Decision Support via Expert Systems

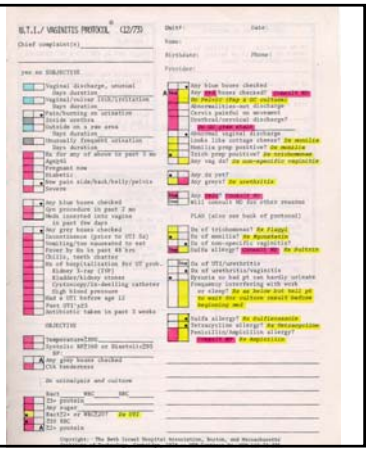
6.872/HST950
April 1, 2004

Components of an Expert System

- Knowledge
  - In various forms: associations, models, etc.
- Strategy
  - Baconian, exhaustive enumeration, on-line, etc.
- Implementation
  - Programs, pattern matching, rules, etc.

Flowchart

BI/Lincoln Labs
Clinical Protocols
1978



Codifying Human Knowledge

- Decomposition into "chunks" of knowledge, chaining of inferences
- Matching of case data to prototypical situations
- Using causal models (pathophysiology) to figure out cases

Mycin—Rule-based Systems

- **Task: Diagnosis and prescription for bacterial infections of the blood (and later meningitis)**
- **Method:**
  - **Collection of modular rules**
  - **Backward chaining**
  - **Certainty factors**

RULE037

IF the organism
1) stains grampos
2) has coccus shape
3) grows in chains

THEN
There is suggestive evidence (.7) that the identity of the organism is streptococcus.

Mycin consult

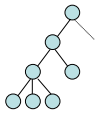
--------PATIENT-1--------
1) Patient's name: **FRED SMITH**
2) Sex: **MALE**
3) Age: **55**
4) Have you been able to obtain positive cultures from a site at which Fred Smith has an infection? **YES**
--------INFECTION-1--------
5) What is the infection? **PRIMARY-BACTEREMIA**
6) Please give the date when signs of INFECTION-1 appeared. **5/5/75**
The most recent positive culture associated with the primary-bacteremia will be referred to as:
--------CULTURE-1--------
7) From what site was the specimen for CULTURE-1 taken? **BLOOD**
8) Please give the date when this culture was obtained. **5/9/75**
The first significant organism from this blood culture will be called:
--------ORGANISM-1--------
9) Enter the identity of ORGANISM-1. **UNKNOWN**
10) Is ORGANISM-1 a rod or coccus (etc.)? **ROD**
11) The gram stain of ORGANISM-1: **GRAMNEG**
. . .

Davis, *et al.*, *Artificial Intelligence* **8**: 15-45 (1977)

How Mycin Works

- To find out a fact
  - If there are rules that can conclude it, try them
  - Ask the user
- To "run" a rule
  - Try to find out if the facts in the premises are true
  - If they all are, then assert the conclusion(s), with a suitable certainty
- Backward chaining from goal to given facts

- *Dynamically traces out behavior of (what might be) a flowchart*
  - *Information used everywhere appropriate*
  - *Single expression of any piece of knowledge*



Explore Mycin's Use of Knowledge

**** Did you use RULE 163 to find out anything about ORGANISM-1?**

RULE163 was tried in the context of ORGANISM-1, but it failed because it is not true that the patient has had a genito-urinary tract manipulative procedure (clause 3).

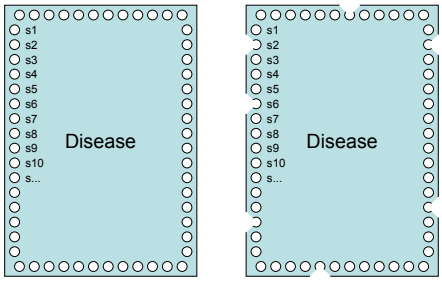
**** Why didn't you consider streptococcus as a possibility?**

The following rule could have been used to determine that the identity of ORGANISM-1 was streptococcus: RULE033

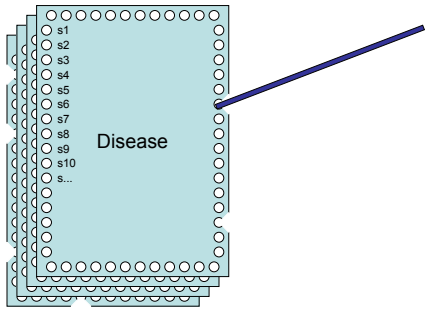
But clause 2 ("the morphology of the organism is coccus") was already known to be false for ORGANISM-1, so the rule was never tried.

