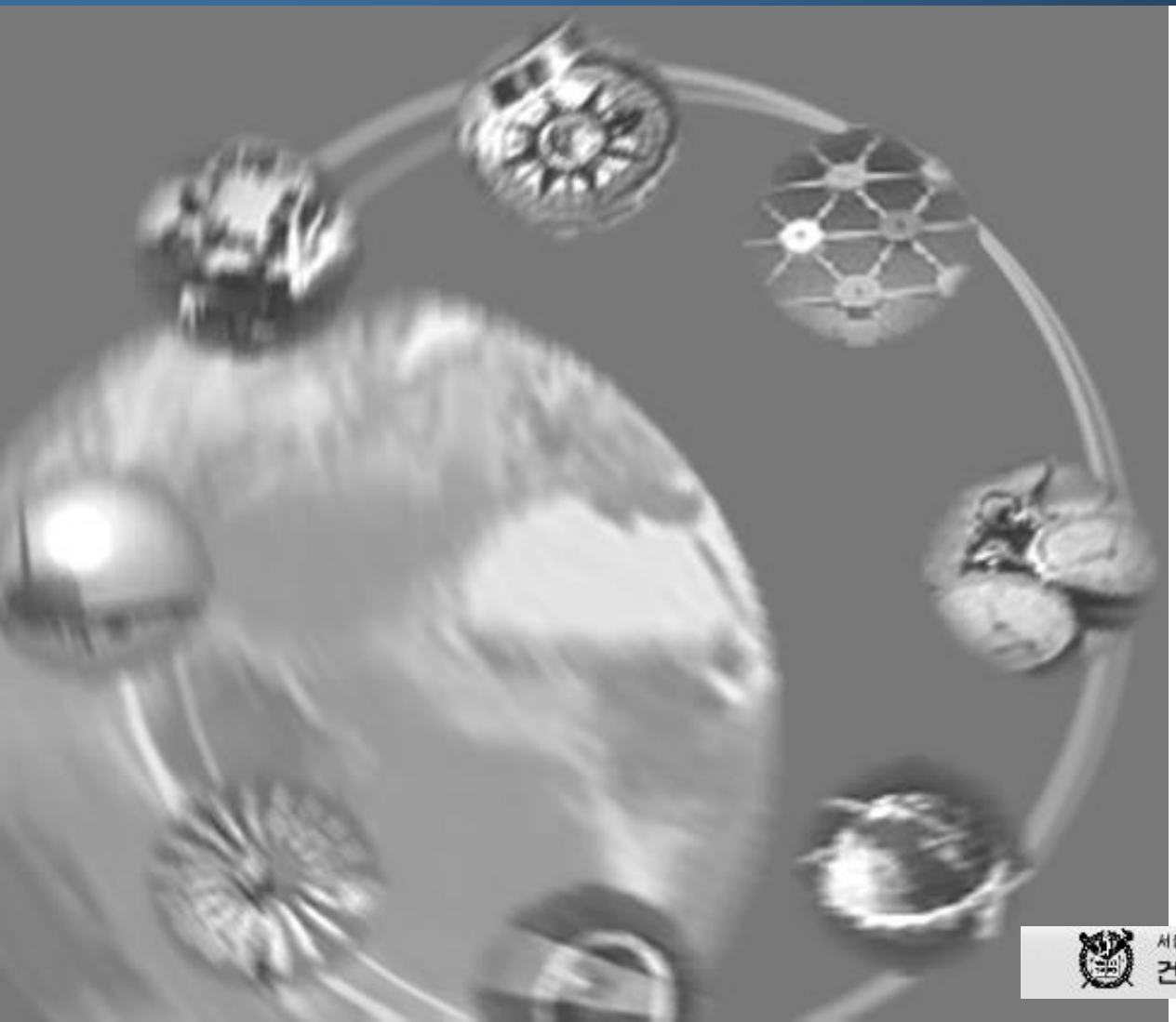
# Formulating a simple model structure

401.661 Advanced Construction Technology

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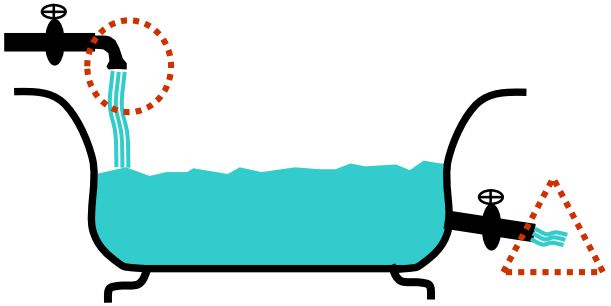
# Equilibrium

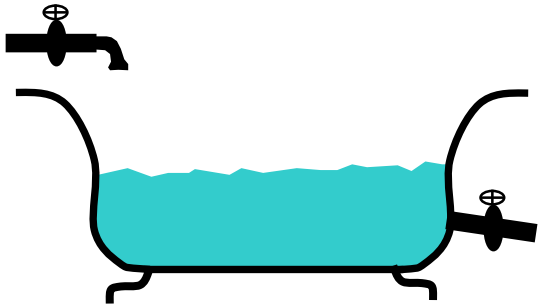
- Stock in equilibrium when unchanging
  **System in equilibrium when <u>all</u> its stocks are unchanging.*
- Dynamic Equilibrium
  *e.g., # of US senate*

inflow = outflow



- Static Equilibrium
  **Same contents. e.g., # of Bach cantatas*

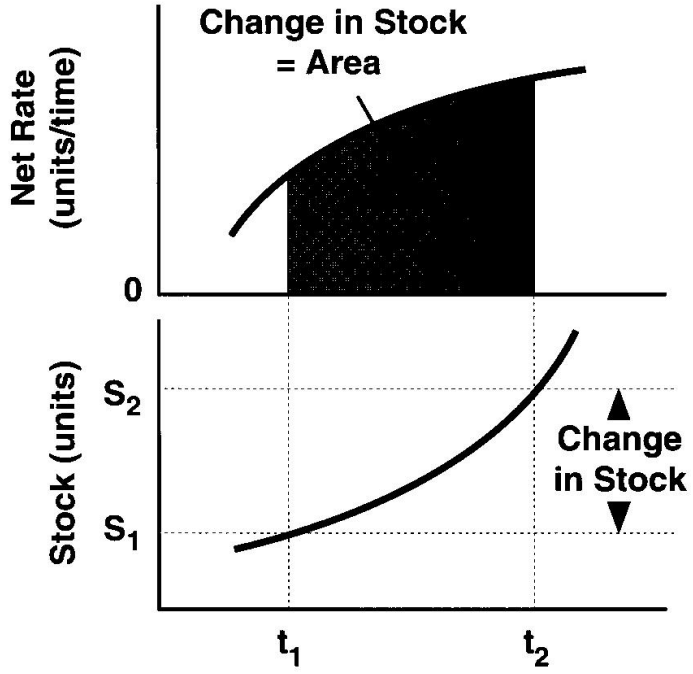
inflow = outflow = 0



# Integration & Differentiation

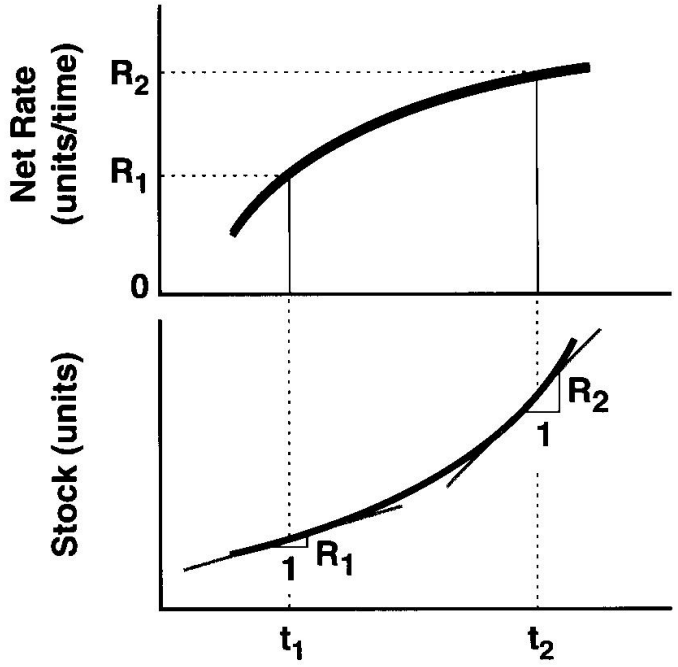
Stocks accumulate or *integrate* their net flow. The quantity added to a stock over any interval is the area bounded by the graph of the net rate between the start and end of the interval. The final value of the stock is the initial value plus the area under the net rate curve between the initial and final times.

In the example below, the value of the stock at time $t_1 = S_1$. Adding the area under the net rate curve between times $t_1$ and $t_2$ increases the stock to $S_2$.




The slope of a line tangent to any point of the trajectory of the stock equals the net rate of change for the stock at that point. The slope of the stock trajectory is the *derivative* of the stock.

