Clinical decision support (CDS) and Arden Syntax

*Educational material, part 1*

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www.meduniwien.ac.at/kpa (academic)

Better care, patient safety, and quality assurance by Medexter, Vienna, Austria
Artificial Intelligence in Clinical Medicine
A multiplicity of intelligences

1. LINGUISTIC
A mastery and love of language and words with a desire to explore them.
Poets, writers, linguists: T. S. Eliot, Noam Chomsky, W. H. Auden

2. LOGICAL-MATHEMATICAL
Confronting and assessing objects and abstractions and discerning their relations and underlying principles.
Mathematicians, scientists, philosophers: Stanislaw Ulam, Alfred North Whitehead, Henri Poincaré, Albert Einstein, Marie Curie

5. BODILY-KINESTHETIC
Controlling and orchestrating body motions and handling objects skillfully.
Dancers, athletes, actors: Marcel Marceau, Martha Graham, Michael Jordan

6. and 7. PERSONAL INTELLIGENCES
Accurately determining moods, feelings and other mental states in oneself (intrapersonal intelligence) and in others (interpersonal) and using the information as a guide for behavior.
Psychiatrists, politicians, religious leaders, anthropologists: Sigmund Freud, Mahatma Gandhi, Eleanor Roosevelt

Artificial intelligence (AI)—applicable to clinical medicine

• **Definition**: AI is the science of artificial simulation of human thought processes with computers.


• It is the *decomposition* of an entire clinical thought process and its separate artificial simulation—also of simple instances of “clinical thought”—that make the task of AI in clinical medicine manageable.

• A functionally-driven science of AI that extends clinicians through computer systems step by step can immediately be established.

  ↓

  artificial-intelligence-augmented clinical medicine
Clinical decision support
Towards clinical decision support

Steps of natural progression

- patient administration
  - admission, transfer, discharge, and billing

- documentation of patients’ medical data
  - electronic health record: all media, distributed, life-long (partially fulfilled)

- patient and hospital analytics
  - data warehouses, quality measures, reporting and research databases, data and text mining, patient study recruitment
  ... population-specific

- **clinical decision support**
  - safety net, quality assurance, evidence-based
  ... **patient-specific**
Digitalization in medicine

- Healthcare systems
- Patient data
- Medical data
- Patient care
- Images, signals
- Systems biology
- Molecular medicine

- Macro: National and transnational eHealth
- Micro: 
  - HIS, EHRs, interoperability
  - EMRs, data models, ontologies
  - Expert systems, CDS, ML, NLP
  - ML, imaging and visualization
  - Modelling and simulation
  - Bioinformatics
Digitalization in clinical medicine

- Stage I: Digitizing medical patient data
  - EHRs, EMRs, health apps, images, bio-signals, national, ...

- Stage II: Digitizing clinical workflows
  - In-patient care, wards, departments, out-patient care, home care, chronic care, ...

- Stage III: Digitizing medical knowledge
  - Anatomy, physiology, pathophysiology, nosology, pharmacology, pharmacogenomics, ...

Clinical decision support—Applying knowledge to data

Clinical demand

- Better care
- Patient safety
- Quality assurance
- Cost reduction
Clinical decision support: Infinite extent

Medical data

- national health systems
- EHR, EMR
- GP SW
- mobile health apps

Medical knowledge with processing engines

+ alerts, reminders, recommendations, calculations, ...
+ hepatitis serology, toxoplasmosis serology, ...
+ rheumatology for GPs, ...
+ rheumatology for clinics, ...
+ HAI alerts, surveillance, reports, ...
+ guidelines for diabetes, ...
+ hepatitis at pregnancy, ...

Data systems + knowledge systems

Infinite content complexity

Infinite clinical subjects
Clinical medicine

- History data
- Symptoms
- Signs
- Laboratory test results
- Bio-signals
- Images
- Genetic data

Examination

Subspecialities

Medical guidelines

Medication history

Symptomatic therapy

Differential diagnosis

Differential therapy

Prognosis

Patient
Clinical medicine: high complexity

- **sources of medical knowledge**
  - factual/causal
  - definitional
  - statistical
  - heuristic

- **layers of medical knowledge**
  - observational and measurement level
  - interpretation, abstraction, aggregation, summation
  - pathophysiological states
  - diseases/diagnoses, therapies, prognoses, management decisions

