System Dynamics

System Dynamics
Dr Daniel Chalk

System Dynamics

- A modelling method in which system structures (components and the way in which they relate) are captured.

Fundamental principle of SD :

Structure determines behaviour

Qualitative System Dynamics

- Create map of influences and their directionality

- Identify feedback loops within the map (the "causal loop diagram")

- Draw insight from the map and its associated feedback loops to better understand system behaviour
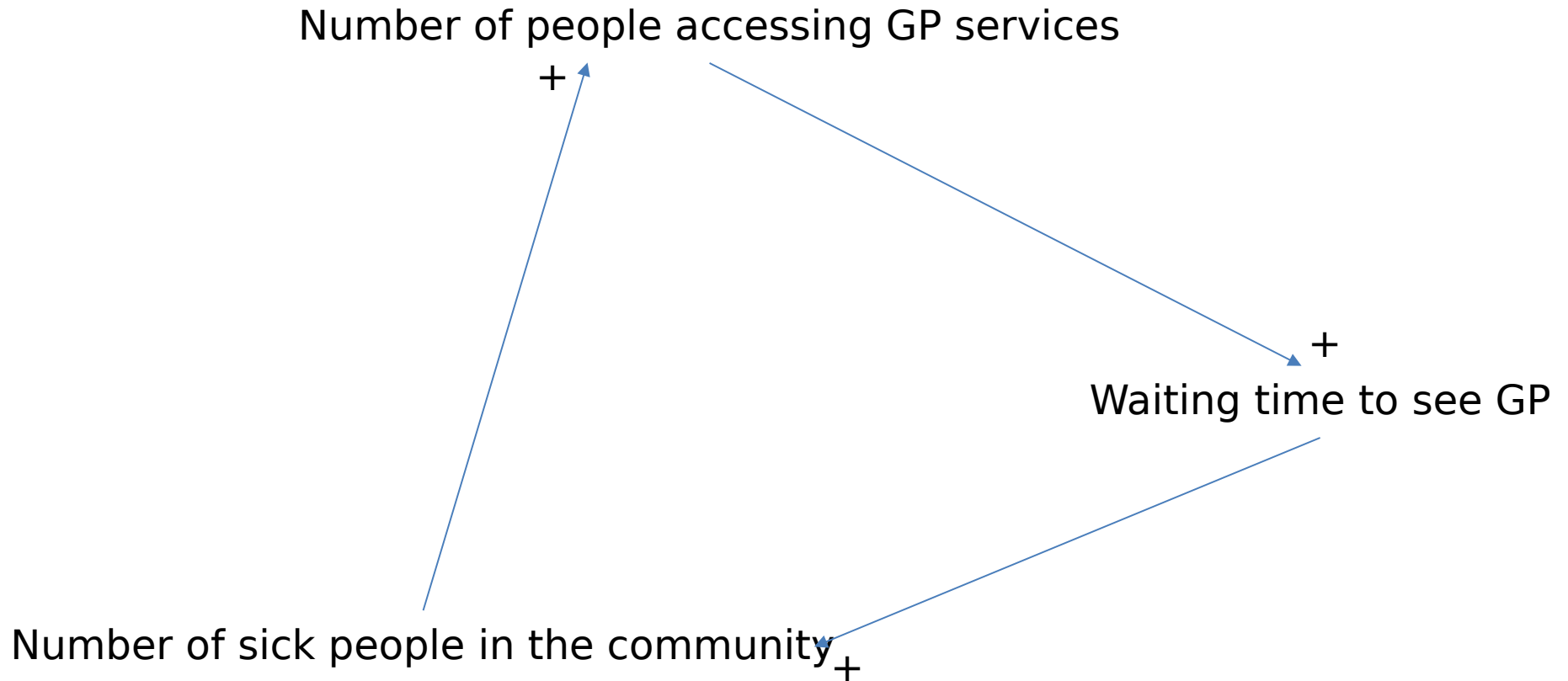
Example influences

Number of people
accessing GP services $\xrightarrow{\hspace{4cm}+}$ Waiting time to see GP

