Structure and Behavior of Dynamic Systems

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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.

Like all systems, the complex system is an interlocking structure of feedback loops… This loop structure surrounds all decisions public or private, conscious or unconscious. The processes of man and nature, of psychology and physics, of medicine and engineering all fall within this structure.

—Jay W. Forrester, Urban Dynamics (1969), p. 107

- The behavior of a system arises from its structure.

- That structure consists of the feedback loops, stocks and flows, and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it.

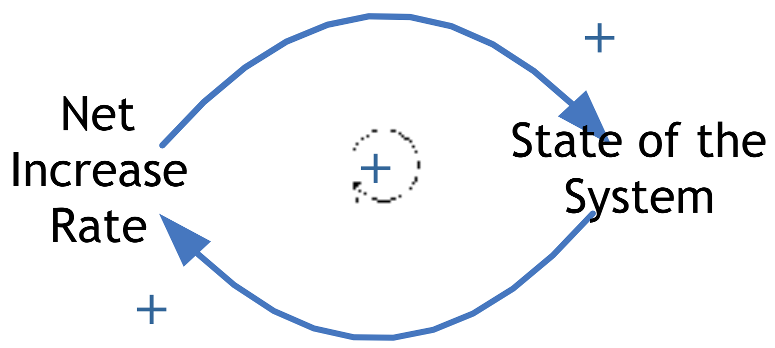
Fundamental Modes of Dynamic Behavior

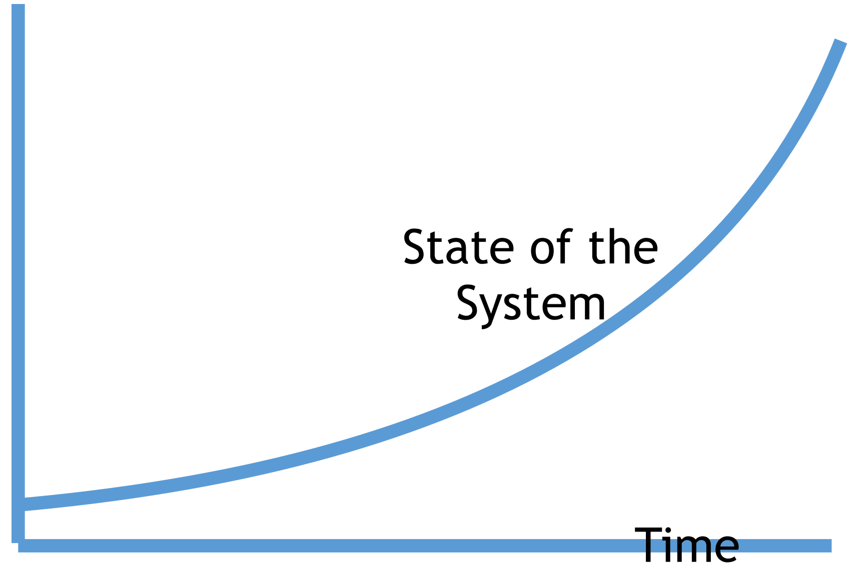
1. Exponential Growth
2. Goal Seeking
3. Oscillations
4. S-Shaped growth
5. Growth with Overshoot
6. Overshoot and Collapse

} *more complex modes arise from the nonlinear interaction of these basic structures*

Exponential Growth

- Exponential Growth arises from positive (self-reinforcing) feedback.



