Pramod Parajuli
Simulation and Modeling, CS-331

Chapter 5
System Dynamics

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Introduction

Control theory – analysis of response of a system for given input signal

Dynamics

- Dynamic change in lots of parameters of systems
- Study of influence of parameters on the stability or growth of the system

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Exponential Growth and Decay Models

- Rate of change
- Let k is the fraction of the capital that determines the interest

$$\frac{dx}{dt} = kx \qquad x = x_0 e^{kt}$$

$$x = x_0 \quad \text{at } t = 0$$

- In other words, logarithm of the variable increases linearly with time

Decay - same as growth model except the initial value decays

$$\frac{dx}{dt} = -kx \qquad x = x_0 . e^{-kt}$$

$$x = x_0$$

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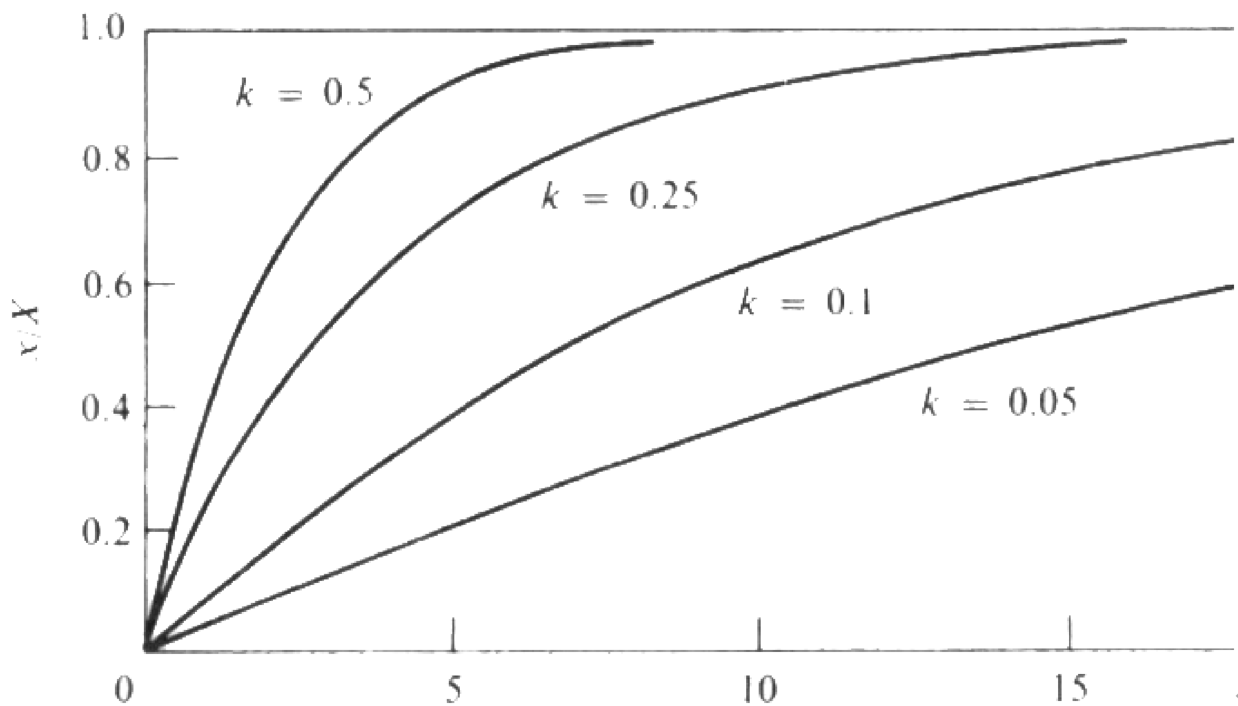
Modified exponential growth models

If the max./min. value is limited by some aount

e.g. house holds and $$\frac{dx}{dt} = k(X - x)$$

$$x = X(1 - e^{-kt})$$



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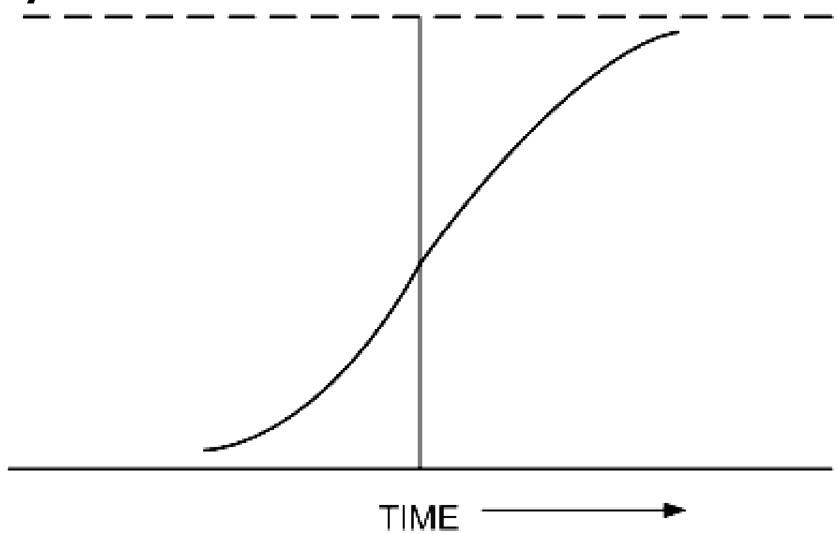
Logistic Curves