Davis, *et al.*, *Artificial Intelligence* **8**: 15-45 (1977)

Even Simpler Representation



Diagnosis by Card Selection

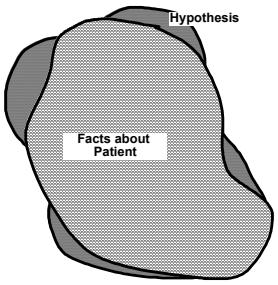


Diagnosis by Edge-Punched Cards

- Dx is intersection of sets of diseases that *may cause* all the observed symptoms
- Difficulties:
  - Uncertainty
  - Multiple diseases

~ "Problem-Knowledge Coupler" of Weed

Taking the Present Illness—Diagnosis by Pattern Directed Matching

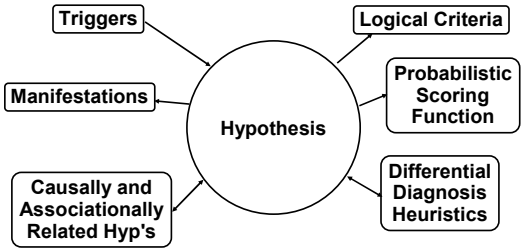


PIP's Theory of Diagnosis

- From initial complaints, *guess* suitable hypothesis.
- Use current active hypotheses to guide questioning
- Failure to satisfy expectations is the strongest clue to a better hypothesis; *differential diagnosis*
- Hypotheses are *activated, de-activated, confirmed* or *rejected* based on
  (1) logical criteria
  (2) probabilities based on:
  findings local to hypothesis
  causal relations to other hypotheses

The Scientific Method

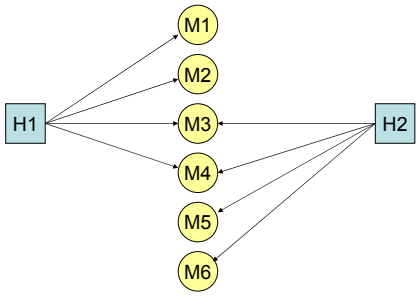
Memory Structure in PIP



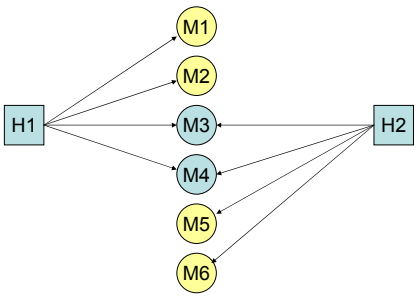
PIP's Model of Nephrotic Syndrome

NEPHROTIC SYNDROME, ***a clinical state***
FINDINGS:
1* Low serum albumin concentration
2. Heavy proteinuria
3* >5 gm/day proteinuria
4* Massive symmetrical edema
5* Facial or peri-orbital symmetric edema
6. High serum cholesterol
7. Urine lipids present
IS-SUFFICIENT: Massive pedal edema & >5 gm/day proteinuria
MUST-NOT-HAVE: Proteinuria absent
SCORING . . .
MAY-BE-CAUSED-BY: AGN, CGN, nephrotoxic drugs, insect bite, idiopathic nephrotic syndrome, lupus, diabetes mellitus
MAY-BE-COMPLICATED-BY: hypovolemia, cellulitis
MAY-BE-CAUSE-OF: sodium retention
DIFFERENTIAL DIAGNOSIS:
neck veins elevated → constrictive pericarditis
ascites present → cirrhosis
pulmonary emboli present → renal vein thrombosis

