Clinical Decision Support Systems
HINF 1100

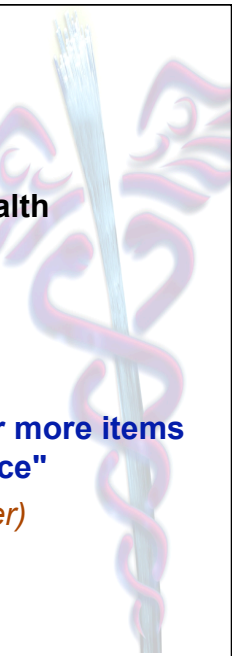
Clinical Decision Support Systems

"Any computer program designed to help health professionals make clinical decisions"

(Shortliffe)

"Active knowledge systems which use two or more items of patient data to generate case-specific advice"

(Wyatt & Spiegelhalter)



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CDSS Objectives

- **Improved patient safety**
- **Improved quality of care**
- **Improved efficiency in healthcare**

- **HOW …**
  - Knowledge-based problem-solving and decision making
  - Making better use of patient data
  - Supporting all tiers of a healthcare system

CDSS Functionalities

- **Medical Decision Support**
  - Diagnosis
    - Reasoning medical knowledge
  - Test selection
    - Decision analysis, checking appropriateness criteria
  - Treatment choice
    - Decision analysis to check risks
  - Prognosis
    - Quality of life assessment

- **Therapy Critiquing and Planning**
  - Checking inconsistencies, errors and omissions (applied to CPOE)
  - Using clinical pathways to plan the patient's treatment journey

CDSS Functionalities

- **Answering questions/Education**
  - Personal guidance
  - Access to best-evidence
- **Monitoring actions**
  - Background detection of events
  - Alerts & Reminders
- **Optimizing clinical workflow**
  - Scheduling
  - Resource identification
  - Communication methods

CDSS Successes

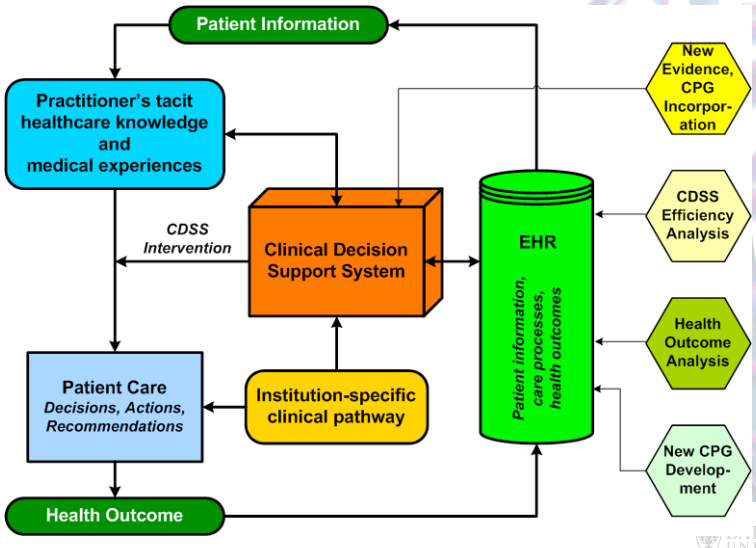
- **CDSS impacts**
  - **Guideline adherence**
  - **Best-evidence access**
  - **Patient surveillance**
  - **Medication errors**
  - **Patient safety**
  - **Resource utilization**
  - **CPOE use**
    - **Guidance at the point of ordering can help physicians order appropriate tests**

Source: Chaudhry et al., 2006; Bates et al., 2003; Austin et al., 1994; Linder, Bates and Lee, 2005; Tierney et al., 2003; Bates and Gawande, 2003; Bates, 2004; McDonald et al., 2004

