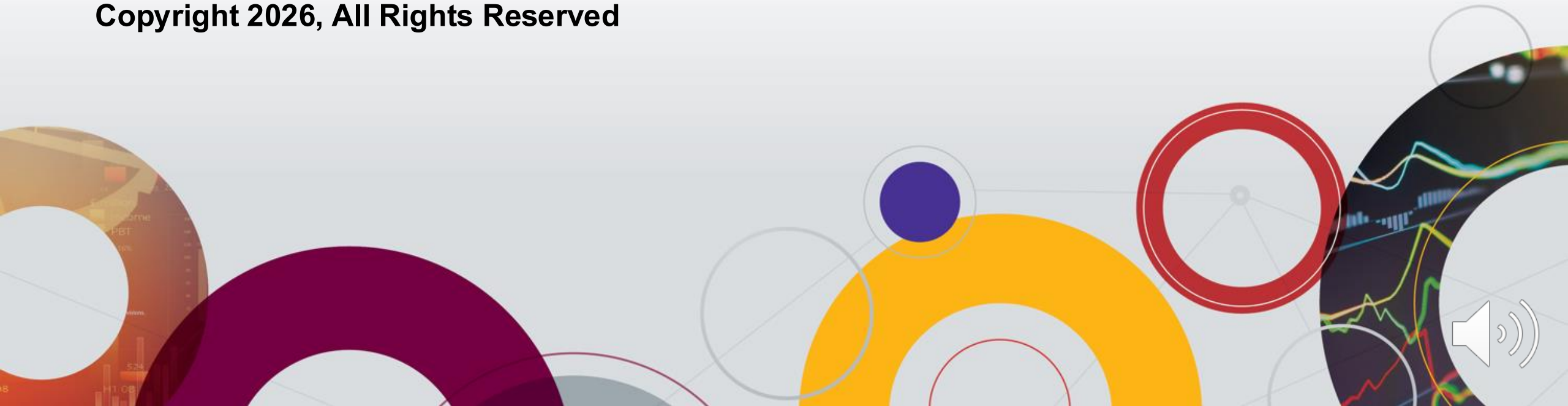


2.3 Computer Hardware and Software

10x10 – Introduction to Biomedical Informatics & Artificial Intelligence
William Hersh, MD, FACMI, FAMIA, FIAHSI
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Computer components

Hardware

- Physical parts of computer
- Common parts include
 - Central processing unit (CPU)
 - Memory
 - Auxiliary storage
 - Input and output devices

Software

- Instructions for computer, created by programming
- Commonly includes
 - Operating system
 - Applications or programs
 - Programming languages and development tools

Computer hardware

CPU generally refers to the chips at the core of a computer

- Motherboard of a computer typically contains the CPU and supporting hardware

Memory typically refers to the active memory on chips in a computer

- Random access memory (RAM) is the memory on the motherboard that loses state when power discontinued
- RAM has faster access but flash memory maintains state when power discontinued

Auxiliary storage

Two types – active and archival

- Active storage is used for information needed all the time
 - Typically on magnetic disks, although flash or solid-state memory is increasingly used
- Archival storage is information needed less urgently, e.g., backup or older information
 - Often done using magnetic tape but also optical storage, hard disks (local or remote), and other media

Input devices

Most common device is the keyboard

With the advent of graphical user interfaces, the mouse and trackpad (on laptops) have become common input devices

Another modality is speech input (Sen, 2019) – important in healthcare, with two general speech recognition approaches

- Front end – real-time input with clinician correction during input
- Back end – clinician correction done after transcription

Output devices

Have typically been the monitor and printer

Monitors have improved dramatically, with increasing size, resolution, and number of colors

- Original monitors were 72-96 [dots per inch \(dpi\)](#)
- Most printers output 600+ dpi
- [Newer higher-resolution displays](#), e.g., “retina display” of Apple devices, have 250 (computer) – 460 (iPhone) dpi
- Televisions have standard, e.g., original HD (aka, 720p) 1280x720 and 4K 4096x2160
- Amount of memory used based on “depth” of pixels, i.e., number of colors – typically up to 32 bits per pixel, and for video, frame rate, i.e., frames per second

