Clinical Decision Support Systems:
An Overview and Discussion

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Outline

- CDSS – what's in a name?
- Requirements
- Architectures
- Short reviews
- Challenges and MET research experience: MET3-AE CDSS
- Next steps in decision support: personalized and executable clinical practice guidelines
- CDSS for predictive diagnostics
- CDSS for space medicine
- Implementing CDSS

CDSS

A **clinical decision-support system**: *any computer program designed to help healthcare professionals to make clinical decisions*

"In a sense, any computer system that deals with clinical data or knowledge is intended to provide decision support." (Musen, Shahar, Shortliffe)

1. Tools for information management
2. Tools for focusing attention
3. Tools for providing patient-specific recommendations
   - Diagnostic recommendations
   - Patient management recommendations (including treatment)

CDSS

- Vast field that includes among others:
  - Electronic health records (EHR)
  - Computerized physician order entry (CPOE)
  - Pharmacy systems
  - Laboratory systems
  - Alerting systems
  - Recommender (diagnostic) systems
  - Clinical information-retrieval systems (CIR)
- Different stakeholders and different point of views
  - Healthcare professionals (physicians, nurses, etc.)
  - Managers
  - Developers

Requirements for effective CDSS

- Speed is everything
- Anticipate needs and deliver in real time
- Fit into workflow
- Little things can make a big difference
- Make interactions easy
- Changing direction is easier than stopping
- Summarize patient data
- Create shareable modules available across intra and extra nets

Bates et al., *JAMIA*, 2003
Sittig et al., *JBI*, 2008

CDSS architectures

- Stand-alone systems (1959 – now)
  - Autonomous support functionality
- Integrated systems (1967 – now)
  - Embedded support functionality (usually in the EHR)
- Systems based on service/agent models (2005 – now)
  - Distributed support functionality (usually among the components of the HIS infrastructure)

Wright et al., *IJMI*, 2008

Stand-alone systems

Leeds Abdominal Pain System (University of Leeds)

- Goal: To diagnose abdominal pain and find possible explanation given available findings
- How it works: Uses Bayesian reasoning to identify possible diagnosis/explanation of abdominal pain (7 possibilities – from appendicitis to non specific pain); extensive clinical trials in the past

- Reference: de Dombal FT, Leaper DJ, Staniland JR, McCann AP, Horrocks JC. Computer-aided Diagnosis of Acute Abdominal Pain. *BMJ* 1972; 2 (5804):5-9.

Stand-alone systems

MYCIN (Stanford University)

- Goal: To de-emphasize diagnosis and concentrate on management of patients who have infection
- How it works: Reasons using ~600 production rules provided by the experts and representing knowledge on infectious diseases and their treatments

- Reference: Buchanan BG, Shortliffe EH. *Rule Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project*. Addison-Wesley 1984.

Stand-alone systems

DXplain (Massachusetts General Hospital, Boston)

- Goal: To generate ranked list of diagnoses given clinical findings
- How it works: Uses Bayesian reasoning to identify candidate diagnoses from a comprehensive database of over 4500 clinical manifestations and over 2000 different diseases

- Reference: Barnett GO, Famiglietti KT, Kim RJ, Hoffer EP, Feldman MJ. DXplain on the Internet. *Proceeding of AMIA Annual Symposium* 1998:607-11

Stand-alone systems

Isabel (Imperial College School of Medicine, London)

- Goal: To provide differential diagnoses for a set of clinical findings
- How it works: Uses text indexing and retrieval techniques to match findings to potential diagnoses by analyzing digitized pediatric textbooks

- Reference: Ramnarayan P, Britto J. Paediatric clinical decision support systems. *Archives of Disease in Childhood* 2002;87(5):361-2

Integrated systems

RMRS (Regenstrief Medical Institute and Wishard Memorial Hospital, Indianapolis)

- Goal: To generate reminders for physician to undertake specific actions given patient state
- How it works: Uses over 1400 rules encoded in a specialized language (CARE) to suggest an observation (Type I), or a diagnostic study (Type II), or an initiation/change of therapeutic plan (Type III); fully integrated with EHR

- Reference: McDonald CJ, Overhage JM, Tierney WM, Dexter PR, Martin DK, Suico JG, et al. The Regenstrief Medical Record System: a quarter century experience. *International Journal of Medical Informatics* 1999;54(3):225-53

Integrated systems

Help (LDS Hospital, Salt Lake City)

- Goal: To generate event-driven warnings, notifications and reports
- How it works: Uses decision rules encoded in Arden syntax and grouped into Medical Logical Modules (MLM) to identify events of interest and to generate and distribute appropriate output; fully integrated with EHR

- Reference: Haug PJ, Rocha BH, Evans RS. Decision support in medicine: lessons from the HELP system. *International Journal of Medical Informatics* 2003;69(2-3):273-84

Systems based on service/agent models

SEBASTIAN (Duke University Medical Center, Durham)

- Goal: To provide diversified support services (patient- and population-specific) that can be used by other systems
- How it works: Services accessible over the Internet apply knowledge represented in XML-based Executable Knowledge Modules (EKMs) in response to the requests; efforts to establish HL7 standard for clinical decision support services

- Reference: Kawamoto K, Lobach DF. Design, implementation, use and preliminary evaluation of SEBASTIAN, a standards-based Web service for clinical decision support. *Proceedings of AMIA Annual Symposium* 2005:380-4

Systems based on service/agent models

K4Care (FP6 project financed by EU)

