Information Integrity Technology Development using System Dynamics.

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Overview of I*I Technology.

- The I*I Technology takes system's approach to solve real world open ended problems by developing IS with integrity. These open-ended problems have multiple goals and many factors.
- The effectiveness of the problem solving would increase only when all possible variables (multiple goals and many factors) are recognized and modeled.
- Steps to develop I*I System are:-

  - Develop environment topology through enterprise knowledge management, sensors, correlation.
  - Develop effective Acquisition cycle of databases.
  - Develop effective Utilization cycle to the user.
  - Feedback for further improvement. These feedback are internal as well as external to the system and are represented through the System Dynamic model.

Need of System Dynamic Model

- The focus of a System Dynamics (SD) study is not a system, whatever that is , but a problem.
- The problem that one address from the perspective of SD have atleast two features in common.
  - They involve quantities which change over time.
  - They involve the notion of feedback.
- The SD approach applies to dynamic problems arising in feedback systems.

System Dynamics Method

The methodology

- identifies a problem,
- develops a dynamic hypothesis explaining the cause of the problem,
- builds a computer simulation model of the system at the root of the problem,
- tests the model to be certain that it reproduces the behavior seen in the real world,
- devises and tests in the model alternative policies that alleviate the problem, and
- implements this solution.

Formal Model.

- The most visible feature of the SD is its use of **formal**, **quantitative computer model.**
- A Model stands for a representative essentially a simplification of slice of reality. A SD model is a laboratory tool.
- The purpose to have a model is to gain understanding, so that the problem to which the model is addressed may be minimized.

Advantages of Formal Model.

A formal model has two advantages over the informal so-called mental models on which human decisions are based.

- They are explicit and communicable.
- They handle complexity more easily.

Problem Definition

Any problem viewed from the system dynamics perspective is likely to be first seen in terms of a graph of one or more variables over time.

- This aids in identifying variables in a system that are the symptoms of the problem.
- This also help to start the process that will lead to the formulation of formal quantitative feedback models.

Simulation

- A descriptive model of the system has been assembled, but the human mind is not able to deal with the inherent dynamic complexity of such a situation.
- A descriptive model is equivalent to a high order nonlinear differential equation.
- A simulation is a language translation from original description to each decision point in the model and feed the results to other connected decision points to become the basis for the next round of decision.

Success in any domain will follow when there is training to develop designers of a system rather than operators.

Great designs are those that emphasis on removing the causes of problems rather than trying to counteract the symptoms

Feedback Structure

- Feedback is transmission and return of information.
- A feedback structure is a setting where existing conditions lead to decisions that cause changes in the surrounding conditions, that influence later decisions.
- To obtain a feedback structure of a system Causal Loop diagram is generated.

What is feedback ?

Feedback is a process whereby some proportion or in general, function, of the output(e.g. signal) of a system is passed (fed back) to the input.

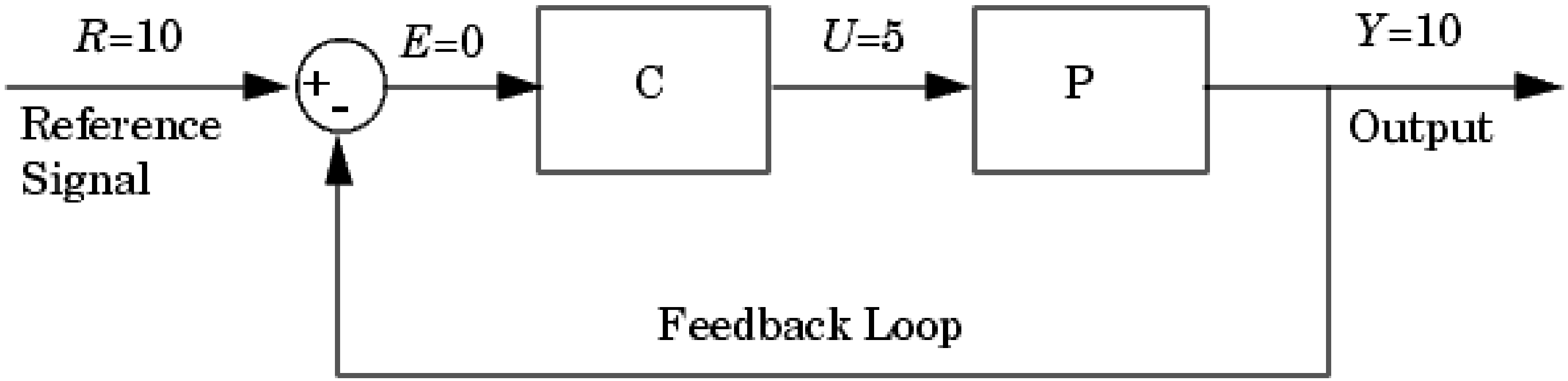
Often this is done intentionally, in order to control the Dynamic behaviour of the system.

Feedback is observed or used in various areas dealing with complex systems, such as engineering(e.g. software development), architecture, biology and economics

What is a feedback loop ?

