Apakah System Dynamics itu?

- **System Dynamics**: **Pemodelan dan simulasi** komputer untuk mempelajari dan mengelola **sistem umpan balik yang rumit** (*complex feedback systems*), seperti sistem ekonomi, sistem lingkungan, sistem sosial, dll.
- Sistem:
  - Kumpulan elemen yang saling berinteraksi, berfungsi bersama untuk tujuan tertentu.
  - Umpan balik menjadi sangat penting
- Masalah dinamik
  - Mengandung jumlah (kuantitas) yang selalu bervariasi
  - Variasi dapat dijelaskan dalam hubungan sebab akibat
  - Hubungan sebab akibat dapat terjadi dalam sistem tertutup yang mengandung lingkaran umpan balik (*feedback loops*)

Sejarah

- **Cybernetics** (Wiener, 1948): studi yang mempelajari bagaimana sistem biologi, rekayasa, sosial, dan ekonomi dikendalikan dan diatur
- **Industrial Dynamics** (Forrester, 1961): mengaplikasikan prinsip "cybernetics" ke dalam sistem industri
- **System Dynamics**: karya Forrester semakin meluas meliputi sistem sosial dan ekonomi
- Dengan perkembangan komputer yang sangat cepat, System Dynamics menyediakan kerangka kerja dalam menyelesaikan permasalahan sistem sosial dan ekonomi

Tahap Pemodelan System Dynamics

1. Identifikasi masalah
2. Membangun hipotesis dinamik yang menjelaskan hubungan sebab akibat dari masalah termaksud
3. Membuat struktur dasar grafik sebab akibat
4. Melengkapi grafik sebab akibat dengan informasi
5. Mengubah grafik sebab akibat yang telah dilengkapi menjadi grafik alir System Dynamics
6. Menyalin grafik alir System Dynamics ke dalam program komputer (DYNAMO, Stella, Vensim, Powersim) atau persamaan matematika

Aspek penting

- Berfikir dalam terminologi hubungan sebab akibat
- Fokus pada keterkaitan umpan balik *(feedback linkages)* diantara komponen-komponen sistem
- Membuat batasan sistem untuk menentukan komponen yang masuk dan tidak di dalam sistem

Hubungan Sebab Akibat

- Berfikir sebab akibat adalah kunci dalam mengorganisir ide-ide dalam studi System Dynamics
- Gunakan kata `menyebabkan` atau `mempengaruhi` untuk menjelaskan hubungan antar komponen di dalam sistem
- Contoh yang logis (misalnya hukum fisika)
  - makan→ berat bertambah
  - api → asap
- Contoh yang tidak logis (sosiologi, ekonomi)
  - Pakai sabuk pengaman → mengurangi korban fatal dalam kecelakaan lalu lintas

Umpan balik (Feedback)

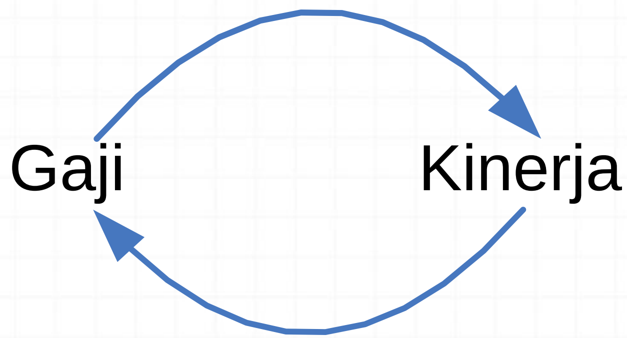
- Berfikir sebab akibat saja tidak cukup
  - **laut** → evaporasi → awan → hujan → **laut** → ...
- Umpan balik untuk mengatur/mengendalikan sistem, yaitu berupa suatu sebab yang terlibat dalam sistem namun dapat mempengaruhi dirinya sendiri
- Umpan balik sangat penting dalam studi System Dynamics

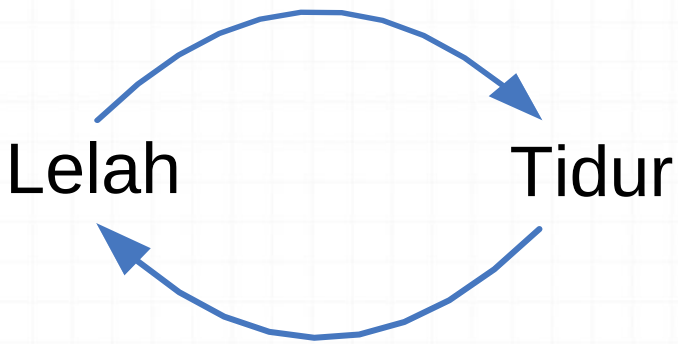
Causal Loop Diagram (CLD)

CLD menunjukkan struktur umpan balik dari sistem

- Gaji VS Kinerja
  - Gaji → Kinerja
  - Kinerja → Gaji

- Lelah VS Tidur
  - Lelah → tidur
  - Tidur → lelah ?