In the example below, the slope of the stock trajectory at time $t_1$ is $R_1$, so the net rate at $t_1 = R_1$. At time $t_2$, the slope of the stock is larger, so the net rate at $t_2 = R_2$ is greater than $R_1$. The stock rises at an increasing rate, so the net rate is positive and increasing.



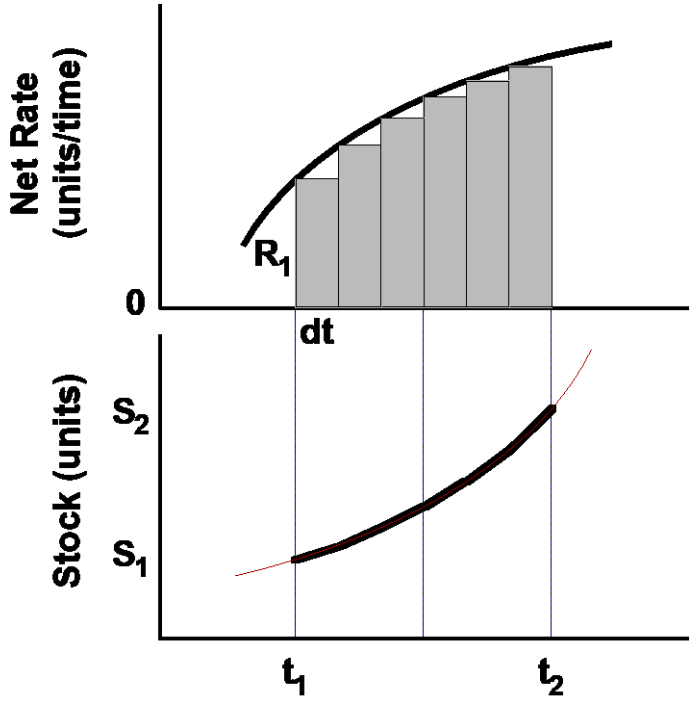
# Calculus without Mathematics

Quantity added during interval of length dt

= R (units/time) * dt (time)

*R = the net flow during the interval

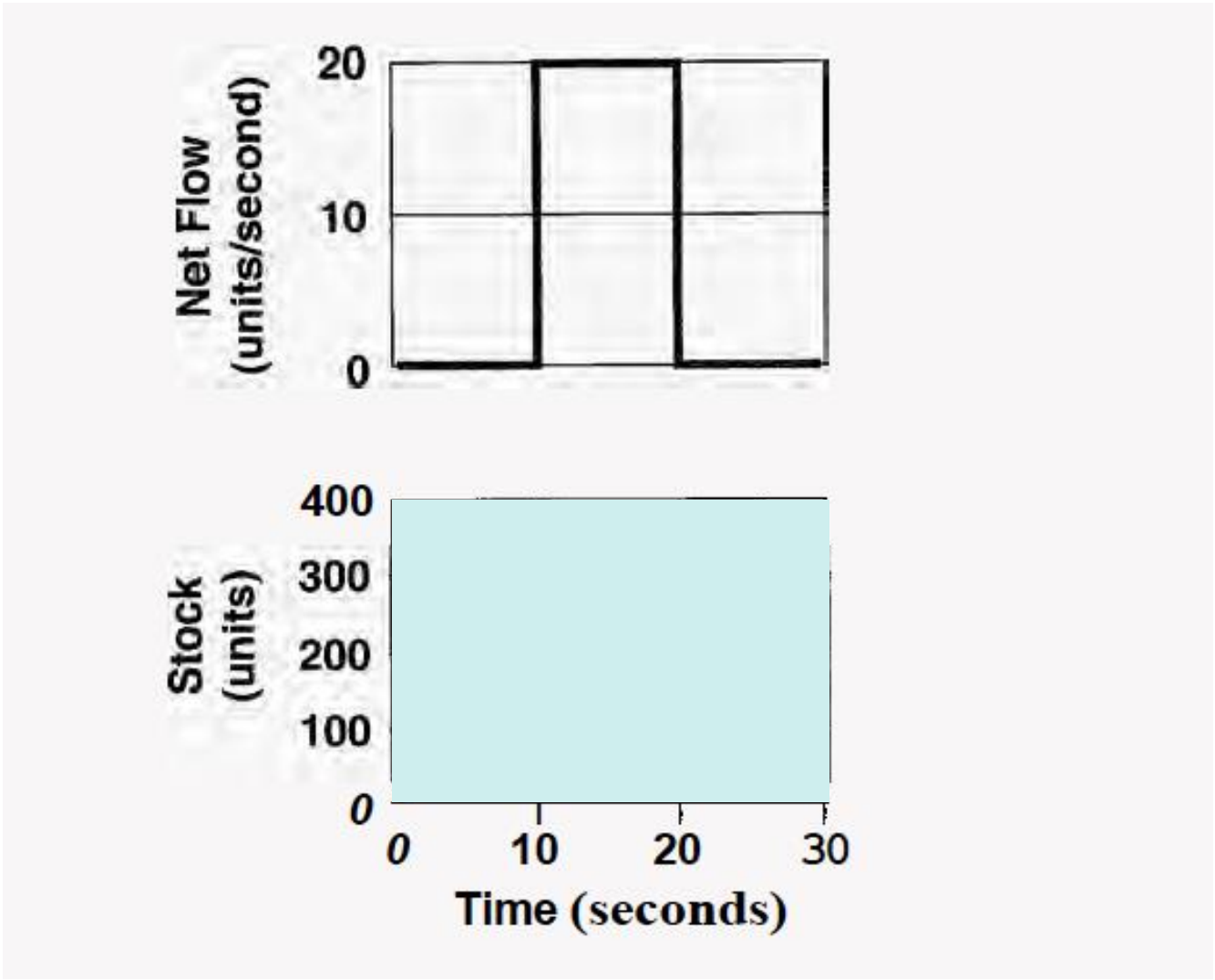
## Concrete Mixer Example




- Area of each rectangle= $R_i dt$
- Adding all six rectangles = Approximation of total water added
- How to increase accuracy?

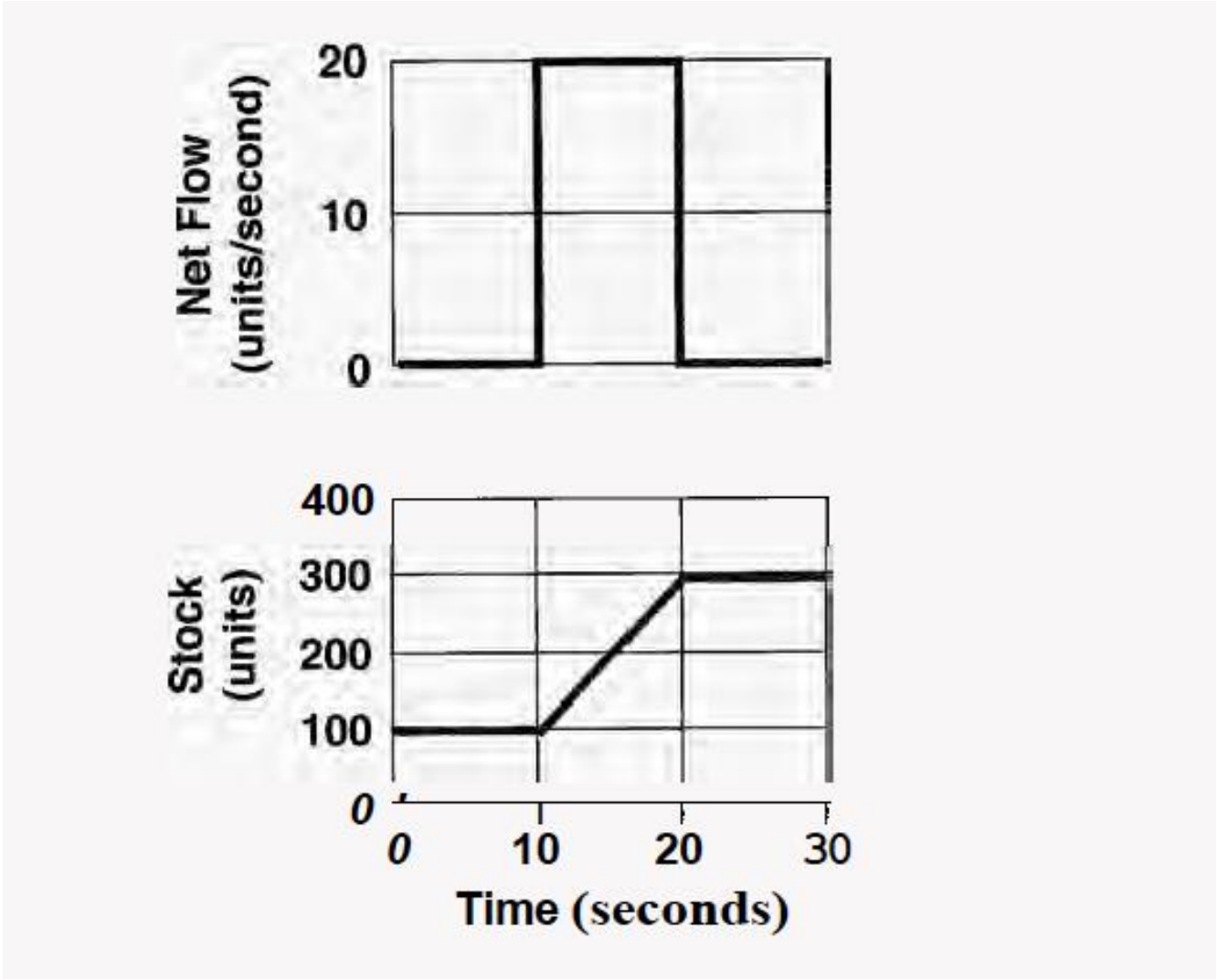
# Challenge it!

