Building from Cognitive Data: A Model of Visual Diagnostic Expertise in Pathology in Service of an Intelligent Tutoring System

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Overview

- Background
- Cognitive analysis of expertise in Pathology
- Design/development of an Intelligent Tutor in Pathology

Background

- Great expectations of Computer-Assisted Instruction (CAI) – not just in Medicine – have not been met.
- Cognitive science, AI, and education researchers developing Intelligent Tutoring Systems in other domains.
- Evaluation results of these systems are promising.
- Few systems of this kind have been developed in medical domains.

Why An Intelligent Tutor in Diagnostic Pathology?

- A difficult task to learn, residents start as complete novices.
- Many rare patterns must be learned.
- Limited exposure to parts of the domain.
- Necessary technology becoming available – digital archives, whole-slide-imaging, “virtual microscopes”.

Intelligent tutors are different

- Opportunity to build factual knowledge AND learn how to APPLY that knowledge.
- Make implicit aspects explicit and visible.
- Highly interactive - give guidance as student works by identifying and prevent errors in the intermediate steps.
- Flexible and adaptive curriculum – sequence of problems dependent on student’s development.
- A virtual apprenticeship - “scaffolding”.

Cognitive data is necessary to build an intelligent tutor

- Every domain/task is different.
- Expert model
- Student model
- Interface

A Cognitive Analysis of Expertise in Diagnostic Pathology

Research Objectives

- Identify the cognitive processes that expert pathologist's use.
- Describe how novices and intermediates are different.
- Characterize the kinds of errors made by novice and intermediate subjects, and their frequencies.
- Use this information to develop a teaching system in this domain

Information-Processing

- Newell and Simon methodology
- Gain access to the cognitive processes by having subjects verbalize their thoughts as they perform a task (verbal protocols).
- Trace processes, aggregate and compare across level of expertise.
- Use protocols to identify errors.
- Verbalization doesn't alter performance, if you give the right kinds of instructions.

Cases & Subjects

- Standardized set of cases in breast pathology
- 10 Novices – 3rd year medical students
- 10 Intermediates – 2nd and 3rd year residents
- 10 Experts – Attending pathologists with >10 years experience

Data Collection

The data

- ~29 hours of digital video
- 117 coded verbal protocols containing 7079 coded verbal segments (~90% complete)

Coding the protocols

Subject 1 – VS/Case 1

Total time: 8:09
Time until final diagnosis suggested: 3:36

Holds slide up to light (0:22):
This is a great big biopsy of something.
It looks like it might be a prostate at this power.
And even looking…just holding the slide up to the light.
I'm seeing some rather scary looking blue areas.
Right out near the capsule.
I'm getting a very early warning about this slide.
Let's see what it looks like under the scope.

4X (2:13):
Starting out at low power.
Let's see. So we scan around a little bit.
It turns out that my…Huh.
It is the prostate.
The architecture was so distorted
that it took me a while of scanning around to be certain
that I was indeed looking at prostate.
What finally gave it away to me was that was within some of the ducts I'm seein
lamenated concretions that are typical of prostatic tissue.

Transcribe verbatim

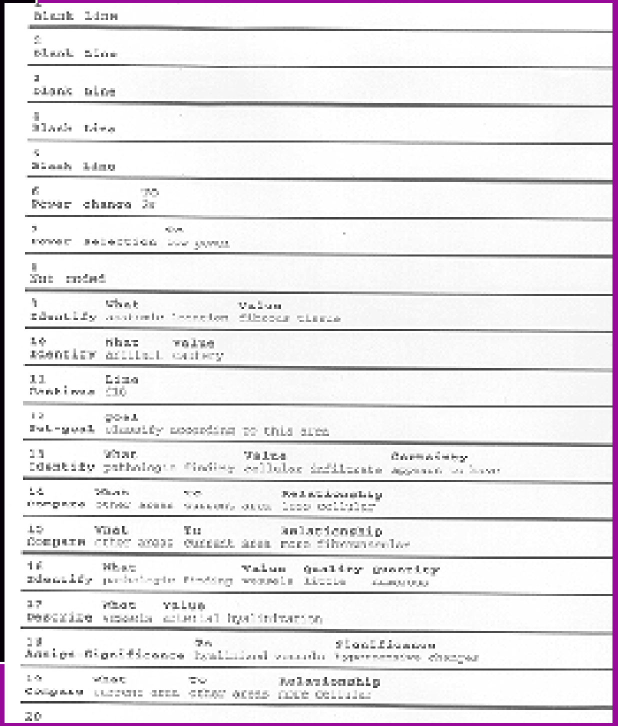
Data Examination:
Identify-anatomic-location
Identify-histologic-cue
Identify-historical-cue

