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The Nature of Intelligent Analytics

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ABSTRACT

Intelligent analytics is an emerging paradigm in the age of big data, analytics, and artificial intelligence (AI). This chapter explores the nature of intelligent analytics. More specifically, this chapter identifies the foundations, cores, and applications of intelligent big data analytics based on the investigation into the state-of-the-art scholars' publications and market analysis of advanced analytics. Then it presents a workflow-based approach to big data analytics and technological foundations for intelligent big data analytics through examining intelligent big data analytics as an integration of AI and big data analytics. The chapter also presents a novel approach to extend intelligent Big Data analytics to intelligent analytics. The proposed approach in this chapter might facilitate research and development of intelligent analytics, big data analytics, business analytics, business intelligence, AI, and data science.

Keywords: Intelligent analytics, intelligent big data analytics, big data analytics, artificial intelligence (AI), business analytics, big data, data science, analytics intelligence.

1 INTRODUCTION

Big data, analytics, Artificial Intelligence (AI) and their integration are at the frontier for revolutionizing our work, life, business, management, and organization as well as healthcare, finance, e-commerce, and web services (Henke & Bughin, 2016) (Lohr, 2012 February 11) (John, 2013) (Sun & Huo, 2019) (Chen & Zhang, 2014) (Laney & Jain, 2017) (Russell & Norvig, 2010). Big data and its emerging technologies including big data analytics have been not only making big changes in the way the business operates but also making traditional data analytics and business analytics bring forth new

big opportunities for academia and enterprises (Sun, Sun, & Strang, 2016; Sun, Zou, & Strang, 2015; McAfee & Brynjolfsson, 2012). Big data analytics has big market opportunities. For example, International Data Corporation (IDC) forecasts that big data and business analytics (BDA) revenue will be $274.3 billion BY 2022 with a five-year compound annual growth rate (CAGR) of 13.2% from 2018 to 2022 (IDC, 2019).

AI and business intelligence (BI) have penetrated into modern analytics that at least includes augmented analytics, embedded analytics, mobile analytics, and cloud analytics (Eiloart, 2018) (Howson, Richardson, Sallam, & Kronz, 2019). For example, Amazon Web Services (AWS): Amazon QuickSight is a cloud analytics and BI service for performing ad hoc analysis and publishing interactive dashboards (Howson, Richardson, Sallam, & Kronz, 2019). Gartner predicts that 30% of new revenue growth from industry-specific solutions will include AI technology by 2021 (Laney & Jain, 2017). AI-derived business value is forecasted to increase to $US3.9 trillion in 2022 from $US1.2 trillion of 2018 (Pettey & van der Meulen, 2018), 325% jump! IDC predicted global spending on AI systems will more than double to $79.2 billion in 2022 with a compound annual growth rate (CAGR) of 38.0% over the 2018-2022 forecast period (IDC, 2019).

Intelligent big data analytics is an emerging science and technology based on AI (Russell & Norvig, 2010), and is becoming a mainstream market adopted broadly across industries, organizations, and geographic regions and among individuals to facilitate decision making for businesses and individuals to achieve desired business outcomes (Laney & Jain, 2017) (Sun, Sun, & Strang, 2018) (Sun Z. , 2019) (INFORMS, 2014). Intelligent big data analytics in particular and intelligent analytics in general have become a disruptive technology for effective innovation and decision making in the digital age (Holsapplea, Lee-Postb, & Pakath, 2014) (Davis, 2014). However, the following issues have still been ignored to some extent in academia, industries, and governments.

1. What are fundamentals of intelligent analytics?
2. What is the relationship between big data analytics and intelligent analytics?
3. How can we integrate big data analytics and AI?

This chapter will address these three research issues through exploring the nature of intelligent analytics. More specifically, this chapter identifies the theoretical and technological foundations, cores, and applications of intelligent big data analytics through an investigation into the state-of-the-art scholars' publications and market analysis of advanced analytics. Then it examines intelligent big data analytics as an integration of AI and big data analytics through presenting a workflow-based approach to big data analytics and technological foundations for intelligent big data analytics. The chapter uses a multidisciplinary approach to significantly extend intelligent big data analytics to intelligent analytics and looks at augmented analytics as a kind of intelligent analytics.

The remainder of this chapter is organized as follows: Section 2 identifies foundations, cores, applications as fundamentals of intelligent big data analytics. Section 3 argues that intelligent big data analytics = big data analytics + AI. This is a basis and motivation for Section 4. Section 4 presents an inclusive approach to intelligent analytics. Section 5 examines augmented analytics as intelligent analytics. It is an example of intelligent analytics taking into account the state of art advanced analytics in the global market of analytics. Sections 6 provides discussion and implications as well as future research directions of this research. The final section ends this chapter with some concluding remarks and future work.

From a viewpoint of research methodology, this chapter has used a multidisciplinary approach consisting of business, logical, algebraic, and systematic, research as a search method. For example, in order to identify foundations, cores, applications of intelligent big data analytics based on the principle of "research as a search", this chapter uses Scopus indexed publications search, which reflects the state of the art research of the scholars on intelligent big data analytics worldwide. Then it uses the market analysis provided by Gartner, which reflects the start of the art research and development of the modern analytics industry. Both are excellent complements for understanding the state-of-the-art intelligent big data analytics. This chapter also uses business, logical, algebraic, and systematic approach to examine intelligent big data analytics as an integration of AI and big data analytics and proposes the technological foundation of intelligent big data analytics as a hierarchical structure. This chapter uses logical, algebraic, and systematic (software engineering) approach to extend intelligent big data

analytics to intelligent analytics inclusively and proposes a novel system architecture of intelligent analytics as an intelligent system.

