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Navigating Uncertainty in Digital Finance Based on DIKWP Model

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Abstract: The paper examines the various uncertainties encountered in high-frequency trading (HFT) environments and delves into the multiple challenges faced by HFT firms in navigating the Dodd-Frank Wall Street Reform and Consumer Protection Act (referred to as the "Dodd-Frank Act"), particularly during the initial stages of its enactment. These challenges include the ambiguity surrounding the definition of HFT, the lack of clarity regarding regulatory requirements and boundaries, inconsistencies in enforcement resulting from deviations in understanding the content, and the absence of detailed descriptions of the Act's provisions. These hurdles significantly impact not only the daily operations of HFT firms but also pose higher demands on their long-term strategic planning and risk management. Drawing upon the Data, Information, Knowledge, Wisdom, and Purpose (DIKWP) model, this study employs an innovative analytical framework. Through the comprehensive application of concept space, cognitive space, and semantic space, it provides a systematic methodology for identifying and analyzing the aforementioned issues. This approach not only aids firms in better comprehending and adhering to complex regulatory requirements but also enables them to explore new business opportunities and competitive advantages while ensuring compliance.

Keywords: DIKWP model; uncertainty analysis; concept space; cognitive space; semantic space

1. Introduction

In the era of digital finance, the emergence of high-frequency trading (HFT) systems signifies a significant advancement in financial markets, utilizing sophisticated algorithms and high-speed data networks to execute trades at speeds measured in milliseconds or even microseconds, surpassing the capabilities of human traders [1]. These systems analyze market conditions and execute orders based on predetermined criteria, aiming to profit from minute price discrepancies across different trading venues. The introduction of HFT is marked by its ability to enhance liquidity, narrow spreads, and improve market efficiency, yet it has also raised concerns regarding market stability and fairness [2]. Within these HFT systems, proprietary algorithms are strictly confidential, making it challenging for regulatory agencies and participants to fully comprehend their operations and impact [3,4]. Consequently, this has spurred regulatory and legislative actions aimed at ensuring the healthy functioning of markets. The implementation of the Dodd-Frank Act represents a significant strengthening of financial market regulation [5], aiming to mitigate systemic risks and safeguard consumers' financial interests by bolstering regulatory frameworks.

Against this backdrop, HFT enterprises confront unprecedented compliance challenges, particularly due to the ambiguous definition of HFT and regulatory boundaries within the legislation. These challenges not only affect the daily operations of enterprises but also significantly impact their strategic decision-making. To address these challenges, we introduce the Data, Information, Knowledge, Wisdom, and Purpose (DIKWP) model [6,7], aiming to conduct an in-depth analysis of the key issues faced by HFT in the regulatory compliance process through this model. The DIKWP model provides a systematic

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analytical framework by distinguishing and correlating five dimensions: Data, Information, Knowledge, Wisdom, and Purpose, and processing them into corresponding Data Graph (DG), Information Graphs (IG), Knowledge Graphs (KG), Wisdom Graphs (WG), and Purpose Graphs (PG). Under the guidance of purpose [8], it assists financial enterprises in better understanding and managing complex regulatory requirements. Specifically, this study categorizes challenges as the "4-N" problems: Incompleteness, Inconsistency, Imprecision, and Incorrectness, which highlight the uncertainties faced by enterprises in complying with regulations. To address the challenges of uncertainty, we will explore and analyze the action strategies and decision-making processes of HFT enterprises in the face of the Dodd-Frank Act through concept space, cognitive space, and semantic space[8].

- Concept Space provides us with a framework for understanding and organizing the relationship between regulatory requirements and business practices. By mapping key concepts and their interactions, it reveals the possibilities and challenges of compliance pathways;
- Cognitive Space focuses on cognitive activities in the decision-making process, including how to identify, process, and utilize information to form knowledge, wisdom, and purpose, to support compliance and business decisions;
- Semantic Space emphasizes the relationships between semantic units, including the associations and dependencies among vocabulary, regulations, and concepts, thereby ensuring the accurate transmission and interpretation of information and knowledge.

Through the comprehensive analysis of these three spaces as shown in Figure 1, this paper not only explores how HFT companies can ensure compliance while seeking new business opportunities but also proposes strategies for utilizing the DIKWP model to enhance internal compliance auditing, risk management capabilities, and communication with regulatory agencies. This multidimensional analytical approach provides new perspectives and tools for understanding and addressing regulatory challenges in the financial technology field, assisting HFT enterprises in maintaining competitiveness and innovation in a complex regulatory environment. The main contributions of this paper are as follows:

1. **Innovative application of the DIKWP model:** Our study innovatively applies the DIKWP model to analyze and address the complexity involved in HFT and its regulation. This approach enables a nuanced understanding of the regulatory challenges and operational uncertainties faced by HFT companies, providing a structured framework for addressing these issues;
2. **Addressing uncertainty in HFT regulations:** We analyzed the inherent uncertainty in regulations affecting HFT practices during the early stages of the Dodd-Frank Act. By dissecting issues related to vague definitions, regulatory requirements, interpretational differences, and lack of detailed descriptions, this research offers clear insights for more effectively managing regulatory compliance;
3. **Elaboration on Concept, Cognitive, and Semantic Spaces:** We provide detailed explanations and a set of definitions and analytical methods for Concept Space, Cognitive Space, and Semantic Space within the context of the DIKWP model. This enhances understanding of how HFT companies interpret, adapt to regulatory requirements, and formulate strategies around regulatory demands, thereby leveraging these spaces to improve operational coordination and decision-making.

