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

Lecture 1: Motivation

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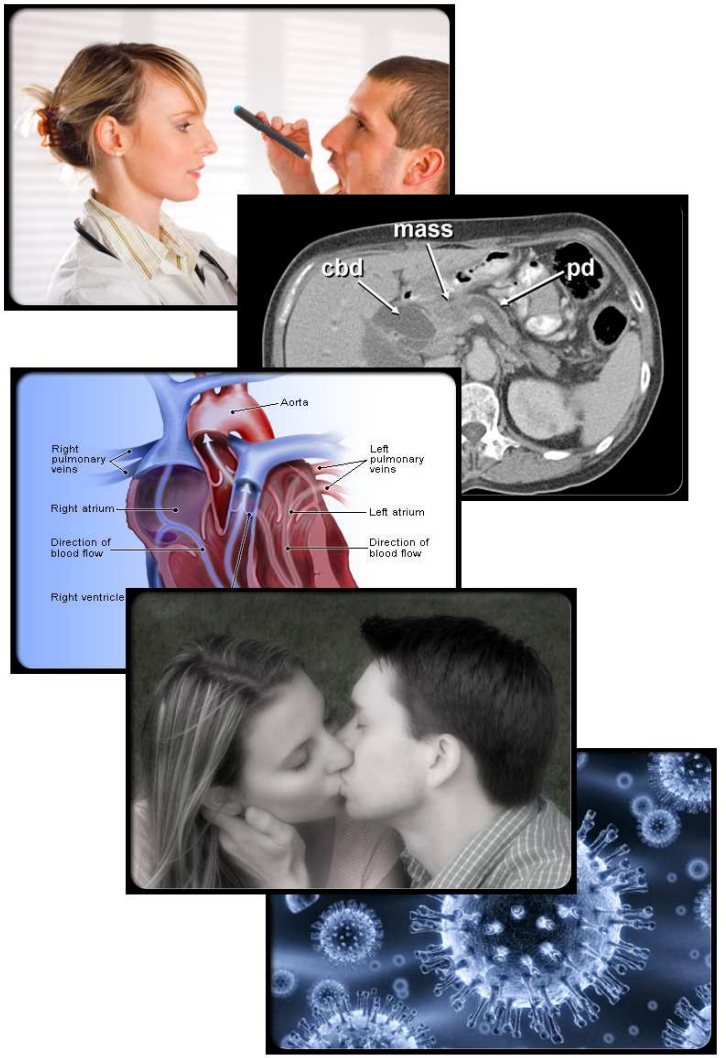
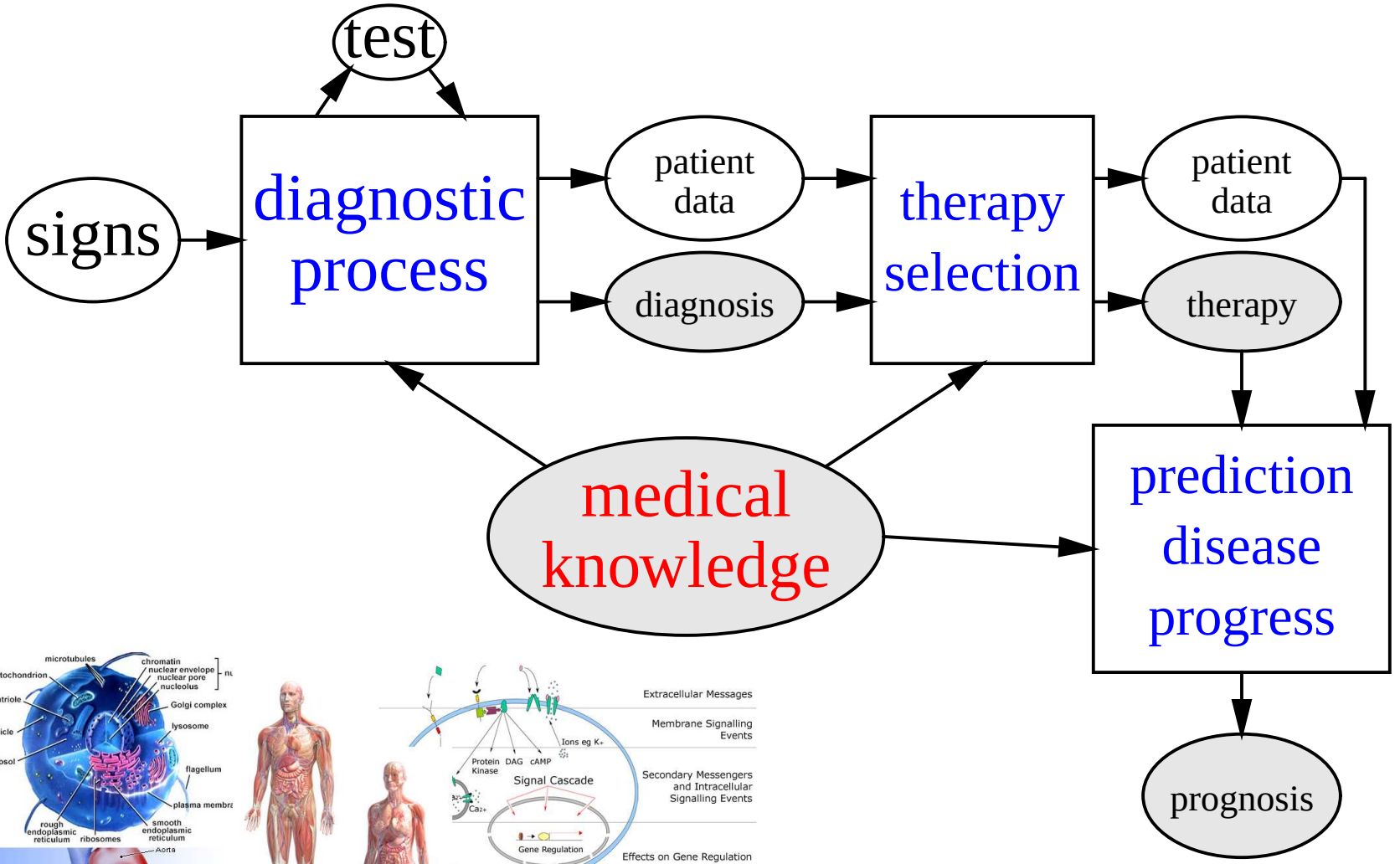
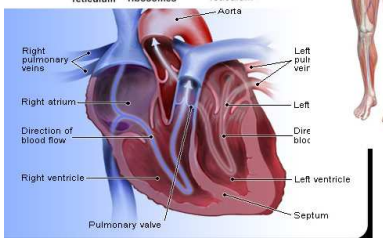
Why Medicine and AI?