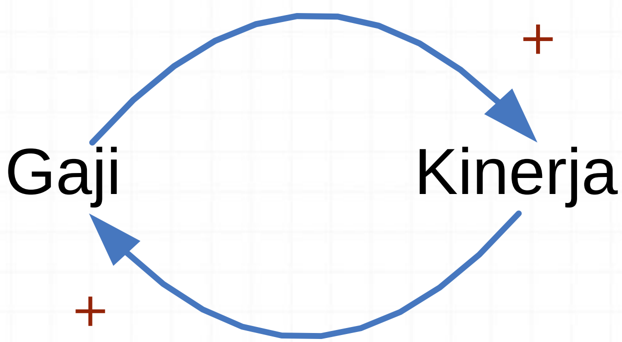


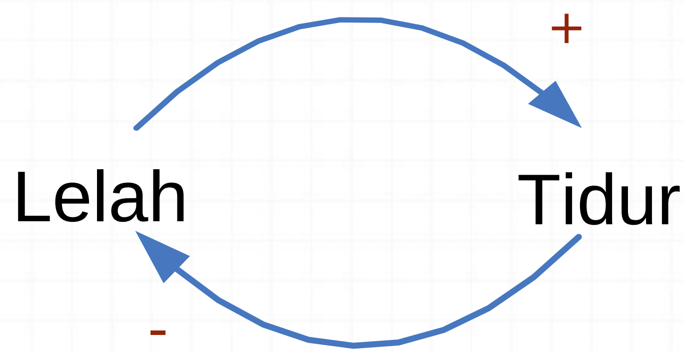


Penanda CLD

(**+**) : jika penyebab naik, akibat akan naik (pertumbuhan, penguatan), jika penyebab turun, akibat akan turun

(**-**) : jika penyebab naik, akibat akan turun, jika penyebab turun, akibat akan naik





