A Critical Review of Database Administration Developments and Research in Contemporary Digital Environments

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***Abstract* – This paper provides a literature review of current database developments and research. What constitutes a database alongside the scope of digital environments, contemporary database models, and trends are discussed with development implications. Findings are that databases by description have changed little despite huge progress; digitals environments are smarter and more internet bound than ever; and that security, governance, and strategic hurdles are squeezing the adoption of recent technologies. With over a third of administrators handling more than one-hundred databases, these results show that technical synergies between digital environments and back-end developments are vital to the survival of enterprises.**

Index Terms – Contemporary; Database; Development; Digital; Research.

I. Introduction

A. *Background*

Data is the lifeblood of our economy, so goes the adage concerning vitality of societal innovation [1]. Truth in that may be found from mobile devices stockpiling data to steer company survival with insights [2]. Certainly, data is proving its worth in health systems during global crisis [3]. Yet to be a decision-making resource, data needs an abode. Particularly, this is the case for businesses mining value from warehoused data [4]. Nowadays, data is treated like intangible assets for trading [5] [6]. While traceable to ancient Egypt, data debates in this digital age challenge the storage locus at the database.

B. *Context*

In our present era, data tends to be administered by a 'database'. Because new information technology (IT) is triggered by corporate demand for efficiencies there is an onus on having robust storage [7]. We point that manner of operational control towards database base management systems (DBMS) of which there are numerous types. While DBMSs serve to invoke queries on datasets *inter alia* [8], the method and machinery behind that object differs vastly.

There is a common divide when hosting databases. The industry consensus usually reduces the choice to on-premise or in cloud service deployment [9]. But there are more discussions to have about the nature of those places in terms of environments. As databases are no longer a function of magnetic tape, the environments enabling them are thought to be digital [10]. These digital environments are the product of an information revolution, implementing infrastructures to a ubiquitous level of internetworked and exchanged information [11].

Growing rates of change in computing causes greater strides in back-end developments for rivalling companies [12] [13]. With over six decades of transformation in database machinery, the march for 'value' is now part of the 5vs for post-relational 'Big Data'. Yet the fringe of such movement sees familiar principles. Among them, a return to locality of needs from 1960s [14] and Small Data [15]. These cycles [16] open up research into what a database ought to be while questioning how businesses adopt one.

C. *Motivation*

Contemporary database administration is a tale of technological uprising. But the origins, purposes, and implications of those developments and research are open to discussion. This paper conducts a literature review based on those foundations by questioning:

1) What is database administration and a digital environment?

2) How is database administration developing in digital environments?

3) What sort of discussions concern database development and research?

Thereafter, a conclusion will summarise the findings of the review before ending with a proposal for future work.

II. Literature Review

A. *What is database administration and a digital environment?*

Digitality exceeds the birth of databases [17] shaped by computing changes over seventy years [14]. Let us breakdown the distinctions:

1) Nomenclature: The characteristics of a generic contemporary database often borrow similar terms from the earliest 1960's source [18] seen from Table I.

TABLE I
DEFINITIONS OF DATABASE

Definitions
''[D]ata base' is a collection of entries containing item information that can vary in its storage media and in the characteristics of its entries and items' [18]
'[A] collection of information stored on a computer systematically so that it can be checked using a computer program to obtain information from the database' [8]
'[A] collection of raw objects or information, organized in a systematic way so that it can be retrieved or manipulated easily and efficiently' [19].
'A database is a collection of data that are interconnected with each other that is stored on computer hardwareserver [*sic*] and required a software to manipulate the data' [20]
'A database is a collection of data items that provides an organizational structure for information storage' [21]
'A database is a structured repository of information. This can be a traditional relational database, wherein data are organized into tables. Or it can be the trendier NoSQL variety, which works more like a key-value file system or dictionary' [22].