2 FOUNDATIONS, CORES, AND APPLICATIONS OF INTELLIGENT BIG DATA ANALYTICS: THE STATE OF THE ART

This section presents foundations, cores, applications of intelligent big data analytics based on the principle of "research as a search".

We searched Scopus (https://www-scopus-com.ezproxy.federation.edu.au/) for "intelligent big data analytics" (for short, hereafter, IBA) using search strategy: TITLE (intelligent AND big AND data AND analytics) (22 January 2020) and found 44 document results. In order to analyze the related work of the found 44 document results, we classify each title of them into three categories based on

1. What is for IBA?
2. What is deep exploration to IBA?
3. What is IBA for?

The answer to the first question is the theoretical and technological foundations for developing IBA. The answer to the second question is the theoretical and technological development of IBA. The answer to the third question is the applications of IBA. From a viewpoint of research methodology, such a classification is significant for developing intelligent analytics in general, and intelligent big data analytics in particular.

The mentioned 44 research publications are summarized as follows, based on the above three categories,

1. 10 out of 44 research publications address what is for IBA. These publications cover ontology-based workflow generation, intelligent multi-engine resource scheduler, ontology-based service discovery, intelligent interfaces, intelligent computing, semantic data ingestion, intelligent data traffic adaptation, software architecture design, intelligent query placement strategy, and intelligent technologies and applications. This implies that only a few strong theoretical and technological enablers for developing IBA. More theoretical and technological foundations are required to develop IBA.
2. 10 out of 44 research publications address what deep exploration is to IBA. These research publications cover model design, intelligent health data analytics, data-less big data analytics, adaptive e-commerce website ranking, big data management, a managerial framework, a theoretical framework, dynamic big data analytics. This implies that deep explorations into IBA have not been reflected very much by quality research publications.
3. 24 out of 44 research publications address the third question. These research publications cover the following applications of IBA: intelligent manufacturing, intelligent transportation, teaching, prediction of driver's intent, prediction of air pollution, predictive enterprise, intelligent process prediction, e-Commerce metasearch and ranking system, sustainable retail environment, knowledge discovery, surgery risk assessment, intelligent management of autonomous vehicles, intelligent mobile service provisions of customer relationship management (CRM), big video data, intelligent urban transport, cloud computing, travel, intelligent automation, and surveillance video system. This implies that the applications of IBA are still very isolated based on the quality research publications.

44 research publications indexed by Scopus demonstrate that

1. The number of publications (intelligent big data analytics is a part of the title of article) indexed by Scopus has been dramatically increased from 2016 to 2020 (5/2016, 6/2017, 11/2018, 10/2019, 5/2020, accessed on 23 01 2020). Only seven articles were published before 2016.
2. Where is "intelligent" in research and development of intelligent big data analytics? We find from the mentioned 44 research publications that "intelligent" has been used in the foundation

of intelligent big data analytics, and deep exploration into intelligent big data analytics and applications of intelligent big data analytics. For example, intelligent technologies/techniques (as foundations) for intelligent big data analytics, and intelligent technologies/techniques in intelligent big data analytics and intelligent applications of intelligent big data analytics.

3. Among 44 founded results, only 13 publications use "intelligent big data analytics" as a key word in their titles, 31 publications use "big data analytics" as a key word in their titles.

Now we turn to marketing analysis on intelligent big data analytics. The annual magic quadrant for analytics and BI platforms of Gartner (Howson, Richardson, Sallam, & Kronz, 2019) has a significant impact on the market of intelligent analytics and also their research and development. 2019's Magic Quadrant for analytics and BI platforms includes 21 software vendors, they have been classified into four categories: leaders, challengers, visionaries, and niche players. The leaders are Microsoft, Tableau, ThoughtSpot, Qlik. The challenger is MicroStrategy. The following Table 1 is the summary of leaders and challenger based on the mentioned three questions and (Howson, Richardson, Sallam, & Kronz, 2019). The detailed analysis of these 21 software vendors is available to the readers, if required.

Table 1. Foundations, cores and applications of leading analytics and BI platforms

Software vendors	What is for big data analytics?	What Functions of big data analytics?	What is big data analytics for?
Microsoft, Power BI	data preparation, visual-based data discovery, interactive dashboards, augmented analytics, Azure Machine Learning, text, sentiment and image analytics. agile, self-service analytics, conversational analytics	A platform of integrating data preparation, visual-based data discovery, interactive dashboards, augmented analytics, complex data models with integrated advanced analytics	Self-service, analytics and BI tool, decentralized analytics, agile, centralized BI provisioning
MicroStrategy	Augmented analytics, semantic graph, data manipulation, enterprise-grade security and an in-memory columnar data store, cloud BI and augmented analytics	A platform combining data preparation, visual-based and NLQ-based data discovery and exploration, dashboards and mobile capabilities with enterprise analytics and BI	Decentralized analytics Agile, centralized BI provisioning, governed data discovery
Qlik, Qlik Analytics Platform	data management, conversational analytics, multicloud deployments, big data, data preparation, data cataloguing and embedded analytics, augmented analytics, social media analytics	Qlik Sense, cognitive engine, business-value-based messaging, Data Literacy Project campaigns, and multiple conference	Decentralized analytics, agile centralized BI provisioning
Tableau	data preparation and profiling, visual exploration and data manipulation	augmented analytics	Decentralized analytics, agile, centralized BI provisioning
ThoughtSpot	augmented analytics, NLP, R, data preparation, visual exploration, dashboards and architecture	Search-based interface with augmented analytics	Decentralized analytics, agile, centralized BI provisioning.

