SHADED: Shapley Value-based Deceptive Evidence Detection in Belief Functions

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Outline

- Deceptive evidence
- Deceptive evidence detection based on Shapley values
- Experiments
- Takeaways

Outline

A possible decision-making strategy in belief functions

Let $\mathbf{M} = \{m_1, m_2, \ldots, m_n\}$ be a set of mass functions defined on the same frame of discernment $\mathbf{\Omega}$.

Dempster's combination rule

$$m(A) = (m_1 \oplus m_2)(A) = \frac{1}{1-\mathcal{K}} \sum_{B \cap C = A} m_1(B) m_2(C), \quad \forall A \subseteq \mathbf{\Omega}, \tag{1}$$

where $\mathcal{K}$ is the degree of conflict between the two mass functions, defined as:

$$\mathcal{K} = \sum_{B \cap C = \emptyset} m_1(B) m_2(C). \tag{2}$$

Pignistic transformation

$$BetP(\omega_k, m) = \sum_{A \subseteq \mathbf{\Omega}, \omega_k \in A} \frac{m(A)}{|A|}, \quad \forall \omega_k \in \mathbf{\Omega}. \tag{3}$$

Use expected utility maximization associated with the pignistic probability to make the decision.

Problem of Dempster's combination rule

It may produce counter-intuitive results.

Common solutions

1. Modify and improve the evidence combination rules
2. Evaluate the reliability of evidence and discount it

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Another possible solution

If a piece of evidence is determined as deceptive, then it should not be combined!

Source of deception

1. Intentional deception
2. Natural causes

What is deceptive evidence in belief functions?

Definition (Deceptive evidence)

For a certain fusion system (i.e., Dempster's combination rule), deceptive evidence either reverses the intuitive (reasonable) target or increases the uncertainty of the fusion result by supporting the intuitive (reasonable) target.

Remarks[1]

- **Deceptive evidence is different from conflict evidence.**
- **Deceptive evidence is related to both the evidence and the combination rule.**

Evidence	$m(\{\omega_1\})$	$m(\{\omega_2\})$	$m(\{\omega_3\})$
m_1	0.7	0.3	0
m_2	0.8	0.2	0
m_3	0.3	0.3	0.4

[1] Kang, Bingyi, and Chunjiang Zhao. "Deceptive evidence detection in information fusion of belief functions based on reinforcement learning." Information Fusion 103 (2024): 102102.

Strong deceptive evidence

Definition (Strong deceptive evidence)

For a given set of credible evidence and a certain fusion system (i.e., Dempster's combination rule), strong deceptive evidence is a piece of or a group of evidence that can alter the intuitive (reasonable) decision.

Evidence	$m(\{\omega_1\})$	$m(\{\omega_2\})$	$m(\{\omega_3\})$
m_1	0.7	0.3	0
m_2	0.8	0.2	0
$\boldsymbol{m_3}$	**0**	**1**	**0**
$m_1 \oplus m_2$	0.903	0.097	0
$m_1 \oplus m_2 \oplus m_3$	0	1	0

Weak deceptive evidence

Definition (Weak deceptive evidence)

For a given set of credible evidence and a certain fusion system (i.e., Dempster's combination rule), weak deceptive evidence is a piece of or a group of evidence that can not alter the intuitive (reasonable) decision but can increase the uncertainty associated with the decision.

Evidence	$m(\{\omega_1\})$	$m(\{\omega_2\})$	$m(\{\omega_3\})$
m_1	0.7	0.2	0.1
m_2	0.8	0.1	0.1
$\boldsymbol{m_3}$	**0.2**	**0.7**	**0.1**
$m_1 \oplus m_2$	0.949	0.034	0.017
$m_1 \oplus m_2 \oplus m_3$	0.882	0.110	0.008

Some proposed deceptive evidence detection methods

1. Negation or the complement of true evidence[2]
2. Falsity degree based on conflict and entropy[3]
3. Shapley value of evidence based on distance[4]
4. Belief gravitational clustering[5]
5. Reinforcement learning with off-policy Q-learning[6]

[2] Pichon, Frédéric, Didier Dubois, and Thierry Denoeux. "Relevance and truthfulness in information correction and fusion." International Journal of Approximate Reasoning 53.2 (2012): 159-175.

