

# Querying and Visualizing Electronic Health Records

**Taowei David Wang**

Catherine Plaisant

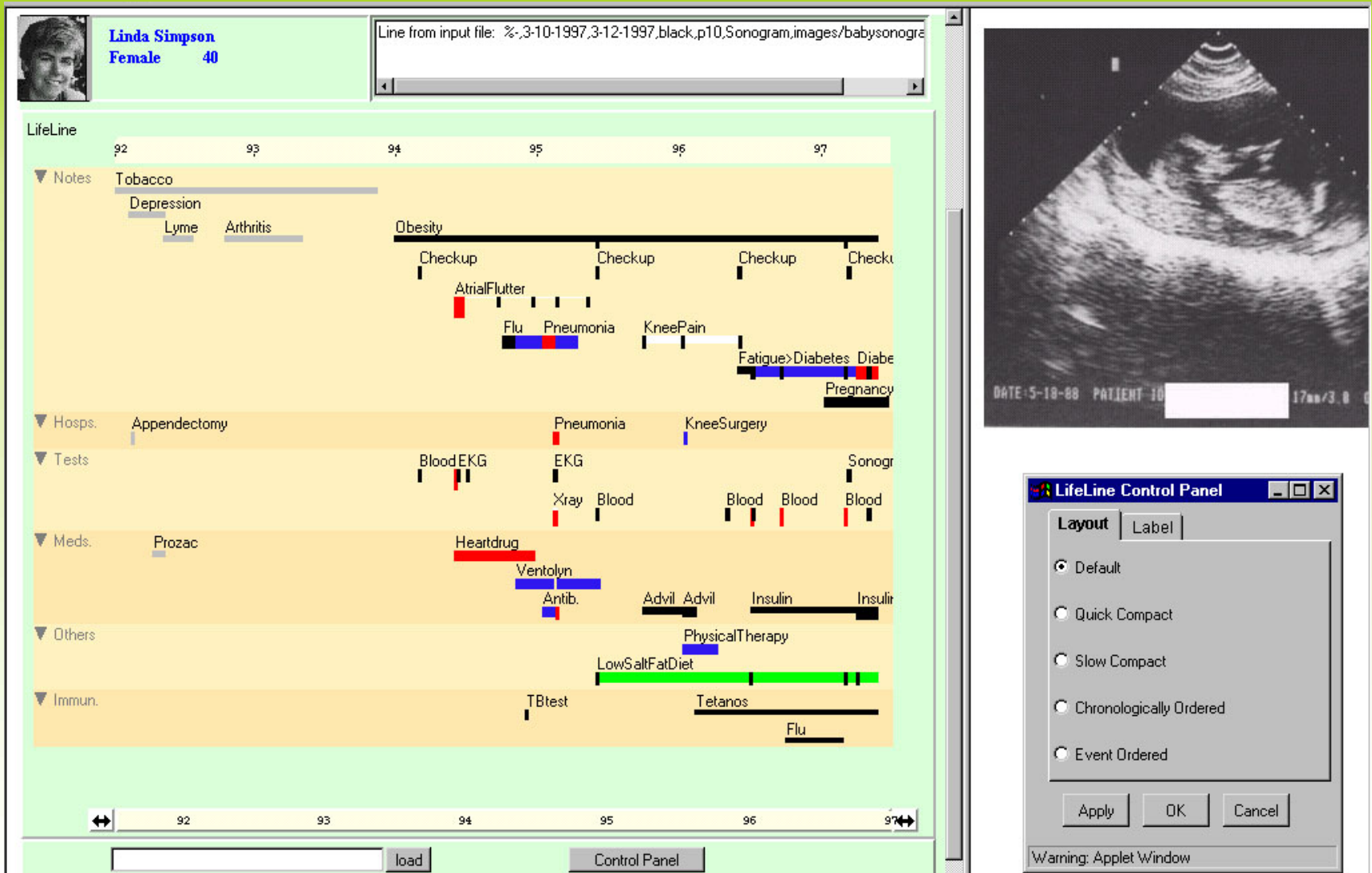
Ben Shneiderman

Stanley Lam



Human-Computer Interaction Lab, University of Maryland

# LifeLines: Overview of Patient Record

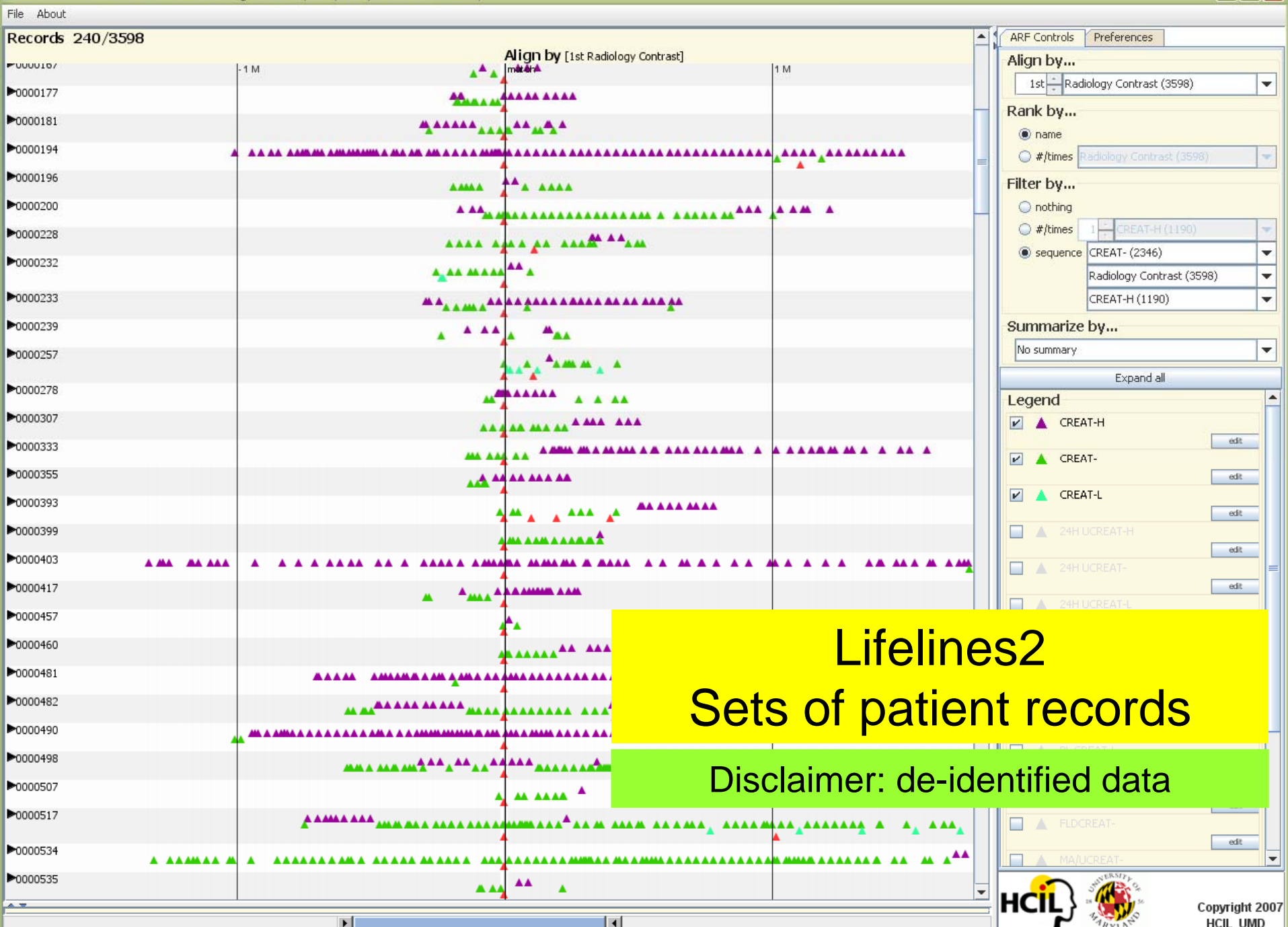


# Single record → Millions of records

- Large databases of Electronic Health Records (EHRs):
- Observational studies
- Recruitment for clinical trials
- Hospital metrics
- Alarm design and testing
- etc.