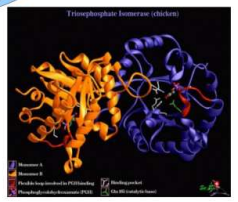
- Challenging problems
- Highly relevant research (every one becomes ill somewhere in life)
- Lots of improvements possible: mistakes, wrong judgements made by medical professionals
- Many research oppor-tunities



Clinical Reasoning







Its Computerisation: Not Easy

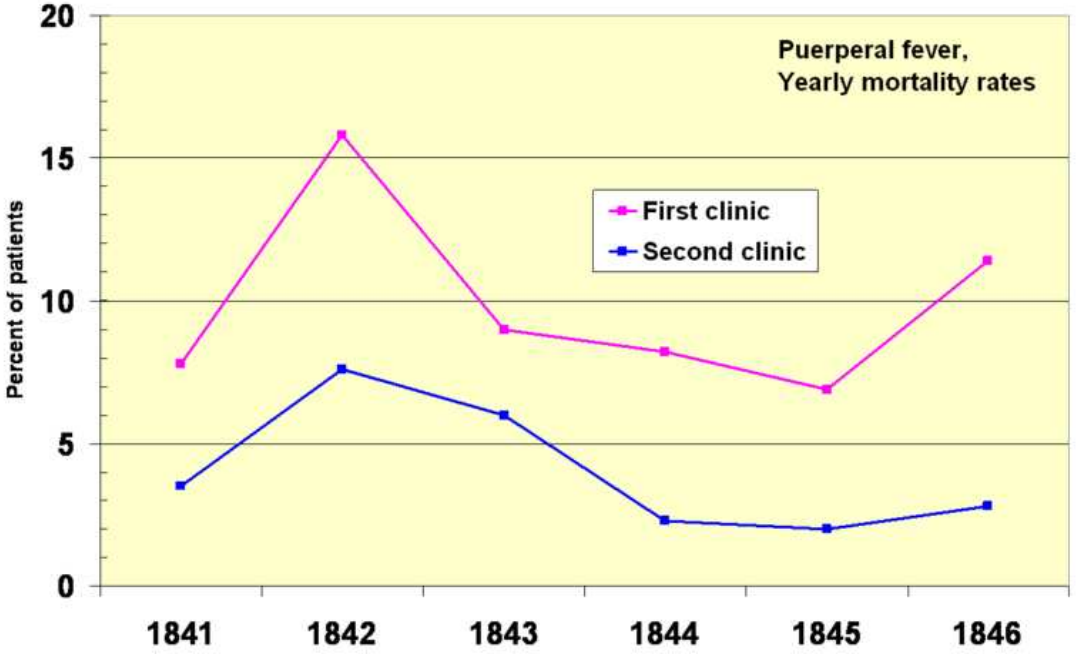
- Early academic AI attempts, e.g.:
  - Diagnosis and treatment of sepsis using rule-based system: MYCIN (1974–1979)
  - Diagnosis of disorders in internal medicine (e.g., gastrointestinal, rheumatoid, endocrine disorders): INTERNIST-I (1975–1985)
  - Diagnosis of glaucoma by Causal ASsociationel NETwork: CASNET (1971–1978)
- Commercial AI attempts:
  - Quick Medical Reference (QMR) – based on INTERNIST-I (discontinued 2001)
  - DXplain (1984–) – http://dxplain.org

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 inferface

Do Clinicians need 'Support'?

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



- Ignaz Semmelweis (1818–1865): infection after child birth can be drastically cut by hand washing

Today . . .

