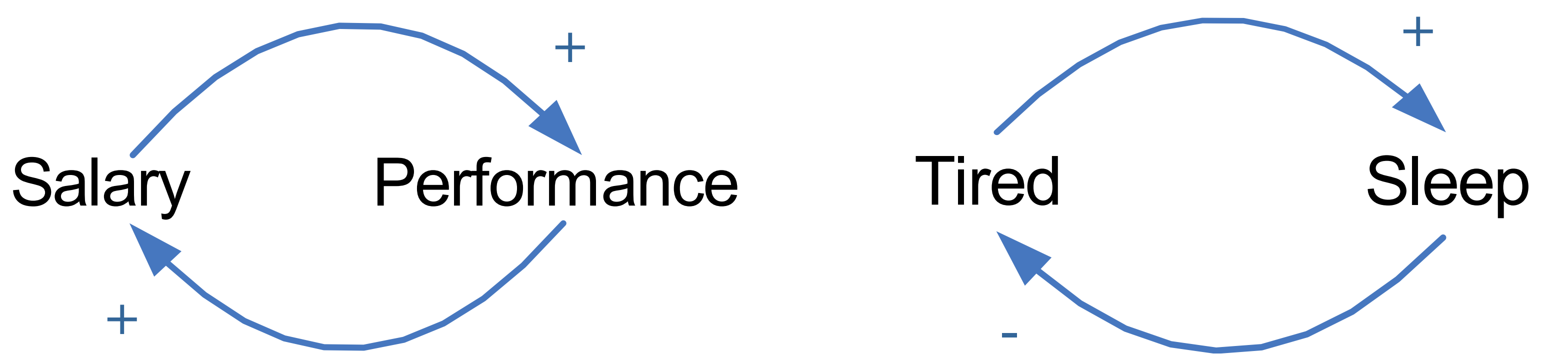




Augmenting CLD 1 (Labeling Link Polarity)

- Signing: Add a '+' or a '−' sign at each arrowhead to convey more information
- A '+' is used *if the cause increase, the effect increases* and *if the cause decrease, the effect decreases*
- A '-' is used *if the cause increases, the effect decreases* and *if the cause decreases, the effect increases*

Signing Arcs



Augmenting CLD 2 (Determining Loop Polarity)

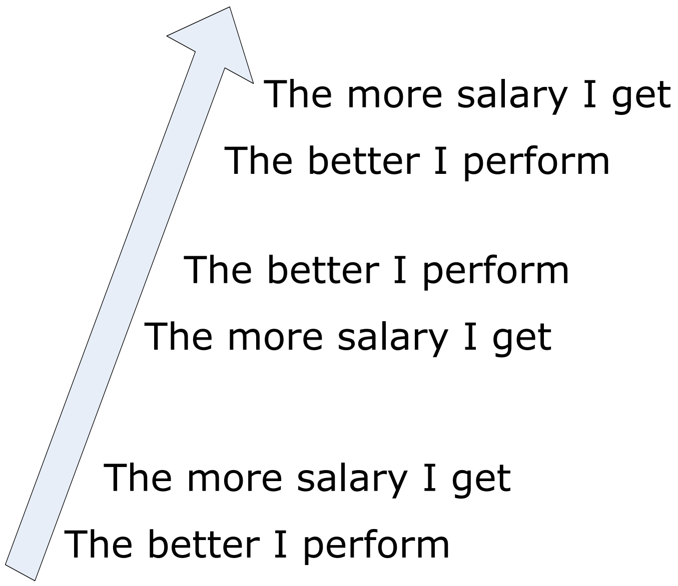
- Positive feedback loops
  - Have an even number of '–' signs
  - Some quantity increase, a "snowball" effect takes over and that quantity continues to increase
  - The "snowball" effect can also work in reverse
  - Generate behaviors of growth, amplify, deviation, and reinforce
  - Notation: place 

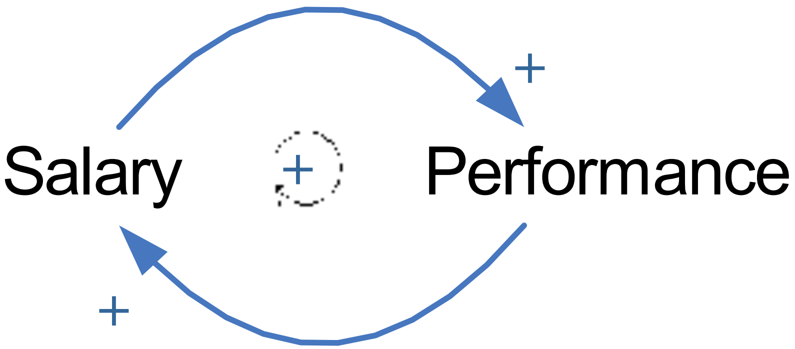
symbol in the center of the loop
- Negative feedback loops
  - Have an odd number of "–" signs
  - Tend to produce "stable", "balance", "equilibrium" and "goal-seeking" behavior over time
  - Notation: place 