- Goal: To manage and synchronize actions of a team of professionals providing care to disabled or chronically ill elderly patients
- How it works: Multiple agents representing specific team members cooperate according to a guideline in order to support care and assistance

- Reference: Isern D, Moreno A, Sanchez D, Hajnal A, Pedone G, Varga LZ. Agent-based execution of personalised home care treatments. *Applied Intelligence* 2011, 34(2), 155-180

Systems based on service/agent models

MET3 (University of Ottawa, Children’s Hospital of Eastern Ontario, Ottawa)

- Goal: To help creating different disease-specific CDSSs that provide diagnostic and treatment recommendations
- How it works: Specialized agents use different types of clinical knowledge represented as ontological models to derive diagnostic and treatment suggestions

- Reference: Sayyad-Shirabad J, Wilk Sz, Michalowski W., Farion, K. Implementing an Integrative Multi-agent Clinical Decision Support System with Open Source Software, *Journal of Medical Systems*, (in press) 2010; Wilk Sz, Michalowski W, Farion K, Sayyad Shirabad J., MET3-AE System to Support Management of Pediatric Asthma Exacerbation in the Emergency Department. *Proceedings, Studies in Health Technology and Informatics*, 2010, 841-845

CDSS challenges

- Data
- Predictive/decision models
- Acceptance, evaluation and validation

Data

- Deficiency in data
  - Paucity of centers with EHR
  - Few comprehensive clinical data repositories

- Syntactic and semantic interoperability
  - SNOMED CT, LOINC not used/enforced
  - HL7 as a standard

Predictive/decision models

- Expert versus data-driven
  - How to capture the tacit knowledge of experts?
  - What source of existing knowledge?
    - Does retrospective data work?
    - Can we overcome data issues between sources?

- Clinical decision rules versus "non-traditional" models
  - How good a decision model should be?
  - What's best when multiple rules/models need to interact?

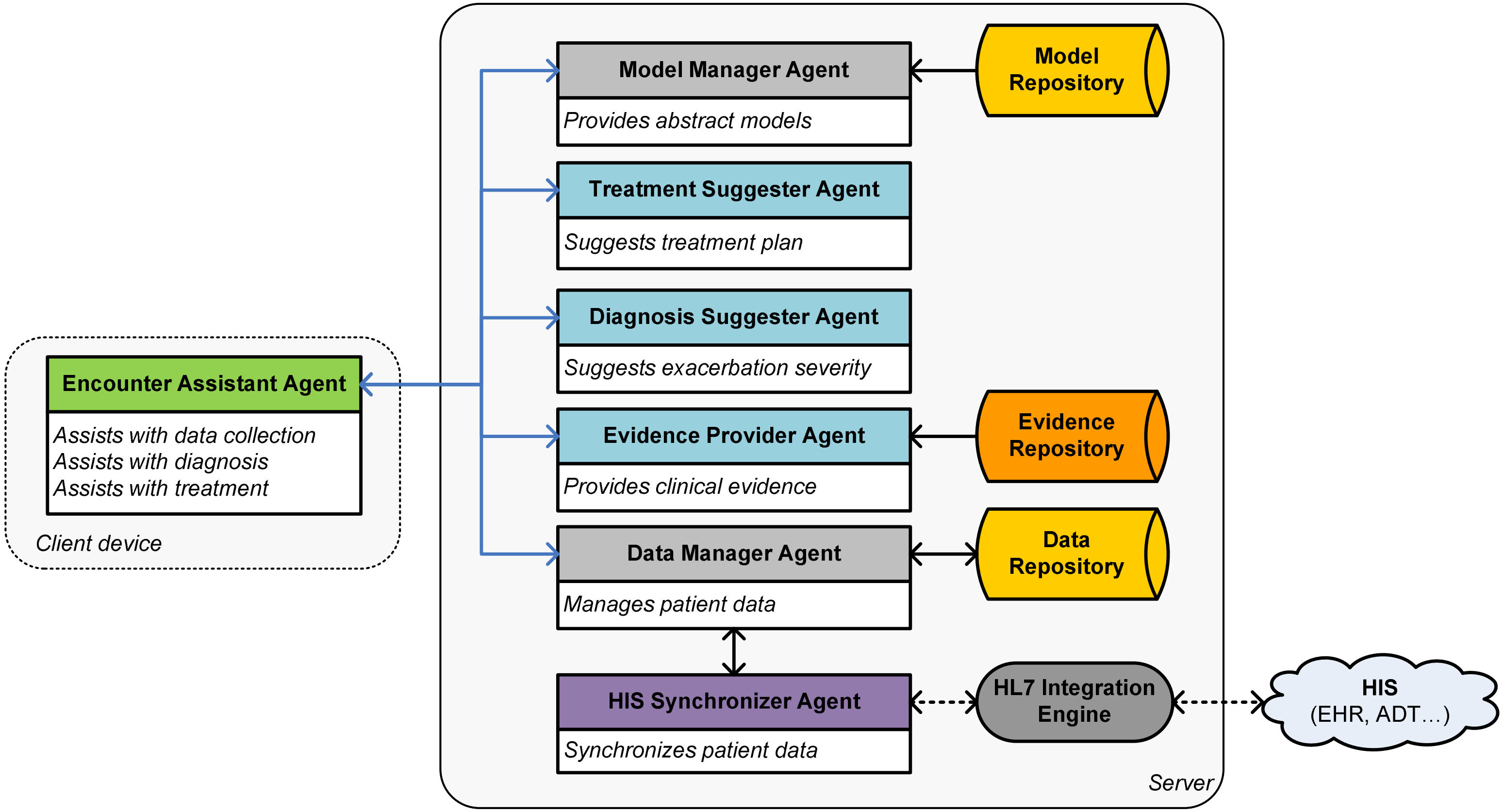
Acceptance, evaluation and validation

- What outcomes need to be measured?
  - Patient care
  - MD performance
  - Monetary
- What level of accuracy is clinically acceptable, legally defensible?
- By what methods to evaluate?
  - Do we need RCT evidence? At what level of randomization?
    - Patient
    - MD
    - System
- Motivation to use CDSS and usability of a system