**Initial stock level = 100 units**



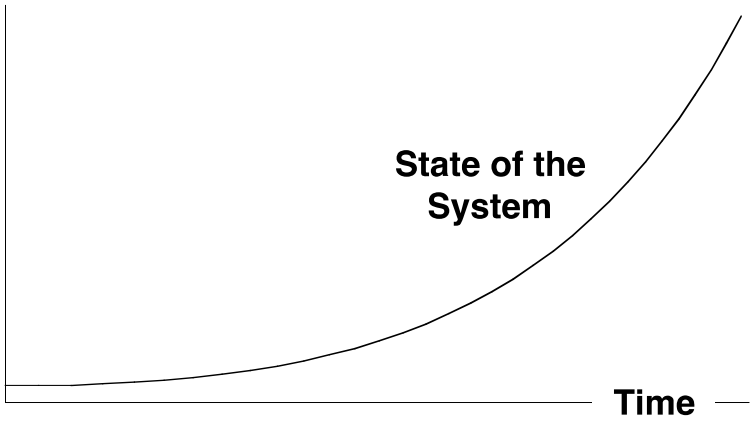
# Challenge it!

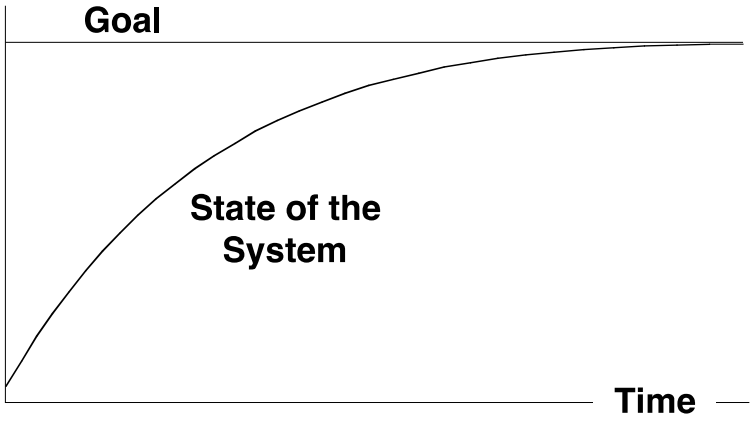
**Initial stock level = 100 units**

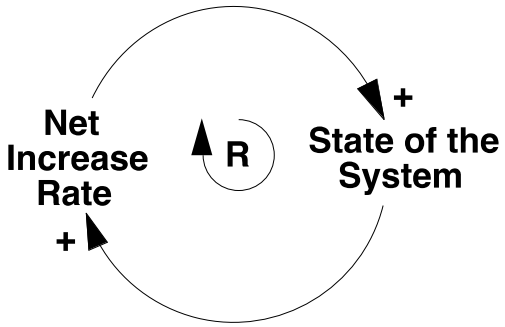


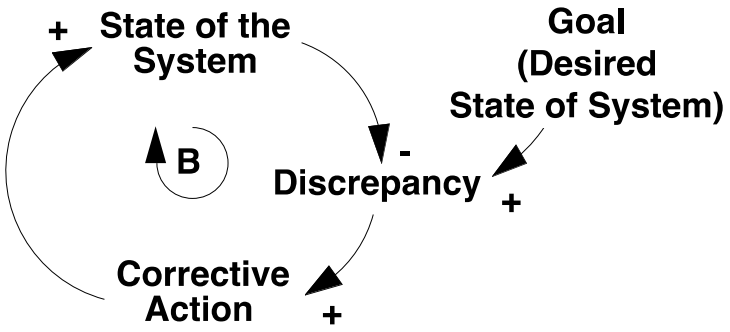
# Fundamental Modes

- Positive feedback causes exponential growth, while negative feedback causes goal-seeking behavior.



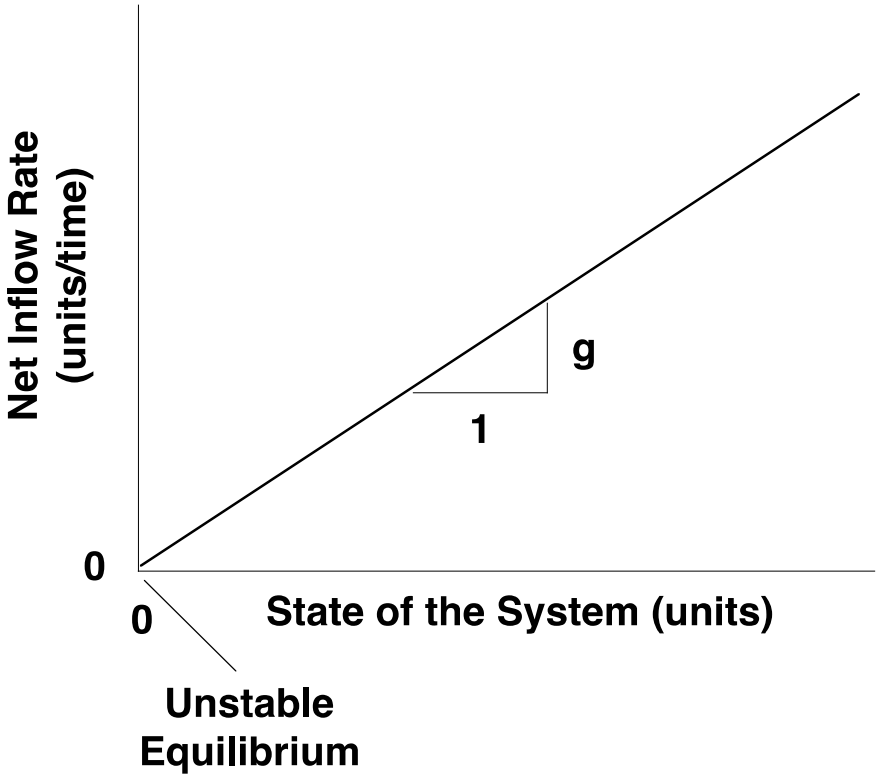



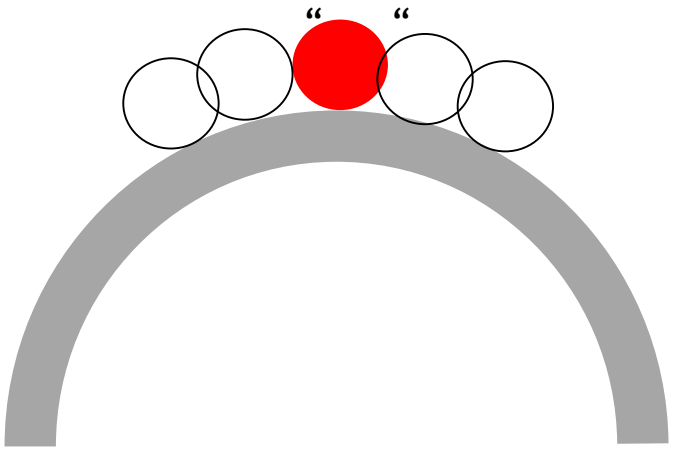



▪Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

**dS/dt = Net Inflow Rate = gS**




**Unstable Equilibrium**



***Phase plot for the first-order, linear positive feedback system***



▪Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

# Power of Positive Feedback

- Paper Folding
- The Rule of 70

Positive feedback leads to exponential growth, when the fractional net increase rate is constant.

