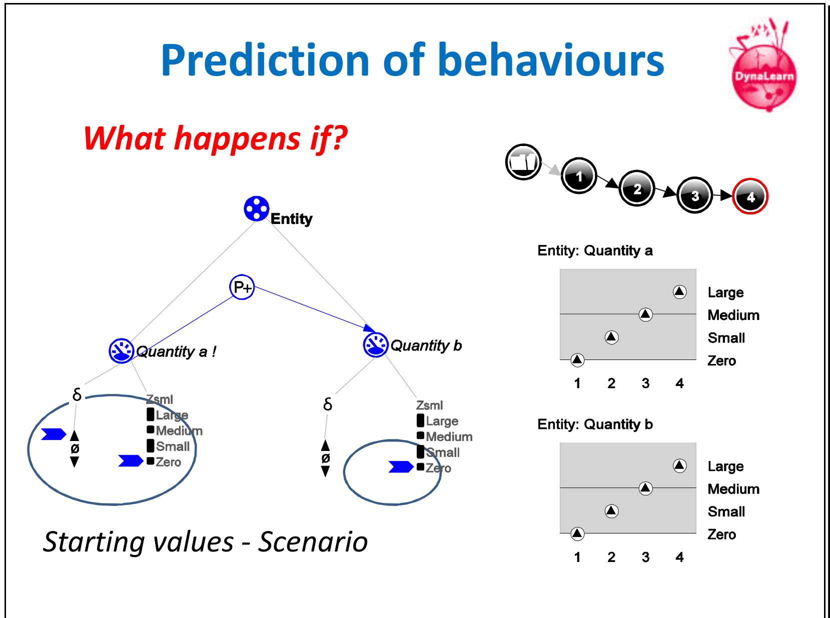
Conceptual Modelling:

How can we qualitatively describe behaviour and causality?

Background

Conceptual modelling using Qualitative Reasoning allows for behaviour to be derived from the structure of a system. Qualitative conceptual models are built by describing the entities that belong to a system, the quantities that characterise the entities and the possible qualitative states the system can be in, the structural relations between the entities (configurations) and any agents that may be acting on the system. To be able to derive behaviour from this system the appropriate causal relations between quantities must be determined. This series of slides presents the different types of relationships between quantities and how these can be used to describe and generate behaviour in simulations.

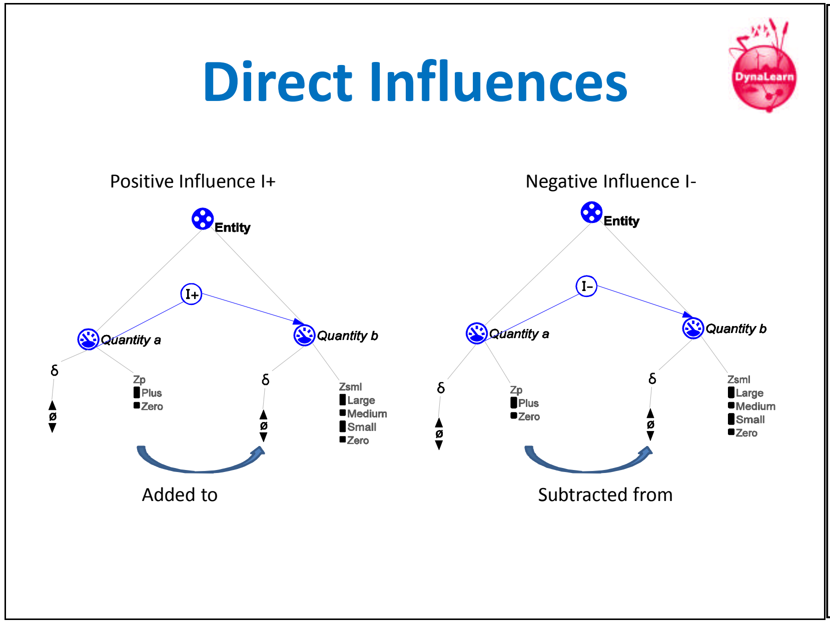


Systems behaviour in qualitative conceptual models is derived through ***simulations*** addressing specific ***scenarios***. These scenarios can be seen as "what if?" questions that can be asked of the model.

For example, in this slide the question "*what happens to **Quantity b** if **Quantity b** starts at Zero and **Quantity a** is Zero and increasing?*" In this question the scenario has specified the starting conditions for the behaviour in terms of the magnitude and derivative of the quantities concerned. To be able to answer this question the modeller has to specify what causal relationship there is between these two quantities. In this slide this causal relationship is represented as a P+ acting from *Quantity a* to *Quantity b* (see later slide for explanation).

