Translation from Natural Language to Stock Flow Diagrams

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Abstract

Mental models are bases to recognise phenomena and make plans to improve situations. They can be expressed in model builders' natural language. It is also necessary to examine mental models using a computer simulation. The Computer simulation requires expressions, which can be translated into computer codes. Therefore, model builders need to translate their model from their own natural language to simulation-friendly language, i.e. stock flow diagrams in System Dynamics. It is widely recognised that this translation is sometimes difficult not only for people who are beginners of System Dynamics but also for people who are experienced in the field. This paper discusses a possible translation procedure and shows an application of it. The proposed procedure is designed to use a subset of a natural language as an intermediate language. This idea is applicable regardless of variety of natural language.

1 Introduction

System Dynamics encourage us to understand complex real systems as a whole and examine one's mental model using computer simulations. It is useful to deal with our social or business issues because our surroundings and our own activities are interrelated and often have time delays. These issues cannot be dealt with in isolation so that we cannot grasp the whole of our problems intuitively.

However, even if one can effectively grasp the whole of one's problem, there is another challenge: making models, which can be examined by computer simulation. It can be defined as the difficulty of translation from mental models to formal models. Mental models can be expressed in model builders' own language and formal models can be expressed in System Dynamics languages. Formal models in System Dynamics language are expressed in stock flow diagrams. Thus, this difficulty can be understood as the problem concerning a translation from natural language to stock flow diagrams.

The reason for this difficulty is still being examined. As Sweeney and Sterman (2000) clarified, it is challenging for most people. Moreover, we know that it is sometimes difficult to understand fully causal relationships from experience. Nevertheless, it is neccesary to obtain formal models from our mental models in order to utilise our understanding or plans derived from our mental models effectively. Practical methods for translation are required.

There are several methods which indicate how to change or translate our mental model from one's natural language to stock flow diagrams. For example, there is a broad employment of nouns in natural language sentences in order to extract elements of stock flow diagrams, or to examine "Snapshot test" in order to discern elements' type: stock, flow, or auxiliary variables (Sterman 2000). Object oriented software development methods also use this approach (Jacobson et al. 1992). It is logically acceptable and model builders should effectively use the method. However, to acquire this thoroughly takes considerable time and the formal model parts corresponding to particular mental model's elements are not always clearly defined.

Richmond (1992) explained how to make stock flow diagrams using metaphor: stock variables are subjective words, flow variables work as verb words for another variable which has a role of subjective words, and auxiliary variables are used as adverb words.

The argument which says his explanation using metaphor is just heuristics or it is also one of metaphor seems persuasive.

Nevertheless, we can find that metaphor helps us effectively not only to learn dynamic systems but also to make our own stock flow diagrams.

Our purpose in this paper is to suggest the translation from our natural language to System Dynamics' language, *i.e.* stock flow diagrams through intermediate language. Using this translation method, model builders can obtain their own mental models in a stock flow diagram style. The intermediate language is a subset of general natural languages derived from all patterns of combinations of variables in stock flow diagrams. The definition of meaning of each variable type is based on metaphor by Richmond (1992).

2 Methods

In order to make a series of expressions for giving mental model descriptions, we define two categories of meaning of diagrams: meanings of each basic variable type and meanings of combinations of two arbitrary variables. As mentioned in the introduction, we employ Richmond's idea concerning meanings of each basic variable type with an additional procedure. In addition, we show a set of natural language expressions, which can be suitable to use in descriptions concerning models' contents.

2.1 Each basic variable type

There are three definitions of basic variable types in stock flow diagrams: stock, flow, and auxiliary variable. Various kinds of System Dynamics simulation software implement other types. However, almost all such variables can be equivalent to combinations of the three basic variables. Hence, it does not cause any problem to omit consideration concerning non-basic variables.

Richmond (1992) explained meanings or roles of basic variables as seen in Table 1. The description is focused on promotion of general readers' familiarity of System Dynamics. It is possible to say that he explained dynamic systems metaphorically. Therefore, it is reasonable that he did not give any mathematical explanations for the relationship between the variable types and meaning in natural language.