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

$\Rightarrow$ We can investigate compliance

Clinical Guidelines

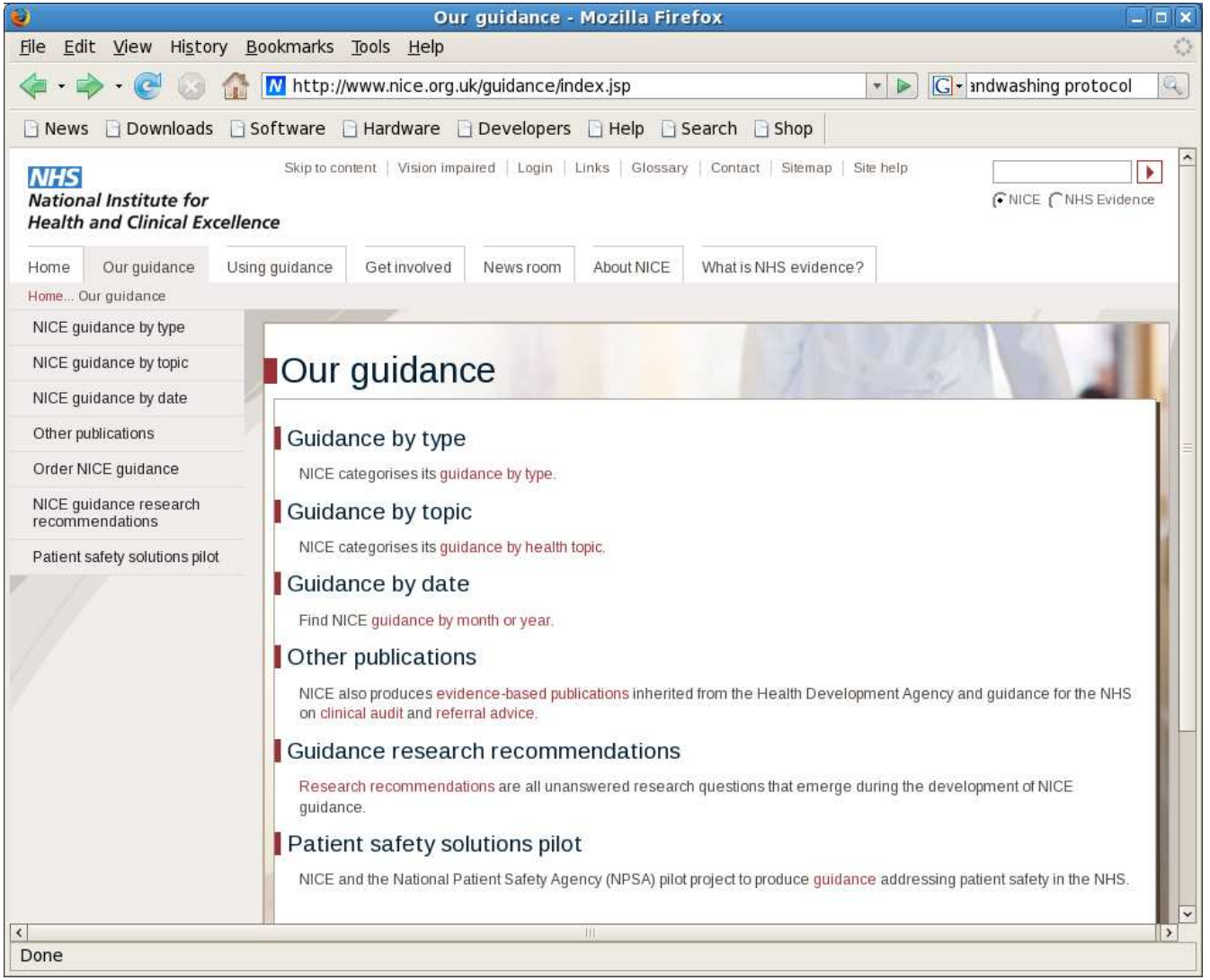
Definition: clinical (practice) guidelines: systematically developed statements to assist practitioners and patients decisions about appropriate health care in specific clinical circumstances

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?

