Shakespearian information: Transfer entropy of associated character interactions within Much Ado About Nothing.

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The classical Shakespearian comedy Much Ado About Nothing is analyzed for the amount of information present in the character patterns between its scenes. This measure, known as transfer entropy, displays a sizable deviation from random. These deviations imply that characters within this play carry more information in their pasts about their own futures, than do other characters about their futures. Additionally, projected target-source character pairs display higher than average transfer entropies, given the later's compulsory occupations at the receiving end of ploys by the former.

I. INTRODUCTION

Shakespeares prowess as a playwright requires no introduction [1–3]. As such, Much Ado About Nothing (MAAN), one of Shakespeare's most renowned comedies was deemed an appropriate test case for the application of transfer entropy (TE) measures on the structure of character interactions within performance art [1]. The motive for application of an information measure to performance art is twofold: (i) Are patterns present within character interactions of this art which reveal the plot, either purposefully by the author or subliminally, and (ii), can the information architecture itself be used as a fingerprint of the playwright given the potential for it to derive a sizable amount of its behavior from the subconscious proclivities of the playwright.

Equity of causal efficacy does not exist for characters within performance art. Major characters drive the plot and the behavior of others more significantly than do their minor counterparts. It is possible that this heterogeneity may be captured by the TE conveyed between various character pairs.

TE is an information measure used to asses the amount of information gained about the future state of a target object by knowing the history of a separate source object [4]. Within the context of performance art, this may be understood as the future presence of specific characters (targets) based on the current presence of others (sources).

MAAN is hypothesized to have high transfer entropy values for specific character pairs given the structure of its interwoven plots. The play revolves chiefly about two separate ploys. Each ploy is designed to trick specific characters into performing actions of which they themselves would never willingly engage. The first is designed to spur love where it is not, the second, to divide it where it naturally arises. Hereafter these plots will be referred to as the love-plot and the hate-plot, respectively. Though the play begins with each ploy sharing the spotlight, the hate-plot dominates the penultimate moments. If all pairwise character interactions are consider for TE, it is predicted that the masterminds of these plots may impart an increased knowledge about the future states of their targets, relative to their targets own histories.

Therefor, of the myriad other interactions taking place within the play, it may be expected that Don Pedro, Claudio, and Leonato, share a high transfer entropy with the targets of their love-plot, Beatrice and Benedick. Meanwhile Don John, Conrad, and Borachio might share high transfer entropy as well via the hate-plot upon Claudio and Hero.

II. MODEL DESCRIPTION

In order to apply TE to Shakespeare's work, the original written form of MAAN was divided according to its 17 natural scene, and then into sub-scenes (66 in all). The sub-scene division was necessary in order to reflect both character entrances and departures from the stage, signifying natural divisions in the dialog. In this formulation characters are represented as nodes, while interactions between characters are represented as edges. All characters present in a given sub-scene were given credit for their participation with each other in the form of unit-weight edges. For example, if Boratio and Claudio are engaged in a dialog, and Hero later enters the scene, Boratio and Claudio will be given a unit towards their edge weights for both sub-scenes, whereas Hero will only get a single unit weight for her participation in the second of these two sub-scenes. The pairwise interactions between all participants within all sub-scenes of a scene were then summed, providing the weight of the edge between them (such as that displayed in FIG. 1 for the total play) before being converted to boolean values of either present or absent for further use in TE measurements (FIG.'s 2 and 3). Boolean values were selected based simply on non-zero edge weights per scene.

TE was calculated via

$$T_{Y\to X} = \sum_{(x_n^k, x_{n+1}, y_n)} p(x_n^k, x_{n+1}, y_n) \log_2 \left(\frac{p(x_{n+1}|x_n^k, y_n)}{p(x_{n+1}|x_n^k)} \right)$$

