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4D-1 – Data Analytics

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Clinical Informatics
Board Review Course

Clinical Informatics Subspecialty Delineation of Practice (CIS DoP)

Domain 1: Fundamental Knowledge and Skills (no Tasks are associated with this Domain which is focused on fundamental knowledge and skills)

Clinical Informatics

K001. The discipline of informatics (e.g., definitions, history, careers, professional organizations)
K002. Fundamental informatics concepts, models, and theories
K003. Core clinical informatics literature (e.g., foundational literature, principle journals, critical analysis of literature, use of evidence to inform practice)
K004. Descriptive and inferential statistics
K005. Health Information Technology (HIT) principles and science
K006. Computer programming fundamentals and computational thinking
K007. Basic systems and network architectures
K008. Basic database structure, data retrieval and analytics techniques and tools
K009. Development and use of interoperability/exchange standards (e.g., Fast Health Interoperability Resources [FHIR], Digital Imaging and Communications in Medicine [DICOM])
K010. Development and use of transaction standards (e.g., American National Standards Institute X12)
K011. Development and use of messaging standards (e.g., Health Level Seven [HL7] v2)
K012. Development and use of ancillary data standards (e.g., imaging and Laboratory Information System[LIS])
K013. Development and use of data model standards
K014. Vocabularies, terminologies, and nomenclatures (e.g., Logical Observation Identifiers Names and Codes [LOINC], Systematized Nomenclature of Medicine --Clinical Terms [SNOMED-CT], RxNorm, International Classification Of Diseases[ICD], Current Procedural Terminology [CPT])
K015. Data taxonomies and ontologies
K016. Security, privacy, and confidentiality requirements and practices
K017. Legal and regulatory issues related to clinical data and information sharing
K018. Technical and non-technical approaches and barriers to interoperability
K019. Ethics and professionalism

The Health System

K020. Primary domains of health, organizational structures, cultures, and processes (e.g., health care delivery, public health, personal health, population health, education of health professionals, clinical research)
K021. Determinants of individual and population health
K022. Forces shaping health care delivery and considerations regarding health care access
K023. Health economics and financing
K024. Policy and regulatory frameworks related to the healthcare system
K025. The flow of data, information, and knowledge within the health system

Domain 2: Improving Care Delivery and Outcomes

K026. Decision science (e.g., Bayes theorem, decision analysis, probability theory, utility and preference assessment, test characteristics)
K027. Clinical decision support standards and processes for development, implementation, evaluation, and maintenance
K028. Five Rights of clinical decision support (i.e., information, person, intervention formats, channel, and point/time in workflow)
K029. Legal, regulatory, and ethical issues regarding clinical decision support
K030. Methods of workflow analysis
K031. Principles of workflow re-engineering
K032. Quality improvement principles and practices (e.g., Six Sigma, Lean, Plan-Do-Study-Act [PDSA] cycle, root cause analysis)
K033. User-centered design principles (e.g., iterative design process)
K034. Usability testing
K035. Definitions of measures (e.g., quality performance, regulatory, pay for performance, public health surveillance)
K036. Measure development and evaluation processes and criteria
K037. Key performance indicators (KPIs)
K038. Claims analytics and benchmarks
K039. Predictive analytic techniques, indications, and limitations
K040. Clinical and financial benchmarking sources (e.g., Gartner, Healthcare Information and Management Systems Society [HIMSS] Analytics, Centers for Medicare and Medicaid Services [CMS], Leapfrog)
K041. Quality standards and measures promulgated by quality organizations (e.g., National Quality Forum [NQF], Centers for Medicare and Medicaid Services [CMS], National Committee for Quality Assurance [NCQA])
K042. Facility accreditation quality and safety standards (e.g., The Joint Commission, Clinical Laboratory Improvement Amendments [CLIA])
K043. Clinical quality standards (e.g., Physician Quality Reporting System [PQRS], Agency for Healthcare Research and Quality [AHRQ], National Surgical Quality Improvement Program [NSQIP], Quality Reporting Document Architecture [QRDA], Health Quality Measure Format [HQMF], Council on Quality and Leadership [CQL], Fast Health Interoperability Resources [FHIR] Clinical Reasoning)
K044. Reporting requirements
K045. Methods to measure and report organizational performance
K046. Adoption metrics (e.g., Electronic Medical Records Adoption Model [EMRAM], Adoption Model for Analytics Maturity [AMAM])
K047. Social determinants of health
K048. Use of patient-generated data
K049. Prediction models
K050. Risk stratification and adjustment
K051. Concepts and tools for care coordination
K052. Care delivery and payment models