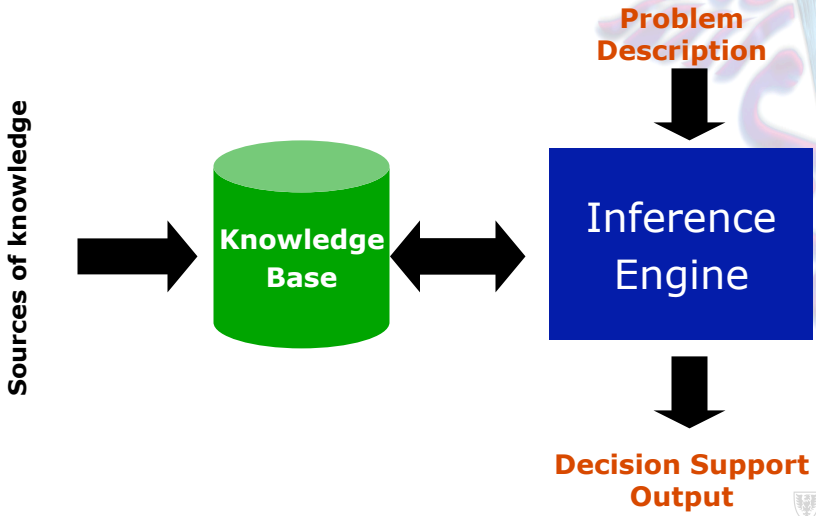
CDSS Components

- **Decision Model**
  - Model of the disease
  - Algorithms to process the knowledge to derive decisions
- **Knowledge Base**
  - Domain knowledge
  - Diagnostic and treatment constraints
- **Information Model**
  - Data elements needed for making decisions
    - Patient record
- **Result Specification**
  - Representation of the output, actions, etc
- **Application Environment**
  - Interface with other systems and users

CDSS Interactions



CDSS Architecture



Symbolic Knowledge

- **Diagnosis of Breast Cancer**

IF Bare nuclei <= 2.0 AND Clump thickness <= 7.0 AND Normal nuclei <= 3.0
AND Uniformity of cell size <= 3.0
THEN Benign

IF Bare nuclei <= 2.0 AND Bland chromatin <= 4.0 AND Clump thickness <= 7.0
AND Uniformity of cell size <= 3.0
THEN Benign

IF Bare nuclei >= 8.0 AND Clump thickness <= 7.0 AND Normal nuclei <= 3.0
AND Uniformity of cell size <= 3.0
THEN Malignant

IF Bare nuclei >= 8.0 AND Clump thickness <= 7.0 AND Normal nuclei <= 3.0
AND Uniformity of cell size <= 3.0
THEN Malignant