The modified exponential growth model gives large slope at beginning

But the reality is somehow different



A logistic function is a combination of exponential and modified exponential function that describes the real process

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Logistic Curves

Modeled using;

$$\frac{dx}{dt} = k.x.(X - x)$$

If x is very smaller than X, then (X-x) will be x, (starting point)

$$\frac{dx}{dt} = k.X.x$$

Again, if x is very much near to X, (saturation point)

$$\frac{dx}{dt} = k.X.(X - x)$$

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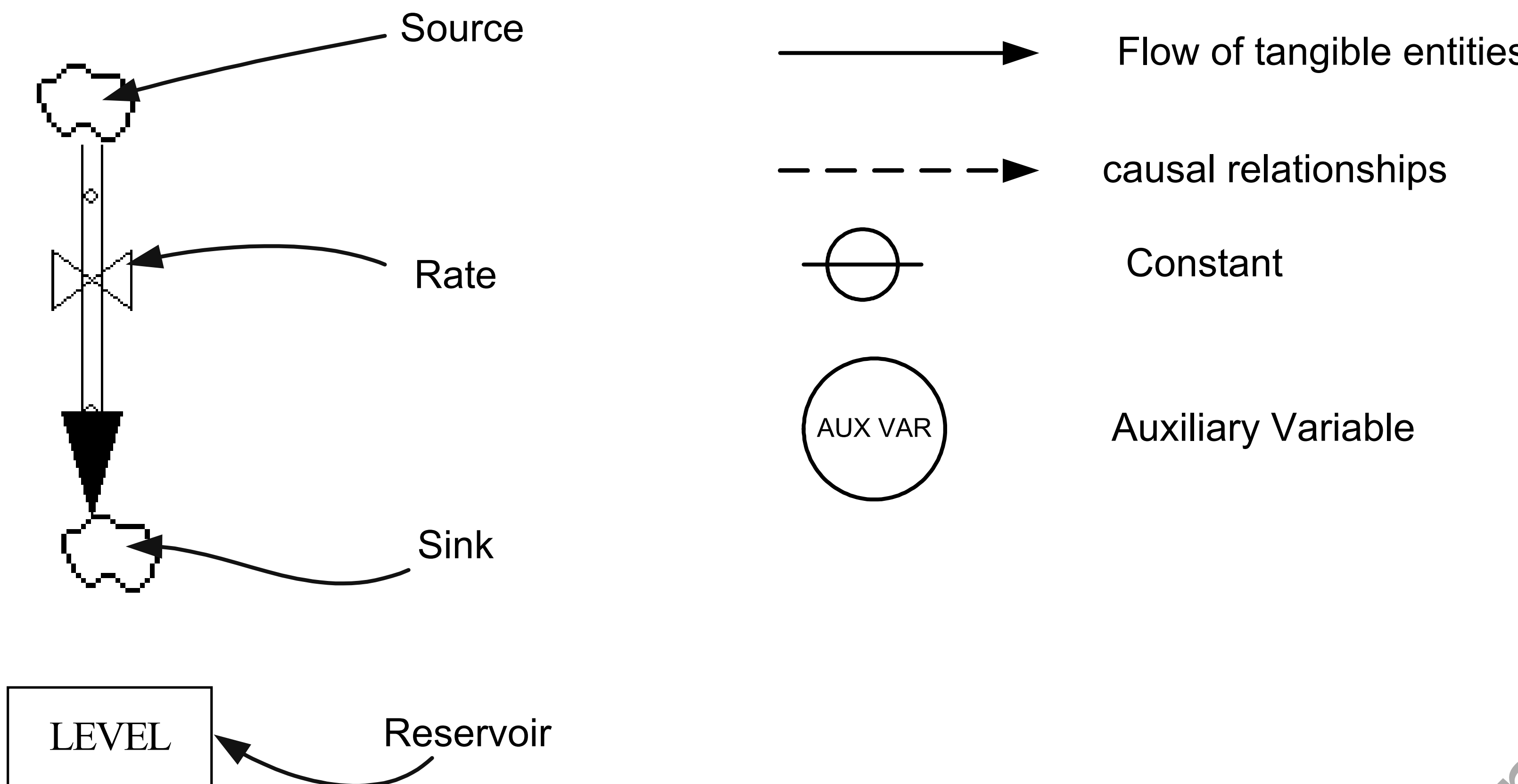
System Dynamics Diagrams