$2S(0) = s(0)\exp(gt_d)$

$t_d = \ln(2)/g$, where $\ln(2) = 0.6931\ldots$

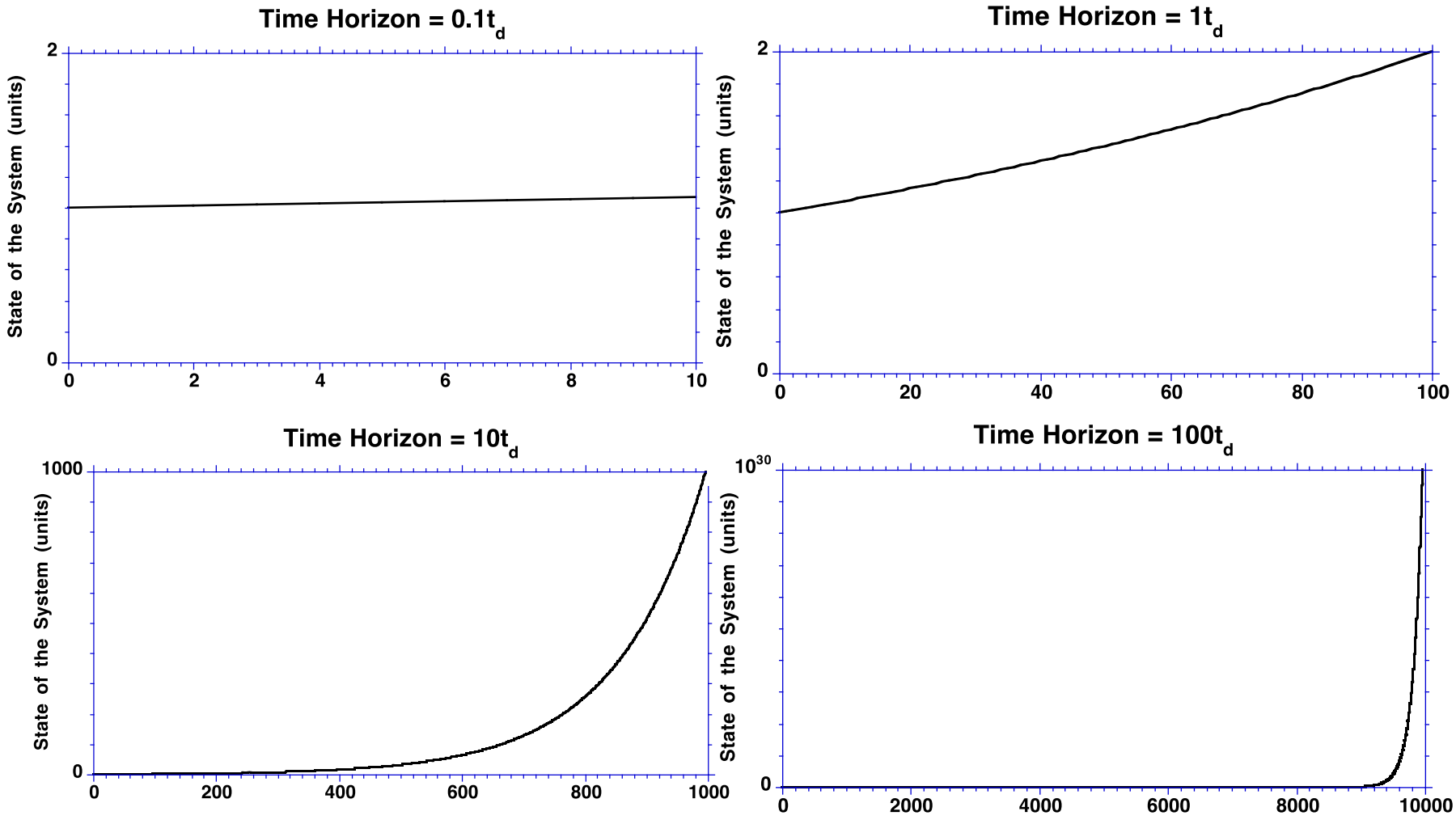
$t_d = 70/(100g)$

E.g., an investment earning 7%/year doubles in 10 yrs

# Misperception of Exponential Growth

- We tend to assume a quantity increases by the same *absolute* amount per time period, while exponential growth *doubles* the quantity in a fixed period of time.

- The counterintuitive characters of exponential growth can be seen by examining it over different time horizons.




## Exponential growth over different time horizons

**The state of the system is given by the same growth rate of 0.7%/time period in all cases (doubling time = 100 time periods).**



- Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

- No real quantity can grow forever (positive feedback processes approach their limits rapidly and often unexpectedly).

## An old French riddle

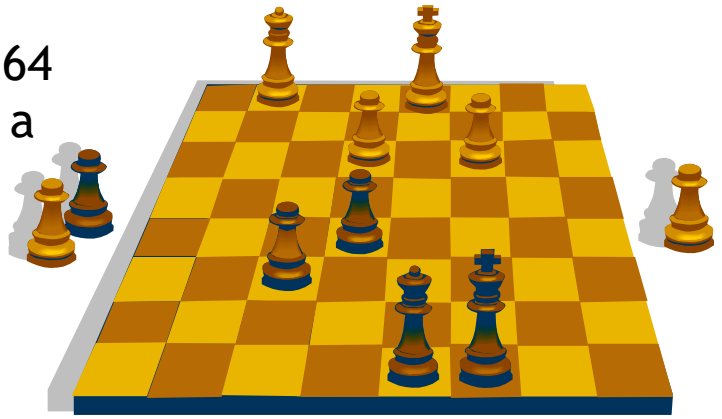
- A water lily doubles in size each day.
- It would completely cover the pond in 30 days.
- On what day will it cover half the pond so you have to cut it back?

- As limits are approached, nonlinearities always weaken the positive loops and strengthen the negative feedbacks.

## An old Persian legend

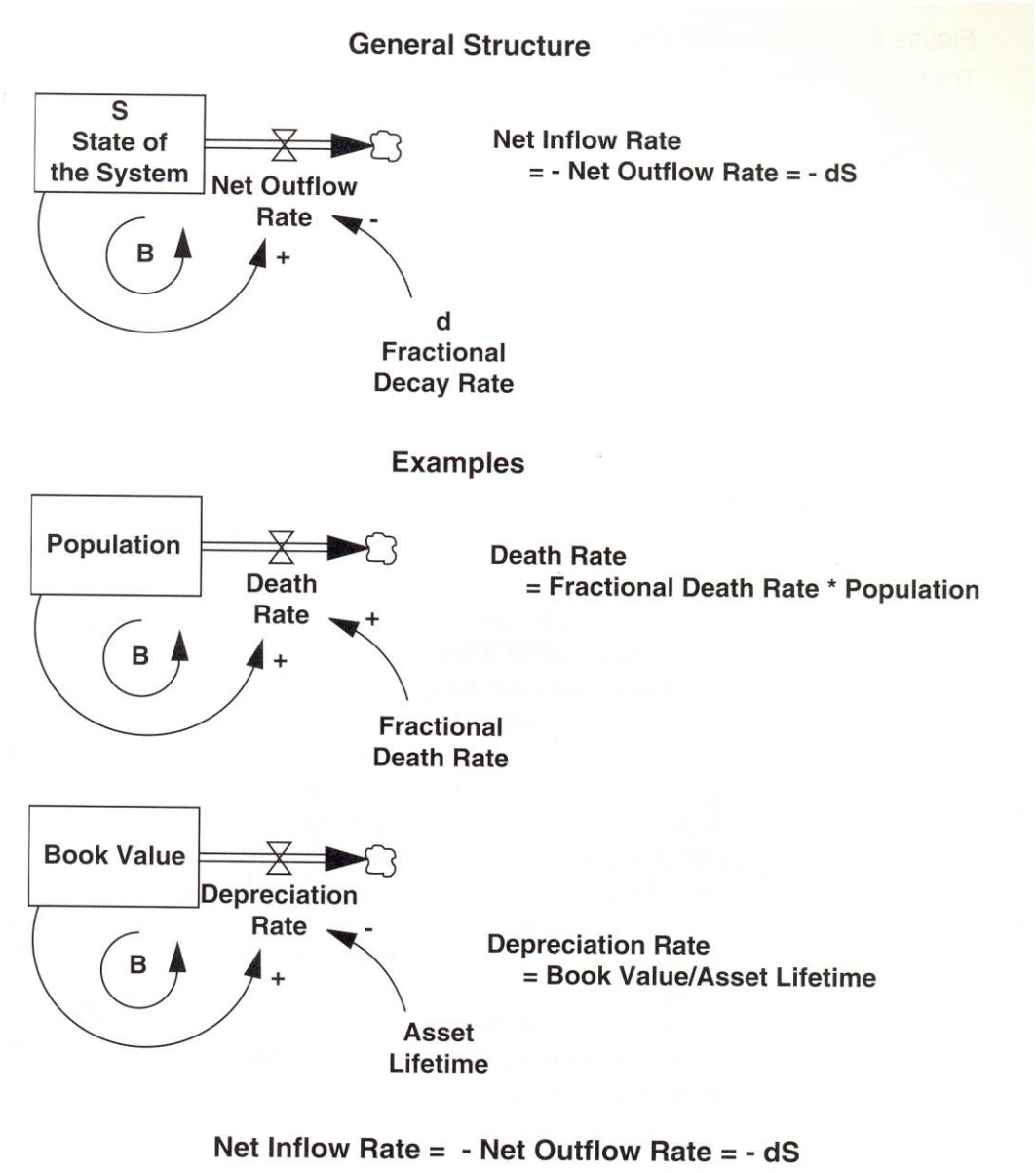
- A courtier presented a chessboard to his king.
- Requesting the king give him in return a grain of rice for the square of the board, 2 grains for the 2nd square...
- Is it feasible?

* The total quantity of rice on all 64 squares would cover all of Iran to a depth of more than 5 feet.