MET3-Asthma (MET3-AE)

- A CDSS for ED management of pediatric asthma patients implemented using MET3 environment
  - Supports early management (around 1 hour after triage)
  - Interacts with hospital information systems (ADT, EHR)
  - Interacts with the *Cochrane Library* to provide patient-specific evidence associated with possible treatment options
  - Uses data-driven diagnostic model for predicting severity of exacerbation and integrates with the guideline for treatment options

MET3-AE: Agent-based CDSS

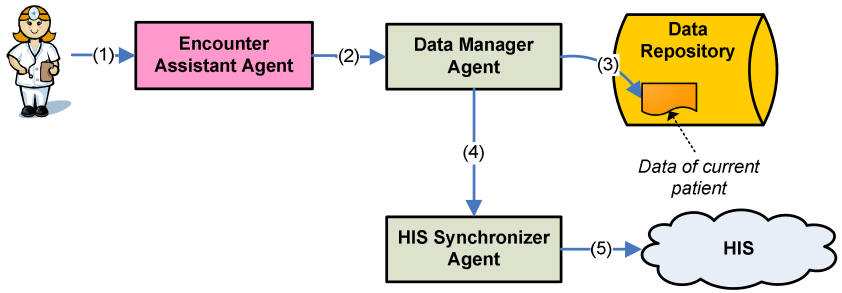


Data collection

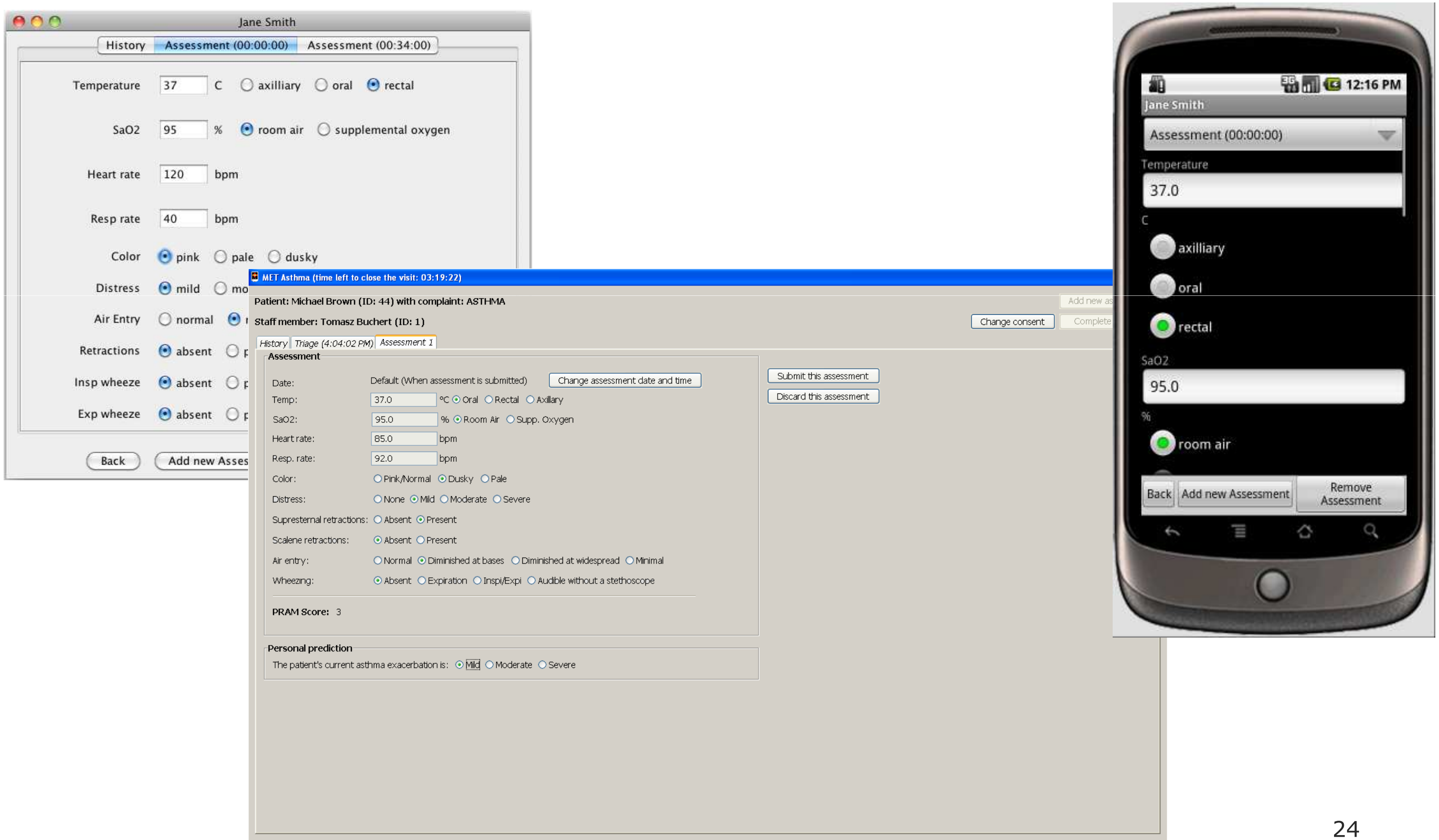
- Issues
  - Interpreting medical jargon and shorthand
  - Paper-based charting and documentation
  - Novice vs. expert
  - Clinician-friendly GUI
  - Integration with legacy systems

