From Big Data to Massive Data: Towards a Massive Data Storage Solution for the Internet of Senses

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Abstract—**The increased maturity of current digitalization techniques expands the scope of practical deployments in various fields, including the precipitation of "digital biology" as a novel and highly important new field of research. This research area specializes in the convergence of various digital technologies and investigations into biology, offering the possibility to produce new comprehension of and applications for living systems by leveraging frameworks of digital technology. The enhanced scope of current capacities in computation facilitates simulated models of multifaceted biological artefacts and novel ways to gather, analyze, and interpret data, moving far beyond the primitive scope of legacy solutions in this field. This paper explores potential "massive data" databases, developing a conceptual model to move beyond the existing "big data" paradigm.**

Keywords—massive data, internet of senses (IoS), digital biology, digital chemistry, bio-ecology-based storages

I. INTRODUCTION

Initial data digitization opened a panorama of hitherto impossible abilities in decision-making for strategy and operations, leveraging multi-granular analyses. The latter have become increasing sophisticated and evident in modern data warehousing and supply chain deployments. With the convergence of modern digitalization and smart technologies, the current big data paradigm has emerged, whereby data is gleaned from many diverse sources with differing speeds and amounts to be synergized in largely automated decision-making systems, thereby generating immense value for stakeholders, including direct users, supply chain partners (upstream and downstream), end customers. Recent breakthroughs in technologies for the storage, processing, and computation of big data, with commensurate advances in AI and data science solutions, have driven rapid data analytics adoption worldwide.

A diverse array of specific applications and products are continuously devised and rolled out, and at the current juncture the technological maturity of this research and practice area, broadly referred to as the "Fourth Industrial Revolution," has set the scene for novel understandings of data and its uses, intersecting the formerly independent realms of the digital, physical, and biological, with commensurate transformative implications for production, distribution, management, and governance [1]. Broader and methodologically oriented inquiries have explored the ways in which associated technologies can generate behavioral data using the biology of systems [2], and the shortcomings of the paradigmatic transition to digitalization for the biotech field, especially with regard to synthetic biological research [3]. One specific area of interest in this regard is the field of chemical and biological storage systems for digitally serialized molecular data, as attested by many recent studies, as described below.

Tohgha et al. analyzed quantum dot nanofluids encapsulated in fluorescent polymers, to understanding digital applications in micro fluid research, such as electrowetting [4]. Another microfluid study by Menezes et al. [5] tested a device using droplets to accelerate the rate at which samples can be partitioned in sequence. In some instances, distinctive new fields of research are being devised, such as the digitalization of reticular chemistry [6], while other analysts have charting future directions for research into potential pore-scale models for digital research in biology, chemistry, and physics [7].

While all fields are inherently interesting, the realm of digital biology is particularly important concerning human societies due to its more obvious and immediate implications for healthcare services. Various studies have begun exploring digital biological tools, such as to predict specificity among T cells using machine learning [8]. Furthermore, biosensing using digital tools is increasing the rate of quantification of bacteriophage analysis, indicating digital biology's potential to revolutionize analysis even for single objects [9]. In summary, the all-encompassing scope of potential application for digital biology offers diverse and rich avenues for future research and product development in all areas of human activity, not least healthcare and education, where socio-economic development can be optimally facilitated.

II. BACKGROUND

A. Big Data

Big data has proliferated into various aspects of everyday life, including human interactions, society, and social media platforms [10]. It is characterized by its vast volume, complexity, and real-time generation, necessitating advanced management and sophisticated analytical and processing methodologies to distill meaningful insights [11]. In the context of a globally interconnected marketplace, the scope of data sources extends beyond merely structured data to encompass unstructured data as well, which includes items without standardized formats, such as textual content, natural language, health records, communications, and photographic materials. Within the domain of computer science, data is perceived as a foundational raw material, transforming abstract concepts into categorizable entities or alternate forms [10]. Consequently, big data analytics plays a crucial role in processing and integrating substantial volumes of data, thereby facilitating strategic decision-making processes within organizations [12].