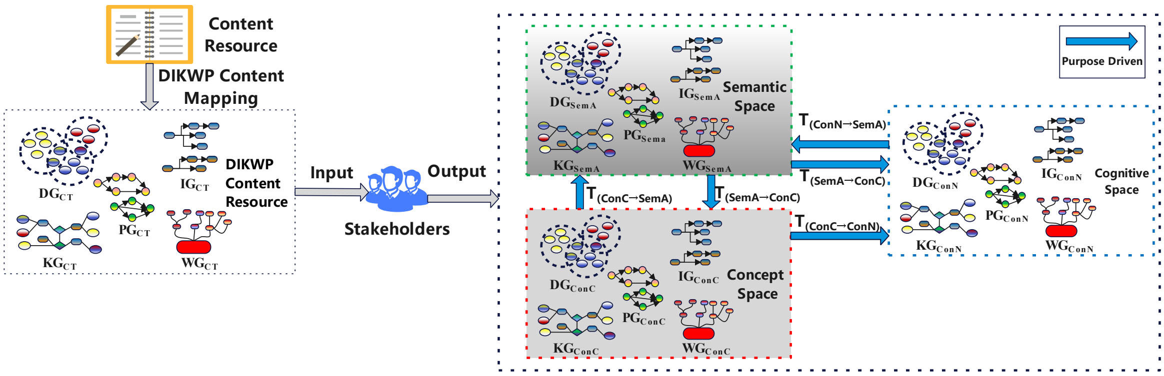

Figure 1. Analysis and processing of concept space, cognitive space, and semantic space under purpose driven.

2. Problem description

One of the primary challenges of HFT lies in the inherent uncertainty of input data content and output results[9]. The rapid execution speed and algorithmic nature of HFT imply that minor errors or delays in market data could lead to significant and unpredictable outcomes, potentially exacerbating market volatility. Departing from the context of HFT, characterized by its real-time nature and speed, we have reviewed previous research and identified a series of short-term issues that may affect the profitability of systems. We classify these issues into types based on market, internal, and regulatory aspects, each type encompassing several sub-issues, with each sub-issue potentially serving as a factor influencing the profitability of HFT. We categorize each type of problem into several domains, wherein we summarize each sub-issue, provide examples, and assign numerical identifiers for semantic association e_x.

2.1. *Uncertainty in market conditions*

The behavior of financial markets is exceedingly complex, influenced by political events[10,11], market sentiment[12,13], corporate performance[14], and numerous other factors[15–18]. These conditions are subject to constant change, resulting in inherent uncertainty in market predictions.

2.1.1. Political factors

- **Geopolitical tensions (e_1):** Geopolitical tensions, such as sudden outbreaks of conflict, wars, or sanctions, typically lead to fluctuations in global stock markets. These fluctuations not only impact global markets but also have a particular influence on companies or industries with significant interests in regions of geopolitical tension. For instance, during a political crisis in 2014, concerns over escalating tensions between Country A and Country B led to turmoil in the global energy markets. Country A is one of the world's largest natural gas suppliers, and any threat to its supply capacity could result in energy price volatility. During this period, stocks related to the energy sector, especially European energy companies reliant on Country A's energy supplies, may experience price fluctuations. HFT may exploit this volatility by swiftly buying and selling energy stocks to generate profits, while closely monitoring any further political developments that could affect energy supply and prices.
- **Policy changes (e_2):** Changes in government or international organizations' policies, such as adjustments to trade policies or monetary policies, can significantly impact economic activities and the profitability of multinational corporations. For example, in 2018, Country D's imposition of tariffs on goods from Country C intensified global trade tensions, leading to profound effects on global stock markets, commodity markets, and currency markets. High-frequency traders may analyze the impact of such policy changes on different markets and assets, adjusting stock trading strategies swiftly in the short term to capture price fluctuations and generate profits.

2.1.2. Market sentiment

Investors' emotions and expectations can also significantly impact market prices, often based on investors' perceptions rather than actual economic indicators.

- **Market overreaction (e_3):** Market participants may overreact to certain news or events, leading to sharp short-term fluctuations in asset prices that may be unrelated to fundamentals. For example, if the CEO of a large technology company suddenly announces resignation, even though the long-term impact of this resignation on the company's fundamentals may be limited, the stock price may experience a significant decline in the short term due to market sentiment. High-frequency traders can profit from these short-term price fluctuations by capturing them swiftly after the news is announced, trading based on anticipated systematic model expectations.
- **Unconfirmed news (e_4):** Unconfirmed news or rumors spread on social media and news websites can quickly alter market sentiment, causing short-term fluctuations in the prices of certain assets. For instance, if rumors about the imminent acquisition of a listed company circulate online, even though this news is unconfirmed, the company's stock price may temporarily rise due to investors buying in. High-frequency traders may capitalize on these short-term price movements for trading, but they also face high risks because once the news is confirmed to be false, the stock price may quickly fall back, indicating precise control over risk assessment is required.
- **Herd behavior (e_5):** Investors may mimic the behavior of other investors rather than make investment decisions based on their analysis, leading to herd behavior in the market, and exacerbating asset price fluctuations. For example, when a particular stock or industry suddenly becomes favored by the market, a large number of investors may follow suit and buy-in, driving up prices. However, this price increase is often not supported by the fundamentals of the company. Once the trend reverses, followers may rush to sell their stocks, causing prices to plummet sharply. High-frequency traders can identify the formation and reversal of such trends through algorithms, thus swiftly entering and exiting the market when market sentiment changes, capturing profits.

2.1.3. Counterparty

Counterparty uncertainty is a key challenge in HFT, as the outcome of the market depends not only on the decisions of individual participants but also on the collective behavior of all market participants[19–21]. The presence of this uncertainty complicates the formulation and execution of HFT strategies.