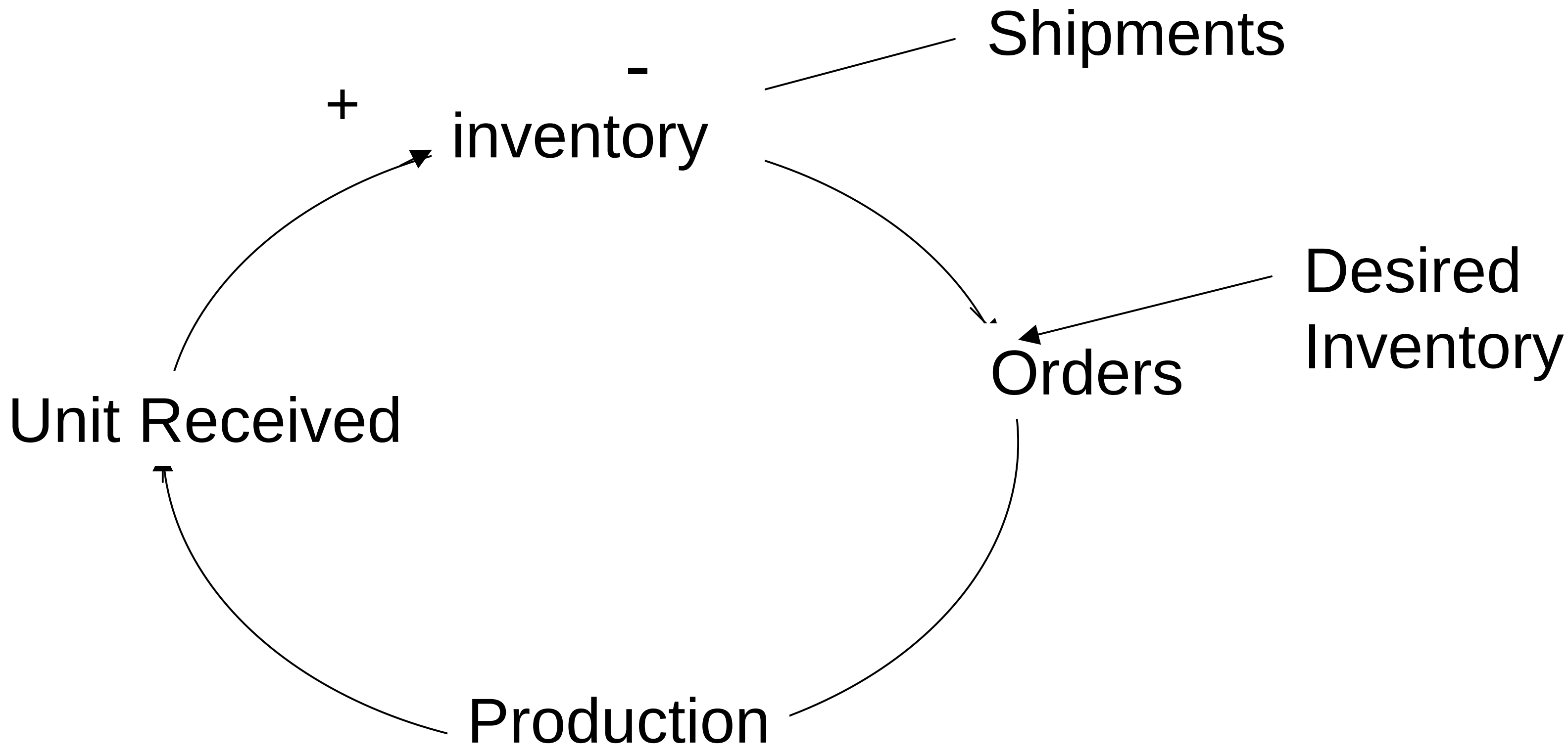
- A diagram that depict information flow in a system.
- Arrowed lines are usually drawn, directed from input through the system and to output.
- The feedback is shown by arrowed line, directed from output outside the system to an input, resulting in a loop on the diagram, called feedback loop.

A System with Feedback Loop



The model represented in this figure is at equilibrium. Consider linearizing the plant, P, about this equilibrium operating point by changing the input signal, *U*, by a small amount, *u*, and measuring the change in the output signal, *y*.

An example of an inventory feedback loop



Types of feedback loop

1. A feedback loop is positive:

$$A \xrightarrow{+} B$$

- If A adds to B.
- If change in A produces a change in B in the same direction.

---

2. A feedback loop is negative:

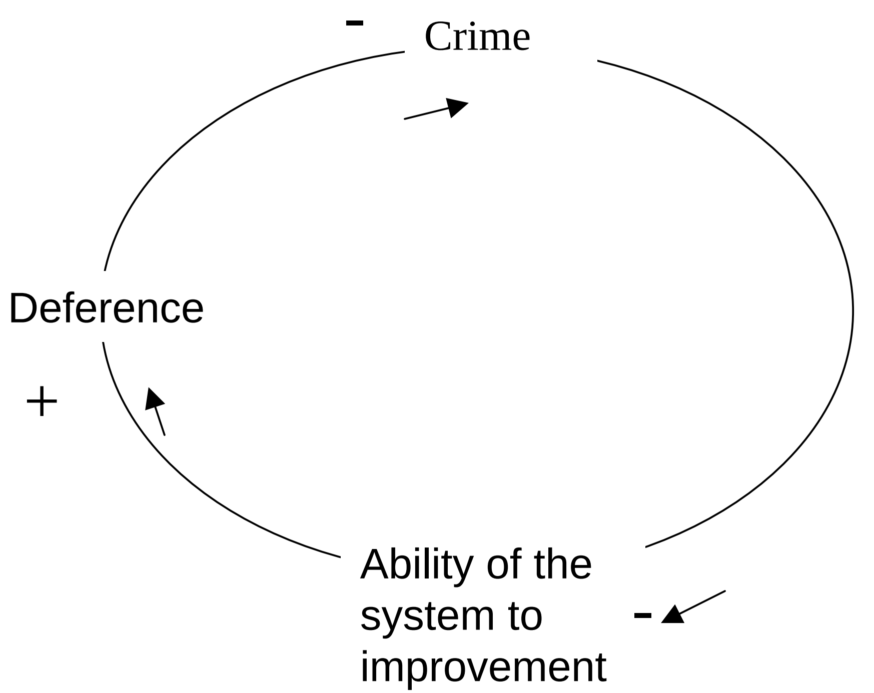
$$A \xrightarrow{-} B$$

- If A subtracts to B.
- If change in A produces a change in B in the opposite direction.

Polarity of feedback loop in diagrams.

- A feedback loop is +ve if it contains an even number of negative links.
- A feedback loop is -ve if it contains an odd number of negative links.
- Polarity is the algebraic product of the signs of its links.

An example of a +ve feedback loop.

