Recognizing Deception in Trajectories

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Abstract

This study examines how the movement patterns of individuals may reveal their intent. Subjects were asked to deceive an imaginary observer using a paper-and-pencil test. Geographical and qualitative methods were used to analyze the data. The results showed that deceptive intent can be detected in the subjects' trajectories. Additionally, conformity of trajectories was observed.

Keywords: Cognitive Science; Representation; Pattern Recognition; Human Experimentation; Spatial Cognition.

Introduction

We know that physical signs can be revealing. For example, Ekman has convincingly argued that micromovements of facial muscles during conversation correlate with lying (1969). In dangerous situations, however, it may not be possible to interrogate an adversary. For example, someone intending to destroy a building may not pause to engage in conversation. In such situations, early detection of movement patterns may serve as the only observable behavior that can be used to distinguish between friendly and hostile behaviors (Popp, Armour, Senator, & Numrych, 2004).

Intent is generally considered to be a form of internal cognitive activity which may be inferred or identified via external behavioral representations or certain characteristics (Singh & Asher, 1990). Figure 1 is loosely based on Gallagher's model (2000): intentions generate thoughts, which generate motor commands, which manifest themselves in motor behaviors. Movements plotted over time constitute *trajectories*. In this paper, we employ the term to refer to the paths our human subjects plan to use in response to the problems posed to them. If intent is a background cognitive decision-making process, trajectories are projections of human interactions and can provide additional alerting mechanisms to an observer (Horvath & Rudas, 2004; Wing, Ballin, & Krishnamurthy, 2004).

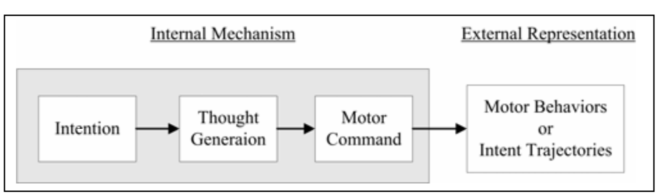

Figure 1: Cognitive representation of intent process.

Prior studies on deceptive intent detection have provided a theoretical foundation based upon Expectancy Violation Theory (EVT), Interpersonal Deception Theory (IDT), and signal detection theory (SDT) (Burgoon et al., 2004; Burgoon et al., 2005). EVT identifies behaviors that constitute any violation-of-expectation against normal verbal and/or non-verbal behavioral patterns; IDT maps process-oriented behavioral cues, especially interpersonal deception; and SDT assumes actual intent versus perceived judgment can be reflected in the difference between two sets of probability distributions (Burgoon et al., 2004; Burgoon et al., 2005). These theories suggest that behaviors or trajectories captured from external events may reveal adversarial or deceptive intent.

Historically, research has examined intent through the application of behavioral cues including verbal communication (e.g. Vrij, Edward, Roberts, & Bull, 2000), facial expression (e.g. Cohn, Schmidt, Gross, & Ekman, 2002), and hand/head movements. Physical cues (e.g. hand gestures), for instance, have been used to identify hostile or benign intentions (Burgoon et al., 2004; Burgoon et al., 2005). These studies suggest hostile intent may be recognizable through close analysis of behavior.

Pragmatically, being able to strategically detect adversarial or deceptive intent allows for a priori countermeasures before the execution of aggressive behavior. Surveillance events can be modeled using attributes and behaviors (Remagnino & Jones, 2001). In particular, intentions may be understood from patterns of simple movements (Zacks, 2004). For example, trajectories have been investigated as an aid in air traffic control (ATC) for security and safety purposes. Using aircraft trajectories as information to differentiate adversarial or benign intent is considered one key element affecting air traffic controllers' operational concepts (Reynolds, Histon, Davison, & Hansman, 2002).

Previous studies have also reported the significance of movement features in the segmentation of trajectories, especially in a goal-oriented human activity involving route selection and obstacle avoidance (Zacks, 2004). In other words, movement features may reveal plans. Goal-oriented human path planning includes parameters such as heading direction, angle, and distance (Fajen, Warren, Temizer, & Kaelbling, 2003): when people move around obstacles, they do so in reference to their destination, and therefore might unwittingly reveal their destination to an attentive observer.

The premise of this study is that deceptive intent can be identified on the basis of behavioral information such as patterns of movement toward a target.

Experiment

The experiment investigated human cognitive process regarding deceptive intent. A general task of deceiving a surveillance system was introduced.

