

PROPOSING A CLASSIFICATION OF FEEDBACK LOOPS IN FOUR TYPES

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With this paper a differentiation of feedback loops in four types is proposed. Refining the common twofold classification in “positive” (or “escalating”) and “negative” (or “balancing”) the four proposed types are “enhancing” (indicated by a “+” in causal loop diagrams), “excluding” (“x”), “stabilizing” (“-”) and “swinging” (“~”). In this way it is differed between escalating loops in which all components grow (or fall) together (“enhancing”) and those in which some components grow while others fall (“excluding”). Negative loops with time delays are called “swinging” as they typically loose their ability to balance and rather show oscillating or even chaotic behavior. The relevance of the proposed nomination is shown on examples from population dynamics and traffic as well as on the “Shifting the Burden”-Archetype and the Pig Cycle.

Keywords: causal loop diagram, feedback loop, classification, nomination, time delay, cooperation, competition, predator-prey, shifting the burden, pig cycle

1. INTRODUCTION

Causal loop diagrams (CLDs) and feedback loops are commonly used in systems literature and practice to illustrate the structure and behavior of various systems (Binder, Vox, Belyazid, Haraldsson, and Svensson 2004, Richardson 1986, Senge 1990, Wolstenholme 2003). Yet, the common differentiation used for feedback loops is a twofold one, discerning positive and negative loops. Due to the problem that in many cases positive loops show rather problematic behavior and negative loops usually keep things calm and steady, they are also called escalating and balancing respectively. But by choosing these names, which are accurate in many cases, it can come to misleading interpretations in many other cases. Positive loops are escalating but this can happen in two very distinct ways as shown later and negative loops together with a relevant time delay show oscillating behavior that can even involve escalating oscillations, depending on the time delay and other parameters (Senge 1990).

2. THE SENSE OF NEW ILLUSTRATION METHODS

As stated by Ossimitz (2000) and Ossimitz and Lapp (2006), the known and used illustration methods have an important impact on what and how we think, as well as on how we are able to communicate

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our thoughts to others. The development of systems thinking would not be able without the development of appropriate illustration methods and vice versa. This by itself is an enhancing feedback loop, as both are growing together.

Here we propose an enhancement to causal loop diagrams that should give the ability of new and quicker interpretation of feedback loops.

3. CAUSAL LOOP DIAGRAMS

Causal loop diagrams are a qualitative method of showing systemic interrelations. It is based on cause-and-effect relations between variables and shows its systemic behavior through the combination of several such relations in a network. Each relation is either shown as “positive” (or “reinforcing”, indicated by a “+”) for monotonously increasing or “negative” (“opposing”, “-“) for monotonously decreasing functions between cause and effect.

When combining these relations to a network the focus usually is on feedback loops, as they “are the building blocks of system dynamics”, and, “the essential components and interactions in a system can be communicated quickly and concisely in a causal loop diagram” (Richardson, 1986). There have been wide discussions on the usability of causal loop diagrams as they lack the differentiation between information links and rate-to-level links or flows as in system dynamics models (Richardson, 1986). Binder, Vox, Belyazid, Haraldsson and Svensson (2004) give a concise overview over their current applications: “Causal Loop diagrams (CLDs) have long been used in standard system dynamics practice for purposes connected with simulation modeling. They are nowadays mostly used prior to simulation analysis, to depict the basic causal mechanisms hypothesized to underlie the reference mode of behavior over time, that is, for articulation of a dynamic hypothesis of the system as endogenous consequences of the feedback structure (Randers, 1980, Richardson, 1999, Sterman, 2000). It also forms a connection between structure and decisions that generate system behavior. Later, CLDs have started to be used for purposes not necessarily related to model building, namely, for detailed system description and for stand-alone policy analysis (Wolstenholme, 1999, Homer and Oliva, 2001).