symbol in the center of the loop

CLD with Positive Feedback Loop

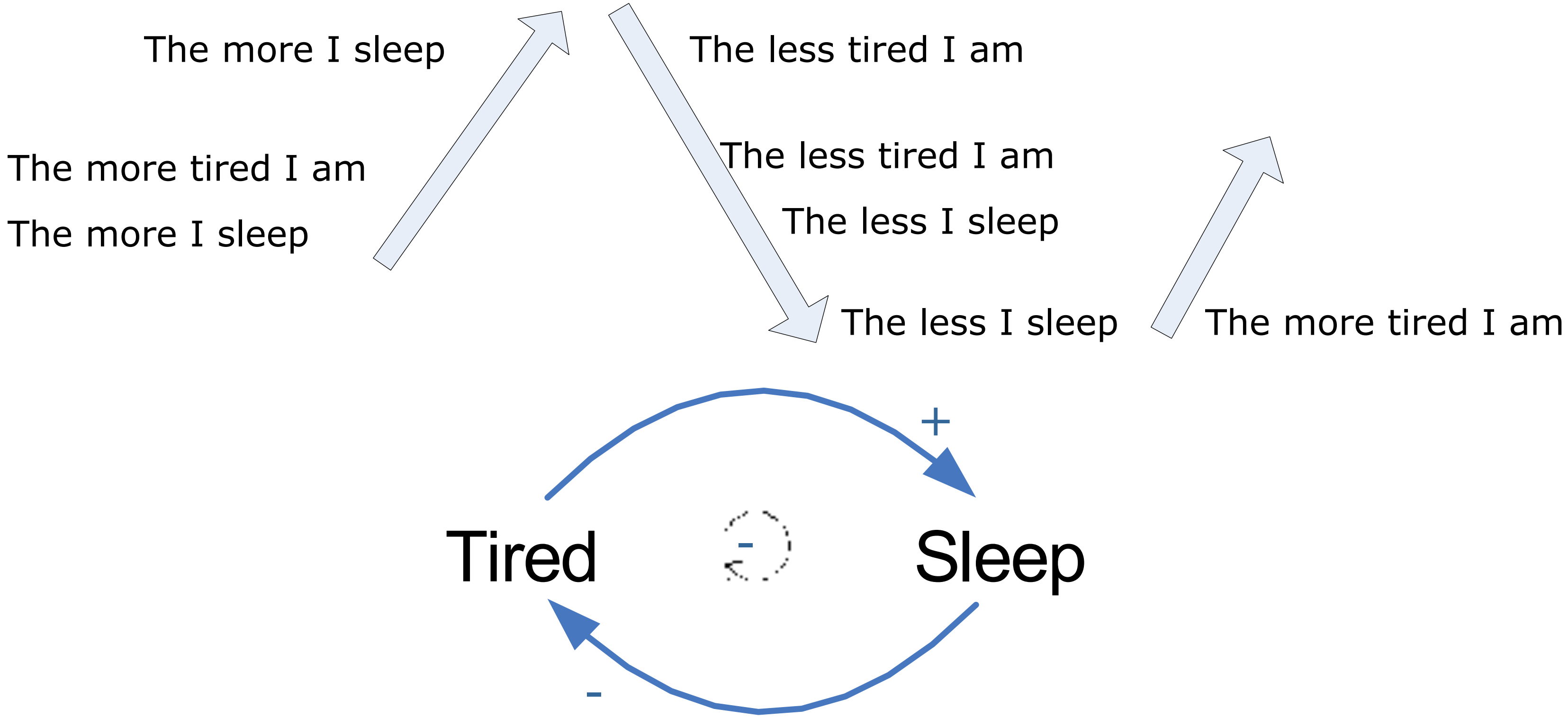
- Salary → Performance, Performance → Salary