This causal information allows the reasoning engine to infer a possible behaviour (a series of sequential qualitative states) for this scenario. This behaviour is presented as a behaviour path and a graphical value history of the two quantities.

In DynaLearn there are two main types of causal relations.



1) Direct Influences

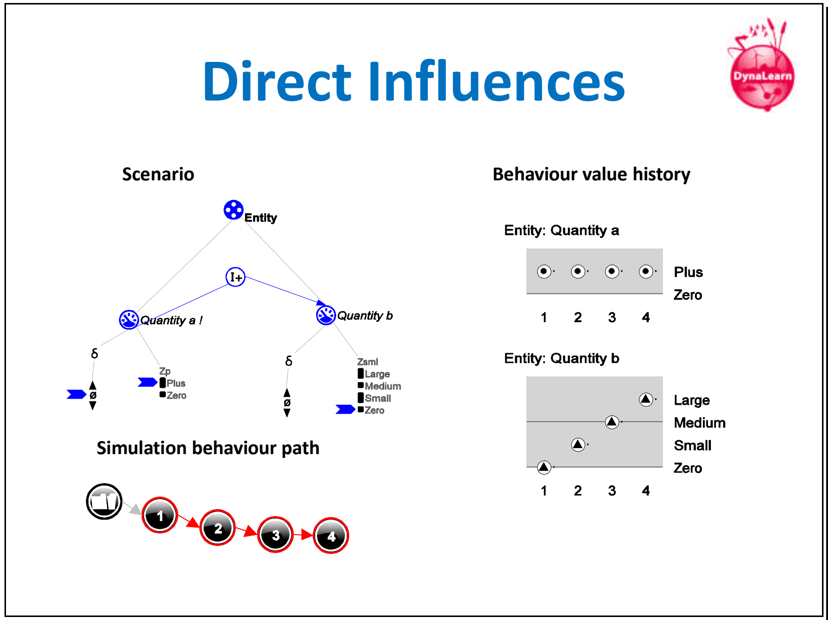
Direct influences are the primary causal relation in DynaLearn and can be seen as the primary cause of change within a system. Fundamentally direct influences "I" represent situations where it is the **magnitude** of a quantity that affects the behaviour of a second target quantity. This is it is the magnitude of *Quantity a* that influences the derivative of *Quantity b*.

There are two types of Direct influence

I+ A direct positive influence – a positive magnitude in *Quantity a* causes *Quantity b* to increase.

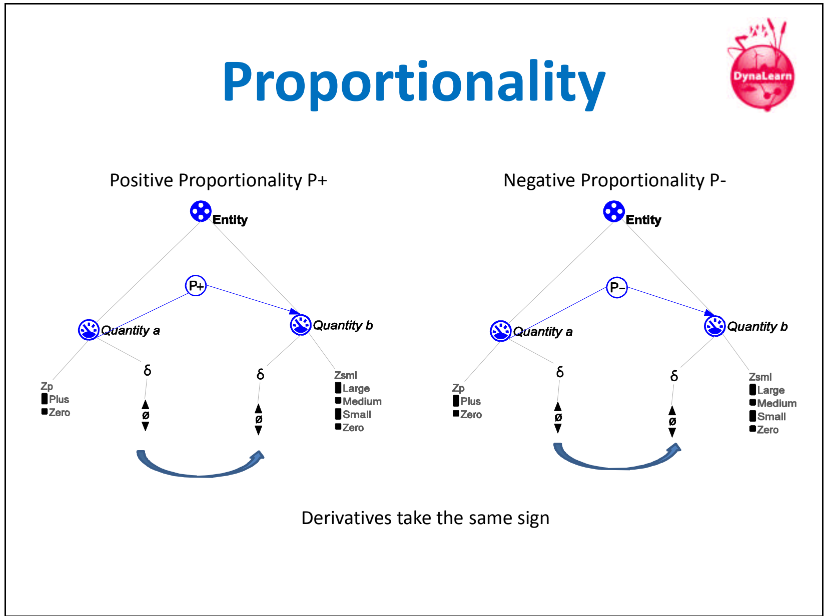
I- A direct negative influence – a positive magnitude in *Quantity a* causes *Quantity b* to decrease.

Direct influences are generally used to represent the relationship between rate variables representing the actions of processes on state variables.