Another form of output is computer text-to-speech

Computer software

Software is organized into computer programs

- Classic view: *Algorithms + Data Structures = Programs* (Wirth, 1976)

In reality, computer programs are built on layers of abstraction so programmer can focus on appropriate level of detail (Abelson, 1996)

- Classic example is operating system but also interfaces to graphical user interfaces (GUIs), database systems, networks, etc.
- Programs interact with each other via an application programming interface (API) that defines rules and protocols for interacting

Operating systems

Provide file, display, networking, etc., services to users and programmers

- Users get file management, set-up and maintenance, utilities
- Programmers get standard interface to various services so they need not “reinvent the wheel,” such as file access, display, network connection, etc.

Some well-known operating systems

Windows – most widely used

Macintosh OS (macOS) – original commercial GUI

Unix – originally oriented to higher end workstations and servers

- Open-source Linux has emerged as alternative to Windows and MacOS

Smartphone and tablet operating systems – two market leaders, but there are others

- iOS/iPadOS – iPhone and iPad (Apple)
- Android – open source, from Google

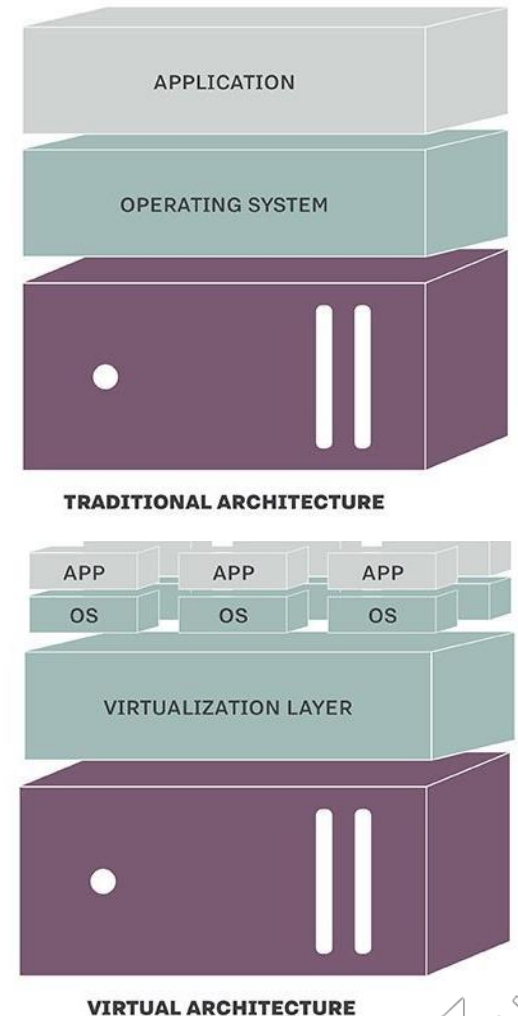
Virtualization and containerization

Virtual (software) machines separated from underlying hardware (TechTarget, 2019)

- Isolates machines from underlying hardware, e.g.,
 - Windows on a Macintosh (Parallels, VirtualBox, VMWare) – has changed with new Apple ARM CPUs
 - Linux on Windows (VirtualBox, VMWare)
- Emulators provide specific systems, e.g., [older macOS in browser](#) (Cunningham, 2022; Lovejoy, 2022)

Newer approach is containers, which are smaller and simpler

- Best known approach is Docker (Nickoloff, 2019)
- Emerging standard tool for managing containers across Internet is Kubernetes (Lukša, 2021)



Programming languages, or code

Computer programs run in machine language, the code of bits that gives instructions for moving and manipulating data

Assembly language is machine language with mnemonics for operations

“High-level” computer languages operate at a higher level of abstraction, hiding the complexity of moving and manipulating data

Assembly language

SET A, 2

SET B, GLC

ADD A, B

SET B, REG

High-level language

$B = 2 + GLC$



Major programming languages

C, C++, C# – used in many modern applications

MUMPS – used in many early medical applications

- Now renamed to M and with many modern enhancements

BASIC – common in early days of PCs

Python – originated as “scripting” language for Unix and Web, but achieving larger-scale use, e.g., in machine learning applications (Downey, 2016)

Java – attempt to create standard language for Web applications

JavaScript – scripting language for Web browsers

R – important language for statistics and data analytics (Wickham, 2017)

Programming languages (cont.)