Domain 3: Enterprise Information Systems

K053. Health information technology landscape (e.g., innovation strategies, emerging technologies)
K054. Institutional governance of clinical information systems
K055. Information system maintenance requirements
K056. Information needs analysis and information system selection
K057. Information system implementation procedures
K058. Information system evaluation techniques and methods
K059. Information system and integration testing techniques and methodologies
K060. Enterprise architecture (databases, storage, application, interface engine)
K061. Methods of communication between various software components
K062. Network communications infrastructure and protocols between information systems (e.g., Transmission Control Protocol/Internet Protocol [TCP/IP], switches, routers)
K063. Types of settings (e.g., labs, ambulatory, radiology, home) where various systems are used
K064. Clinical system functional requirements
K065. Models and theories of human-computer (machine) interaction (HCI)
K066. HCI evaluation, usability engineering and testing, study design and methods
K067. HCI design standards and design principles
K068. Functionalities of clinical information systems (e.g., Electronic Health Records [EHR], Laboratory Information System [LIS], Picture Archiving and Communication System [PACS], Radiology Information System [RIS] vendor-neutral archive, pharmacy, revenue cycle)
K069. Consumer-facing health informatics applications (e.g., patient portals, mobile health apps and devices, disease management, patient education, behavior modification)
K070. User types and roles, institutional policy and access control
K071. Clinical communication channels and best practices for use (e.g., secure messaging, closed loop communication)
K072. Security threat assessment methods and mitigation strategies
K073. Security standards and safeguards
K074. Clinical impact of scheduled and unscheduled system downtimes
K075. Information system failure modes and downtime mitigation strategies (e.g., replicated data centers, log shipping)
K076. Approaches to knowledge repositories and their implementation and maintenance
K077. Data storage options and their implications
K078. Clinical registries
K079. Health information exchanges
K080. Patient matching strategies
K081. Master patient index
K082. Data reconciliation
K083. Regulated medical devices (e.g., pumps, telemetry monitors) that may be integrated into information systems
K084. Non-regulated medical devices (e.g., consumer devices)
K085. Telehealth workflows and resources (e.g., software, hardware, staff)

Domain 4: Data Governance and Data Analytics

K086. Stewardship of data
K087. Regulations, organizations, and best practice related to data access and sharing agreements, data use, privacy, security, and portability
K088. Metadata and data dictionaries
K089. Data life cycle
K090. Transactional and reporting/research databases
K091. Techniques for the storage of disparate data types
K092. Techniques to extract, transform, and load data
K093. Data associated with workflow processes and clinical context
K094. Data management and validation techniques
K095. Standards related to storage and retrieval from specialized and emerging data sources
K096. Types and uses of specialized and emerging data sources (e.g., imaging, bioinformatics, internet of things (IoT), patient-generated, social determinants)
K097. Issues related to integrating emerging data sources into business and clinical decision making
K098. Information architecture
K099. Query tools and techniques
K100. Flat files, relational and non-relational/NoSQL database structures, distributed file systems
K101. Definitions and appropriate use of descriptive, diagnostic, predictive, and prescriptive analytics
K102. Analytic tools and techniques (e.g., Boolean, Bayesian, statistical/mathematical modeling)
K103. Advanced modeling and algorithms
K104. Artificial intelligence
K105. Machine learning (e.g., neural networks, support vector machines, Bayesian network)
K106. Data visualization (e.g., graphical, geospatial, 3D modeling, dashboards, heat maps)
K107. Natural language processing
K108. Precision medicine (customized treatment plans based on patient-specific data)
K109. Knowledge management and archiving science
K110. Methods for knowledge persistence and sharing
K111. Methods and standards for data sharing across systems (e.g., health information exchanges, public health reporting)

Domain 5: Leadership and Professionalism

K112. Environmental scanning and assessment methods and techniques
K113. Consensus building, collaboration, and conflict management
K114. Business plan development for informatics projects and activities (e.g., return on investment, business case analysis, pro forma projections)
K115. Basic revenue cycle
K116. Basic managerial/cost accounting principles and concepts
K117. Capital and operating budgeting
K118. Strategy formulation and evaluation
K119. Approaches to establishing Health Information Technology (HIT) mission and objectives
K120. Communication strategies, including one-on-one, presentation to groups, and asynchronous communication
K121. Effective communication programs to support and sustain systems implementation
K122. Writing effectively for various audiences and goals
K123. Negotiation strategies, methods, and techniques
K124. Conflict management strategies, methods, and techniques
K125. Change management principles, models, and methods
K126. Assessment of organizational culture and behavior change theories
K127. Theory and methods for promoting the adoption and effective use of clinical information systems
K128. Motivational strategies, methods, and techniques
K129. Basic principles and practices of project management
K130. Project management tools and techniques
K131. Leadership principles, models, and methods
K132. Intergenerational communication techniques
K133. Coaching, mentoring, championing and cheerleading methods
K134. Adult learning theories, methods, and techniques
K135. Teaching modalities for individuals and groups
K136. Methods to assess the effectiveness of training and competency development
K137. Principles, models, and methods for building and managing effective interdisciplinary teams
K138. Team productivity and effectiveness (e.g., articulating team goals, defining rules of operation, clarifying individual roles, team management, identifying and addressing challenges)
K139. Group management processes (e.g., nominal group, consensus mapping, Delphi method)

Knowledge Statements from the DoP

K039. Predictive analytic techniques, indications, and limitations

K078. Clinical registries

K079. Health information exchanges

K101. Definitions and appropriate use of descriptive, diagnostic, predictive, and prescriptive analytics

K102. Analytic tools and techniques (e.g., Boolean, Bayesian, statistical/mathematical modeling)

K103. Advanced modeling and algorithms

K109. Knowledge management and archiving science

K110. Methods for knowledge persistence and sharing

K111. Methods and standards for data sharing across systems (e.g., health information exchanges, public health reporting)