MET3-AE: Data collection

- MET3-AE is available at the POC on different computing devices
- MET3-AE interacts with other hospital systems
- MD-driven GUI



MET3-AE: data collection GUI



Diagnosis formulation

- Issues
  - Patients have complex, multisystem diseases
  - MDs have different abilities and practice styles
  - Nobody likes “cook book medicine”
  - Lack of quality data to develop good diagnostic models

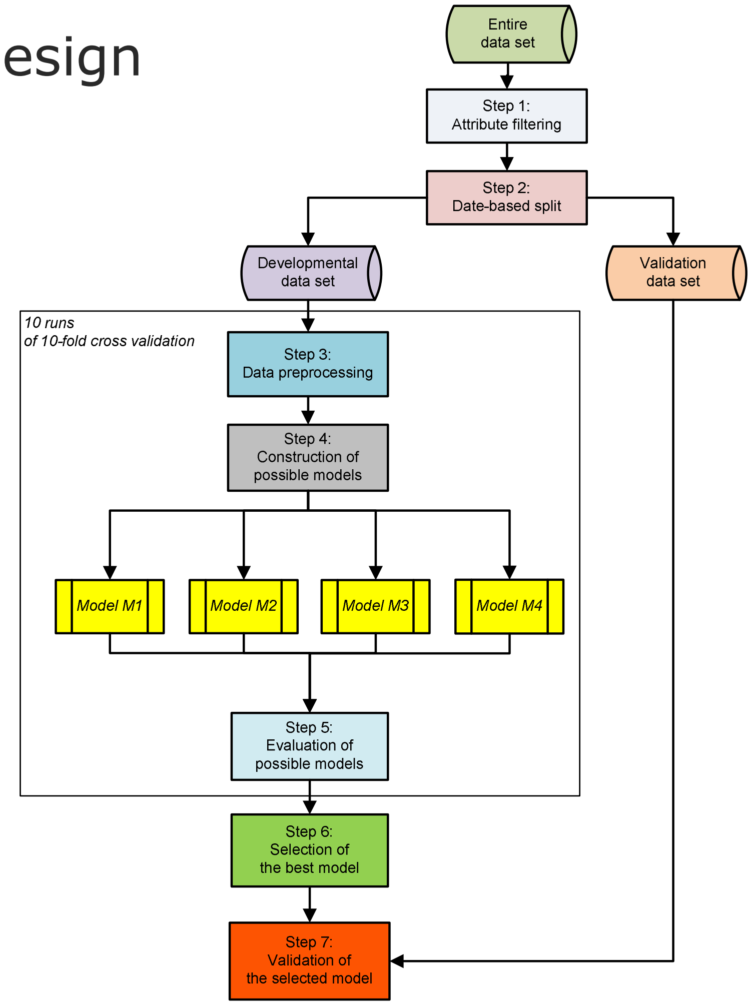
MET3-AE: Diagnostic model

- Retrospective chart study with included patients identified using ICD-10 codes (manually verified by MD) and data items transcribed by a trained abstractor
- Advanced data mining to build diagnostic model
  - Filtering of data using domain knowledge to remove questionable records
  - Normalizing values of age-dependent attributes
  - Using robust prediction models with regards to missing values
  - Involving MD in model's evaluation

MET3-AE: Model development

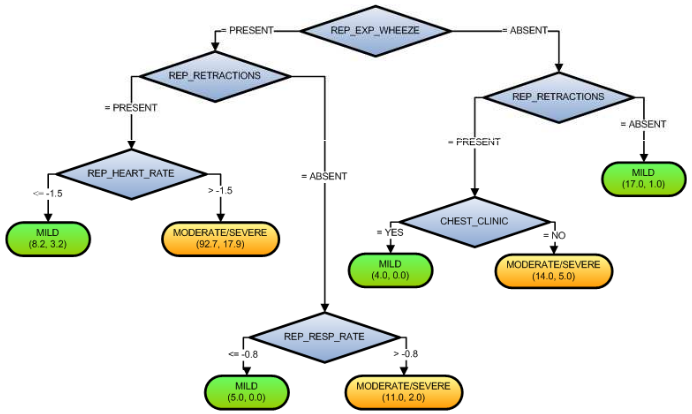
- Comprehensive experimental design and evaluation

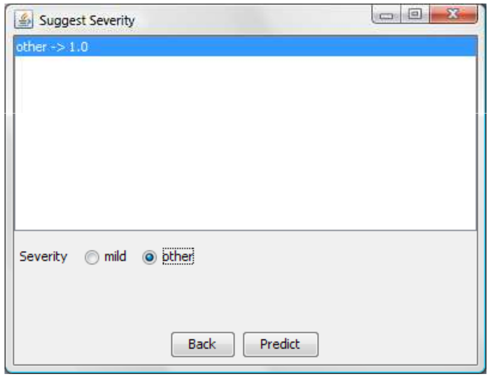
Model	Sensitivity	Specificity
Tree-based with record filtering	**76%**	**65%**
Tree-based with record filtering and contextual normalization	**84%**	**71%**
Logistic regression	69%	68%