Method

Participants Twenty-five graduate students from Stevens Institute of Technology were recruited. There were 21 males and 3 females. Their ages averaged 25 and 33 years, respectively. Two participants (both are males) were dropped from the analyses because their responses were illegible.

Apparatus A paper-and-pencil test was administered to support this study. Four types of experimental configurations were developed (Figure 2). Within each configuration, a designated target was marked in one of the three circles while the other two circles served as decoys. A starting point was illustrated using a human-shape silhouette. In one configuration (Figure 2b), square obstacles in a lattice-like placement were positioned between the target/decoys and the starting point. All control and experimental conditions were randomly presented to participants.

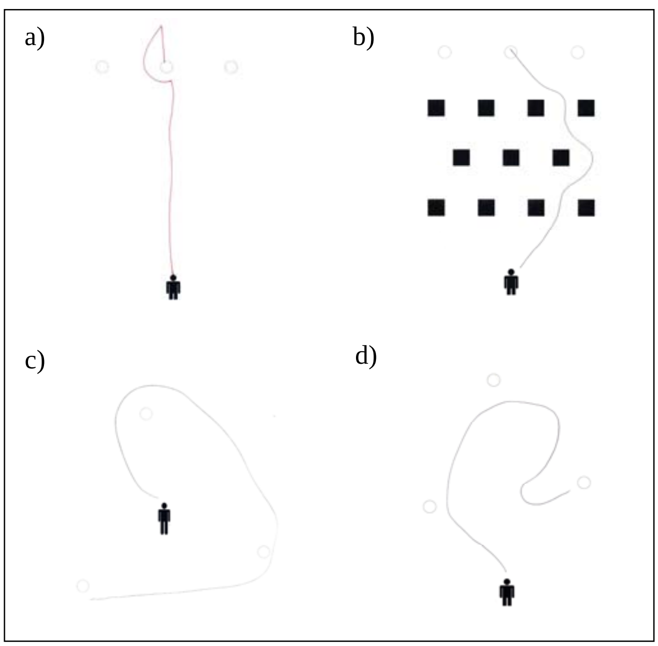

Figure 2: Actual hand drawings of trajectories from the experimental group: a) line configuration; b) line configuration with obstacles; c) circular configuration; d) triangular configuration.

Two general task statements were articulated for control and experimental conditions. For the control condition the task statement instructed participants to "Draw a route that you NORMALLY would take from the starting point to Target," whereas for the experimental condition the task statement read "Draw a route from the starting point to Target, at the same time do NOT give away what your target is. Be creative." An experimental packet for each participant contained a total of 24 testing configurations and a questionnaire attached as an appendix. Participants were asked to draw on each testing sheet per the task instructions. At the end of the experiment, participants were instructed to fill out the questionnaire that gathered participants' elaborations and demographic information.

Results and Analyses

Both geographical and qualitative measures were developed in this study. Data collected from the experiment were analyzed and the results are presented in the following order: geographical analysis, qualitative measures and its reliability, and elaborations.

Geographical Analysis

A paper with 1cm x 1cm cells as a grid reference was mapped onto each testing sheet. A continuum of a trajectory entering and leaving a cell was considered one visit based upon the approach developed by Meratnia and de By (2002). These frequency counts of trajectories in each grid cell were calculated and tabulated. A frequency map for each experimental configuration was graphed. In the following discussion, a designated target at the upper left corner was taken as the example in each experimental configuration. Different levels of grayscale in each frequency map denote the level of density, i.e., the darker color the cell, the higher density trajectories were present.

Figures 3a and 3b compare the frequency data obtained from both control and experimental groups as the designated target (denoted with a letter T) and decoys lined up on top and the starting point (denoted with an S) located at the bottom of the grid. The trajectories generated from the control group (Figure 3a) are relatively direct paths compared to those in the experimental group. Most participants generated a straight line between the starting point and the designated target. In contrast, the trajectories in the experimental group (Figure 3b) are diverse. Within the reverse triangle of the starting point/target/decoy, participants evenly utilized each grid cell.

After adding several obstacles between the target, decoys, and the starting points, trajectories are more confined. As shown in Figure 4a, most participants in the control group selected similar paths, which is restricted obliquely between obstacles along the upper left and lower right direction. Although it is difficult to notice any conformity of trajectories in the experimental configuration (Figure 4b), there participants tend to use certain grid cells and obstacles. In particular, the obstacle which is the second nearest object from the designated target was highly utilized.