Often involves temporal comparison relative to an important event  
(e.g. heart attack, start of a treatment, 1<sup>st</sup> diagnosis of cancer)





Lifelines2  
Sets of patient records

Disclaimer: de-identified data

# Lifelines2

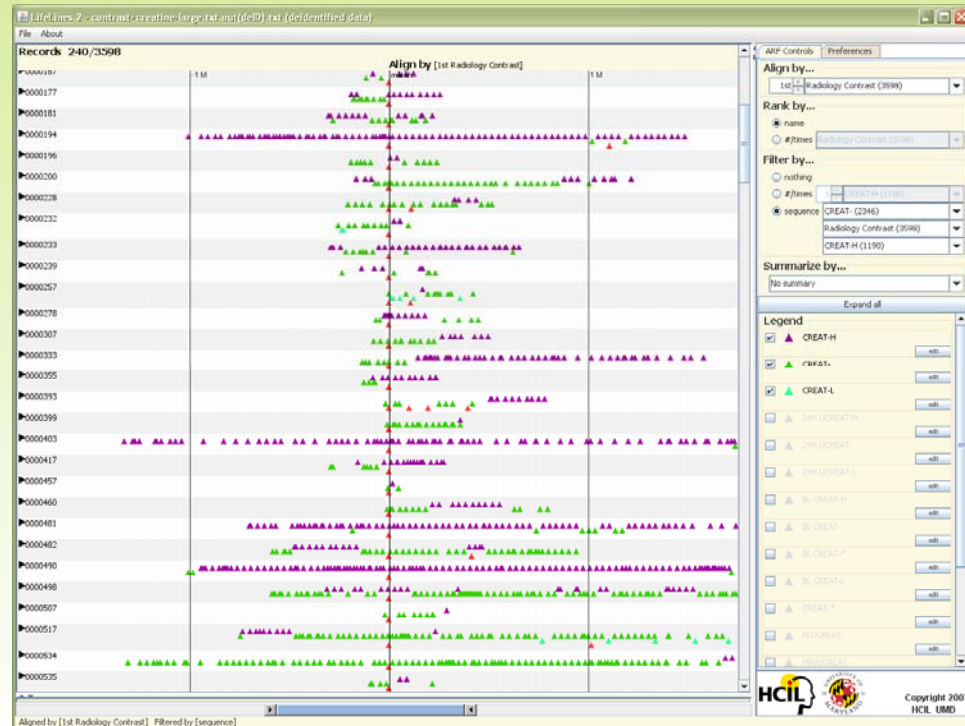
- Introduce powerful combination of simple operations  
**Align, Rank, Filter, and Summarize**

- Multiple records simultaneously visible
- Align by sentinel events
- Rank by frequency
- Filter by events
- Summaries

- Focus on **Point Events**

- Diagnosis, treatments, etc.

- Measure  
**Benefits of Alignment**

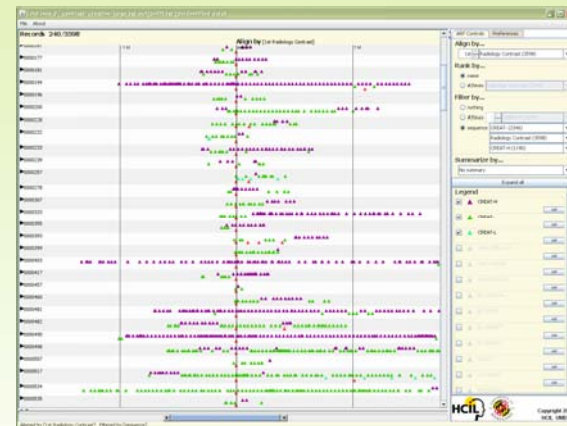


# Context

Search  
millions of records



Interactive  
visualization of results



LifeLines2

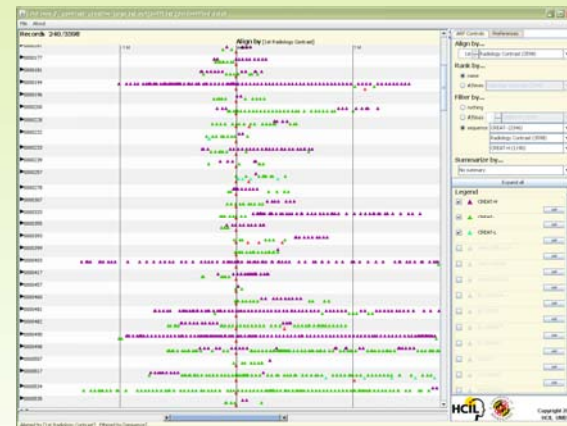
# Context

Search  
millions of records



Interactive  
visualization of results

Writing SQL not an option!



LifeLines2



# Context

```
SELECT TOP 200
*
FROM
  contrast contrast_1,
  contrast contrast_2,
  contrast contrast_3
WHERE
  1=1 AND
  [contrast_1].[Lab Test] = 'CREAT' AND
  [contrast_2].[Value] BETWEEN '0.6' AND '1.2' AND
  [contrast_2].[Lab Accessioning Time] < [contrast_1].[Radiology Exam Time] AND [contrast_2].[Lab Accessioning Time] > dateadd(Day, -2, [contrast_1].[Radiology Exam Time]) AND
  [contrast_1].[Account] = [contrast_2].[Account] AND
  [contrast_3].[Value] > ([contrast_2].[Value] * (1 + 50 * .01)) AND
  [contrast_3].[Value] > ([contrast_2].[Value] + 1) AND
  [contrast_3].[Lab Accessioning Time] > [contrast_1].[Radiology Exam Time] AND [contrast_3].[Lab Accessioning Time] < dateadd(Day, 5, [contrast_1].[Radiology Exam Time])
AND
  [contrast_2].[Account] = [contrast_3].[Account]
```