- **imprecision, uncertainty, and incompleteness**
  - imprecision (=fuzziness) of medical concepts
    * due to the unsharpness of boundaries of linguistic concepts
  - uncertainty of medical conclusions
    * due to the uncertainty of the occurrence and co-occurrence of imprecise medical concepts
  - incompleteness of medical data and medical theory
    * due to only partially known data and partially known explanations for medical phenomena

- **“gigantic” amount of medical data and medical knowledge**
  - patient history, physical examination, laboratory test results, clinical findings
  - symptom-disease relationships, disease-therapy relationships, gene-drug relationships, ...
  - terminologies, ontologies: SNOMED CT, LOINC, UMLS, ...

specialization, teamwork, quality management, computer support ➔ CDS
- studies in Colorado and Utah and in New York (1997)
  - errors in the delivery of health care leading to the death of as many as 98,000 US citizens annually
- causes of errors
  - error or delay in diagnosis
  - failure to employ indicated tests
  - use of outmoded tests or therapy
  - failure to act on results of testing or monitoring
  - error in the performance of a test, procedure, or operation
  - error in administering the treatment
  - error in the dose or method of using a drug
  - avoidable delay in treatment or in responding to an abnormal test
  - inappropriate (not indicated) care
  - failure of communication
  - equipment failure
- prevention of errors
  - we must systematically design safety into processes of care
Approaches to CDS

- Medical publications
  - Abstracted texts
  - CDS
    - Display
      - Authoritarian
        - e.g., UpToDate by Wolters Kluwer
- “Big” imaging data
  - Pattern recognition
  - CDS
    - Annotation
      - Empirical, low level
        - e.g., Watson Health by IBM
- “Big” structured data
  - Data mining
  - CDS
    - Induction
      - Empirical, low level
- “Big” published texts
  - Text mining
  - CDS
    - Induction
      - Empirical, high level
    - Deduction
      - Axiomatic
        - Knowledge Engines by Medexter
Knowledge design
based upon

individual “proprietary” knowledge

consensual “institutional” knowledge

written documents

designed knowledge for the digital age

multi-stakeholder Kaizen events

computerized medical knowledge

e.g., EHR alerts, MES, AppStore apps, SaaS apps, CDS Hooks, medical knowledge engines

Kai – change; Zen – (continuous) improvement
EHRs with CDS through knowledge-based AI

Patient’s medical data
- Symptoms
- Signs
- Test results
- Clinical findings
- Bio-signals
- Images
- Diagnoses
- Therapies
- Nursing data
- Standardization
- Telecommunication
- Chip cards

Physician’s medical knowledge
- Anatomy
- Biochemistry
- Physiology
- Pathophysiology
- Pathology
- Nosology
- Therapeutic knowledge
- Disease management
- Subjective experience
- Intuition

Medical knowledge acquisition by clinicians + knowledge engineers

Information systems
- Induction
- Deduction
- Medical statistics
- Clustering & classification
- Data & knowledge mining
- Machine learning
- Clinical decision support
- Medical expert systems

Knowledge-based systems
- Diagnosis
- Therapy
- Prognosis
- Management

Integration
- Telemedicine
Machine-learning AI as shortcut

- Symptoms
- Signs
- Test results
- Clinical findings
- Bio-signals
- Images
- Diagnoses
- Therapies
- Nursing data

- Standardization
- Telecommunication
- Chip cards

- Many patients
- General knowledge

- Medical statistics
- Clustering & classification
- Data & knowledge mining

- Induction

- General knowledge

- Deduction

- Anatomy
- Biochemistry
- Physiology
- Pathophysiology
- Pathology
- Nosology
- Therapeutic knowledge
- Disease management

- Subjective experience
- Intuition

- Information systems

- Knowledge-based systems

- Telemedicine

- Integration
Moni by Medexter for HAI surveillance: Knowledge design
**Moni:**

Healthcare-associated infection surveillance at ICUs

* Septicemias
  - primary, secondary, device-associated, unknown origin

* ICU-acquired pneumonias
  - bronchitis, pneumonia, various degrees of mibi confirmation

* Urinary tract infections
  - mibi-confirmed, not mibi-confirmed

* Central-venous-catheter-related infections
  - local, global, no positive blood culture, mibi-confirmed
Use it as part of your EMR or as stand-alone application

Medical Knowledge
medical logic modules

CDS Engine

The prediction:
In the future, any clinical activity will be either supported or substituted by Medical Knowledge Engines.