Note that 'information' is used in [8]. However, references [23] [24] disagree that data and information are equivalent [25]. In [20], interconnected data is posited but this form of relational structure contradicts storage of unstructured data [26]. Reference [22] makes an attempt at distinguishing these classes. All references, together suggest an administrative side e.g. 'retrieved or manipulated' [19] encapsulated by a DBMS synonymous with Fig. 1.

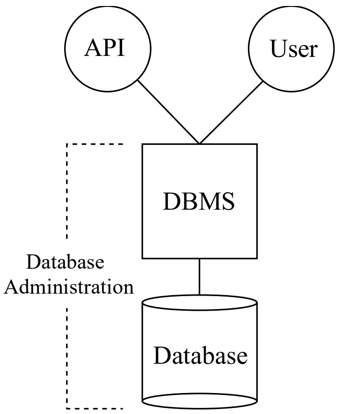

Fig. 1 Database and DBMS distinction – adapted from [27, p. 169]

2) Classification: A layperson tends to possess general database understandings akin to Table I whereas a database administrator (DBA) may differentiate details according to DBMS taxonomy [28] depicted in Fig.2.

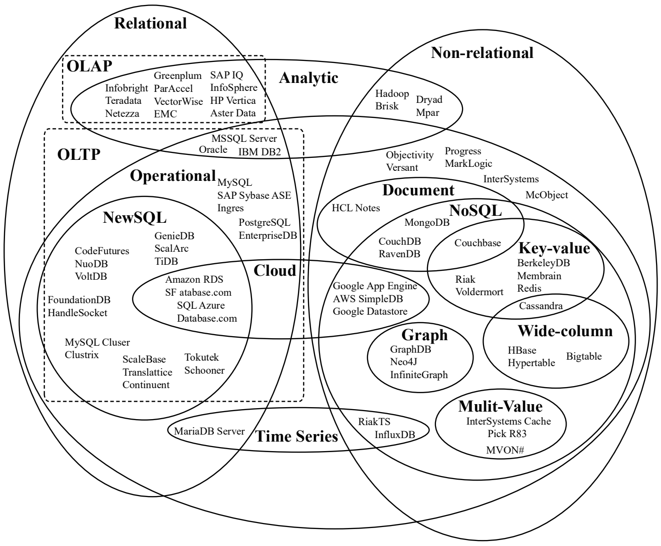

Fig. 2 Classification of Databases – adapted from [29] Defunct DBMSs, CalpontDB, Akiban, Drizzle, were removed and time-series and multi-value categories were added

As Fig. 2 shows, there are currently two main database classes: relational (RDBMS) and non-relational (DBMS). RDBMS arranges tuples into interlinked data tables to run set theory based Structured Query Language (SQL) [28]. Tables are typically normalised to promote Atomicity, Consistency, Isolation, and Durability (ACID) [30]. Databases can exist without relational tables meaning 'NoSQL' is used. Schema-less 'NoSQL' [28] sponsors at least four other models: document, key/value, graph, and wide-column using other query languages e.g. SPARQL [31]. Further models also include multi-value and time-series. Without referential keys, NoSQL supports a different consistency model that is Basically Available, Soft state, and Eventually consistent (BASE) [32]. According to Brewer's theorem while traditional relational databases have consistency, unlike NoSQL it does not shard data over distributed nodes [33]. NewSQL databases seek to remedy this shortfall through higher vertical scalability and productivity [34].

3) Digital: Speaking about digital can seem an abstraction but it is not [35]. To an extent this is owing to the overlay between the technical transition of analogue signals into binary digital and the implementation of technologies in digital infrastructures as a social and technical process [36]. Respectively, we refer to these as digitisation and digitalisation, but the capabilities of the latter to advance services, platforms and optimise value make it different [37]. The gist of digital is that it is not really about computers and technology but serving people in different ways [38]. In other words, it carries a propensity to change customer value for businesses keen to leverage technological opportunity [39].