OK

Writing SQL not



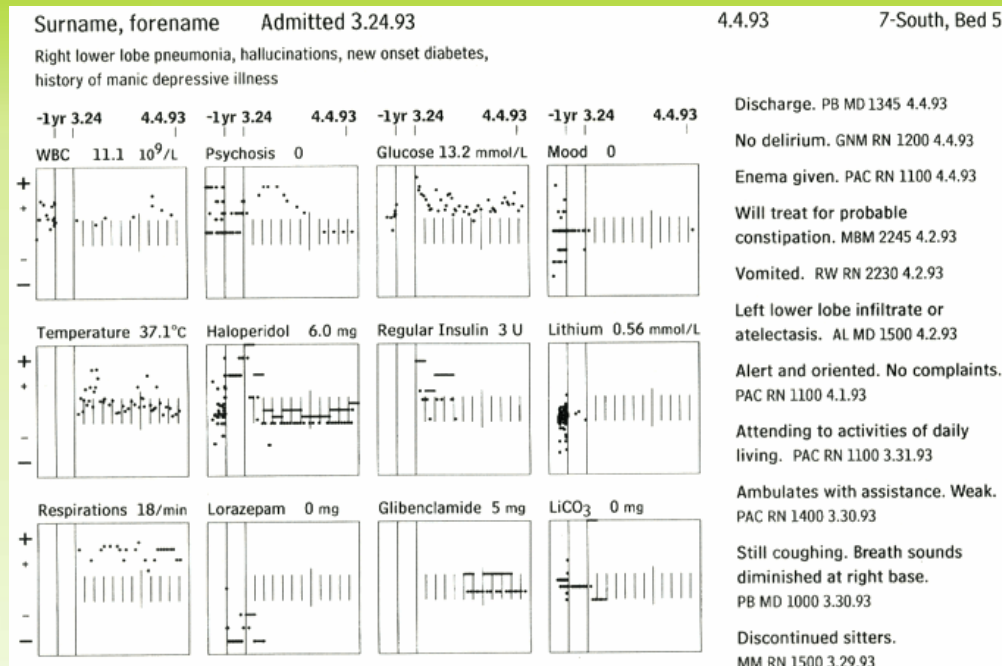
LifeLines2



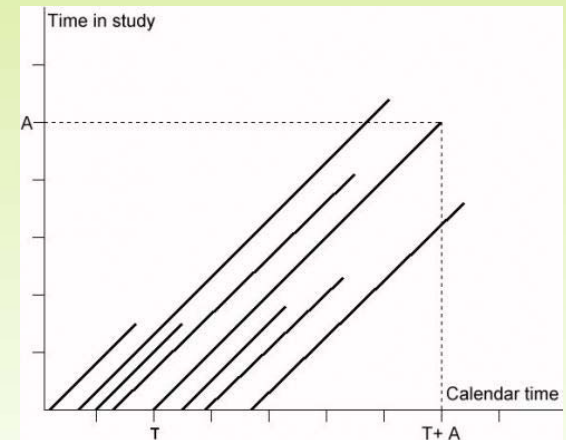


- **Sample of Related work**
- Demo
- (Quick) Report on studies
- Ongoing & Future work

# Static views



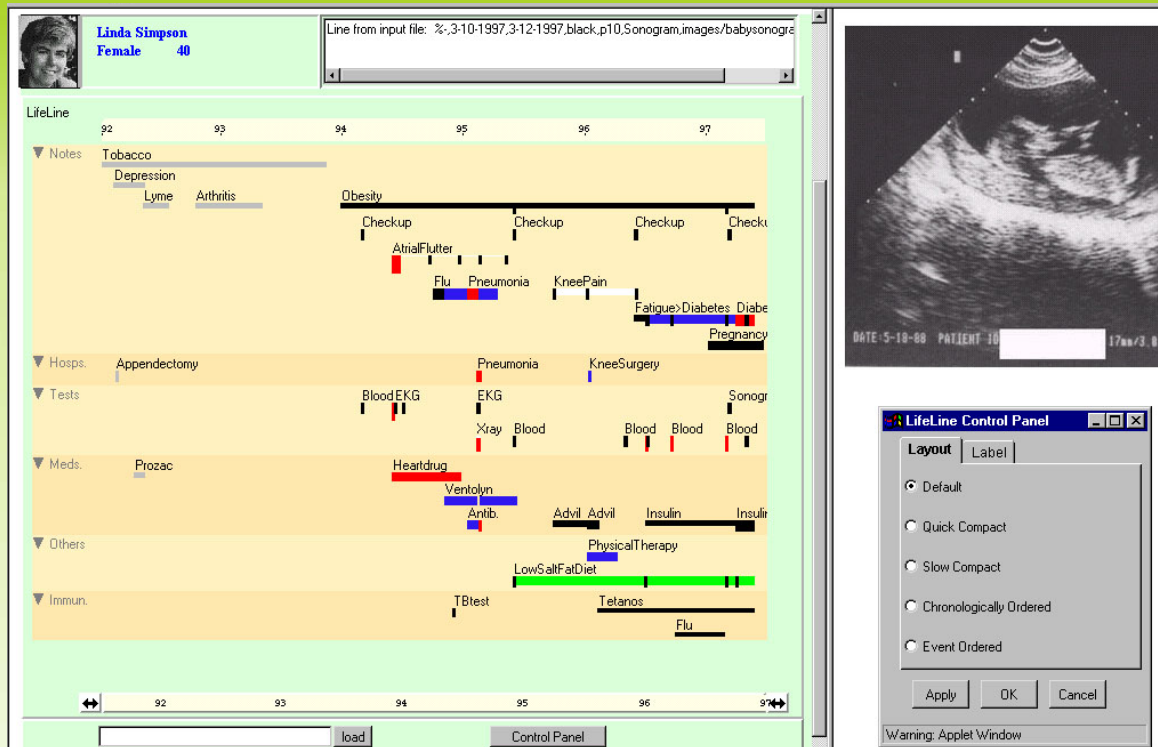
**Powsner & Tufte, 1994**



**Lexis diagrams (Bertin)**

# Lifelines and improvements

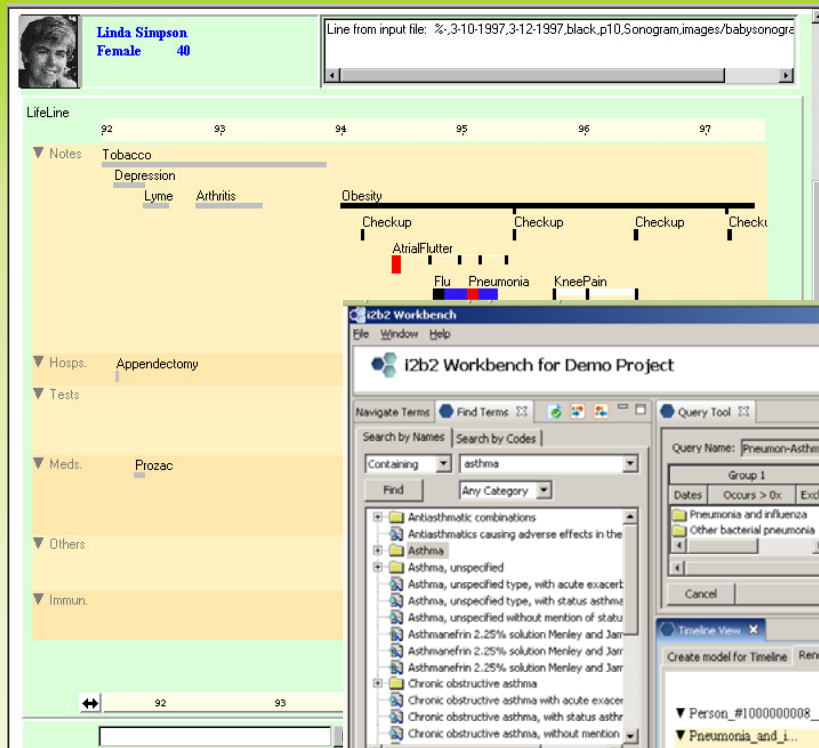
Overview of categorical and/or numerical data (semantic zoom)