The above discussion demonstrates that

1. Modern analytics and BI innovations around visual-based exploration have become mainstream since 2017 (Howson, Richardson, Sallam, & Kronz, 2019).
2. Decentralized analytics and agile centralized BI provisioning are main applications of big data analytics
3. Big data analytics, advanced analytics, and modern analytics have drawn increasing attention in academia, industry, and government (IDC, 2019) (Howson, Richardson, Sallam, & Kronz, 2019) (Sun Z. , 2019) (IDC, 2019). They have successfully applied to many industries including finance, banking, marketing, health care, and enterprise management. Many vendors in the modern analytics and BI market have double-digit revenue growth (Howson, Richardson, Sallam, & Kronz, 2019).

3 INTELLIGENT BIG DATA ANALYTICS = AI + BIG DATA ANALYTICS

The interrelationship among big data, analytics, and AI have drawn increasing attention (Sun Z. , 2019). Intelligent big data analytics is similar to analytics intelligence mentioned in (Wang, 2012). The difference between them is that the latter is limited to the data in cyberspace or the Web. The similarity between them is that incorporating AI into analytics is a huge global and social need in the near future (Wang, 2012). The intelligent big data analytics discussed in this section is an answer to such global and social needs.

3.1 Big Data analytics: A Workflow Centric Framework

First, we describe two use cases below.

Peter feels not well today. He visits Dr Paul. Paul provides a description on Peter's illness based on descriptive analytics. Paul diagnoses Peter's symptoms based on diagnostic analytics. Paul provides a prediction for Peter's illness based on predictive analytics. Finally, Paul provides a prescription on Peter's illness based on prescriptive analytics.

ABBA (it is a fictional name) is a global system company. Its enterprise system ASSA is well known in the big data industry. However, recently, the enterprise system has not been running well. The CEO of ABBA invites a global system service company (BAAB) for help. BAAB system engineer, Dr Weber visits ABBA and investigates the enterprise system ASSA. Weber first diagnoses ASSA based on the diagnostic analytics of BAAB. Weber provides a description on ABBA's malfunction based on the descriptive analytics. Then Weber provides a prediction of ASSA's malfunction based on the predictive analytics of BAAB. Finally, Weber provides a prescription on how to fix ASSA's malfunction based on the prescriptive analytics of BAAB.

The above two cases have a lifecycle of the workflow: Description $\rightarrow$ diagnosis$\rightarrow$ prediction $\rightarrow$ prescription. As well-known, data analytics has been classified into four categories: Descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics (Kumar, 2015) (Sun Z. , 2019) (INFORMS, 2014) (Sharda, Delen, & Turba, 2018) (Gartner-diagnostic analytics, 2020) (LaPlante, 2019), briefly,

$$\text{Data analytics: } = \text{data descriptive analytics} + \text{data diagnostic analytics} + \text{data predictive analytics} + \text{data prescriptive analytics} \quad (1)$$

The above use cases and the classification of data analytics leads to a workflow-based lifecycle of data analytics, illustrated in Figure 1.

The proposed workflow-based lifecycle of analytics demonstrates that data analytics has penetrated into each of a lifecycle of the business workflow (Sathi, 2013) (Howson, Richardson, Sallam, & Kronz, 2019). One stage of the lifecycle corresponds to one analytics (one-to-one correspondence), as illustrated in Figure 1. Descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics form a workflow centric analytics platform. In order to improve the effectiveness and efficiency of all the mentioned analytics, the platform has a central mechanism, called analytics engine (Sathi, 2013). The analytics engine manipulates a centralized database, information base, knowledge base, and wisdom base. It processes analytical algorithms, models, tools and transforms the input to the output. One of analytical tools is online analytical processing (OLAP), massively used in business and e-Commerce industry (Laudon & Laudon, 2016).

Figure 1. A workflow-based lifecycle of analytics

These four analytics can share the same data, information, knowledge, and wisdom. Therefore, an integrated analytics platform (system) consists of descriptive analytics, diagnostic analytics, predictive analytics, and prescriptive analytics (DIKW analytics), which have the centralized database, information base, knowledge base, and wisdom base (DIKW base), as shown in Figure 2.

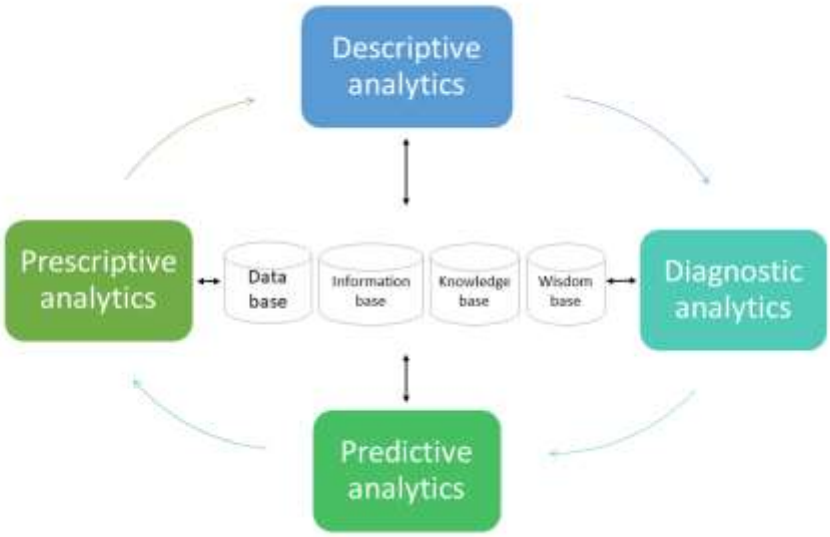

Figure 2. An integrated analytics platform.