[3] Schubert, Johan. "Counter-deception in information fusion." International Journal of Approximate Reasoning 91 (2017): 152-159.

[4] Zhou, L., Cui, H., Huang, C., Kang, B., Zhang, J.: Counter deception in belief functions using Shapley value methodology. Int. J. Fuzzy Syst. 24(1), 340–354 (2022)

[5] Cui, Huizi, et al. "BGC: Belief gravitational clustering approach and its application in the counter-deception of belief functions." Engineering Applications of Artificial Intelligence 123 (2023): 106235.

[6] Kang, Bingyi, and Chunjiang Zhao. "Deceptive evidence detection in information fusion of belief functions based on reinforcement learning." Information Fusion 103 (2024): 102102.

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- **Deceptive evidence detection based on Shapley values**
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Shapley value

Let $(\mathbf{N}, v)$ be a coalitional game (or cooperative game) where

- $\mathbf{N}$ is a set of n players,
- payoff function $v : 2^{\mathbf{N}} \to \mathbb{R}$ maps the subsets of players (coalitions) to a real number.

The Shapley value representing the marginal contribution of player i is defined as:

$$\varphi_i = \sum_{S \subseteq \mathbf{N} \setminus \{i\}} \frac{|S|!(n - |S| - 1)!}{n!} [v(S \cup \{i\}) - v(S)] \tag{4}$$

In our case

- **Each evidence $\to$ a player**
- **Combination rule and pignistic transformation $\to$ payoff function**

Overview of the SHADED method

Step 1.1 Combined decision via Dempster's combination rule

$$cd = \arg\max_{\omega \in \mathbf{\Omega}} BetP(\omega, \bigoplus_{i=1}^{n} [m_i]). \tag{5}$$

Step 1.2 Reasonable decision via Murphy's averaging approach

$$rd = \arg\max_{\omega \in \mathbf{\Omega}} BetP(\omega, \bigoplus_{i=1}^{n} [m]), \text{ where } m = \frac{1}{n} \sum_{i=1}^{n} m_i. \tag{6}$$

Remark: this approach can keep the majority opinion

Overview of the SHADED method

Step 2. Shapley values associated with the reasonable decision for each piece of evidence

$$\varphi_i = \sum_{S \subseteq \mathbf{M} \setminus \{m_i\}} \frac{|S|!(n-|S|-1)!}{n!} \left[BetP(rd, \bigoplus_{m_j \in S \cup \{m_i\}} [m_j]) - BetP(rd, \bigoplus_{m_j \in S} [m_j]) \right] \quad (5)$$

By setting $BetP(rd, \emptyset) = 1/K$ with K the number of states of nature, then $\varphi_0 = 1/K$.

Properties

1. Efficiency: $BetP(rd, \bigoplus_{i=1}^{n} [m_i]) = \sum_{i=0}^{n} \varphi_i$
2. Symmetry: if $m_i = m_j$, then $\varphi_i = \varphi_j$
3. Dummy: if $m_i(\mathbf{\Omega}) = 1$, then $\varphi_i = 0$

Overview of the SHADED method

Step 3. Nature of each piece of evidence

- Credible evidence : $CE = \{m_i \mid \varphi_i \geq 0, m_i \in \mathbf{M}\}$
- Deceptive evidence : $DE = \mathbf{M} \setminus CE$
- If $cd = rd$, no strong deceptive evidence and only (or no) weak deceptive evidence
- If $cd \neq ed$, must exist strong deceptive evidence, and the rest is weak deceptive evidence

Remark

These Shapley values can be used as reliability evaluation for sources of evidence.