- **Competitors executing similar strategies (e_6):** When multiple participants in the market simultaneously execute similar trading strategies, competition may lead to diminishing profit margins. If multiple high-frequency traders are exploiting the same arbitrage strategy, such as a rapid response strategy based on certain economic indicators, arbitrage opportunities in the market may quickly disappear, as the first participant to execute the trade captures the profit, leaving subsequent participants finding the market adjusted without the expected profit space.
- **Opposing strategy opponents (e_7):** Other traders may be executing strategies that are entirely opposed to yours, which may directly impact your trading results negatively. For instance, if one HFT firm is executing a buy strategy based on pattern recognition, while another firm may be executing a sell strategy based on the same data or predictive model. If the latter's trading volume is larger or executed faster, it may lead to market price trends contrary to the expectations of the former, resulting in losses for the former.
- **Unpredictable market participant behavior (e_8):** Market participant behavior may be driven by various factors, including irrational behavior, making it extremely difficult to predict the behavior of other participants. For example, the 2021 GameStop (GME) trading event[22] demonstrated the extreme unpredictability of collective market participant behavior when driven by non-traditional factors such as collective action

on social media. This behavioral pattern is far from predictable based on traditional financial theories and is challenging for HFT algorithms to accurately forecast.

- **Opponents using covert strategies (e_9):** New participants may continuously join the market, employing covert strategies or using technologies not widely known, adding additional uncertainty to market behavior. For example, an emerging HFT firm may develop an advanced artificial intelligence algorithm capable of identifying and exploiting minor fluctuations in the market more rapidly. The deployment of such a new algorithm may suddenly alter market dynamics, causing unexpected impacts on existing participants.

2.2. Uncertainty of internal conditions

The internal condition uncertainty of HTF firms poses a significant issue, as it directly impacts the speed of trade execution and the efficiency of data processing. This uncertainty may stem from various factors, including the stability of technical equipment, the performance of software systems, the reliability of network connections, and the proficiency of personnel in financial expertise and legal understanding [23]. Changes or failures in these factors may result in delays or interruptions in trade execution, thus affecting the effectiveness of trading strategies. Therefore, continuous optimization of internal conditions is imperative for HFT firms to ensure the stability and efficiency of trading systems as well as the professionalism of personnel, thereby guaranteeing the successful execution of trading strategies.

2.2.1. System uncertainty

- **Network latency (e_{10}):** In HFT, even milliseconds of delay can lead to significant losses, as market conditions can change drastically within extremely short periods. For instance, suppose a trading firm relies on the fastest network connection from New York to London to execute arbitrage strategies. However, due to the cross-geographical nature, the risk associated with network connectivity is much higher compared to intra-geographical risks. If this network connection experiences delays due to technical issues, the firm may miss out on executing lucrative trades, or worse, may fail to withdraw in time before market conditions deteriorate, resulting in losses.
- **Processing latency (e_{11}):** The impact of processing latency on HFT is significant, as in this trading mode, the advantages of every millisecond or even microsecond can determine profits or losses. For example, a company encounters technical issues during the development of its trading system, resulting in a 5-millisecond delay in the execution of trade orders. Although seemingly insignificant, in the world of HFT, such delays can have substantial effects. Due to execution latency, when the company's algorithms identify an arbitrage opportunity and attempt to execute trades, market prices have already adjusted, causing the arbitrage opportunities to vanish. This implies that the company may have missed out on numerous potentially profitable trading opportunities.
- **System failures (e_{12}):** Defects introduced during software updates or modifications are common issues in HFT systems. Even with rigorous testing, defects may remain undetected, especially those that manifest only in actual trading environments. For instance, a financial services company in 2012 updated its trading software one day, and a flaw in the new software resulted in abnormal behavior of the trading system, erroneously executing millions of orders at high speed that should not have been executed. Within less than an hour, this system failure incurred hundreds of millions of dollars in losses for the company. This event underscores the importance of software updates and defect management in HFT systems. When new code runs in an actual trading environment, even after rigorous testing, undiscovered software defects may exist.

2.2.2. Differences in content understanding

Differences in content understanding have complex implications for HFT, as they can both increase market volatility and provide opportunities for traders employing different strategies. For HFT firms, understanding the diversity in information interpretation within the market and leveraging advanced natural language processing (NLP) techniques and machine learning algorithms to enhance the accuracy and responsiveness of their information parsing are key to improving trading efficiency and profitability. Additionally, this underscores the need for regulatory bodies to be as clear and precise as possible when disseminating market-sensitive information to minimize unnecessary market fluctuations.

- **Differences in market data interpretation (e_{13}):** Various HFT algorithms may interpret the same set of market data differently, leading to divergent or diversified trading decisions. For instance, during the release of significant information in the stock market, different HFT systems may have varied interpretations of the positive or negative impact of the data. Some algorithms may interpret it as a bullish signal and opt to buy related stocks, while others may perceive it as bearish and choose to sell. Such differences in content understanding can increase market volatility in a short period.
- **Diverse interpretations of news reports (e_{14}):** News reports and announcements often contain ambiguous or multi-interpretable language, prompting different trading systems to interpret this information based on their algorithms. For example, if a large tech company's financial report exceeds market expectations but its future revenue forecast appears slightly conservative, various HFT systems may react differently. Some may focus on the short-term bullish aspects and buy, while others may be concerned about the uncertainty in long-term revenue forecasts and choose to sell. Such diversity in news interpretation can lead to significant fluctuations in stock prices.
- **Differing interpretations of regulatory announcements (e_{15}):** Regulatory announcements from governing bodies typically have a direct impact on the market, but the complexity of their language and terms sometimes leads to varying interpretations and expectations. For example, if a regulatory agency issues new rules aimed at tightening oversight of HFT, some trading entities may interpret it as a direct threat to their business model and decrease trading activities. In contrast, others may seek gray areas within the new regulations, attempting to adjust their strategies to continue leveraging the advantages of HFT. Such differing interpretations of regulatory content may result in divergent behaviors among market participants, consequently affecting market structure and liquidity.