# Negative feedback and Exponential Decay

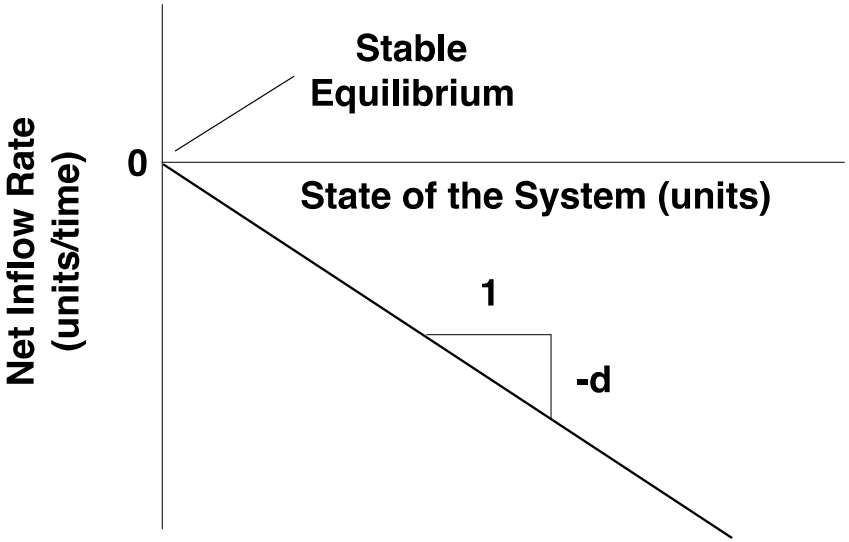
- First-order negative feedback systems generate goal-seeking behavior. When the system is linear, the behavior is pure exponential decay.

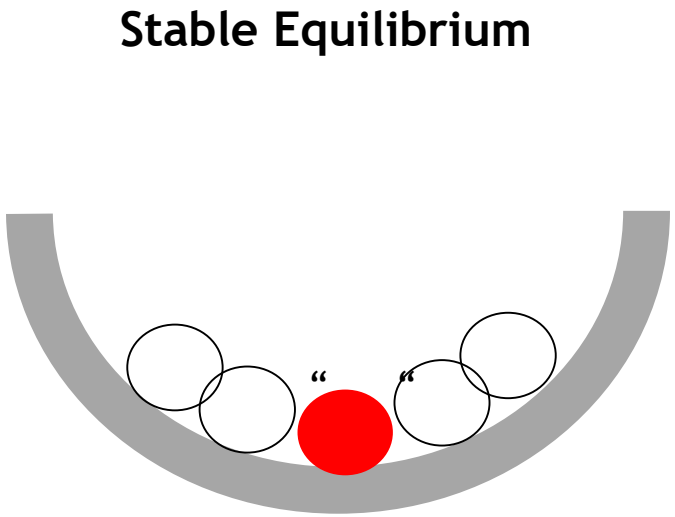





Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

**Net Inflow Rate = - Net Outflow Rate = - dS**



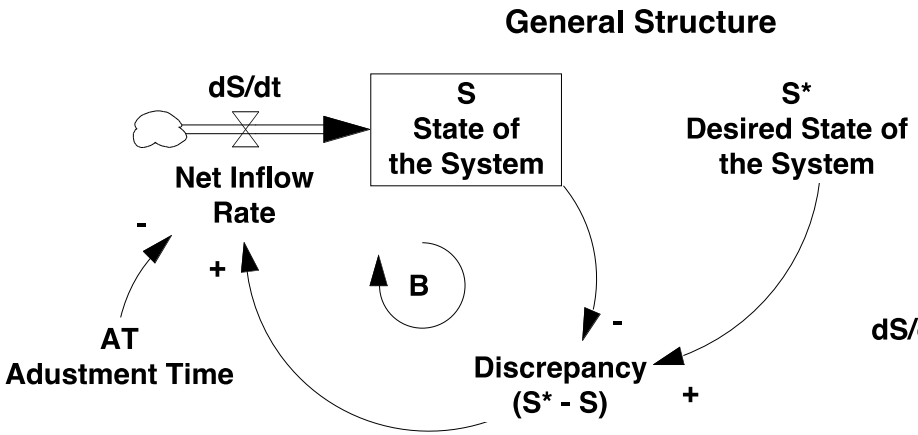



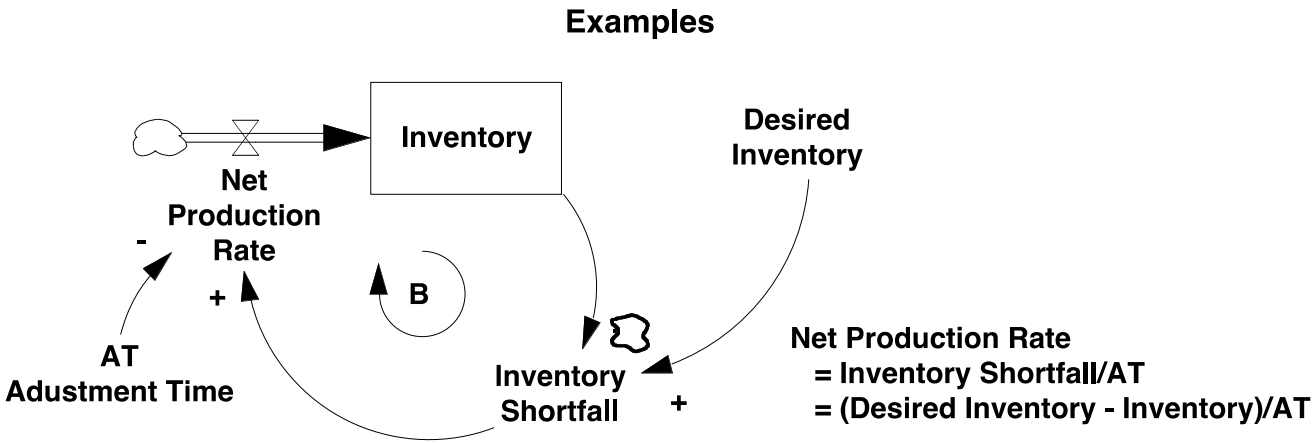

***Phase plot for exponential decay via linear negative feedback***

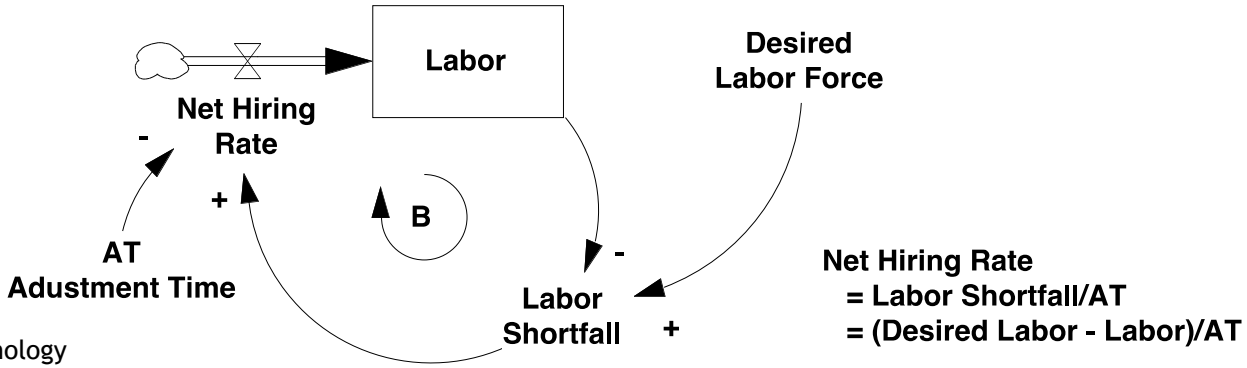


▪Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

**First-order linear negative feedback system with explicit goals**






- Sterman, J., "Business Dynamics", Mcgraw-Hill, 2000

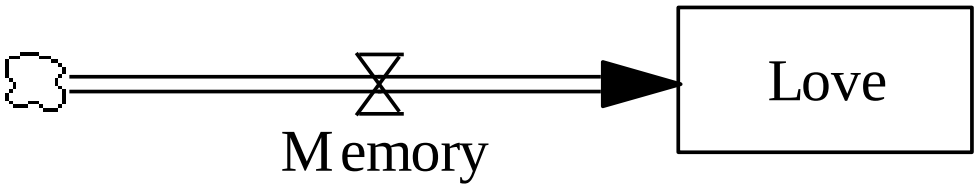
# Modeling Practice: Human Behavior

# Romeo & Juliet

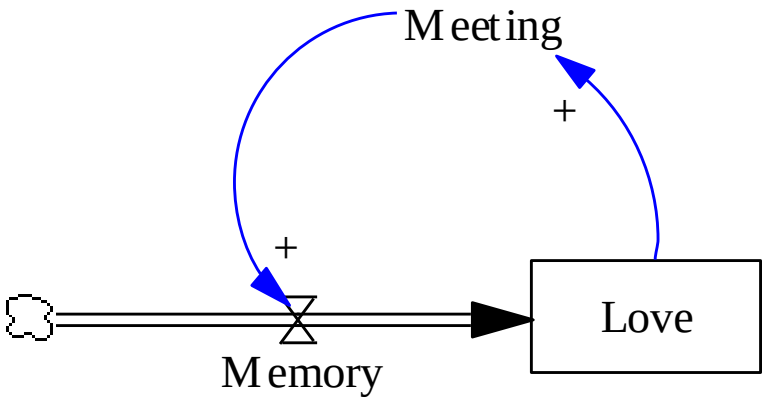
- Identify dynamics associated with love between a beast and a beauty.
- It could be matured, leading to marriage.
- Often it is broken as well.