The other common notation for system dynamics and system thinking are Stock-and-Flow diagrams (SFDs). Proponents of CLDs laud their accessibility to non-experts and claim that SFDs are useful only for people who understand how they work. Proponents of SFDs criticize the ambiguity and lack of detail in CLDs which prevents simulation of the modeled systems and prefer at least to start with stocks first (Ford, 1999). Haraldsson (Haraldsson, 2004) and others propose to use CLDs for brainstorming and then to switch to an SFD which models the system exactly.” SFD’s distinguish graphically and numerically between stocks, which are associated with time-points, and inflows and outflows related to stocks, which are associated with time-intervals.

4. RELEVANCE OF FEEDBACK LOOPS

Feedbacks are the essential building blocks of causal loop diagrams as they display the shift from linear cause-and-effect thinking to circular systems thinking. Feedback loops are understood as more than just the sum of their components and are treated as something distinct. In describing causal loop diagrams mostly the behavior of feedback loops is described. Senge (1990) and Wolstenholme (2003) use them to describe archetypes of system behavior.

Consequently feedback loops are assigned symbols to show their behavior. This nomination is based on the influence that one element of the loop has on itself via the loop. Thus it is differentiated between positive feedback loops in which every element reinforces itself and negative feedback loops in which every element opposes itself. Consequently positive loops are also called “escalating” as changes reinforce themselves and negative loops are called “stabilizing” as changes tend to be diminished.

However this definition of feedback loops is still based on the influence the elements have, whereas feedback loops are seen as a distinct wholeness, with behavior that is not only based on what

its components do. Therefore a definition is proposed in this paper that is based on the behavior of feedback loops as a whole.

5. EXCLUDING AND ENHANCING FEEDBACK LOOPS

Positive feedback loops can be seen in two fundamentally different types, which can only be distinguished with the common denomination, when looking at the symbols each link within the loop has, and cannot be discerned when those symbols are missing like in Senge (1990).

Let us look at a simple feedback loop, consisting of just two elements. It is considered “positive”, when either both links are positive or negative (Fig. 1a and b) and can even be seen without symbols upon the links (Fig. 1c).

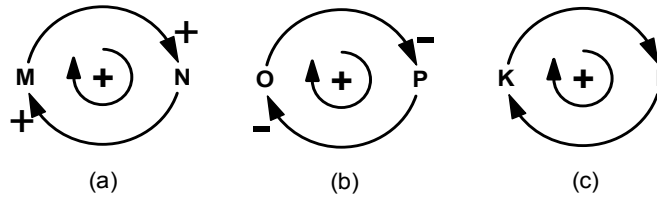


Fig. 1: A simple feedback loop in traditional notation

By showing the symbols upon the links it is obvious that in (a) both elements M and N will grow or fall together, while in (b) one element (O or P) grows while the other one drops. (c) shows a „positive“ or „escalating“ feedback loop. There is no way to say, whether a growth in K will lead to a growth or fall in L.

Yet the behaviour of these loops is totally different: While Fig. 1a can be the model of a cooperative situation in which both sides enhance each other, Fig. 1b shows a competitive situation where every gain of one side causes a loss of the other. The former could be a symbiotic relationship whereas the latter could be a competition for the same food-source between two populations. Hence we suggest to discern between two “subtypes” of escalating feedback. In Fig. 2 these types are discerned by naming the first “enhancing” with the symbol “+” and the second “excluding”, symbolized with “x”.

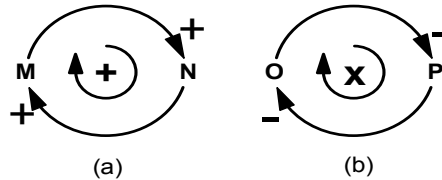


Fig. 2: (a) is enhancing feedback, (b) is excluding feedback. The difference between both types is now clearly visible by just looking at the symbol for the feedback loop.

The proposed differentiation exists on the level of meaning, not on the formal level. By exchanging one element with its opposite, e.g. the gain of customers by the loss of customers, you would get the other type. So formally an excluding feedback loop between O and P would become enhancing between O and -P (not P), but this change would not be meaningful usually.