CLD dengan Positive Feedback Loop

- Gaji → Kinerja, Kinerja → Gaji

Semakin gaji naik

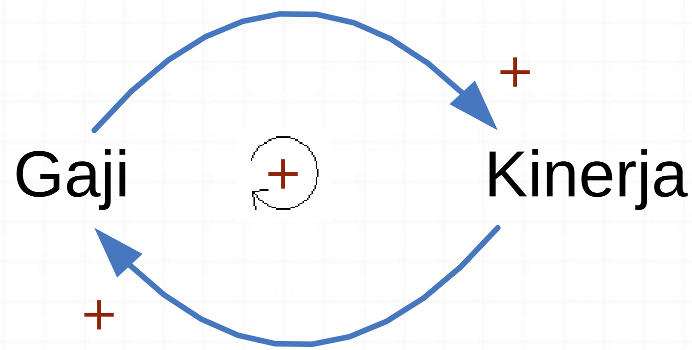
Semakin baik kinerja

Semakin baik kinerja

Gaji akan semakin naik

Semakin gaji naik

Semakin baik kinerja



CLD dengan Negative Feedback Loop

- Lelah → Tidur, Tidur → Lelah

The more I sleep

The less tired I am

The more tired I am

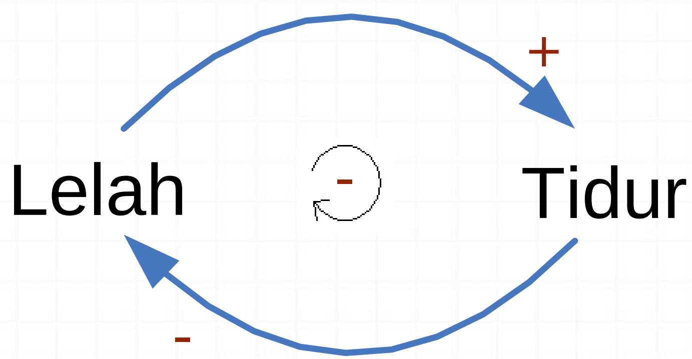
The more I sleep

The less tired I am

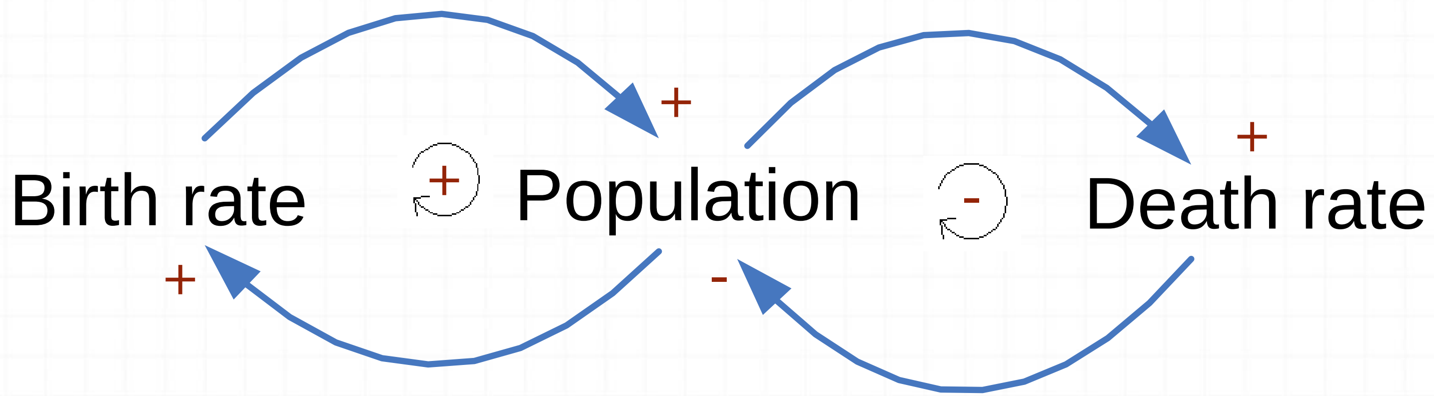
The less I sleep

The less I sleep

The more tired I am

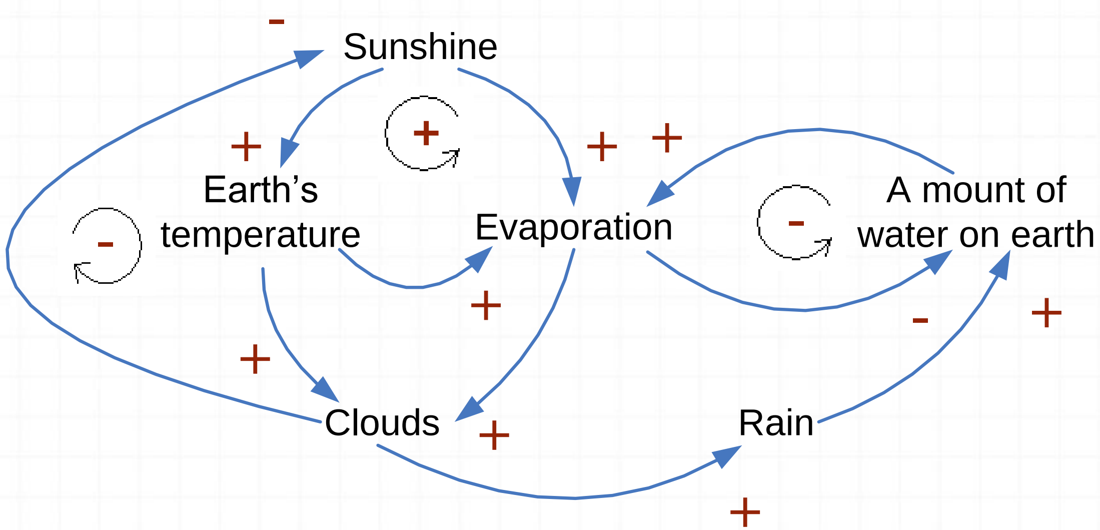


CLD with Combined Feedback Loops (Population Growth)