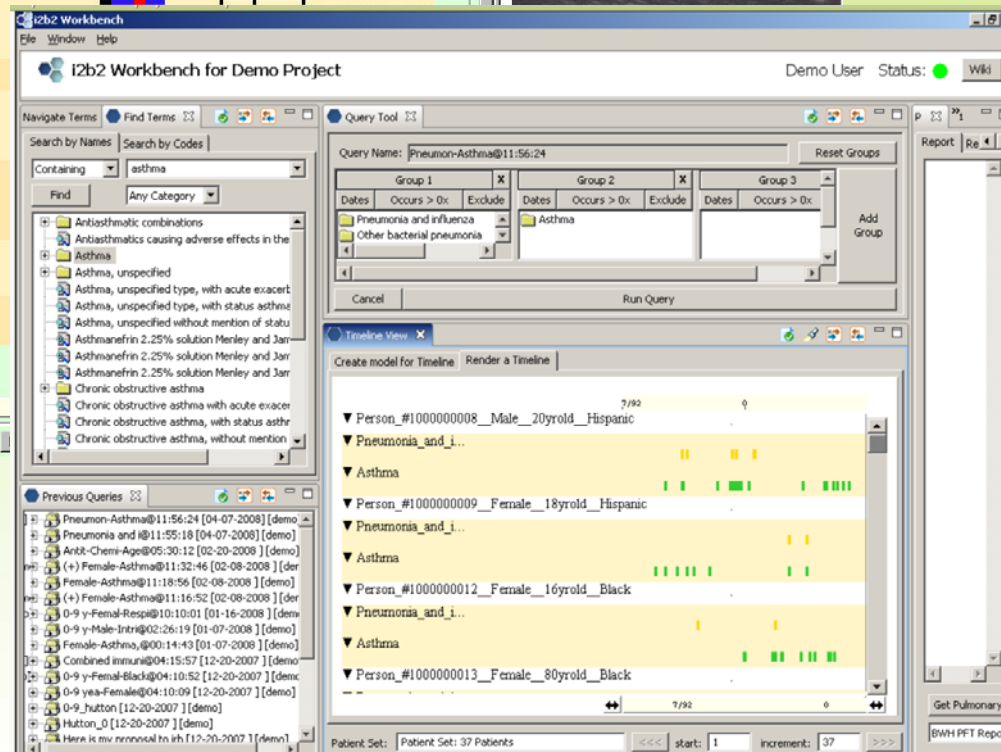
Plaisant, CHI 96, AMIA 98

# Lifelines and improvements

Overview of categorical and/or numerical data (semantic zoom)



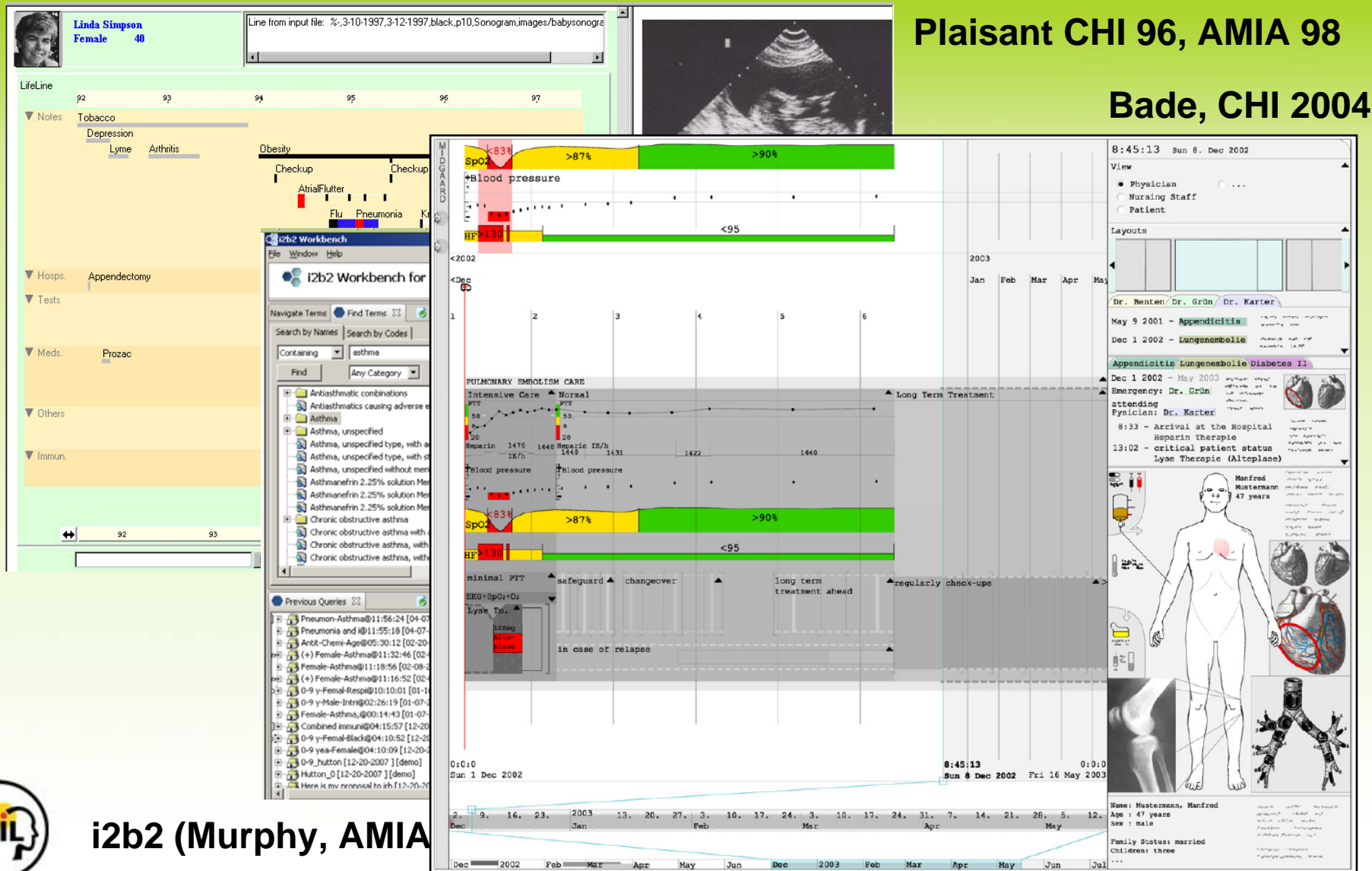
Plaisant, CHI 96, AMIA 98



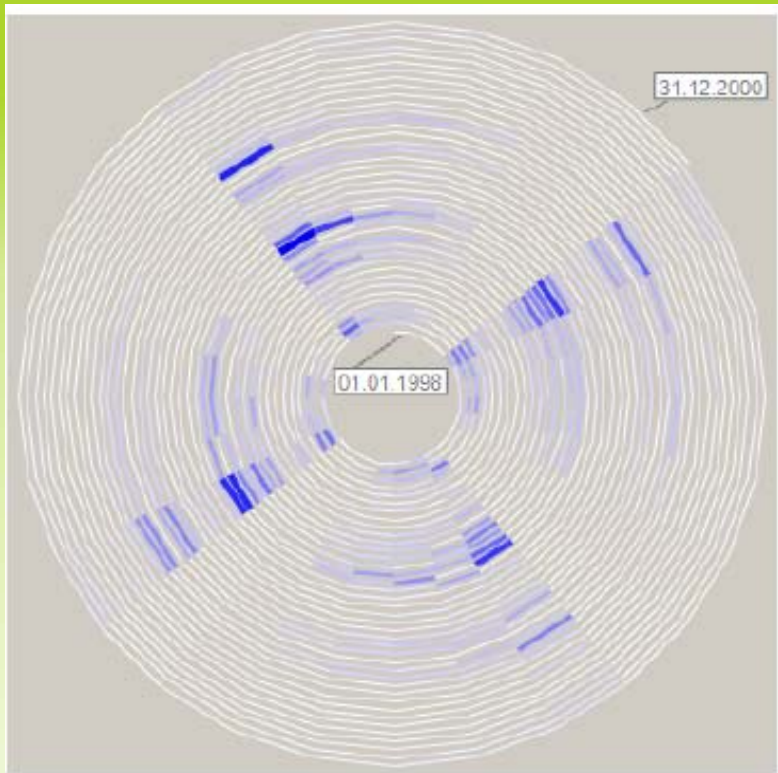
i2b2 (Murphy, AMIA 07)