Recommended variables: love, meetings, quarrels, understanding, expectation, memory

# What makes LOVE?...

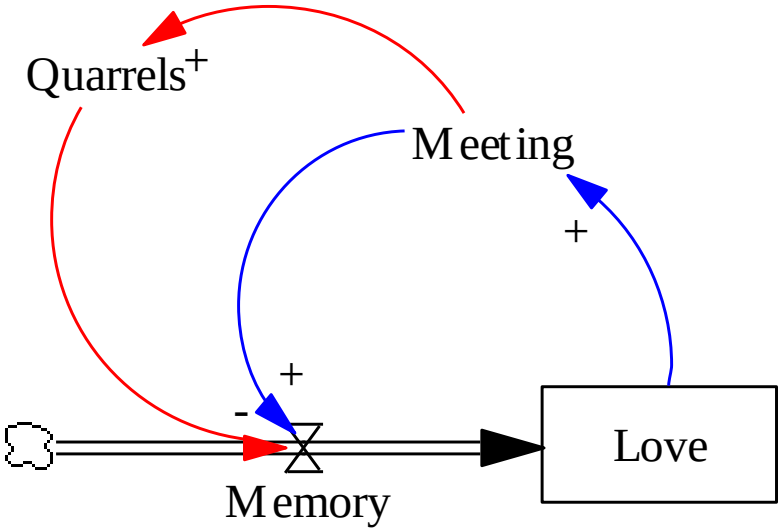


# Memories are from?...

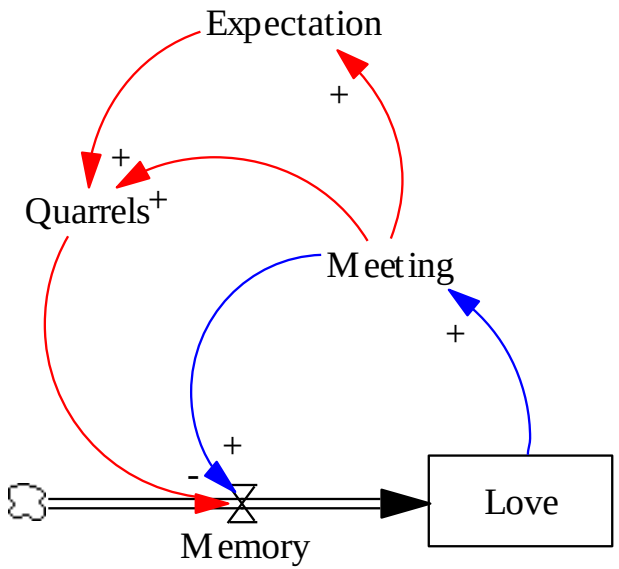



**Generally this continues for a while..**

# BUT, as having more meetings…

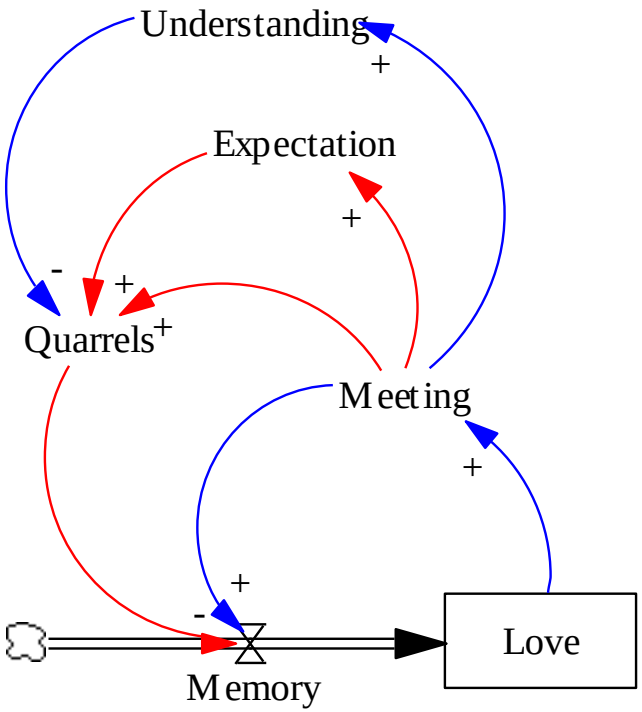


# What makes this?…

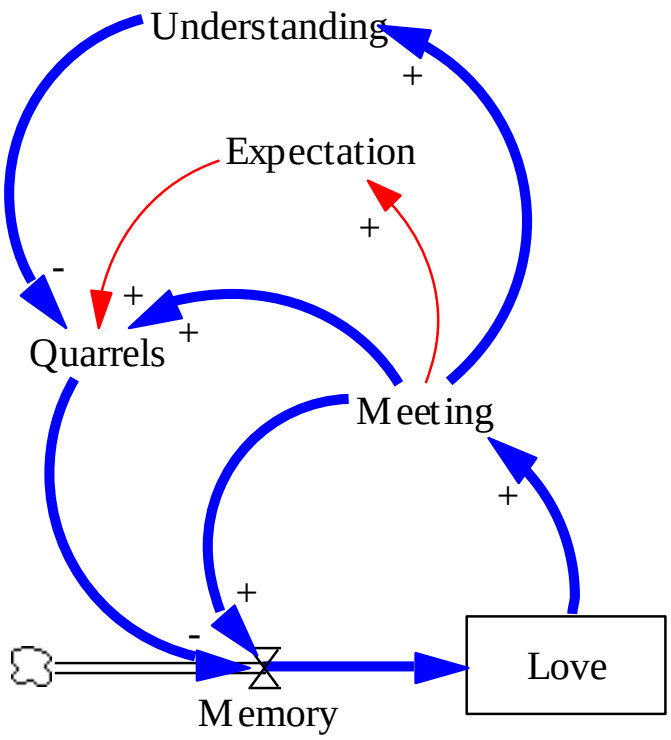


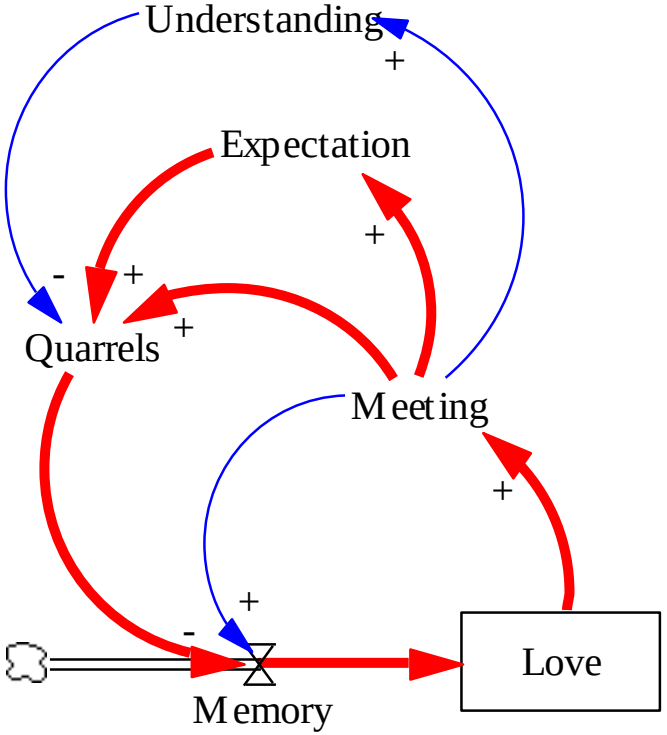

**End of story here to some couples**

# This is also true…



# Two types


Understanding
+
Expectation
+
-
+
+
Quarrels
Meeting
+
+
-
Memory
Love


Understanding
+
Expectation
+
-
+
+
Quarrels
Meeting
+
+
-
Memory
Love

# Assignment 5:
# any suggestions to a couple in danger?

# Model improvement:
# Your suggestions?

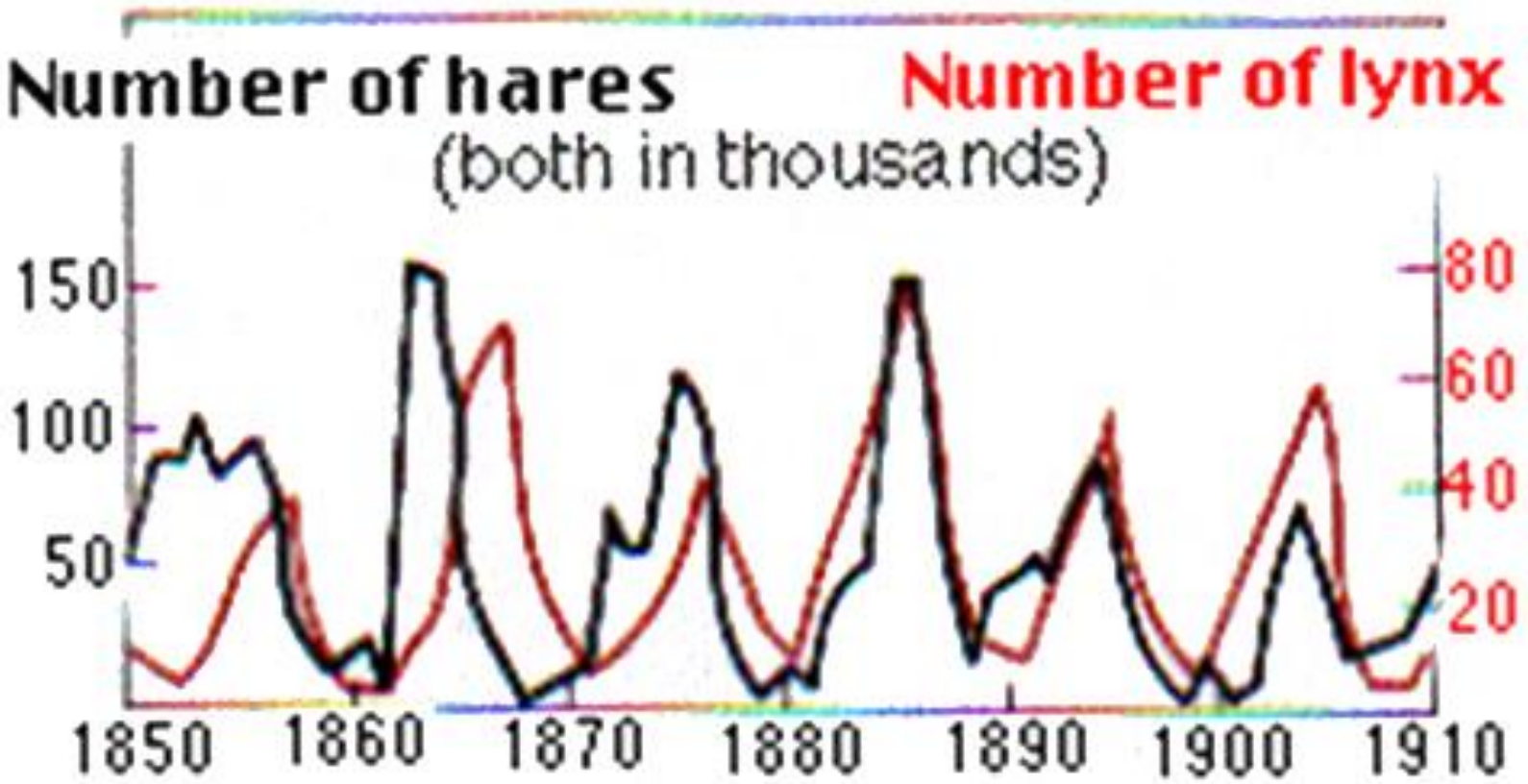
# Modeling Practice: The Food Chain



http://holmes-partee.wikispaces.com/Case5-Rabbits+and+Lynx+SFD

# Problem statement

## Why does their population oscillate?



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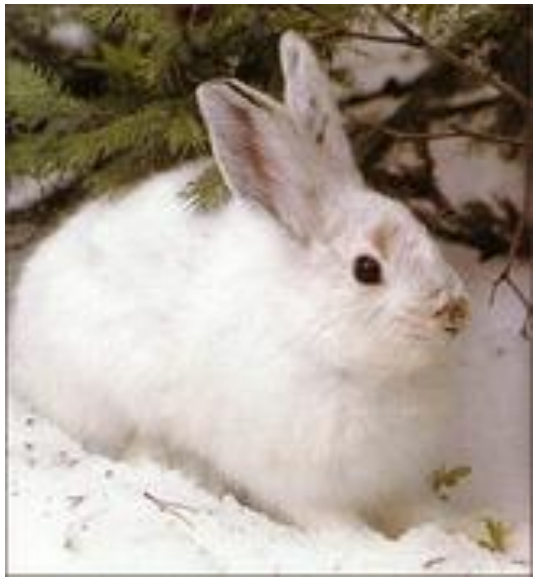
# Rabbit: Prey



It all begins with the birth rate of the rabbits which increase their population. These rabbits will grow and reproduce, thus also increasing the birth rate. However, some of them would encounter the disease. Since the disease will spread rapidly in a bigger population, this would also increase the death rate of the rabbits. The loop of the birth rate and population shows positive feedback, while the loop made by population, disease incidence and death rates denote negative feedback.