Data-exploration and explanation:
Integrate-findings
Note-absent-findings

Data Interpretation:
Statement-of-hypothesis
Confirm-with-present-finding
Disconfirm-with-absent-finding
Reject-hypothesis
Search-discriminator

Control Processes:
Assess-barriers-to-progress
Evaluate-declarative-knowledge
Recall-diagnostic-categories

Develop coding scheme



Code protocols

An example protocol: An expert diagnosing DCIS

<u>Expert E7:</u>

3 Okay let's look at low power
4 I think the tissue is breast → *identify-anatomic-location*
5 I recognize some normal
6 Here is in situ carcinoma → *statement-of-hypothesis*
7 I have to find out if there is any invasion → *set-goal-identify*

An example protocol:
An intermediate diagnosing DCIS

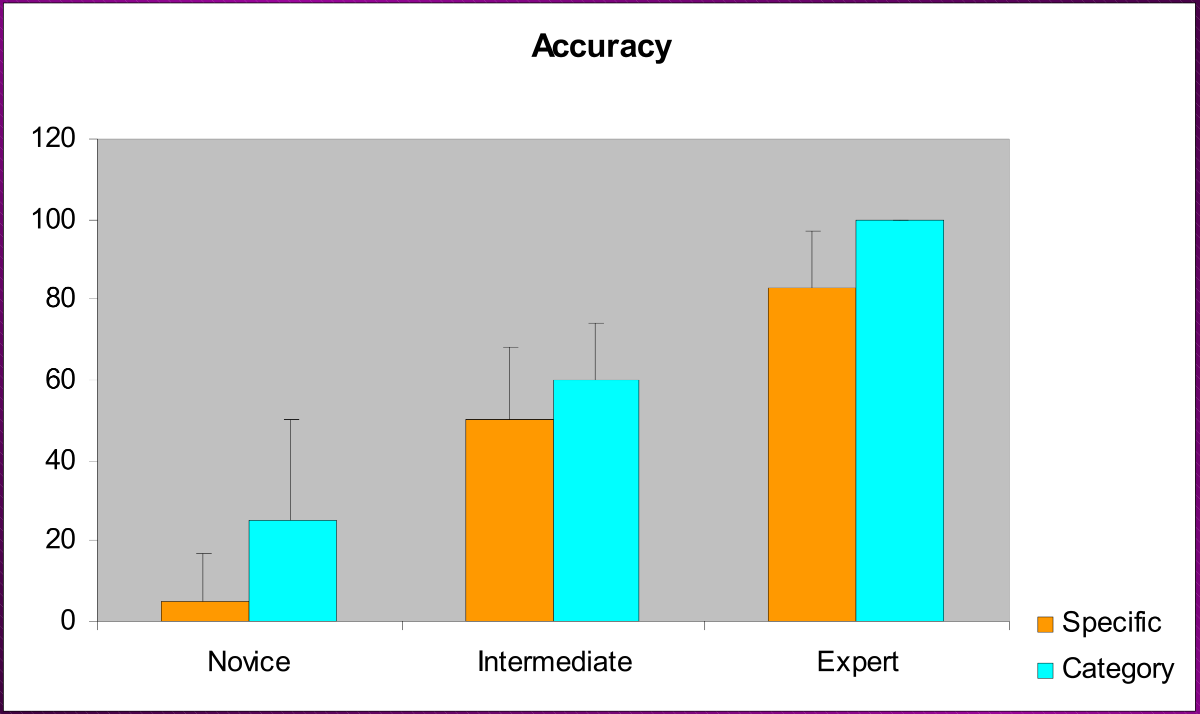
<u>Intermediate I5:</u>

20	and some of the ducts that are expanded with small cells	→ *identify-histologic-cue*
4	with focal, possibly central, area of necrosis.	→ *identify-histologic-cue*
5	So just scan this slide around and try to determine some focal areas that I want to concentrate and focus on.	
6	Now I'm looking at some of the ducts that are expanded.	
25	And some of these ducts, they also have holes,	→ *identify-histologic-cue*
26	and these are sort of punched-out holes,	→ *identify-histologic-cue*
27	very uniform, which…	→ *identify-histologic-cue*
29	So at this magnification, I think it is a DCIS.	→ *statement-of-hypothesis*

Processes & Themes

- Search, Identification, Interpretation
- Transition to accurate, and then automatic searching
- Evolution of visual efficiency
- Shift from explicit feature identification and inference to rapid implicit pattern matching
- Certainty about evidence lags accuracy about evidence
- Development of goal-structured search and discrimination

Overall accuracy



Identifying cognitive errors

With combined video and protocol analysis, it is often possible to trace an incorrect diagnosis to a very specific cognitive error:

- A case of LCIS misdiagnosed because the anatomic structure itself was misclassified.
- A case of carcinoma where the correct diagnosis was made on an area of normal tissue.