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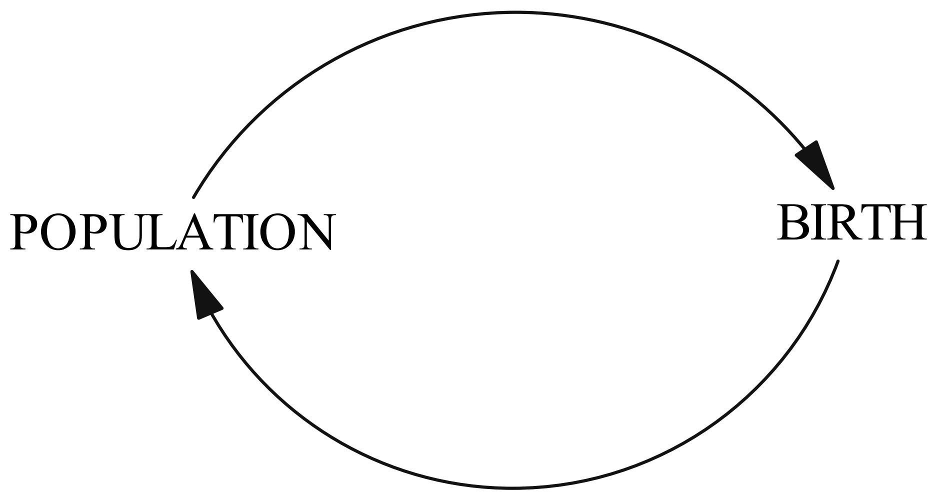
Causal Loop Diagrams in Systems

Causal loop diagrams (CLD's) are a way of attempting to understand some of the inter-relationships which occur within all systems and processes. They trace cause and effect through a system and, in particular, try to model feedback.



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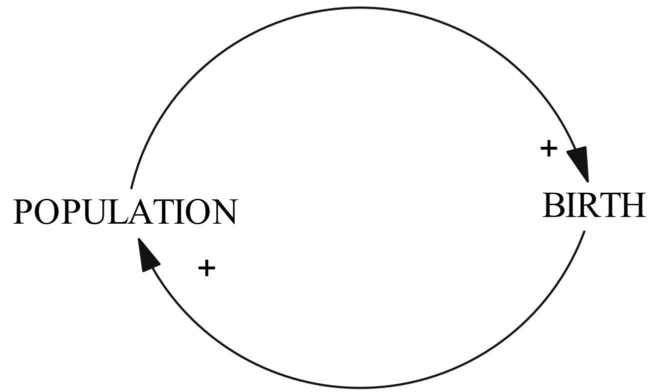
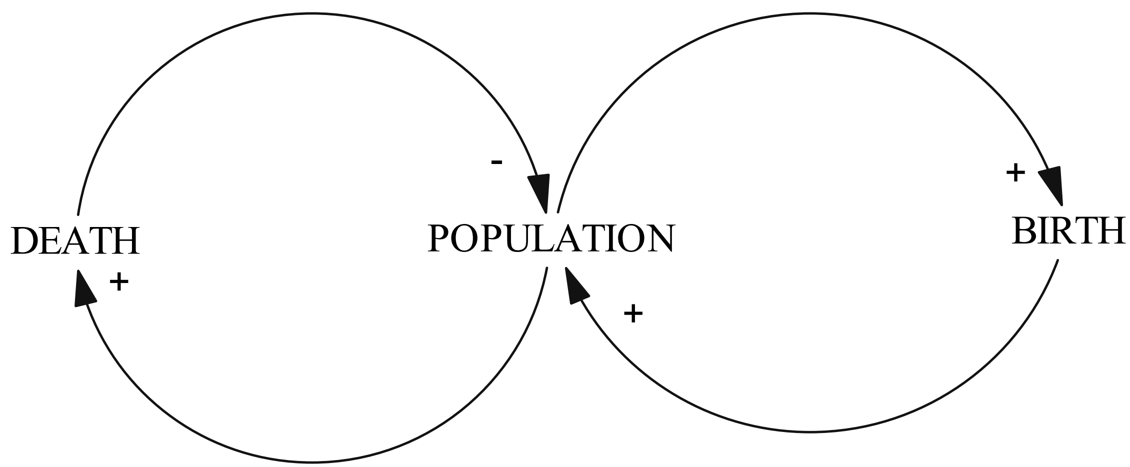
Causal Loop Diagrams in Systems





