

The healthcare IT landscape

1.1 How we got here and the growth of healthcare IT

As a member of the modern healthcare workforce, technology seems like an inextricable part of the clinical experience. For many, interacting with the myriad components of healthcare technology can represent an onerous aspect of clinical work and the blame for such burdensome interactions is commonly placed on IT departments and hospital management as being woefully out of touch with providers on the front lines. While this certainly bears some truth, there is much more to the story of how healthcare IT has evolved. In this section, we will discuss the developmental history of modern healthcare IT with the goal of understanding of the dynamics that have shaped its current incarnation.

Without reaching back too far in the history of healthcare, it can be said that much of the deep history of medical practice (mainly that preceding the late 19th century) was without a central organizing force.¹ Professional and intellectual societies certainly offered a central space for aggregating and sharing knowledge of diagnostic and treatment practices, and yet healthcare remained largely a cottage industry of individual practitioners. Clinical luminaries such as Dr. William Osler certainly improved upon this state of personalized, artisanal medicine by leading in the development of more consistent and robust training processes in the form of the clinical residency, the routine use of laboratory testing, and the establishment of routine clinical rounds but, still, the professional implementation of healthcare was situated mainly in the small clinic and placed within the hands of the expert individual.²

The advent of modern health insurance, however, represented a deeply transformative force in healthcare. Although there had been insurance products focused on disability and coverage for accidents, it was not until the 1920s that hospitals began offering payment plans through which patients could cover medical expenses themselves. These hospital-based policies quickly became aggregated into the first Blue Cross organizations in the 1930s. The second World War accelerated the growth of structured medical expense coverage as the wage freeze drove employers to create and offer employer-sponsored health benefits as a means of attracting employees.³ This was mirrored in a Federal effort to provide such coverage benefits to those without employer-sponsored or private plans, leading to the development of Medicare in the mid-1960s.⁴ Further maturation of insurance instruments brought about more complex

processes for defining and submitting claims, such as the creation of diagnosis-related groups in the 1980s, which required more data to be provided to insurers.⁵

Healthcare systems responded to thinning profit margins and increasingly complex requirements for successful reimbursement by consolidating into large, multiinstitution integrated delivery networks. These became a popular trend in the 1990s and required hospitals to share and reconcile information not just intra- but intermurally.⁶ Importantly, the 90s and 2000s brought about an increasing concern on the part of payers (largely the Centers for Medicare and Medicaid Services) that physician fee-for-service practice was susceptible to exploitation through overutilization of tests and procedures. The response was a shift toward outcomes-based payment instruments, which again heightened the demand both for more detail in claims submissions and for analytical reporting of key performance and outcomes measures such as readmission rates.⁷

The relevance of these historical punctuations and their impact on the implementation of healthcare cannot be understated. With the rapid growth and development of health insurance and the accordant rise in healthcare costs, the industry itself became financially operated by the insurance industry and, as a direct consequence, the mechanics of healthcare became increasingly parceled into claimable and billable services. Healthcare facilities, in an attempt to render billable services at scale, became powerful instruments of insurance revenue provided that they could efficiently track and execute services rendered and their resulting claims.

This historical context lends strong justification to the axiom that data are the currency of healthcare because without the ability to track and organize data in order to prove that services were justified and implemented, the entire hospital organism ceases to function. It is unsurprising, then, that some electronic systems naturally arose from this demand but perhaps equally unsurprising that, for many institutions, such systems did not. Early examples of electronic health information systems began to appear in the 1960s with Massachusetts General Hospital's creation of MUMPS, a database and early programming language for storing patient record data on mainframe systems and the subject of an entire chapter of this book, and the Regenstrief Institute's development the first electronic medical record system shortly thereafter. Although such systems provided clear benefit in the ability to store, retrieve, and organize record data, these earlier attempts were often confined to government hospitals and more tech-forward medical institutions, while mainstream physician practices and hospitals were turned off by the high cost and staffing demands required to maintain and operate these systems.