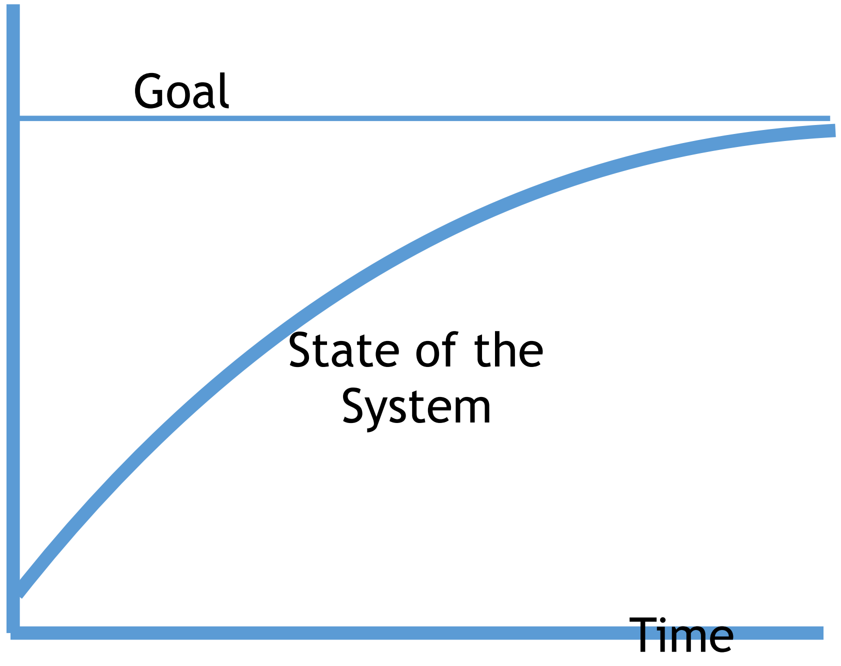


Exponential Growth

- The larger the quantity, the greater its net increase, further augmenting the quantity and leading to ever-faster growth.
- Example: population and net birth rate
- Pure exponential growth has a remarkable property called constant doubling time. No matter how large, the state of the system doubles in a fixed period of time.
- Does positive feedback always lead to growth? Example?

Goal Seeking

- Goal Seeking arises from negative feedback.

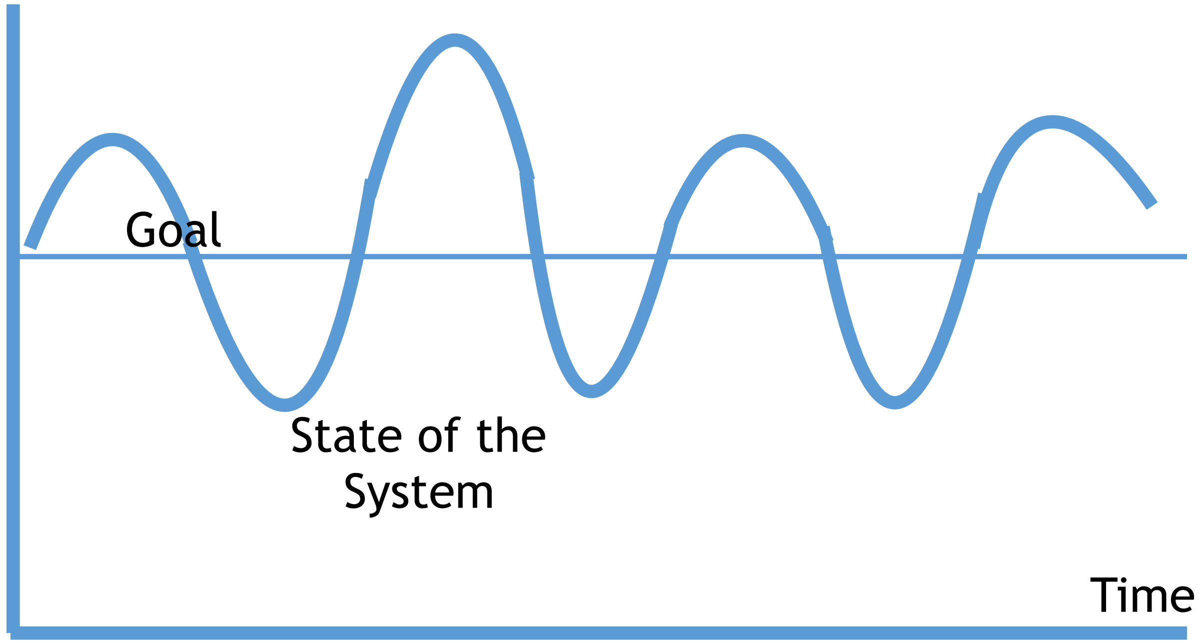


Goal Seeking

- Positive feedback loops generate growth, amplify deviations, and reinforce change.
- Negative loops seek balance, equilibrium, and stasis
- Negative feedback loops act to bring the state of the system in line with a goal or desired state.
- They counteract any disturbances that move the state of the system away from the goal.
- Example: a cup of tea cools via negative feedback until it reaches room temperature.

Oscillation

- Like goal-seeking behavior, it is caused by negative feedback loops, with time delays.



Oscillation

- In an oscillatory system, the state of the system constanty overshoots its goal or equilibrium state, reverses, then undershoots, and so on.

- Overshooting arises from the presence of significant **time delays** in the negative loops.

- The time delays cause corrective actions to continue even after the state of the system reaches it goal, forcing the system to adjust much, and triggering a new correction in the opposite direction.

- Oscillation can arise if there is only a delay in any part of the negative loop.