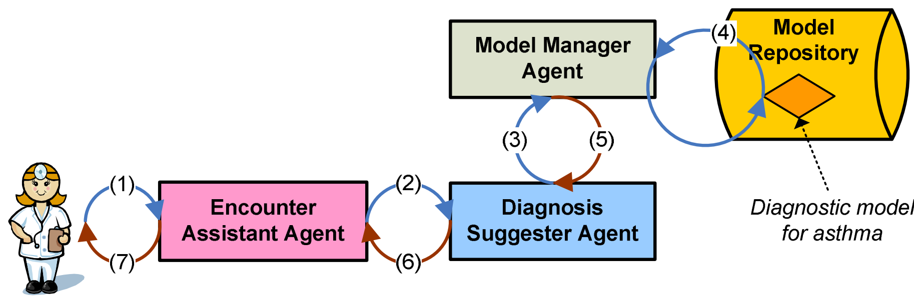


MET3-AE: Model implementation

- Computer implementation for non-obstructive use







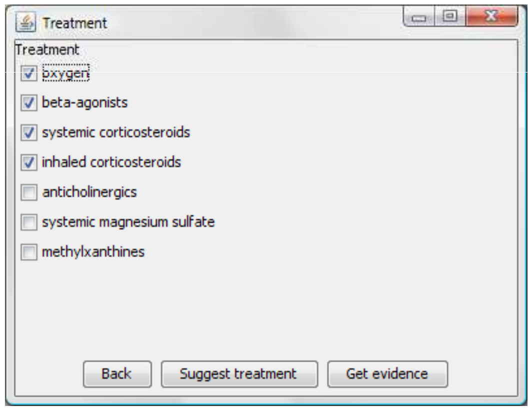
Treatment planning

- Issues
  - Variability in treating the same condition
  - Guidelines are population-based instead of patient-specific
  - Drug-drug and drug-disease interactions

MET3-AE: Treatment planning

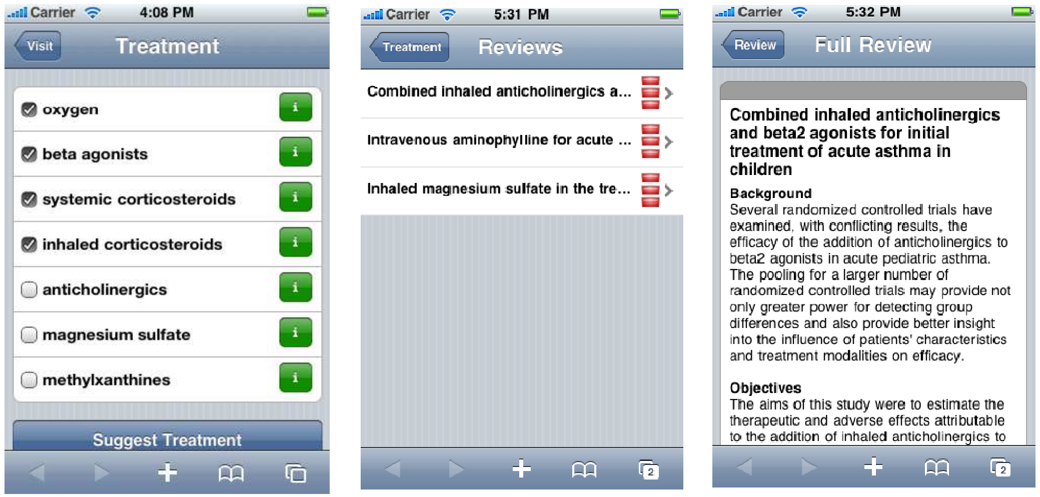
- Linking patient data and diagnosis with CAEP (Canadian Association of Emergency Physicians) guideline

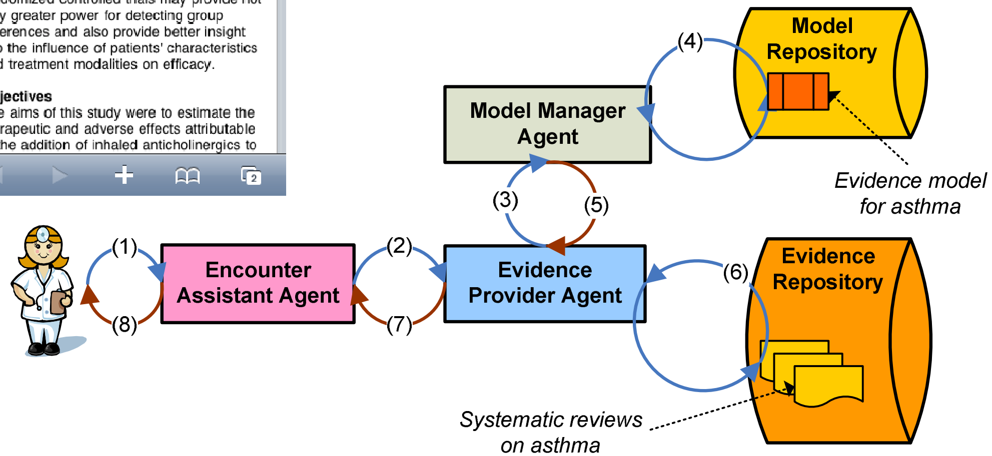
ASSESSMENT	PRE-TREATMENT	TREATMENT
MILD • nocturnal cough • exertional dyspnea • increased use of β-agonists • good response to β-agonists	• O_2 saturation >95%, PEF, FEV_1 >75% predicted or personal best	• ± O_2 • β-agonists • consider systemic corticosteroids
MODERATE • normal mental status • abbreviated speech • dyspnea at rest • partial relief with β-agonists and required more than q 4h	• O_2 saturation >92-95%, PEF, FEV_1 50-75% predicted or personal best	• O_2 100% • β-agonists • systemic corticosteroids • consider anticholinergics
SEVERE • altered mental status • difficulty speaking • laboured respirations • persistant tachycardia • no pre-hospital relief with β-agonists at usual dose	• O_2 saturation <92% • PEF, FEV_1 <50% predicted or personal best	• 100% O_2 • frequent or continuous β-agonists • systemic corticosteroids • systemic magnesium sulfate • consider anticholinergic • consider methylxanthines
NEAR DEATH • exhausted, confused • diaphoretic, cyanotic • apnea • decreased resp. effort • failing heart rate	• O_2 saturation <80% (despite supplemental O_2) • PEF, FEV_1 not appropriate	IF NEAR DEATH OR DETERIORATING ↓ RAPID SEQUENCE INTUBATION



