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Abstract *Among the several definitions of* system *that exist, there are some that appear more commonly than others, although in slightly different shapes. It is argued that these definitions are not exclusive enough, i.e. things which are not systems could be regarded as systems, according to these definitions. At the same time, there are definitions which are more specific but according to which some kinds of systems would not be systems. Using the underlying assumptions of many authors, a general, more exact definition of* system *is proposed. Central to the definition is to ensure that parts of the system should not be isolated from other parts. This definition is used to define some central systems theory concepts.*

Introduction

There are many definitions of *system*. Even though they might differ in many respects, several of the most common textbook definitions are very similar. At the same time, they, to some extent, lack precision and are somewhat misleading. The motive for writing this article is the thought that the textbook definition could and should be clarified and the idea that a more mathematical definition could provide more precision and clarity. To use mathematical and logical language and symbols has no value *per se*, but is an aid when one desires precise descriptions. Unclear definitions, on the other hand, must be seen as undesirable. Initially, the author had the intention to use graphs (as described in Rosen, 1991), but it would then have been necessary to restrict the scope of the definition to systems which do not have relations of greater degree than two, so that could not be done. There might nonetheless be certain similarities. The reader will notice that all illustrations use directed graphs.

Background: earlier definitions and their weaknesses

The perhaps most common systems definition occurs with some minor variations. "A system", Langefors (1995, p. 55) says: "is a set of entities with relations between them". The definition used by Miller (1995, p. 17) is similar: "A system is a set of interacting units with relationships among them". So is the definition used by van Gigch (1991, p. 30): "A system is an assembly or set of related elements". According to Klir (1991, p. 5).

$$\mathbf{S} = (T, R),$$

> where **S**, *T*, *R* denote, respectively, a *system*, a *set of things* distinguished within **S** and a relation (or, possibly, a set of relations) defined on *T*.

Some other (more clarifying) definitions will be considered below, but let us first consider in what ways these definitions are unclear, i.e. in what ways they could be misinterpreted. Langefors' and Klir's definitions are more or less equivalent. I will use Klir's definition as a case in point to demonstrate some undesirable consequences of these definitions. We shall see that, while

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everything that is a system is covered, not everything that is not a system is excluded.

Assume that we accept Klir's definition. The following would then be a system (with a as its single element):

$$(\{a\}, R) \text{ where } R = \{(a, a)\}$$

Clearly, this cannot be a system, since it contains only one "thing". If we add the condition that there must be at least two "things" in T, would that make the definition correct? No, it would not, and we shall see why.

Consider the following system, consisting of four elements, a, b, c, and d, and a relation, R, where $R = \{(a, b), (b, c), (c, d), (d, a)\}$, as shown in Figure 1. We can consider this a system, and it is a system according to the definition. That is as it should be.

According to the definition, the following examples (as shown in Figures 2 to 4) are also systems:

(1) $T = \{a, b\}$
$R = \{(a, b)\}$

(2) $T = \{a, b, c, d\}$
$R = \{(a, b), (b, a), (b, c), (d, c)\}$

(3) $T = \{a, b\}$
$R = \{(a, b), (b, a)\}$

This is somewhat awkward. System 3 is clearly a system; that is correct. Systems 1 and 2 cannot be systems, because some elements or groups of elements are independent of the rest of the system (if they were supposed to be

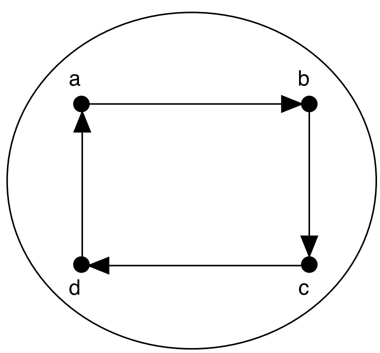

Figure 1.
An ordinary system

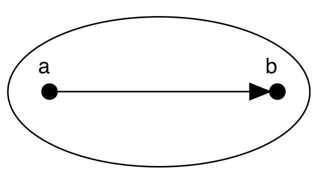

Figure 2.
A system according to Klir's definition (system 1)

concrete systems, this would mean that they did not work as systems). Every definition of *system* must also avoid the following (which the definition used does not):

(4) $T = \{a, b, c, d\}$

$R = \{(a, b), (b, a), (c, d), (d, c)\}$

This system (as illustrated in Figure 5) is not one system, but two.