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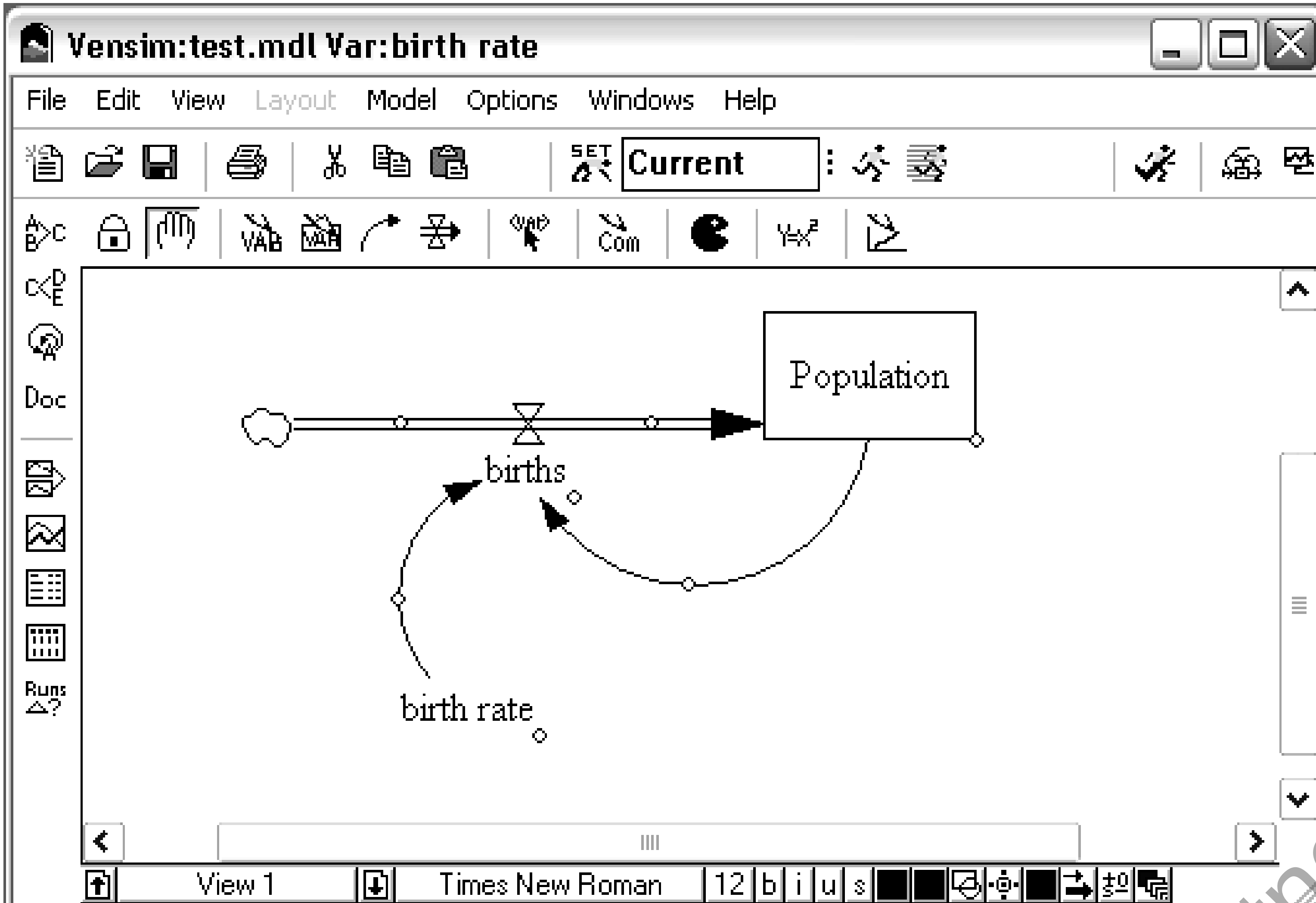
Vensim PLE – Simple dynamic model



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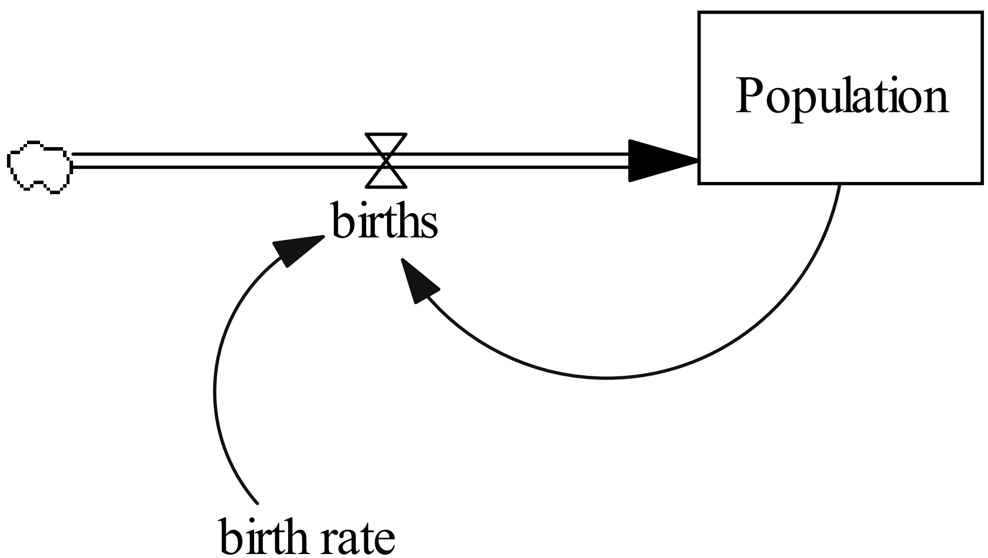
Vensim PLE – Simple dynamic model