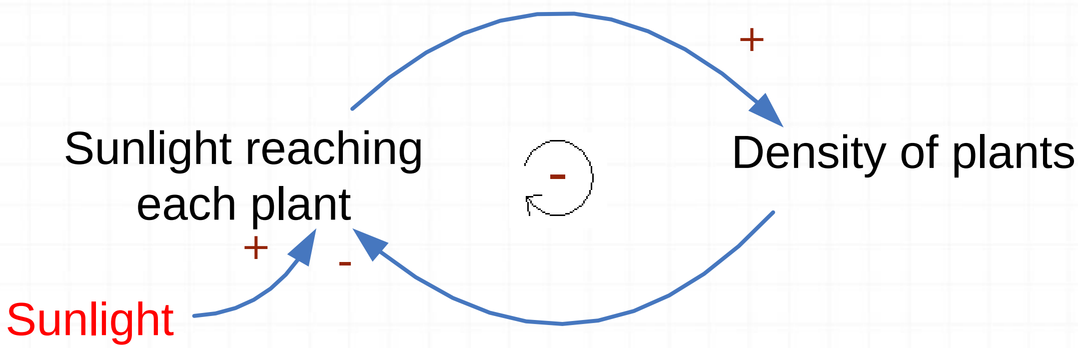
CLD with Nested Feedback Loops (Self-Regulating Biosphere)

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



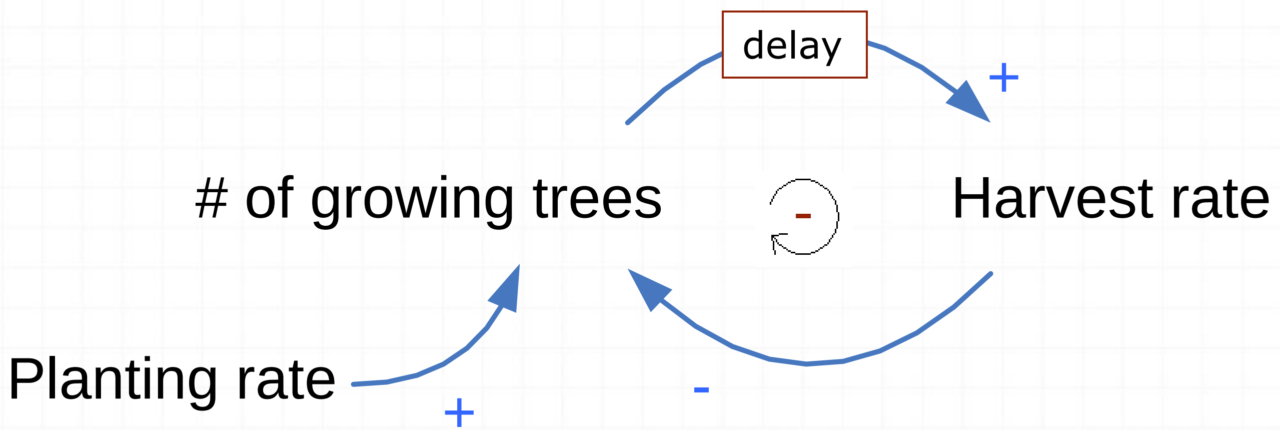
Exogenous Items

- 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

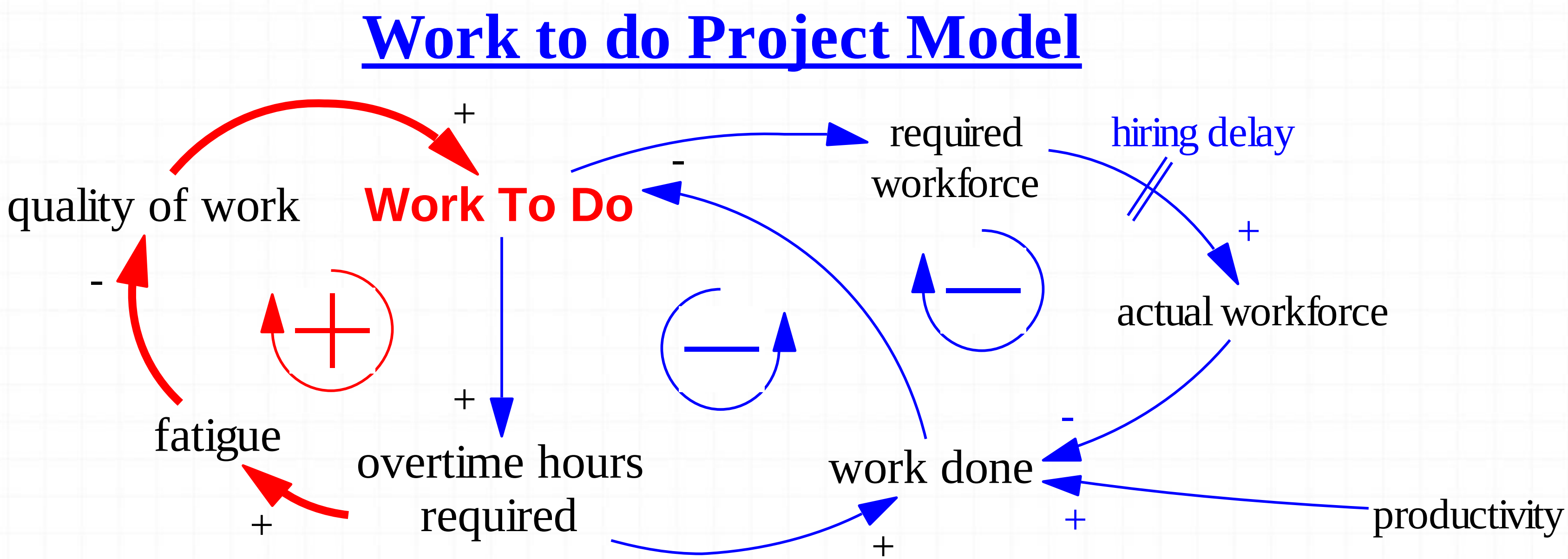
- Systems often respond sluggishly (dgn malas=tidak seketika)
- From the example below, once the trees are planted, the harvest rate can be '0' until the trees grow enough to harvest