The medical knowledge
- clinically proven knowledge: rules, tables, decision trees, guidelines, scores, algorithms, ...
- evidence-based, application-ready knowledge packages
- knowledge design or knowledge through machine learning

The CDS engine
- HL7’s Arden Syntax medical knowledge representation and processing, with fuzzy methodologies
- scalable from cloud-based services to mobile apps
Clinical decision support with knowledge engines

**DIAGNOSIS**
- alerts, reminders, to-do lists
- clinical test interpretations and temporal abstraction
- (tele)monitoring of chronic conditions
- differential diagnostics
  - rare diseases, rare syndromes
  - further diagnostic procedures
  - multi-morbidity
- genetics, proteomics
  - molecular variations

**PROGNOSIS**
- illness severity scores, prediction rules
- trend detection and visualization

**THERAPY**
- drug alerts, reminders, calculations
  - indication, contraindications, redundant medications, cost-effective substitutions
  - dosage calculations, drug-drug and gene-drug interactions
  - adverse drug events
- management of antimicrobial therapies
  - susceptibility and resistance rates
- pharmacogenomics

**HOSPITAL MANAGEMENT**
- computerized evidence-based workflows, clinical guidelines, protocols, SOPs
- surveillance criteria and quality benchmarking
A “holy grail” of clinical informatics is scalable, interoperable clinical decision support.

according to
Kensaku Kawamoto
HL7 Work Group Meeting,
San Diego, CA, September 2011
Arden Syntax
Arden Syntax: HL7- and ANSI-approved

- An **HL7 standard language** for writing situation-action rules, procedures, or knowledge bases that trigger results based on clinical events detected in patient data

- Each module, referred to as a medical logic module (MLM), contains sufficient knowledge to make at least a single medical decision
  - extended by medical knowledge packages (MKPs) consisting of interconnected MLMs for complex clinical decision support

- **Continuous development**
  - The Health Level Seven Arden Syntax for Medical Logic Systems, version 2.9—including fuzzy methodologies—was approved by Health Level Seven (HL7) International and the American National Standards Institute (ANSI) in 2013.
  - The latest version, Version 2.10—including ArdenML, an XML-based representation of Arden Syntax MLMs—was approved in 2014.

⇒ healthcare industry and academic users
History

• 1989: A first draft of the standard was prepared at a meeting at the Arden Homestead, New York. Arden Syntax was subsequently adopted as a standard by the American Society for Testing and Materials (ASTM) as document E 1460, under subcommittee E 31.15 Health Knowledge Representation.

• 1992: Arden Syntax version 1.0

• 1998: sponsorship moved to HL7 International (Arden Syntax Work Group)

• 1999: Arden Syntax version 2.0 approved by HL7 and the American National Standards Institute (ANSI)

• 2013: Fuzzy Arden Syntax (Arden Syntax version 2.9)

• 2014: Arden Syntax version 2.10

• Continuous development
<table>
<thead>
<tr>
<th>Version</th>
<th>Year</th>
<th>Important changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>2002</td>
<td>new string operators; reserved word “currenttime” returns the system time</td>
</tr>
<tr>
<td>2.5</td>
<td>2005</td>
<td>object capabilities: create and edit objects; XML representation of MLMs (except logic, action and data slot)</td>
</tr>
<tr>
<td>2.6</td>
<td>2007</td>
<td>UNICODE encoding; additional resources category to define text resources for specific languages; time-of-day and day-of-week data types; “localized” operator to access texts in specific languages</td>
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<tr>
<td>2.7</td>
<td>2008</td>
<td>enhanced assignment statement; extended “new” operator to allow easy and flexible object instantiation</td>
</tr>
<tr>
<td>2.8</td>
<td>2012</td>
<td>additional operators for list manipulation; operators to manipulate parts of given date and time values; switch statements; keyword “breakloop” for aborting a loop; number of editorial corrections</td>
</tr>
<tr>
<td>2.9</td>
<td>2013</td>
<td><strong>Fuzzy</strong>: fuzzy data types, fuzzy sets, and fuzzy logic; adjustment of all available operators to be able to handle fuzzy data types</td>
</tr>
<tr>
<td>2.10</td>
<td>2014</td>
<td>XML representation of MLMs (including logic, action and data slot)</td>
</tr>
</tbody>
</table>
What is Arden Syntax?

• ... a knowledge representation standard primarily meant for medical knowledge.

• ... used for sharing computerized health knowledge bases across personnel, information systems, and institutions.

• ... organized in modules. Each module is referred to as a medical logic module (MLM) and contains sufficient knowledge to make at least a single medical decision.

• ... a computer-interpretable format that is used by clinical decision support systems.