B. Moving Towards Digital Biology, Chemistry and Branches

The following subsections discuss the main developments that contribute to massive data.

1) *Digital Biology*

Digital biology entails the use of data-intensive computational methods to solve complex biological problems. It plays a pivotal role in managing and analyzing the voluminous data generated in genomic studies, biomarker discovery, and personalized medicine. Overbeek et al. [13] discussed "the SEED platform and the Rapid Annotation of microbial genomes using Subsystems Technology (RAST)" platforms, showcasing how big data technologies facilitate consistent and accurate genome annotations across thousands of genomes [13]. The revolution of big data in science, particularly in the life sciences, is driven by the data generation-related revolution in available and emerging technologies, and the deployment of analytical tools in a more "open science" data environment. This underscores big data's capabilities to discover patterns and generate novel concepts and models [14].

2) *Digital Chemistry*

In the field of digital chemistry, big data aids in the elucidation of molecular dynamics, drug discovery, and materials science. Big data issues in computational chemistry pertain to the role of advanced molecular dynamics simulations in generating large datasets that are essential for understanding molecular processes [15].

3) *Seed Storage*

The storage of seeds involves maintaining their viability and genetic integrity over time, which is crucial for biodiversity conservation and agricultural productivity. Technologies such as the SEED platform facilitate the organization and analysis of genetic data from diverse plant species, enabling researchers to understand seed longevity and optimize storage conditions. The work on the SEED database exemplifies the application of big data in enhancing the understanding and management of seed storage [13].

4) *Food Printing*

Food printers represent a fusion of 3D printing technology and culinary science, allowing for the creation of customized and nutritious food items. The integration of big data with food printing technology enables the design of food products that cater to individual dietary needs and preferences. Advancements in food printing indicate how digitalized food design and nutrition control are revolutionized by extrusion-based food printing technologies [16].

III. MASSIVE DATA STORAGES

With the advancement of biotechnologies and nanotechnologies, a wide spectrum of possibilities commenced changing our understanding of what can be done with digital systems and how we can deal with biological, chemical, and physical units. Such possibilities were previously not available, due to the confines of the traditional interface of screens and audio when dealing with computers. The development of internet of senses (IoS) requires massive data storages that combine both data and essential ingredients to produce the desired realistic effects. The following subsections list some different database styles enabling IoS.

A. *Flavor Databases*

Digital flavor has been studied in a variety of different ways, such as stimulating the taste [17] and synthesizing devices [18]. Recently, a device was developed by Homei Miyashita from Meiji University using ten flavored canisters including essential flavors of salty, sour, sweet, bitter, spicy, and savory, enabling people to taste the food on the screen by licking it, which creates a multi-sensory viewing experience [19]. Efforts in a similar direction were also made by Alan Chalmers from Warwick University [20] and Adrian Cheok from City University London. Such devices require complex data processing concerning the combination of essential flavors and electric stimulation needed to produce a specific flavor, and data associated with flavor is needed to produce an accurate effect. The following are some data storage based initiatives in this regard:

- FlavorDB, established by Garg et al. [21], is designed to compile a comprehensive data warehouse of flavor molecules, integrating diverse viewpoints on flavor characterizations, functions, and natural sources. It aims to map the spectrum of flavor and odor molecules, linking food ingredients to their origins, utilizing various databases and research for its collection of 25,595 molecules. The database includes both synthetic and naturally derived compounds, offering a user-friendly interface for exploring these molecules and supporting data-driven flavor research.

- BitterDB focuses on detailing 1,041 compounds identified as bitter, providing extensive information on their molecular properties, sources, and bitterness categories. each of them offers information in regard to its molecular properties, references for the compounds, bitterness categories in detail (e.g. bitter-sweet or slightly bitter), derivation of compound indication (natural source or synthetic) . Additionally, BitterDB introduced "BitterPredict", a tool for classifying compounds' bitterness based on chemical structure [22]. It emphasizes the relationship between bitter compounds and taste receptors, The design enables finding specific compound with advanced search. It can be searched by name, identifier and 2D structure. The compound data are extracted manually from knowledgebases such as Pubchem, while the receptors data acquired from UniProt and UCSC [22].