4D-1 Data Analytics

Descriptive, diagnostic, predictive, and prescriptive analytics

Analytical tools and techniques

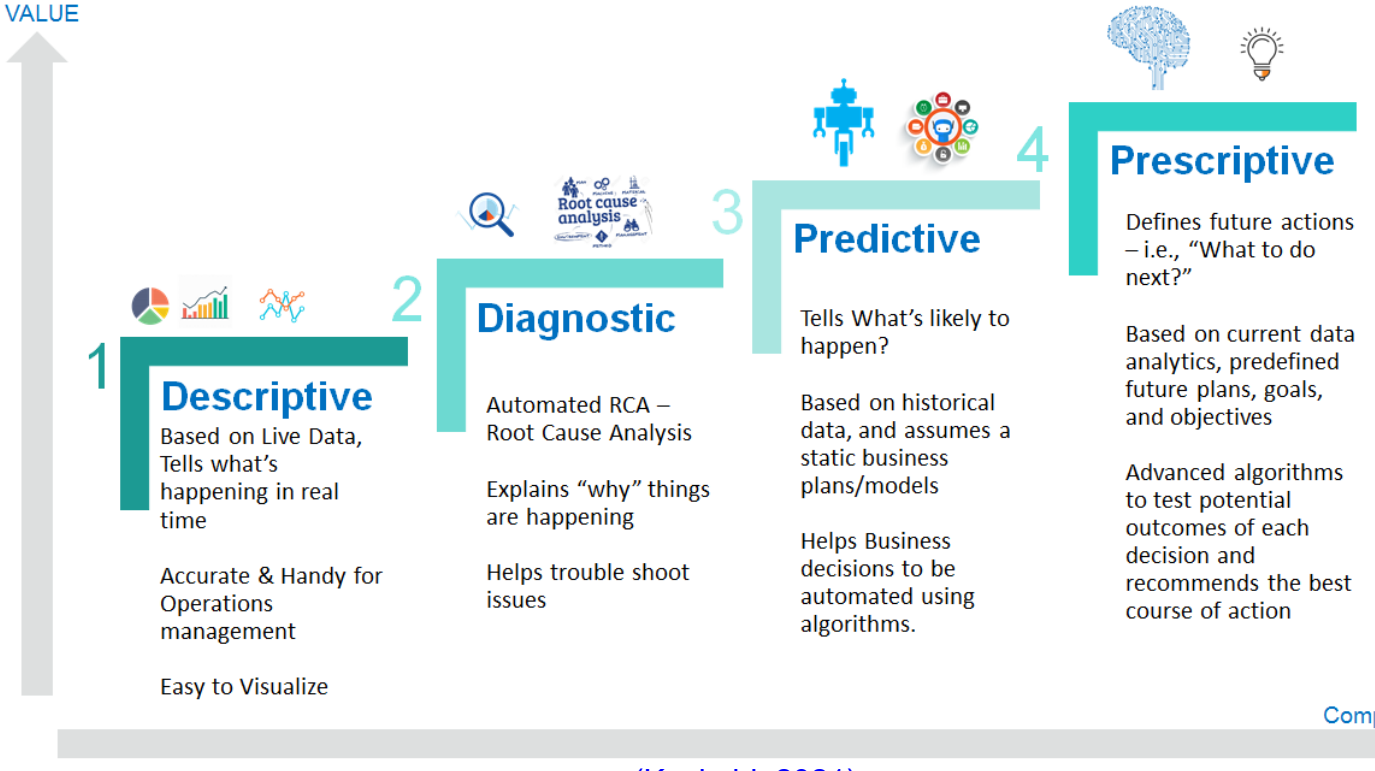
Knowledge management

Clinical registries

Health information exchange

Public health reporting

Definitions of descriptive, diagnostic, predictive, and prescriptive analytics



(Kachchi, 2021)

Analytic tools and techniques

Rationale and overall approach (Davenport, 2017)

Models and modeling

- Boolean
- Bayesian
- Statistical/mathematical modeling

Models and modeling (Kuhn, 2013)

Can be built for any level of analytics

Most common model used is predictive, i.e., predictive analytics

- Just because we can predict something does not mean we can do anything about it

Predictive model aims to identify association between one or more variables (predictors) and another variable (outcome)

Advanced modeling and algorithms – often use machine learning methods

Steps in creating predictive model (Kuhn, 2013)

Obtain/prepare data set

- Should be of adequate size and quality

Feature selection and feature engineering

- Variables in data set are typically called “features”
- Select features suitable for creating predictive model
- May “engineer” features from data, e.g., average blood pressure over time

Splitting the data

- To avoid “overfitting” the model from the data, split it into training and test sets
- May add third validation set when there is need to test generalizability of the model and fine-tune it before it is final model

Creating predictive model (cont'd)

Model validation and model diagnostics

- Validation assesses how well the model fits the data, e.g., Q-Q plot, Cook's Distance plot, or root mean square error (RMSE)
- Accuracy diagnosed by various measures, e.g.
  - Sensitivity, specificity, area under curve (AUC)
  - Recall (sensitivity), precision (positive predictive value), F1 (combination of recall and precision)

Cross-validation

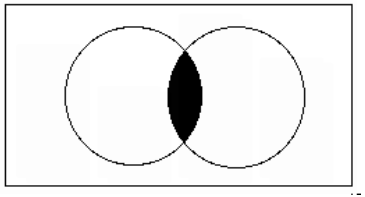
- Data split into training and test sets multiple times, with each set trained and validated

Error analysis

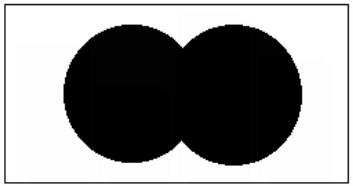
- Analysis of cases where model performed incorrectly to look for patterns