Sub-Symbolic Knowledge

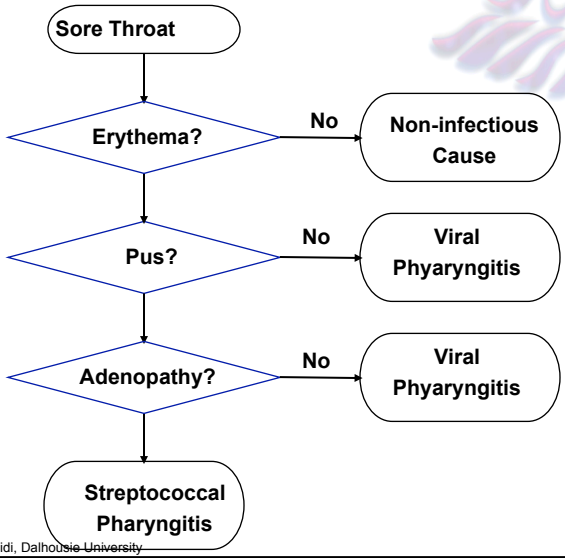
- breast cancer.data

704097, 1, 1, 1, 1, 1, 1, 2, 1, 1, benign.
1320077, 1, 1, 1, 1, 1, 1, 1, 1, 1, benign.
1223003, 5, 3, 3, 1, 2, 1, 2, 1, 1, benign.
640712, 1, 1, 1, 1, 2, 1, 2, 1, 1, benign.
1345452, 1, 1, 3, 1, 2, 1, 2, 1, 1, benign.
1206089, 2, 1, 1, 1, 1, 1, 3, 1, 1, benign.
1056784, 3, 1, 1, 1, 2, 1, 2, 1, 1, benign.
1167439, 2, 3, 4, 4, 2, 5, 2, 5, 1, malignant.
320675, 3, 3, 5, 2, 3, 10, 7, 1, 1, malignant.
1206841, 10, 5, 6, 10, 6, 10, 7, 7, 10, malignant.
1166654, 10, 3, 5, 1, 10, 5, 3, 10, 2, malignant.
1100524, 6, 10, 10, 2, 8, 10, 7, 3, 3, malignant.
1253955, 8, 7, 4, 4, 5, 3, 5, 10, 1, malignant.
1344121, 8, 10, 4, 4, 8, 10, 8, 2, 1, malignant.
760239, 10, 4, 6, 4, 5, 10, 7, 1, 1, malignant.
1257470, 10, 6, 5, 8, 5, 10, 8, 6, 1, malignant.

Decision Rules

- **Decision Rules is a representation of knowledge**
  - Encapsulates logic and flow of logic
  - IF-THEN statements
    - Mapping of a condition to a conclusion
- **Decision Rules are represented in two formats**
  - Procedures
  - Production rules

Decision Rule -->Procedural Knowledge Decision Tree



Decision Rules: Production Rules

- **Action rules**
  - IF *<condition>* THEN *<action>*
  - Condition represents a logical statement
    - Satisfaction of the condition leads to the action
  - Systolic BP > 120
  - (Systolic BP > 120) AND (Pulse > 80)
- **Production rules are kept in a knowledge base**
  - IF NOT(erythema AND pus AND adenopathy)
    THEN Diagnosis = "non-infectious cause"
  - IF erythema AND NOT(pus AND adenopathy)
    THEN Diagnosis = "viral pharyngitis"
  - IF erythema AND pus AND NOT(adenopathy)
    THEN Diagnosis = "viral pharyngitis"
  - IF erythema AND pus AND adenopathy
    THEN Diagnosis = "streptococcal pharyngitis"
- **Inferencing is used to derive conclusions**

Logical Expressions

- Comprise a number of logical variables that can have a value TRUE or FALSE.
- Each logical variable denotes some concept.
  - Logical expressions for arrhytmia diagnosis

E1	All RR intervals are regular
E2	All QRS complexes are identical
E3	QRS durations are longer than 120 msec
E4	Heart rate is higher than 100 beats/min
E5	P waves are present
E6	Heart rate is lower than 40 beats/min
E7	Negative P in II and positive P in aVR
E8	No. of P waves/No. of QRS complexes <= 1.1
E9	No. of P waves/No. of QRS complexes > 1.1
E10	PR interval regular

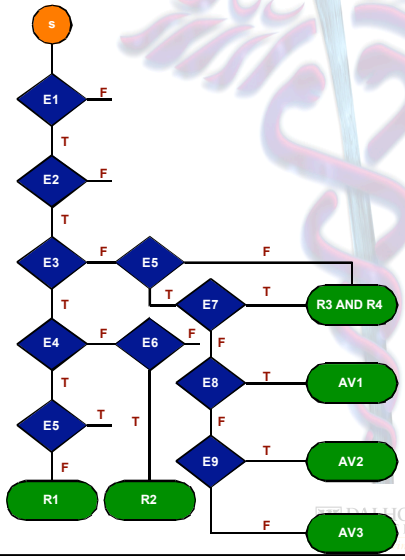
Logical Expressions—TRUTH TABLE

- Logical expressions for arrhytmia diagnosis

Rule	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Diagnosis
1	T	T	T	T	F	--	--	--	--	--	Ventricular tachycardia
2	T	T	T	F	--	T	--	--	--	--	Idioventricular rhythm
3	T	T	F	--	F	--	--	--	--	--	Nodal rhythm
4	T	T	F	--	T	--	T	--	--	--	Nodal rhythm
5	T	T	F	--	T	--	F	T	--	--	First degree AV block
6	T	T	F	--	T	--	F	T	--	F	Wandering pacemaker
7	T	T	F	--	T	--	F	F	T	--	Second degree AV block
8	T	T	F	--	T	--	F	F	F	--	Third degree AV block
9	T	T	--	--	T	F	F	T	F	T	Sinus rhythm