The digital transformation proceeded slowly over the concluding decades of the 20th century, but it was 2009, and the passing of the American Reinvestment & Recovery Act (ARRA) that brought unprecedentedly rapid digitization to healthcare organizations. Among the many modernization efforts included in this legislation was the Health Information Technology for Economic and Clinical Health (HITECH) Act, which introduced the concept of meaningful use,

a regulated definition of the implementation and systematic engagement with electronic medical information systems.⁸ Importantly, meaningful use was incentivized through payments disbursed by the Centers for Medicare & Medicaid Services—the largest healthcare payer in the United States. This combined effectively with the aforementioned evolution in health insurance to catalyze the mass transformation of healthcare from paper to digital infrastructure. This transformation has been brisk as healthcare institutions have faced financial pressure to demonstrate meaningful use through pervasive and consistent interaction with electronic information systems and to preserve revenue amid increasing demand for claim auditability, contextual information, and performance monitoring. Likewise, this has created a welcome boom for the providers of electronic health information systems, many of whom had tools based upon more antiquated technology, which were presented with a sudden need to scale through federally driven market demand.

This rapid scaling has not been without its share of serious complications, foremost of which is the security of healthcare information as it flows through complex and often adolescent technical ecosystems. Healthcare institutions are caught between an immense pressure to continue to drive revenue through successfully reimbursed claims, which requires increasing the fluidity of data collection and access, and the grave threats of financial penalty and loss of accreditation that accompany any misadventure in doing so.

1.2 The role of informatics

The trajectory of healthcare information technology and the pressures that have shaped its history and current form hopefully prove useful in understanding why healthcare information systems face the challenges of interoperability for which they are so often criticized. This historical context hopefully also sheds light on why the management of these systems is traditionally focused on risk aversion and change mitigation before technical and developmental creativity and offers some measure of explanation as to why analytics can be so often frustrated by uncooperative technology. The story of the growth and development of healthcare IT is, in essence, one of unsynchronized timing where what is ideal from a technology standpoint, what is achievable from a pragmatic standpoint, and what is imminently necessary from a regulatory compliance standpoint are almost never aligned. This is, however, the setting in which the healthcare informaticist and data engineer work and for whom understanding the many forces that shape the healthcare IT landscape is so critical.

Although this book informs the reader about the many shapes and functions of healthcare data, it also serves as a statement about the expected role of informatics and the locations in which technical creativity must be deployed. Healthcare is a challenging environment but at the time of this writing, new, formerly hypothetical advances in the form of big data, rich reporting, machine learning, and artificial intelligence are nonetheless quickly becoming vehicles for real value in adjacent fields. Granted, their origins are comparatively unencumbered by the

technical debt present in so many healthcare systems, but the need to make healthcare fertile ground for their growth and impact is perhaps more real now than ever before. Thus, the goal of informatics is to understand the often suboptimal anatomy of healthcare IT and the principles of effective problem solving and analytical engineering such that those suboptimal obstacles may not simply be identified or accommodated but that they may be solved. This is a rigorous and ambitious task, but it is wholly worth the requisite effort.

The following three sections will serve as a review of the key pillars of this landscape: architectural aspects, organizational aspects, regulatory forces, and challenges and opportunities. This will serve as a foundation upon which to frame rest of this book. By the end of this chapter, you should feel comfortable understanding how data generally flow throughout a prototypical healthcare IT system and you should have an understanding of the stakeholders involved in healthcare information management and the pressures that define their roles, equipping you to align the value proposition of informatics projects along both technical and organizational axes.

1.3 Common architectural aspects of healthcare IT

Healthcare IT architectures are complex and organic. As such, they often have an admixture of automated and human components, policies, and standards. Understanding this, there are still common design patterns at the core. We focus on the operational landscape, being the set of tools and processes likely to be encountered today in currently deployed systems as these components support the core business functions of most hospitals. As a first step in breaking down the complexity of the healthcare IT organism, consider it across a few key Levels:

- The device Level, which consists of workstations, tablets, phones, telemetry, barcode readers, and all other tools that provide terminal inputs and outputs between the system and the outside world.
- The application Level, which consists of the individual programs and their respective groups of features with which users interact. These consist of items like the electronic clinical documentation or provider order entry applications.
- The communication level, which consists of the standards and networking components required to transfer data between applications. These consist of things like HL7 and DICOM, which we investigate in later chapters.
- The process level, which is more abstract but which refers to enterprise-wide services utilized by elements of the application level. This consists of things such as health information exchanges and master patient Indices.