2.3. Regulatory uncertainty

The uncertainty of regulatory compliance is a significant and intricate issue within the realm of HFT. This primarily arises due to the potential evolution of interpretations of laws and regulatory guidance over time, alongside potential shifts in the enforcement efforts and priorities of regulatory bodies. Such uncertainty may result in trading strategies originally designed to be compliant suddenly facing legal risks[24,25].

2.3.1. Changes in regulatory interpretations

The shifting interpretations of regulations pose a significant source of uncertainty for financial markets, particularly for trading strategies reliant on precise legal interpretations.

- **Increased compliance costs (e_{16}):** Regulatory agencies' new interpretations of existing rules may escalate compliance costs for enterprises. Companies may need to allocate additional resources to comprehend new interpretations, adjust their business processes, update compliance strategies, or even redesign products or services. For instance, financial regulatory bodies may reinterpret rules regarding algorithmic trading, necessitating entities employing algorithms in trading to engage in more frequent self-assessment and reporting. For HFT firms, this could entail investment in advanced compliance monitoring systems, thereby escalating operational costs.

- **Adjustment of business models (e_{17}):** When regulatory interpretations change, businesses may need to modify their business models, especially if the new interpretations impact their core revenue streams. For example, if regulatory bodies decide to classify a widely adopted HFT strategy as market manipulation, trading firms relying on this strategy may have to completely revamp their trading models, potentially affecting their profitability and business continuity.

2.3.2. Regulatory enforcement

Changes in enforcement intensity are particularly crucial in stock markets and the realm of HFT due to the sensitivity of these domains to regulatory environment shifts. Regulatory agencies may alter the enforcement intensity of certain existing regulations or policies, which, while not involving the formulation of new laws or rules, significantly impact the behavior and strategies of market participants.

- **Increased transparency requirements (e_{18}):** Regulatory bodies demanding enhanced transparency in situations necessitating more disclosure of trading information may affect the operational methods of HFT firms. For instance, regulatory agencies may require all trading entities, including HFT firms, to provide more detailed trading data and strategy information to augment market transparency. This may compel HFT entities to adjust their data reporting processes and systems. While this aids regulatory bodies in better monitoring market activities, it may also increase the operational burden and costs for trading firms, as well as the risk of technology strategy leaks.
- **Enhanced monitoring of abnormal trading activities (e_{19}):** Regulatory agencies intensifying monitoring efforts on abnormal trading activities, especially those indicative of market abuse or manipulation, represent a significant change. For example, regulatory bodies adopting more advanced surveillance technologies to identify abnormal trading patterns may more frequently flag certain trading activities of HFT firms as suspicious. This may result in these firms facing more investigations and reviews, compelling them to adjust trading algorithms to mitigate the risk of being flagged by regulatory agencies as suspicious trades.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

3. Problem definition

HFT serves as a vital component of financial markets and is directly influenced by changes in regulatory environments. However, the ambiguity and uncertainty of regulatory announcements present a challenging issue for HFT firms. To address this, we have selected the implementation of regulatory laws such as the Dodd-Frank Act as a case study. Studying how HFT firms respond to these regulatory challenges not only aids in understanding the adaptability and resilience of HFT firms but also provides insights into the stability of financial markets. Enacted in 2010, the Dodd-Frank Act aims to reduce risks in the financial system, enhance transparency, and protect consumer financial rights. This legislation introduces new regulatory requirements for various aspects of the financial markets, including HFT, derivative trading, and bank trading activities. However, the Dodd-Frank Act is expansive in its scope, encompassing many complex provisions and requirements. Some of these provisions are relatively vague, leaving considerable room for interpretation regarding their implementation and enforcement. For instance, in the realm of HFT, the Act mandates stricter oversight of trading activities that may pose risks to market stability. Yet, the specific types of trading activities falling within this category and how to regulate them were initially unclear.

Based on the relevant definitions and methods of the DIKWP model, we conduct DIKWP transformation analysis on the case study across four dimensions: incompleteness, inconsistency, imprecision, and incorrectness, and construct an impact matrix.

3.1. Incompleteness of content

Based on the content in the Table 1, we employ the DIKWP model and semantic existence calculation to analyze the uncertainty issues arising from the incompleteness of the case study's content, while ensuring compliance with the law and the company's profitability purpose. Specifically, we identify the following uncertainties resulting from the content's incompleteness:

- **Lack of descriptive details in the legislation:** Initially, the legislation lacked specific details, including the identification and management of trading activities deemed to pose risks to market stability, compliance with targeted regulatory requirements, understanding regulatory expectations, and addressing potential regulatory enforcement and penalty standards.

Table 1. Analysis of the incompleteness in the transformation of DIKWP elements.

	Data	Information	Knowledge	Wisdom	Purpose
Data	N/A	Ambiguous Legislation: Vague definitions hinder accurate translation into regulatory information.	Unclear Provisions: Lack of explicit guidelines hampers the conversion of data into knowledge.	Diverse Data Interpretation: Varied interpretations may lead to different decision-making strategies.	Unclear Business Objectives: Data fails to directly reflect the company's specific purpose.
Information	Over-Simplification: Simplifying complex information into data may lead to the loss of critical details	N/A	Information Overload: A vast amount of regulatory information may be challenging to integrate into practical knowledge.	Subjectivity in Interpretation: Subjective interpretations of information may influence decision-making.	Disconnect between Information and Objectives: Collected information may not accurately reflect the pathway to achieving purpose.
Knowledge	Underutilization: Existing knowledge fails to translate into practically actionable data.	Lag in Updates: Delayed knowledge updates result in inaccurate information interpretation.	N/A	Knowledge Limitations: Inherent knowledge may restrict innovative decision-making.	Execution Bias: Existing knowledge may not fully align with the requirements for implementing new regulations.
Wisdom	Practice Deficiency: Wisdom is challenging to directly translate into specific data operations.	Ethical Considerations: Ethical and moral considerations influence information processing.	Innovation Constraints: Traditional wisdom may limit the acceptance of new knowledge.	N/A	Decision Conflicts: Considerations based on wisdom may conflict with business purpose.
Purpose	Difficulty in Concretizing Objectives: purpose is challenging to be transformed into clear data forms.	Goal-oriented Information Selection: Selecting information based on purpose may overlook crucial data.	Strategy Formulation: Purpose guide the formation and application of knowledge strategies.	Value-Driven Decision Making: Purpose influence the application of wisdom and decision-making direction.	N/A