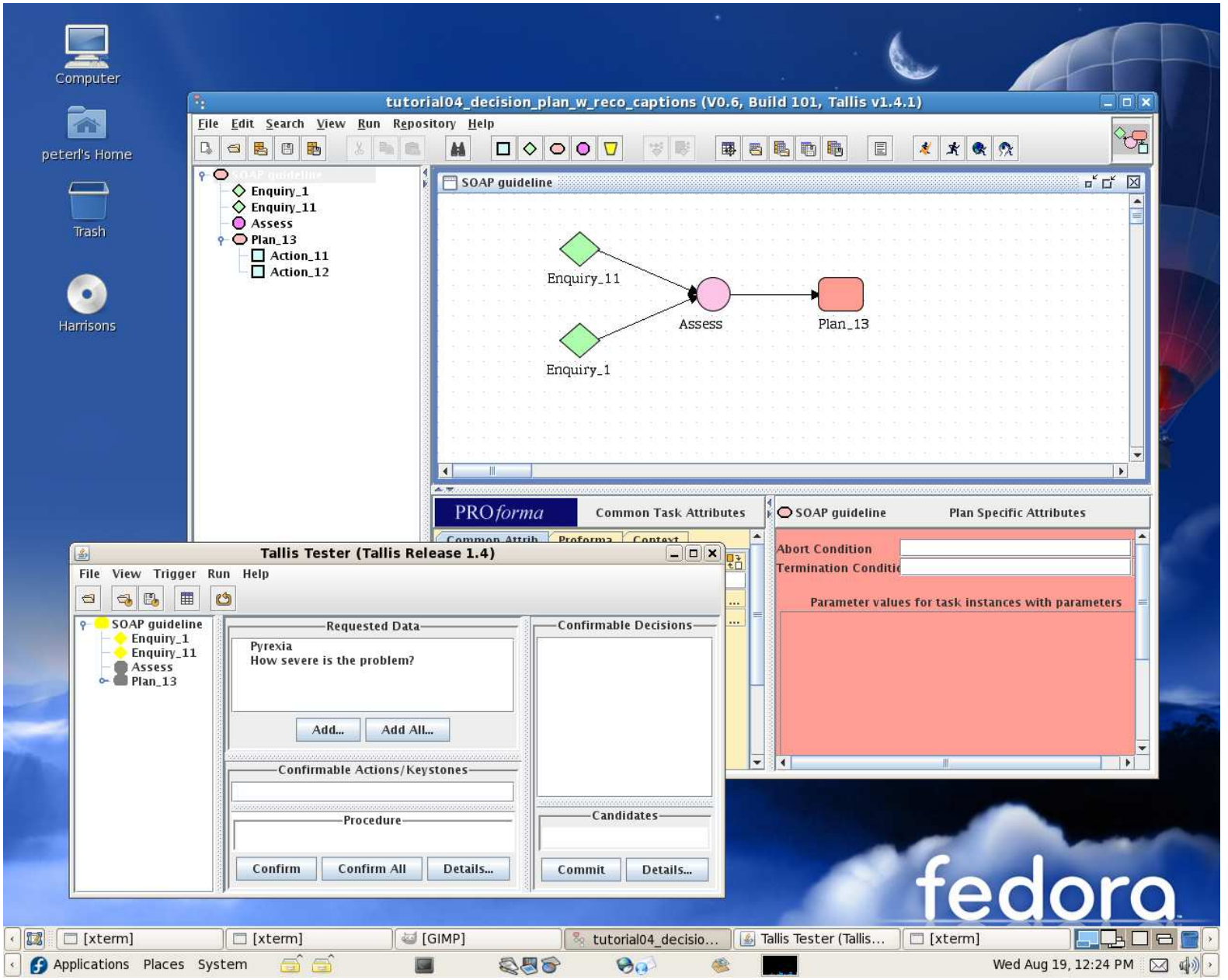
Protocols and guidelines:

- 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

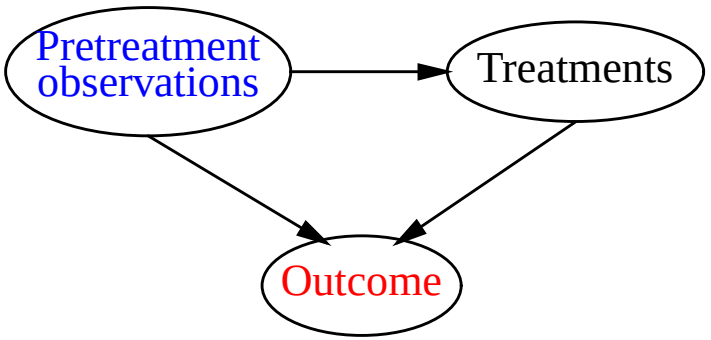
Ingredients (knowledge representation):