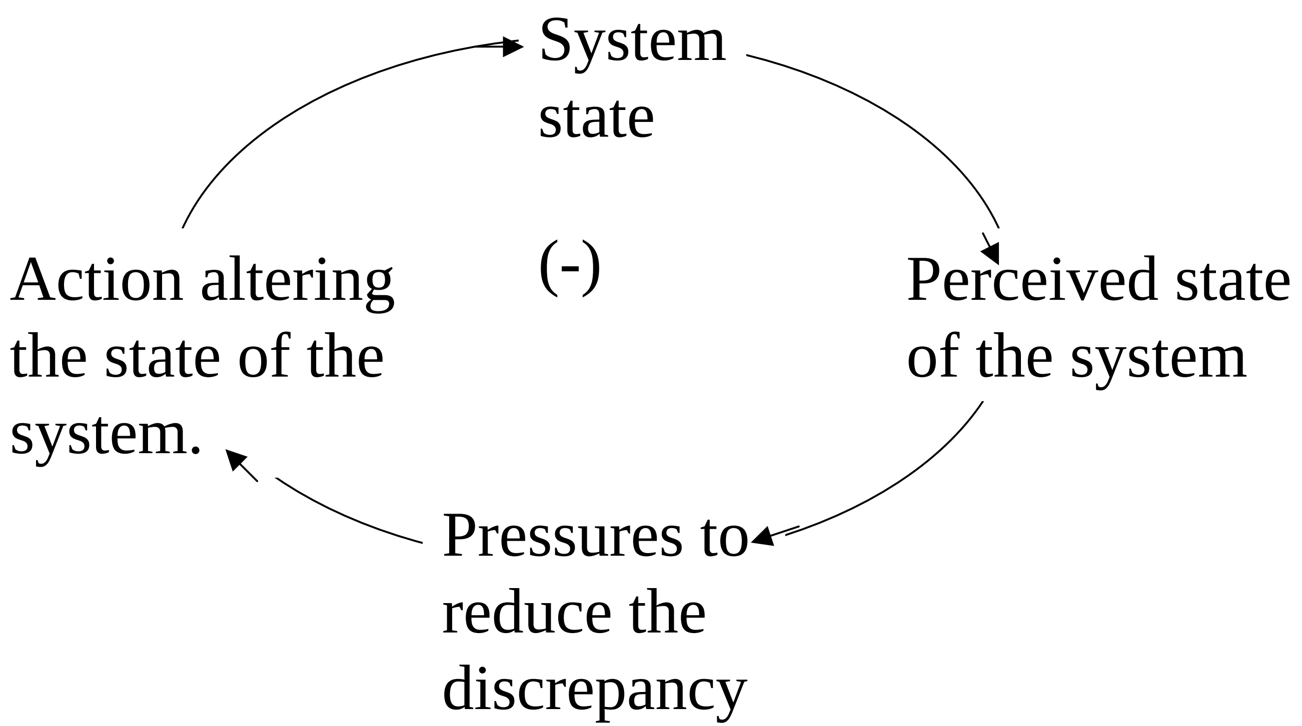


Note:

➢A +ve feedback increases output.

Hence amplifies, deviates and destabilizes the system.

An example of –ve feedback loop



Note:

- A –ve feedback reduces output.

Hence the system with –ve feedback loop strive to control and stabilizes.

Feedback in economics and finance

- A system prone to hunting (oscillating) is the stock market, which has both positive and negative feedback mechanisms. This is due to cognitive and emotional factors belonging to the field of behavioral finance.

For Example:-

  - When stocks are rising (a bull market), the belief that further rises are probable gives investors an incentive to buy (positive feedback); but the increased price of the shares, and the knowledge that there must be a peak after which the market will fall, ends up deterring buyers (negative feedback).
  - Once the market begins to fall regularly (a bear market), some investors may expect further losing days and refrain from buying (positive feedback), but others may buy because stocks become more and more of a bargain (negative feedback).

Feedback in nature

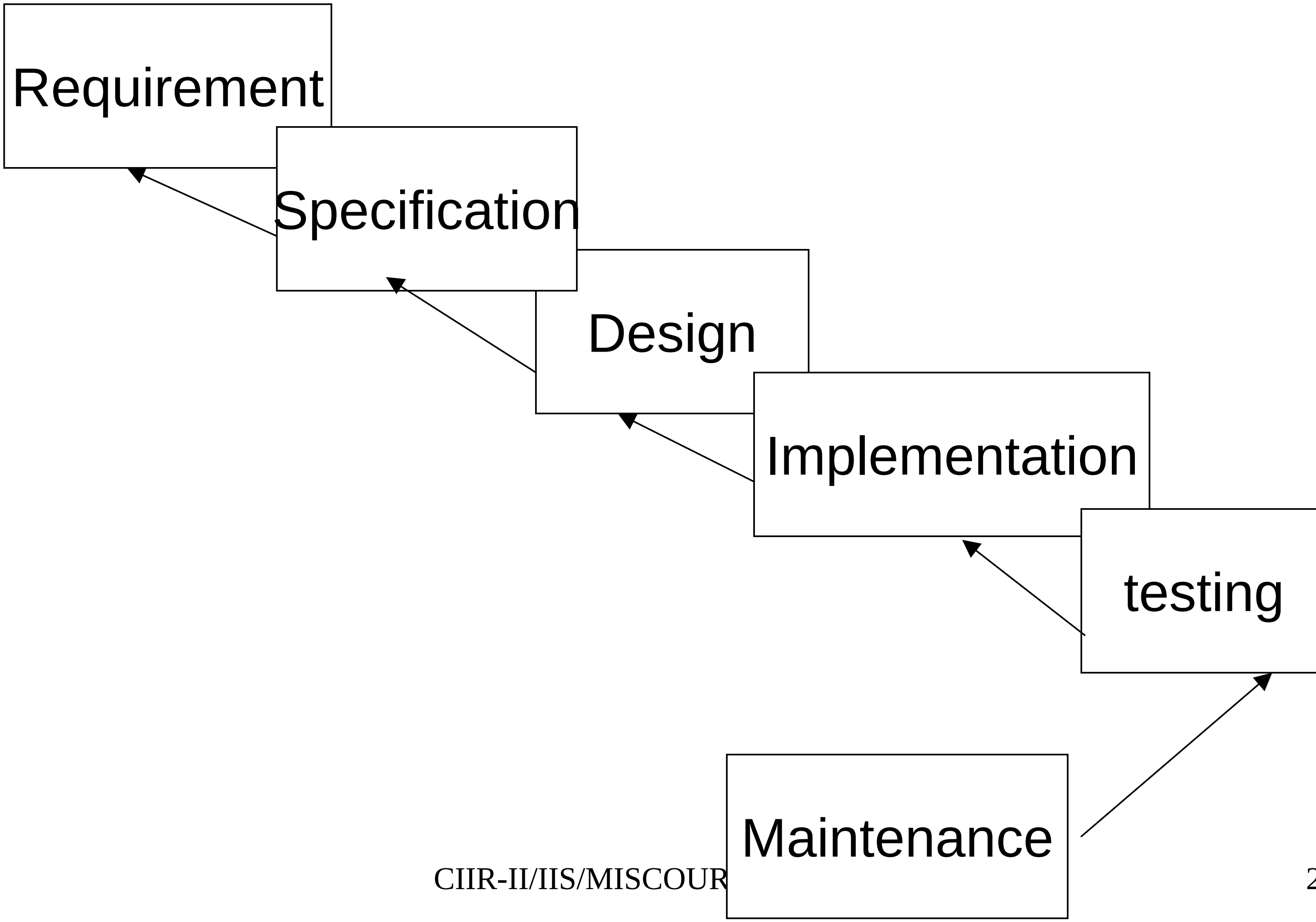
- For example, in an organism, most positive feedbacks provide for fast auto-excitation of elements of endocrine and nervous systems (in particular, in stress responses conditions) and play a key role in regulation of morphogenesis, growth, and development of organs, all processes which are in essence a rapid escape from the initial state. Homeostasis is especially visible in the nervous and endocrine systems when considered at organism level.