Situation 1 could be avoided by demanding that every relation be symmetric, but this would be an unnecessarily strong constraint. It would also be possible to change the definition so that it would require every element to have a relation to every other element. This, too, would solve the problem but would be an unnecessarily strong constraint; many things which are systems would be excluded.

Some of the "systems" above do not form an integrated whole, as is required in one of Skyttner's (1996, p. 35) definitions: "A system is a set of interacting units or elements that form an integrated whole intended to perform some

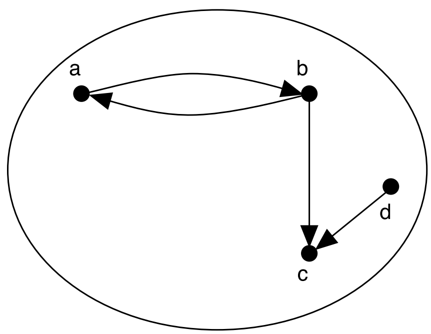

Figure 3.
A system according to Klir's definition (system 2)

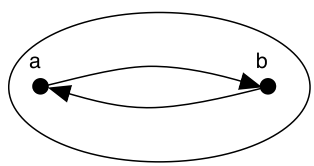

Figure 4.
A system according to Klir's definition (system 3)

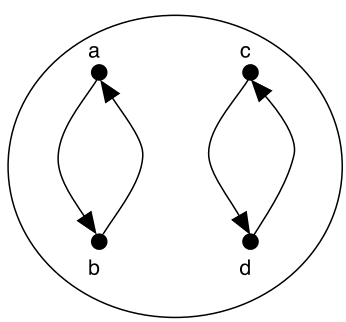

Figure 5.
A system according to Klir's definition (system 4)

function". (The author of this article will not assume that a system has to be intended to perform some function, which will allow him to consider, for example, planetary systems, which, as far as we know, are not intended to perform some function, to be systems.) Nor does every system above satisfy Ackoff's (1981, p. 15) conditions:

(1) *The behavior of each element has an effect on the behavior on the whole.*

(2) *The behavior of the elements and their effects on the whole are interdependent.*

(3) *However, subgroups of the elements are formed, each has an effect on the behavior of the whole and none has an independent effect on it.* To put it in another way, the elements of a system are so connected that independent subgroups of them cannot be formed.

"A system, therefore, is a whole that cannot be divided into independent parts." As you can see, there are in fact independent subgroups in 4, and in 1 and 2 there are elements which either are not affected by or related to the other elements or do not affect or relate to the other elements.

Before attempting to formulate a general definition of the systems concept, something has to be said about what kind of relations might occur in a system and the limitations set by some authors.

von Bertalanffy (1968) and Miller (1995) speak of interaction. Flood and Carson (1993) follow Jones (1982) and talk about how the behaviour of one element is influenced by another element. Ackoff (1981) assumes that the elements are capable of behaviour and that relations affect that behaviour. Jones (1982, p. 44) admits that her demand that "a system element must normally be capable of *behaviour* – that is, it has some significant property or properties which may change [. . .] is not so much a logical necessity as a practical point" (she considers these elements to be of little interest, and this is also the case with certain types of relations). "The idea of a relationship is bound up with that of behaviour. We suggest that a relationship can be said to exist between A and B if the behaviour of either is influenced by the behaviour of the other" (Jones, 1982, p. 45).

The author of this article would argue that, while it is perfectly legitimate to consider only certain kinds of systems (e.g. concrete systems), depending on what one's purpose might be, and not others, there is no reason to a priori restrict the general definition of *system* to those only. If one has defined *system*, then specifications can be added at will. Otherwise, if one is not prepared to give a completely general definition, one should not say: "A system has such and such properties". Rather, one should say: "Systems of this kind/the kind of systems that we are interested in are things that have these properties".

Jones (1982) claims that most of the authors who have defined *system* "seem to state or imply that the relationships are between pairs of elements. It should, therefore, be possible to represent any well-defined system by a network diagram, with the nodes representing the elements and the lines the relationships". This, however, seems most uncertain. Theoretically, a relation could be of any degree, not just binary. In practice, there seems to be at least relations of the degree of three that could be of interest and where there is no clear "direction" of the relationship (the "direction" of the relationships is shown by the use of arrows in Jones' (1982) diagrams). A relation like that would be expressed as, for example, "*a* buys *b* from *c*". The mere possibility that such a relation might occur is enough to justify that they should be regarded.