MET3-AE: Treatment planning GUI

- Providing patient-specific evidence from the Cochrane Library associated with possible treatment options





MET3-AE: Clinical trial

- Conducted in the ED of CHEO as a pilot study including the team of MDs, residents and nurses
- Enrolled about 120 patients
- The major goal was to evaluate and compare predictive accuracy of MDs, PRAM score and MET3-AE
- The secondary goal was to verify the acceptance of clinicians of the advanced CDSS in the ED

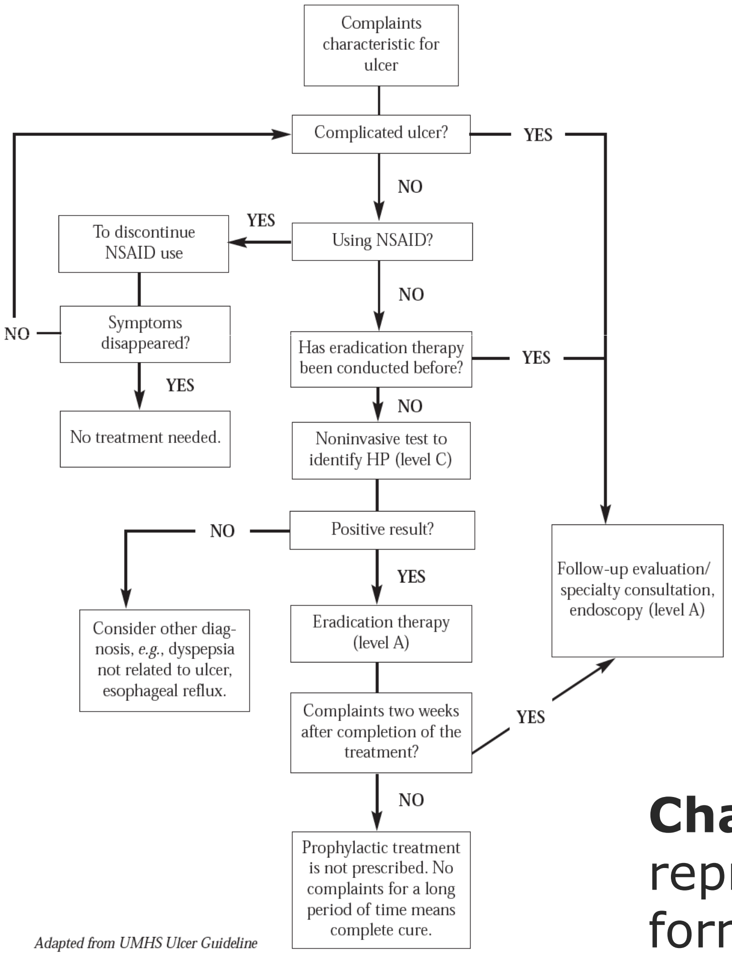
Next step in CDSS: Personalized and executable Clinical Practice Guideline (CPG)

- **CPG**: *systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances*

- Motivation for the CPG development and use:
  - Minimize number of medical errors
  - Practice evidence-based medicine
  - Improve patient outcomes
  - Control costs

CPG

DIAGNOSTIC ALGORITHM

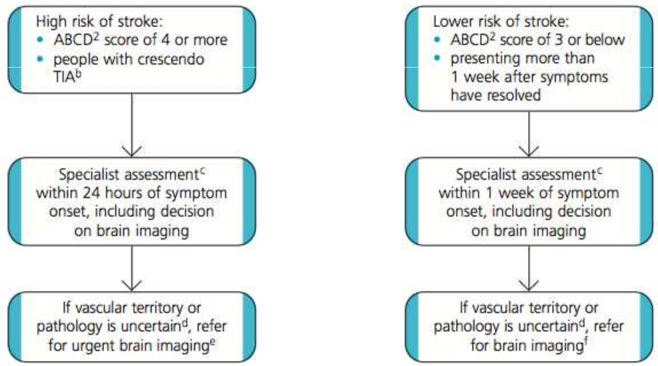


Adapted from UMHS Ulcer Guideline

People with TIA – assessment, early management and imaging

- Start daily aspirin (300 mg) immediately.
- Introduce measures for secondary prevention as soon as the diagnosis is confirmed, including discussion of individual risk factors.