*As the number of people accessing GP services **increases**, the waiting time to see a GP **increases** (Both go in the same direction)*

Number of people
admitted to hospital $\xrightarrow{\hspace{4cm}-}$ Number of beds available
in hospital

*As the number of people admitted to hospital **increases**, the number of beds available in the hospital **decreases** (Each goes in opposite directions)*
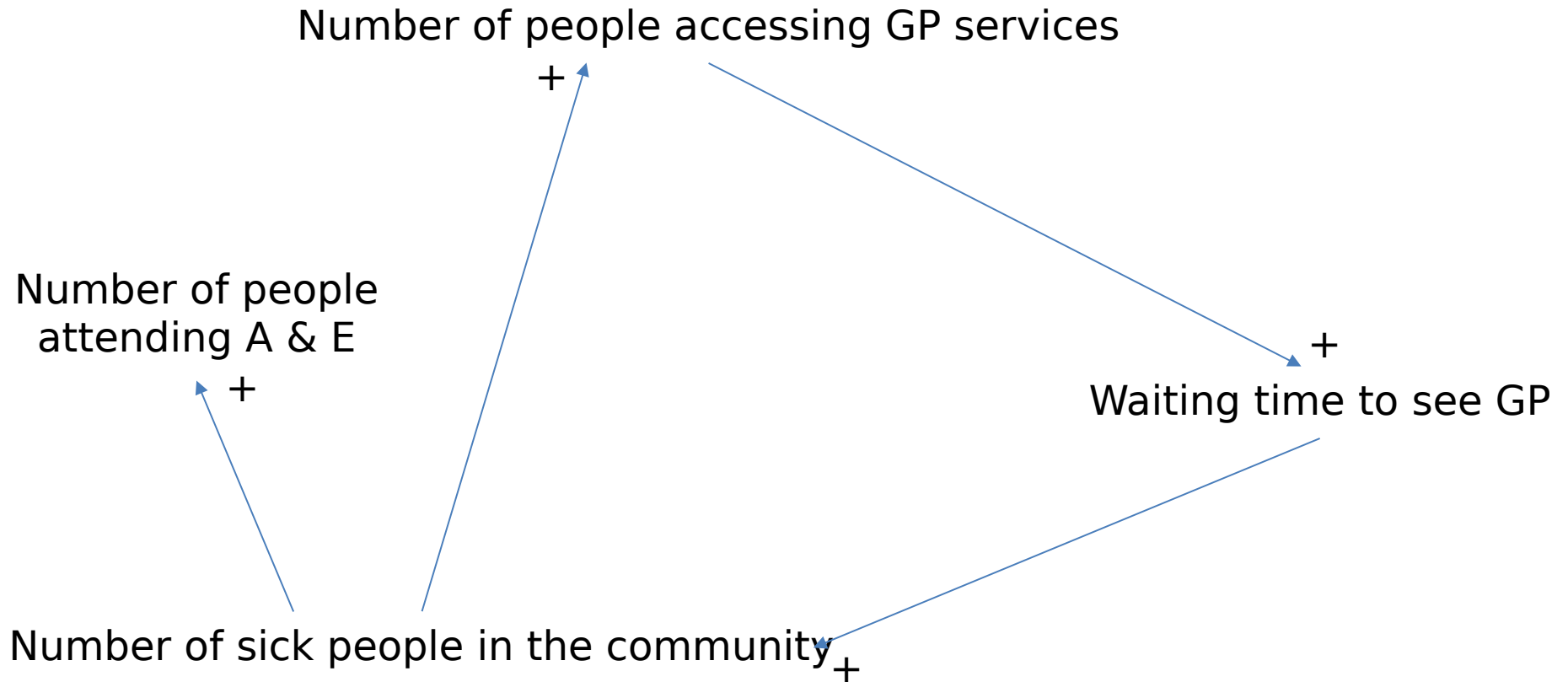
Reinforcing Loops ("Vicious Circles")