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

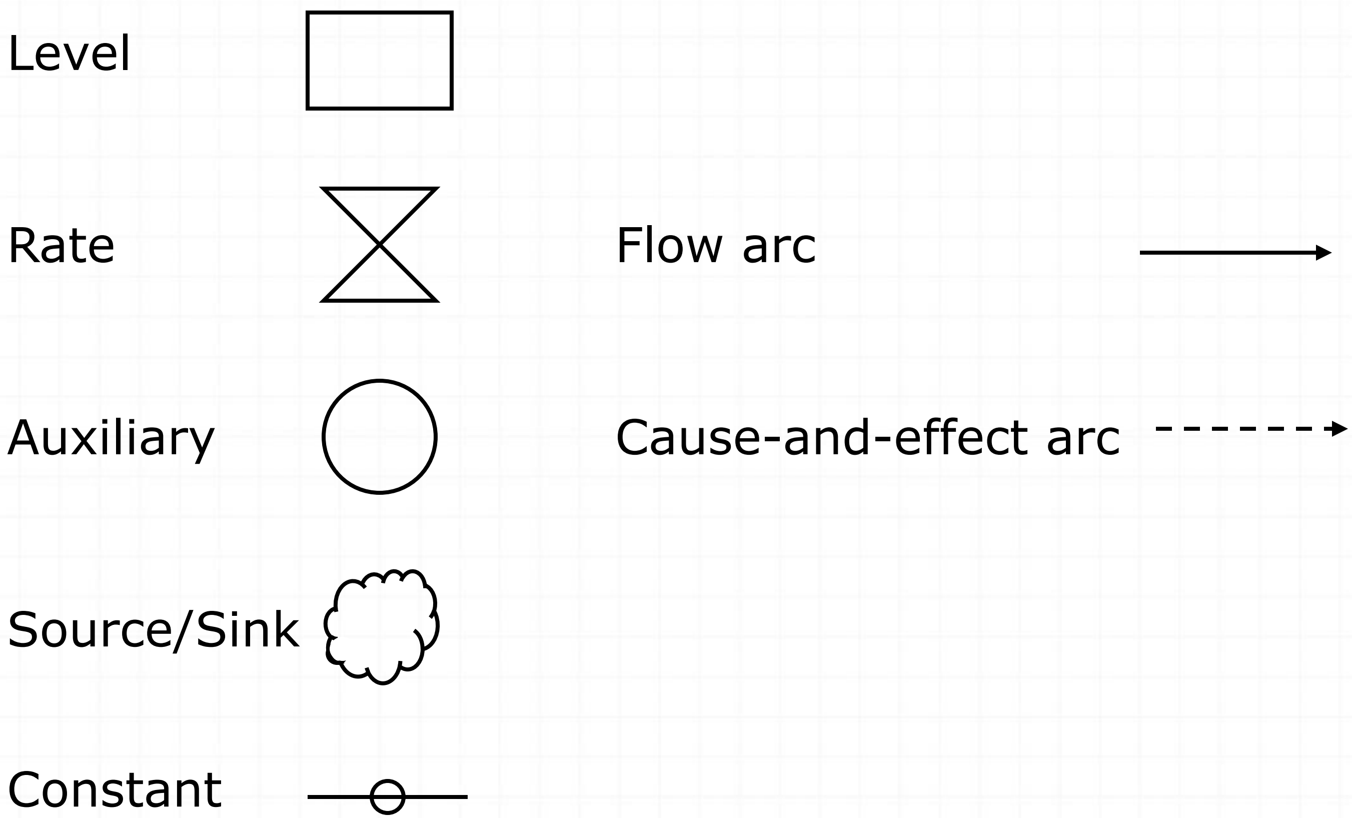
Example



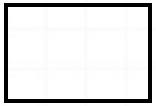
Work to do Project Model
quality of work
Work To Do
required
workforce
hiring delay
actual workforce
fatigue
overtime hours
required
work done
productivity
+
-
+
-
+
-
+
+
+
+