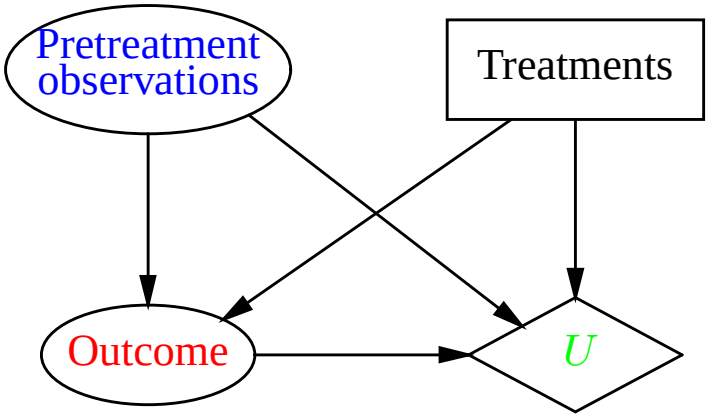
- Uncertainty (probability theory) and decision theory
- Intuitive qualitative notions, such as:
  - causal relations
  - associations
  - actions
  - outcomes
  - justification
  - . . .

$\Rightarrow$ Probabilistic graphical models, such as Bayesian networks, and influence diagrams offer a good start

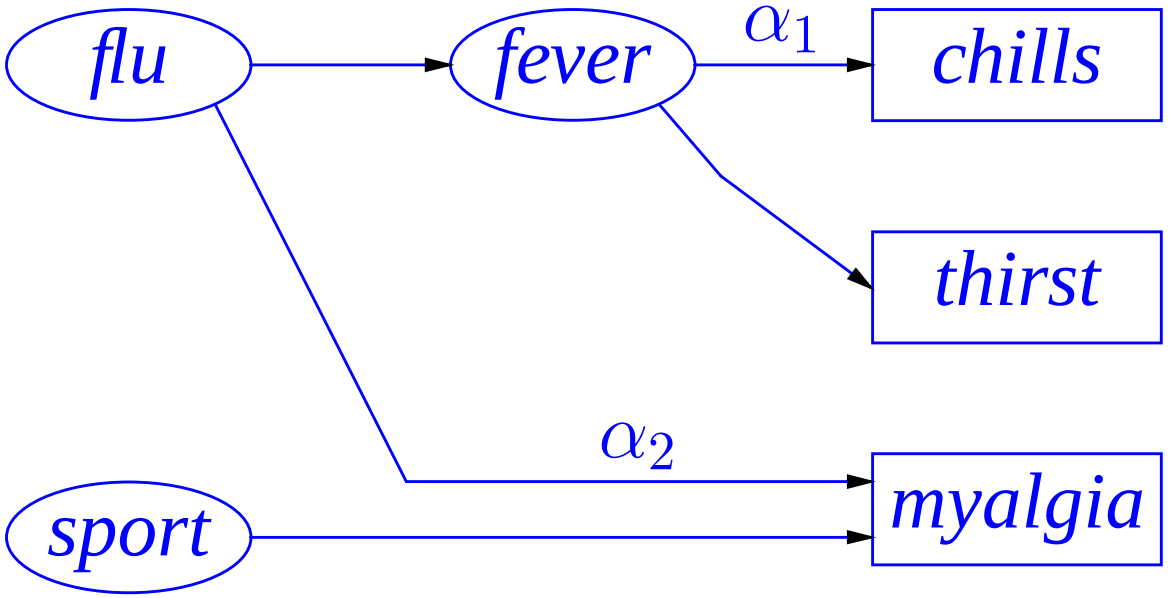
Problem Solving

- A diagnosis d^* is maximum a posteriori assignment $d^* = \text{argmax}_d P(d \mid e)$, 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: $a^* \in \text{argmax}_a \sum_o P(o \mid e, a) u(a, o, e)$





Now in Logic



- Causal model $\mathcal{R}$
- Observed facts: $F = \{myalgia, thirst\}$
- *Not* to be explained: $C = \{\neg chills\}$
- 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