- SuperSweet database targets sweetening agents, both natural and artificial, aiming to explore their interaction with receptors. It houses over 8,000 sweet molecules, sourced from literature and databases like PubChem. SuperSweet is designed for ease of use, offering various browsing methods and information on calories, 3D structures, and therapeutic roles of sweet molecules. SuperScent, a relational database, catalogues a diverse collection of 2,147 volatile compounds, focusing on aroma without including smell receptors. It sources data from literature and online, providing two primary search functionalities for molecules by ID or name and a unique "Scent tree" feature for navigating through classes of aromas [24].

Each database serves a unique purpose within flavor research, offering specialized tools and resources to facilitate the exploration and understanding of flavor, bitterness, sweetness, and scent compounds.

B. *Seed, Plant, and Herbal Databases*

There is a macroeconomic tendency seeking to protect the natural environment by creating storages for seeds, grains, plants, and herbs, considering current climate change and natural disasters. Some databases were created to help advancing medical and manufacturing practices, while new initiatives are conserving advanced storages in an attempt to save the future.

- The NutriChem database is pivotal for exploring the medicinal value of diet and the effects of natural compounds on disease, emphasizing the chemical mechanism of food on health. NutriChem 2.0 enhances this by integrating data on approved drugs and dietary compounds, indicating potential pharmacodynamics [25, 26].
- The TargetMol's Natural Product Monomers Library encompasses 1880 natural compounds from various sources, designed for high throughput and content screening, supporting new drug discovery and pharmacological research, with detailed documentation and compound structures [27].
- The New Dietary Ingredients (NDI) Database, developed by the American Herbal Products Association, serves as a resource for submitting and viewing new dietary ingredients, aiming to support the herbal trade and ensure a diverse range of herbal products. It focuses on accurate identification and offers over 950 NDI notifications for search [28].
- WebMD offers a comprehensive health information platform, including a database for researching health problems, treatments, and details on vitamins, supplements, and medications. It collaborates with health professionals to provide reliable medical advice and user experiences on various treatments [29].
- ETHMEDmmm, hosted by the University of Toyama, catalogues about 29,000 crude drug examples from ethno-medicine, aiming to support medical research on herbal medicines by providing data and scientific information on crude drugs. It allows searches by various criteria and offers insights into herbal origins and chemical structures [30].
- TBtools is a user-friendly software integrating over 100 functions designed to meet the demand for big data analyses in biology, from sequence processing to interactive data visualization, showcasing how software tools are evolving to handle big data in seed storage and other biological applications [31].

These databases collectively support the exploration of medicinal values in diets and natural products, drug discovery, herbal trade, health information dissemination, and research on ethno-medicines, each with unique features tailored to specific research and information needs. Established new initiatives of seed vaults include the Svalbard Global Seed Vault, which stores millions of seed varieties to protect agricultural diversity. It also covers digital data vaults preserving cultural heritage and the upcoming Microbiota Vault to conserve beneficial microbes. Additionally, futuristic concepts such as a lunar ark for genetic material storage are being explored. These initiatives serve as insurance policies against extinction, ensuring critical biological and cultural preservation [32], but also can help in developing genetically mutated seeds with nee features.

C. *Food Printers as Databases*

3D-printed food technology is revolutionizing the culinary world by enabling the creation of customized, intricate food designs using edible materials. This technology offers numerous benefits, including the ability to tailor food shapes, textures, and nutritional content to meet specific dietary needs and preferences. It also presents opportunities for sustainable food production and reduced waste. However, challenges such as high costs and limited ingredient compatibility remain significant barriers to widespread adoption [33, 34]. Studies are emerging seeking to comprehensively analyze extrusion-based food printing technology's impacts on food texture design and nutrition control, discussing the role of big data in enhancing food design and addressing technical bottlenecks [35].