Boolean operators

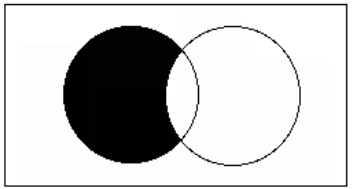
AND – only items present in all sets



OR – items present in any sets



NOT – items present in one set but not other



Bayesian statistics

Based on Bayes' theorem, which calculates probability based on prior probability and new information

Assumptions of Bayes' theorem

- Conditional independence of predictors – no relationship between different predictors for a given outcome
- Mutual exclusivity of conditions – one predictor can only explain one outcome
- Commonly used in diagnostic models, e.g., patient findings are predictors and disease(s) diagnosed is (are) outcomes

Bayes' Theorem generalized form

Probability of disease i in the face of evidence E, out of a set of possible j diseases is:

$$P(D_i|E) = \frac{P(D_i)\,P(E|D_i)}{\Sigma\, P(D_j)\,P(E|D_j)}$$

Translation of formula: probability of an outcome given one or more predictors

In case of diagnosis, can be calculated from

- Prior probability of the disease – can be estimated from prevalence of disease
- Probability of findings occurring in disease

Implementation and limitations of Bayesian approach

Early system was Leeds Abdominal Pain System (de Dombal, 1975)

- Most successful implementation, used in diagnosis of acute abdominal pain
- Performed better than physicians – accuracy 92% vs. clinicians 65-80%, better in 6 of 7 disease categories
- But difficult to use and not transportable to other locations (Berg, 1997)

Limitations of Bayesian statistics for diagnosis

- Findings in a disease are usually not conditionally independent
- Diseases themselves may not be mutually exclusive
- When multiple findings important in diagnosis, reaches high computational complexity quickly

Knowledge management (KM) and archiving science

Many healthcare organizations and EHR systems maintain knowledge assets in different ways (Wright, 2011)

Recommended practices for clinical decision support and KM include attention to (Ash, 2012)

- Workflow
- Knowledge management
- Data as a foundation for CDS
- User-computer interaction
- Measurement and metrics
- Governance
- Translation for collaboration
- Meaning of CDS
- Roles of special, essential people
- Communication, training, and support

Commercial solutions the answer?

- e.g., Zynx, Lexicomp, EHR vendors, etc.

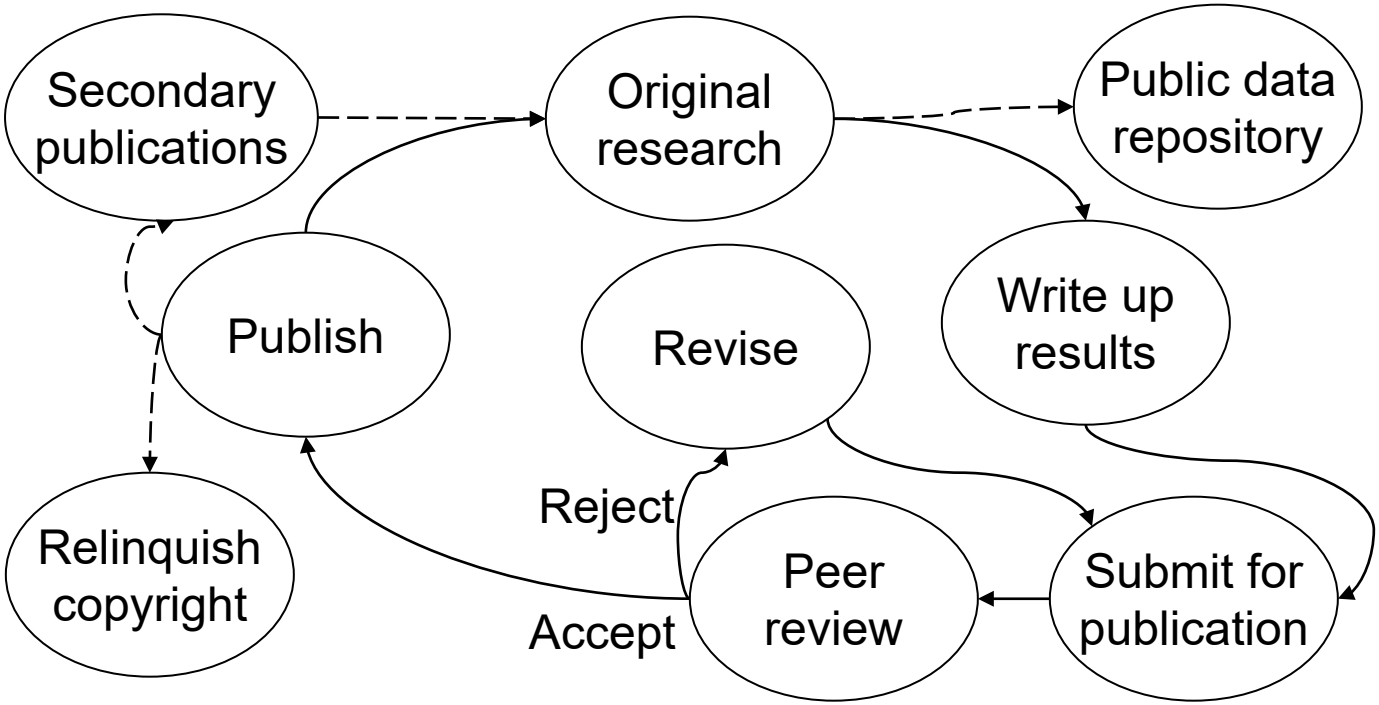
Methods for knowledge persistence and sharing