Design and development of an Intelligent Tutoring System in Pathology

Building from cognitive data

This is a multi-step process requiring three different sets of skills.	Model these processes using a model-tracing approach.
Searching the slide is a difficult first step.	Include rules for searching and magnification use; connect the model to a virtual microscope.
Acquisition of skill often accompanied by uncertainty in classifying evidence.	Require the student to explicitly relate image features to diagnostic criteria. Give feedback.
Rapid pattern matching is preceded by explicit inference.	Make these explicit reasoning steps visible to the student, require that they argue for and support their Dx in a reasoning interface.

Model-tracing tutors

- One type of Intelligent Tutor
- Production-rule model of expert built in.
- System dynamically creates the student model.
- Every action in the interface mirrors an intermediate cognitive step.
- *Prevent mistakes* with immediate feedback – because each user action must match a fire-able sequence of rules or it is not allowed.
- Many different paths can be allowed.
- *Offers hints* by stepping ahead in the model.
- *Spot reasons for mistakes* and point them out to student – “Buggy rules”.
- Employ sequences that builds skills, and target the skills that have not been mastered for additional instruction.

A prototype model-tracing tutor in Pathology

- Production-rule expert model developed from the protocol analysis.
- Tutor Development Kit (TDK) – Lisp environment for ITS development.
- A test domain – Proliferative epithelial lesions of breast.
- Interface building on existing technologies for whole-slide capture and web-based display.
- Model makes inference from symbolic information that must be coded for each slide (no machine vision).

Future Work

- Complete protocol analysis – final data aggregation, statistical testing .
- Instantiate the tutor in a specific sub-domain of pathology – add to generic rule-set and build knowledge representation (WMEs).
- Connect the model to existing “virtual microscope” system .
- Develop knowledge-tracing and sequencing