1.4 Device and application levels

The device level is largely self-explanatory and so we can begin with a focus on the application level as that with which most users in healthcare directly interact. Most healthcare IT systems consist of several core applications, each serving specific roles. Often, the segregation of these elements is not immediately apparent to the end user and there is really no individual user who interacts with all of these application components. Nonetheless, they still exist with separate and complementary concerns. Exemplary core applications and their main purposes are as follows:

- *Computerized provider order entry (CPOE)*: This allows clinical personnel to enter medication, laboratory, and procedure orders electronically, storing and transmitting these order messages.
- *Pharmacy information system*: This exists to serve the pharmacy, allowing its users to track incoming orders, dispense ordered medications, and manage pharmacy inventory among other things.
- *Electronic prescribing (e-prescribing)*: This allows clinical personnel to enter prescriptions, storing a history of prescription orders and transmitting those orders electronically to partner pharmacies.
- *Electronic medication administration*: This tracks the timing of medication order fulfillment and may be used to record metadata such as patient discomfort or alterations to normal protocol.
- *Laboratory information system (LIS)*: This exists to record laboratory test orders after dispatch from the CPOE as well as test results upon completion. In addition, this application tracks samples, and monitors reagent inventory among other things.
- *Radiology information system (RIS)*: This exists to facilitate scheduling of radiology appointments, implementation of studies, and recording of patient imaging history.
- *Picture archive and communication system (PACS)*: This exists to archive radiology images of all types.
- *Billing and coding*: This exists to track procedure and diagnostic codes, claims, bills, and accounts receivable.
- *Clinical documentation, electronic medical record (EMR)*: This exists to facilitate writing and retrieving notes, viewing laboratory results, and viewing radiology images among other things.
- *Clinical decision support (CDS)*: Perhaps the most abstract and challenging component, this exists to provide clinical staff with diagnoses, suggestions for potential tests or procedures, warnings for errors such as medication interactions, and even current clinical evidence. CDS is most commonly implemented as a collection of alerts and pop-ups within the EMR user

experience leading many to lament the “alert fatigue” resulting from too many popups and warnings. More elegant implementations are almost universally sought but are rarely achieved. As a medical informaticist having a deep understanding of healthcare’s technical and organizational infrastructure coupled with a key analytical skillset, you will hopefully be positioned to develop uniquely engaging and valuable CDS tools.

Each of these components would be an island unto itself save for one critical application known as the interface engine. Interface engines exist to efficiently and securely traffic messages between applications. In order to do this, interface engines are configured with various policies that determine where they should listen for specific messages (e.g., what port), how they should parse messages, and where those messages should go. For example, an interface engine can be instructed to listen specifically for laboratory test result messages from the LIS and to forward those to the EMR so that physicians can view resulted laboratory tests. These rules can be as simple as forwarding messages from one application to another and as complex as listening for a specific category of messages, re-structuring the message (perhaps to accommodate sender and recipient applications, which might have different versions of software and, therefore, expect different message types), and sending the restructured message to multiple recipient applications. Interface engine serves the core duty of being a message broker between applications in the Application Level. Fig. 1.1 depicts a potential schematic for interlinked applications with an interface engine performing the critical role of message broker.

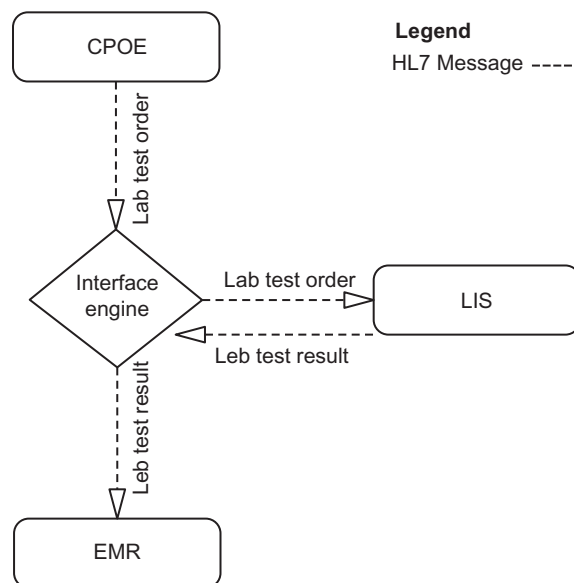


Fig. 1.1

Draft schematic showing the message flow from test order to test result with the interface engine playing the central role in message brokering.