Stock Flow Diagrams	Natural Language
Stock variables	Nouns which represent things or status
Flow variables	Verbs which represent actions or activities
Auxiliary variables	Adverbs which change volume of Flow or combine two or more variables consistently

Table 1. The correspondence between variable types and their meanings

This definition of relationship between variable types and their meaning helps model builders to make System Dynamics models. However, when models are constructed using only this idea, the image of each variable can not be clearly classified as to accumulated value or not. In addition, inappropriate variables' names given directly from sentences which describe phenomena bring vague or plural images of values. For example, the sentence "A car runs." can be translated into a diagram in Figure 1. Model readers cannot guess what material flows in this stock flow system. In addition, model readers might not be able to have the image of accumulation of "distance" which model builders have in mind.

In spite of the relationship between descriptions of phenomena and stock flow diagrams encourages model builders to understand what is occurring in objects and make models. In order to make this idea more effective, therefore, it may be beneficial to add two steps to the procedure of conversion from description of phenomena written in natural language to stock flow diagrams.

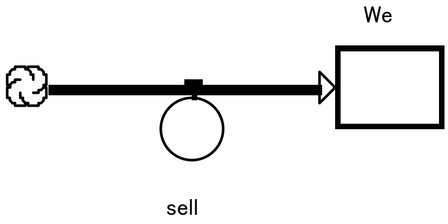

Figure 1. Original diagram
derived from a sentence

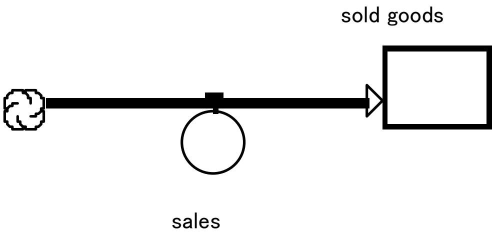

Figure 2. Redrawn diagram
applied the 2 steps in section

The first step: If necessary, change a flow variable's name from a verb or a gerund to a gerund (or equivalent noun) + per time unit.

The second step: Change a stock variable's name from the subject word (noun) of a description about phenomena to its flow variable's name's past participle form + what actually flows in this stock flow combination.

These steps are carried out tacitly when a model builder is well experienced. However, it is essential especially for beginners of System Dynamics or Systems Thinking who really need this kind of guideline.

This changing of variables' names makes their mathematical characteristics and meanings in contexts obvious. For example, the diagram in Figure 1 can be redrawn as in Figure 2.

2.2 Meanings of linkages

Meanings of each variable have been defined using Richmond's metaphor with some extension. Next, we define meanings of each pattern of linkage between two variables in stock flow diagrams.

In this section, we use a typical sample diagram that contains two pairs of stock and flow variables and 2 auxiliary variables (Figure 3). This diagram has all patterns of linkages between any two variables in it. There are 30 patterns of linkage including duplicated patterns, *e.g.* the causal relationship from auxiliary variable A to another auxiliary variable B which has the same structure and meaning as causal relationship having the opposite causal direction in abstract or topological level. Cutting linkage patterns that are duplicated or cannot exist brings only 8 patterns.

We show these causal relationships below with sample sentences which correspond to each linkage pattern.

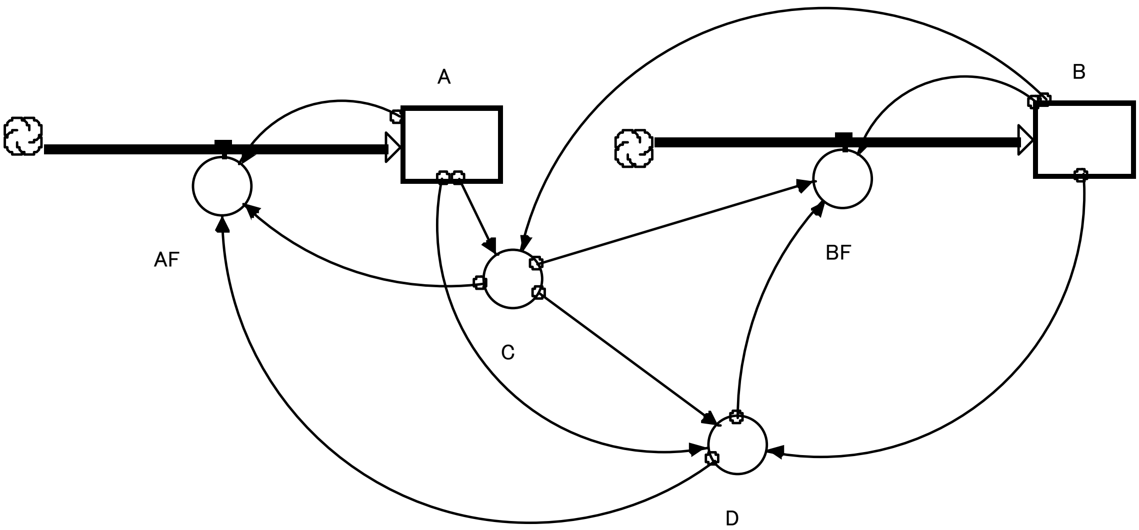

Figure 3. Sample stock flow diagram.