Number of people accessing GP services
+

+
Waiting time to see GP

Number of sick people in the community +

*Reinforcing Loops have an **<u>even</u>** number of (**or zero**) minus signs.*
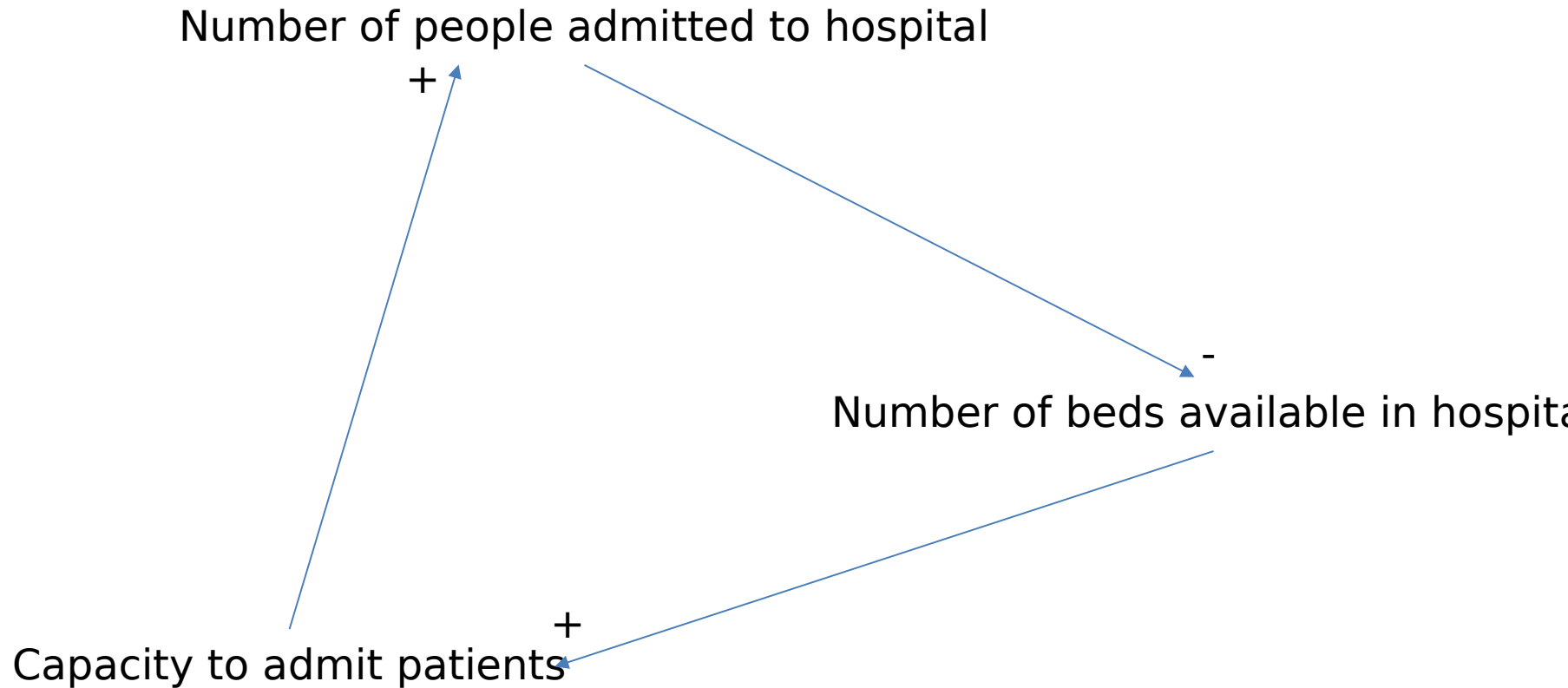*Therefore the **same conclusion is reached each time you loop.***

Reinforcing Loops ("Vicious Circles")

Number of people accessing GP services
+

Number of people attending A & E
+

+
Waiting time to see GP

Number of sick people in the community +

*Reinforcing Loops have an **<u>even</u>** number of (**or zero**) minus signs.*
*Therefore the **same conclusion is reached each time you loop.***