1.5 Communication level

With this context in place, we can now consider the communication level. Each of the aforementioned applications generates and displays data and, therefore, each requires the ability to transmit data to and from other application components. The interface engine serves the role of conveying that information as a message, but it still remains a considerable design requirement to determine how such a message ought to look. Healthcare IT systems are complex assortments of specialized functional units and it is not uncommon for a single system to span different vendors, versions, and technologies across its applications. This makes it all the more critical that there be a rational and consistent definition of how data should look so that each of these applications—and the interface engine that brokers their messages—can package and unpack pieces of information for transmission. Multiple standards exist to support this the most predominant of which is known as HL7v2 as it specifically describes the formatting of messages as sent between components of a larger healthcare record system. Chapter 9 will cover HL7v2 in detail as well as other related communications standards such as HL7v3, CDA, and FHIR, which span both the communication and process levels.

1.6 Process level

Finally, there is the process level, which refers to enterprise-level resources that serve more abstract purposes. Core examples of process-level components include:

- Master Patient Indexes (MPIs)
- Health Information Exchanges (HIEs)

MPIs exist as a registry to coordinate and associate the myriad patient identifiers, which exist within different applications. Many patient registration systems are quite fragile when it comes to permutations in patient names, addresses, and other information such that a patient whose name is John Doe, for example, could present to a hospital in which he already has a patient record but, for whatever reason, could be registered using his middle initial, John R. Doe, which would result in the creation of a new record. When this happens, a situation can easily arise wherein there are two separate patient records both of which actually refer to the same person. When one considers the added complexity of managing records and registrations across hospitals, outpatient centers, surgery centers, and other facilities, the need for a master patient identifier becomes clear. Most MPIs, therefore, are both a database, which contains a master patient identification code and all associated record identification codes, as well as an application that can scan registration data and identify records, which likely refer to the same patient.

HIEs, on the other hand, perform an analogous—albeit far broader—purpose. HIEs often work with MPIs to standardize and organize patient identification, but their focus is on aggregating

comprehensive patient medical record data for the purposes of interfacility transmission and auditing with an aim to reduce repeat testing, readmissions, and medical error. HIEs often receive periodic dispatches of record data from affiliated healthcare facilities, including diagnoses, test results, imaging, prescriptions, orders, and more. HIEs also offer a more organized and central point of data transfer, which can be securely governed.

A special case of a process-level tool is a data warehouse. Where HIEs exist first and foremost to support clinical practice and may accommodate analysis, data warehouses exist for the express purposes of analytics. This distinction runs far deeper than the simple intent by which data are accessed and extends to the tools and techniques used for collecting, storing, and querying data, each of which we will discuss in depth in subsequent Chapters. Suffice it to say that many healthcare institutions have built—or are actively planning to build—an enterprise-level data warehouse along with multiple departmental and project-focused warehouses supporting a variety of data-driven applications. As a medical informaticist, you may propose solutions, which connect to an existing warehouse or you may propose a novel warehouse design altogether. Either way, this brief mention of data warehouses seeks simply to establish their place as a global organizational resource, while much of the remainder of this book will bring additional detail to warehouse design and use and their relationship to the broader concept of a “data lake.”

Additional process-level tools, which are yet to mature within healthcare, are artificial intelligence, real-time analytical monitoring, or data science platforms as these are typically absent from most institutions, at least in any meaningful sense. These represent an exciting future for healthcare informatics as their eventual entry is inevitable. The concepts and tools covered in this Book serve not only to teach the practice of informatics within systems of the present but also to equip readers to lead in the development and implementation of these future tools. We previously introduced CDS as an example at the application level. While this is true of the healthcare IT landscape of the present day, it is very unlikely to remain so in the future. CDS has traditionally had a very constrained definition, which equated to simple and atomic alerts about specific items of information such as a medication interaction or a duplicate order. Going forward, CDS is poised to take a much more intuitive and nuanced role as enabling data and machine-learning technologies give it the ability to perform analysis and render advice with increasing depth. If this book contains anything that amounts to a prediction of future trends, it is that the growth and infusion of intelligence within CDS will alter the mode within which providers interact with the medical record and through which they perform patient care. Of course, this is far from the present state and one significant limiting factor is a difficulty in designing and implementing effective systems for the aggregation and analysis of data. Thus, the effective practice of data engineering and analysis in healthcare will enable CDS to realize its transformative capacity and grow from a discrete application-level entity to a ubiquitous and generalized process-level entity.