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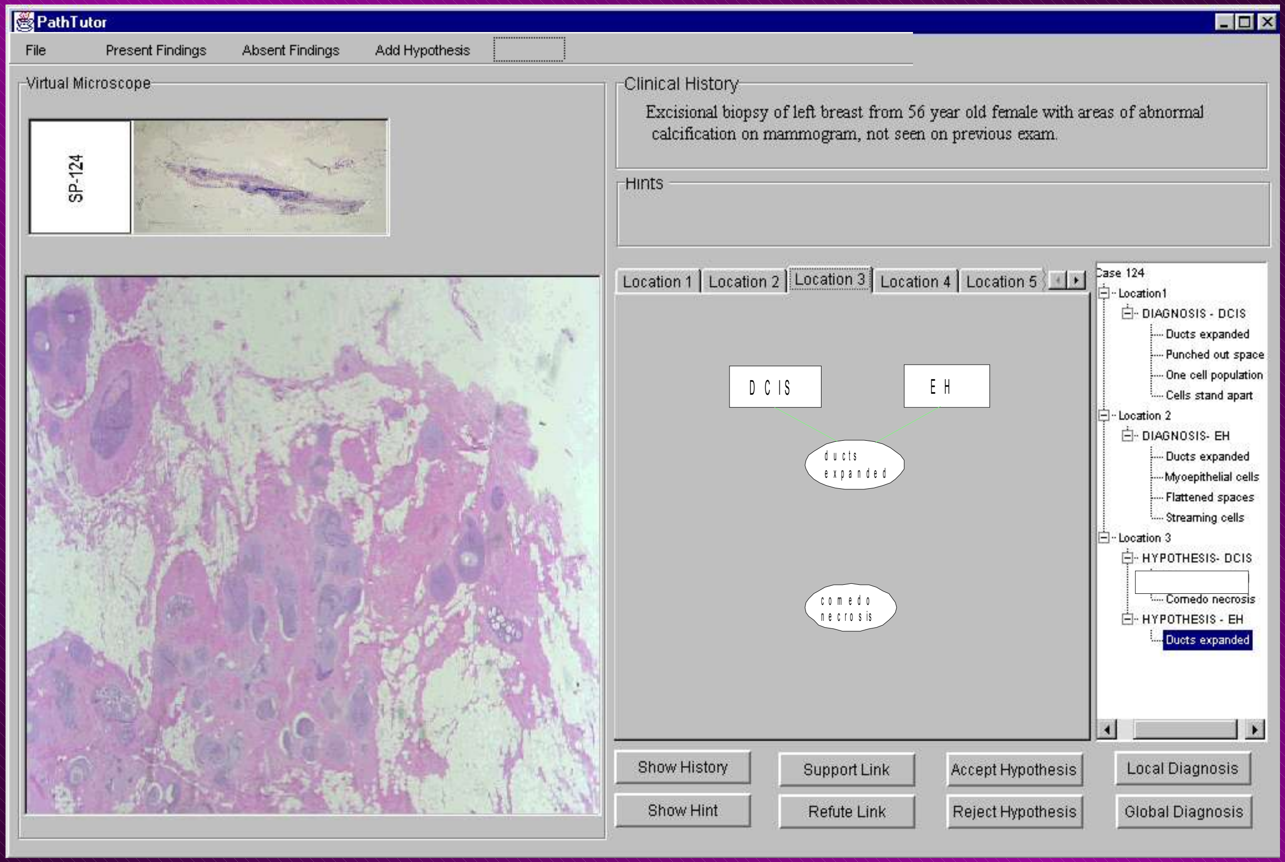
Rule-Set

Observation	Identification	Interpretation
Begin-Search	Note-Informative-Area	Generate-Hypothesis
Focus-Search-Next-Location	Identify-Present-Findings	Support-Hyp-With-Present-Findings
Search	Set-Goal-ID-Absent-Findings	Support-Hyp-With-Absent-Findings
New-magnification	Identify-Absent-Findings	Refute-Hyp-With-Present-Findings
Check-Done		Refute-Hyp-With-Absent-Findings
		Ready-Reject-Hypothesis
		Reject-Hyp-Mutually-Exclusive
		Reject-Hyp-Insufficient-Evidence
		Accept-Hypothesis
		Make-Diagnosis-One-Entity
		Make-Diagnosis-Same-Entity
		Make-Diagnosis-Not-Mutually-Exclusive
		Make-Diagnosis-Mutually-Exclusive

Interface design



Classifying errors across the spectrum of expertise

Search	Never get lesion into view	
	Repeated search of uninformative areas	
Identification	Lesion traversed but not noticed	
	Finding misidentified	
	Normal structure misidentified	
Interpretation	Assign wrong significance	
	Use wrong discriminator	
	Insufficient evidence to accept hypothesis	