3.2. Inconsistency of content

Based on the content in the table 2, we have analyzed the uncertainty issues in the case study resulting from the inconsistency of its DIKWP due to its content, starting from the purpose of not violating the law and ensuring profitability for the company, based on the relevant definitions of the DIKWP model and semantic existence computation. One such issue is:

- **Lack of descriptive details in the legislation:** Initially, the legislation lacked specific details, including the identification and management of trading activities deemed to pose risks to market stability, compliance with targeted regulatory requirements, understanding regulatory expectations, and addressing potential regulatory enforcement and penalty standards.

3.3. Imprecision of content

Based on the content in the table 3, we have analyzed the uncertainty issues in the case study resulting from the imprecision of its DIKWP due to its content, starting from the purpose of not violating the law and ensuring profitability for the company, based on the relevant definitions of the DIKWP model and semantic existence computation. One such issue is:

- **Ambiguity in regulatory requirements and boundaries:** Due to certain provisions of the legislation being rather vague, HFT companies are required to expend more resources in interpreting regulations to ensure compliance with legal requirements. This entails not only direct financial costs, such as hiring legal consultants for advice, but also time costs, especially in the initial phase of new regulations. The uncertainty regarding compliance may necessitate a more cautious approach by companies, thereby slowing down their decision-making and trading speed.

3.4. Incorrectness of content

Based on the content in the table 4, we analyzed the uncertainties arising from the incorrectness of DIKWP in the case, guided by the DIKWP model and relevant definitions of semantic existence computation, without violating the law and ensuring the company's profitability purpose.

- **Misunderstanding of HFT definition:** The lack of clear definition or ambiguity in the definition of HFT in the regulations may lead to misunderstandings among companies. This could result in the incorrect adjustment or cessation of certain legitimate trading strategies, or the oversight of some regulated activities.

In summary, these issues underscore the key challenges that HFT firms face in complying with the Dodd-Frank Act, including the difficulty in interpreting regulations, the increase in compliance costs, and the uncertainty and inconsistency in implementing compliance strategies. The key to addressing these issues lies in enhancing internal compliance auditing and risk management capabilities, and continuously monitoring regulatory changes to ensure the flexibility and adaptability of strategies and operations.

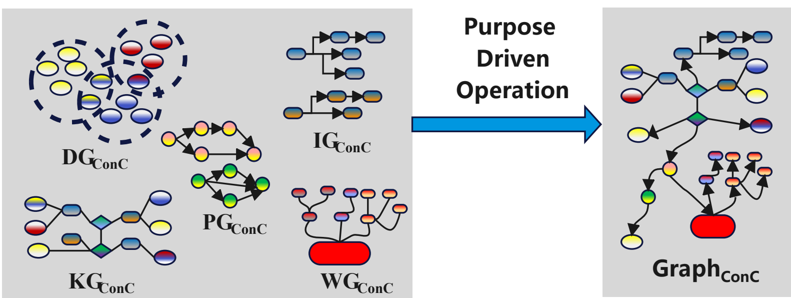

Figure 2. Operation of concept space.

Table 2. Analysis of the inconsistency in the transformation of DIKWP elements.

	Data	Information	Knolwdge	Wisdom	Purpose
Data	N/A	The uncertainty caused by inconsistency lies in the differences in interpreting trading data, such as varying understandings of what constitutes "abnormal trading behavior."	Inconsistencies in data quality and completeness may affect knowledge construction, such as developing risk assessment models based on incomplete trading data.	Subjectivity in data interpretation may influence wise judgments regarding compliance and risk, such as how to remain competitive while adhering to regulatory requirements.	The objectives of data collection may vary due to inconsistent understandings, such as collecting data related to regulatory reporting vs. data related to profit optimization.
Information	N/A	N/A	Different interpretative frameworks of information may lead to inconsistencies in knowledge construction, such as varying understandings of market trends.	In the transformation from information to wisdom, stakeholders' values may result in different uses of the same information, influencing decisions regarding compliance and risk management.	Inconsistent interpretation of information and goal setting may result in a disconnect between objectives and actual operations, such as misunderstandings of regulatory information leading to non-compliant transactions.
Knowledge	N/A	N/A	N/A	The transformation of knowledge into wisdom is influenced by individual or corporate values, which may lead to different applications of compliance and ethical standards.	Inconsistencies between knowledge and purpose may result in strategy implementation not aligning with company objectives, such as conflicts between risk preferences and compliance requirements.
Wisdom	N/A	N/A	N/A	N/A	Wisdom significantly influences the formation of purpose, but differences in individual or team values may lead to different strategies and goal setting.
Purpose	The direction of data collection and analysis is influenced, but if the goals are unclear or changeable, it may result in inconsistent data strategies.	Purpose-driven information needs, if inconsistent with actual operations, may lead to overlooking important information.	Purpose influence the direction of knowledge application, and inconsistency may result in a disconnect between strategic execution and actual needs.	Purpose are influenced by wisdom, but inconsistent values may lead to misjudgments in execution direction.	N/A

Table 3. Analysis of the imprecision in the transformation of DIKWP elements.