6. STABILIZING AND SWINGING FEEDBACK LOOPS

Understanding negative feedback loops as stabilizing has to be seen misleading whenever a relevant time delay is present. “Stabilizing” feedback loops with significant delays typically become oscillating and even chaotic, loosing their ability to stabilize the system’s behavior. The behavioral change caused by time delays has been widely discussed, e.g. by Senge (1990).

A predator-prey system is a typical negative feedback loop with time delay. For such cases the term “swinging” seems to be much more appropriate. It is suggested to use the symbol “~” instead of “-“ in diagrams (Fig. 3).

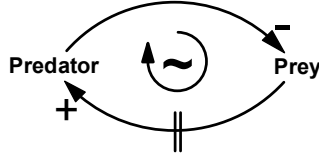


Fig. 3: The swinging feedback loop between predator and prey.

Again this distinction between stabilizing and swinging has to be seen on the level of meaning. There is no common rule that would indicate which time delay causes oscillating behavior, but whenever such behavior is observed or seems to be possible from analysing the model, an indication “swinging” is appropriate.

7. APPLICATION TO WELL-KNOWN EXAMPLES

In order to illustrate the benefits of this distinguishing notation for enhancing/excluding and swinging/stabilizing feedback loops we will present three examples of CLDs.

First we compare a CLD connecting the number of hotels, skiing tourists and the congestion on ski-slopes in a skiing resort with a CLD showing public transportation, traffic by cars and traffic jams. In the classical denotation of feedback loops both CLDs apparently have the same structure, whereas in our proposed classification it becomes clear that the number of hotels and skiing tourists are mutually enhancing while public transportation and traffic by cars are excluding elements.

The same applies to Senge’s (1990) archetype “shifting the burden”: quick fixes and fundamental solution can be seen clearly as excluding in the new classification.

Finally the pig cycle is used as example for a negative feedback loop that is clearly swinging and not balancing.

EXAMPLE 1: Making some structural differences between causal loop diagrams (CLDs) clear.

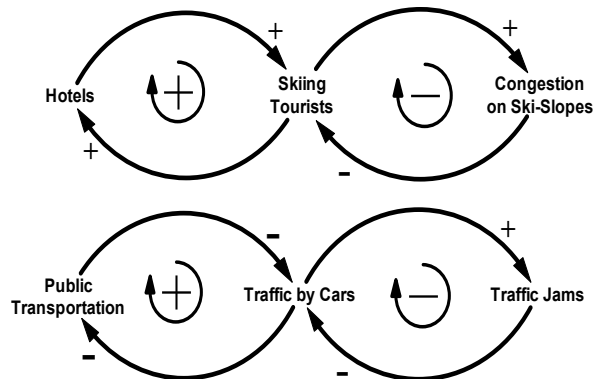


Fig. 4: Classical Notation of CLDs: Both CLDs seem to have the same structure.

In the classical notation the CLDs in Fig. 4 apparently consist of one escalating and one stabilizing loop. One could conclude that they are equivalent. Using the enhanced notation the structural difference between both situations becomes clearer.

In Fig. 5 we see clearly that the traffic induced by cars and the use of public transportation is mutually excluding: the more of the one, the less of the other. This is structurally completely different from the enhancing loop between hotels and skiing tourists.

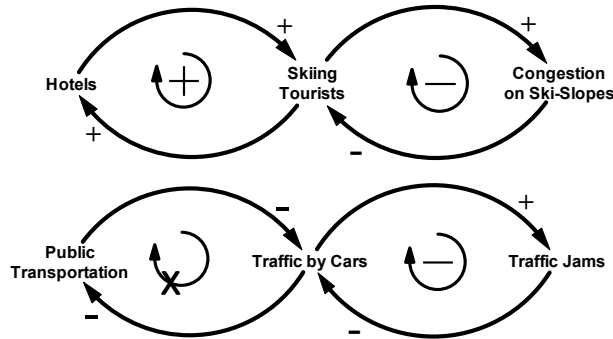


Fig. 5: New notation: The difference between the two examples becomes more obvious; the relation between “Public transportation” and “Traffic by Cars” is excluding while the relation between hotels and tourists is enhancing; thus the symbol “+” gets a refined, new meaning in the proposed classification. The same applies to the symbol “-”, which clearly means balancing and not swinging in this diagram.