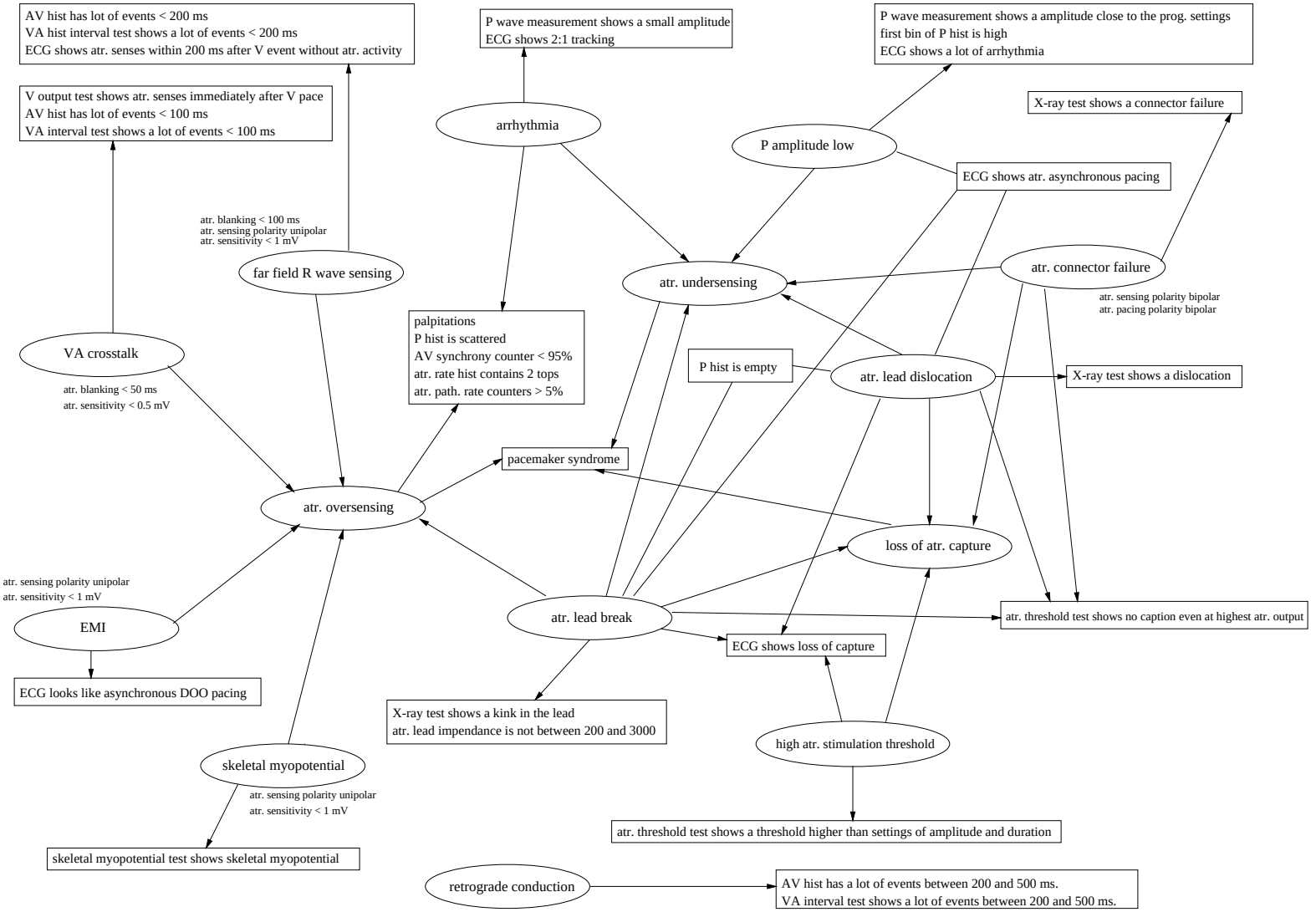
diagnostics

settings

reprogrammed settings

tests

Causal Pacemaker Model



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 interpre-tation