Top languages vary by how measured but generally include Java, C, JavaScript, Python – according to

- [TIOBE](#)
- [IEEE](#)

Explore computer coding – [Blockly](#)

Also growing in popularity are “computational notebooks,” namely Jupyter (Perkel, 2018; Galea, 2018) – advocated for openness, reproducibility, and productivity in research (Figuerdo, 2022)

But some older ones persist, e.g., COBOL, used in many business applications from 20th century, not easily updated

- 800 billion lines of code (Khalili, 2022)

Evolution of programming or coding

Growth of low-code and no-code programming (Hirzel, 2023)

- Often make use of visual programming tools, e.g., drag and drop objects/widgets
- Example: [Orange Data Mining](#) allows no-code data science programming (Patrishkoff, 2023)

Generative AI

- Early application of large language models (LLMs) was creation of computer code, although still require checking validity and accuracy (Poldrack, 2023)
 - Subsequently called “vibe coding” (Delaney, 2025)
- Major impacts on computer science education (Denny, 2024; Johnson, 2024)
- May not improve programmer productivity (Becker, 2025)
- How will programming evolve (Nicolajsen, 2025)?

Open-source software

Approach making source code freely available by building a community to support and extend it and manage it by some sort of standardizing entity

- Best known examples are in horizontal applications, such as operating systems, web servers, and databases; e.g., Linux, Apache, and MySQL
- Less uptake in vertical industries such as healthcare but more prevalent in biomedical research community

Not free per se: Still takes resources (time and/or money) to manage within or external (using consultants) to an organization (Gropper, 2011)

- Common business model is free source code but pay for support, e.g., [RedHat](#)



Open-source software availability

General

- [Source Forge](#) – open-source projects
- [GitHub](#) – version management tool but also repository for open-source software

Healthcare/Biomedicine

- [Source Forge](#)
- [Wikipedia](#)
- Best known may be Veterans Health Information Systems and Technology Architecture (VistA)
– although being phased out

Data management

Databases store large amounts of information in structured and easily accessible format

Most biomedical applications require strong database capabilities

Database components

- Field – unit of data (e.g., heart rate, diagnosis)
- Record – collection of fields making an entry (e.g., patient demographics, chemistry panel)
- Table – collection of records of same type (e.g., all patients, all chemistry panels)

Common modern operation with data from varying sources is extract, transform, and load (ETL)

Database management systems (DBMS)

Computer programs that manage data and access to it, often with programming languages

Different DBMS models

- Flat-file – each and every record has same data
- Relational – most common model, queried via Structured Query Language (SQL)
- Entity-Attribute-Value (EAV) – more flexible structure for representing “sparse” data
- Hierarchical – non-relational, based on MUMPS programming language paradigm

Some fields can be indexed, which allows rapid look-up

- An essential feature for large databases of any type, usually done with B-Trees or hashing

Some DBMS terminology

Essential database operations (CRUD)

- Create record
- Read record
- Update record
- Delete record

Should meet ACID test

- Atomicity – each transaction discrete
- Consistency – data types consistent
- Isolation – handles concurrent transactions
- Durability – once committed, stays committed

Data warehouse – repositories of integrated data from one or more disparate sources

- Data mart is a subset of data warehouse extracted for specific analyses

Data lake – single store of an organization's data



Relational DBMS

Relational model links records to tables – e.g., patients to test results or encounters