One large database for food, FooDB, houses an extensive collection of over 23,000 compounds found in food, making it one of the largest and most comprehensive public resources on food compounds [36]. This database encompasses a wide range of information, including macro and micronutrients, and various food constituents responsible for color, flavor, aroma, and texture. Each chemical entry within FooDB is supported by more than a hundred distinct data fields, offering in-depth compositional, physiological, and biochemical insights. Details provided include compound names, structural information, and descriptors of taste, smell, and color.

Additionally, FooDB incorporates data on the health impacts of foods, drawing from research studies. Users have the flexibility to search or browse the database by names, food sources, descriptors, concentrations, and functions. FooDB's interface allows for tailored exploration; for instance, users can opt for "Food Browse" option, to view foods by their chemical composition, or "Compound Browse", to explore chemicals by their food sources. While FooDB currently serves as a vital tool for individuals seeking detailed information on food compounds, it has yet to reach its full potential due to the absence of features like food detection and automatic query functions [37].

There is also a movement to enable drugs/medicine printing in the future using the same concepts and technologies, which can be highly impactful for healthcare.

D. *Scent and Smell Databases*

Scent and smell databases represent an emerging field where scent can be digitized and transmitted alongside digital media to create a more immersive experience. It explores the potential for checking food freshness online, enhancing gaming experiences (e.g., a product called Gamescent was developed and sold for nearly USD 150 [38]), or for sending scented e-cards [39]. This technology aims to digitize and communicate scents over a distance, offering a new dimension to digital interaction [40]. Olfactory technologies generate scents called haptic scent technologies. Olfactory information processing is enhanced by haptic experiences, influencing both electrophysiological and hemodynamic responses [41]. Increasing numbers of applications are being developed in this regard, including smell detection for early warning of disease [42].

- SuperScent is a comprehensive database designed to enrich users' understanding of smell compositions by providing detailed information on over 2,300 volatile compounds and 9,200 synonyms related to odorants. It classifies volatiles based on their origin, odor groups, and functionality, with data sourced from both web resources and literature. The database's search functionality is versatile, allowing users to find specific smells through various filters such as PubChem ID, name, molecular weight, functional group, and species. SuperScent's rich online resources include extensive data on odor compounds, synonyms, and supplier references, accessible through two main search approaches: by structure or by name. Searching by name enables users to easily locate specific scents, while the molecular structure search facilitates the discovery of compositions and potentially aids in the digital translation of odors by identifying similar odorant structures. This method offers insights into 10-30 similar compound components, enhancing research and development in olfactory science by providing detailed information on the name and structure of relevant compounds [43].

IV. CONCEPTUAL MODELS AND TECHNOLOGY DESIGN

The conceptual model of the developed technological system presented in Fig. 1 applies for massive data storage solution. The solution consists of four parts: a) input technologies, which can handle inputs in digital formats or other forms such as acoustic, chemical, biological, or any desired form that can be sensed using sensors; b) processing technologies, which entail AI algorithms, complex data parsing, and integrations; c) various storage and cartridges for heterogeneous ingredients and essential molecules; and d) an output mechanism or device can rely on precision and nano-technologies. The related concepts are expounded below.

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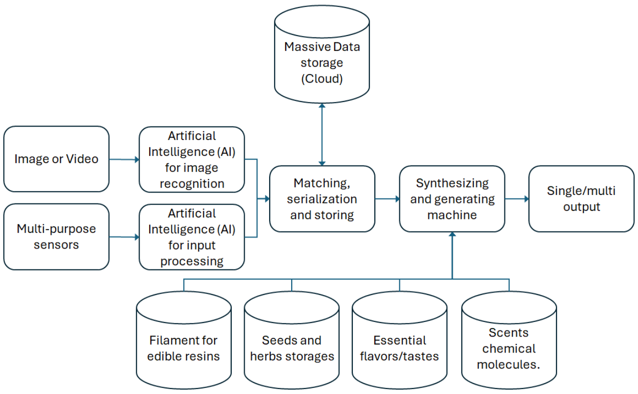