where Y refers to the the source node and X the tar-

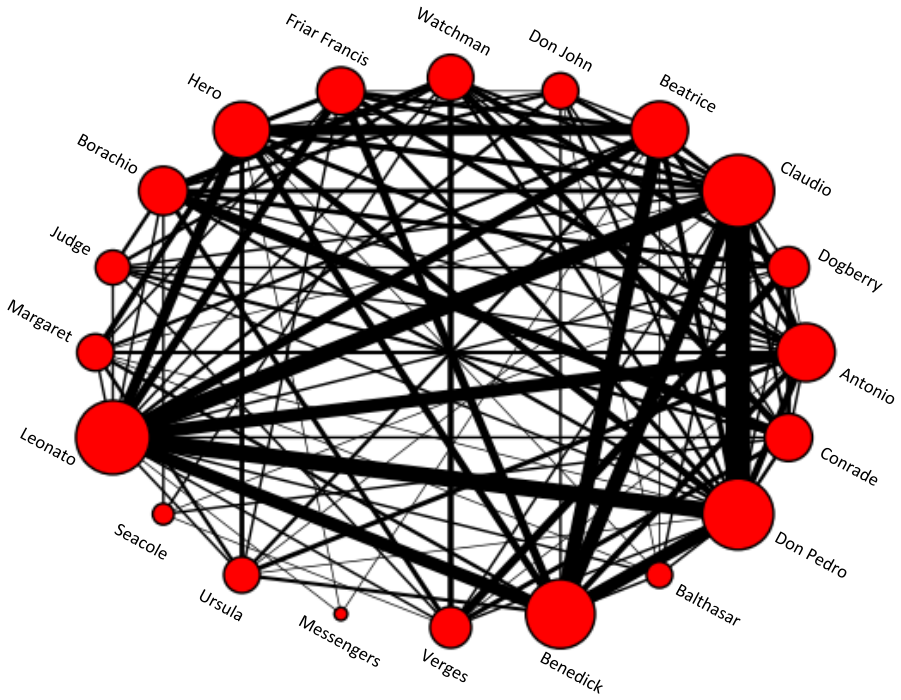

FIG. 1. The summation of all character interactions for the entire play. edge weights reflect total communication, where as the size of the nodes reflect the summation of all incoming communications from any other node.

get. n is an index used to signify the reference time step (scene), and k refers to the history length of the target being compared to be influence of the source [4]. k = 3 for the results in FIG.'s 2 and 3. Values from 1 to 8 were investigated, with 1-4 displaying similar curve behavior and higher values calculating much lower overall TE (data not shown). The summation states that all possible combinations of states will be considered for all possible time steps of length k+1. In short, the above equation compares the amount of information contained within the self-history of character X as to its own future state, with the increased amount of information which would be gleaned if the current status of character Y is known. Therefore TE references the affect of character Y on character X. It is important to note that the two characters do not actually need to interact directly (see FIG. 2). What is being measured here is the patterns which exist within their on-stage appearances, independent of any direct interactions.

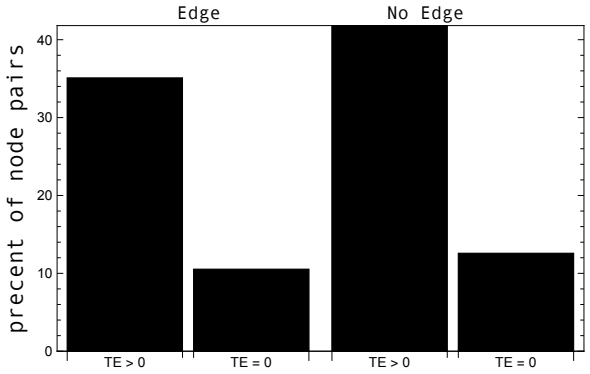

FIG. 2. Percentage of all node pairs categorized by the presence of a connecting edge, and the presence of a non-zero transfer entropy for the couple

III. RESULTS

An overview of all character interactions is displayed in the circular network diagram of FIG. 1. Here, the weights of the connecting edges reflect the total interactions between any two characters throughout all scenes of the play, with the size of the individual character nodes reflecting their total incoming weights. The major and minor characters behave accordingly here, with Claudio, Don Pedro, Leonato, Benedick, Beatrice, and Hero being responsible for the most total interactions, and all accessory individuals relegated to few total interactions. Don John, despite his roll-out of the hate-plot and its cascading effects is nonetheless responsible for relatively few