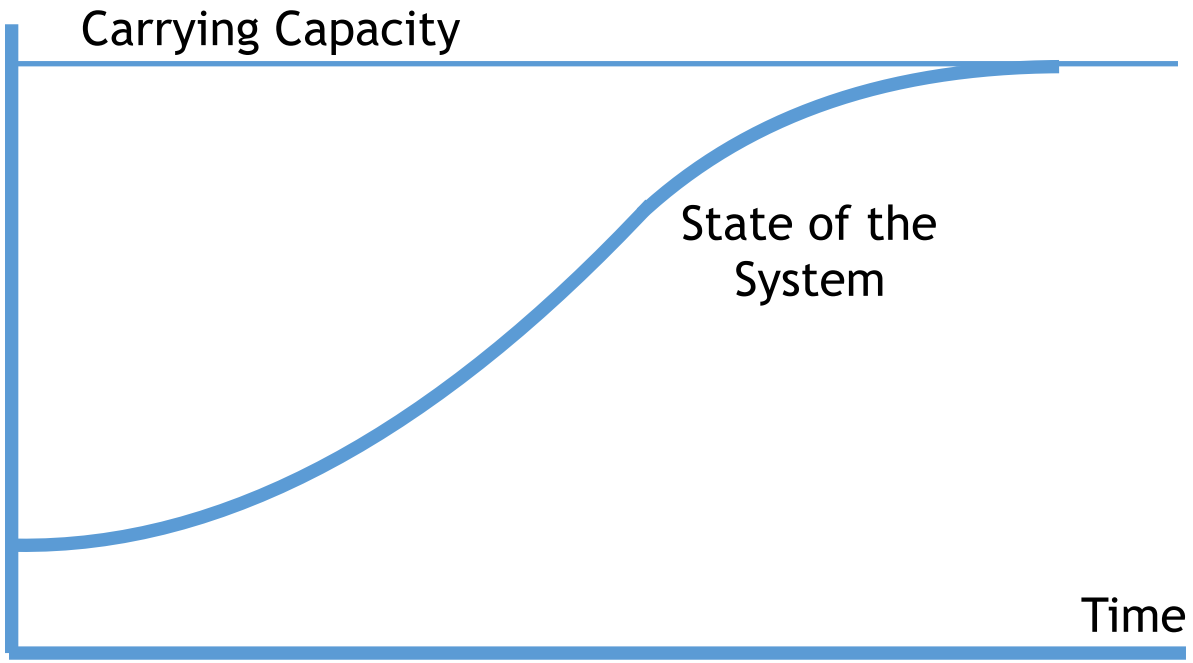
Interactions of The Fundamental Modes

- Three basic modes of behavior, exponential growth, goal-seeking, and oscillation, are caused by three basic feedback structures, positive feedback, negative feedback, and negative feedback with delays.

- More complex patterns of behavior arise through the nonlinear interaction of these structures with one another.

S-Shaped Growth

- Is a real quantity able to grow forever?
- Eventually, one or more constraints (negative feedback loops) halt the growth.



S-Shaped Growth

- A commonly observed mode of behavior in dynamic systems is S-Shaped growth, it is exponential at first, but then gradually slows till the state of the system reaches an equilibrium.

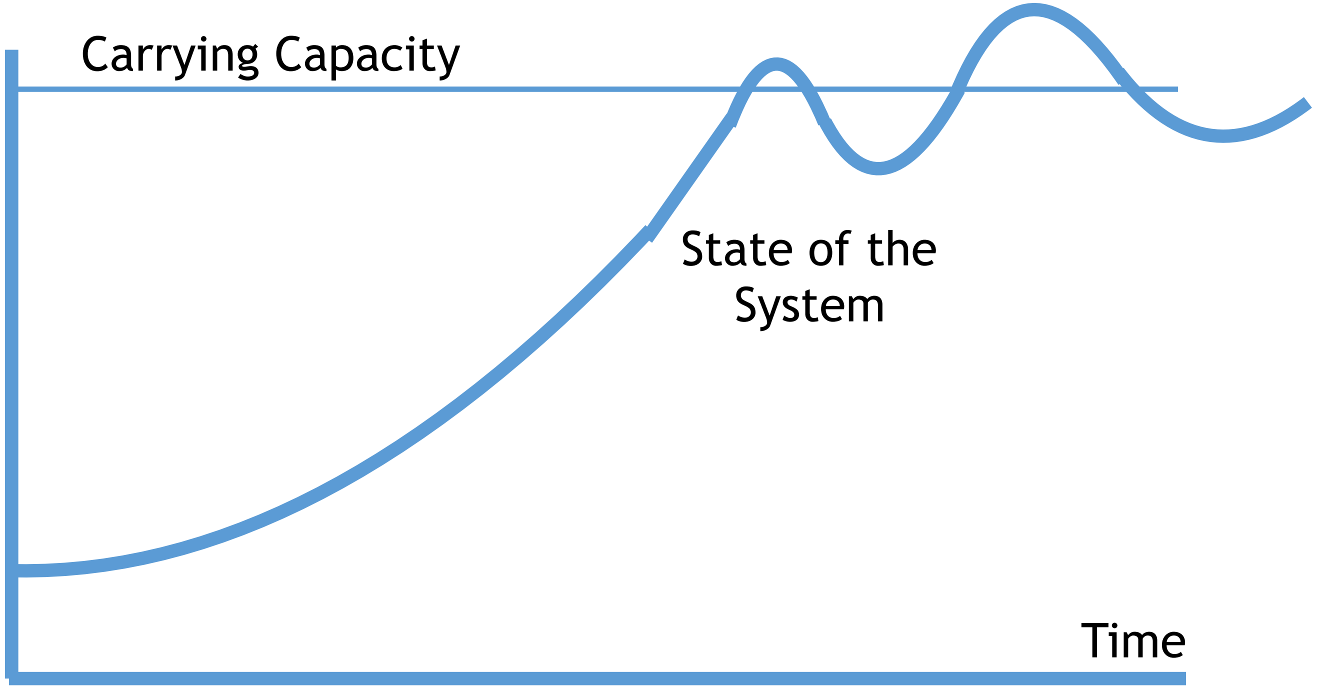
- **Carrying capacity**, an ecological concept, is number of organisms of particular type a system can support that is determined by the resources available in the environment and the resource requirements of the population.