4) Environment: People and organisations gain many beneficial produces from digitalisation including communication mobility and new business models [40]. But the technical corollary of digitalisation means data reservoirs in the masses. Different online analytical processing can be utilised in those environments that also improve the upkeep of systems [41]. In similar vein, an environment might also be a configurable deployment tier for testing and production rollouts on different trust levels [42]. While virtual in a digital sense, these environments may also be virtualised at least to subtract the hardware through emulation or contain the database less the operating system [43]. For on-premise environments, this is often a case of hypervisors and kernel user spaces. Enterprises can also pay web services to host databases as a service (DBaaS) in a cloud [43] [44].

5) Smart: So far we can claim digital environment is a domain functioning over an internetwork and mobile communication infrastructure capable of data ingestion sourced by continuous online mass consumption [45] [46]. However, researchers also recognise that these features are an anchor for 'smart' architecture. As a result, a digital environment can be said to make use of wired/wireless connections with multiple devices to exchange data ubiquitously [47].

B. *How is database administration developing in digital environments?*

As time clicks by, databases are shifting rapidly in multifarious ways [48]. Generally, it is said to be a response to software evolution reacting in turn to factors, for instance operational environments, improved services, and business rules [49]. Some also view that database changes have been critical to securing the digital age [50]. How certain types of database development are ensuing now is a matter of evaluation, which Table II provides in overview.

TABLE II
DATABASE DEVELOPMENT SAMPLE

RDBMS upgrades	New technologies, for example code generators for speedier processing, and graphics processing unit chips to augment RDBMS [51].
Cloud migration	Moving databases to cloud services simplifies admin – c. 50% of companies want this [51].
DBaaS	42% of firms are turning to DBaaS for cheaper automation, analytics, security, storage, and data virtualisation [51].
Graph	Small intents - just over 20% - to utilise graph databases for semantic modelling algorithmic training, and complex analysis. [51].
Multi-model (MDDBMS)	Over 40% of organisations and increasing are adopting multi-model systems [51] means less assorted backend instances [52]
Machine Learning	Slow desirable infrastructure artificial intelligence DBMS uptake [51].
Augmented Data Management	Database administration e.g. tuning, correcting &c can be automated appealing to those wanting to streamline operations [51]

The source [51] provides that much of the trends in Table II are the cause of United States' legislation, akin to the British Data Protection Act 2018, pushing database developments into pliable but more effective administration. To demonstrate, the following are picked:

1) DBaaS: Remarked the quickest rising service model in the cloud, DBaaS is harnessing novel workloads to be put into effect in cloud offerings [53] and in two years' time seventy-five percent of databases will be migrated or deployed there [54]. The appeal for this service is wide in what can be done with a database as per Table II. The technology itself means resources can be provided nigh *ad infinitum* because of virtualisation, resulting in assuring service level agreements that can bind a range of on-demand requirements. In other words, the DBaaS is a makeup of compute and DBMS requisites. Noted in [55], these revolve around the concept of 'readiness' – being able to access the database without major provider interaction; 'deployment rapidity' – databases instances can be provisioned quickly; 'resource pooling' – allowing a choice of database tenders under a multi-tenant model 'service configurability' – adds more parameters to how databases can work in the cloud, and; 'ubiquity' – the database service is hosted with broad network access for global admission.

2) Multi-Model: Even with the gamut of developments, databases are still running under the auspice of RDBMS as a dominant force accounting for eighty percent of the operational marketplace [51]. But there is considerable competition against it from NoSQL and NewSQL DBMSs, which are driving database development into a convergence. For instance, this is observed in Oracle Database 19c, and open source ArangoDB or recently YugaByte [56], which function as multi-model databases (MDDBMS) [34]. As the assortment of data has never been so heterogeneous, strides to federate data models and also different sorts of data across multiple sources for querying are being accomplished in polystore databases. As [57] [58] allude, these two kinds of database environments are not new ideas, having been conceptualised thirty years ago in object-oriented DBMS, but an answer to 'data deluge' manufactured by the Internet of Things (IoT).