EXAMPLE 2: “Shifting the burden”-Archetype (Senge, 1990)

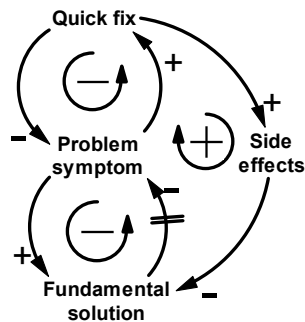


Fig. 6: Classical Notation for the “Shifting the Burden”-Archetype (Senge 1990)

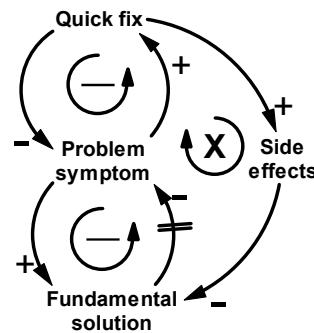


Fig. 7: Extended Denotation shows that “Quick fix” and “Fundamental solution” are mutually excluding.

Using the extended notation in Fig. 7 we find that the positive loop (due to the side-effects) actually is an excluding one. This means practically, that “Quick fix” and “Fundamental Solution” are mutually exclusive. This key aspect of Senge’s (1990) “Shifting the Burden”-Archetype becomes clear in our extended notation.

The enhanced notation in Fig. 9 allows making the key aspect of the Pig Cycle clear: it is swinging, not stabilizing.

8. CONCLUSION AND OUTLOOK

The proposed classification is summed up in Table 9. This summative table shows the usefulness of the proposed classification in comparison with the classical denotation. The major difference between the two types of positive feedback loops and the distinct behaviour of swinging feedback loops is made clear on first sight.

As shown in the table the distinction is based on different criteria for positive and negative feedback loops. Time delays cause a relevant change in behaviour only in negative loops, whereas the question whether elements grow or fall together or opposite does only make sense in positive loops.

This proposal should point on the problems caused by misleading naming of feedback loops and is intended to start a discussion on the topic as well as on the proposed new terms and symbols. It might be useful not to have the common “+” and “-” symbols included in the fourfold nomination to be able to distinguish from CLDs using the twofold method. Else wise it could be useful to start building CLDs in the classical nomination and to add the proposed classification where it seems useful to strengthen the point of excluding or swinging.

EXAMPLE 3: Pig cycle

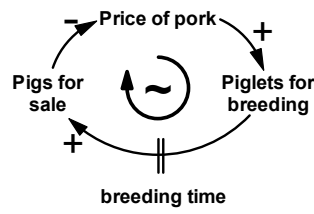
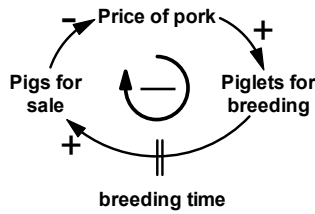


Fig. 8: Classical Denotation of the Pig Cycle as balancing. Fig. 9: Extended Notation highlighting the swinging behavior of the Pig Cycle.

Table 9: Differences between CLD’s classical denotation and the proposed new classification of feedback loops. In the new classification we differentiate between four types according to their distinct behavior. Thus classical positive loops are seen as enhancing or excluding depending on the existence of negative links within the feedback loop, and classical negative loops can be seen as either stabilizing or swinging in the case of a time delay present.

Number of negative links	Time delay	Element’s influence on itself	Classical denotation	Behavior of feedback loop as a whole	Proposed symbols
0		positive (+)		enhancing	
even (>0)				excluding	
odd	No	negative (-)		stabilizing	
	Yes			swinging	

With the proposed classification we want to make the general behavior of feedback loops more easily communicable on first sight and therefore add to the usability of that illustration method in various fields.

Further research on the usability and communicability of the fourfold nomination through reports from systems practice or comparative studies is highly encouraged.

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