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Example

Table: Mass functions

	$m(\{\omega_1\})$	$m(\{\omega_2\})$	$m(\{\omega_3\})$	$m(\mathbf{\Omega})$
m_1	0.30	0.60	0.00	0.10
m_2	0.70	0.00	0.00	0.30
m_3	0.65	0.15	0.00	0.20
m_4	0.75	0.00	0.05	0.20
m_5	0.05	0.45	0.50	0.00
m_6	0.05	0.50	0.45	0.00

Remark

The co-existence of m_5 and m_6 as a group of deceptive evidence!

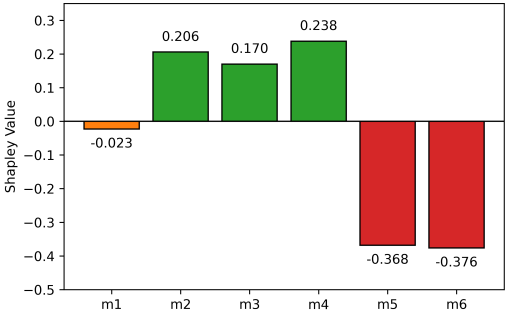

Figure: Shapley values for each evidence

Example

Table: Fusion results of different methods for the second example.

	Method	$p(\omega_1)$	$p(\omega_2)$	$p(\omega_3)$	Reasonable
Consider all	DCR[7]	0.1814	0.7428	0.0758	No
mass functions	Murphy[8]	0.8230	0.1555	0.0215	Yes
Delete $\{m_5, m_6\}$	Kang and Zhao[9]	0.9566	0.0413	0.0021	Yes
Delete $\{m_1, m_5, m_6\}$	SHADED	**0.9762**	**0.0147**	**0.0091**	**Yes**

[7] Dempster, Arthur P. "Upper and lower probabilities induced by a multivalued mapping." Classic works of the Dempster-Shafer theory of belief functions. Berlin, Heidelberg: Springer Berlin Heidelberg, 2008. 57-72.

[8] Murphy, Catherine K. "Combining belief functions when evidence conflicts." Decision support systems 29.1 (2000): 1-9.

[9] Kang, Bingyi, and Chunjiang Zhao. "Deceptive evidence detection in information fusion of belief functions based on reinforcement learning." Information Fusion 103 (2024): 102102.

Detection time cost

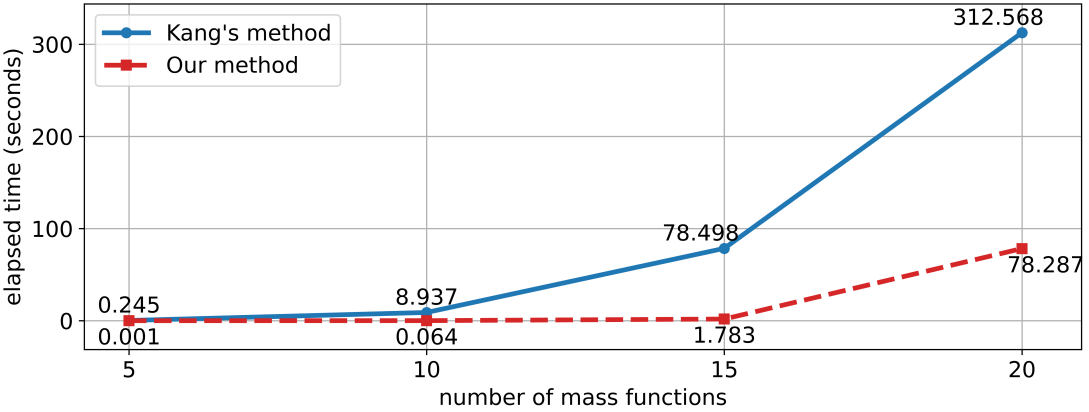

Figure: Time required to detect deception as a function of the number of mass functions

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Takeaways

Summary

- Strong and weak deceptive evidence are defined.
- A new Shapley value-based deceptive evidence detection method is proposed.

Future works

- Detection efficiency problem?
- Determination of the reasonable decision? From a non-supervisory point of view?
- Can Shapley value be a sufficient and necessary condition for deceptive evidence detection?

Thanks for your attention!