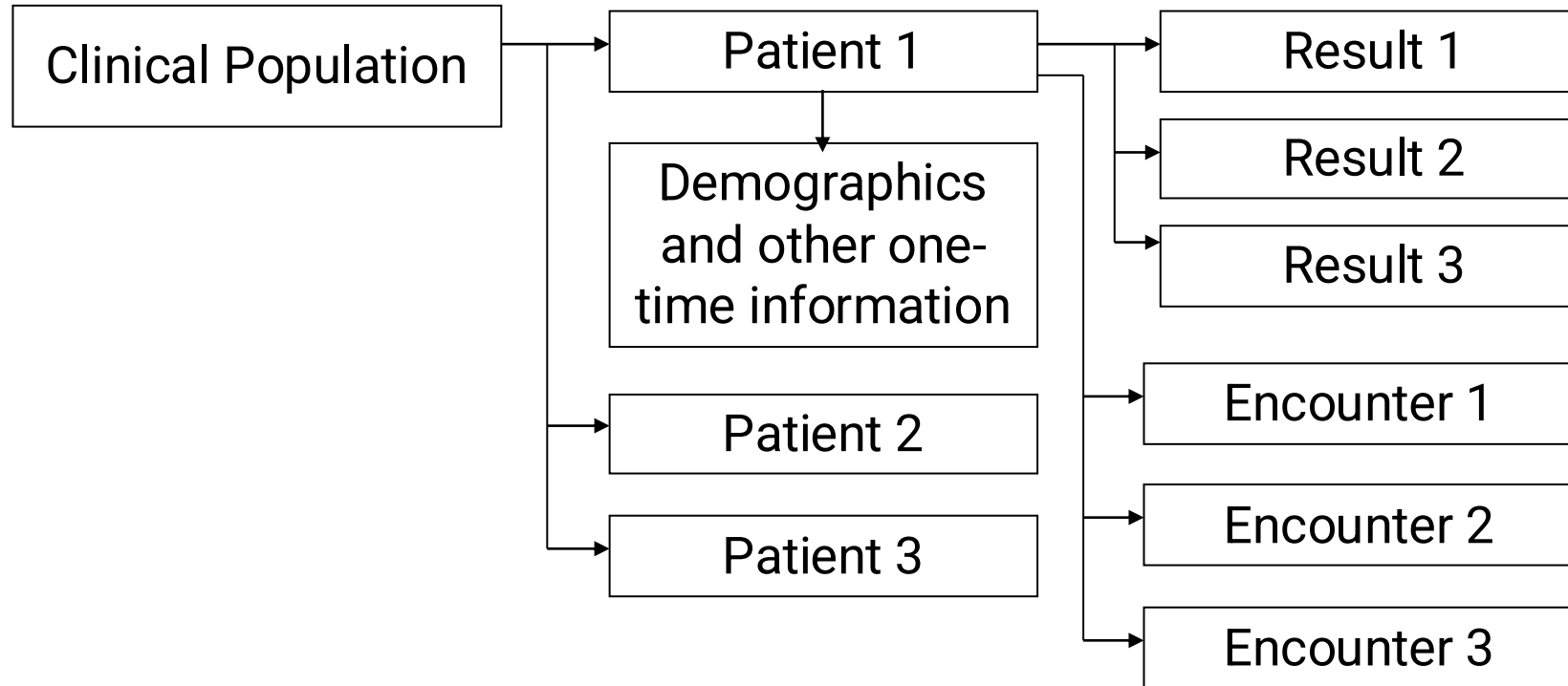
Allows efficiencies

- One-time information (e.g., demographics) stored only once
- Complex queries easier to construct and carry out

Most query capabilities are based on Structured Query Language (SQL) – [tutorial](#)

Has withstood 50 years test of time (Chamberlin, 2024)

Simple relational database layout



Using SQL and JOIN command, can:

- Find all patients with Disease X and on Drug Y
- Find all patients who are over Age X and have not had Test Y
- Find all Test X results for patients with Disease Y

Hierarchical databases

Developed originally for medical applications

Original system was MGH Utility Multi-Programming System (MUMPS) (Greenes, 1969)

Used in early (COSTAR; Barnett, 1976) and later (VistA, Epic) EHR systems

Later called M and now commercially maintained as Cache (Intersystems Corp.)