CLD with Negative Feedback Loop

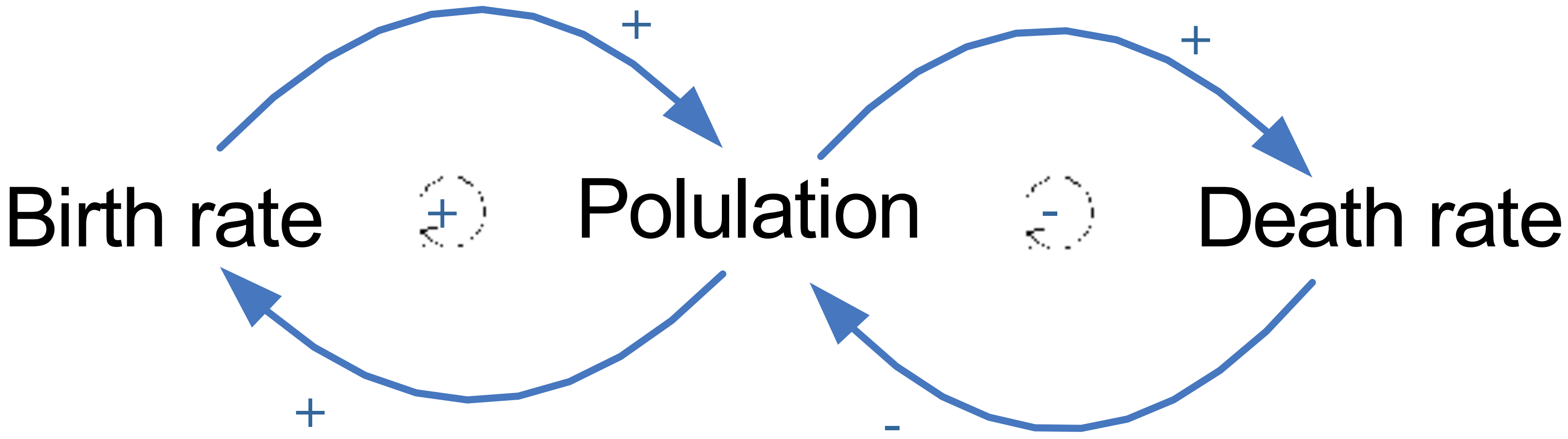
- Tired → Sleep, Sleep → Tired



Loop Dominance

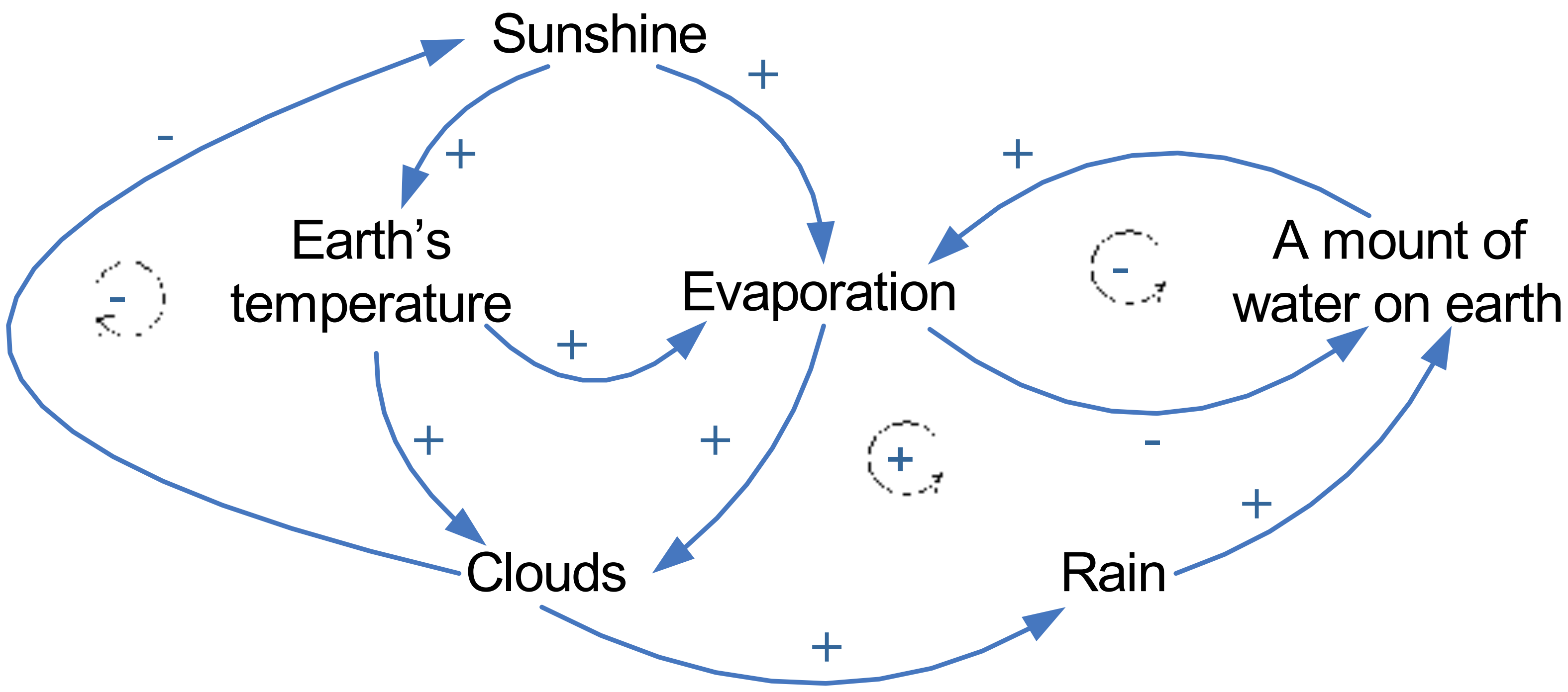
- There are systems which have more than one feedback loop within them
- A particular loop in a system of more than one loop is most responsible for the overall behavior of that system
- The dominating loop might shift over time
- When a feedback loop is within another, one loop must dominate
- Stable conditions will exist when negative loops dominate positive loops

