quadri:
bumps in the road from language to data

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why do we need logic?

Want to distinguish between

A patient does not have a regimen with AZT.

and

A patient has a regimen. The regimen does not have AZT.

Go

axiomatic subject domain theory

- defines concepts in queries.
- describes constructs in database.
- introduces the background knowledge that bridges the gap between them.

SNARK: theorem proving

- full first order logic: resolution
- equality reasoning: paramodulation, rewriting.
- ontology reasoning: sorted logic.
- temporal reasoning: allen temporal interval calculus, date and time arithmetic.
- answer extraction.
- procedural attachment….
    - ➡ created by Mark Stickel at SRI

procedural attachment

- symbols in domain theory linked to procedures:
  - data base look-up
  - other computations
- when symbol appears in search, corresponding procedure is invoked.
- results of computation introduced into proof search.

    ➡ virtual extension of theory

derived objects

- entity allowed in query.
- defined in domain theory.
- not represented explicitly in the data base.
  - duration (finish-time - start-time)
  - “treatment change episode” (tce).

playback time

Show me patients on AZT.

```
there exists a patient14 such that
  there exists a regimen15 such that
    there exists a azt13 such that
      patient14 is a patient and
      patient14 has regimen15,
      regimen15 has azt13 and
      azt13 is azt
```

donkey anaphora

- *a patient has a regimen with azt.*

  exists(?patient, ?regimen)

  patient-has-regimen(?patient, ?regimen) &

  regimen-has-drug(?regimen, azt)

- *the regimen is of at least 24 weeks.*

  duration(?regimen) ≥ weeks(24)

  - note “the regimen” is outside of the scope of the quantifier for ?regimen.
  - treated by squeezing the new condition inside the scope of the quantifier.

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cardinality quantifiers

- *the regimen has a least 2 drugs.*

```
exists(≥ 2 ?drug)
    regimen-has-drug(?regimen, ?drug)
```

- *translated into*

```
exists(?drug1)
  regimen-has-drug(?regimen, ?drug1) &
  exists(≥ 1 ?drug)
     regimen-has-drug(?regimen, ?drug)  &
     ?drug ≠ ?drug1
```

- *or*

```
card(drugs-of regimen(?regimen) ≥ 2
```

bridge anaphora

- *find a patient with a tce.*

  (failing regimen)•(salvage regimen)