Stock and Flow Diagram

Flow Graph Symbols

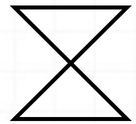


Level/Stock



- Stock, accumulation, or state variable
- A quantity that accumulates over time
- Change its value by accumulating or integrating rates
- Change continuously over time even when the rates are changing discontinuously

Rate/Flow:

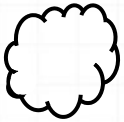


- Flow, activity, movement
- Change the values of levels
- The value of a rate is
  - Not dependent on previous values of that rate
  - But dependent on the levels in a system along with exogenous influences

Auxiliary:

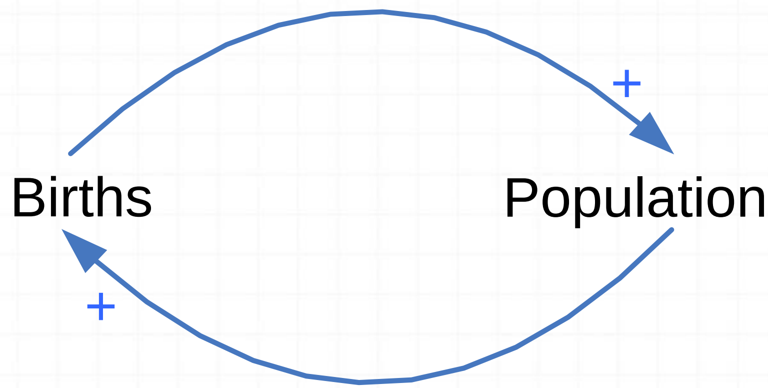
- Arise when the formulation of a level's influence on a rate involves one or more intermediate calculations
- Often useful in formulating complex rate equations
- Used for ease of communication and clarity
- Value changes immediately in response to changes in levels or exogenous influences

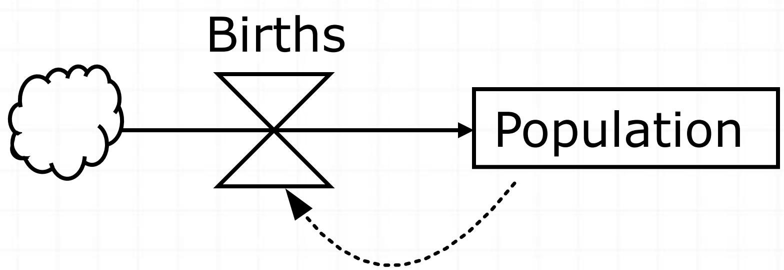
Source and Sink:



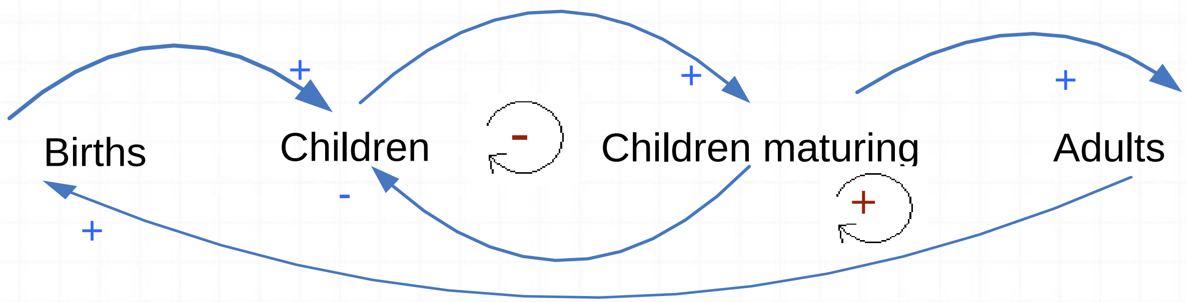
- Source represents systems of levels and rates outside the boundary of the model
- Sink is where flows terminate outside the system