CLD with Combined Feedback Loops (Population Growth)



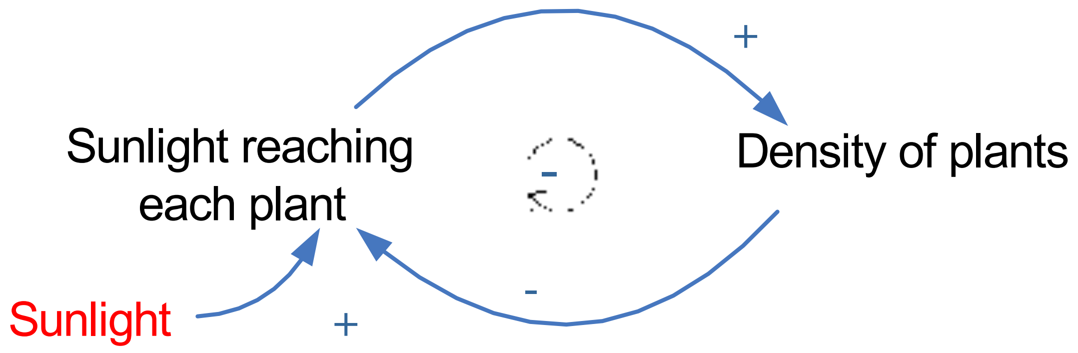
CLD with Nested Feedback Loops (Self-Regulating Biosphere)

- Evaporation → clouds → rain → amount of water → evaporation → …



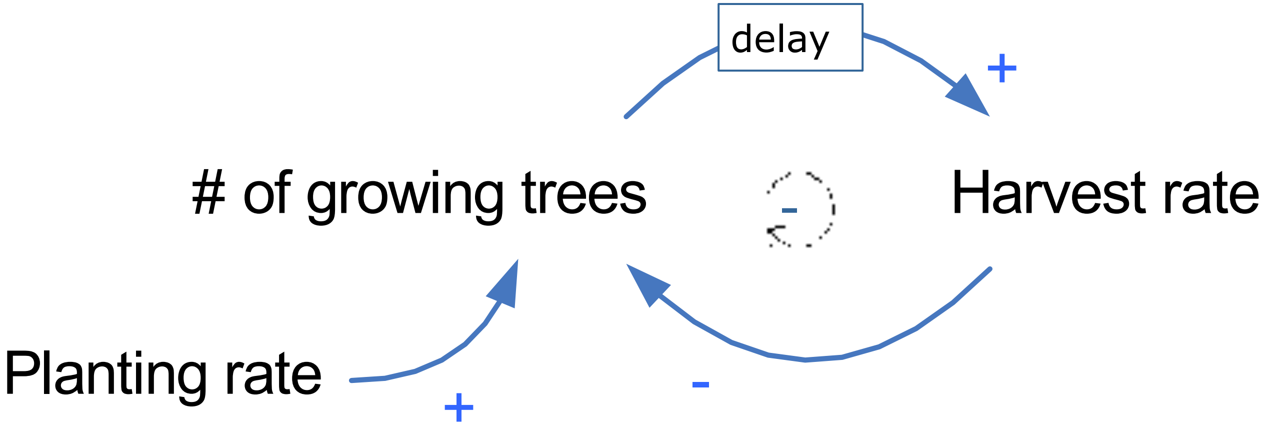
Exogenous Items

- Items that affect other items in the system but are not themselves affected by anything in the system
- Arrows are drawn from these items but there are no arrows drawn to these items



Delays

- Systems often respond sluggishly
- From the example below, once the trees are planted, the harvest rate can be ‘0’ until the trees grow enough to harvest



Practice: Modeling System Dynamics

- Choose a Case Study in **Different** Domain
- Identify a Problem
- Create a Hypothesis (from Grounded Theory)
- Create Causal Loop Diagrams (with Description and Argumentation)
- Write Conclusion

- Submit before: 20 April 2018 (collective via class coordinator)