Block variable (level)– ***Population*** (initial value 1000)

Rate – ***births***

Births – governed by ***birth rate –*** (Population * birth rate)

Constant ***- Birth rate*** – constant factor (0.12)



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Steps – drawing the diagrams

- Use block variable tool to draw '***Population***' block
- Use rate tool to draw '***births***' rate control
- Use variable tool to draw '***birth rate***'
- Draw arrow from '***birth rate***' to '***births***' to indicate the influence of '***birth rate***' on number of births
- Draw arrow from '***Population***' level to '***births***' to indicate the production of '***Population***' and '***birth rate***' results into the actual number of '***births***'

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Steps – the equations

- Click on ‘equations’ tool
- All the variables that need an equation are highlighted. If the variable is already been defined by an equation, then the variable will not be highlighted
- Click on the variable and enter the equations and other preferences as required

- For ‘Population’ enter the initial value as 1000
- For births, enter the equation as; *Population*birth rate*
- For birth rate, put 0.12 (i.e. the fraction)

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Vensim PLE – Simple dynamic model

Steps – checking equations and units

- Use ‘Model->Check model’ to check the validity of the model
- If any problem, the Vensim will present you a dialog box for the variable in which there is some problem. You need to modify the equation/unit representation of the variable
- Use ‘Model->Units Check’ to check validity of each and every units
- If errors are there, then Vensim will present a document which lists the problematic variables and conditions

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Vensim PLE – Simple dynamic model

Steps – running and analyzing the simulation

- Simulate using ‘Tools -> Simulate’
- It will simulate the dynamic model
- But to have interactive simulation, use ‘Tools ->Synthesim’

- While using ‘Synthesim’ you will be able to view the graph plotted against the time in real time

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Vensim PLE – Simple dynamic model

Steps –analyzing the simulation

- View causes of the variance using ‘Causes Tree’ tool
- To view how the variable values are being used, use ‘Uses Tree’ tool
- Use ‘Loops’ tool to view iterations if any
- For summary of simulation, use ‘Document’ tool
- Use ‘causes strip’ to view the values of causes
- Use ‘graph’ to visualize the rate of change
- Use ‘table’ to view tabular data of simulation run
- Use ‘runs’ to compare two or more runs

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Vensim PLE – Simple dynamic model

Tuning and customizing

- Change the ‘initial time’, ‘fin time’, ‘step’ etc. while building new model
- Change the unit of the time according to your model
- Use ‘causes tree’, ‘loops’, ‘uses tree’ etc. to verify the model

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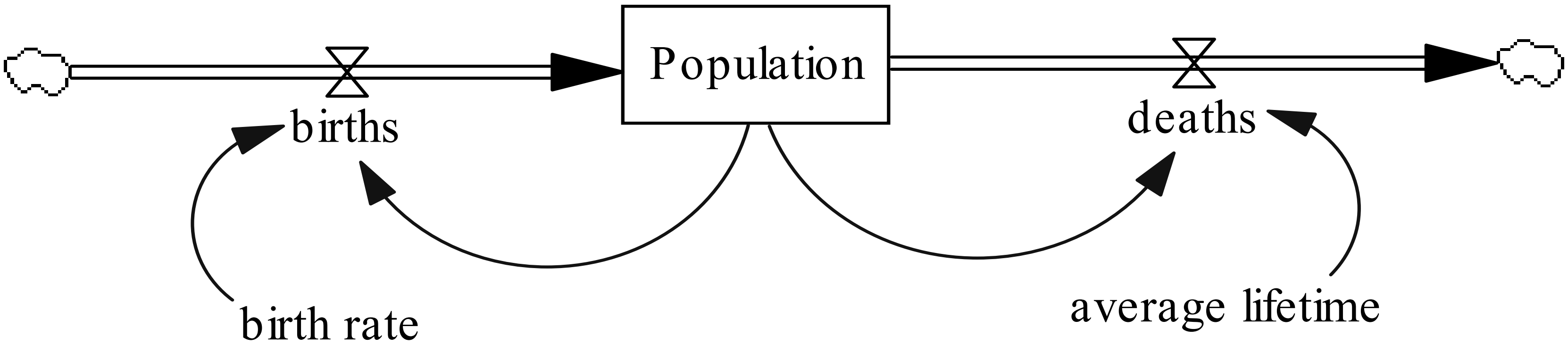
Dynamic model - example