3) Graph: Quite often, graph databases enter the conversation of database development. It is technology that, while seemingly low in receipt [51], has become ever more appealing to business and research, thus far leading in overall popularity since 2013 [59]. Notedly centuries old theoretically, a mathematical graph in database form holds benefits vis-à-vis performance, scalability, and visualisation capabilities [60]. A holistic account is provided in [61] as: searching information is faster, especially on network data; they are 'intuitive' in their representational nature; data storage carries into the petabytes; data deletion and insert are agile; new data types are permissible; appropriate for linked data; leveraged for data mining, and; powerful navigational regular-path queries. Graph DBMSs, are still being produced e.g. recently, JanusGraph and Amazon Neptune, are useful pattern revealing machines because they use nodes, edges and properties to relate pieces of information.

4) Other: Indeed, other developments occurring at the moment are not necessarily regulation spurred but driven popularism seen in frontrunning time-series (Fig. 3). To wit, real-time editing requirements - comparable to online applications, Office on the Web for example - have traversed into database scripting products. Mentioned in [56] PopSQL is one such product granting simultaneous collaboration through subscription that requires a connection to a database to unlock version control, shared queries, forking and visuals. On the other hand, [56] talks about how we are continually favouring open-sourced DBMS like MySQL over corporate paid licences. Consequently, the trending combo, cloud plus open-source, has invented document-storage ACID systems found in YugaByte to cite one, supporting load balancing and auto-sharding.

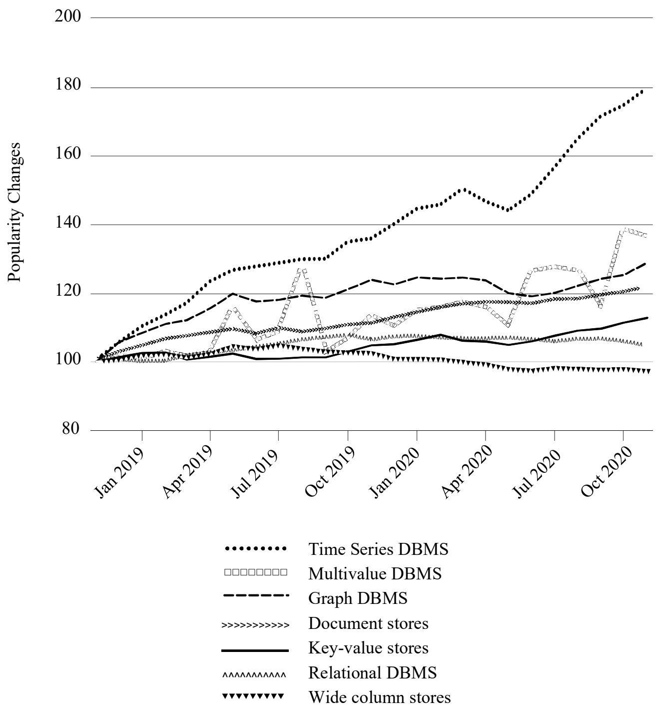

Fig. 3 Database popularities over 24 months adapted from [59]

C. *What sort of discussions concern database development and research?*

1) Security: Insecurity is an inexorable implication of database development by the Anderson's rule [62]. It is an area researchers say is becoming more prone to mishaps resulting from manual DBMS configuration [63]. Bear in mind sensitive data is valuable, not just to a company, but to black hats too. This is a concern for leaders who, notwithstanding the heightened occurrences of breaches, realise databases still remain vulnerable with neither central security nor encryption alongside data protection regulations [64]. Researchers pinpoint smart digital environments a prime target for security threats because of rises in IoT domestic and businesses pervasive computing systems. As [65] have found, attackers are aiming their cyber threats in these environments to compromise vulnerabilities with malware being the most encountered out of fifteen types. The study reveals data breaches in first place and information leakage at thirteenth. Databases do have their own set of security risks too. SQL injections are over fifteen years old but deemed by many the most common database vulnerability [66]. In contrast, some say data breach in the cloud is regarded the most frequent security issue as a service [67]. With a prediction that security issues will inflate one-hundred times in the next five years, researchers and technology corporations alike are looking at ways to combat cyber threats with automation [68].