	Data	Information	Knowledge	Wisdom	Purpose
Data	N/A	Ambiguous regulatory requirements may result in collected data not meeting the expectations of regulatory agencies.	Insufficient data can impact the accurate understanding of regulatory implications.	Data uncertainty leads to incomplete considerations in decision-making.	The imprecision of data results in the inability to accurately devise compliance strategies.
Information	N/A	Imprecise interpretation of information leads to discrepancies in understanding regulations.	The diversity of information results in ethical decision-making dilemmas.	Imprecise information affects the clarity of compliance objectives.	N/A
Knowledge	Enhancing understanding of regulatory purpose.	N/A	Limited knowledge restricts effectiveness in complex decision-making.	Knowledge constraints impact strategy formulation and goal attainment.	Enhancing understanding of regulatory purpose.
Wisdom	Data selection and optimization from the perspective of wisdom.	Wisdom guides deeper information analysis.	Wisdom aids in identifying critical knowledge.	N/A	Wisdom directs goal setting and strategic realignment.
Purpose	Purpose-driven data collection and analysis.	Clear goal-setting guides information gathering and utilization.	Objective-driven accumulation and application of knowledge.	N/A	N/A

Table 4. Analysis of the incorrectness in the transformation of DIKWP elements.

	Data	Information	Knowledge	Wisdom	Purpose
Data	N/A	Data of incompleteness or incorrectness collection.	N/A	N/A	N/A
Information	N/A	N/A	Misinterpretation or oversimplification of information.	N/A	N/A
Knowledge	N/A	N/A	N/A	Decision-making based on incorrect information.	N/A
Wisdom	N/A	N/A	N/A	N/A	Wisdom directs goal setting and strategic realignment.
Purpose	Collecting irrelevant or misleading data.	N/A	N/A	N/A	N/A

4. Problem processing

In order to address the issues encountered in the case analysis presented in the previous section, we will utilize concepts and methods related to concept space, cognitive space, and semantic space to analyze and attempt to address these problems.

4.1. Concept space

Below is a concept space(ConC) definition and attributes tailored to the impact of the Dodd-Frank Act on HFT firms. The construction of the concept space aims to analyze the main issues faced during the implementation of the act and their implications for HFT.

4.1.1. Definition

As illustrated on the right side of Figure 2, a concept space is a collection of related concepts interconnected by specific attributes and relationships, forming a directed or undirected graph based on the symmetry of concept relations. Thus, a concept space can be represented using the following equation:

$$Graph_{ConC} = (V_{ConC}, E_{ConC}) \quad (1)$$

Where V_{ConC} is the set of nodes representing concepts, and E_{ConC} is the set of edges representing relationships between concepts.

4.1.2. Basic attributes

In the concept space, each concept $v \in V_{ConC}$ is associated with a set of attributes $A(v)$ and relationships $R(v, v)$ with other concepts. For the attributes

$$A(v) = \{a_1(v), a_2(v), \ldots, a_n(v)\} \quad (2)$$

where each $a_i(v)$ represents an attribute of concept v. Therefore, the concepts defined for the issues discussed in the previous section are as follows:

- According to the definition of HFT (V_h)[26], where the attribute is:

$$A(v) = \{a_{h1}, a_{h2}, a_{h3}, a_{h4}, a_{h5}\} \quad (3)$$

  the attributes represented by from a_{h1} to a_{h5} respectively are: whether it is algorithmic trading, whether high-speed and sophisticated computer programs or systems are used for trading, order-to-trade ratio threshold, short-term holding threshold, and whether positions are closed at the end of the trading day.
- Regulatory boundaries (V_b), with attributes as follows:

$$A(v) = \{a_{b1}, a_{b2}, a_{b3}, a_{b4}, a_{b5}\} \quad (4)$$

  where attributes represented by a_{b1} through a_{b5} respectively are: statutory item, type of regulation, upper regulatory limit, lower regulatory limit, and penalty content.
- Interpretation details of the legislation (V_d), with attributes as follows:

$$A(v) = \{a_{d1}, a_{d2}, a_{d3}\} \quad (5)$$

  where a_{d1} represents the content of the statute, a_{d2} represents the provisions of the statute, and a_{d3} represents the interpretation of the statute.

4.1.3. Relation

In the concept space, $R(v, v')$ denotes the relationship between concepts v and v'. If the graph is directed, then $R(v, v')$ is not equivalent to $R(v, v)$; if the graph is undirected, then they represent the same relationship. Therefore, based on the previous problem analysis, we can define the relationships accordingly.

- The relationship between HFT definition and legislative interpretation details:

$$R_{hd} = (V_h, V_d) \quad (6)$$

In the preceding equation, the relational link R_{hd} signifies the association between the definition of HFT and the specific interpretation of its regulatory content, thereby ensuring completeness and consistency for stakeholders within the concept space.

- The relationship between regulatory boundaries and legislative interpretation details:

$$R_{bd} = (V_b, V_d) \tag{7}$$

In the previous equation, the relational link R_{bd} signifies the association between each regulatory boundary and the specific interpretation of legislative content, ensuring stakeholders' understanding of the precision and correctness of regulations within the concept space.

4.1.4. Operation

The operation of concept space involves a series of actions performed within the concept space to query, add, or modify concepts and their relations.

- **Query operation:** The querying operation involves retrieving a relevant set of concepts within the concept space based on query conditions q (such as specific attributes or relations). It can be expressed as follows:

$$Q(V_{ConC}, E_{ConC}, q) \rightarrow \{v_1, v_2, \ldots, v_m\} \tag{8}$$

We can utilize the aforementioned equation to query all concepts related to HFT, for instance, retrieving all companies employing HFT within a certain order-to-trade ratio range.

- **Add operation:** We can add a new concept v to the concept set V_c using the following equation:

$$Add(V_{ConC}, v) \tag{9}$$

For example, due to the addition of a new regulation, we need to add the interpretation of this regulation to the corresponding concept set.