Feedback in Software Engineering

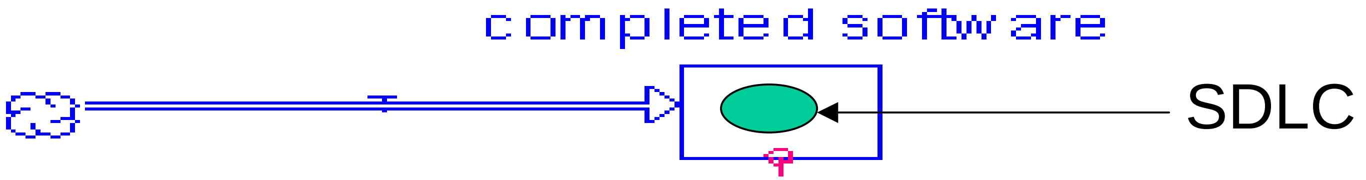
- The **waterfall model** is a software development model in which development is seen as flowing steadily through the phases of requirements analysis, design, implementation, testing (validation), integration, and maintenance.

One can see the feedback loop from one phase to the one previous to it.

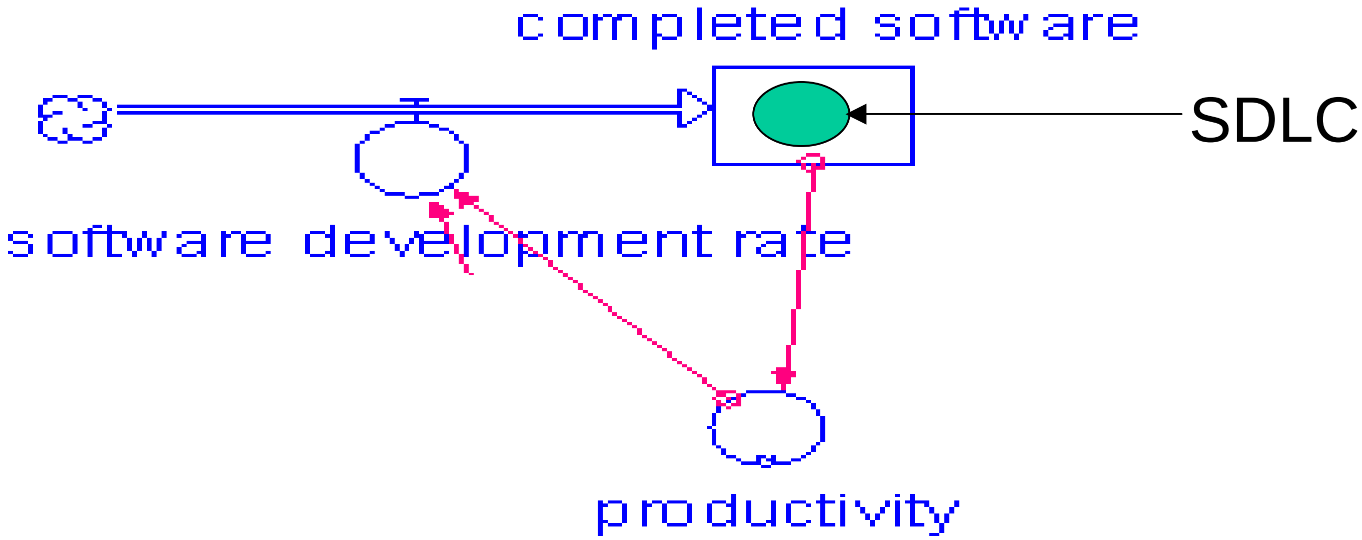
SDLC MODEL


Requirement
Specification
Design
Implementation
testing
Maintenance

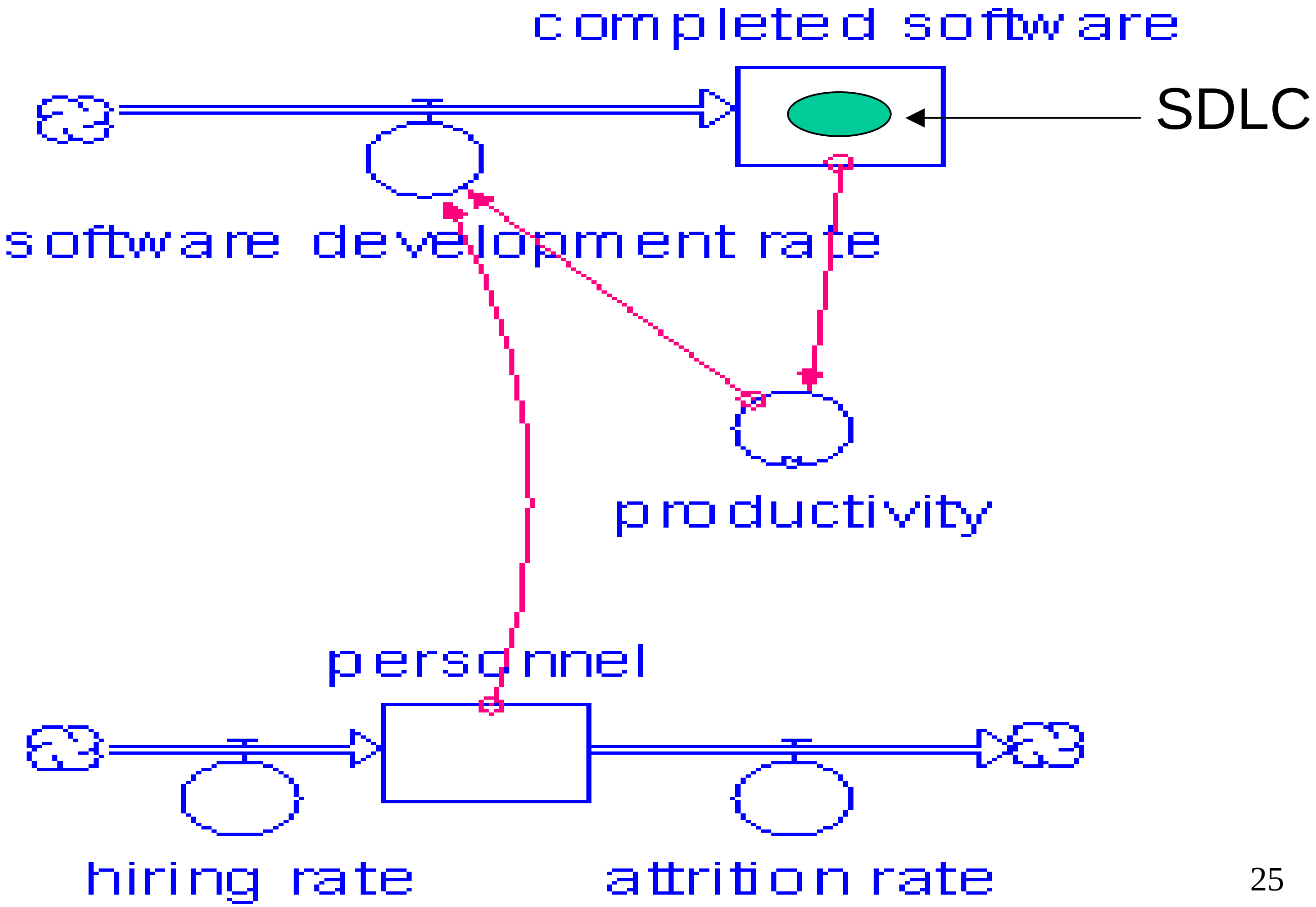
Example
Software Production Model



Example
Software Production Model



Example
Software Production Model



Food for Thought.

- Once a problem has been identified, the modeler explores interconnection among variables.

- Searching for feedback loop the modeler pursues chain of cause and effect until they reconnect with themselves forming a loop.

Types of diagrams

- Causal Loops (Influence diagrams)
- Dynamo Flow (Rate/Level Diagram)

Causal Loops(Influence diagrams)