The integrated analytics platform is a kind of analytics integration. It is also a kind of data integration, because any data, information, knowledge, and wisdom (DIKM) can be considered as the input for the integrated analytics platform.

Big data analytics can be defined as a process of collecting, organizing and analyzing big data to discover, visualize, and display patterns, knowledge, and intelligence within the big data (Sun & Huo, 2019). Similarly, big data analytics can be defined as techniques used to analyze big data, acquire and visualize knowledge and intelligence from big data (Gandomi & Haider, 2015). Applying big as an operation to both sides of equation (1) (Sun & Wang, 2017), we have

Big data analytics = big data descriptive analytics + big data diagnostic analytics + big data predictive analytics + big data prescriptive analytics (2)

This conforms with "the main components of big data analytics include big data diagnostic analytics, big data descriptive analytics, big data predictive analytics, and big data prescriptive analytics" mentioned in (Minelli, Chambers, & Dhiraj, 2013) (Gandomi & Haider, 2015) (Howson, Sallam, & Richa, 2018) (Gartner-diagnostic analytics, 2020) (LaPlante, 2019).

3.2 Intelligent Big Data Analytics

Intelligent big data analytics is AI-driven big data analytics (Sun, Sun, & Strang, 2018) (Sun & Wang, 2017) (Sun Z. , 2019). Therefore, intelligent big data analytics can be represented as

Intelligent big data analytics = Big data analytics + AI (3)

Where + can be explained as "and". Equation (3) means that intelligent big data analytics includes big data analytics and AI and their integration (Wang, 2012) (Sun Z. , 2019). Intelligent big data analytics can be represented as follows through extending Equation (3), applying intelligent as an operation to both sides of (2).

Intelligent big data analytics = intelligent big descriptive data analytics + intelligent big data diagnostic analytics + intelligent big predictive data analytics + intelligent big prescriptive data analytics (4)

Equation (4) shows that intelligent big data analytics consists of intelligent big data descriptive analytics, intelligent big data diagnostic analytics, intelligent big data predictive analytics, and intelligent big data prescriptive analytics. Equation (4) is an extension of existing data analytics (Delena & Demirkanb, 2013) by integrating AI with big data (Sun Z. , 2019).

- Intelligent big data descriptive analytics is intelligent descriptive analytics for big data (Delena & Demirkanb, 2013; Kantardzic, 2011) (Sun, Sun, & Strang, 2018). It is used to discover new, nontrivial information based on AI techniques (Kantardzic, 2011, p. 2), and explain the characteristics of entities and relationships among entities within the existing big descriptive data (Coronel & Morris, 2015, p. 611). It addresses the problems such as what and when happened, and what is happening (Delena & Demirkanb, 2013) (Kumar, 2015) (LaPlante, 2019). For example, intelligent business reports with dashboards for global COVID-19 pandemic is a result from intelligent big data descriptive analytics on big data of the global COVID-19.
- Intelligent big data diagnostic analytics is intelligent diagnostic analytics for big data (Sun, Sun, & Strang, 2018). It is used to examine data or content to answer the question "Why did it happen?" (After one knows what happened, one wants to know why (LaPlante, 2019)), from the historical and current diagnostic data based on AI techniques such as drill-down, data discovery, data mining, and correlations (Gartner-diagnostic analytics, 2020). For example, diagnostic analytics available on the cloud belongs to intelligent big data diagnostic analytics.
- Intelligent big data predictive analytics is intelligent predictive analytics for big data (Sun, Zou, & Strang, 2015). It focuses on forecasting future trends by addressing the problems such as what will happen next? what is going to happen? what is likely to happen? and why it will happen? based on historical and current big data (Kumar, 2015) (Sun Z. , 2019) (LaPlante, 2019). Intelligent big data predictive analytics uses techniques of data mining (predictive mining), statistical modelling, mathematics and AI to create intelligent models to predict future outcomes or events (Delena & Demirkanb, 2013) (Coronel & Morris, 2015, p. 611) (Sharda, Delen, & Turba, 2018). For example, intelligent big data predictive analytics can be used to predict where might be the next attack target of terrorists smartly (Sun, Sun, & Strang, 2018).
- Intelligent big data prescriptive analytics is intelligent prescriptive analytics for big data (Sun, Zou, & Strang, 2015). It addresses the problems such as what we should do, why we should do and what should happen with the best outcome under uncertainty (Minelli, Chambers, & Dhiraj, 2013, p. 5) (Delena & Demirkanb, 2013) (LaPlante, 2019). Intelligent big data prescriptive analytics uses

intelligent algorithms to determine optimal decisions for the future actions (Delena & Demirkanb, 2013). For example, intelligent big data prescriptive analytics can be used to provide an optimal marketing strategy for an e-commerce company.