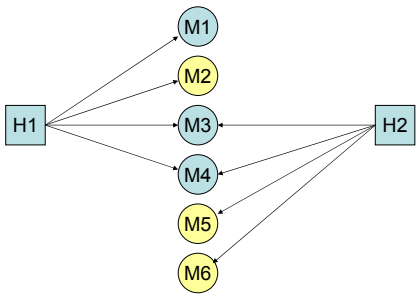
QMR Partitioning



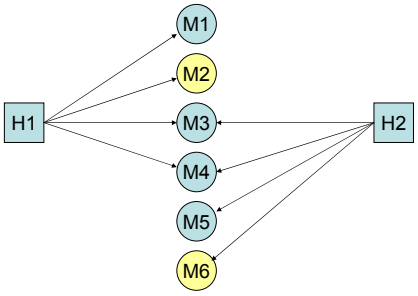
Competitors



Still Competitors



Probably Complementary



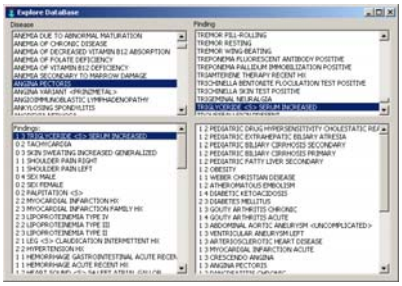
Multi-Hypothesis Diagnosis

- Set aside complementary hypotheses
- … and manifestations predicted by them
- Solve diagnostic problem among competitors
- Eliminate confirmed hypotheses and manifestations explained by them
- Repeat as long as there are coherent problems among the remaining data

Internist/QMR

- Knowledge Base:
  - 956 hypotheses
  - 4090 manifestations (about 75/hypothesis)
  - *Evocation* like P(H|M)
  - *Frequency* like P(M|H)
  - *Importance* of each M
  - *Causal relations* between H's
- Diagnostic Strategy:
  - Scoring function
  - Partitioning
  - Several questioning strategies

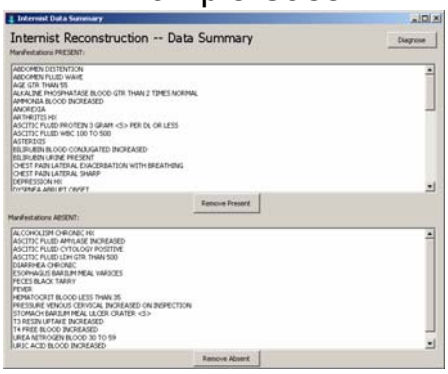
QMR Database



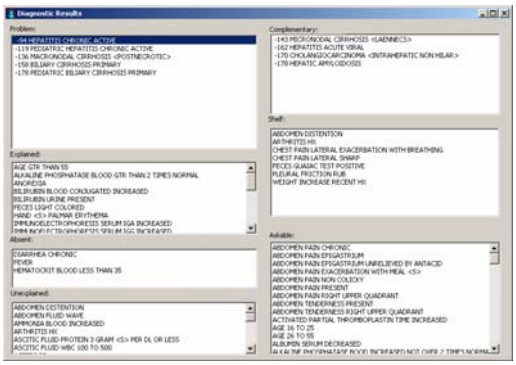
QMR Scoring

- Positive Factors
  - Evoking strength of observed Manifestations
  - Scaled Frequency of causal links from confirmed Hypotheses
- Negative Factors
  - Frequency of predicted but absent Manifestations
  - Importance of unexplained Manifestations
- Various scaling parameters (roughly exponential)

Example Case



Initial Solution



Symptom Clustering for Multi-Disorder Diagnosis

— Tom Wu, Ph.D. 1991

Assume a bipartite graph representation of diseases/symptoms

Given a set of symptoms, how to proceed?