Balancing Loops

Number of people admitted to hospital

+

-

Number of beds available in hospital

Capacity to admit patients

+

Balancing Loops have an __odd__ number of minus signs.
*Therefore a **contradictory conclusion is reached each time you loop.***
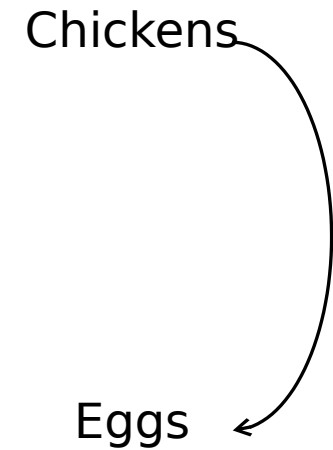
Chicken and the Egg

Let's imagine a simple system. That of the chicken and the egg.
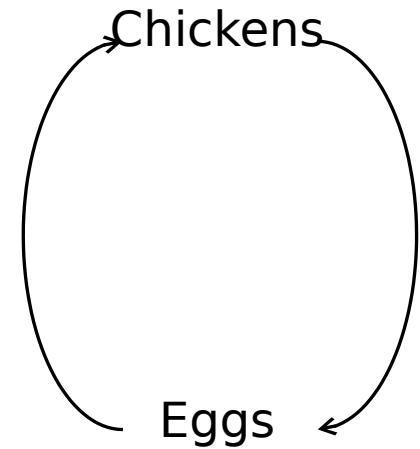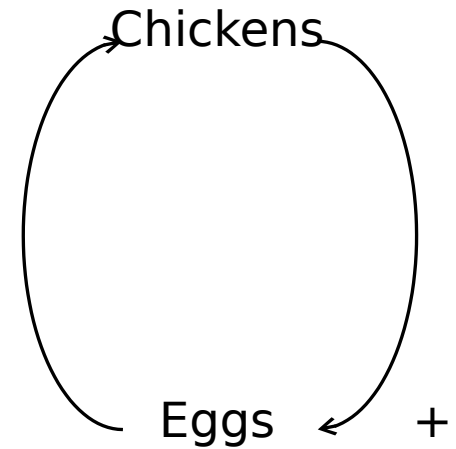
Chicken and the Egg

Chickens lay eggs.

Chickens

Eggs

Chicken and the Egg

Eggs hatch into chickens.

Chickens

Eggs
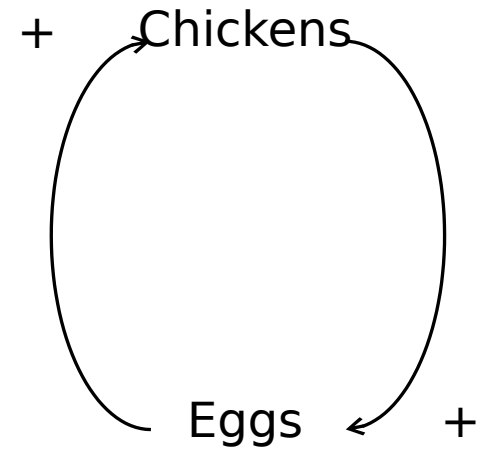
Chicken and the Egg

More chickens mean more eggs laid.

Chicken and the Egg

More eggs mean more chickens hatch.

```
        +    Chickens
              ↗        ↘
            │            │
            │            │
            │            │
              ↘        ↙
             Eggs    ←    +
```

A Reinforcing Loop

Exercise 1

In groups, you will now try building a causal loop diagram that describes the causal influences influencing people adhering to social distancing and other preventative measures during the COVID-19 pandemic.

You should start in the centre of your page by writing a series of entries covering different measures, such as :

Number of people
wearing masks in
required settings
(shops / public
transport etc)

Number of people
staying 2m away
from individuals not
from their household

Number of people
washing their hands
regularly for at least
20 seconds

Next, start thinking about as many factors as you can that *directly* influence each of these numbers, and which are directly influenced *by* the numbers of people adhering to these measures. For each, note with a + or - whether the polarity of the influence is that they both go in the same direction (+) or as one increases, the other decreases (-).