A causal loop diagram shows various information nodes(variables) that are present in the system. It also shows how each node influences the other.

- Mathematically : A directed graph
- Cause-effect model
- Used during system conceptualization
- Non technical representation of the system
- Consists of nodes and links(positive/negative)

Causal loop diagrams *contd…*

- **Variables** are quantities that have ability to change their polarity i.e. they can be, negative or positive, up or down, can rise or fall, etc. .
- Variables represent nouns and noun phrases in the system.
- **Links**(arrows) represent the verbs or the actions.
- Links do not represent **proportional change**.
- **Disaggregate** complex links.
- **Closed** feedback loops.

Causal loop diagrams *contd…*

- **Accumulations**

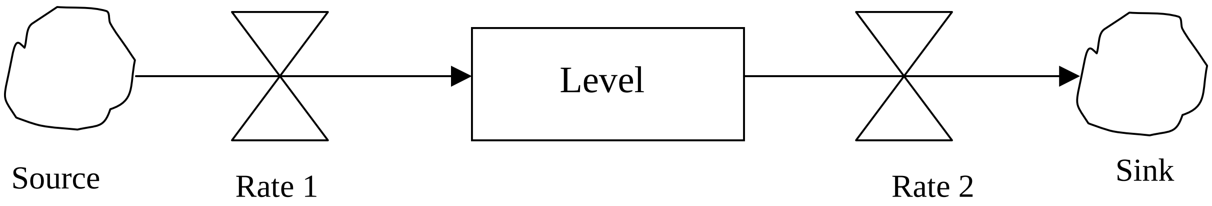
  Feedback systems involve continuous, fluid like processes. An accumulation represents collection of such a fluid like process.

  $$\text{Accumulation} \equiv \text{Stock} \equiv \text{Level}$$
  $$\equiv \text{State variable}$$