1.7 Common organizational aspects of healthcare IT

Stepping away from discrete technical components, we should discuss the organization roles within many healthcare institutions, which govern and maintain various healthcare IT systems. Understanding these stakeholders and the pressures, which shape their roles, is a critical step to identifying and articulating the value of any informatics project and, critically, any important future value can only be accessed through the execution of present projects.

Most healthcare institutions are helmed by a Board of Directors, which typically includes a President and CEO. The Board's responsibilities are usually high-level yet essential and mission-oriented and include concerns such as selection and evaluation of the CEO, approval of mergers and large investments, procurement of trust and other funding sources, and ensuring that an acceptable quality of care is delivered. More specific decisions to this effect are the responsibility of the CEO who makes more tactical decisions regarding how to accomplish these goals and manages other Chief roles in their subsidiary responsibilities.

The CEO is accompanied by several such Chiefs, each of whom owns a key organizational function. Examples include the Chief Financial Officer, Chief Medical Officer, and Chief Operations Officer and, increasingly, several IT-focused management roles, which have grown in scope and relevance over the recent years. The distinction between Chief IT roles can be subtle and generally it is only larger medical centers, which have allocated each of these responsibilities. Nonetheless, a quick review of them is useful:

- Chief Medical Informatics Officer. Most often filled by a physician with a technical background, CMIOs serve the role of understanding and communicating the “front-line” clinical needs to the IT management. CMIOs have both clinical and IT concerns such as whether current or proposed technology drives value to physicians and patients or whether and how to train clinical staff to make better use of technology.
- Chief Technology Officer. Traditionally CTOs focus on a company's own technical product. In healthcare, hospitals generally do not produce technical product as such. Instead, CTOs focus on the development and maintenance of an “IT roadmap,” which frames decisions about which software products, initiatives, and technology to which to allocate time and money.
- Chief Information Officer. While similar in spirit to the CTO, CIOs focus more specifically on the governance and use of health information. CIOs make decisions such as which analytics architectures may be most appropriate or which data points from patient wearables should be collected and how. Moreover, CIOs consider scalability and security throughout these decision-making processes.
- Chief Security Officer. While all IT executives and team members consider the security implications of technological and organizational decisions, the CSO focuses squarely on this matter and manages a hospital's security team. In so doing, the CSO and her team focus on

initiatives such as inventorying all applications in the institution, monitoring applications configuration, vetting new applications, ensuring proper password usage and renewal, and establishing monitoring and protection systems for intrusive network behavior such as phishing or port scanning.

- Chief Data Officer. A more recently evolving role, the CDO is typically responsible for establishing a roadmap and architecture for how analytical data is collected, stored, and used to drive value for an organization. With an increasing trend in federation of hospitals, the role of the CDO is both more complex and more urgent. CDOs concern themselves with the establishment of data warehouses and data lakes, the governance of these repositories, and the leveraging of these data to demonstrate useful insights that impact a hospital's bottom line.

1.8 Physician and nurse informaticists

As clinical professionals in the field, physicians and nurses possess the most specific and granular understanding of the problems facing care delivery and the opportunities for improvement. The physician and nurse informaticist, therefore, are without equal in their ability to take real clinical needs, articulate their cost and the value proposition in solving them, and drive these proposed solutions up the management chain to achieve support from hospital and technical management and ultimately to benefit patients, departments, and even entire health systems.

As such many physician and nurse informaticists operate as much in the realm of technology as that of politics with a goal both to articulate the technical “how” of a solution as well as to politically rally managers and colleagues behind the “why.” Many informatics initiatives focus on process exclusively. Examples of these might include anything from documenting “tips and tricks” to improve physician use of the EMR in a specific clinical setting to advocating for the introduction of a new PACS system. Many other informatics initiatives are more conventionally technical and include clinician-led development of analytical reports and dashboards while others are a hybrid to include initiatives such as advocacy for a data warehouse, which may involve direct development of analytical logic alongside gaining political support from the CDO, CIO, and CTO. This book will focus more on the second two—the purely technical and the technical/organizational hybrids—as it seeks to equip physicians, nurses, and other clinical professionals with a substantial technical breadth to conceive of and even build technical solutions to clinically relevant problems.

Regardless of which project is chosen, it will almost certainly require articulating the specific problem being solved and the value added by solving it. Moreover, it will require articulating these things to the technical management (the Chief IT roles and their departments) and doing so using the technical parlance with which they are familiar. Being able to trace a proposed technical solution from the involved applications, messages, and data sources (as described in

this chapter) through the specific analytical and technical components involved in building, it will help to scope an appropriately feasible solution, estimate resource needs alongside technical and organizational impact, and explain the solution details to security and IT collaborators.