Then, look at whether any of these factors link up with other factors you've identified, and the polarity of the causal relationship. Then, start building out – which factors directly influence the factors that you've identified, and what do they directly influence.

Keep building up your map, and remember to be on the lookout for reinforcing and balancing loops, and note them as you find them. What insights can you draw from your map?

You have 1 hour.

Quantitative System Dynamics

Let's go back to our chicken and egg system.

Here, we can build a *quantitative* System Dynamics model, because we can attach some numbers to describe the *rate of flow* between elements in the system.
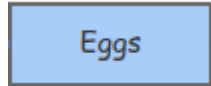
That is, we can say how many eggs chickens lay per unit of time, and how many eggs hatch into chickens per unit of time.

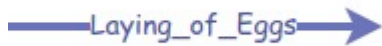But first, we need to understand some core concepts of Quantitative SD Models...

+ Chickens

Eggs +
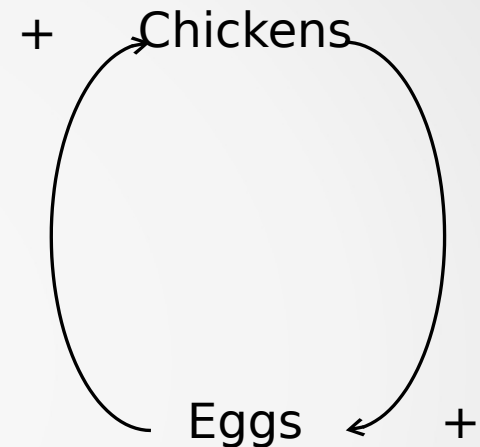
System Dynamics Building Blocks

Here are the key building blocks of a SD model :

Stock : A stock holds the "stuff" that is flowing around the system. Imagine a water tank.

Flow : Flows allow the "stuff" to move around the system. The rate at which the "stuff" flows can be controlled by the valve.
Imagine water flowing through pipes.

Variable : A variable represents something that is not otherwise captured by the model, but will influence a stock's level or a rate of flow.

Link : A link indicates that a stock's level or a flow rate is affected by a stock's level or a variable.
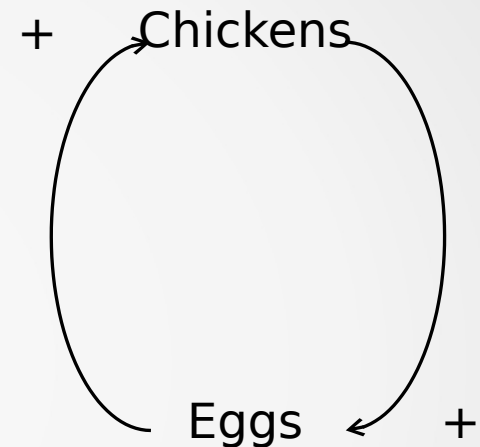
Quantitative System Dynamics

Now, let's say we know that :
- chickens lay, on average, 5 eggs per week
- fertilised eggs take, on average, 21 days to hatch

In our model, we'll start with 100 chickens and no eggs (answering that age old question…)

Let's say we want to track our chicken and egg populations over time.

What do you think will happen in our system?

+ Chickens

Eggs +

Key "Quirks" of SD Models

SD models are a little different from the models that you've seen so far. In particular :

- the entities that are flowing through the model are not represented as individual entities, but as a continuous mass (think of water)
- SD models are not stochastic, but *deterministic*. That means that every time you run a SD model, you'll get exactly the same results.
- with SD models, we're typically interested in generally patterns / dynamics within the system, rather than accurate predictions such as "you need x doctors to meet this demand y% of the time".

Let's look at an example of some of these "quirks" for the Chicken and Egg model. We said that eggs take, on average, 21 days to hatch. Let's imagine we have our time unit representing weeks (as we know chickens lay an average of 5 eggs per week).

How do you think we will describe the number of eggs hatching per week?

Key "Quirks" of SD Models

How do you think we will describe the number of eggs hatching per week?