- Assess risk of subsequent stroke as soon as possible using a validated scoring system[a] such as ABCD^2.



- Use diffusion-weighted MRI for brain imaging, except where contraindicated. For these people use CT scanning.

Challenge: lack of de facto standards for representing CPG in a structured and executable format

Proposed methodology

- A constraint logic programming (CLP) approach
- CLP model is composed of:
  - A set of variables $V = \{V_1, V_2, \ldots, V_n\}$ and their respective value domains $D = \{D_1, D_2, \ldots, D_n\}$
  - A set of constraints $C = \{C_1, C_2, \ldots, C_n\}$ that restrict the possible combinations of values assigned to each variable
  - A set of clauses $CL = \{CL_1, CL_2, \ldots, CL_n\}$ that define the logic program, a disjunction of n-ary predicates (literals)

Proposed methodology cont.

- Variables = decision and action steps
- Constraints = restrictions on variables' values derived from a CPG
- Solving a CLP model
  - Fills in missing values
  - Deduces a patient's state from limited information
  - Helps identify if therapy is consistent with a patient's health status (in case of co-morbid condition)

Executable CPG

- Methods
  - CLP expanded with external knowledge (i.e. drug-disease interactions)
- Ability to identify inconsistencies
  - No solution to a combined model
- Ability to revise models as needed
- Customize CPGs to co-morbid condition of a patient
  - Personalized medicine

CDSS for predictive diagnostics

- Provides ability to screen out normal variations while automatically identifying early warning signs of a real problem
  - Event detection and prediction
  - Industrial engineering domain

- MET Group experience
  - Predictive models for triage and diagnostic decisions, development of executable CPGs
  - Assessing expected LOS after radical prostatectomy

MET3-RP: Monitor for radical prostatectomy

Clinical pathway:

- Structured, multidisciplinary plans of care designed to support the implementation of clinical guidelines and protocols.
- Provide detailed guidance for each stage in the management of a patient with a specific condition over a given time period; include progress and outcomes details.
- Used to control patient's progress measured according to standard process and clinical outcomes, e.g., length of stay (*LOS*).

Radical prostatectomy pathway(RPP) describes patient's management (activities, outcomes, variance record) from a post-op to a fourth day of stay in the hospital.

Bayesian belief network (BBN)

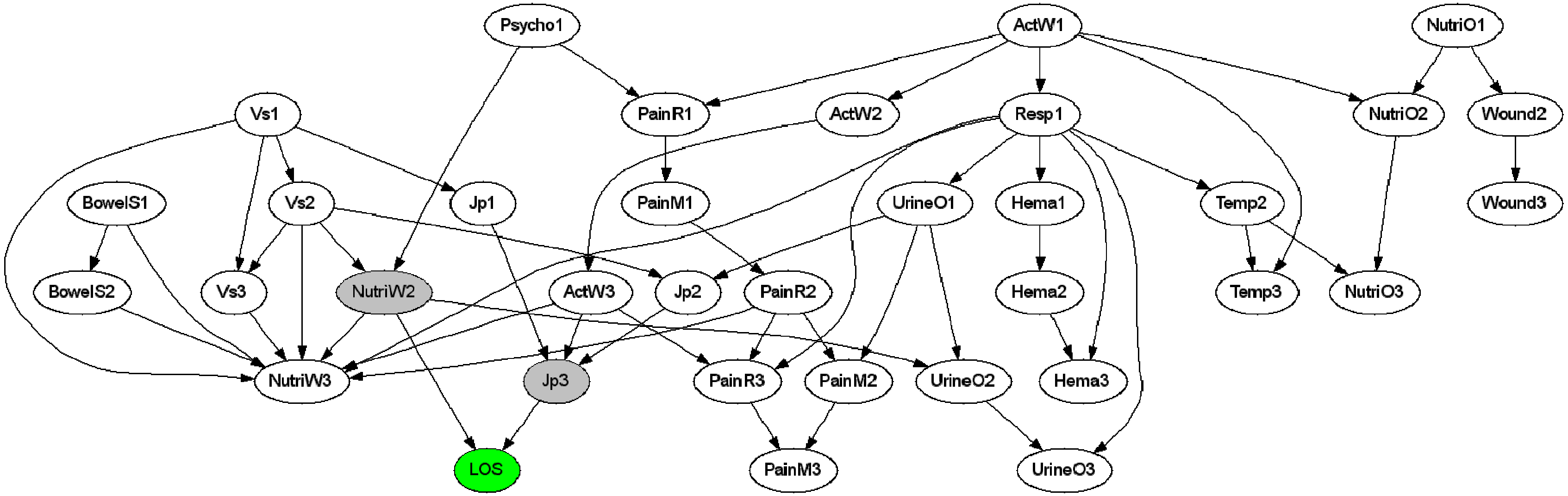
- Models a stochastic process composed of the events with associated conditional probabilities and relationships between these events.
- Generates an answer to conditional-type queries, e.g., *considering the patient's health status on a given day, what impact would occurrence of event "x" have on meeting the expected day of discharge*.
- Used to predict the impact of observed outcomes and activities on the *LOS* on the basis of current observations recorded in the pathway.

MET3-RP: Developing BBN model

- Charts and pathways of patients managed by various clinical teams at The Ottawa Hospital – Civic Campus.
- Data transcribed from patient's records and evaluated by urology specialists for consistency and correctness.

- K2 algorithm to develop the BBN structure and calculate the conditional probabilities from data.