3.3 Technological Foundation of Intelligent big data analytics

The fundamentals of intelligent big data analytics consist of AI and machine learning (ML), mathematics, statistics and data mining, human interface, computer science, operations research, data science and systems (Chen & Zhang, 2014) (INFORMS, 2014) (Sun & Huo, 2019). The techniques for intelligent big data analytics encompass a wide range of mathematical, statistical, modeling and algorithm techniques (Coronel & Morris, 2015, p. 590) (Sun Z. , 2018). Big data analytics always involves historical or current data and data visualization (LaPlante, 2019) (Sathi, 2013). This requires big data analytics to use data mining (DM) to discover knowledge from a data warehouse (DW) or a big dataset in order to support decision making (Turban & Volonino, 2011) (Holsapplea, Lee-Postb, & Pakath, 2014; Davis, 2014). DM employs advanced statistical and analytical tools to analyze the big data available through DWs and other sources to identify possible relationships, patterns and anomalies and discover information or knowledge for business decision making (Coronel & Morris, 2015, p. 590; Kantardzic, 2011) (Delena & Demirkanb, 2013). In DM, regression and classification are usually used for prediction, predictive mining and analytics, while clustering and association are used for description or descriptive mining and analytics (Fan, Lau, & Zhao, 2015). DW extracts and obtains the data from operational databases and external open sources, providing a more comprehensive data pool (Coronel & Morris, 2015, p. 590; Holsapplea, Lee-Postb, & Pakath, 2014). Big data analytics also uses statistical modeling (SM) to discover knowledge through descriptive analysis that can support decision making (Sun, Zou, & Strang, 2015). Visualization technologies including display technologies as an important part of big data analytics make knowledge patterns and information for decision making in a form of figure or table or multimedia. In summary, big data analytics can facilitate business decision making and realization of business objectives through analyzing existing data and future trends, creating predictive models to forecast future threats and opportunities, and optimizing business processes to enhance organizational performance using the mentioned techniques (Delena & Demirkanb, 2013; Chen, Chiang, & Storey, 2012). Therefore, big data analytics can be represented technically below (Sun, Zou, & Strang, 2015; Holsapplea, Lee-Postb, & Pakath, 2014; Chen, Chiang, & Storey, 2012).

$$\text{Big data analytics} = \text{Big data} + \text{data analytics} + \text{DW} + \text{DM} + \text{SM} + \text{ML} + \text{visualization} + \text{optimization} \quad (5)$$

Equation (5) reveals the fundamental relationship between big data, data analytics, and big data analytics, that is, big data analytics is based on big data and data analytics. It also shows that computer science, data science, AI, and statistics play a dominant role in the development of big data analytics through providing latest techniques and tools of DM, DW, ML and visualization (Sun Z. , 2018; Davis, 2014). SM and optimization still play a fundamental role in the development of big data analytics (Minelli, Chambers, & Dhiraj, 2013) (Sun & Huo, 2019).

Equations (3), (4), and (5) are a concise representation for the technological components of intelligent big data analytics. Figure 3 illustrates these equations on intelligent big data analytics and their interrelationships (Sun, Sun, & Strang, 2018).

Apache Hadoop is a platform of big data analytics (Reddy, 2014). As an open source platform for storing and processing large datasets using clusters and commodity hardware, Hadoop can scale up to hundreds and even hundreds of nodes (Sun & Huo, 2019).

The current leading DW includes Amazon's Redshift, Google's BigQuery, Microsoft's Azure SQL Data Warehouse, and Teradata (Tableau, 2015).

Apache Spark is one of the most popular big data analytics services. It is a big data analytics platform for several enterprises (Tableau, 2015; Reddy, 2014). Spark provides dramatically increased large-scale data processing compared to Hadoop, and a NoSQL database for big data management

(Coronel & Morris, 2015; Reddy, 2014). Apache Spark has provided Goldman Sachs with excellent big data analytics services (Tableau, 2015).

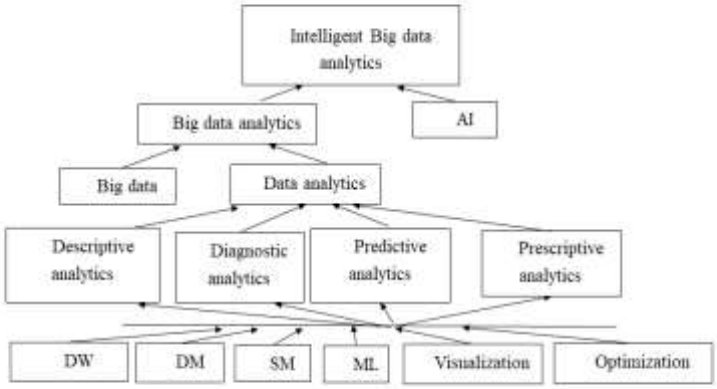

Figure 3. An ontology of intelligent big data analytics

Applying intelligent as an operation to both side of Equation (5) (Sun & Wang, 2017), we have

$$\text{intelligent big data analytics} = \text{intelligent big data} + \text{intelligent data analytics} + \text{intelligent DW} + \text{intelligent DM} + \text{intelligent SM} + \text{intelligent ML} + \text{intelligent visualization} + \text{intelligent optimization} \quad (6)$$

Where intelligent big data can be considered as big data. Equation (6) means that intelligent big data analytics at least includes big data, intelligent data analytics, intelligent data warehousing, data mining, intelligent statistical modelling, ML, intelligent visualization and intelligent optimization (Delena & Demirkanb, 2013) (Sun & Wang, 2017) (Sun, Sun, & Strang, 2018) (Sun Z. , 2019), because data mining and ML are themselves intelligent techniques. Equation (6) demonstrates that AI plays a central role in transforming big data analytics to intelligent big data analytics through penetrating into each component of big data analytics.

4 INTELLIGENT ANALYTICS: AN INCLUSIVE PERSPECTIVE

This section extends intelligent big data analytics to intelligent analytics based on an inclusive approach.

Intelligent analytics is an emerging paradigm in the age of big data, analytics, and AI (Sun Z. , 2019). Incorporating AI into big data analytics have become a hotspot in many research fields such as business, information systems, operations research, data science, and computer science (INFORMS, 2014) (Sun Z. , 2019). However, the following issues are still significant for academia, industries and governments.

1. Is intelligent big data analytics the unique form of intelligent analytics?
2. What are fundamentals of intelligent analytics?
3. How can we apply mathematical methods and thinking to intelligent analytics?