If we could "guess" an appropriate clustering of the symptoms so that each cluster has a single cause …

(s2, s3, s7) (s1) (s5, s9)

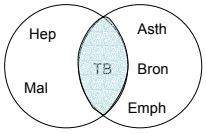
d5 d6 | d3 d7 d8 d9 | d1 d2 d4

d1 → s1
d2 → s2
… → s3
dk → …
sn

… then the solution is (d5, d6) x (d3, d7, d8, d9) x (d1, d2, d4)

Clustering Alternatives

Symptom	Possible Causes
Fever	TB, Hepatitis, Malaria
Cough	TB, Asthma, Bronchitis, Emphysema

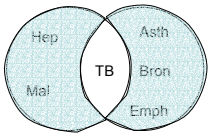


H1

Fever, Cough
TB

H2

Fever	Cough
Hep Mal	Asth Bron Emph



Synopsis in Renal Disease

- Diseases
  - Hypertension (HTN)
  - Acute glomerulonephritis (AGN)
  - IgA nephropathy (IgA)
  - Prerenal azotemia (PRA)
  - Hepatorenal syndrome (HRS)
  - Renal vasculitis (RV)
  - Congestive heart failure (CHF)
  - Aldosteronism (Aldo)
  - Constrictive pericarditis (Peri)
  - Diabetic ketoacidosis (DKA)
  - Analgesic nephropathy (AN)
  - Hypokalemic nephropathy (HKN)
  - Chronic renal failure (CRF)
  - Renal tubular acidosis (RTA)
- Symptoms
  - High urine osmolality (Osm↑)
  - High urine specific gravity (Sg↑)
  - Low urine sodium (Na↓)
  - Low urine pH (pH↓)

	HTN	AGN	IgA	PRA	HRS	RV	CHF	Aldo	Peri	DKA	AN	HKN	CRF	RTA
Osm↑	X	X	X	X	X	X								
Sg↑	X	X	X	X	X	X	X							
Na↓				X	X		X	X	X					
pH↓		X		X						X	X	X	X	X

After Osm↑

Osm↑
HTN
AGN
IgA
PRA
HRS
RV

	HTN	AGN	IgA	PRA	HRS	RV	CHF	Aldo	Peri	DKA	AN	HKN	CRF	RTA
Osm↑	X	X	X	X	X	X								
Sg↑	X	X	X	X	X	X	X							
Na↓				X	X		X	X	X					
pH↓		X		X						X	X	X	X	X

Add Sg↑

Osm↑, Sg↑
HTN
AGN
IgA
PRA
HRS
RV

Cover

	HTN	AGN	IgA	PRA	HRS	RV	CHF	Aldo	Peri	DKA	AN	HKN	CRF	RTA
Osm↑	X	X	X	X	X	X								
Sg↑	X	X	X	X	X	X	X							
Na↓				X	X		X	X	X					
pH↓		X		X						X	X	X	X	X

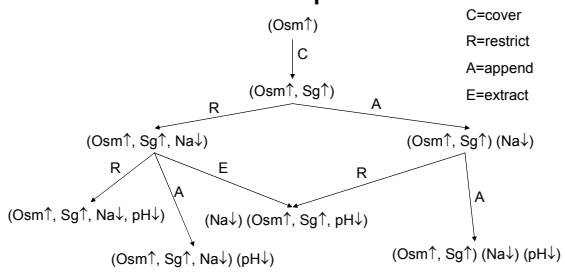
Add Na↓

Restrict *Append*

Osm↑, Sg↑, Na↓		Osm↑, Sg↑		Na↓
PRA	or	HTN		Aldo
HRS		AGN		CHF
		IgA		Peri
		RV		

	HTN	AGN	IgA	PRA	HRS	RV	CHF	Aldo	Peri	DKA	AN	HKN	CRF	RTA
Osm↑	X	X	X	X	X	X								
Sg↑	X	X	X	X	X	X	X							
Na↓				X	X		X	X	X					
pH↓		X		X						X	X	X	X	X

Search Space



	HTN	AGN	IgA	PRA	HRS	RV	CHF	Aldo	Peri	DKA	AN	HKN	CRF	RTA
Osm↑	X	X	X	X	X	X								
Sg↑	X	X	X	X	X	X	X							
Na↓				X	X		X	X	X					
pH↓		X		X						X	X	X	X	X

Symptom Clustering is Efficient

- **Like in any "planning island" approach, reducing an exponential problem to several smaller exponential problems vastly improves efficiency, *if it captures some insight into the problem.***
- **Wu's algorithm (SYNOPSIS) will keep a compact encoding even if it overgenerates slightly.**
  - **E.g., suppose that of the set of diseases represented by (d5, d6) x (d3, d7, d8, d9) x (d1, d2, d4), d6 x d8 x d1 is not a candidate. To represent this precisely would require enumerating the 23 valid candidates. Instead, the factored representation is kept.**

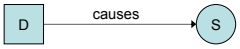
In a diagnostic problem drawn from a small subset of the Internist database, it is a *power of 3* faster and a *power of 5* more compact than standard symptom clustering.