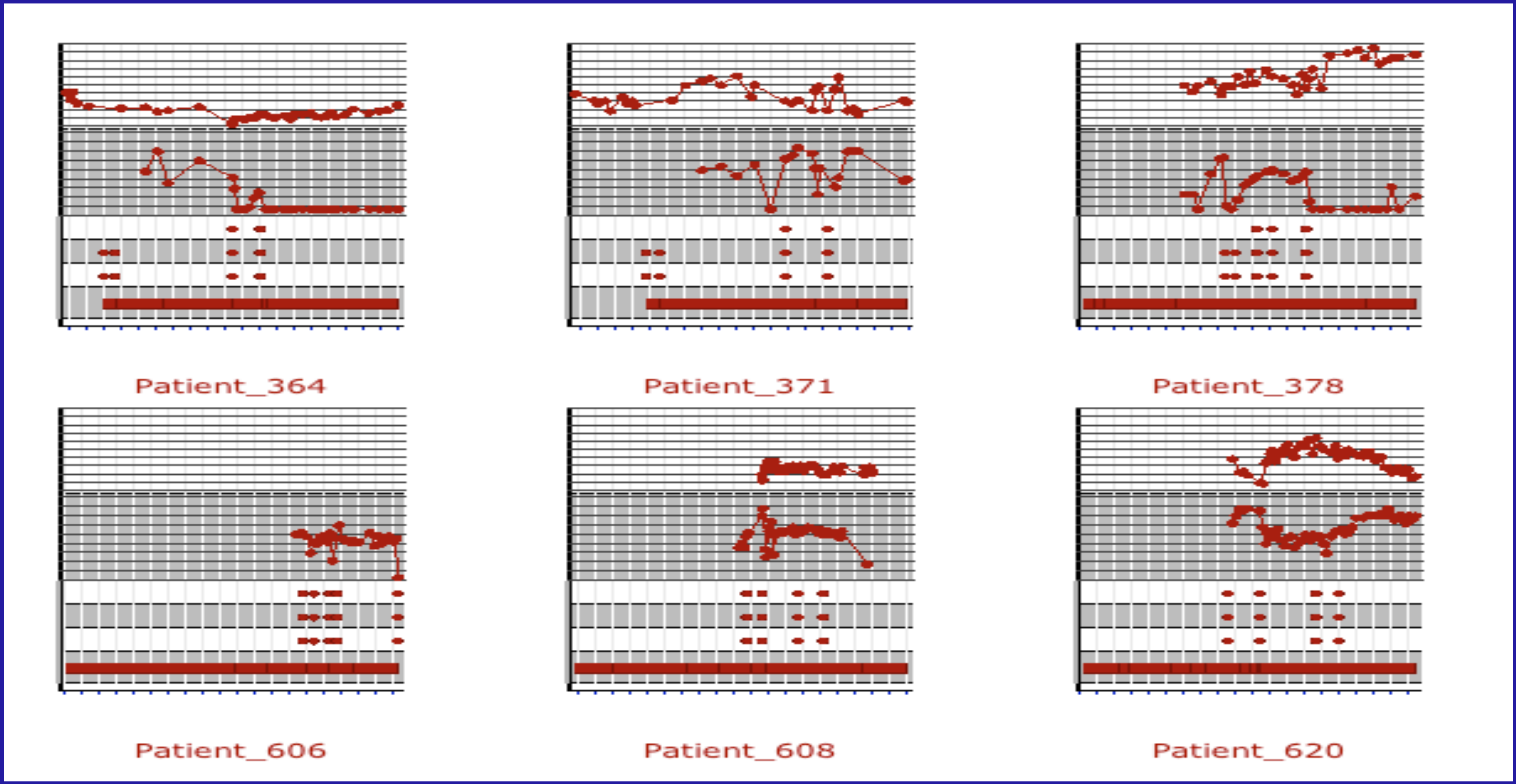
- *The patient has a high viral load 24 weeks before the baseline.*
  - what is the “baseline”?

evaluation

- SweetInfo: provides graphical answers to queries….
- evaluation replicates a discovery from the literature.
- adding a box to the HIV database treatment change episode page.

SweetInfo Display

What patients had a high viral load after 24 weeks on a regimen with RTV?



metaquadri

- replace hiv theory with arbitrary theory.
- introduce vocabulary.
- pass sort structure back into parser to remove ambiguities.
- allow new axioms to be introduced as declarative English sentences.

what's the problem?

- provide access to novice users- physicians and researchers.
- a single query can require access to multiple databases.
- answers may need to be deduced or computed.
- database languages (e.g. sql) require specialized expertise.

how is this different from google, watson, siri, etc.?

- understanding of question.
- precise answers to questions.
- understanding of subject domain.
- focused subject domain.

our approach

- ask questions in english.
- translate into a logical form.
- reason in a theory of the subject domain (HIV treatment).
- allow the reasoner to access appropriate databases.

the quadri team

natural language—parc.

- cleo condoravdi (now stanford csli)
- dan bobrow
- kyle richardson (now university of stuttgart)

reasoning—sri

- richard waldinger
- tomer altman

database and hiv expertise—stanford

- amar das
- robert shafer
- soo-yon rhee

funding: NIH National Library of Medicine

hiv ontology

- patients
- regimens
- drugs
- viral loads
- mutations (genetic tests)
  - stanford hiv database
    - shafer, rhee

example

- What patients on azt exhibited a high viral load?
- parc's xle translates into logical form (a theorem).

  exists(?patient)[patient-has-regimen…
- sri's snark proves theorem and extracts answer from proof.

  patient-id(605) ….
- stanford's hiv-db (and others) provides data.

axiomatic hiv theory

- defines concepts in query language.
- describes capabilities of data sources.
- provides background knowledge to link them together.
  - sorted axiomatic theory.
  - independent of any one data source.
- includes ontology.