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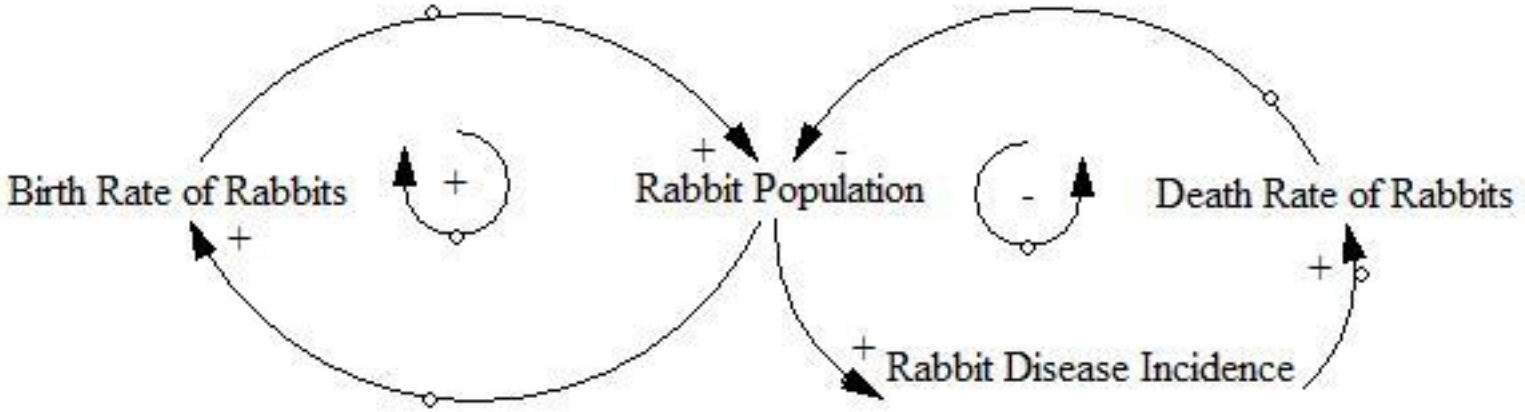




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# Lynx: Predator

the loop starts with the birth rate of the lynx, which increases the population. While the population increases, the food supply would decrease as they would compete among themselves for the food. The lower the food supply, the higher the starvation rate would be. This would ultimately lead to decreasing the population. However, if food supply increases, more lynx would survive to reproduce and increase their population.



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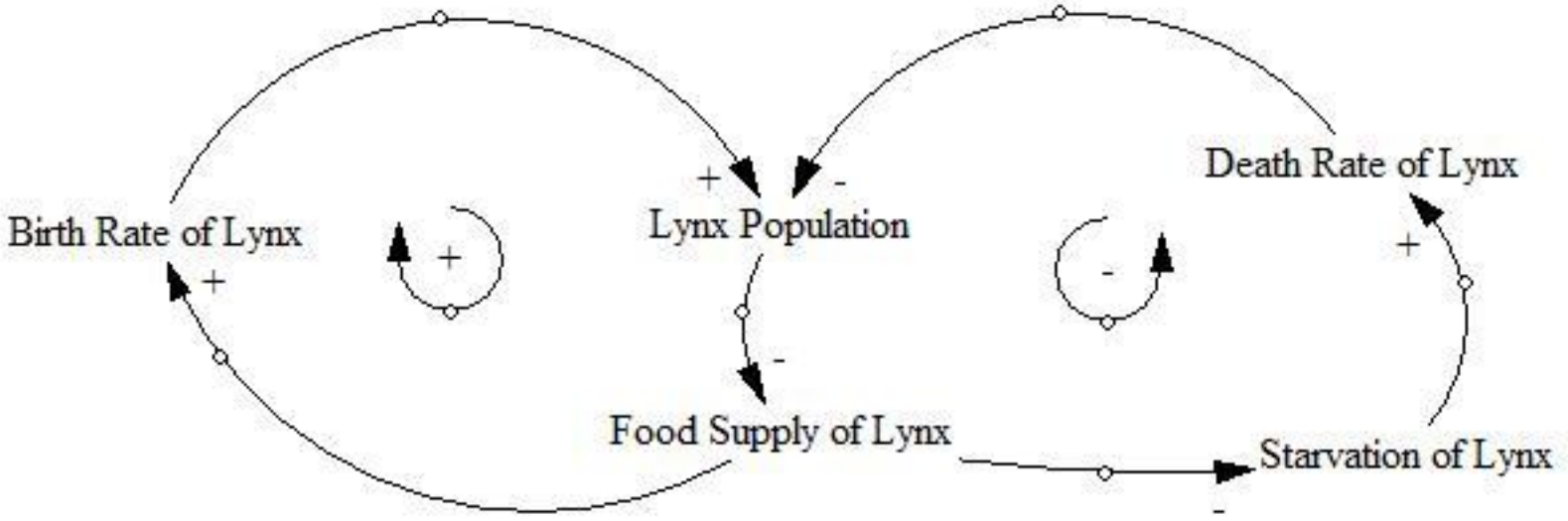




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# Putting together

Lastly, to put these two loops of separate entities together, links are made between the food supply of the links and the rabbit population and death rate. Since lynx hunt rabbits as their food and means of sustenance, this would all depend on how many rabbits are present in the same place. The more rabbits there are, the more food supply the links will have. That is why this is given a positive polarity. However, as the lynx consume the rabbits as their prey, the death rate of the rabbits increases. Their population would also decrease, which would subsequently lead to starvation and death of the lynx. This is another negative feedback loop.