Direct influences act such that it is the magnitude of the rate variable that causes change in the magnitude of the state variable, this causing the state variable to change (have a positive or negative derivative). Therefore, the behaviour of *Quantity b* is independent of the behaviour of *Quantity a*. If *Quantity a* is related to *Quantity b* via a direct positive influence then *Quantity b* will increase if *Quantity a* has a positive magnitude, even if the magnitude of *Quantity a* is itself decreasing or steady. The only way that *Quantity a* would not be affecting *Quantity b* in this sort of causal relationship would be if *Quantity a* had a zero value.

In the example on the left it can be seen that *Quantity a* has a positive but steady value and that due to the I+ relationship going to *Quantity b* that *Quantity b* is increasing from Zero to Large passing through four qualitative states. In all this behaviour the value and behaviour of *Quantity a* does not change.



2) Proportionalities

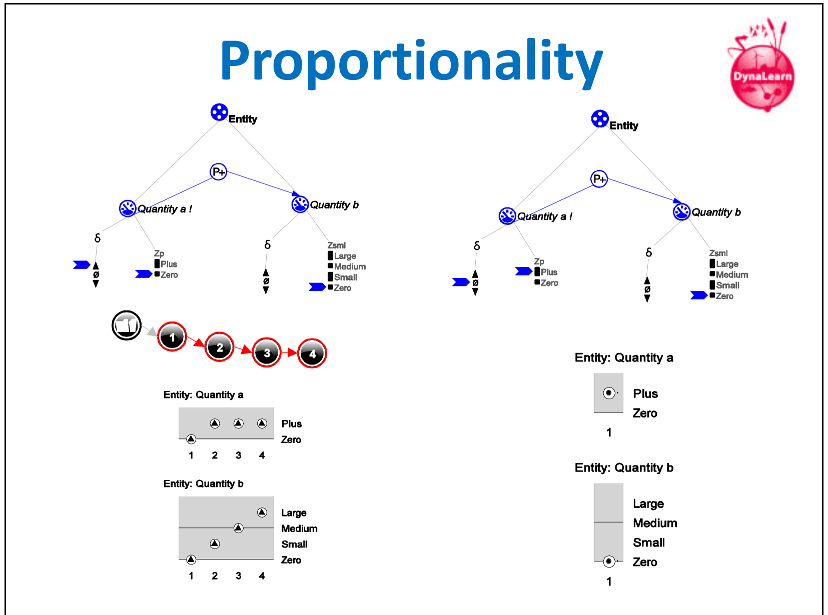
Indirect influences or **Proportionalities** are the secondary causal relations in DynaLearn and can be seen to propagate the effects of change within a system. Fundamentally proportionalities "P" represent situations where it is the **behaviour** of a quantity (state variable) that affects the **behaviour** of a second target quantity. This is it is the derivative of *Quantity a* that influences the derivative of *Quantity b*.

There are two types of Direct influence

P+ A positive proportionality – a positive derivative in *Quantity a* causes *Quantity b* to increase.

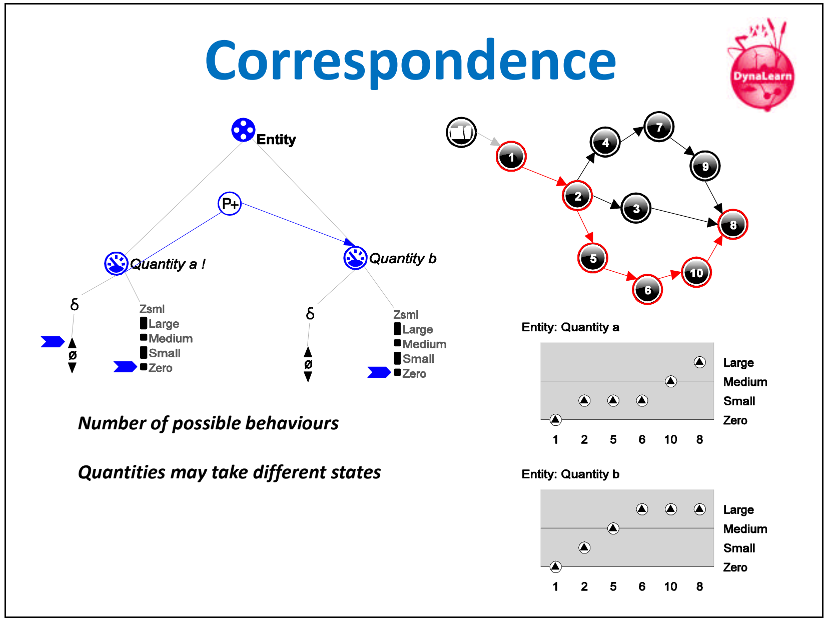
I- A negative proportionality – a positive derivative in *Quantity a* causes *Quantity b* to decrease.