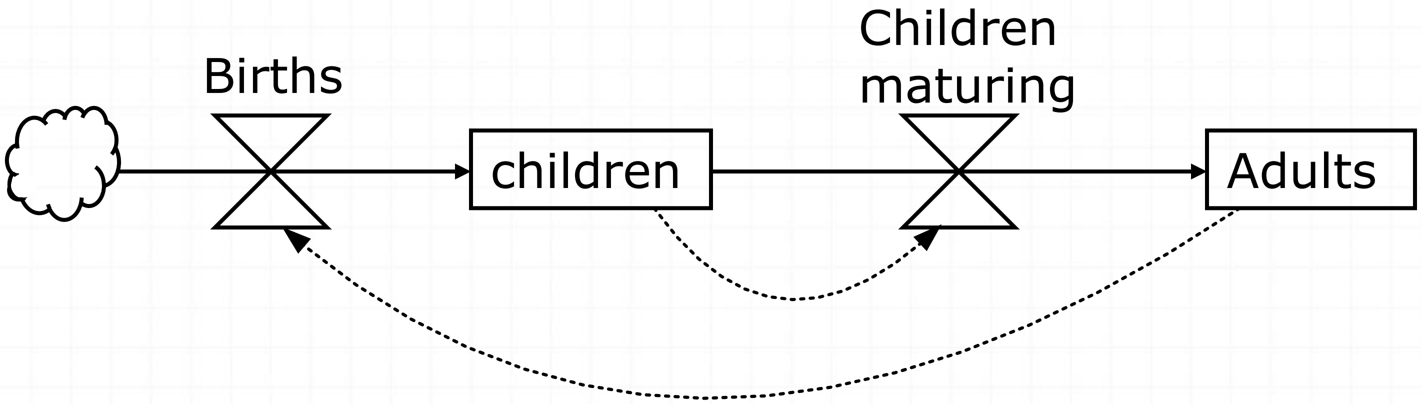
Example 1
(Population and birth)

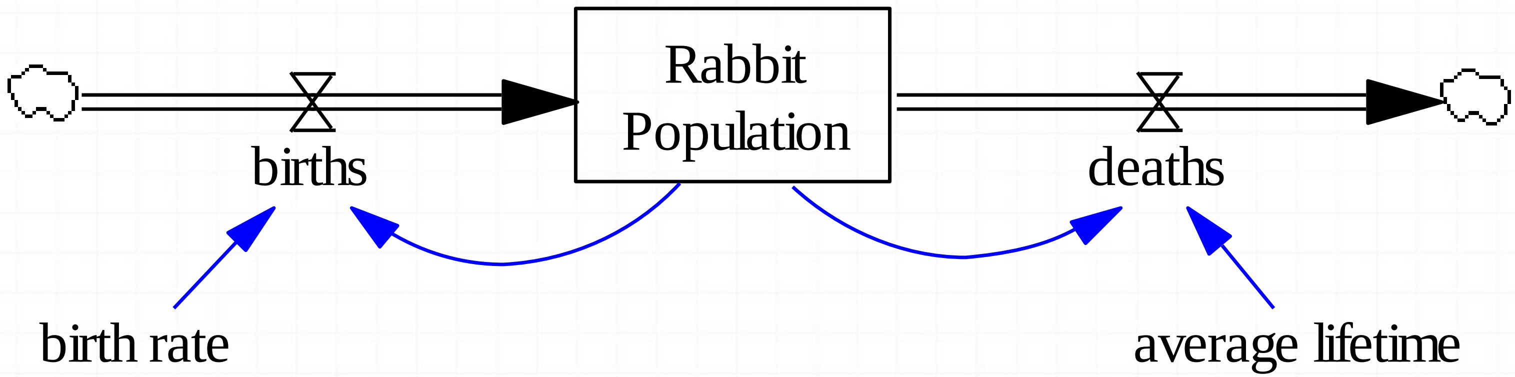




Example 2
(Children and adults)







- average lifetime = 8
- Units: Year

- birth rate = 0.125
- Units: fraction/Year

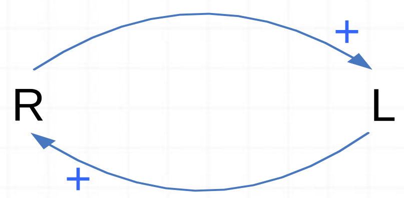
- births = Population * birth rate
- Units: rabbit/Year

- deaths = Population / average lifetime
- Units: rabbit/Year

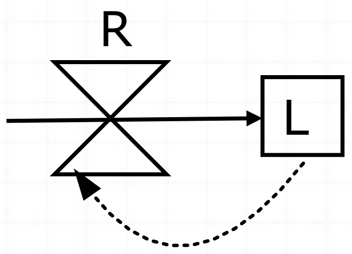
- Population = INTEG(births - deaths,1000)
- Units: rabbit