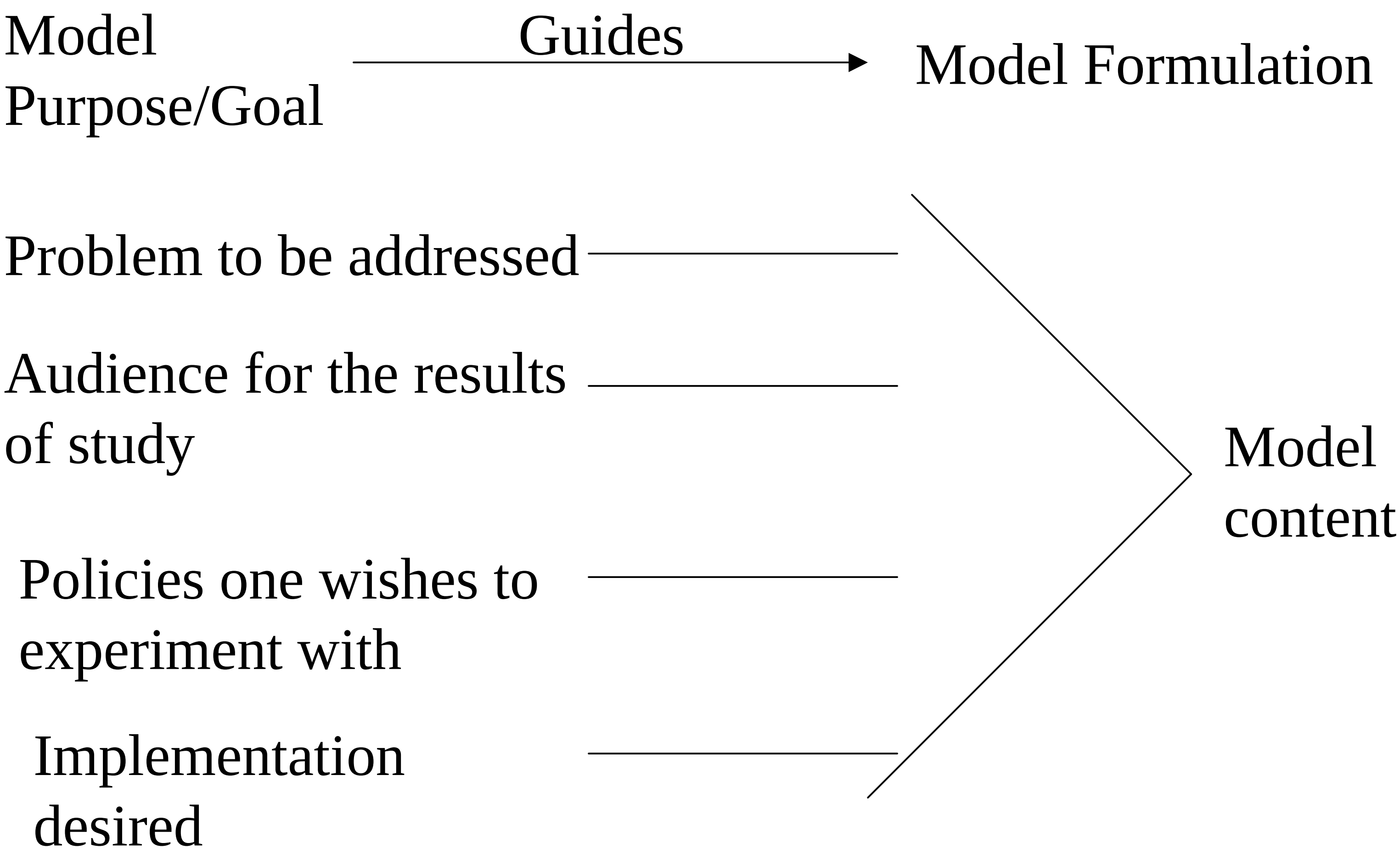
- **Rates**

  Flows increasing or decreasing levels are called rates.

Causal loop diagrams



Model Purpose



Fundamental Purpose of System Dynamics Model

- The Goal of a modeling effort is to improve understandings of the relationships between feedback structure and dynamic behavior of a system.
- Mere building a good model will not ensure implementation, implementation needs to be planned far from the beginning.

Model Purpose and Problem Definition

- Problem Definition focuses on the problem
- Model purpose focuses less on the nature of the problem and more on the audiences for study,what should be included and what should be excluded and the kind of implementation intended.

System Boundary

The boundary of the system is the imaginary line separating what is considered (for modeling purpose) inside the system and what is considered to be outside.

What determines where the system boundary ought to be drawn?

- First criteria for a correctly drawn system boundary is the closing of feedback loops in the system.
- Include all quantities that are dynamically significant for the purpose of the model.

Categorizing the system variables

1. Variables which are explicitly within the boundary.
2. Variables which are implicitly represented within the boundary by the way of aggregation or interpretation.
3. Variables which are outside the boundary

   - near to the system boundary

   - far from the system boundary

Introduction to DYNAMO.

What is Dynamo ?

- Dynamo is a computer simulation language.
- Its name is a merger of two words "dynamic models", indicating its use: modeling **real-world systems** so that their **dynamic behavior** over **time** may be traced by a computer.
- Dynamo is intended to be usable by people who are not familiar with computers, as well as by experienced programmers.

Elements of DYNAMO

- Constant and Variable
- Level equation
- Rate equation
- Auxiliary equation
- Table function
- N equation
- Spec statement
- Print and Plot statement
- Documentation
- Run statement
- Rerun
- Delay, Smooth and Informational Delay

Constant and Variable

Constant : Quantity whose value can not change at all in the course of simulation.

e.g.

C CONST=20

Variable : Quantity whose value change in the course of simulation.

All variables are written with timescripts.

e.g.

COFFEE.K

Level Equation

- A variable that **accumulates over time an inflow and/or an outflow is** a level variable and the equation in which the accumulation is computed is called a level equation.

- A level equation has a **fixed format** in Dynamo.

e.g.

L LEVEL.K=LEVEL.J+DT*(INFLOW.JK-OUTFLOW.JK)

Rate Equation

- The variables **representing the inflows and outflows** in level equations are usually computed in equations termed rate equations.

- **It does no have a standard form.**

e.g.   R CHNG.KL=CONST*(ROOM-COFFEE.K)

It is computed at time K, and its value hold constant over the time interval from K to L.

Auxiliary Equation

- The **additional algebraic computations**, capturing information needed in the formulation of the rate equation, is termed as auxiliary equation.

- It is a **computation representing information** in a feedback system.

- **It does not have a standard form.**

e.g.

A DISC.K=ROOM-COFFEE.K

R CHNG.KL=CONST*DISC.K

TABLE

When it is desirable to use an auxiliary that is a **nonlinear relationship**, then such a relationship can be captured in a table function.

e.g.

```
A  SE.K=TABLE(TSE,DDRM.K,0,10,1)
T  TSE=400/388/348/292/212/152/100/60/32/12/8
```

Note: Values of SE are computed from the table by **linear interpolation.**

N Equation

It is used to **assign an initial value to a level variable**.

All level variables in a model must be assigned initial values.

e.g.

L INV.K=INV.J+DT*(ORDRCV.JK-SHPMTS.JK)

N INV=1000

SPEC Statement

It is used to determine the details of computer simulation. It **specify four parameters** (constants).

- DT (smallest time interval)
- LENGTH (time period of simulation)
- PRTPER (print time interval)
- PLTPER (plot time interval)

e.g.

SPEC DT=0.5/LENGTH=100/PRTPER=10/PLTPER=2

PRINT and PLOT Statement

PRINT statement lists the variable names whose values are to be **printed out in tabular form.**

e.g.

PRINT INV,ORDRCV,SHPMTS,AVSALE

PLOT statement names the variables to be plotted together on **a single graph.**

e.g.

PLOT RAR=R/RBR=1,RDR=2,RKR=K/LYNX=L/AVKPL=+

Documentation

There are three statements:

1. * statement
2. NOTE statements

e.g.

```
 * INVENTORY CONTROL MODEL, V 3.7
L SICK.K=SICK.J+DT*(INF.JK-CURE.JK)
N SICK=2
NOTE   INFECTED POPULATION (PEOPLE)
L SICK.K=SICK.J+DT*(INF.JK-CURE.JK) INFECTED PEOPLE
```

RUN Statement

- Identify individual **simulation runs**.

- A descriptive heading could be placed at the end of the model listing.

  e.g.

  RUN BASE SIMULATION

RERUN

- After running the model once, Dynamo shifts into **rerun mode.**

e.g.

TYPE RERUN

C DUR=5

RUN DURATION=5

DUR

PRESENT 5.000

ORIGINAL 10.00

DELAY

Delays are such an important part of the structure of feedback systems that Dynamo has several delay functions preprogrammed for the convenience of the modeler.