- Resources needed are many for a system, but which resource is most important, so the related negative feedback loop is dominant.

- A system generates S-Shaped Growth only if **two critical conditions are met**:
    - Negative feedback loop must not include any significant time delays.
    - The carrying capacity must be fixed.

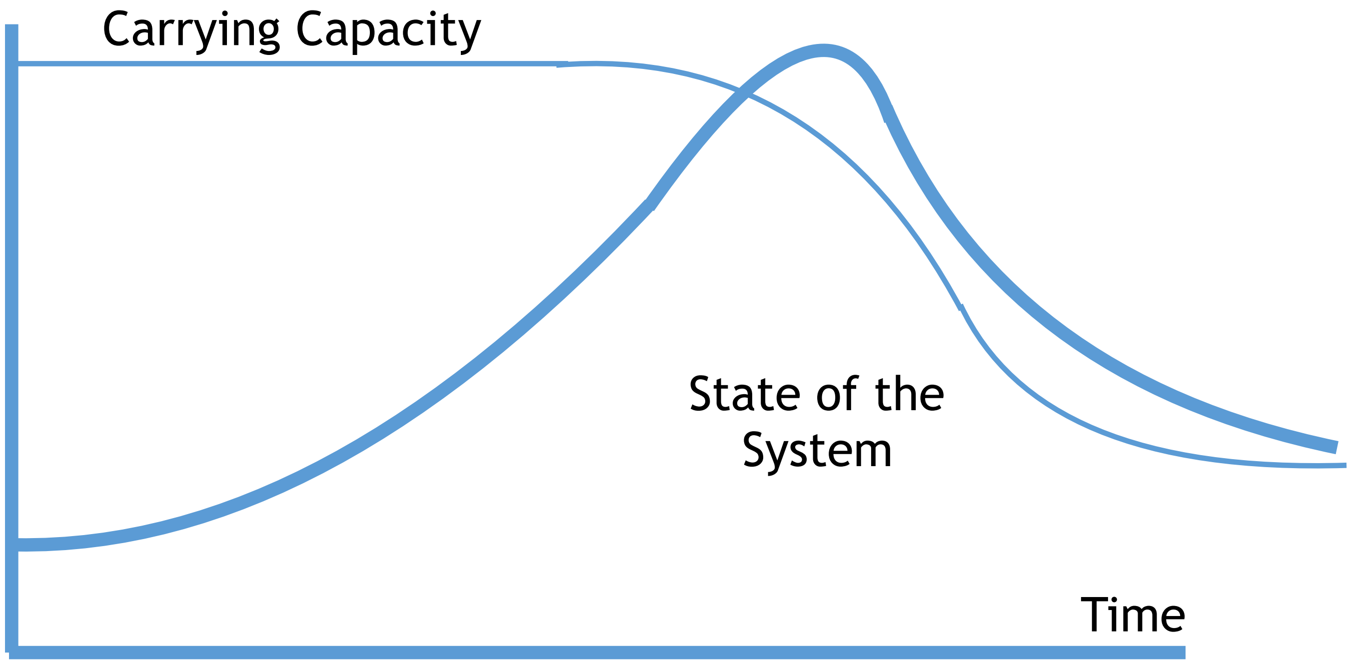
S-Shaped Growth with Overshoot

- S-Shaped Growth requires the negative feedback loops that constraint growth to act swiftly as the carrying capacity is approached.
- Often, however, there are significant time delays in these negative loops.
- Time delays in the negative loops lead to the possibility that the state of the system will overshoot and oscillate around the carrying capacity.



Overshoot and Collapse

- The second critical assumption underlying S-Shaped Growth is that the carrying capacity is fixed.
- Often, however, **the ability of the environment to support a growing population is eroded or consumed** by the population itself.
- Negative net increase rate, no equilibrium.



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