# Lifelines and improvements

Overview of categorical and/or numerical data (semantic zoom)

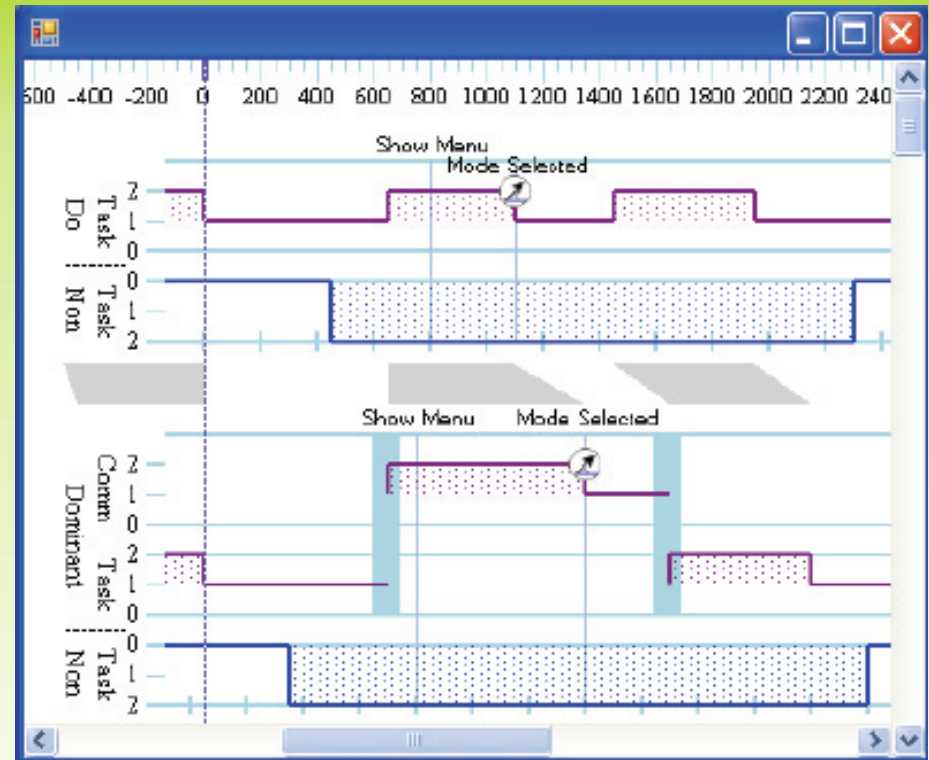


# Temporal Visualizations



**Spiral Graph: Weber, 01  
(based on Carlis, UIST 89)**

Periodic data



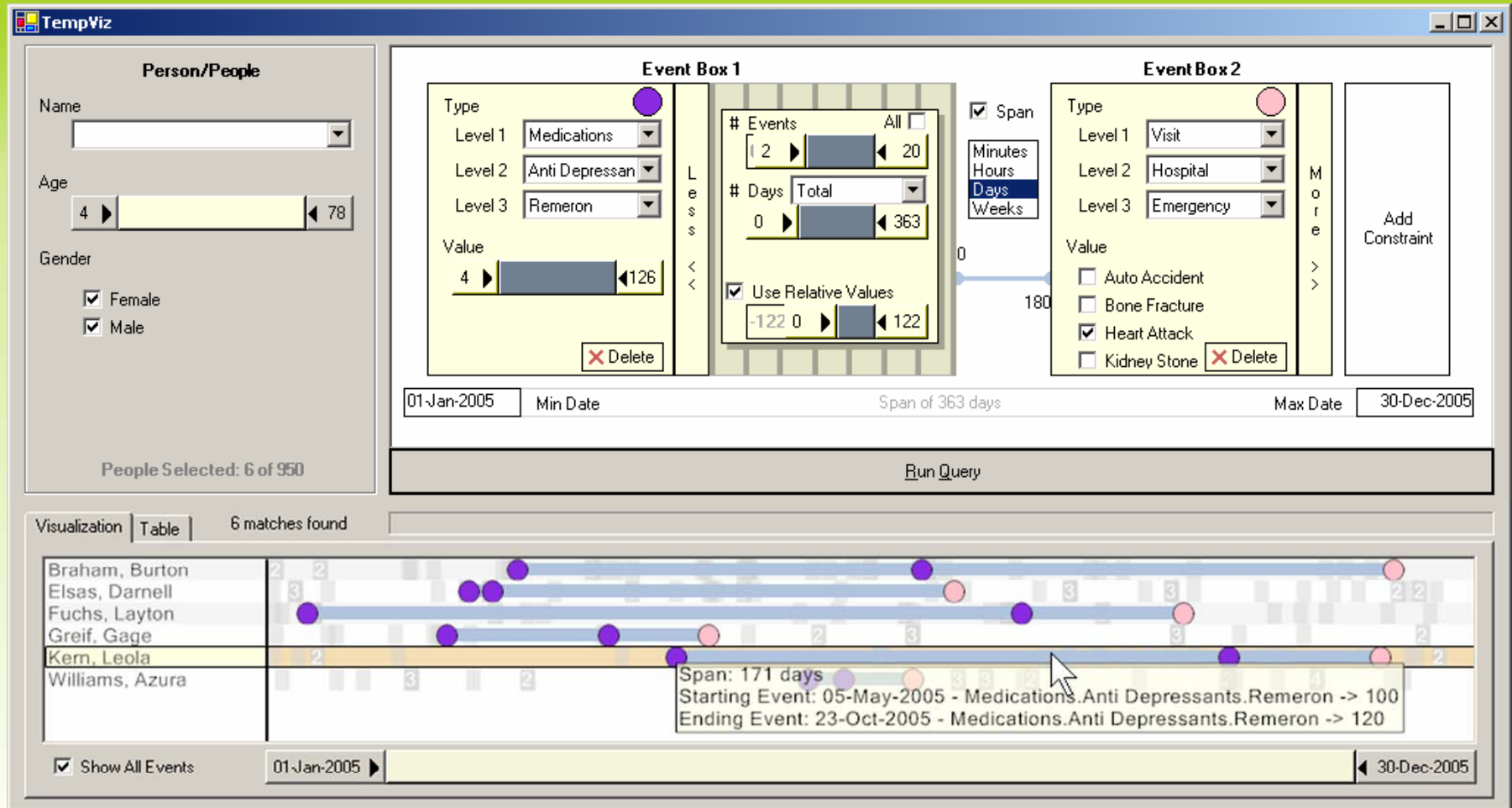
**ExperiScope (Guimbretiere, CHI 07)**

One of many example of manual alignment



# PatternFinder

Specification of complex temporal queries on categorical data



Fails, VAST 06

Ball and chain display of matches





- Related work 4
- **Demo LifeLines2**
- Report on studies
- Ongoing & Future work

**Scenario:** Study relationship between asthma and pneumonia

1) Run query



2) Preview results

# Scenario: Study relationship between asthma and pneumonia

## 1) Run query Find all patients who have both Asthma and Pneumonia diagnoses

The screenshot displays the i2b2 Workbench interface for a Demo Project. The main window is titled "i2b2 Workbench for Demo Project" and shows a "Query Tool" window. The "Query Name" is "Pneumon-Asthma@11:56:24". The "Query" window shows three groups of terms:

- Group 1: Pneumonia and influenza, Other bacterial pneumonia
- Group 2: Asthma
- Group 3: (Empty)

The "Run Query" button is visible. Below the query tool, the "Timeline View" window shows a list of patients with their diagnoses over time. The patients listed are:

- Person #100000008\_Male\_20yroid\_Hispanic
- Person #100000009\_Female\_18yroid\_Hispanic
- Person #100000012\_Female\_16yroid\_Black
- Person #100000013\_Female\_80yroid\_Black

The timeline view shows green bars representing diagnoses. The "Patient Set" is 37 Patients. The "start" date is 1 and the "increment" is 37.