Logical Expressions—FLOW CHART

- **Logical expressions for arrhytmia diagnosis**



Logical Expressions—RULES

- **Logical expressions for arrhytmia diagnosis**

IF {E1, E2, E3, E4, E5'} THEN Ventricular tachycardia

IF {E1, E2, E3, E4', E6} THEN Idioventricular rhythm

IF {E1, E2, E3', E5'} THEN Nodal Rhythm

IF {E1, E2, E3', E5, E7} THEN Nodal Rhythm

IF {E1, E2, E3', (E5' + E5, E7)} THEN Nodal Rhythm

Rule-Based Decision Support Systems

- **A knowledge processing Inference Engine 'infers' solutions from the given knowledge**
  - Derives new information based on given information.
  - Derives conclusions based on new and given information.
    - Given the following facts A, B, C, D
      - If A and B → X
      - If C and X → Y
      - If D and Y → Z (conclusion)
  - Inference is based on a Reasoning Strategy.
    - Forward Chaining
    - Backward Chaining

Inference Mechanism: Forward Reasoning

- **From Data to Conclusion**
  - Initiate with a set of known facts (logical expressions)—i.e. *working knowledge*
  - Derive new facts using rules
    - Rules whose premises match the working knowledge are fired.
    - Conclusion of the fired rule is added to the working knowledge
  - Continue until a goal state is reached OR until no further rules have premises that match the working knowledge

Inference Mechanism: Forward Reasoning

- **Obtain problem information (i.e. working knowledge) and place it in the *working memory*.**
  - Patient parameters passed directly from EMR
  - Physicians observations
- **Scan the rules (one by one), looking for one rule whose premise(s) match the working knowledge.**
- **If such a rule is found it is fired.**
  - Rule's conclusion is added the working memory.
  - Rule is tagged as being fired so it is not checked again.
- **Cycle to find more rules whose premise match the updated working knowledge**
  - Rules that previously were not fired may fire now.
- **Continue until**
  - No rules fire in consecutive cycles
  - No more rules left to fire
  - The desired goal is achieved.

Forward Reasoning: Diagnosing Throat Infection

- **Rules**

RULE 1

IF	The patient has a sore throat
AND	We suspect a bacterial infection
THEN	We believe the patient has a throat infection

RULE 2

IF	The patient has temperature > 100
THEN	The patient has fever

RULE 3

IF	The patient has been sick for over a month
AND	The patient has a fever
THEN	We suspect bacterial infection

- **Working Knowledge**
  - Patient's temperature = 102
  - Patient has been sick for two months
  - Patient has a sore throat

Forward Reasoning: Diagnosing Throat Infection

- **Cycle 1**

Not Fire
RULE 1
P1: The patient has a sore throat T
P2: We suspect a bacterial infection F
C: We believe the patient has a throat infection

Fire
RULE 2
P1: The patient has temperature > 100 T
C: The patient has fever

Fire
RULE 3
P1: The patient has been sick for over a month T
P2: The patient has a fever T
C: We suspect bacterial infection

Working Memory

- Patient's temperature = 102
- Patient has been sick for two months
- Patient has a sore throat

- Patient's temperature = 102
- Patient has been sick for two months
- Patient has a sore throat
- The patient has fever

- Patient's temperature = 102
- Patient has been sick for two month
- Patient has a sore throat
- The patient has fever
- We suspect bacterial infection

Forward Reasoning: Diagnosing Throat Infection

- **Cycle 2**

RULE 1
P1: The patient has a sore throat T
P2: We suspect a bacterial infection T
C: We believe the patient has a throat infection

Fire
RULE 2
P1: The patient has temperature > 100
C: The patient has fever

Fire
RULE 3
P1: The patient has been sick for over a month
P2: The patient has a fever
C: We suspect bacterial infection

Working Memory

- Patient's temperature = 102
- Patient has been sick for two months
- Patient has a sore throat
- The patient has fever
- We suspect bacterial infection

- Patient's temperature = 102
- Patient has been sick for two months
- Patient has a sore throat
- The patient has fever
- We suspect bacterial infection
- We believe that patient has throat infection