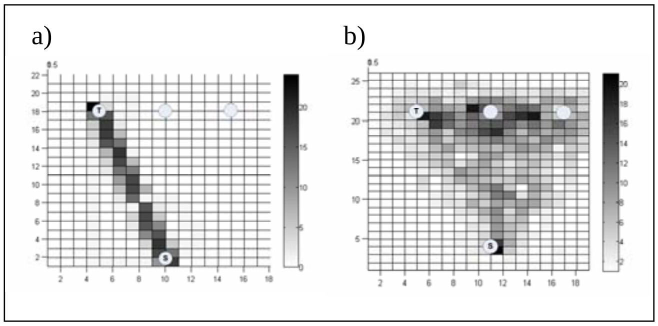

Figure 3: Line configuration without obstacles: a) control group; b) experimental group.

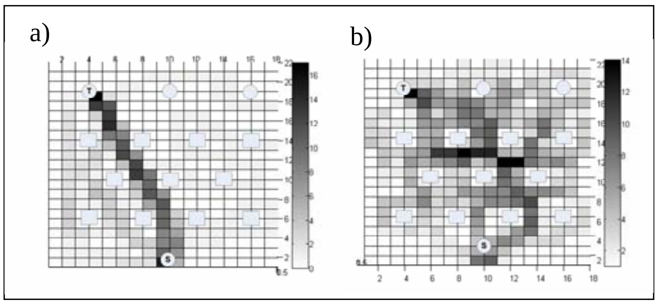

Figure 4: Line configuration with obstacles: a) control group; b) experimental group.

In addition to the line configurations–either with or without obstacles–circular and triangular configurations were developed (Figures 5 and 6). Trajectories in the circular and triangular control configurations (Figures 5a and 6a) fell on a straight line between the starting points to the designated targets. On the other hand, no definitive moving pattern can be determined in the experimental configurations (Figures 5b and 6b).

Qualitative Measures

In addition to geographical data analysis, we developed qualitative measures to address our hypothesis that there might be some structure to the movements we observed. Qualitative measures in this study comprise 38 characteristic variables in representing specific patterns of trajectories (Table 1). Each variable was deduced from the trajectories drawn by participants. If a trajectory contained a turn with a sharp angle, the qualitative measure, "sudden turn," was denoted. The measures were developed to increase internal reliability (or internal consistency) and overall validity. Coding of qualitative measures was assessed by three researchers.

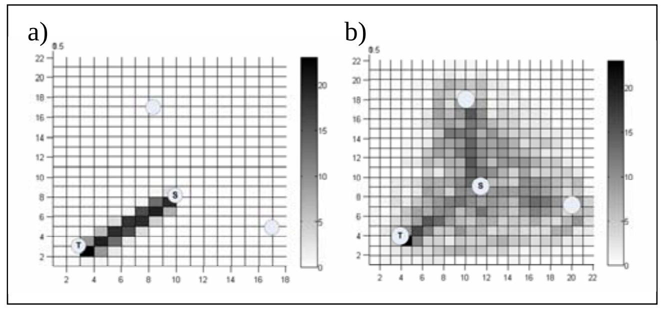

Figure 5: Circular configuration: a) control group; b) experimental group.

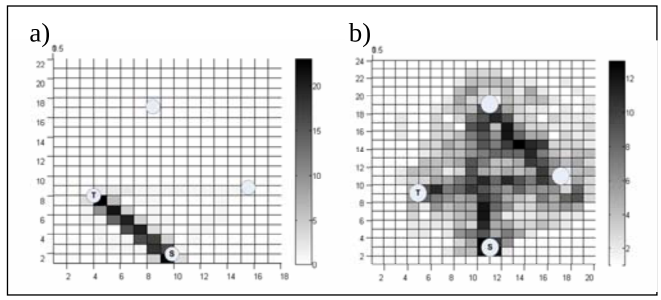

Figure 6: Triangular configuration: a) control group; b) experimental group.

The coefficient alpha of each qualitative variable was calculated (Cronbach, 1951). When at least two experimenters found coding trajectories inapplicable, for example, trajectories did not begin from the starting point, data were removed. Two sets of data that did not pertain to the goal of the task statements were discarded. Overall coefficient alphas for the 38 qualitative variables were calculated and ranged from 0.76 ("straight to a decoy") to 0.94 ("initial move ahead to the designated target). The average reliability was 0.86 indicating strong agreement among researchers and an acceptable qualitative coding approach. Pooled statistics (Table 1) of each qualitative measure reveal that in the line configurations with and without obstacles as well as the circular configuration, participants tended to initially move away in reference to target locations. Corresponding patterns of trajectories to each column in Table 1 are shown in Figure 2. Additionally, the top two variables that were highly consistent in each configuration are summarized in Table 2. This suggests that individuals may be inclined to move away from targeted destinations in order to obscure their deceptive intention. In other words, they overcompensate, a tendency seen in other forms of deceitful behavior, such as those discussed by Ekman (1969).

