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Efficiency, unused capacity and transmission power as indicators of the Triple Helix of university–industry–government relationships

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ABSTRACT

In this paper, we show that an information source composed with n random variables may be split into 2^n or $2^n - 1$ "states"; therefore, one could compute the maximum entropy of the source. We derive the efficiency and the unused capacity of an information source. We demonstrate that in more than two dimensions, the transmission's variability depends on the system configuration; thus, we determine the upper and the lower bounds to the mutual information and propose the transmission power as an indicator of the Triple Helix of university–industry–government relationships. The transmission power is defined as the fraction of the total 'configurational information' produced in a system; it appears like the efficiency of the transmission and may be interpreted as the strength of the variables dependency, the strength of the synergy between the system's variable or the strength of information flow within the system.

1. Introduction

Indicators have become a key aspect of works on university–industry–government relations (Meyer, 2012). Leydesdorff (1991) introduced information theory into research collaboration network analysis. Later on, transmission or mutual information was proposed as an indicator of the relations between university, industry and government (Leydesdorff, 2003). Leydesdorff and Ivanova (2013) and Ivanova and Leydesdorff (in press) dealt with mutual redundancy. So, research collaboration, in general, and university (U), industry (I) and government (G) research relations, in particular, may be measured using information theory tools as stated by Von Bertalanffy (1973, p. 94). Mutual information is interpreted as the extent to which a system is controlled by an actor, or self-organized and mutual redundancy as the positional counterpart of the generation of uncertainty in relational communications.

Several studies used mutual information to analyze university–industry–government relations in different areas (e.g. Khan & Park, 2011; Leydesdorff, 2009; Leydesdorff & Sun, 2009; Ye, Yu, & Leydesdorff, 2013). Mutual information is a scalar (Ivanova & Leydesdorff, in press). It is called 'configurational information' (cf. Leydesdorff, 2003); it has lower and upper bounds that also depend on the system's configuration. Therefore, it may be difficult, even impossible, to compare a system to another or the same system over times with respect to this indicator. For example, how to compare two systems S_1 and S_2 if the upper bound to the transmission of one system (say S_1) is lower than the lower bound to the transmission of the other system (say S_2)? We argue that mutual information is not sufficient for systems' comparison purpose. Doing so may

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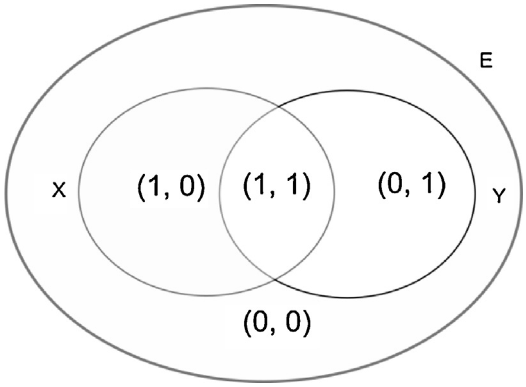

Fig. 1. Events in case of two random variables with alphabet {0, 1}.

lead to misinterpretation or bias. In this paper, we first show that one can split the entropy of a n-dimensional system into 2^n additive parts, each engendered by an atom from the sets related to the considered variables; we derive efficiency and unused capacity to characterize a Triple Helix of university–industry–government relationships system. We propose the transmission power, which relates the absolute value of the transmission to its lower or upper limits.

2. Methodological background

Let us assume that an event occurs with the probability p. Shannon (1948) defined the associated entropy as

$$H = -p \times \log_2 p - (1-p) \times \log_2(1-p) \quad (1)$$

where $\log_2$ is the logarithm to the base 2; the entropy may however be computed to other bases e.g. 3, 4, etc.). More generally, if $X = (x_1, x_2, \ldots, x_n)$ is a random variable and its components occur with the probabilities $p_1, p_2, \ldots, p_n$ respectively, then the entropy generated by X is (Shannon, 1948; Shannon & Weaver, 1949):

$$H_X = -\sum_{i=1}^{n} p_i \times \log_2 p_i \quad (2)$$

For two random variables X and Y (two dimensions), the joint entropy H_{XY} is

$$H_{XY} = H_X + H_Y - T_{XY} \quad (3)$$

T_{XY} is called mutual information or transmission. It is lower than or equal to H_{XY}.

$$T_{XY} = H_X + H_Y - H_{XY} \quad (4)$$

In case of three random variables X, Y and Z (three dimensions), the joint entropy is (Leydesdorff, 2003; Leydesdorff & Ivanova, 2013):

$$H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \quad (5)$$

and the transmission is:

$$T_{XYZ} = H_X + H_Y + H_Z - H_{XY} - H_{YZ} - H_{XZ} + H_{XYZ} \quad (6)$$

3. Splitting a composed source into its states

An information source is a random variable that produces symbols (Cover & Thomas, 2006; Le Boudec, Thiran, & Urbanke, 2013; Mori, 2006; Shannon, 1948). An information source may also be composed of two or more random variables. Assume that the values of the random variable are “0, the source does not produce” and “1, the source produces”. We build, by this way, the alphabet $A = \{0, 1\}$ of a source with only one random variable; its cardinality is 2. If the source is composed with two random variables, then the alphabet becomes $A \times A = A^2 = \{0, 1\} \times \{0, 1\} = \{(0, 0),(0, 1),(1, 0),(1, 1)\}$; its cardinality is $2^2 = 4$. Each element of the source’s alphabet constitutes an event. Then, the entropy of the source is:

$$H_{XY} = -p(0,0) \times \log_2 p(0,0) - p(0,1) \times \log_2 p(0,1) - p(1,0) \times \log_2 p(1,0) - p(1,1) \times \log_2 p(1,1) \quad (7)$$

Using the Venn diagram, the events of which probabilities are referred to in Eq. (7) may be represented like in Fig. 1 where E stands for the universal set, X the subset engendered by the random variable X and Y that of Y.