Initial time = 0
Time step = 0.125

Final time = 100
Units for time = Year

Box variable = Population
Constant variable= birth rate
Constant variable= average lifetime

Rate = births
Rate = deaths

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Dynamic model - example

Object type	Name	Int^n	Equation	Initial value	Unit
Box variable	Population	births-deaths		1000	People
Rate	births		Population*birth rate		People/year
Rate	deaths		Population/average lifetime		People/year
Constant variable	birth rate			0.23	Fraction/year
Constant variable	average lifetime			70	year

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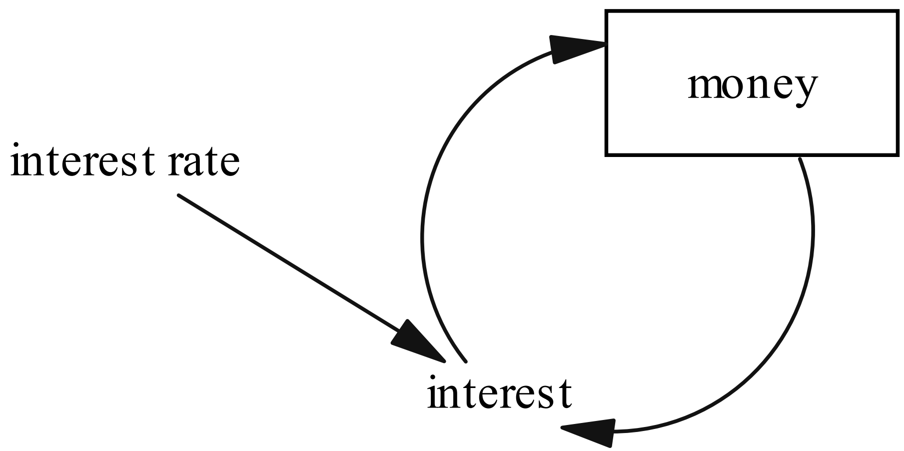
Exponential Growth

Suppose that you deposit $100 in the bank. If the interest rate is 10% per year (compounded daily) and you wait 100 years what will happen?



Classroom demonstration

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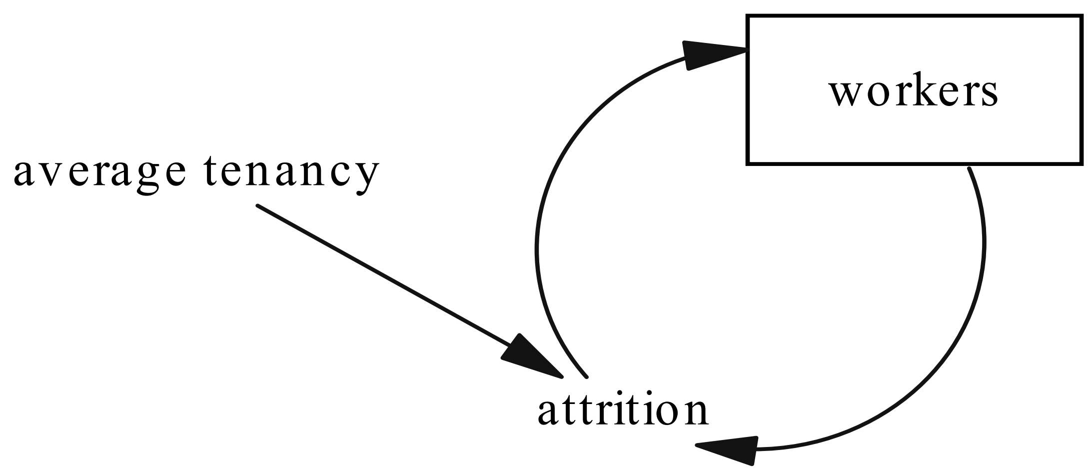
Exponential Decay

Suppose that you have 100 people working for you and you decide never to hire anyone again. Your average worker hangs around for 10 years. What will happen to your workforce?