sample axiom

high(viral-load, ?measurement)
    ⇔ log(?measurement) ≥ 4

- i.e, a viral load measurement is high if and only if its log is greater than or equal to 4.

challenges in use of natural language

- language of query different from language of data source.
  - qualitative vs. quantitative
  - approximate vs. precise
- english is highly ambiguous.
- query may be expressed as a sequence of questions.

mapping english to symbols

patients on azt ⇒

patient-has-regimen(?patient, ?regimen) &
regimen-has-drug(?regimen, azt)

- domain dependent.
- **?regimen** implicit.

ambiguity

- *patients had a regimen with azt.*

  azt modifies regimen (correct) or
  azt modifies had (wrong).
- *I had a martini with an olive*   vs.
  I had a martini with Olivia.

(A martini can have an olive but cannot have Olivia.)

approaches to ambiguity

- use ontology to discard syntactically plausible but semantically meaningless readings.
- e.g., azt is a drug
  - a regimen can have azt.
  - azt cannot have a regimen

domain knowledge reduces ambiguity

Find patients who had a high viral load after 24 weeks on a regimen with azt.

- 62 readings without subject domain knowledge.
- 1 reading with subject domain knowledge.

logical form

Find patients who had a high viral load after more than 24 weeks on a regimen with azt.

```
ex(?pat, ?reg)
   patient-has-regimen(?pat, ?reg) &
   regimen-has-drug(?reg, azt) &
   ex(?viral-test, ?time-point)
     patient-has-test(?pat, ?viral-test) &
     test-has-time(?viral-test, ?time-point) &
     test-has-result(?viral-test, ?test-result) &
     submeasurement(viral-load, ?test-result, high) &
     ex(?time-interval)
        duration(?time-interval)  ≥ 24*weeks &
        start-time(?time-interval) = start-time(?regimen) &
        finish-time(?time-interval) = ?time-point.
```

playback

- logical form(s) translated back into unambiguous (if clunky) English.
- user may select among alternatives.
- user may rephrase query if necessary.

playback example

- english: *Find patients who have no regimens with azt.*
- playback:

there exists a patient1 such that
for all regimen2's,
patient1 is a patient and it is not so that
patient1 has regimen2 and
regimen2 has azt

theorem proving: SNARK

- automatic first-order logic.
- includes ontology reasoning.
- answers to queries extracted from proof.
- special procedures for temporal reasoning.
- *procedural attachment.*

"'You must know—' said the Judge: but the Snark exclaimed 'Fudge!'"

procedural attachment

- symbol in theory linked to
  - access of a table in data source.
  - other procedures
- when the symbol occurs in the proof search, the procedure is invoked.
- result of the procedure is introduced into the proof.
- axiomatic theory virtually extended.
  - e.g. patient-has-regimen(patient17, ?regimen)