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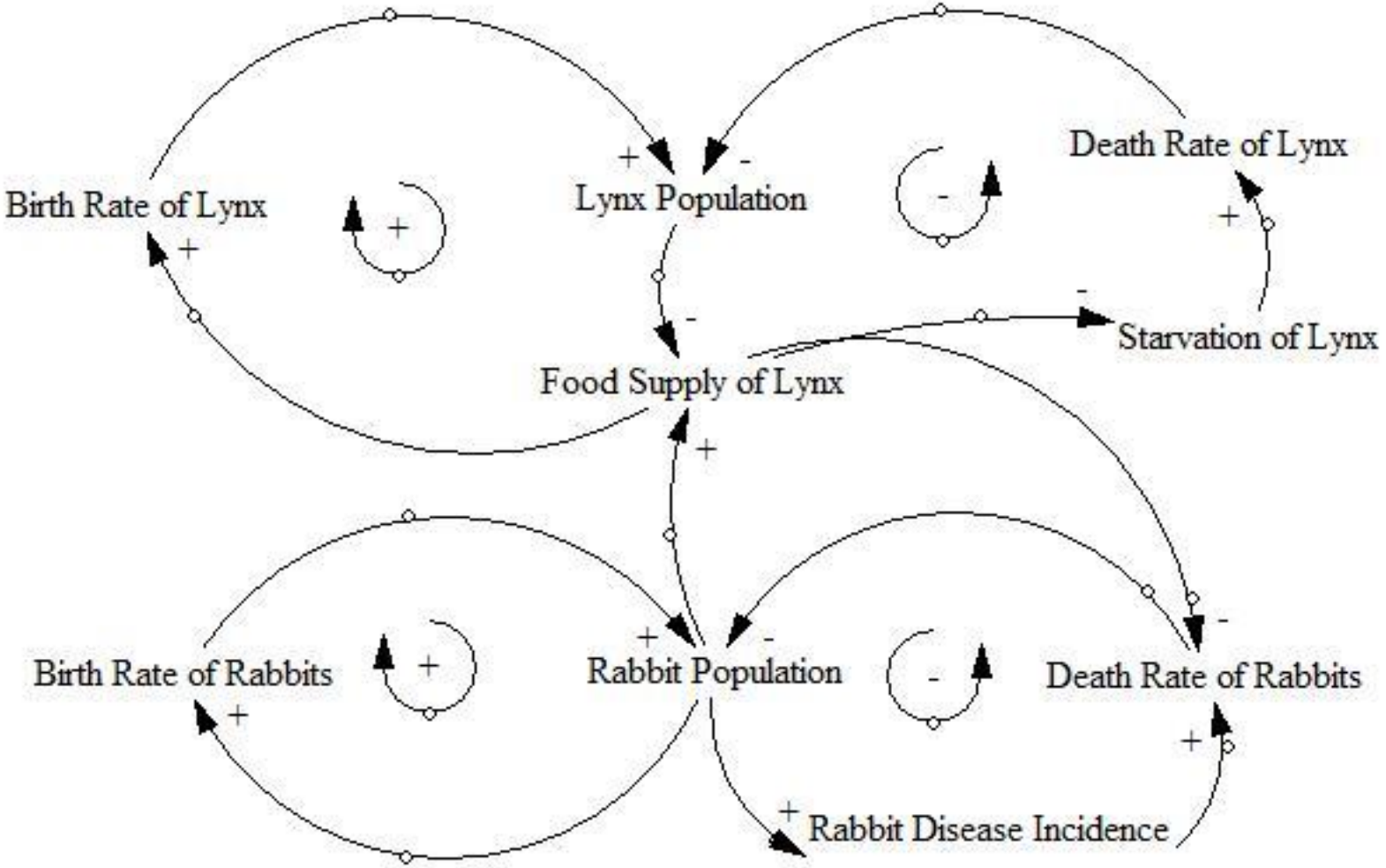




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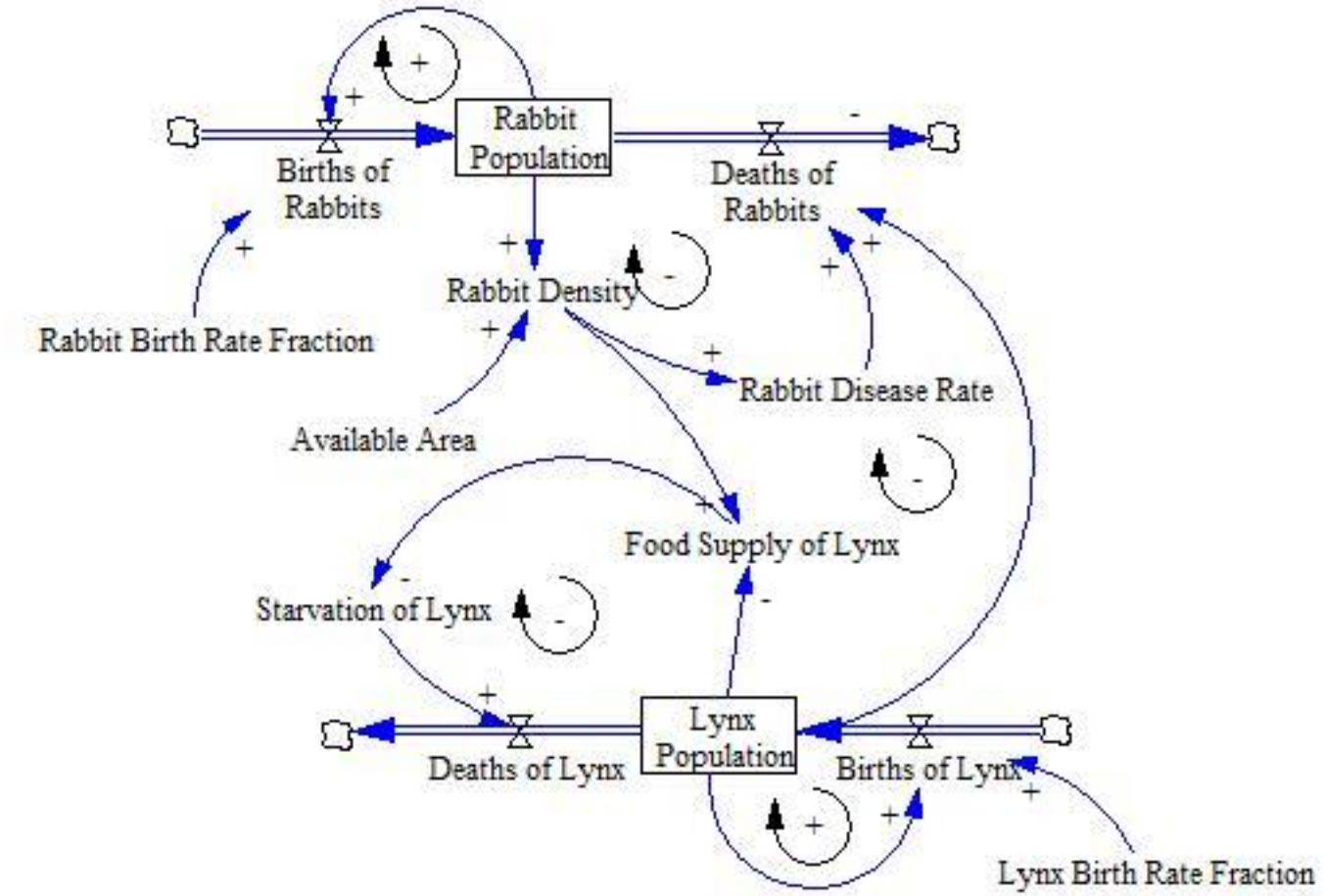
# S&F model



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# Assignment 6:
# Build a quantitative model and demonstrate how & why the population of Lynx and Rabbit oscillate.

# References


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