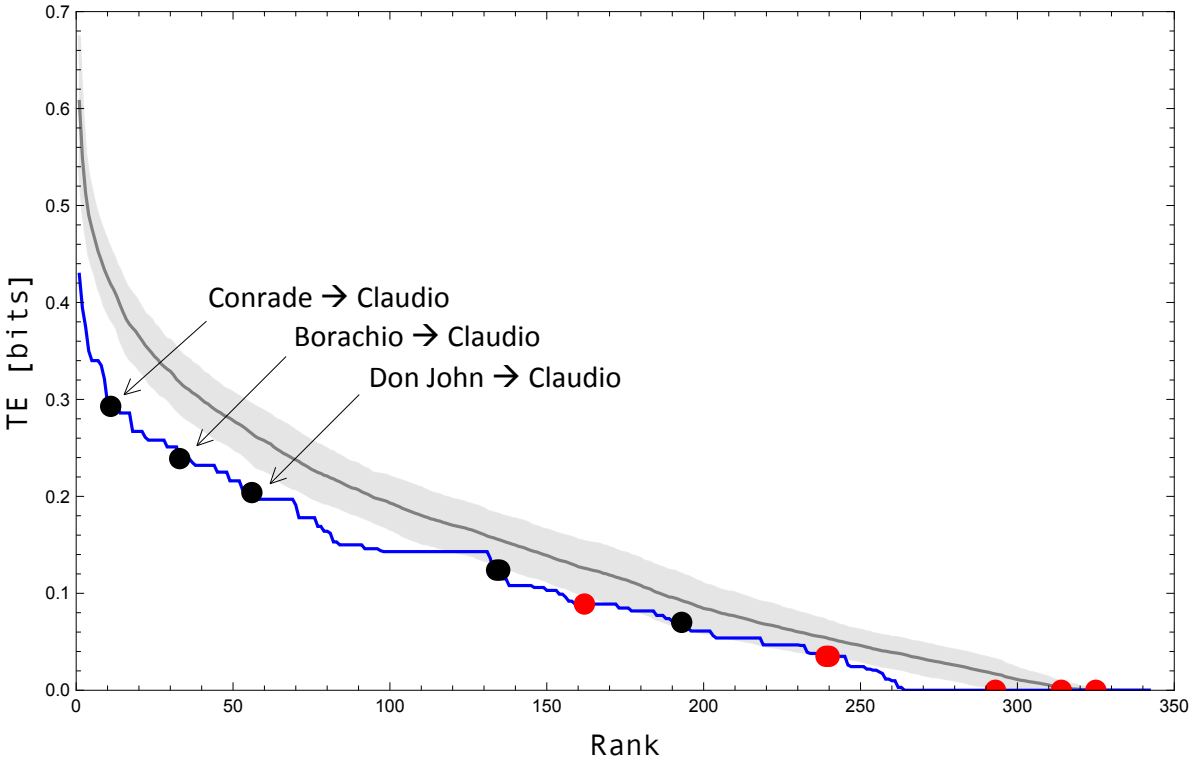

FIG. 3. TE of all node pairs in rank order. The blue line reflects the characters in the play, where as the gray line and associated soft gray region reflect randomized interactions and single the standard deviation region. History length k = 3. Black dots signify the affects of hate-plot perpetrators (Don John, Conrad and Borachio) on Claudio and Hero, with Red dots signifying the effects of the love-plot perpetrators (Don Pedro, Leonato, and Claudio) on Benedick and Beatrice.

interactions, however this is also to be expected. After initiating his plot, he made relatively few appearances, instructing his henchman Conrad and Borachio to carry out the misdirections required to see his plan to fruition.

The transfer entropy statistics displayed in FIG. 2 evidence a system where the majority of node pairs (77%) contain a non-zero transfer entropy. Slightly more than half of which, do no share an edge with one another (42% vs. 35%). The lack of edges existing between character pairs which display positive TE is expected, given the oscillatory structure of the plot sequence, whereby the love and hate plots are visited in a semi-deterministic alternating fashion. As noted above, direct interaction is not necessary for positive TE values, simple correlation of appearance patterns is sufficient, even if those patterns are offset in time.

FIG 3 displays the TE of all character pairs in rank order (blue lines) against a randomly generated network of character interactions (gray line with + - 1 SD gray region). The random rank ordered TE was generated by randomly setting a character as either present or absent in a given scene, constrained only by the total number of characters present for the entire play, which was set equal to the value of the real data.

It is of note that the entire TE character line is below that of the randomized network, and except for one location, is also below one standard deviation.

IV. DISCUSSION

When the transfer entropy is viewed in rank order against randomized networks (blue line in FIG 3 against the gray region), it becomes apparent that the sequence

of source character appearances imparts less information on the targets than if the characters were brought in at random. Thus, the characters appear to contain more information about their future in their own pasts than if their pasts were randomized, and this has the effect of decreasing the influence of other characters relative to the random associations. Still, we consider which characters have the greatest predictive capacity on the future of others (high TE values skew to the left of FIG. 3. The seven highest values for transfer entropy (not explicitly labeled) imply that only three characters, Conrad, Borachio, and Don John impart the most information about the future states of other characters, most specifically Benedick and Claudio.

This result is entirely fitting given the roles of these three in perpetrating the penultimate hate-plot on Claudio. The specific effects of all three perpetrators on Claudio are directly identified in FIG. 3. The relative placement of the love-plot (red dots) vs. the hate-plot (black dots) also appears to fall in line with their changing relative importance as the play matures.

This first pass at applying TE measures to performance art suggests trends which may be uncovered through comparison to other works. Do all artistic performance pieces display negative deviations from random in their TE measures? Can distance from random be correlated with qualitative measures of the same works given artistic focuses on suspense? Can the shape of the curve be further associated with style of individual playwrights? Potentially even to the point of inferring authorship?

Thus, application of TE measurements may be used to unveil quantitatively accessible trends which may be pitted against qualitative assessments of the worth of such art.

[1] Shakespeare W. Much Ado about Nothing: By Shakespear. R. Walker , Change-Alley, Cornhill; 1735.

[2] Shakespeare W, Budd FE. Much ado about nothing. Cambridge University Press; 1936.

[3] Ornstein R. Shakespeare's comedies: from Roman farce to romantic mystery. Newark [Del.]: University of Delaware Press; London; Cranbury, NJ: Associated University Presses; 1986.

[4] Kim H, Davies P, Walker SI. New scaling relation for information transfer in biological networks. Journal of The Royal Society Interface. 2015;12(113):20150944.