MET3-RP: Structure of the BBN model



MET3-RP CDSS

- Developed with a help of MET3 environment
- Allows predicting chances of timely discharge
- Allows estimating variances from the RPP
- Easily expandable to support pathways for other clinical conditions

CDSS for space medicine

- Requirements
  - Asynchronous medicine
  - Increased degree of autonomy
  - Limitation of the accessible resources
  - Intuitive and “smart” GUI
  - Vertical and horizontal (crew medical officers, ground personnel, etc.) integration
- Current solutions
  - Telemedicine
  - Telemedicine Instrumentation Pack (TIP)
  - Space Medicine Patient Condition Database (PCDB)
  - Crew Healthcare System (CHeCS)

Expected medical care capabilities of space medicine CDSS

- Monitoring and prevention
  - Lookout for typical in space environment health issues that should be identified before they occur and preventive action(s) should be taken

- Diagnosis of a health condition and therapeutic intervention
  - Use of a “space-adjusted” CPG to diagnose a condition and identify most effective therapeutic action

Implementing CDSS

- Systems
  - DXplain – diagnosis (SaaS)
  - ISABEL – diagnosis (SaaS)
  - UpToDate – medical evidence (SaaS)
  - EgaDSS – CPGs and reminders (FLOSS)
  - Tallis/Arezzo – CPGs (COTS)
  - MET3 (FLOSS)

- Components/Tools
  - MSBNx – BBN (COTS)
  - WEKA – data mining (FLOSS)
  - JADE/WADE – MAS (FLOSS)
  - Protégé – ontologies (FLOSS)
  - JESS – rule-based reasoning (FLOSS)
  - LUCENE – text indexing and retrieval (FLOSS)

Useful links:
http://www.openclinical.org/dss.html
http://www.informatics-review.com/decision-support/

Selected publications of the MET Group

1. Sz. Wilk, M. Michalowski, M. Hing, W. Michalowski, K. Farion "Reconciliation of Concurrently Applied Clinical Practice Guidelines using Constraint Logic Programming", *Proceedings, 6th International Symposium on Health Informatics and Bioinformatics*, Izmir, 2011 (pp. 138-144).
2. Sz. Wilk, W. Michalowski, K. Farion, J. Sayyad Shirabad "MET3-AE System to Support Management of Pediatric Asthma Exacerbation in the Emergency Department", *Studies in Health Technology and Informatics*, vol. 160 no. 2 2010 (pp. 841-845).
3. D. O'Sullivan, Sz. Wilk, W. Michalowski, K. Farion "Automatic Indexing and Retrieval of Encounter-specific Evidence for Point-of-Care Support", *Journal of Biomedical Informatics*, vol. 43 no 4, 2010 (pp. 623-631).
4. J. Shirabad, Sz. Wilk, W. Michalowski, K. Farion "Implementing and Integrative Multi-agent Clinical Decision Support System with Open Source Software", *Journal of Medical Systems* (forthcoming).
5. K. Farion, W. Michalowski, Sz. Wilk, D. O'Sullivan, S. Matwin "A Tree-based Decision Model to Support Prediction of the Severity of Asthma Exacerbations in Children", *Journal of Medical Systems*, vol. 34 no. 4 2009 (pp. 551-562).
6. K. Farion, W. Michalowski, Sz. Wilk, D. O'Sullivan, S. Rubin, D. Weiss "Clinical Decision Support System for Point of Care Use: Ontology Driven Design and Software Implementation", *Methods of Information in Medicine*, vol. 48 no. 4 2009 (pp. 17-36).
7. M. Hine, K. Farion, W. Michalowski, Sz. Wilk "Decision Making by Emergency Room Physicians and Residents: Implications for the Design of Clinical Decision Support Systems", *International Journal of Healthcare Information Systems and Informatics*, vol. 4 no. 2, 2009 (pp. 17-36).
8. J. Sayyad-Shirabad, Sz. Wilk, W. Michalowski, K. Farion "MET3: An Integrative Open Source Based Multiagent Clinical Decision Support System" in K. Vanhoof *et al*. (Eds) *Intelligent Decision Making Systems: Proceedings of the 4th International ISKE Conference*. World Scientific Proceedings Series on Computer Engineering and Information Science, Hasselt, 2009 (pp. 319-326).
9. K. Farion, W. Michalowski, S. Rubin, Sz. Wilk, R. Correll, I. Gaboury "Prospective Evaluation of the MET-AP System Providing Triage Plans for Acute Pediatric Abdominal Pain", *International Journal of Medical Informatics*, vol. 77 no. 3, 2008 (pp. 208-218).
10. Sz. Wilk, W. Michalowski, D. O'Sullivan, K. Farion, S. Matwin "Engineering of a Clinical Decision Support Framework for the Point of Care Use", *Proceedings of the AMIA 2008 Biomedical and Health Informatics*, American Medical Informatics Association, 2008 (CD ROM).
11. C. Kuziemsky, D. O'Sullivan, W. Michalowski, Sz. Wilk, K. Farion "A Constraint Satisfaction Approach to Data-driven Implementation of Clinical Practice Guidelines", *Proceedings of the AMIA 2008 Biomedical and Health Informatics*, American Medical Informatics Association, 2008 (CD ROM).
12. W. Michalowski, Sz. Wilk, A. Thijssen, M. Li "Using a Bayesian Belief Network Model to Categorize Length of Stay for Radical Prostatectomy Patients", *Health Care Management Science*, vol. 9 no. 4 2006 (pp. 341-348).

CDSS research @ uOttawa

www.mobiledss.uottawa.ca