DELAYS represent a material delay.

The delay functions provided by Dynamo are:

- ✓ **DELAY1** (first-order delay)
- ✓ **DELAY3** (third-order delay)
- ✓ **DELAYP**

SMOOTH

For the **averaging and smoothing processes** in dynamic system, Dynamo provides a function for the purpose called SMOOTH.

e.g.

A SVAR.K=SMOOTH(VAR.K,STIME)

DLINF3

SMOOTH function introduces information delay, a first-order exponential information delay.

DLINF3 is a third-order information delay.

e.g.

A SV3.K=DLINF3(VAR.K,STIME)

Functions

- **Mathematical Functions**
  - SQRT(X)
  - SIN(X)
  - COS(X)
  - EXP(X)
  - LOGN(X)
- **Logical Functions**
  - MAX(A,B)
  - MIN(A,B)
  - CLIP(A,B,X,Y)
  - SWITCH(A,B,X)

- Test functions
  - STEP(A,B)
  - RAMP(A,B)
  - PULSE(A,B)
  - NOISE()

Rate Equation

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Flow of content

1. **Auxiliary Equations**
   a. Auxiliary Equation types
   b. System concept as algebraic computations
   c. An example
   d. Table Functions
   e. An example
   f. Formulating table function for ELBC
2. **Levels**
   a. The Snapshot Test for Levels
   b. Effect on behavior
   c. Decoupling of rates
   d. Potential for disequilibrium
   e. Very fast and very slow accumulations

Auxiliary Equations

Auxiliary Equations

- Represent
  - Information in the system
  - Range of quantities
  - Algebraic computations
- Have no standard form.
- Can not be characterized by the type of dimension used in the equation.
- Involve rates, levels, or other auxiliaries.
- E.g. widgets, man months, widgets/month, etc. .

Auxiliary Equation Types

- Auxiliaries can involve two types of computations
  - Algebraic computations

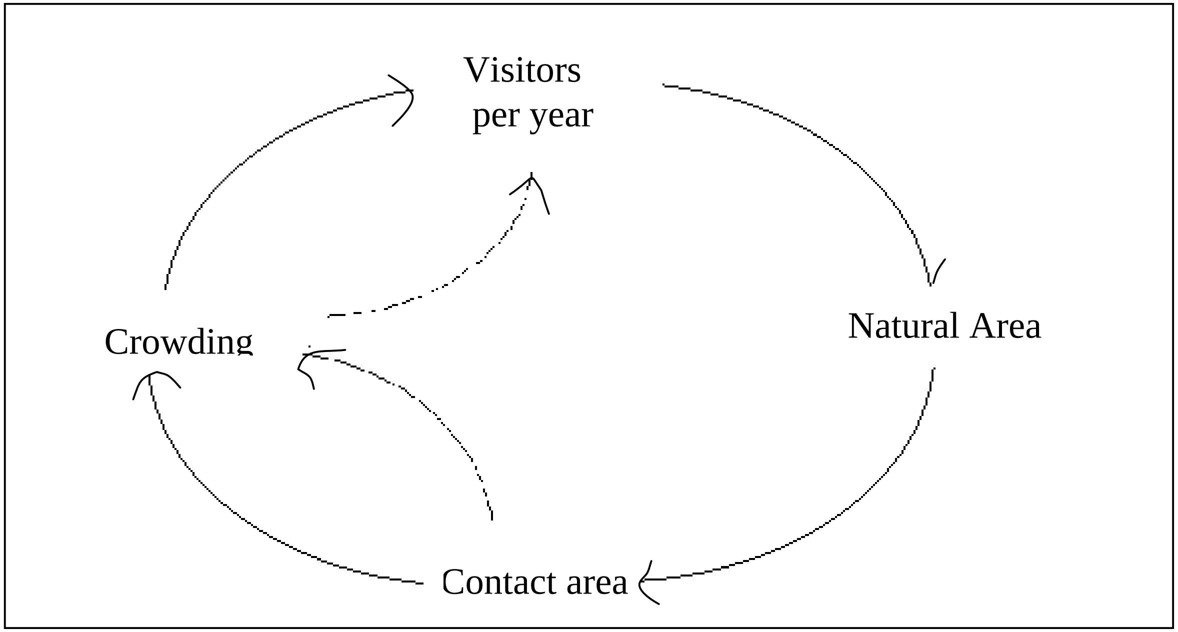
    (System concepts represented as algebraic expressions)
  - Table Functions

    (System concepts represented as complicated algebraic expressions)

System concept as an algebraic expression

- Developing an auxiliary equation
  - Think of the concept as a quantity
  - Focus on the effects of the quantity
- If the quantities involved have the same units then quantities are added (subtracted) otherwise they are multiplied (divided) somehow.

Example



Quantity : VDENS
Effect : VPY, CA

A VDENS.K=VPY.K/CA.K

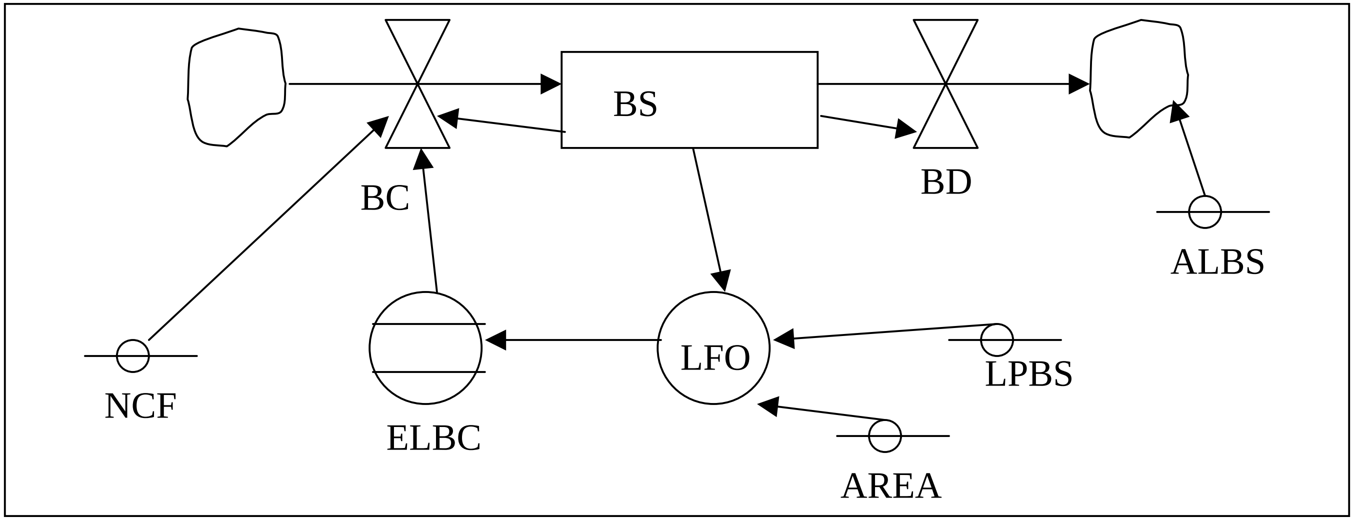
where,

VDENS	= visitors density (people/acre/year)
VPY	= visitors per year (people)
CA	= contact area (acre)