Homework

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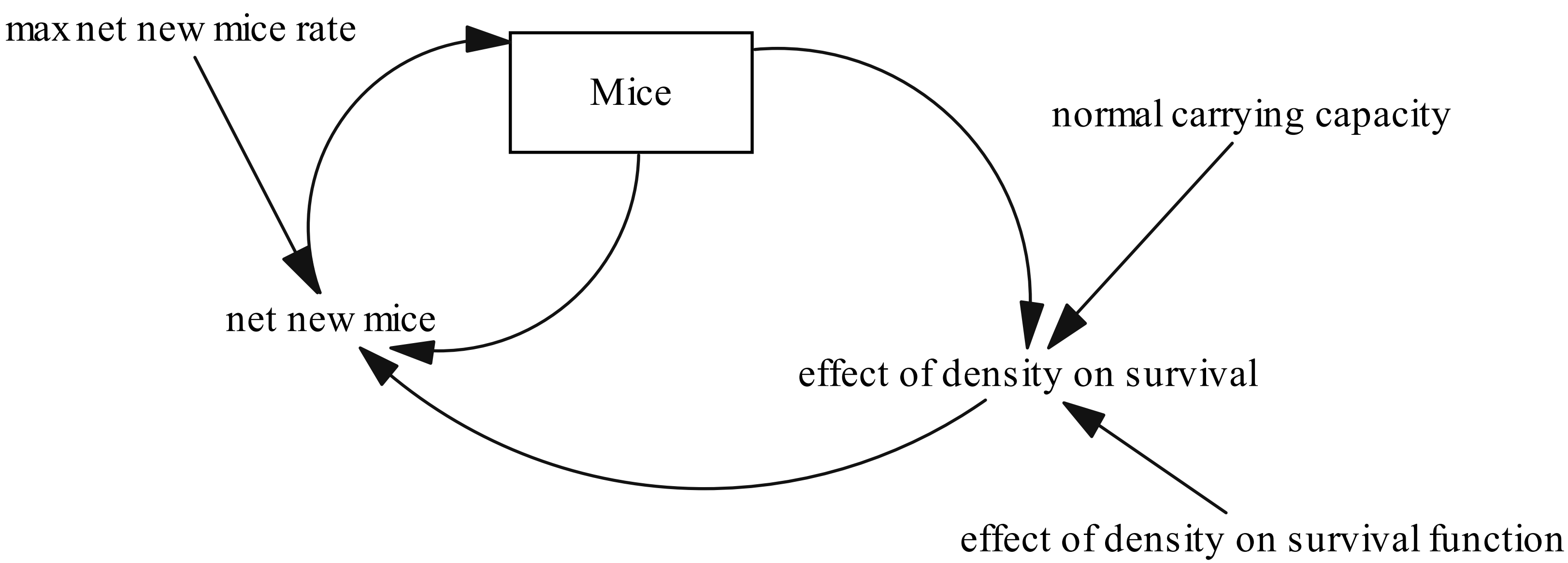
Logistic Curves

Suppose that you let some mice loose in your house and don't try to kill them. What will happen to the mouse population?



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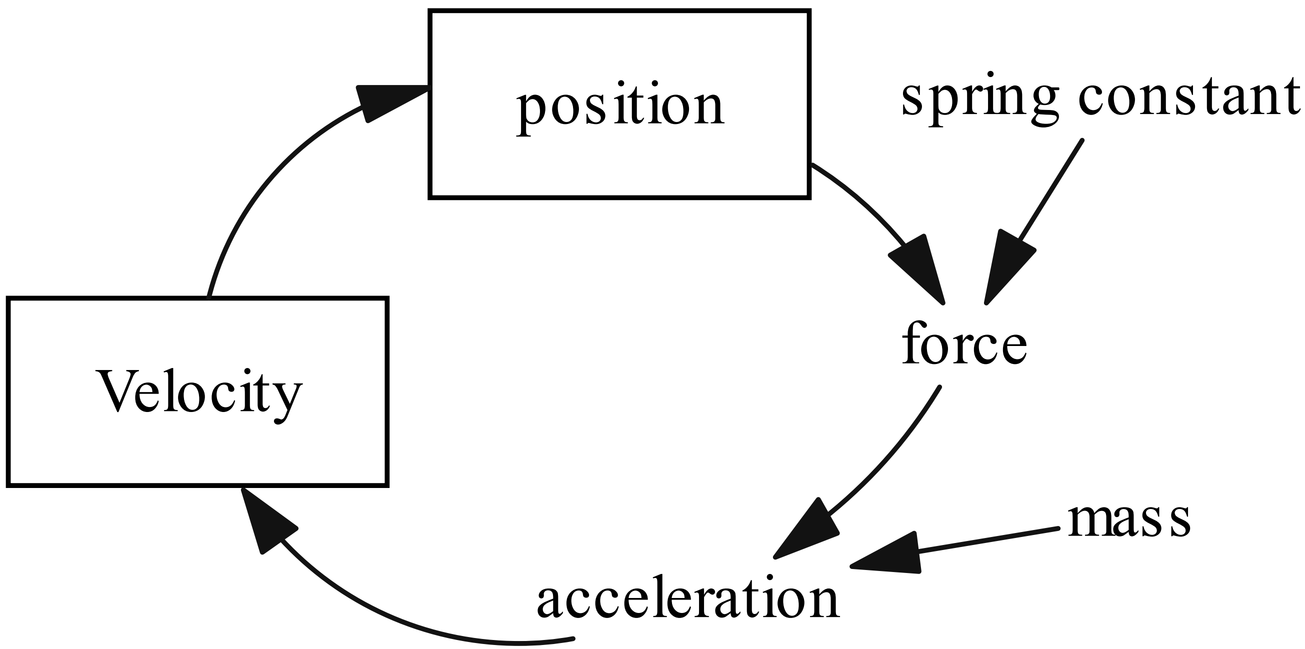
Oscillation