Fig. 1. Massive Data Solution's conceptual model

In contemporary technological landscapes, a vast array of products integral to various facets of daily life incorporate embedded systems capable of executing a multitude of functions. These products span a wide spectrum, including but not limited to microwave ovens, printers, washing machines, automobiles, and aircraft control systems [44]. The framework for this analysis is rooted in the concept of real-time embedded products. Ganssle and Barr [45, p. 228] defined real-time systems as "entities that must adhere to stringent timeliness constraints, often reflected in non-negotiable deadlines". They also described an embedded system as "a combination of computer hardware and software, which may be supplemented by mechanical or other components, dedicated to performing a specific function" [45, pp. 90-91]. Given these definitions, it is clear that the aforementioned products fit well within this conceptual framework. This analysis uses the theoretical foundations of this framework to examine these products. The conceptual models for the Digital Scent System, Digital Flavor System, Digital Plant/Herbal, and Digital Seeds are presented in Fig. 2, highlighting the key components and applications of each system within the broader context of massive data for digital bio-ecology. The diagram in Fig 3. depicts the workflows of the overall massive data storage system.

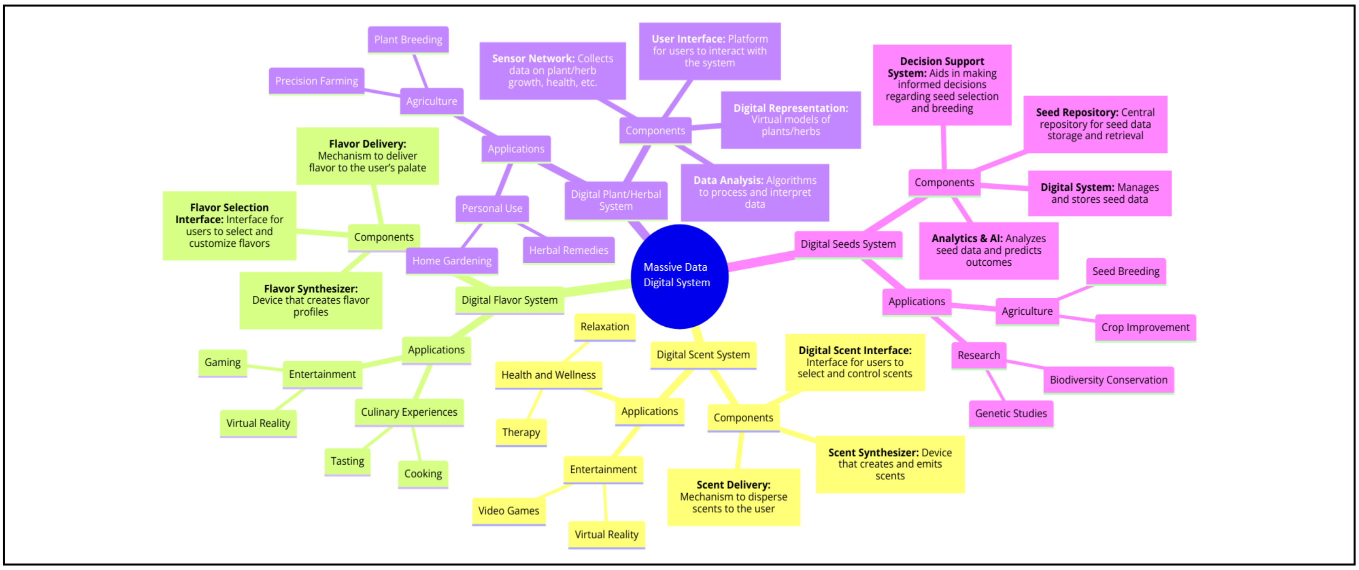

Fig. 2. Massive data types and applications

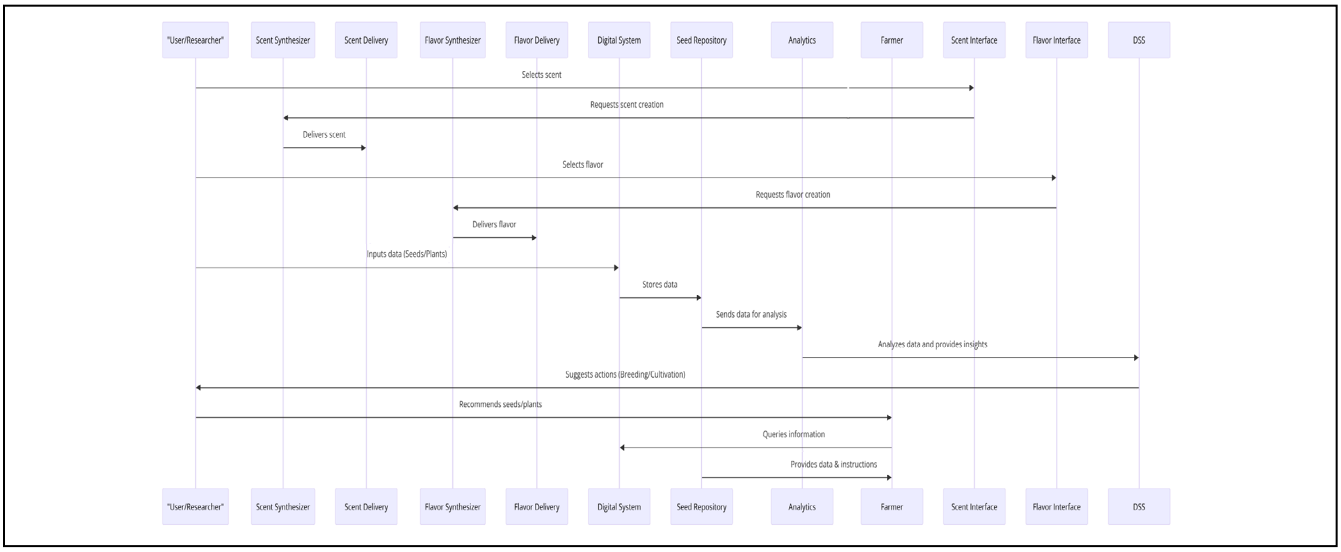

Fig. 3. Possible workflow of massive data storage system

The data is big, with high velocity, variety, volume and veracity. However, it is not only digital data in itself; rather it is combined with biochemistry, natural, and genetic artefacts, requiring material storage able to preserve ingredients (e.g., using preservatives, cooling, heating, or compression), to minimize the impacts of natural