- **Modify operation:** Furthermore, we can maintain the relevant attributes of existing concepts through the following operation:

$$Update(V_{ConC}, v, A(v)) \tag{10}$$

For example, due to changes in the thresholds for HFT stipulated in the regulations, we need to modify the threshold attribute in the HFT definition clause to update the concept space.

Through the above formal representation, HFT firms can more clearly identify and understand the specific impacts of the Dodd-Frank Act on their businesses, particularly in terms of definition misunderstandings, regulatory ambiguity, inconsistent enforcement, and missing details in the act's description. This aids companies in formulating more effective strategies to ensure compliance while optimizing their trading strategies and operational efficiency.

4.2. Cognitive space

The Cognitive Space (ConN) provides a framework for describing and analyzing cognitive processes, namely how input data or information is transformed into understanding, decision-making, or action. This concept is particularly crucial in handling data, information, knowledge, wisdom, and Purpose (DIKWP) as it reveals how individuals or systems understand and respond to the external world through unique cognitive processing. Below is a formal description of the definition and processing of cognitive space.

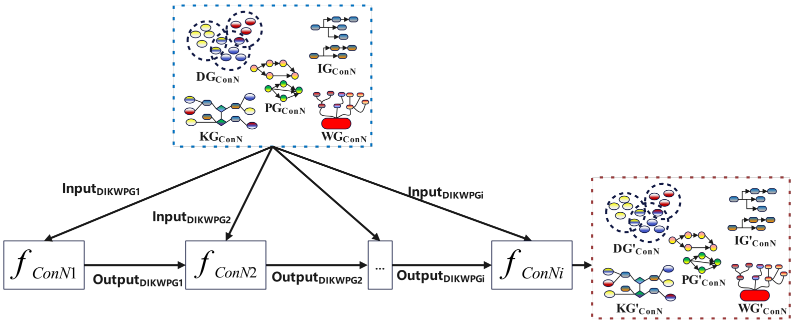

Figure 3. Input and output of cognitive space.

4.2.1. Definition

Function Set:

$$R = \{f_{ConN_1}, f_{ConN_2}, \ldots, f_{ConN_n}\} \tag{11}$$

where each function $f_{ConN_i} : Input_i \rightarrow Output_i$ represents a specific cognitive processing process, where $Input_i$ is the input space and $Output_i$ is the output space.
Therefore, the processing functions for the cognitive content understanding and execution of n financial companies are represented as:

$$R = \{f_{ConN_{u1}}, f_{ConN_{u2}}, \ldots, f_{ConN_{un}}\}. \tag{12}$$

4.2.2. Input and output space

- **Input space** $Input_i$ represents the collection of perceived data or information in Figure3, which can originate from observations from the external world, signals received from other systems, or internally generated data.For the cognitive content input space of n financial companies, there is only one, denoted as $Input_{u1}$, representing the input of legislative content.
- **Output space** $Output_i$ represents the collection of processed understandings or decisions in Figure3, which may include categorization of information, formation of concepts, determination of purpose, or establishment of action plans. For the cognitive content output space of n financial companies, there are n spaces, denoted as

$$Output_u = \{Output_{u1}, Output_{u2}, \ldots, Output_{un}\}, \tag{13}$$

representing the same legislative content input but with potentially varying output spaces for each company.

4.2.3. Cognitive processing

Each cognitive processing function f_{ConN_i} can be further refined into a series of substeps, including data preprocessing, feature extraction, pattern recognition, logical reasoning, and decision making. These substeps collectively constitute a complete cognitive pathway from raw data to final output.
Representation of substeps, for each f_{ConN_i}, it can be represented as:

$$f_{ConN_i} = f_{ConN_{i(5)}} \circ f_{ConN_{i(4)}} \circ \cdots \circ f_{ConN_{i(1)}} = (Input_i) \tag{14}$$

where $f_{ConN_{i(j)}}$ with j representing the j^{th} substep processing function, and $\circ$ denotes function composition. Therefore, for each financial company, with the same legislative content composing the input space, the inconsistency in cognitive processing leads to inconsistency in the output space. This can explain the deviation in understanding the legislation among financial companies, resulting in the erroneous adjustment or cessation of certain legitimate trading strategies, or the oversight of activities subject to regulation.

In the DIKWP model, the cognitive space transforms data, information, knowledge, wisdom, and purpose into specific understanding and actions through the unique cognitive processes of individuals or systems. By employing different cognitive processing functions, the system can implement the most appropriate processing strategies for different types of inputs, achieving efficient and accurate decision-making.

4.3. Semantic space

The semantic space(SemA) is a collection of semantic units interconnected through specific associations and dependency relationships, collectively constituting an objective representation of information and knowledge. Widely accepted concepts and linguistic rules within the semantic space facilitate the transmission and exchange of meaning.

4.3.1. Definition

We represent this using a graph:

$$Graph_{SemA} = (V_{SemA}, E_{SemA}) \tag{15}$$

where V_{SemA} represents semantic units (words, sentences, etc.), and E_{SemA} represents the associations and dependency relationships between semantic units.

4.3.2. Semantic units and relations

In the semantic space, a series of operations correspond to querying, adding, or modifying semantic units and their relationships.

- **Query operation:**

$$Query(V_{SemA}, E_{SemA}, q) \tag{16}$$

  The previous equation returns a set of semantic units that satisfy the query condition q.
- **Add operation:** $Add(V_{SemA}, v)$, adds a new semantic unit v to the set V_{SemA}.
- **Update operation:** $Update(E_{SemA}, v, v', e)$, updates or adds the relationship e between semantic units v and v'.

4.3.3. Operation and Application

Based on the relevant definitions and concepts of the semantic space, we attempt to analyze and address the issues faced by financial firms in executing the legislation regarding HFT mapped into the semantic space as discussed in the previous section. Here, we focus on analyzing the issue of "inconsistency in execution due to content interpretation bias" within the semantic space.