Consider the problem of a spring pushing a weight on a frictionless horizontal surface



Homework

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Home Work

Develop Vensim model for figure

- 5-9 (a, b)
- 5-10
- 5-11
- 5-12

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Time delays

The Constants can be expressed as time constants

e.g. $C_1 = 1/T_1$

which represents that there is time lag of T_1 time unit before the variable associated with C_1 changes

To represent a delay; Let x is the unit of a level. D is average time units to process a unit of x. Then dx/dt is defined as;

$$\frac{dx}{dt} = \frac{x}{D}$$

$$rate = \frac{x}{D}$$

$$Delay = \frac{Level}{Rate}$$

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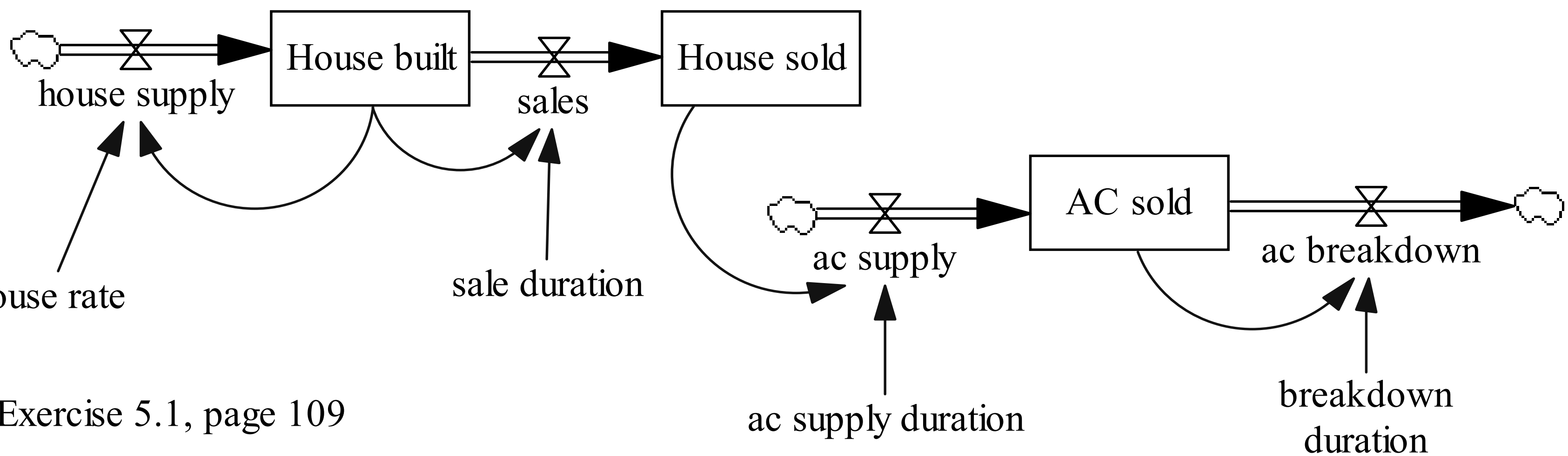
Exercises – Chapter 5, Gordon

Q. 5-1



Exercise 5.1, page 109

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Exercise – 5.1

(01) ac breakdown=AC sold/breakdown duration
Units: unit/Month

(02) AC sold=INTEG (+ac supply-ac breakdown, 0)
Units: unit

(03) ac supply = House sold/ac supply duration
Units: unit/Month

(04) ac supply duration = 10
Units: Month

(05) breakdown duration = 25
Units: Month

(06) FINAL TIME = 100
Units: Month
The final time for the simulation

(07) House built= INTEG (house supply-sales,1000)
Units: unit

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Exercise – 5.1

(08) house rate=0.125
Units: 1/Month
(09) House sold= INTEG (sales, 0)
Units: unit
(10) house supply=house rate*House built
Units: unit/Month
(11) INITIAL TIME = 0
Units: Month
The initial time for the simulation
(12) sale duration=5
Units: Month
(13) sales=House built/sale duration
Units: unit/Month

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