Table 1: Pooled statistics of qualitative measures for each configuration.

Variable ID	Qualitative Measures	dT[1]	dO[2]	dC[3]	D3[4]
1	single decoy	0.27	0.24	0.15	0.19
2	double decoys	0.67	0.33	0.67	0.72
3	90 degree turn	0.43	0.57	0.24	0.44
4	sudden turn	0.63	0.69	0.57	0.65
5	overshoot passing target	0.37	0.13	0.27	0.23
6	overshoot passing decoy	0.64	0.24	0.41	0.53
7	u-turn	0.57	0.56	0.76	0.52
8	horizontal zigzag/sinusoidal	0.28	0.32	0.04	0.15
9	vertical zigzag/sinusoidal	0.08	0.39	0.05	0.05
10	loop with decoy	0.31	0.11	0.28	0.31
11	loop with target	0.13	0.01	0.13	0.07
12	loop in other area	0.12	0.20	0.15	0.15
13	circular or curvature	0.69	0.59	0.64	0.52
14	edgy (angular) movement	0.51	0.59	0.47	0.53
15	initial move-away (before the 1st direction change)	0.80*	0.72*	0.80*	0.75
16	initial move-ahead	0.49	0.59	0.65	0.80*
17	straight to decoy - 1st destination is decoy	0.71	0.24	0.61	0.73
18	straight toward decoy - heading toward decoy	0.52	0.29	0.45	0.65
19	straight to target - no decoy	0.11	0.43	0.17	0.20
20	straight toward target	0.13	0.04	0.11	0.21
21	coming back to starting point	0.08	0.01	0.41	0.17
22	pivoting after target	0.21	0.08	0.13	0.19
23	pivoting before target	0.28	0.29	0.13	0.15
24	pivoting after decoy	0.37	0.12	0.31	0.47
25	pivoting before decoy	0.47	0.20	0.47	0.53
26	multiple approaches to target	0.31	0.08	0.20	0.21
27	multiple approaches to the same decoy	0.31	0.09	0.23	0.33
28	passing midpoint between target & decoy	0.27	0.11	0.07	0.12
29	passing midpoint between decoys	0.20	0.07	0.07	0.07
30	obsessive looping	0.15	0.11	0.15	0.08
31	concentric circles around decoy	0.05	0.01	0.03	0.03
32	concentric circles around target	0.04	0.00	0.03	0.00
33	concentric circles around starting point	0.00	0.00	0.09	0.00
34	looping around obstacles	0.00	0.25	0.00	0.00
35	use of passing red zone obstacle at the last smooth movement	0.00	0.53	0.00	0.00
36	use of passing non red zone obstacle at the last smooth movement	0.00	0.60	0.00	0.00
37	maneuvering obstacles	0.03	0.64	0.00	0.00
38	city-block movement	0.09	0.21	0.00	0.01

[1] Line experimental configuration, target is the middle circle.
[2] Line experimental configuration with obstacles, target is the middle circle.
[3] Circular experimental configuration, target is the circle at the left.
[4] Triangular experimental configuration, target is the circle at the right.
* The most exhibited qualitative characteristic identified in trajectories.

Table 2: Summary of reliabilities for each configuration.

Configuration	Qualitative item & its reliability
Line w/o obstacles	Initial move away from target (.845)
	Straight to decoy (.732)
Line w/ obstacles	Maneuvering obstacles (.860)
	Initial move away from target (.800)
Circular	Initial move away from target (.868)
	U-turn (.794)
Triangular	Initial move away from target (.789)
	Initial move ahead towards target (.789)

An exploratory analysis using a Self-Organizing Map technique (SOM: Kohonen, 2001) was conducted. SOM transforms high dimension data into a low dimensional space, which is similar to Principal Component Analysis (PCA). In contrast to PCA, SOM is nonlinear, which is particularly appealing for analyses on categorical data. SOM also provides eye-catching features, such as a characteristics map for each variable containing its association with others. Since some trajectory components, such as "maneuvering obstacles," appear only in one configuration, it is reasonable to omit these components in an analysis. As a result, a total of 34 qualitative variables were analyzed using the SOM technique. Table 1 details a full description of each variable. Subplots in Figure 7 illustrate characteristics of the 34 variables, relative to all other variables. That is, in one subplot, a particular cell corresponding to the same cell in every other subplot contains the same data point. This assists in visualizing co-occurrences of different trajectory characteristics. In each subplot, cell colors represent the probability of the corresponding characteristics to be exhibited, where for example the probability is 0 within a dark blue cell, 1 in a dark red cell, and 0.5 in a yellow cell.

