The Model-based Approach to Computer-aided Medical Decision Support

*Lecture 1: Motivation*

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Why Medicine and AI?

- Challenging problems
- Highly relevant research (every one becomes ill somewhere in life)
- Lots of improvements possible: mistakes, wrong judgements made by medical professionals
- Many research opportunities
Clinical Reasoning

- **signs**
- **diagnostic process**
- **test**
- **patient data**
- **therapy selection**
- **therapy**
- **medical knowledge**
- **prediction disease progress**
- **prognosis**
Its Computerisation: Not Easy

- Early academic AI attempts, e.g.:
  - Diagnosis of disorders in internal medicine (e.g., gastrointestinal, rheumatoid, endocrine disorders): INTERNIST-I (1975–1985)
  - Diagnosis of glaucoma by Causal ASSociationel NETwork: CASNET (1971–1978)

- Commercial AI attempts:
  - Quick Medical Reference (QMR) – based on INTERNIST-I (discontinued 2001)
Why Failure?

- Focus on **diagnostic** systems: after entering set of findings $\Rightarrow$ differential diagnosis
- First generation programs: **immature** technology, PhD projects
- Don’t offer the support clinicians want to have
- Computational infrastructure too primitive until 2000
- Clinicians had little computer literacy until $\pm 1995$
- No integration with electronic patient record systems (still not generally available)
- Bad computer interface
Do Clinicians need ‘Support’?

- Obstetric clinics at Vienna General Hospital mid 1800s
- Doctors (1st clinic) versus midwives (2nd clinic):

  ![Graph showing puerperal fever yearly mortality rates]

- Ignaz Semmelweis (1818–1865): infection after child birth can be drastically cut by hand washing
Hand hygiene in the intensive care unit: prospective observations of clinical practice

Pol Arch Med Wewn, 2008; 118 (10): 543-547

Ismael A. Qushmaq, Diane Heels-Ansdell, Deborah J. Cook, Mark B. Loeb, Maureen O. Meade

Abstract. INTRODUCTION: Adherence to hand hygiene recommendations in the intensive care unit (ICU) is variable and moderate, at best. OBJECTIVES: To measure adherence to hand hygiene recommendations among ICU clinicians in a prospective observational study in 6 multidisciplinary ICUs among 4 hospitals. . . . RESULTS: The rate of adherence to current recommendations was 20%. . . .
Protocols

2002 Centers for Disease Control and Prevention Guidelines for the prevention of intravascular catheter-related infections:

- Wash your hands before inserting a central venous catheter
- Clean the skin with chlorhexidine
- Use of full-barrier precautions during CVC insertion
- Avoid the femoral site
- Remove unnecessary central venous catheters

⇒ We can investigate compliance
Clinical Guidelines

Definition: clinical (practice) guidelines: systematically developed statements to assist practitioners and patients decisions about appropriate health care in specific clinical circumstances

Characteristics:

- Guidelines are based on scientific evidence (results from RCTs for example — evidence-based medicine)
- In conjunction with considerations such as safety, availability, and cost effectiveness
- Aim: improving health-care outcomes and reduce costs of care
NICE
National Institute for health and Clinical Excellence
Example: NICE DM2 Guideline

DM2 GL: ORAL GLUCOSE CONTROL THERAPIES (2):
Thiazolidinediones (glitazones)

**R40** If glucose concentrations are not adequately controlled (to HbA1c <7.5% or other higher level agreed with the individual), consider, after discussion with the person, adding a thiazolidinedione to:

- the combination of metformin and a sulfonylurea where insulin would otherwise be considered but is likely to be unacceptable or of reduced effectiveness because of:
  - employment, social or recreational issues related to putative hypoglycaemia
  - barriers arising from injection therapy or ...
  - ...
  - ...

...
Which Decision Support is Best?

Protocols and guidelines:
- Evidence based (reflect scientific evidence)
- Have been shown to have a positive effect on quality of care
- Non-interactive, often very lengthy textual documents (with fixed structure)
- Are hard to personalise

Decision-support systems in AI:
- Interactive
- Offer one or more problem solving modes
- Poor relationship to scientific evidence
- Poor integration with clinician’s work flow
Computer-based Guidelines
The Model-based Approach

Management (diagnosis, treatment, prognosis) can be formalised: meta-model, e.g.,

- What is a diagnosis?
- What is a prognosis, etc.

Medical knowledge is also modelled (object model)

Deployment of:
- probabilistic graphical models, in particular Bayesian networks
- logical methods
Knowledge Formalisation

Ingredients (knowledge representation):

- Uncertainty (probability theory) and decision theory
- Intuitive qualitative notions, such as:
  - causal relations
  - associations
  - actions
  - outcomes
  - justification
  - ...

⇒ Probabilistic graphical models, such as Bayesian networks, and influence diagrams offer a good start
Problem Solving

- A **diagnosis** $d^*$ is maximum a posteriori assignment $d^* = \arg\max_d P(d \mid e)$, where $e$ observed **evidence** (symptoms, test results)

- **Prognostic** reasoning; determine **outcome** $o$: $P(o \mid e, a)$, with $a$ a sequence of treatment actions

- **Optimal** treatment:
  $$a^* \in \arg\max_a \sum_o P(o \mid e, a)u(a, o, e)$$
Now in Logic

Causal model $\mathcal{R}$

- Observed facts: $F = \{\text{myalgia}, \text{thirst}\}$
- Not to be explained: $C = \{\neg \text{chills}\}$

Formally: $D$ is a *diagnosis*, iff:

1. $\mathcal{R} \cup D \models F$ (covering prediction)
2. $\mathcal{R} \cup D \cup C \not\models \bot$ (consistency condition)
Pacemaker Programming

- display patient information
- show settings
- display histograms, counters, holters
- provide treatment advice
- enter patient data
- change settings, perform tests

diagnostics
settings
reprogrammed settings
tests
Conclusions

- Clinicians need (computer-based) tools that support clinical reasoning.
- Clinicians should be supported to **explore** problems:
  - what if the patient is treated in this way?
  - what if this diagnostic test is omitted?
  - …
- Reasoning should include uncertainty (= available scientific evidence from data and literature).
- Bayesian networks are a good start; a suitable probabilistic logic still needs to be developed.
Plan for this Week

- **Tuesday:**
  Probabilistic graphical models and conditional independence

- **Wednesday:**
  Design of a Bayesian network for clinical problem

- **Thursday:**
  Use of causal independence in modelling

- **Friday:**
  Probabilistic graphical models meet logic
Example: VAP in the ICU

- Problem: diagnosis and antimicrobial treatment of patients with ventilator-associated pneumonia (VAP)

- About 15-20% of ICU patients develop VAP

- Mortality rate: up to 40%

- Up to 50% of used antibiotics in ICUs are prescribed for airway infections
Example: Image Interpretation

- national breast cancer screening programme
- decision-making under uncertainty
- interpretation of image features in terms of probabilistic graphical models
- from single- to multi-view interpretation