Knowledge generation

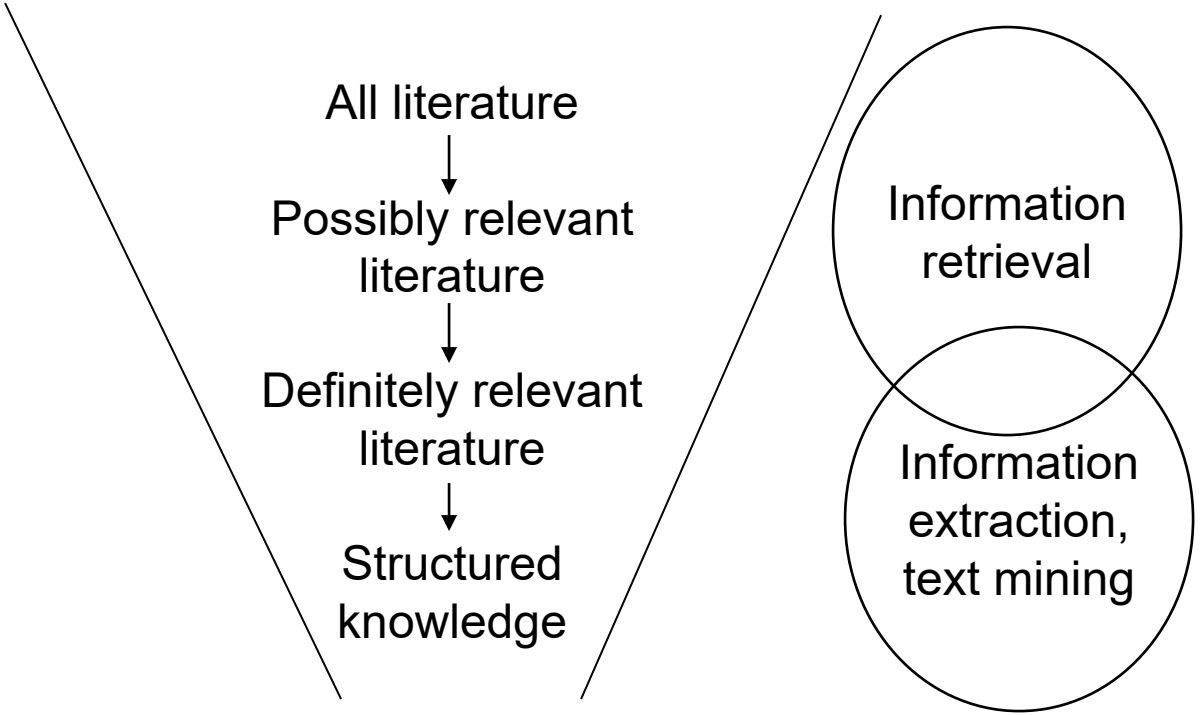
Knowledge acquisition

For persistence and sharing, need appropriate approaches for knowledge representation

Knowledge generation (Hersh, 2020)



Knowledge acquisition (Hersh, 2020)



Knowledge representation for persistence and sharing

Many approaches, e.g., (Greenes, 2018)

- Rules – typically IF-THEN
- Algorithms or flow charts
- Bayesian
- Scoring systems, e.g., Quick Medical Reference (QMR) (Miller, 1986) or DxPlain (Barnett, 1987)

Sharable forms, e.g., Arden Syntax (Hripcsak, 1994; Jenders, 2018)

Clinical registries

More limited collection of data than an EHR

- Can be separate from EHR or extract of data from it (Dreyer, 2009; Hersh, 2011)

Typically oriented to one or small number of diseases, most often chronic diseases

Typical functions (Blumenthal, 2017)

- Patient reports – status of monitored conditions
- Exception reports – outliers, overdue for care
- Aggregate reports – how is care team delivering recommended care

Health information exchange (HIE)

“Anytime, anywhere access to clinical information for the care of patients”

- Dr. William Yasnoff, former Sr. Advisor, NHII, 2004

“Data following the patient”

- Dr. Carolyn Clancy, Director, AHRQ, 2007

“I refuse to speak of HIE as a noun, HIE is a verb”