1.9 Regulatory aspects of healthcare IT

If it was not already apparent from the preceding discussion, regulation drives the state of healthcare. Regulation exists in many forms, some of which we have already introduced but we will summarize some key points here. The desire to organize the economics of healthcare has generated regulations focused on billing, which have heavily influenced the design of healthcare record systems. Moreover, the urgency of their deployment, being motivated by their benefit to patient safety, was actually made tangible by meaningful use, which resulted in a digitized healthcare landscape that was comparatively far more mature in its ability to support billing and coding than in its ability to support flexible exploration and analysis. Adding to this, the Health Insurance Portability & Accountability Act (HIPAA), which established several important regulations around protection and confidential handling of patient health information, has created a perception among many that flexible data flow and flawed security are synonymous. This is, of course, untrue but it is very likely that an informatics project will be scrutinized under a vague notion of HIPAA compliance. It is critical to mention that HIPAA compliance is real and incredibly important, but it is also quite achievable even while building technically creative and robust tools. Finally, a more recent advancement of special relevance to this book is the 21st Century Cures Act and the FDA's newly proposed framework for regulating AI in healthcare. These regulations establish a distinction between CDS tools, which are regulated medical devices and those that are not based upon whether the underlying logic of such tools are auditable by human users. In other words, the boundaries between a decision support tool and a medical device—even if that device consists solely of software—are in the transparency of the methods by which the CDS tool analyzes data and formulates conclusions. Although early, the regulatory borders starting to take root are traced at the edges of model design and transparency, which are top-level considerations for analytical projects aimed at supporting clinical workflows.

1.10 Challenges and opportunities

Finally, we address two general challenges within healthcare IT and the symmetric opportunities they present. First among these is the challenge of visibility. In many institutions, many of the discussions that would normally depend upon operational data occur in the absence of it as the collection and presentation of relevant information is too cumbersome to incorporate routinely into decision-making processes. This leaves healthcare stakeholders in a difficult position of having to prioritize quality improvement, investment, staffing, and other initiatives

without a quantitative framework in which to compare potential needs. The result is that many institutions select projects based upon assumptions about their relevance or based upon what seems most feasible to accomplish. Unfortunately, while healthcare operations are full of potential projects, the Pareto principle, or “80–20 rule,” would tell us that only a few of these really move the needle. Without the ability to identify the 80 from the 20 in such cases, many teams routinely deploy time and effort to resolve trivial issues while leaving significant problems unsolved. The symmetric opportunity this presents is one of systematic assessment of needs areas and selection of worthwhile projects, resulting in more effective teams and more satisfied stakeholders. This opportunity is situated well within the data engineering and analysis wheelhouse since it is impossible to describe current operations or plan future ones without effective use of data.

The second challenge is one of communication. An often-encountered practice in healthcare is the use of analytical report writers who, while very useful for reasons of efficiency and organization, often have a nonoverlapping scope of practice and knowledgebase compared to those requesting reports. This results in a workflow where abstract clinical questions, which originate from providers, are sent “over the fence” to be translated into SQL queries and charts by analysts who are nonclinical. Suboptimal results take two forms: one in which visualizations are incorrect and based on misunderstandings and one in which correct reports are produced but the number of revisions required to do so represents inordinate cost with regard to clinician and analyst time. Understanding proper analytical process and the way in which data must be transformed in order to achieve a desired result may allow for more self-service analysis or at the very least deepen this communication such that accurate reports are efficiently produced. As with improved visibility, this is a workforce multiplier across teams and projects.

1.11 Conclusion

This chapter has hopefully served to illuminate many of the common technical and political components, which comprise a healthcare organization’s IT landscape and to provide a foundation of context for conceptualizing technological solutions. Going forward, the subsequent chapters will each cover important and specific technical concepts such as databases, big data tools, machine-learning techniques, and cloud design patterns in greater detail. By the end of this book, you will be able to take your keen understanding of clinical and operational problems and articulate your proposed solution with an understanding of where healthcare data originate from, how they travel, how they are stored and processed, and who is critically responsible for those aspects. Additionally, you will be able to speak confidently in terms of important and relevant technologies for aggregating and processing data at scale.

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