procedural attachments to multiple data sources

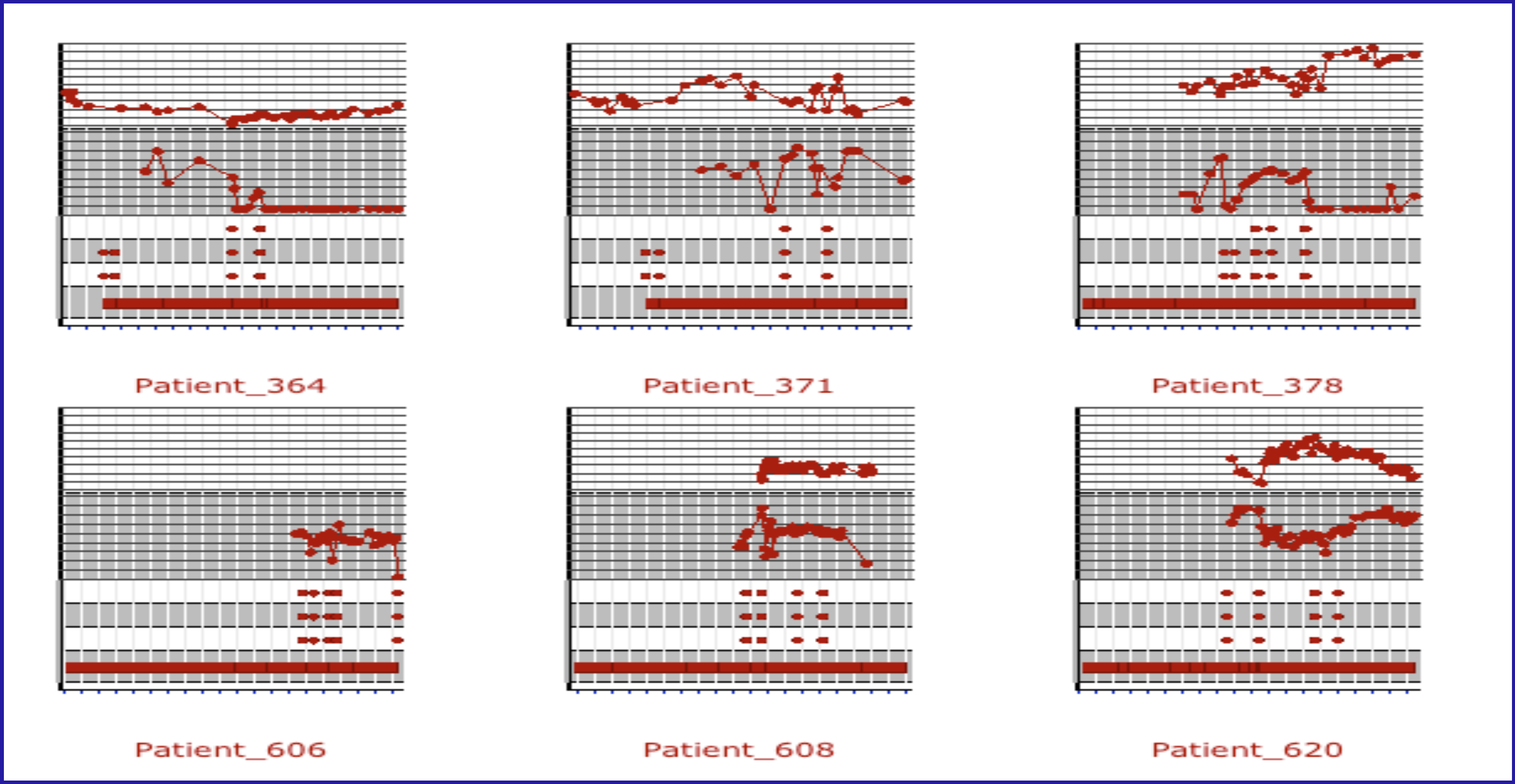
- patient-has-regimen, patient-has-test
  the stanford hiv drug resistance data base.
- other american and european sources planned.

display answers

- multiple proofs: multiple answers.
- user may request visual display of answers.
- SweetInfo project (Stanford) provides visual display of HIV data.
- evaluation of Quadri anticipated using SweetInfo test questions.

SweetInfo Display

What patients had a high viral load after 24 weeks on a regimen with RTV?



explanation

- axioms and procedural attachments from the proof are used to construct an English paragraph that explains and justifies the answer and provides the provenance of the data invoked.

Sample Explanation

A patient has a high viral load if the log of the viral load is at least 4. The duration of a time interval is the difference between its finish point and its start point. ….

Patient 378 was on a regimen that started 29 August 1993. Patient 378 had a viral load of log 5 on 30 November 1999. …

English transcriptions of

- axioms
- results of procedural attachments.

complex queries: multiple questions

- *Find patients who exhibited m184v.*
- *The patients were on azt.*
- *The patients had a high viral load after more than 24 weeks on the regimen.*

testing

- allow access to quadri via the stanford hiv database-the quadri box!

future work

- expressing new knowledge in English.
- adaptation to new subject domains
  - breast cancer
- providing health care information to patients.

new knowledge: high viral load

- English: *A viral load is high if and only if the log of the viral load is greater than or equal to 4.*
- Logic:

  high(viral-load, ?measurement)

  ⇔ log(?measurement) $\geq$ 4