- We define a semantic unit $v_{SEmALawUB}$ to represent interpretation bias, which belongs to the legal semantic space:

$$Graph_{SemALaw} = (V_{SemALaw}, E_{SemAlaw}) \tag{17}$$

- We can use query operations to retrieve units of inconsistency in the execution process:

$$Query(V_{SemALaw}, E_{SemAlaw}, q_{UBias}) \rightarrow \{v_{SEmALawUB}\} \tag{18}$$

  where condition q is interpretation bias in law.
- The addition operation can be utilized to enrich the semantic space of legal understanding:

$$Add(V_{SemALaw}, v_{SEmALawUC}) \tag{19}$$

  where $v_{SEmALawUC}$ represents semantic units reflecting accurate legal comprehension.

- Furthermore, the semantic space can also be refined through update operations, as illustrated by the following equation.

$$Update(V_{SemALaw}, v_{SEmALawUC}, v_{SEmALawUB1}, e_{UBias}) \tag{20}$$

where e_{UBias} is comprehending bias and the purpose of this operation is to establish new semantic units, $v_{SEmALawUB1}$, representing the understanding biases existing alongside the accurate legal comprehension $v_{SEmALawUC}$.

The semantic space not only aids in identifying and resolving issues encountered in the execution of the Dodd-Frank Act but also provides a methodological approach to clarify the interpretation and application of the act through precise semantic operations. This allows for the identification of misunderstandings, ambiguities, and semantic units in execution, and facilitates continuous optimization and updates through new understandings, enriching the semantic space. Such an approach not only helps clarify ambiguous sections of the act but also fosters effective communication among different stakeholders regarding the interpretation and implementation of the act, ensuring regulatory compliance and transparency.

4.4. Crossing-space processing of DIKWP

4.4.1. Mapping from concept space to Cognitive space

- **Definition:** The concepts in the concept space are combined through the intrinsic cognitive mechanisms of individuals or systems, along with personal experience and knowledge, to form unique understandings and interpretations.

$$T_{ConC \to ConN} : ConC \to ConN \tag{21}$$

Equation (21) represents the process from the concept $c \in ConC$ to cognitive processing $r \in ConN$, reflecting how individuals understand and interpret concepts.

- **Application:** For instance, financial firms adjust parameters related to high-frequency trading based on their trading and system development experience, ensuring compliance with the concept attributes $A(v) = \{a_{b1}, a_{b2}, a_{b3}, a_{b4}, a_{b5}\}$ of the regulatory boundary V_b. Hence, this process can be regarded as a mapping from the concept space to the cognitive space.

4.4.2. Mapping from cognitive space to semantic space

- **Definition:** Transforming internal understanding within the cognitive space into semantic expressions that can be comprehended and accepted by the external world.

$$T_{ConN \to SemA} : ConN \to SemA \tag{22}$$

Equation (22) represents the transformation from cognitive processing to semantic expression, encompassing the selection and organization of language and symbols to accurately articulate cognitive content.

- **Application:** For instance, in situations where regulatory boundaries are ambiguous, some provisions merely describe illegal boundaries descriptively rather than quantitatively. However, as current computer systems require qualitative analysis of inputs to ensure the accuracy of outputs, it is necessary not only to represent these fuzzy boundaries in the semantic space and input them but also to first convert the expression of fuzziness into concepts in the cognitive space before processing them into parameters of the trading system to ensure compliance with legal standards. In the aforementioned process, we can interpret and express the mapping and processing from cognitive space to semantic space using Equation (22).

4.4.3. Feedback from Semantic Space to Concept Space and Cognitive Space

- **Definition:** Feedback from the external world to semantic expression is transmitted through the semantic space, thereby influencing concept space and cognitive space, forming a closed-loop process of cognitive updating and learning.

$$T_{SemA \to ConC} : SemA \to ConC \quad (23)$$

$$T_{SemA \to ConN} : SemA \to ConN \quad (24)$$

  Equations (23) and (24) respectively represent the feedback process from semantic expression to concept updating and cognitive updating, achieving dynamic adjustments and learning of internal understanding and concepts in response to external feedback.
- **Application:** For instance, when a financial company faces penalties, it generates new semantic content and expressions regarding the regulatory boundaries of the legislation. The penalties prompt the company to develop new conceptual attributes regarding the legislation and to perform corresponding operations on its previously vague concept space. As the concept space changes, the mapping function $T_{ConC \to ConN}$ from concept space to cognitive space varies accordingly, resulting in new cognition that is reflected in concrete actions. This refers to the process of handling the "4-N" problems under the acceptance of external feedback and purpose-driven circumstances, as outlined in the definition: this process constitutes a closed-loop cognitive updating and learning process.

In summary, we integrate the mapping and feedback processes to form a dynamic and interactive DIKWP model framework, where concept space, cognitive space, and semantic space interact and influence each other, presenting the complete process from subjective understanding to objective semantic processing.

5. Conclusions

Through the application of the DIKWP model, we conducted an in-depth analysis of the complex challenges faced by HFT firms in adapting to and complying with the Dodd-Frank Act. These challenges encompass various dimensions, including the ambiguity of legal definitions, the vagueness of regulatory requirements, the inconsistency in enforcement standards, and the lack of detail in the act, which we categorized into the "4-N" problems for analysis. We provided a comprehensive analytical framework involving Concept Space, Cognitive Space, and Semantic Space, followed by a case study analysis and practical application. This not only revealed effective strategies for identifying and addressing these challenges faced by HFT firms but also demonstrated how to enhance operational efficiency while ensuring regulatory compliance. In summary, our proposed methodology not only holds significant practical value for management and compliance professionals in HFT firms but also offers profound insights and theoretical support for financial regulators, policymakers, and researchers in financial technology.

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