Forward Reasoning: Diagnosing Throat Infection

- **Cycle 3**

RULE 1 (Fire)
P1: The patient has a sore throat
P2: We suspect a bacterial infection
C: We believe the patient has a throat infection

RULE 2 (Fire)
P1: The patient has temperature > 100
C: The patient has fever

RULE 3 (Fire)
P1: The patient has been sick for over a month
P2: The patient has a fever
C: We suspect bacterial infection

Working Memory

- Patient's temperature = 102
- Patient has been sick for two months
- Patient has a sore throat
- The patient has fever
- We suspect bacterial infection
- We believe that patient has throat infection

Conclusion

Stop as no more rules left

Inference Mechanism: Backward Reasoning

- **From Hypothesis/Goal to Data**
  - Initiate with rule(s) whose conclusion is the hypothesis/goal that needs to be checked.
    - Attempt to prove the premise of the rule given the *working knowledge*.
    - The rule will only fire if its premise is true.

    IF Patient has a sore throat **AND** Patient has bacterial infection
    THEN Patient has a throat infection

  - Prove the individual premises of the rule. If all premises are TRUE then the hypothesis/goal is also TRUE.
    - Each premise of the rule is turned as a sub-goal to be proven.
    - Search the rules in a recursive manner to acquire evidence for proving the sub-goals and the goal.
  - If a premise is not supported by any of the given rules it is a *Primitive*
    - Ask the user to confirm the *primitive*.
    - The user's answers are placed in the working memory.
  - Continue until
    - All sub-goals are proven
    - All goals are proven (or cannot be proven.

Backward Reasoning: Confirming a Diagnosis

- **Rules**

RULE 1

IF	There are signs of throat infection
AND	There is evidence that the organism is streptococcus
THEN	Patient has strep throat

RULE 2

IF	The patient's throat is red
THEN	There are signs of throat infection

RULE 3

IF	The morphology of the organism is grampos
THEN	There is evidence that the organism is streptococcus

- **Hypothesis/Goal**
  - Patient has strep throat

Backward Reasoning: Confirming a Diagnosis

- **Goal: Patient has strep throat**

Working Memory

Step 1

- Find rule that has goal in the conclusion part

  Rule 1 found

IF	There are signs of throat infection
AND	There is evidence that the organism is streptococcus
THEN	Patient has strep throat

- Is premises of rule 1 true

  NO

Step 2

- Prove premise 1 of Rule 1 (sub-goal1)
- Find rule that has sub-goal1 in the conclusion part

  Rule 2 found

IF	The patient's throat is red
THEN	There are signs of throat infection

- Is premises of rule 2 true

  NO

Backward Reasoning: Confirming a Diagnosis

- Goal: Patient has strep throat

Working Memory

Step 3
- Prove premise 1 of Rule 2 (sub-goal2)
- Find rule that has sub-goal2 in the conclusion part
  - No rule found
- Premise 1 of Rule 2 is a primitive (ask the doctor)
- System: Is the patient throat red
- Doctor: YES

- Patient throat is red

Step 4
- The doctor's positive response proves that premise 1 of Rule 2 is TRUE (sub-goal2 has been proven true)
- Rule 2 fires
- Add conclusion to working memory
- Sub-goal 2 has been proven

- Patient throat is red
- There are signs of throat infection

Backward Reasoning: Confirming a Diagnosis

- Goal: Patient has strep throat

  Rule 1

  IF There are signs of throat infection
  AND There is evidence that the organism is streptococcus
  THEN Patient has strep throat

Working Memory
(sub-goal 1)
- Patient throat is red
- There are signs of throat infection

Step 5
- Prove premise 2 of Rule 1 (sub-goal3)
- Find rule that has sub-goal3 in the conclusion part
  - Rule 3 found

    IF The morphology of the organism is grampos
    THEN There is evidence that the organism is streptococcus
- Is premises of rule 3 true
  - NO

Backward Reasoning: Confirming a Diagnosis

- Goal: Patient has strep throat

  Rule 1

  IF There are signs of throat infection

  AND There is evidence that the organism is streptococcus (sub-goal 3)

  THEN Patient has strep throat

Working Memory

(sub-goal 1)