- Farzad Mostashari, Director, ONC, 2012

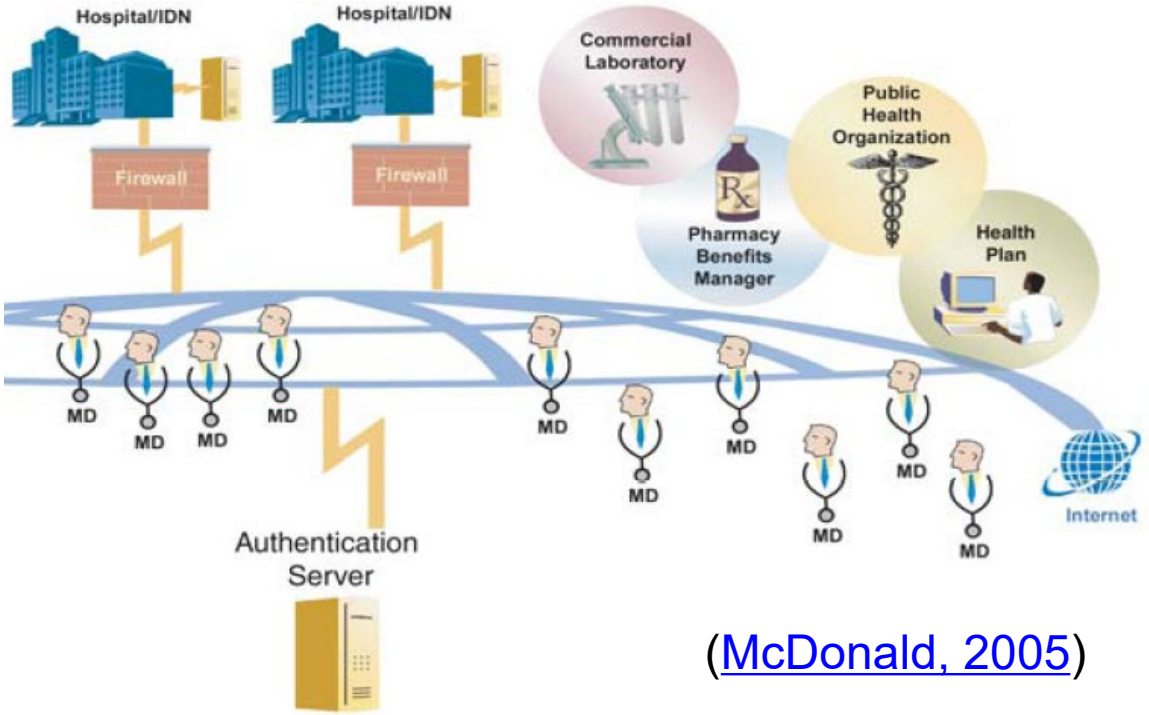
“Electronic sharing of data among hospitals, physicians, clinical laboratories, radiology centers, pharmacies, health plans (insurers), and public health departments.” (Some may add “patients.”) (GAO, 2010)

Requires that information be interoperable and flow seamlessly across business boundaries (Kuperman, 2011)

Recognized need led to investment under HITECH: $564 million in grants to states

Overview textbook (Dixon, 2016)

What does/should HIE look like?



(McDonald, 2005)

Types of HIE (Williams, 2012)

Directed – direct sending and receiving of information to support planned care ("push")

- e.g., referral, transfer, etc.

Query-based – finding information to support unplanned care ("pull")

- e.g., emergency care

Consumer-mediated – consumers aggregating and using their own information

- e.g., aggregate and share

Also classified as public vs. private (Perna, 2014)

The original: Indiana Health Information Exchange (IHIE)

Launched in mid-1990s (Biondich, 2004; McDonald, 2005)

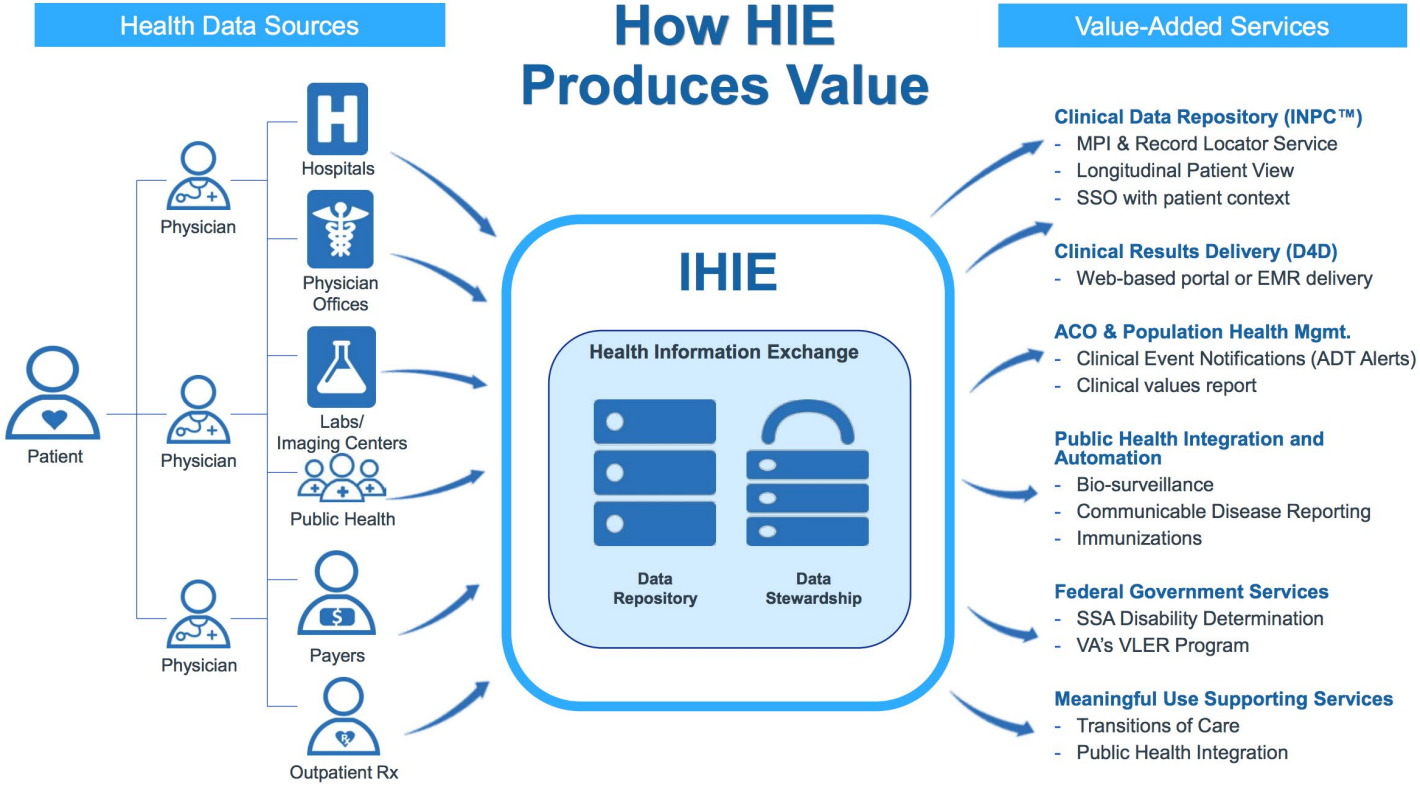
Originally Indiana Network for Patient Care (INPC); business unit became IHIE