Some possible linkages are omitted.

[1] A stock variable to its own flow variable

(From A to AF and from B to BF in Figure3)

- "More A makes itself grow/diminish more rapidly/slowly."
- "AF equals A."
- "AF is a function of A."

[2] A stock variable to a flow variable which is not connected to this Stock

(From A to BF and from B to AF in Figure3)

- "More A makes B grow/diminish more rapidly/slowly."
- "BF equals A."
- "BF is a function of A."

[3] A stock variable to an auxiliary variable

(From A to C or D and from B to C or D in Figure3)

- "More A, more/less C."
- "C equals A."
- "C is a function of A."

[4] A flow variable to its own stock variable

(From AF to A and from BF to B in Figure3)

- "A's change consists of AF."
- "A increases/decreases by AF."
- "More AF leads to more/less rapid growth/attenuation of A."
- "AF changes A."

[5] A flow variable to another flow variable

(From AF to BF and from BF to AF in Figure3)

- "When A changes more, B changes more/less."
- "The volume of A's change determines the volume of B's change."
- "More AF, more/less BF."
- "BF equals AF."
- "BF is a function of AF."

[6] A flow variable to an auxiliary variable

(From AF to C or D and from BF to C or D in Figure3)

- "More AF, more/less C."
- "C equals AF."
- "C is a function of AF."

[7] An auxiliary variable to a flow variable

(From C to AF or BF and from D to AF or BF in Figure3)

- "More C brings more/less change to A."
- "More C, more/less AF."
- "AF equals C."
- "AF is a function of C."

[8] An auxiliary variable to another auxiliary variable

(From C to D and from D to C in Figure3)

- "More C, more/less D."
- "D equals C."
- "D is a function of C."

Pattern [4] is the most basic linkage; it is a natural characteristic of stock flow structures. Hence, most products of software for System Dynamics simulation produce this linkage automatically.

Each combination has a sentence that contains "is a function of." This expression can be variously changed. For example, "C is part of D," "C is the sum of A and B," and "C is the product of D and A."

Of course, the sample sentences are only part of all possible expressions. It is possible to add more expressions. However, in order to prepare a convenient and simple method of model building, sample sentences should be kept to a minimum.

Using the extended Richmond's idea and this set of sentences, model builders can translate from the descriptions describing phenomena in natural language to stock flow diagrams. Although there are similar expressions in the set of sample sentences, we can determine which structure is suitable for each case in many cases.

3 Application

In this section, we show a sample of translation from a natural language description to a System Dynamics stock flow diagram. This process is achieved through reorganisation of variable names and a transformed story written in limited expressions shown in section 2. In order to clarify our explanation, each sentence is numbered. These numbers are not for indication of time series but for distinctions between the sentences. The sentences that have the same number in an original story and transformed story correspond to each other.

Sample original story:

(1) The number of Theme Park visitors has gradually increased.
(2) The number of the visitors in this year increases by the number of newcomers.
(3) The number of newcomers is affected by media advertisement effect.
(4) The number of visitors in this year consists of the newcomers and repeaters.
(5) The repeat rate is 20 %.
(6) Visitors decrease by the number of non-repeaters.
(7) Experienced people increase by the number of newcomers.
(8) The number of newcomers is declined through growth of the number of people who have already visited.
(9) This is because they are part of inexperienced people.
(10) The number of newcomers is the difference between the population in their commercial area and the experienced people.
(11) The non-repeaters are defined by the repeat rate.

Next, we transform these sentences in order to have sentences, which are easily translated to stock flow diagrams. In this step, it is recommended to unify various expressions of the same ideas in order to keep our models simple and clear. It is not necessary for our purpose. Nevertheless, stock flow diagrams as outputs of this procedure should be simple and understandable. Therefore, the candidates for variables in stock flow diagrams should be reduced beforehand. In this sample case, we do not have these candidates. Moreover, we should delete comments which cannot be used in stock flow diagrams and duplicated explanations. Some comments have important information to define equations. However, we are concentrating on stock flow structure here. In this case, our sentence (8) is a duplicated explanation. This sentence is a shortcut of the causal relationship described in sentences (9) and (10).