# Scenario: Study relationship between asthma and pneumonia

## 1) Run query Find all patients who have both Asthma and Pneumonia diagnoses

The screenshot displays the i2b2 Workbench interface for a Demo Project. The main window is titled "i2b2 Workbench for Demo Project" and shows a "Query Tool" window. The "Query Name" is "Pneumon-Asthma@11:56:24". The "Query Tool" window contains three groups of criteria:

- Group 1:** Pneumonia and influenza, Other bacterial pneumonia
- Group 2:** Asthma
- Group 3:** (Empty)

The "Previous Queries" list on the left shows several queries, including "Pneumon-Asthma@11:56:24 [04-07-2008] [demo]". The "Timeline View" window at the bottom shows a list of patients with their demographic information and a timeline of events. The patients listed are:

- Person #1000000008\_Male\_20yroid\_Hispanic
- Person #1000000009\_Female\_18yroid\_Hispanic
- Person #1000000012\_Female\_16yroid\_Black
- Person #1000000013\_Female\_80yroid\_Black

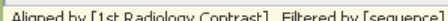
The timeline for each patient shows events for "Pneumonia\_and\_i..." and "Asthma". The "Patient Set" at the bottom indicates 37 patients, with a start of 1 and an increment of 37.

## 2) Review results



# Demo





# Two user studies

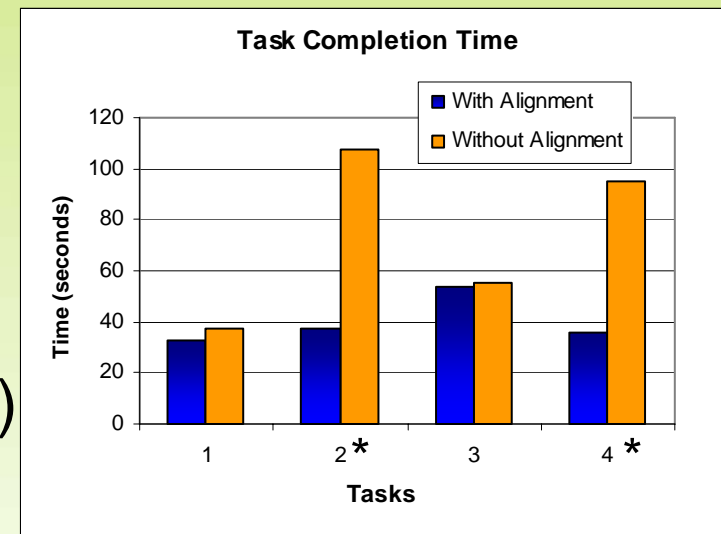
- Controlled experiment  
(some training, measure speed and error)
- Domain expert qualitative study  
(no training, think aloud, discussion)





# Two user studies

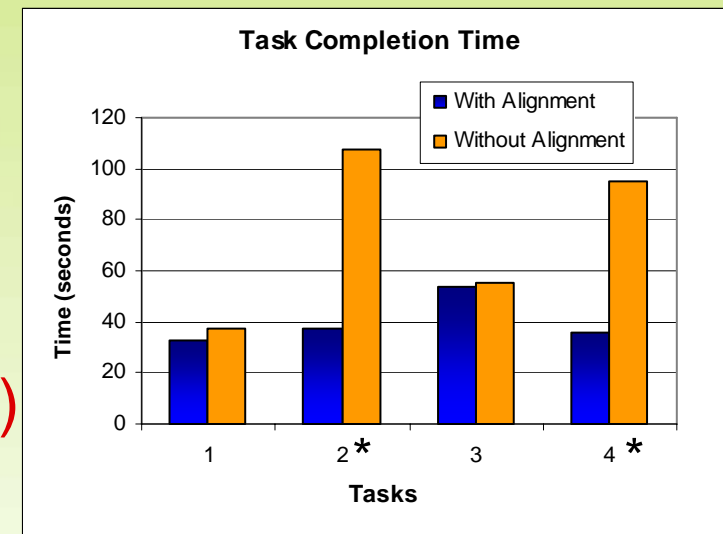
- Controlled experiment  
(some training, measure speed and error)
  - Benefit of alignment: **YES** (Significant improvement on complex tasks)
  - 20 participants: grad students  
Data: synthetic student record data  
Tasks checked as domain independent
- Domain expert qualitative study  
(no training, think aloud, discussion)



# Two user studies

- Controlled experiment  
(some training, measure speed and error)
  - Benefit of alignment: **YES** (Significant improvement on complex tasks)
  - 20 participants: grad students  
Data: synthetic student record data  
Tasks checked as domain independent

- Domain expert qualitative study  
(no training, think aloud, discussion)



- Learnability **GOOD** (challenges with interpretation of data more than UI)
- General feedback and suggestions **Suggestions**
- 4 participants: nurse, physician, 2 prof. of nursing
- All experienced with EHR and medical research