Table Functions

- A table function is a technique for specifying a relationship graphically in a model.
- Tables usually represent complex nonlinear relationships among variables.

Example



R BC.K=NCF*BS.K*ELBC.K

where,

BC	= business construction (structures/year)
NCF	= normal construction fraction (fraction/year)
BS	= business structures (structures)
ELBC	= effect of land on business construction (dimensionless)

Formulating table function for ELBC

- First we find on what factors does ELBC depends.
  - It depends only upon LFO .
- Now, find coordinates corresponding to some known LFO values.
  - when, LFO = 1, then ELBC = 0.

    So, (1,0) can be one of the point.
  - Find no effect point (i.e. ELBC = 1)

    Find a reference condition for LFO at which ELBC = 1.

    Let it be 0.6.

    So, (0.6,1) can be another point.

Formulating table function for ELBC

- Slope of the table (curve)
  - Negative loop, so the slope is also negative
- Shape of the table (two alternatives)
  - Alternative 1
    - From LFO = 0 to LFO = 0.6 : Straight line. (ELBC constant)
    - Beyond 0.6 : Curved line.
  - Alternative 2
    - S-shaped curve

Selection of a particular alternative depends upon the modeler and the behaviour of the variable being modeled

Formulating table function for ELBC

- According to alternative 2, the equation will look like :

A ELBC.K=TABLE(TELBC,LFO.K,0,1,0.1)

T ELBC=1.3/1.28/1.25/1.22/1.118/1.1/1/.7/.3/.1/0

where,

TELBC	=	table for ELBC
ELBC	=	effect of land on business construction(dimensionless)

LEVELS

Levels

- A level variable is an accumulation over time, a storage device for material, energy, or information.
- Rates of flow increase or decrease the levels accumulated.
- All levels are accumulations but not all accumulations are levels.
- Level equations have a predictable form.
- Levels are sources of all dynamic behavior in system dynamics model.

The Snapshot Test for Levels

- Imagine stopping time in the system, freezing all flows.
- Now, potential level variables are those that still exist and have meaning in the snapshot.
- E.g. people, inventory, bank balance, etc.

Note : Not all quantities that continue to exist in a snapshot test are levels (constants, auxiliaries).

Levels

- Effect on behavior
  - LEVELS
    - An abrupt change in one may produces a smooth pattern in the other.
  - AUXILIARY
    - An abrupt change in one produces a direct abrupt change pattern in the other. No delays.

Example : Hire/Fire in an organisation.

Levels

- Decoupling of rates
  - One of the defining characteristics of levels.
  - Absorbs inequalities in inflows and outflows.

  - Example

Production ⟶ Inventory ⟶ Orders

Levels

- Potential for disequilibrium

  Equilibrium in a dynamic system is a situation in which all inflows exactly balance their corresponding outflows.

  – Adding a level to a model adds a possibility of disequilibrium
  – Examples
    - System with one level
    - System with two or more levels.
  – Oscillation

Levels

- Very fast and very slow accumulations
  - Types of accumulations

    Depending upon the frequency with which accumulations change in the given time frame, we have,

    - Constants (Never changing)
    - Levels (Slow changing)
    - Auxiliaries (Fast changing)

Parameters and Initial Values

- Parameter selection
- Process of determining the initial values of system levels
- Necessary accuracy

Kinds of parameters

- Parameters that represent measurement
- Conversion factors
- Normal or Reference parameters
- Parameters that represent adjustment times

Kinds of parameter estimates

Parameters can be estimated 3 ways:-

- from firsthand knowledge of a process
- from data on individual relationships in a model
- from data on overall system behavior

example

L DP.K=DP.J+DT*(DNGR.JK-DPR.JK)

NOTE   DEER POPULATION

R DNGR.KL=DGRF.K*DP.K

NOTE   DEER NET GROWTH RATE(DEER/YEAR)

Where

DPR = deer predation rate

DGRF = deer growth rate factor

Selecting initial values of levels

Three general situations:

- To match some historical situation
- To initialize the model in equilibrium
- To initialize model for growth(or decline)

example

L LEV.K=LEV.J+DT*(IN.JK-OUT.JK)

N LEV=?

R IN.KL=EXOG.K

R OUT.KL=LEV.K/TCONST

OUT = IN

LEV/TCONST = EXOG

LEV = EXOG*TCONST

Where

EXOG = a constant or a variable determined as a function of time

TCONST = time constant associated with the level

Principles of model formulation

- All level variables represent accumulations. They can be changed only by moving their contents between levels,sources,or sinks.
- Information is not a conserved flow.Information from a single source can be transmitted to other variables in the system without diminishing the source.
- In any conserved flow subsystem, the rate and level variables must alternate.
- Levels are changed only by rates.
- Only information links can connect between conserved subsystems.

Cont.

- Rates depend,in principle, only on levels and constants.
- Most rates are not instantaneously knowable by most actors in the systems.There can be no rate to rate connections in a model.
- Every feedback loop in a model must contain atleast one level.
- Level variables completely describe the system condition.
- In every model equation the units of measure must be consistent. Terms added together or subtracted must have identical units.

Cont.

- Levels and rates cannot be distinguished by their units of measure.
- Within any subsystem of conserved flow, all levels have the same units of measure and all rates are measured in those same units divided by time.
- Like every variable in the model,every parameter should have a meaningful interpretation or counterpart in the real system.
- All rate equations should make sense even under extreme or unlikely conditions.
- Distinguish between desired conditions and actual conditions.

Cont.

- Distinguish between actual conditions and perceived conditions.
- Decisions can be based only on available information.