- https://www.ihie.org/

Consists of

- Central (community) clinical repository with patient-oriented view
- Secure network for delivering clinical data messages to/from repository
- Tools and processes for standardizing the data and using it for different purposes
- Formal agreements among all participants spelling out processes, allowable uses, and HIPAA compliance

IHIE sources and services



A big challenge is patient linkage

Originally used matching algorithm of Sideli (1991)

- Matches on name, social security number, gender, and date of birth

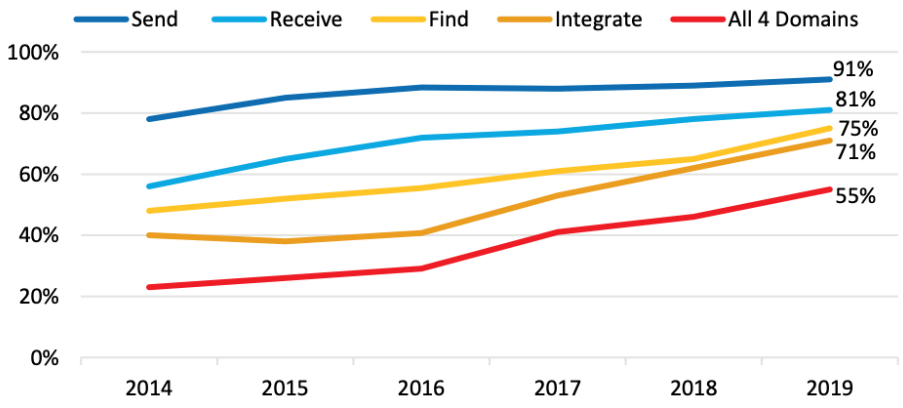
Experimented with other linkage algorithms (Grannis, 2003; McFarlane, 2016)

- Aim to minimize false positive linkage even at expenses of false negatives

One global patient index record for each patient

- Linked to patient records, institutional systems (McFarlane, 2016)

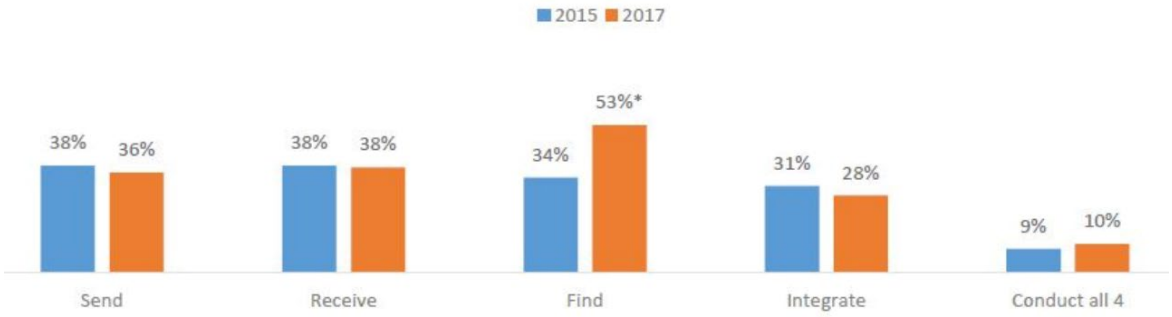
Usage of HIE in US has grown – hospitals (Johnson, 2021)



	Send		Receive	
Methods	**2018**	**2019**	**2018**	**2019**
Non-Electronic Method				
Mail or fax	71%	68%*	76%	76%
eFax using EHR	66%	70%*	52%	56%*
Electronic Method Not Using Third-Party or Network				
Provider portal that enables viewing of another organizations' EHR system	49%	55%*	37%	41%*
Interface connection between EHR systems (e.g. HL7 interface)	42%	45%	30%	31%
Access to other organizations' EHR system using login credentials	37%	45%*	26%	26%
Electronic Method Using a Third-Party or Network				
HISPs that enables messaging via DIRECT protocol	61%	65%*	49%	55%*
State, regional, or local HIE	59%	62%*	46%	51%*
EHR vendor-based network that enables exchange between users of a single EHR vendor	43%	47%*	41%	47%*
National networks that enables exchange across different EHR vendors (e.g. CommonWell, Carequality)	35%	41%*	32%	40%*

Source: 2018-2019 AHA Annual Survey Information Technology Supplement.
Notes: *Significantly different from previous year (p<0.05).