Guide search via probabilities, if we have a reasonable model(!)

More Expert Systems

- Causality?
- What's in a Link?
- Temporal reasoning
- Quantitative reasoning
- Model-based reasoning
- Workflow

Meaning of Representation?

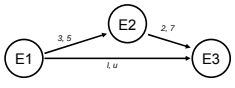


- Always? →probability
- Magnitude? →severity; bad cold → worse fever?
- Delay? →temporality
- Where? →spatial dependency
- Under what conditions? →context
- Interaction of multiple causes →physical laws
- Cross-terms →high-dimensional descriptions

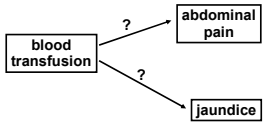
Temporal Reasoning

- **Keeping track of multiple forms of temporal relations (Kahn '75)**
  - **The time line**
    - **"On Dec. 12 last year . . ."**
  - **Special reference events**
    - **"Three days after I was hospitalized in 1965 . . ."**
  - **Temporal Ordering Chains**
    - **"It must have been before I graduated from high school."**
- **Constraint propagation (Kohane '87)**
  - **Primitive relation: *e*1, *e*2, *l*ower, *u*pper bounds**
  - **Heuristics for propagation based on semantic grouping**

$3 \le T(E2)-T(E1) \le 5$
$2 \le T(E3)-T(E2) \le 7$
Therefore
$l{=}5 \le T(E3)-T(E1) \le 12{=}u$

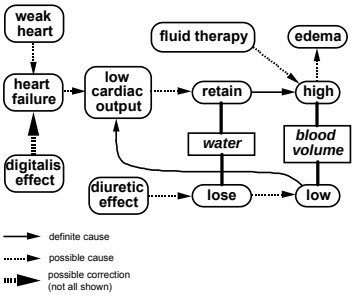


Exploiting Temporal Relations

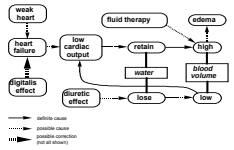


- transfusion precedes both abdominal pain and jaundice *implies* transfusion-borne acute hepatitis B
- as in 1, but only by one day
- jaundice occurred 20 years ago, transfusion and pain recent
- Can be very efficient at filtering out nonsense hypotheses.

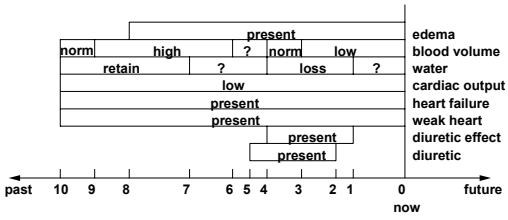
Interpreting the Past with a Causal/Temporal Model

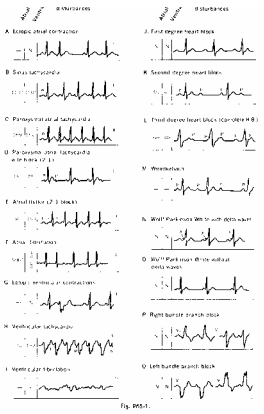


Postdiction



Long, Reasoning about State from Causation and Time in a Medical Domain, *AAAI 83*



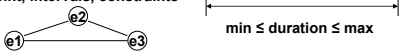


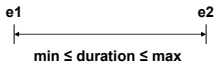
Temporal Representation can be Complex

Time

The usual:

- **point, intervals, constraints**

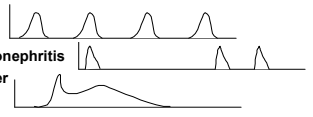




- **timelines, reference events, fuzz, …**

The unusual

- **cyclic edema**
- **focal glomerulonephritis**
- **patterns of fever**



Systems issues

- **flow of "now"**
- **supporting the illusion of "instantaneous" decision-making within a temporal reasoner**
  - **correcting the past**
  - **reasoning by hindsight**