Thus, the definition will not be limited to any specific kind of relation (like interaction), and it will not assume anything about the degree of the relations in the system.

Definitions

A system consists of a set, M, and a non-empty set of relations on M, R, satisfying the following conditions:

(1) $|M| \geq 2$.

(2) From every member of M there is a path to every other member of M.

Let a and b be any elements of M:

(1) There is a path from a to b, if $(a, b) \in R_1$, where $R_1 \in R$.

(2) Let the relation $R_2 \in R$ and the degree of R_2 be n, where $n > 2$. Let $a_1, a_2, \ldots, a_n$ be members of M. Let $\exists x(x \in \{a_1, a_2, \ldots, a_n\} \wedge x = a) \wedge \exists y(y \in \{a_1, a_2, \ldots, a_n\} \wedge y = b)$. Let R_2 $(a_1, a_2, \ldots, a_n)$. Then there is a path from a to b, and there is a path from b to a.

(3) There is a path from a to b, if there is an element $c \in M$ such that there is a path from a to c and there is a path from c to b.

Simply put, a system has to consist of at least two elements. Since a system is not an aggregate, there must be connections between them. The underlying ideas in Ackoff's (1981) definition are used. The second condition ensures that there cannot be any independent subgroups. In a concrete system, if an element affects parts of the system but is not affected by it, then it is outside the system, and if an element is affected by parts of the system but does not affect any part of the system, then it is outside the system, too. Clearly, if we were to study an organisation and found a person who did not in any way interact with the rest of the system, then we would not say that he/she was a part of it.

It does not necessarily have to be just one type of relation in the system (which is in line with common sense and what Klir (1991) writes).

As an example of the definition, consider the following system: Let the universal set (U) be $\{a, b, c, d, e, f\}$. The system consists of the set $\{a, b, c, d\}$ and the relation $R = \{(a, b), (a, c), (b, a), (c, d), (d, c), (d, b)\}$. There is, for example, a path from a to every element in the system, i.e. c, d, b, and a. On the other hand, there cannot be a system consisting of the set U and the relation $R_1 = \{(a, b), (a, c), (b, a), (c, d), (d, c), (d, b), (f, a), (b, e)\}$ (of which R is a subset). There cannot be any path from any element to f (even though there is a path from f to any other element). Likewise, there is no path from e to any element (even though there is a path from any other element to e). The entities e and f are outside the system (as illustrated in Figure 6).

What could be part of a system depends very much on what relations are considered. For any concrete system on earth, there must surely be a set of relations so that one could claim that everything on earth is related to at least one element in the system and vice versa, but what relations are considered depends on the purpose of the one considering the system.

If an element a is related to an element b, it is not necessarily the case that b is related to a, and, therefore, there can be a path from a to b, while there is not a path from b to a (e.g. a sees b, but b does not see a). The reader might ask why the same notion of "direction" is not applied in the case of relations of a higher degree than two. The reason is that it does not seem meaningful in the same way (and in the case of a concrete system, it is hard to see how elements in such a relation could not be affected by the other ones).

Using these definitions, other basic general systems theory concepts can be defined.

Let S_1 and S_2 be systems, where S_1 consists of the set M_1 and the set of relations R_1, and S_2 consists of the set M_2 and the set of relations R_2:

S_1 is a subsystem of S_2, if $S_1 \in M_2$ or

(1) $S_1 \neq S_2$;

(2) $M_1 \subseteq M_2$; and

(3) for every relation $R \in R_1$ there is a relation $R_3 \in R_2$ for which it is true that $R \subseteq R_3$.

An example of two subsystems can be seen in Figure 7:

S_1 is a suprasystem of S_2, if S_2 is a subsystem of S_1.

A system, S_1, interacts with/affects/has a relation to another system, S_2, if there is a relation between at least one element in S_1 and at least one element in S_2.

From this definition, it follows that, if the system S_3 is a subsystem of S_1 and S_2, then S_1 has a relation to S_2 and S_2 has a relation to S_1.