Usage of HIE has grown – ambulatory (Patel, 2019)



Data or document type	Send			Receive			Find		
	2015	2017	Diff (*)	2015	2017	Diff (*)	2015	2017	Diff (*)
Summary of care Record	21%	24%		25%	29%	*	N/A	N/A	
Medication lists	27%	29%		26%	31%	*	24%	35%	*
Patient problem lists	25%	27%		23%	28%	*	25%	27%	
Medication allergy lists	25%	28%		24%	30%	*	20%	30%	*
Imaging reports	23%	25%		29%	34%	*	36%	48%	*
Laboratory results	27%	28%		37%	40%		37%	48%	*

SOURCE: National Electronic Health Record Survey, 2015 and 2017.
NOTES: * Significant difference between 2015 and 2017 (p-value<0.05)

Evidence of benefit for HIE

Several systematic reviews in recent years (Hersh, 2015; Menachemi, 2018)

Earlier studies of outcomes showed modest benefits asking limited questions (Hersh, 2015)

Recent review showed (Menachemi, 2018)

- Fewer duplicated procedures, reduced imaging, lower costs, and improved patient safety
- Studies evaluating community HIEs more likely to find benefits than studies evaluating enterprise HIEs or vendor-mediated exchanges

COVID-19 has exposed weaknesses in HIE and exchange with public health system (Foraker, 2020)

Public health reporting

Notifiable diseases in US must be reported to the CDC – case definitions defined explicitly

- https://www.cdc.gov/nndss/about/
- Reporting is de-identified

Reportable diseases must be reported to states

- Defined by states, e.g., Oregon reportable diseases
  - http://www.oregon.gov/oha/ph/DiseasesConditions/CommunicableDisease/ReportingCommunicableDisease/Pages/index.aspx

Timeliness of reporting can also vary by state, e.g., Oregon

- Immediate (anthrax, plague)
- Within 24 hours (rabies, polio)
- Within one working day (most others)
- Within 7 days (lead poisoning)

What is typically reported?

Foodborne or waterborne diseases – e.g., Cholera, E. coli, Salmonella, etc.

Sexually transmitted infections – e.g., Chlamydia, Syphilis, HIV/AIDS

“Traditional” infectious diseases – e.g., tuberculosis (TB), meningitis

“Exotic” diseases – e.g., SARS, Creutzfeld-Jakob, etc.

Environmental diseases – e.g., lead poisoning, pesticide exposures, etc.

Maternal and child health – e.g., infant mortality, birth defects, etc.

Efforts to improve public health reporting

Incomplete report long identified as a problem (Doyle, 2002)

HITECH required public health reporting in meaningful use measures (Wu, 2014)

- Immunization information
- Electronic laboratory results
- Syndromic surveillance
- Cancer registries
- Specialized registries

Benefit of HIE for public health reporting

- Adding data from HIE identified 4.4 times as many cases as spontaneous paper-based methods and identified those cases 7.9 days earlier (Overhage, 2008)
- Still room for improvement in completeness of reporting (Dixon, 2017)

Data sharing across public health and clinical sources

Merging of EHR, public health, and other sources of data

- Infectious disease surveillance (Simonsen, 2016)
- Community health record (CHR) combining EHR, public health, social services, and other data (Hatef, 2019)
- Digital Bridge to advance electronic case reporting from EHR and other data – https://digitalbridge.us/

Adding location-based data to a clinical data warehouse (Gardner, 2019)

Use of artificial intelligence in historically resource-poor settings (Hosny, 2019; USAID, 2019)

Syndromic surveillance

Syndromic surveillance: “An investigational approach where health department staff, assisted by automated data acquisition and generation of statistical alerts, monitor disease indicators in real-time or near real-time to detect outbreaks of disease earlier than would otherwise be possible with traditional public health methods” (Henning, 2004)

Recognition of the value of public health information systems and their infrastructure increased after events of 9/11 (Lane, 2001)

Skeptics, however, view syndromic surveillance as a distraction from key functions of public health (Reingold, 2003)

Has made increasing use of Internet data, e.g., search engines, social media, etc. (Paul, 2017)

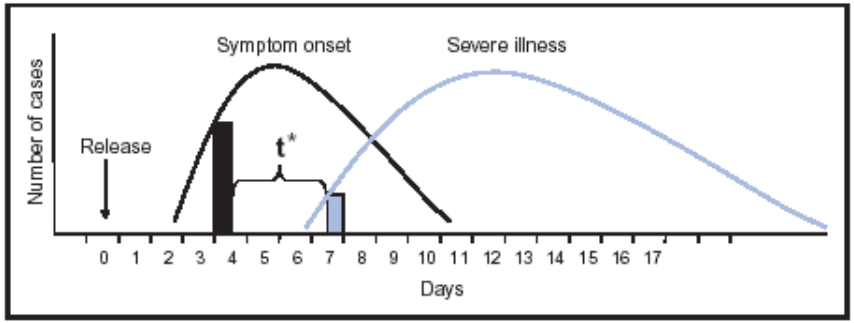
CDC program is National Syndromic Surveillance Program

- https://www.cdc.gov/nssp/

What is objective of syndromic surveillance?

"Identify illness clusters early, before diagnoses are confirmed and reported to public health agencies, and to mobilize a rapid response, thereby reducing morbidity and mortality" (Henning, 2004)

FIGURE. Syndromic surveillance — rationale for early detection



* t = time between detection by syndromic (prediagnostic) surveillance and detection by traditional (diagnosis-based) surveillance.

Key Readings

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