deterioration and ingredient spoilage. It requires powerful processing, artificial intelligence, and nano technologies to reach a realistic outcome and provide smooth experience to users. More applications opportunities will emerge in the near future due to the development of virtual reality and metaverse applications.

V. CONCLUSION

Research fields germane to the IoS and digitalized storage for diverse functions are quickly developing many different specialties. Current and emerging technologies can enable people to empirically ascertain olfactory and gustatory properties of remote products (i.e., to experience the taste and smell of things prior to buying online products), or to use 3D printing to produce medicine where needed. Other solutions include image-documenting flora or artefacts to be subsequently reconstituted and appreciated with visual and tactile products, as well as virtual communications increasingly offering a simulacrum of real-world communicate. Such potential products are enabled by the looming massive data context, with increased synergy between digital and tangible formats, facilitated by digital biology and chemistry, nanotechnology, AI, and other supporting technologies. Digital bio-ecology enables spanning the formerly independent realms of the digital and “real-life” worlds, offering unprecedented opportunities in innumerable fields. However, challenges that remain to be addressed include fissiparous research efforts and a lack of homogeneity and standardization required to realize the full potential of these technologies. Ongoing massive data development will ultimately require the development of coherent standards to couple massive data (i.e., data storage and communication technologies in addition to data itself) to facilitate interoperability, while enshrining commensurate legal, ethical, and safety considerations in all aspects and particular solutions.

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