This section will address these three issues.

Data, information, knowledge, and wisdom (for short, DIKM) have played a significant roles in computing and ICT in the past few decades and led to data computing, information computing,

knowledge computing, and wisdom computing (for short, DIKM computing) (ACM/IEEE/AIS, 2019). For example, data computing includes data science, technology, engineering, management and systems, and so on (Sun & Huo, 2020). DIKEW computing covers almost all the aspects of current ICT with applications. Therefore, data, information, knowledge, and wisdom are elements for the digital age in general and for intelligent analytics in particular. Therefore, all science in the digital age is like a tree of which four elements, namely, data, information, knowledge, and wisdom are the roots, mathematics and computing the trunk, and all the other sciences the branches that grow out of this trunk, inspired by the work of (Descartes, 1637) (Wiki-Descartes, 2020).

Furthermore, data analytics can be defined as the "art of examining, summarizing, and drawing conclusions from data". (Norusis, 1997). Let x be a variable, then, this definition of data analytics can be extended below.

x analytics is the "art of examining, summarizing, and drawing conclusions from x." (7)

When x is information, knowledge, and wisdom respectively, we have information analytics, knowledge analytics, and wisdom analytics.

Data analytics can also be defined as a method that "uses data to learn, describe and predict something" (Turban & Volonino, 2011, p. 341). Let y be a variable, this definition of analytics can be extended below.

y analytics is a method that "uses y to learn, describe and predict something" (8)

When y is information, knowledge, and wisdom respectively, we have information analytics, knowledge analytics, and wisdom analytics.

Combining (7) and (8), we have

x analytics is the art of examining, summarizing, and drawing conclusions from x to learn, describe and predict something. (9)

Where x is an element of {data, information, knowledge, wisdom}. We have information analytics, knowledge analytics, and wisdom analytics. Data, information, knowledge and wisdom can be considered as an input for an analytics system for processing. The processing of this analytics system is to examine, summarize, and draw conclusions from x. The goal of this analytics is to learn, describe and predict something (Sun Z., 2019).

The above discussion demonstrates that data analytics is not all forms of analytics. Information analytics, knowledge analytics, and wisdom analytics are extended forms of data analytics. In such a way, data analytics, information analytics, knowledge analytics, and wisdom analytics (for short, DIKM analytics) can be considered as the basic form of analytics, taking into account DIKM (Sun & Huo, 2020). Briefly,

Analytics: = data analytics + information analytics + knowledge analytics + wisdom analytics (10)

In other words, analytics consists of data analytics, information analytics, knowledge analytics and wisdom analytics, at a fundamental level. At a higher level, analytics can be a system of integrating a few analytics at the fundamental level. If we consider data analytics, information analytics, knowledge analytics, and wisdom analytics as the atomic level, then we have three levels of integrated analytics. The top (4^{th}) level of analytics is the analytics integrating data analytics, information analytics, knowledge analytics and wisdom analytics. From a Boolean structure viewpoint (Sun & Xiao, 1994) (Lang, 2002) (Johnsonbaugh, 2013), there are 16 (2^4) different kinds of analytics based on equation (10).

As well-known, big data is significant for innovation, competition, and productivity in the digital age (McKinsey, 2011) (Sun & Huo, 2019), then big information, big knowledge, big wisdom are also significant for effective management, decision making and innovation for development of economy, society and even nations, because many governments and organizations have carried out a number of initiatives on development of information industry (e.g. China, China has the Ministry of Information Industry), knowledge economy (e.g. Australia) and wisdom cities (e.g. China, China has launched many national projects for developing wisdom cities). Therefore, big information analytics, big knowledge analytics, and big wisdom analytics should have played same significant role as that of big data analytics

in the digital age, although currently some of academia, industries and governments have technically ignored them, just as they ignore the rules of lockdown and social distancing in the age of coronavirus pandemic. Therefore, applying big as an operation (Sun & Wang, 2017) to both sides of equation (10), we have

Big analytics: = big data analytics + big information analytics + big knowledge analytics + big wisdom analytics (11)

Equation (11) have extended the result on big analytics in (Sun, Strang, & Li, 2018), in which big analytics is a representation of big data analytics.

Now, let intelligent analytics be intelligent big analytics, apply intelligent as an operation to both sides of equation (11), we have

Intelligent analytics = Intelligent big data analytics + intelligent big information analytics + intelligent big knowledge analytics + intelligent big wisdom analytics. (12)

Similarly, we can use Boolean structure to have 4 levels of integrated analytics and have 16 (2^4) different kinds of intelligent analytics based on equation (12).

Equations (9) to (12) forms an inclusive approach on intelligent analytics. We searched Google.com and scholar.google.com for each component of intelligent analytics listed in (12) on 15 August 2020. The searched number of websites or scholarly publications demonstrates that academia and industries are still focusing either intelligent analytics or intelligent big data analytics. Intelligent big information (or knowledge or wisdom) analytics are not yet appealing to the mainstream in the analytics and BI market though data, information, knowledge and wisdom have a very close relationship.

5 AUGMENTED ANALYTICS AS INTELLIGENT ANALYTICS

This section will examine augmented analytics as intelligent analytics.

Augmented analytics is data analytics that uses "enabling technologies such as ML and AI to assist with data preparation, insight generation and insight explanation to augment how people explore and analyze data in analytics and BI platforms" (Gartner-augmented analytics, 2020). It can be also defined as "a technology that automates the selection and preparation of data, the generation of insights, and the communication of those insights" (LaPlante, 2019, p. 5)

The features of augmented analytics include automated data preparation, automated insight generation and explanation, NLQ and natural language narration, as well as content creation (Howson, Richardson, Sallam, & Kronz, 2019).