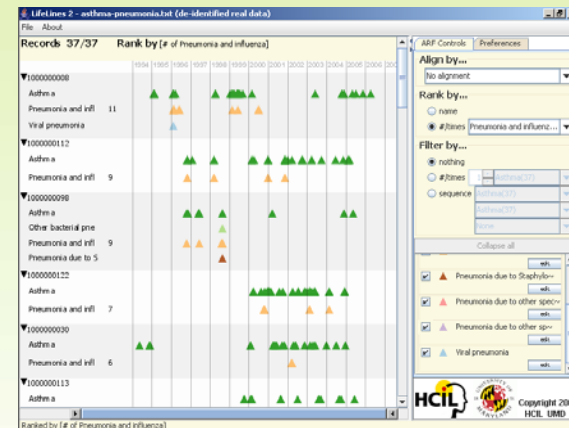


# Context

Search  
millions of records



Interactive  
visualization of results



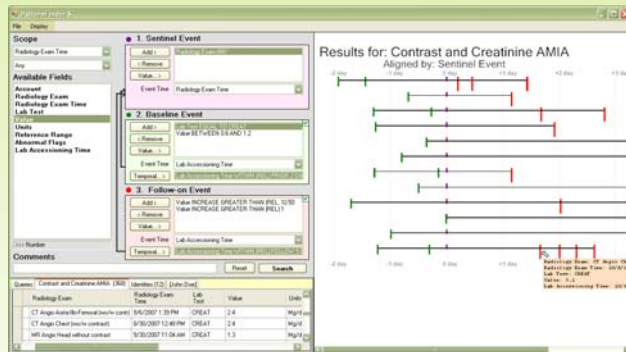
LifeLines2

# Context

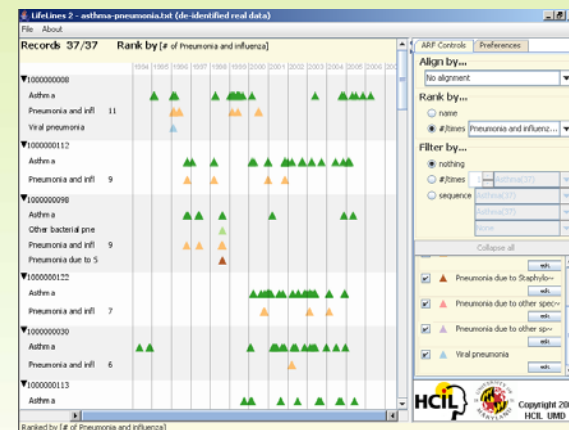
Search  
millions of records



Interactive  
visualization of results

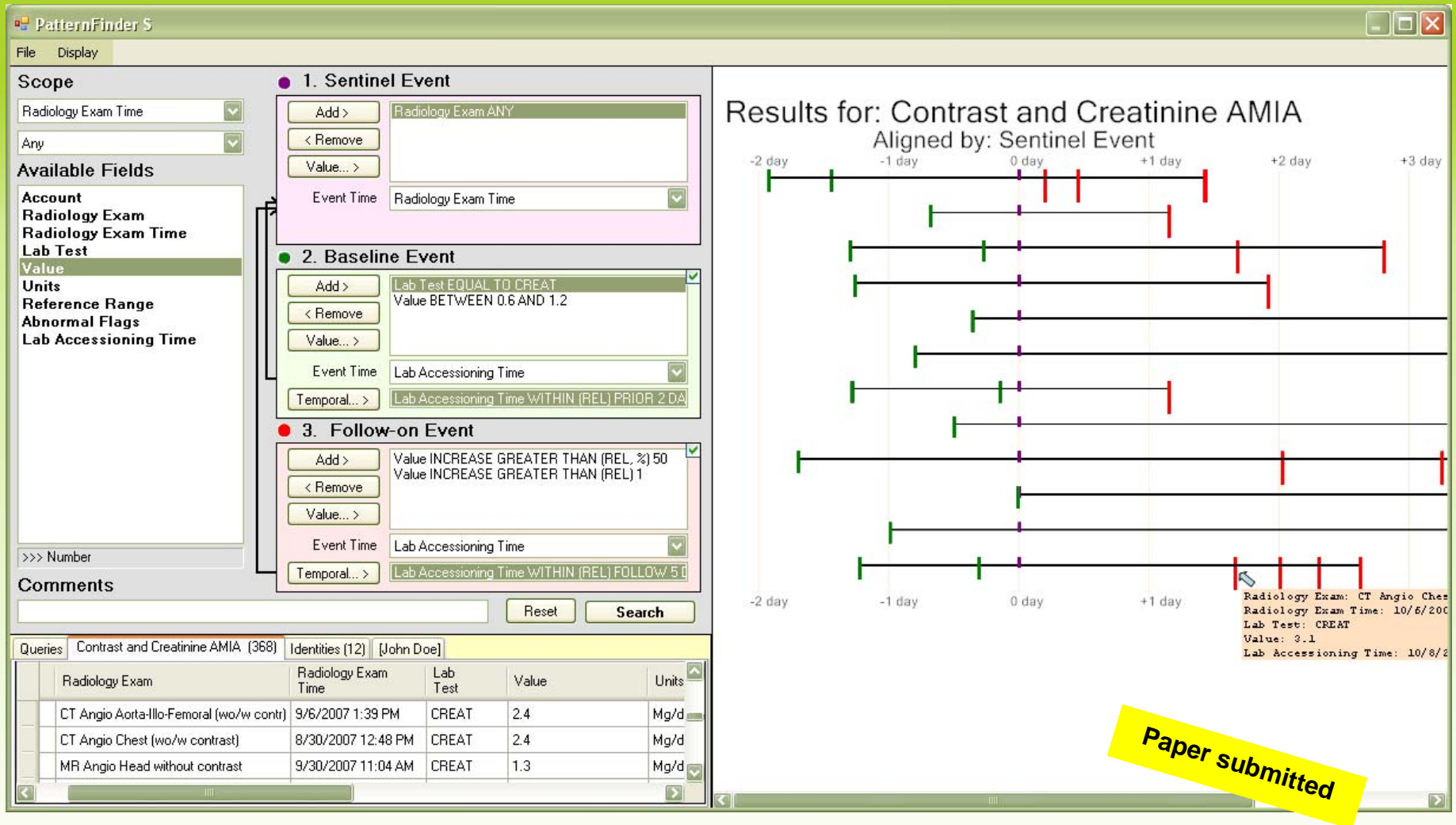


PatternFinder  
in Amalga (formerly Azyxxi)



LifeLines2

# Combine Alignment with PatternFinder



Washington Hospital Center



# Integrate Align-Rank-Filter in i2b2



Harvard Medical School, Partners HealthCare



# In summary...

- **Align Rank, Filter, and Summarize**  
Powerful combination of simple operations to explore temporal categorical data (events)
- **Performance benefit of alignment: significant**
- **Impact:** Integration in 2 large operational EHR systems
- **Many applicable domains:**
  - Highway incident log
  - Student records
  - Web logs
  - Vehicle fleet records







Human-Computer  
Interaction Lab  
University of Maryland

[News + Events](#)[About HCIL](#)[People](#)[Research](#)[Publications](#)[Academics](#)

quick find ::  
[Current Research Projects](#)

20+ years of  
[Tech Report Online](#)

15+ years of  
[Video Reports](#)

NEWS



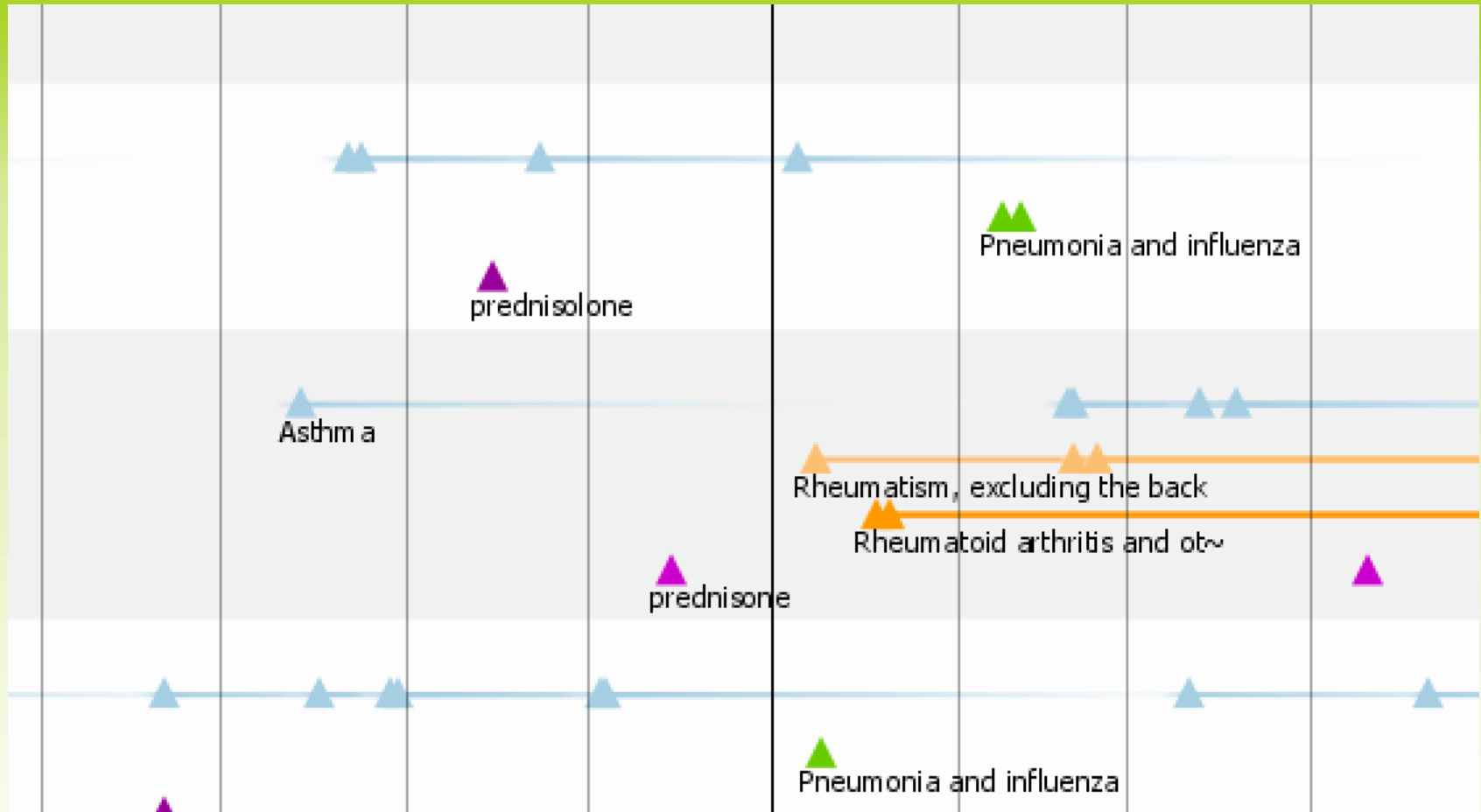
# Thank you!