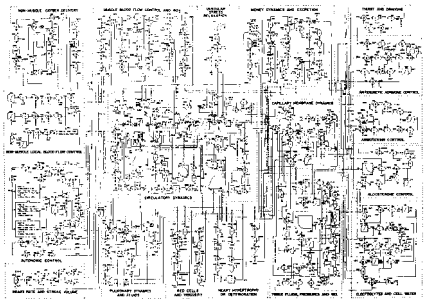
The Surprisingly Normal pH

- Diarrhea causes bicarbonate (alkali) loss
- Vomiting causes acid loss
- Therefore, normal pH is a manifestation of {diarrhea + vomiting}!

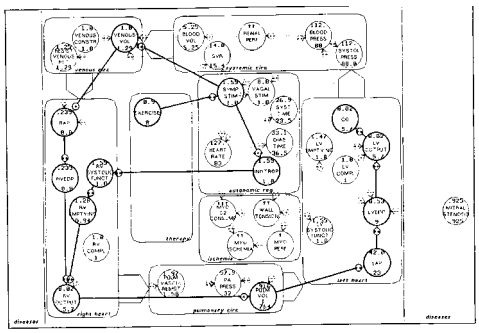
Reasoning from Models

- Model handles all possible interactions, without having explicitly to anticipate them all
- Reasoning: Fit parameters to a physiological model, then predict consequences to suggest
  - other expected findings
  - reasonable interventions
- Qualitative models
- Combining associational and model-based reasoning

Guyton's Model of Cardiovascular Dynamics



Long's Clinical Model of Heart Failure Predictions for Mitral Stenosis with Exercise



Physiological Knowledge

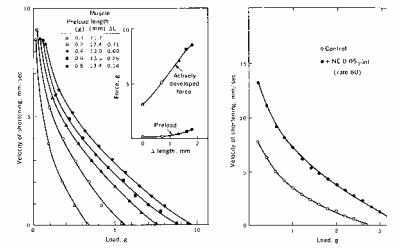
"All variations in myocardial contractile activity can be expressed as displacements of the force-velocity curve. However, there are two fundamental ways in which the force-velocity curve can be shifted. Figure {left} shows a family of force-velocity curves obtained from an isolated cardiac muscle; each curve was obtained at a different preload, i.e., with a different degree of stretch on the muscle. Note that changing the preload has altered the intercept of the force-velocity curve on the horizontal axis; i.e., it has increased the isometric force developed by the muscle. However, these alterations in preload have not altered the intrinsic velocity of shortening, since all the curves extrapolate to the same intercept on the vertical axis. Thus, a change in initial length of heart muscle shifts the force-velocity curve by altering the total force which can be developed by the muscle.

This type of shift in the force-velocity curve may be contrasted with that obtained when a positive inotropic agent, such as norepinephrine or digitalis, is added to the muscle while the initial length is held constant (Fig. {right}). These agents not only increase the force which the muscle is capable of lifting, i.e., the intercept of the force-veolocity curve on the horizontal axis, but also increase the velocity of shortening of the unloaded muscle, i.e., the extrapolated intercept on the vertical axis."

— Harrison's (6th ed.)

Figures comparing force-velocity curves

Normal cat-muscle **Inotropic Agent**



Clinical Knowledge

"… from the clinical point of view, heart failure may be considered to be a disease state in which an abnormality of myocardial function is responsible for the inability of the heart to pump blood at a rate commensurate with the requirements of the metabolizing tissues. Though a defect in myocardial contraction always exists in heart failure, this disorder may result from a *primary abnormality* in the heart muscle or it may be secondary to a *chronic excessive work load*. It is important to distinguish heart failure from (1) states of *circulatory insufficiency* in which myocardial function is not primarily impaired, such as cardiac tamponade, hemorrhagic shock, or tricuspid stenosis, (2) conditions in which there is *circulatory congestion* because of abnormal salt and water retention but in which there is no serious disturbance of myocardial function, and (3) conditions in which the normal heart is suddenly presented with a load which *exceeds its capacity*, e.g., accelerated hypertension."