- Patient throat is red
- There are signs of throat infection

Step 6

- Prove premise 1 of Rule 3 (sub-goal4)
- Find rule that has sub-goal4 in the conclusion part
- No rule found, therefore Premise 1 of Rule 3 is a primitive (ask the doctor)
- System: Is the morphology of the organism = grampos
- Doctor: YES

Step 7

- Doctors response proves that premise 1 of Rule3 is TRUE (sub-goal4 has been proven)
- Proven
- Rule 3 fires
- Add conclusion to working memory

- Patient throat is red
- There are signs of throat infection
- The morphology of the organism is grampos

- Patient throat is red
- There are signs of throat infection
- The morphology of the organism is grampos
- There is evidence that the organism is streptococcus

Backward Reasoning: Confirming a Diagnosis

- Goal: Patient has strep throat

  Rule 1

  IF There are signs of throat infection

  AND There is evidence that the organism is streptococcus (sub-goal 3)

  THEN Patient has strep throat

Working Memory

- Patient throat is red
- There are signs of throat infection
- The morphology of the organism is grampos
- There is evidence that the organism is streptococcus

Backward Reasoning: Confirming a Diagnosis

Working Memory

Step 8
- Prove premise 1 of Rule 1 (sub-goal1)
- Is premise in working memory?
  YES
- Sub-goal 1 has been proven

Step 9
- Prove premise 2 of Rule 1 (sub-goal3)
- Is premise in working memory?
  YES
- Sub-goal 3 has been proven

Step 10
- Rule 1 has been proven—it fires
- Add conclusion to working memory

- Patient throat is red
- There are signs of throat infection
- The morphology of the organism is grampos
- There is evidence that the organism is streptococcus
- Patient has strep throat

Handling Uncertainity

- Rules are not perfect! There is a degree of uncertainity.
- The conclusion of a rule is associated with a confidence factor.

  IF There are signs of throat infection AND
  There is evidence that the organism is streptococcus
  THEN Patient has strep throat (CF = 0.85)

- The premises of a rule can also be associated with a confidence factor.

  IF There are signs of throat infection (CF = 0.75) AND
  There is evidence that the organism is streptococcus (CF = 0.90)
  THEN Patient has strep throat (CF = 0.85)

- The final confidence of the conclusion is determined by various methods.

Handling Uncertainity: Combining CF

- **CF's associated with each condition of the premise are combined to produce the certainty factor for the overall premise.**
  - CF(P1 and P2) = MIN{CF(P1), CF(P2)}
  - CF(P1 or P2) = MAX{CF(P1), CF(P2)}
- **The CF for the conclusion of the rule is obtained by multiplying the combined CF of the premise with the CF of the conclusion.**

Handling Uncertainity: Combining CF

Rule is (P1 AND P2) OR P3 → R1 and R2

CF(P1) = 0.6 **CF(P2) = 0.4** **CF(P3) =0.5** **CF(R1) = 0.7** **CF(R1) = 0.3**

STEP 1: Calculate combined CF of premise

CF{P1(0.6) AND P2(0.4)} = MIN (0.6, 0.4) = 0.4
CF{0.4 OR P3(0.5)} = MAX (0.4, 0.5) = 0.5

So ..

CF for the combined premise is 0.5

STEP 2: Calculate CF of each conclusion statement

CF(R1) = CF for R1 * CF for the combined premise
CF(R1) = 0.7 * 0.5 = 0.35

CF(R2) = CF for R2 * CF for the combined premise
CF(R2) = 0.3 * 0.5 = 0.15

So …

R1 is added to the working memory with the CF of 0.35
R2 is added to the working memory with the CF of 0.15

Representing Rules for Expert Systems

RULE 1

IF The patient has a sore throat CF = 0.59
AND We suspect a bacterial infection CF = 0.75
THEN We believe the patient has a throat infection CF = 0.48

RULE 2

IF The patient has temperature > 100 CF = 0.75
THEN The patient has fever CF = 0.79

RULE 3

IF The patient has been sick for over a month CF = 0.80
AND The patient has a fever CF = 0. 90
THEN We suspect bacterial infection CF = 0.60

THE END