From Causal Loop Diagram To Simulation Models 1

Causal Graph



Flow Graph



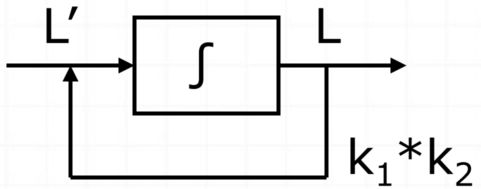
Equations

$dL/dt = k_1 * R(t)$

$R(t) = k_2 * L(t)$

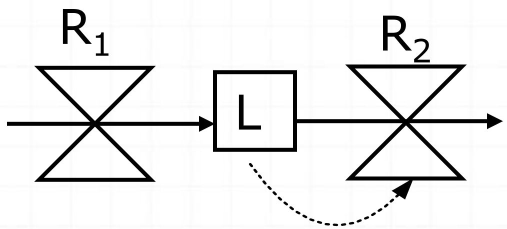
$\rightarrow dL/dt = k_1 * k_2 * L(t)$

Block Model



From Causal Loop Diagram To Simulation Models 2

Flow Graph



Equations

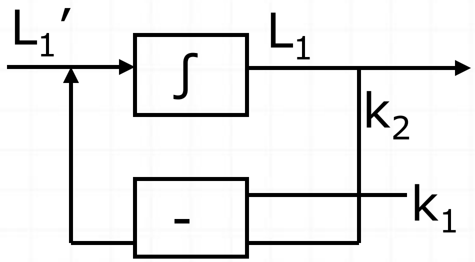
$dL/dt = R_1 - R_2$

$R_2 = k_2 * L$

$R_1 = k_1$

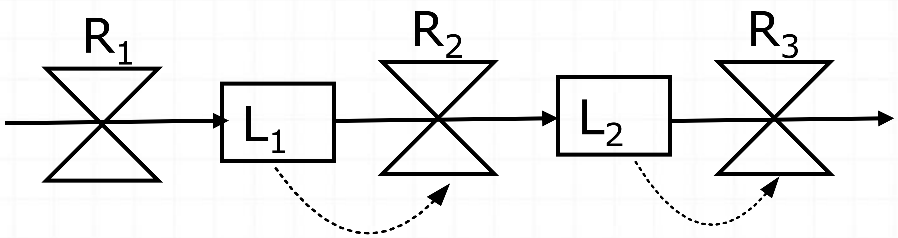
$\rightarrow dL/dt = k_1 - k_2 * L$

Block Model

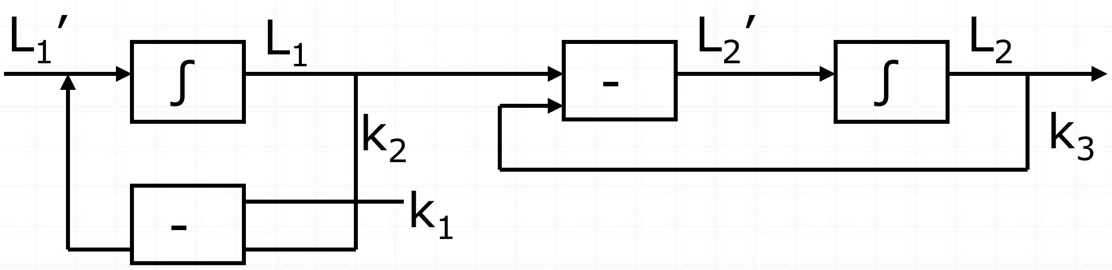


From Causal Loop Diagram To Simulation Models 3

Flow Graph



Block Model



Equations

$dL_1/dt = R_1 - R_2$

$dL_2/dt = R_2 - R_3$

$R_1 = k_1$

$R_2 = K_2 * L_1$

$R_3 = K_3 * L_2$

$\rightarrow dL_1/dt = k_1 - k_2 * L_1$

$\rightarrow dL_2/dt = k_2 * L_1 - K_3 * L_2$

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  - Simulation Model Design and Execution, Fishwick, Prentice-Hall, 1995 (Textbook)
  - Introduction to Computer Simulation: A system dynamics modeling approach, Nancy Roberts et al, Addison-wesley, 1983
  - Business Dynamics: Systems thinking and modeling for a complex world, John D. Sterman, McGraw-Hill,2000