Augmented data preparation on multistructured data is the need to profile, enrich and infer relationships (to automatically generate a model for analysis), and to make recommendations to improve or enhance insights from data, it will stimulate differentiating innovations.

Insight generation is automated for identifying significant segments, clusters, drivers, outliers, and anomalies. Augmented alerting and anomaly detection are new trends in augmented analytics although only a few smaller vendors offer these functions (Howson, Richardson, Sallam, & Kronz, 2019).

NLQ, NLP, NLG and (natural language query, processing and generation) are used to access data and to interpret findings (Howson, Richardson, Sallam, & Kronz, 2019). With the use of voice- and search-based interfaces, the query process (NLQ) changes from a primarily drag-and-drop query-building process into a more search-like experience. NLP includes conversational analytics that integrates chatbots and virtual assistants into the workflow for analytics. NLP allows nontechnical users to easily ask questions from source data (LaPlante, 2019, p. 6). NLG automates the process of translating complex data into text with intelligent recommendations, thereby accelerating analytic insights (LaPlante, 2019). NLG aims to generate explanations of charts, and insights enhance data literacy. NLG uses ML to explain findings that may have been either manually or automatically generated (Howson, Richardson, Sallam, & Kronz, 2019). Natural language narration includes narration of findings and prescriptive actions. These include understanding of data distribution and correlations.

Content creation includes augmented data discovery, augmented alerting, search, and NLP for voice and text, as well as conversational analytics. Conversational analytics represents the convergence of

several technologies, including personal digital assistants, smartphones, bots, and ML (Howson, Richardson, Sallam, & Kronz, 2019). Virtual reality and augmented reality support for a broad range of content analytics and text analytics for use on unstructured data.

Oracle analytics has implemented augmented analytics capabilities across its platform (LaPlante, 2019). Augmentation is a kind of intelligence. Augmented analytics will be a dominant driver of new purchases of analytics and AI, data science, ML platforms, and embedded analytics in the years ahead (Howson, Richardson, Sallam, & Kronz, 2019).

Augmented analytics is a kind of intelligent big data analytics, because it has embedded AI and ML into the data analytics (LaPlante, 2019, p. 2), also because it includes ML-enabled analytics, AI-driven analytics in all phases of the data workflow for analytics, from data preparation to data modeling, insight generation and insight explanation. Augmented analytics is a kind of intelligent data predictive analytics because it assists with insight generation and insight explanation (Kumar, 2015). However, not only big data, but also big information, big knowledge, and big wisdom are required to generate and explain hindsight, insight, and foresight for smart decision making and business solutions. Therefore, how to manage and process big data, big information, big knowledge, and big wisdom based on AI is significant for the future of both augmented analytics and intelligent analytics. We will address it in the future work.

6 DISCUSSION AND IMPLICATIONS

We have mentioned several scholarly researches on data analysis, big data analytics, AI and intelligent analytics. In what follows, this section will discuss the related work, examine theoretical and technical implications of this research as well as limitations and future research directions.

6.1 Discussion

Intelligent analytics has drawn some attention in academia and industries. For example, Rose provides a conceptual framework for defining analytics (INFORMS, 2014). He mentioned analytics can be classified two categories: data centric and decision centric. The former uses data to find interesting insights and information to predicate what might happen. The latter understands the business problem, and determines the specific methodologies and information needed to solve the specific problem. Our workflow-based approach to big data analytics is an important complement to the above classification, because it creates a one-to-one correspondence between a stage in the (business) workflow and data analytics. Therefore, the proposed workflow-based approach to data analytics can be workflow centric, which covers the conceptual framework of analytics (INFORMS, 2014). Furthermore, this research demonstrates that intelligent analytics is a big DIKW centric, AI driven analytics. Therefore, the research of this chapter provided a better understanding of data analytics, big data analytics, intelligent big data analytics, and intelligent analytics.

Chen et al consider intelligent big data analytics as a big data system and use the collective intelligence model and multiagent paradigm to propose a collective intelligence framework to solve the system integration problem in the big data environment (Chen, Li , & Wang, 2015). However, few have discussed the fundamental problems of intelligent big data analytics nor provided an inclusive approach on intelligent analytics. This research identifies theoretical and technological foundations, cores and applications of intelligent big data analytics based on the investigation into the state-of-the-art scholars' publications and market analysis of advanced analytics. It also presents the technological foundations for intelligent big data analytics through examining intelligent big data analytics as an integration of AI and big data analytics. This research demonstrates that intelligent big data analytics is not the unique form of intelligent analytics, which in fact consists of intelligent big data analytics, intelligent big information analytics, intelligent big knowledge analytics, intelligent big wisdom analytics at a fundamental level.

Gartner uses advanced analytics, modern analytics, and augmented analytics to analyze AI and BI, big data, and analytics and their impacts (Laney & Jain, 2017) (Howson, Richardson, Sallam, & Kronz, 2019). With the further development of analytics, either advanced analytics or modern analytics or augmented analytics or intelligent analytics will be selected by the customers, because the general

customers hope to use the simple concept to cover what they perceive just as smartphones to intelligent phones are accepted in the world. Industries and governments also prefer simple terms to jargon words, just as they like big data rather than massive data in the past decade.

From an evolutionary viewpoint, intelligent analytics is a more general form of data analytics (Kantardzic, 2011). Data analytics is an extended form of data mining (Gandomi & Haider, 2015), because data analytics is considered as the whole data mining process or process of knowledge discovery in databases (KDD) (Tsai, Lai, Chao, & Vasilakos, 2015). Therefore, the relationships among data mining, intelligent big data analytics and intelligent analytics can be represented as

Data mining $\subset$ intelligent big data analytics $\subset$ intelligent analytics.