2) Artificial Intelligence (AI): Soon AI will boost productivity with up to fifty percent returns in IT operations, Oracle says [68]. It reports that the technology will infiltrate database administration with built in supervised ML algorithms that work with the data. Use case wise, this is configuration without humans with database parameter initialisation and indexing &c based on learning models proven to optimise performance in automated tuning [69]. But certain repercussions surface the research developments of this form of database AI. ML needs a large quantity of data [51] to be effective with its own hyperparameter optimisation tuning for a start, which researchers are also looking to automate in databases [70]. That is not all, [51] posits that ML for databases will demand more compute resources to process the substantial data volume stored in short time periods. This equates the value of data much closer to the reality of its cost, particularly in cloud environments billing compute by the second [71]. Also, underpinned by fifth generation telecommunications [72], IoT will create circa 847 zettabytes per annum by next year straining the governance of quality data [73]. The view held is that governance needs to be resolved first [51]. Hence concerns about AI geared databases needing enhanced input/output operations per second to cope with 'dynamic' data [74].

3) Migration: Transitioning to the cloud is no doubt on corporate wish lists with over a third of workloads scheduled to be there by 2025 [68]. Doing so in favour of DBaaS will also likely reduce DBMS sales [75]. Conversely, companies are keen to want to trust their existing assets and legacy with cloud services. But migrating database systems to a cloud environment is not the same as shuffling them about physically on premises. Advice is that, strategically, it is proper to lift and shift the back-end with the entire application for rehosting on new infrastructure as-a-service [76]. Physical migration presents a number of challenges though, notably for administrators for whom over a third oversee more than one-hundred databases [77]. One hurdle is that planning would demand accurate knowledge of database workload sizes for each database. While evaluating the source of the migration helps determine the right cloud resource and cost [78], businesses will need to prepare for the added complexity in the integration and data governance too [75]. It is also pointed out in [78] that migration length may protract subject to the database infrastructure because it simply depends on broadband speed. As the article states, this might mean downtime for live applications and hardware upgrades to cut time.

III. Conclusion & Future Work

A. Conclusion

A critical review was offered in this paper on development and research in modern database management from three angles covering: the essence of data storage, technological trends, and technical development implications. This study finds that:

1) Despite today's DBMS miscellany our understanding of what a database is has not changed considerably since it was coined over sixty years ago but the digital milieu in which it operates is older, smart, and business oriented.

2) Database developments are instrumental to the present-day information age with a range of models that have responded to the need for technology efficiencies, with graph, time-series, and multivalve databases taking the lead.

3) Research is conscientious as to security in database developments, especially in cloud environments where data breaches are common but where many companies want their databases to be, plus proposals integrating AI are limited by governance.

B. Future work

Contemporary reporting provides a useful download on current database affairs. But we only receive a byte of the picture beyond which greater landscapes might exist for research. We know that technology is always changing, yet what enterprises focus on now might not be worth knowing tomorrow [79]. Therefore, the next agenda proposed for the study is of emerging databases that might provide investable advantages. In order of the conclusion, this means:

1) Revisiting what constitutes a database in regard to what it ought to be both technically and strategically, what types will come about overtime, and whether the future of digital environments may supersede the need for DBMSs.

2) Pinpointing how databases might contribute to Industrie 4.0 [50], forecasting what sort of storage and in-memory is being engineered for post fifth generation networks environments, and gauging maturity levels of pending databases from scouted technology.

3) Determining what possible challenges DBAs will face with emerging back-end products apropos of maintenance, security, and workloads - plus how AI cloud platforms or mechanisation might solve existing problems [77] and alter the value of data.

The areas above concern incoming database identification in an era where Big Data is obsolete. There are compelling reasons to prepare and roadmap database novelties as the needs of organisations adapt with innovation diffusion over time [12].

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