The definitions above allow us to make a generalisation of the concepts of open and closed systems:

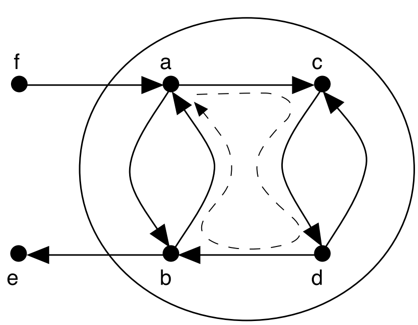

Figure 6.
An example of the definition of system

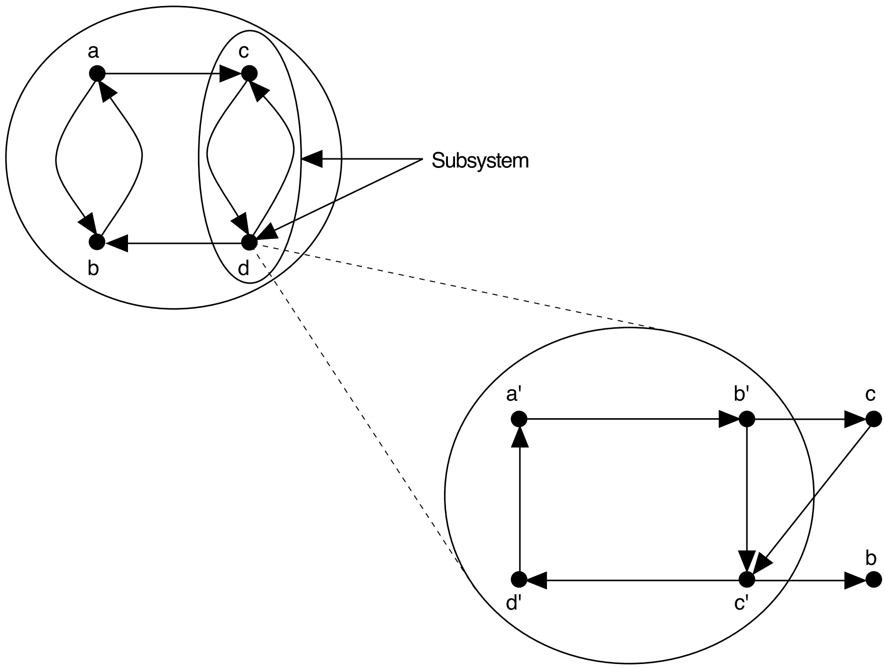

Figure 7.
Two kinds of subsystems

A closed system is a system which has no relation to any other system that is not a subsystem of it and to which no other system that is not a subsystem of it has any relation.

An open system is a system which is not closed.

To specify a particular system one would have to specify the members of M and the relations of R. Other specifics, if any, would also have to be specified, for example, properties of the members of M, properties of the relations of R, and properties of the members of the relations of R, strength of relations etc. Both specific and general rules can be specified, e.g.:

Let $P(x)$ denote the property that x is expensive.
Let $Q(x, y)$ denote the relation that x buys y.
Let a, b, and c be three different persons.
$P(a)$
$\forall x(P(x) \rightarrow Q(b, x) \wedge \neg Q(c, x))$

Discussion

The suggested definition has the following advantages: it is precise, and general systems laws can be deduced from it. Many systems theory concepts can be defined in terms of it. Different types of systems can be defined using the definition. This can be done by adding certain restrictions and characteristics. It does not exclude anything that is a system, as some definitions do (as has been discussed above). It probably does not include anything which is not a system. The treatment of relations with a degree higher than two seems correct in all cases but, even if there would be exceptions, the definition is still not allowing nearly as many non-systems to be called systems as, for example, Klir's (1991) definition, which is one of its greatest advantages.

When studying concrete systems, like organisations, the definition can be used to tell when what is supposed to work as a system in fact does not (assuming that a reasonable set of relations has been chosen by the analyst).

In practice, when modelling a concrete system, it is quite possible that one will find different sets of relations depending on the time span that one considers; for example, if two parts of the organisation communicate once or twice a year, this interaction might very well not be noticed if one considers a shorter time span, say two months; in other cases it might be preferable to consider this as if the relation is sometimes existing and sometimes is nonexistent.

The definition does not require that there should be a path from an element to itself. This follows, however. That means, for example, that every person that is part of a system of people is affected by the way he/she affects others or indirectly affects himself/herself.

Further research

A simple classification of systems could perhaps be based on the greatest degree of the relations in a system. This might provide a measure of how complex the system could be at most in relation to the number of elements and relations. This is an idea that has not been explored in this article.

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