ANSWER : Number of Eggs / 3

WHY?
If we had 1 egg, it would take 3 weeks (21 days) to hatch. In SD world, this means that one third (or 1/3) of the egg would hatch per week.

If we had 2 eggs, each week one third of each egg would hatch. Which means after week 1, we'd have two one-thirds of eggs hatched (or 2/3 of an egg hatched). Think about it after three weeks, we'd expect 2 chickens. 3 x (2/3) = 6/3 = 2

Essentially, we're saying :
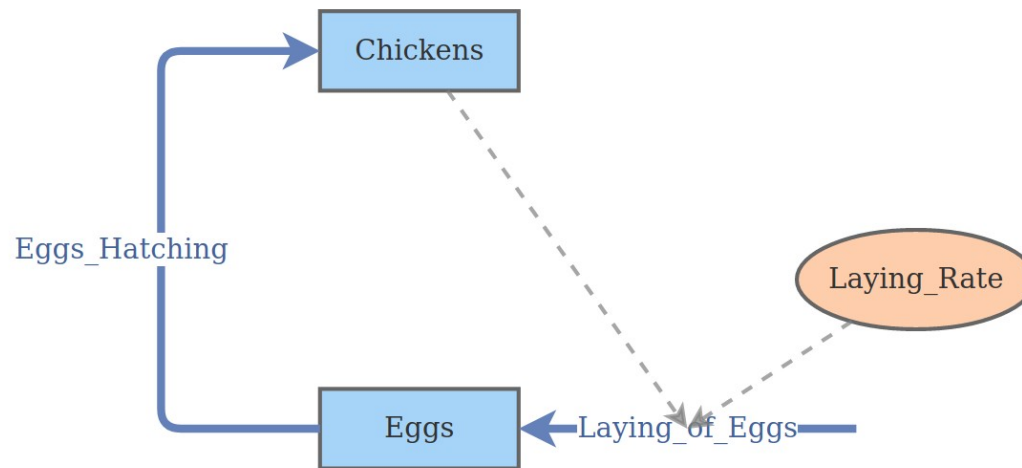eggs hatching per week = number of eggs x 1 / 3 (a third of each egg we have).
Which we simplify to : Number of Eggs / 3
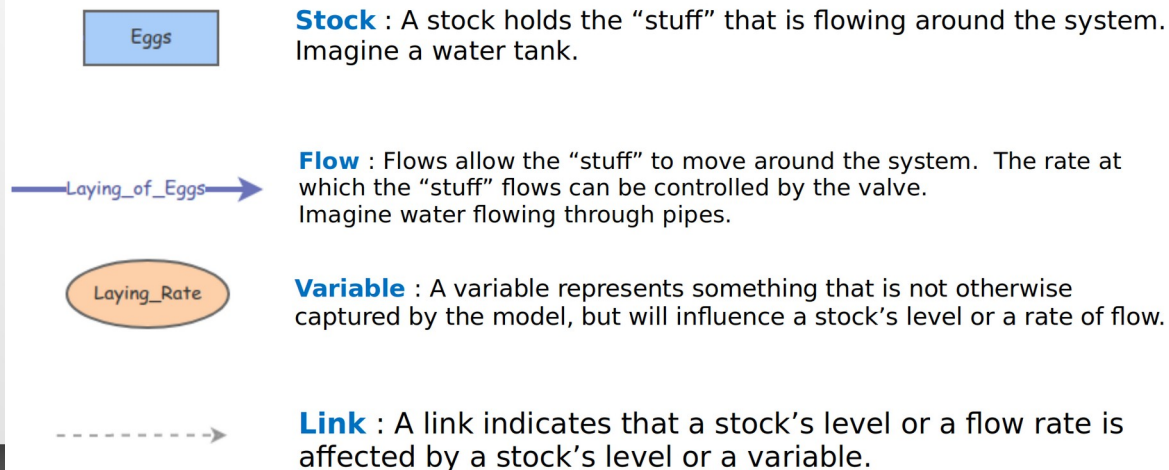
InsightMaker

InsightMaker (https://insightmaker.com/) is an online model building development tool that allows for the development of System Dynamics and Agent Based Simulations.