Proportionalities are generally used to represent the relationship between two state variables and represents how the effects processes propagates through different state variables in a system.



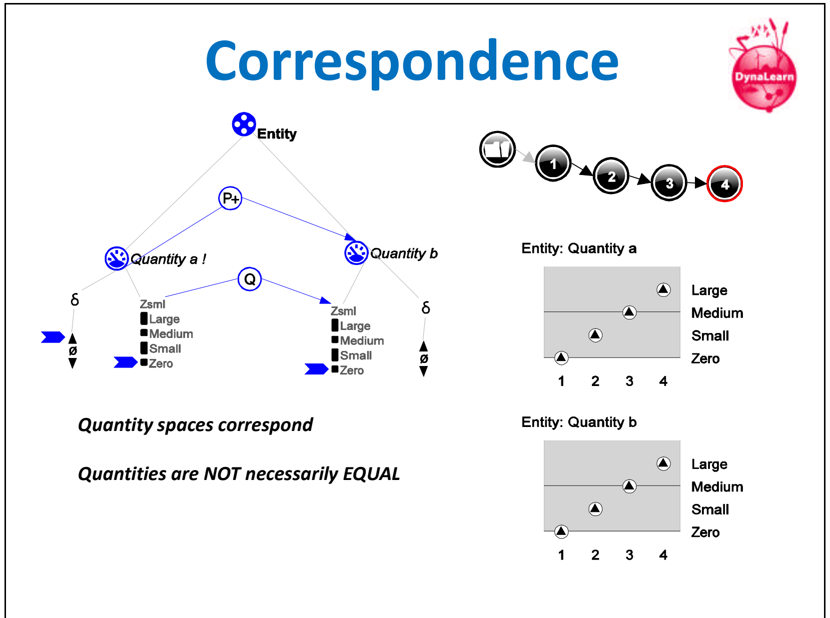
Proportionalities act such that it is the derivative (behaviour) of the first quantity that causes change in the magnitude of the target quantity, thus causing the target quantity to change (have a positive or negative derivative). Therefore, the behaviour of *Quantity b* is dependent of the behaviour of *Quantity a*. If *Quantity a* is related to *Quantity b* via a positive proportionality P+ then *Quantity b* will increase if *Quantity a* has a increasing, independent of the actual magnitude of *Quantity a* itself. The only way that *Quantity a* would not be affecting *Quantity b* in this sort of causal relationship would be if *Quantity a* was itself not changing (steady derivative).

In the examples on the left there are two situations one where *Quantity a* has a zero value but is increasing and one where it has a plus value but is steady. As can be seen in the behaviours and value histories only in the first situation where *Quantity a* is increasing does *Quantity b* change. In the second example even though *Quantity a* has a positive value *Quantity b* does not change because *Quantity a* has a steady derivative.



Given that in qualitative conceptual modelling quantities are described by both the magnitude of the quantity's value and the derivative describing its behaviour, then simulating scenarios and predicting behaviours will require that not only are the causal relationships between the quantities are described (Influences or Proportionalities) but that the relationships between the qualitative states of each quantity (Quantity space values) are also described.

In the example on the left *Quantity a* is related to *Quantity b* via a positive proportionality such that the derivative behaviour of *Quantity b* correlates with that of *Quantity a*. Both the quantities have the same quantity spaces and can exhibit the values Zero, Small, Medium and Large. In the scenario shown both quantities start with a Zero and *Quantity a* is increasing, in this situation a number of different possible behaviours are shown because the model has no information to describe how the quantity spaces of each quantity relate to each other. That is in this situation it is possible for *Quantity b* to have reached a Large value when *Quantity a* is still only Small.



These multiple behaviours are possible because, although the quantity spaces used are similar, the qualitative states used may not represent the same thing for each quantity and indeed for the system in question the values of the two quantities may well be independent. Additionally, there is no assumption (other than for the value Zero) that Small for one quantity space is the same as or even equal to Small for another quantity space.

However, it is possible where appropriate to use quantity spaces to describe the relationship between different quantity spaces, to describe which qualitative states can or must co-occur. There are two main types of correspondence (as well as inverse correspondences of each type):

Full correspondences (Q) – quantity spaces using the same structure can fully correspond (see example in the slide).

Value correspondences (V) – specific values with a quantity space can be denoted as occurring together.