Highly efficient for transactions, less for queries across results and patients

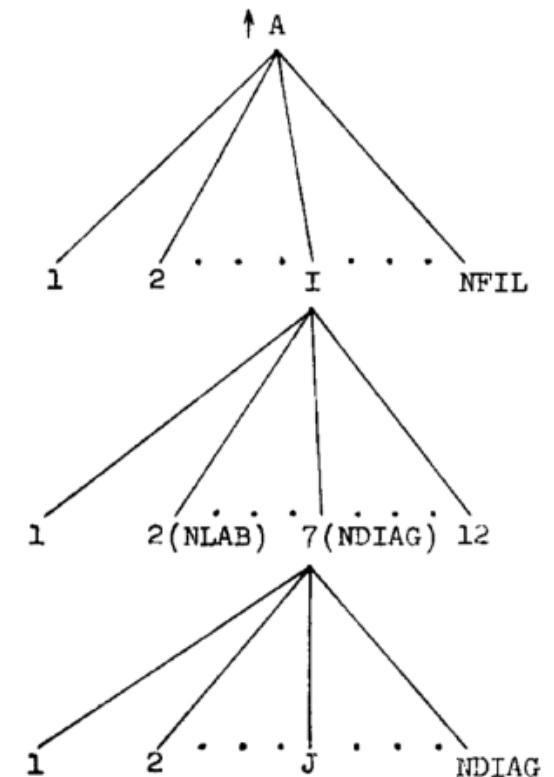
- Analytical applications export to relational systems

PATIENT FILE

PATIENT
NUMBERS

FIELDS OF
Ith PATIENT

DIAGNOSES



Metadata – data about data (Riley, 2017)

“Data about data” – meaning of data elements

Three types of metadata

- Descriptive – describes data element for discovery or identification
- Structural – describes organizational structure of data
- Administrative – information on how to manage
 - Rights management – who can access and when, how, etc.
 - Preservation – archiving and storage

Standard for metadata registries is [ISO 11179](#)

Early algorithms that “changed the future” (MacCormick, 2012)

Search Engine Indexing: Finding Needles in the World’s Biggest Haystack

PageRank: The Technology That Launched Google

Public Key Cryptography: Sending Secrets on a Postcard

Error-Correcting Codes: Mistakes That Fix Themselves

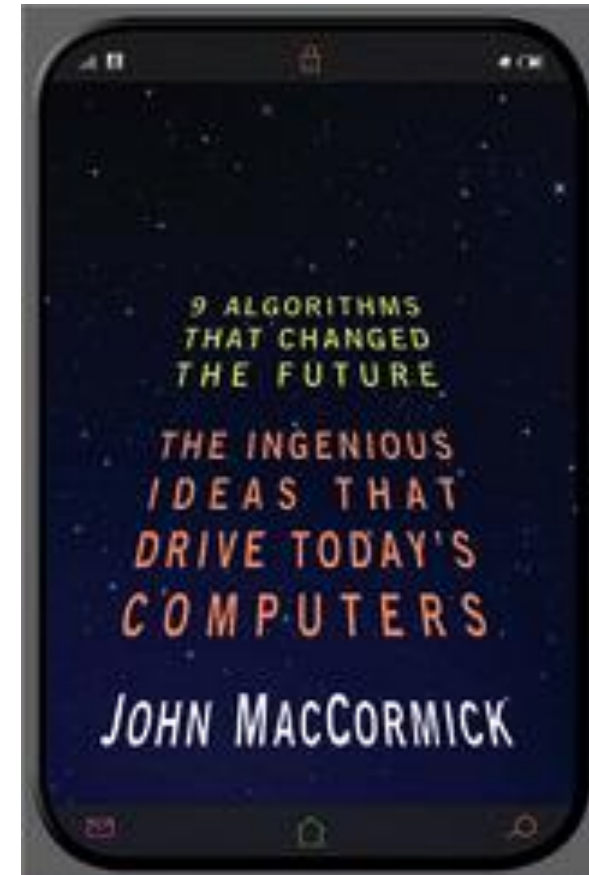
Pattern Recognition: Learning from Experience

Data Compression: Something for Nothing

Databases: The Quest for Consistency

Digital Signatures: Who Really Wrote This Software?

What Is Computable?



“Lines of code” that “changed everything” (Slate, 2019)

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