It uses a simple drag-and-drop interface to allow anyone to put together models quickly and easily, without installing any software, and allowing for models to be shared with anyone anywhere in the world.
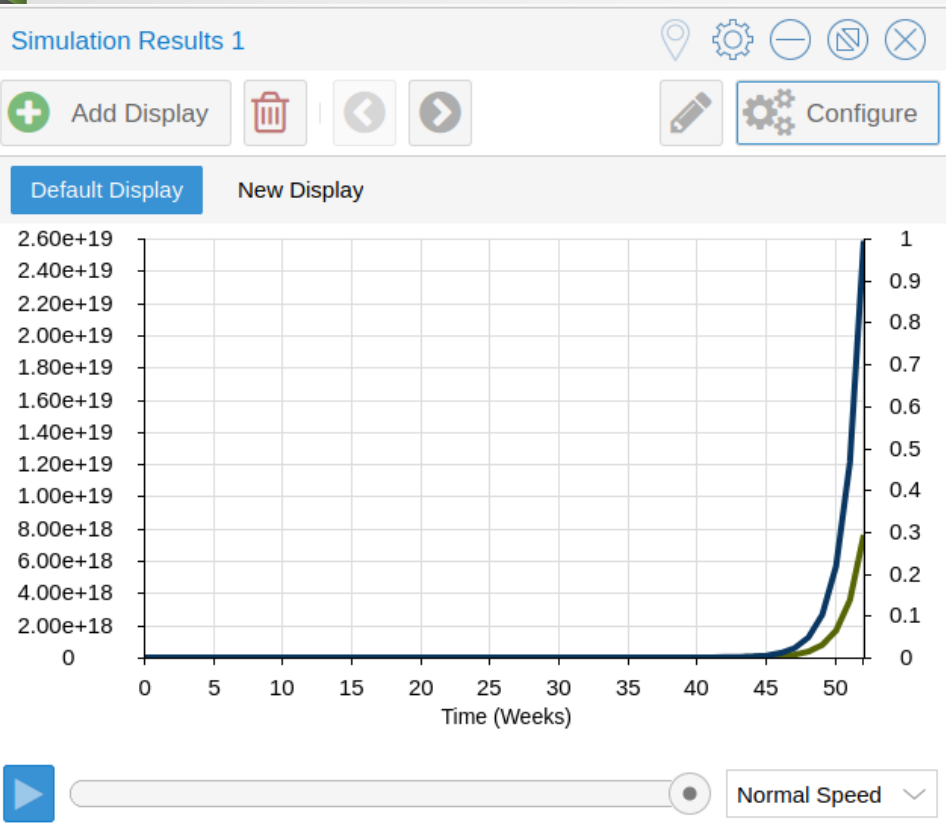
The Chicken and Egg Model

https://insightmaker.com/insight/112161/ChickensEggs

Stock : A stock holds the "stuff" that is flowing around the system. Imagine a water tank.

Flow : Flows allow the "stuff" to move around the system. The rate at which the "stuff" flows can be controlled by the valve. Imagine water flowing through pipes.

Variable : A variable represents something that is not otherwise captured by the model, but will influence a stock's level or a rate of flow.

Link : A link indicates that a stock's level or a flow rate is affected by a stock's level or a variable.

The Chicken and Egg Model

Simulation Results 1

Add Display | Configure

Default Display | New Display

Time	Chickens	Eggs
0	100	0
1	100	500
2	266.666666667	833.333333333
3	544.444444444	1,888.888888889
4	1,174.074074074	3,981.481481481
5	2,501.234567901	8,524.691358025
6	5,342.798353909	18,189.300411523
7	11,405.898491084	38,840.192043896

Download

Normal Speed

100 old + (500 / 3) new

500 previous + 500 new – (500 / 3 ready to hatch)

A Showcase of SD in Action

One of our HSMAs – Dave Spencer – will now present his recent modelling work building a System Dynamics model in InsightMaker to look at the impact of the pandemic on Devon health and social care systems.