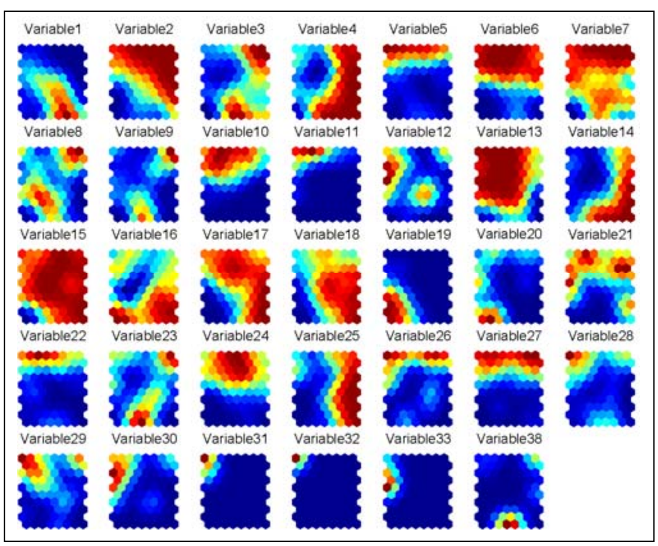

Figure 7: Characteristic maps of qualitative measures.

From the patterns of cells on characteristic maps, the frequency of each variable could be inferred. For example, more dark red cells indicate more frequently observed characteristics as well as more associations among variables.

In addition, this characteristic map helps visualize the relationships between various trajectory characteristics. For example, because Variable 1 (one decoy) and Variable 2 (double decoys) are mutually exclusive, the two corresponding subplots do not share the same dark red cells or areas. Variable 2 and Variable 6 (overshoot decoy) share many dark red cells, which imply many participants who applied the strategy of "double decoys" tended to exhibit "overshoot". Furthermore, Variable 1 and Variable 6 share very little. This phenomenon indicates that those who used the "one decoy" approach were apt not to exhibit "overshoot." We can see in Figure 7 that several variables are often concurrent on deceptive trajectories, including "double decoys," "overshoot passing decoys," "U-Turn," "angular movement," "initial move ahead towards target," and "straight towards decoy." When one of those items is observed, the other characteristics will likely occur. In other words, when the factor "overshoot passing decoys" is identified, then "double decoy" will probably also occur. SOM is a projection of multi-dimensional data on a 2D plot; thus it is possible that some disparate trajectory characteristics may appear to be coexisting in subplots as a side effect of the projection.

Elaborations

In the questionnaire, participants were asked to describe their thought process regarding the experiment. Participants' elaborations in the questionnaire were transcribed. Selected remarks include:

"[I was] trying to get to a target with the most confusing way possible which was basically doodling lines all over the place."
"The normal way was a 'straight' line–the shortest distance between two points. The other [deceptive way] was to go the opposite [direction] then find my way back."
"I chose paths that made it seems like I was going to attack another target [decoy] then deviated at the last minute."
"I tried to throw in some fakes and follow the directions."

These elaborations support qualitative measures being identified, and provide insights of participants' strategic information processing.

Limitations

While the participants said they were conscious of surveillance, they sometimes exhibited behavior that seemed blatantly suspicious. They might have interpreted the surveillance as being intermittent rather than constant; a different framing of the problem might produce different, and more subtle, trajectories (Jian, Matsuka, & Nickerson, in press). In addition, with more participant training, deceit may become harder to detect. Many studies of verbal deceit have found that some people are much more convincing liars than others. Future research with larger samples might examine whether or not some individuals are more talented than others at deception through movement.

Conclusion

The results from this study suggest that trajectories provide information regarding adversarial intent, even when the adversary is aware of that he or she is under hypothetical surveillance.

In conclusion, participants initially tended to move away from the starting point in reference to the designated target. They tend to move in a jerky way as they approach the target. Future research might introduce dynamic obstacles and targets in order gauge the reactions they elicit. The current study suggests that movement can provide clues as to intent.

Acknowledgments

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