This means that data mining as an intelligent technique is a foundation of intelligent analytics. However, the difference between intelligent analytics and data mining is that the former discovers AI-driven knowledge and wisdom not only from big data but also from big information, big knowledge and big wisdom.

6.2 Theoretical and Technical implications

The theoretical implication of this research is that it provides an inclusive approach for understanding the interrelationship among big data, information, knowledge, wisdom, analytics, and AI and their integration. Intelligent analytics is not only intelligent big data analytics. Fundamentally, intelligent analytics consists of intelligent big data analytics, intelligent big information analytics, intelligent big knowledge analytics and intelligent big wisdom analytics. This inclusive approach will pave a new way for developing intelligent analytics with applications.

The technical implication of this research is that the proposed approach on intelligent analytics in general and intelligent big data analytics, intelligent big information analytics, intelligent big knowledge analytics, intelligent big wisdom analytics in particular can attract more researchers and practitioners to undertake the research and application of intelligent analytics for more effective management decision making in business workflow.

6.3 Limitations

A limitation of this chapter is that it should consider intelligent descriptive, diagnostic, predictive and prescriptive analytics as one dimension, and the technological components of intelligent analytics as another dimension. Therefore, one of future research directions is to provide the matrix analysis for intelligent analytics.

Another limitation of the chapter is that it should have provided more practical examples for readers to better understand proposed theoretical discussion.

6.4 Future research directions

Intelligent analytics is an integrated analytics paradigm of big data, big information, big knowledge, big wisdom, analytics and AI. It provides smart solutions to business, marketing and services through intelligent analytical technologies, methodologies, tools, and applications embedded in workflow-driven intelligent analytics systems. Intelligent analytics is a term that embodies the realization of a historic and current vision of how big data, big information, big knowledge, bid wisdom, analytics and AI will revolutionize the world of business, organizations, society and our lives to create a society of analytics intelligence, forever and irrevocably (Davis, 2014) (Sun Z. , 2019). Therefore, one of the future research directions is to address systems integration among intelligent analytics, augmented analytics and modern analytics (Howson, Sallam, & Richa, 2018).

Analytics thinking and analytics intelligence will play a critical role in research and development of big data analytics and intelligent analytics, just as computing thinking has played a significant role in computing in the past two decades. However, how can analytics thinking and analytics intelligence influence research and development of intelligent analytics with applications? This is a significant issue. Therefore, another future research direction is to address this issue through theoretical and technological research with real-world examples.

7 CONCLUSION

The objective of this chapter is to propose a unified nature for intelligent analytics as an integration between analytics and AI. This chapter presents an inclusive approach to intelligent analytics, which treats many aspects of intelligent analytics and business analytics using mathematical methods and AI in a unified way. The main three contributions of this research to intelligent analytics with applications are 1. It identified the theoretical and technological foundations, cores of intelligent big data analytics with applications; 2. It integrated AI techniques with big data analytics through proposing a workflow-based approach to big data analytics and technological foundations for intelligent big data analytics; 3. It demonstrates that intelligent analytics is an integration between analytics and AI taking into account big data, big information, big knowledge and big wisdom and their close relationships. This research also demonstrates that 1. Data, information, knowledge, and wisdom are four elements underpinning the digital age. 2. Intelligent analytics has analytical tools and techniques including DM, DW, SM, and ML. Therefore, the proposed approach in this chapter might facilitate research and development of intelligent analytics, intelligent big data analytics, analytics intelligence and AI.

In the future work, as an extension of future research directions and our research of Section 4, we will investigate 2D analysis for big data, big information, big knowledge and big wisdom as a dimension, and descriptive analytics, diagnostic analytics, predictive analytics, prescriptive analytics as another dimension based on AI and ML to form a unified framework of intelligent analytics. We will also develop a unified theory for analytics thinking and analytics intelligence.

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This section provides a list of 13 additional readings for intelligent big data analytics.

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10KEY TERMS AND DEFINITIONS

This section provides eight terms related to the topic of this chapter. For detailed information on each of the terms please read the related books or papers.

Intelligent big data analytics is science and technology about collecting, organizing and analyzing big data to discover patterns, knowledge, and intelligence as well as other information within the big data based on artificial intelligence and intelligent systems.

Intelligent analytics is science and technology about collecting, organizing and analyzing big data, big information, big knowledge and big wisdom to transform them to intelligent information, intelligent knowledge, and intelligent wisdom based on artificial intelligence and analytical algorithms and technologies.

Artificial intelligence (AI) is science and technology concerned with imitating, extending, augmenting, automating intelligent behaviors of human beings.

Big data is data with at least one of the ten big characteristics consisting of big volume, big velocity, big variety, big veracity, big intelligence, big analytics, big infrastructure, big service, big value, and big market.

Data mining is a process of discovering various models, summaries, and derived values, knowledge from a given collection of data. Another definition is that it is the process of using statistical, mathematical, logical, AI methods and tools to extract useful information from large databases.

Data science is a field that builds on and synthesizes a number of relevant disciplines and bodies of knowledge, including statistics, informatics, computing, communication, management, and sociology to translate data into information, knowledge, insight and intelligence for improving innovation, productivity and decision making.

Intelligent system is a system that can imitate, automate some intelligent behaviors of human beings. Expert systems and knowledge-based systems are examples of intelligent systems.

Machine learning is concerned about how computers can adapt to new circumstances and to detect and extrapolate patterns.