Sample transformed story:

(1) [deleted]
(2) The number of the visitors in this year increases by newcomers.
(3) The newcomers are defined by an advertisement effect.
(4) [deleted]
(5) [deleted]
(6) Visitors decrease by non-repeaters.
(7) Experienced people increase by newcomers.
(8) [deleted]
(9) The newcomers are part of inexperienced people.
(10) The inexperienced people are the difference between population in their commercial area and the experienced people.
(11) The non-repeaters are defined by the repeat rate.

Next, we can obtain a stock flow diagram from the transformed story. There are many nouns, verbs and other information. However, they can be assigned one type (stock, flow or auxiliary variable) using the extended Richmond idea (explained in section 2.1) and relationships shown in section 2.2. In this case, it is obvious that each stock flow connection deals with the number of people so that we omit the variable name consideration explained in section 2.1. The areas or elements defined by each transformed sentence are indicated in Figure 4 with numbered dotted lines.

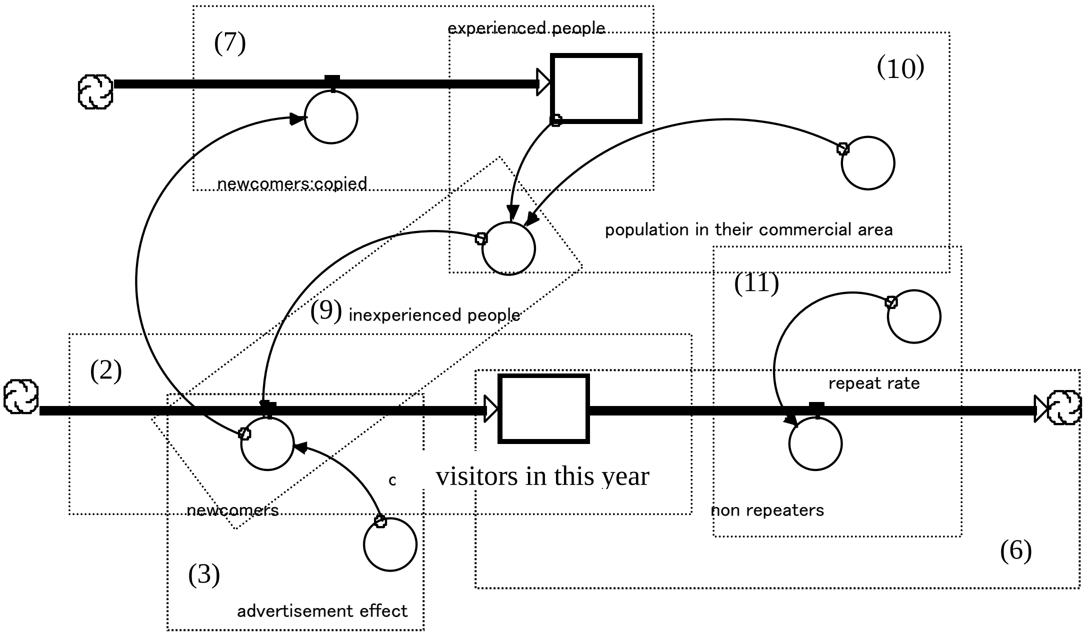

Figure 4. Theme Park Model

4 Discussion

The sample model shown in section 3 can be understood as a sort of a diffusion model. One general method to build the diffusion model is to use an analogy with biological models, *e.g.* spread of infectious disease. Morita (1997) explains the transition of a number of customers Tokyo Disney Resort using the analogy of the infectious model.

This kind of use of analogy often helps model builders. It eliminates time to consider the structure of models. It also allows us not to have to work out the equations. However, it cannot show any evidence that the selected existing model is appropriate for the subject of research. If a model builder does not know the proper existing model, he/she might alter information that correctly describes phenomena in order to fit his idea to the existing model's structure. Moreover, it is possible to prevent him/her from understanding the appropriate system's boundaries.

System Dynamics encourages us to understand a performance and a causal relationship as a whole, not as a divided piece. In order to utilise this point, it is necessary to consider how we deal with model construction not through other people's understanding, *i.e.* existing models, but directly through model builders' own understanding.

5 Acknowledgements

I would like to thank Mr. David Watts (Graduate School of Education, University of Bristol) for his meaningful comments. This research is a part of my productions of “Senshu Research Abroad Program 2003.”

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