[www.cs.umd.edu/hcil/lifelines2](http://www.cs.umd.edu/hcil/lifelines2)

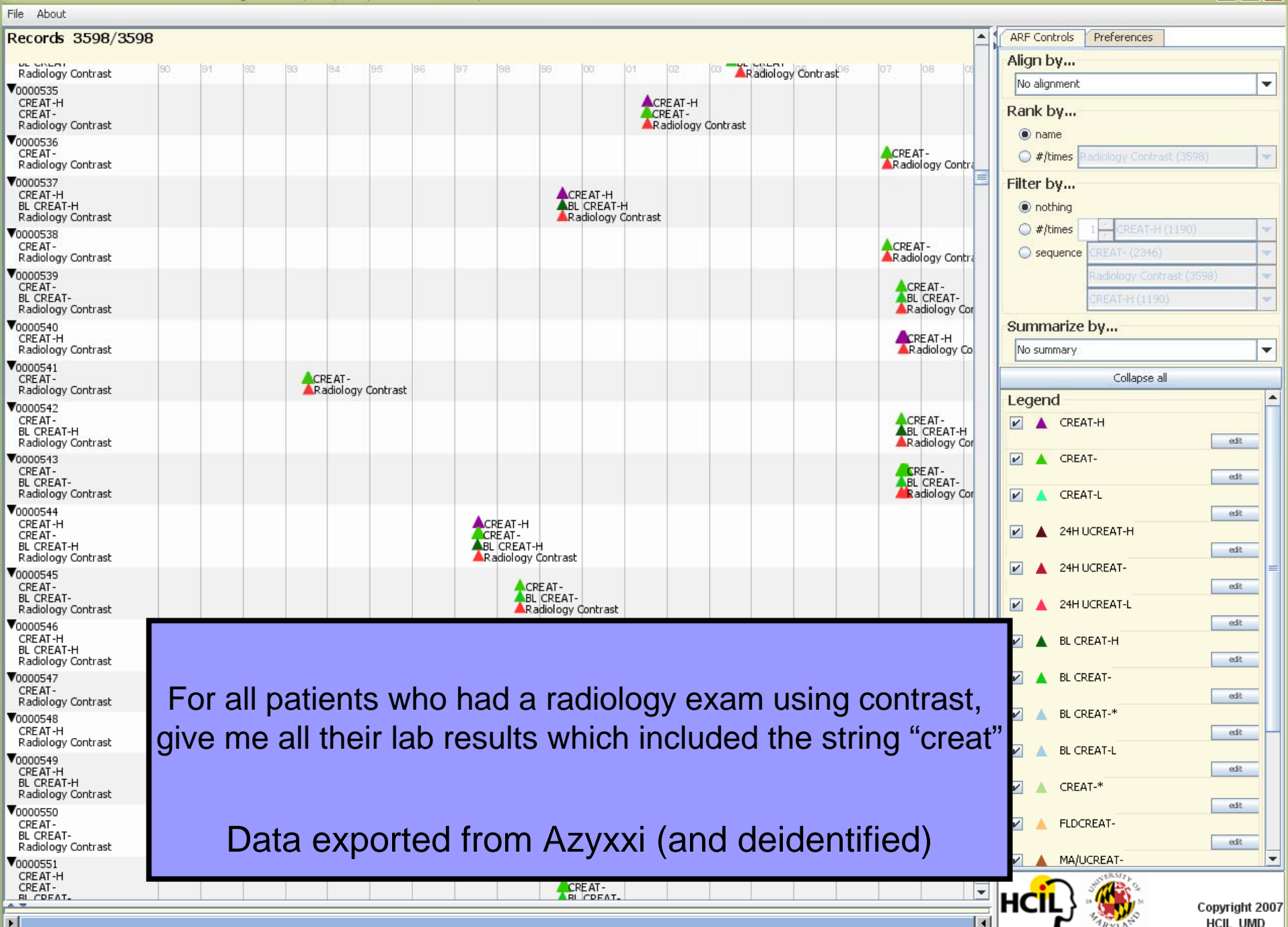




# Fading intervals



back



Records 3598/3598

	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
▼0000537 CREAT-H Radiology Contrast											▲CREAT-H ▲Radiology Contrast							
▼0000538 CREAT - Radiology Contrast																	▲CREAT - ▲Radiology Contrast	
▼0000539 CREAT - Radiology Contrast																	▲CREAT - ▲Radiology Contrast	
▼0000540 CREAT-H Radiology Contrast																	▲CREAT-H ▲Radiology Contrast	
▼0000541 CREAT - Radiology Contrast				▲CREAT - ▲Radiology Contrast														
▼0000542 CREAT - Radiology Contrast																	▲CREAT - ▲Radiology Contrast	
▼0000543 CREAT - Radiology Contrast																	▲CREAT - ▲Radiology Contrast	
▼0000544 CREAT-H CREAT - Radiology Contrast									▲CREAT-H ▲CREAT - ▲Radiology Contrast									
▼0000545 CREAT - Radiology Contrast											▲CREAT - ▲Radiology Contrast							
▼0000546 CREAT-H Radiology Contrast																	▲CREAT-H ▲Radiology Contrast	
▼0000547 CREAT - Radiology Contrast																	▲CREAT - ▲Radiology Contrast	
▼0000548 CREAT-H Radiology Contrast																	▲CREAT-H ▲Radiology Contrast	
▼0000549 CREAT-H Radiology Contrast																	▲CREAT-H ▲Radiology Contrast	
▼0000550 CREAT - Radiology Contrast												▲CREAT - ▲Radiology Contrast						
▼0000551 CREAT-H CREAT - Radiology Contrast											▲CREAT-H ▲CREAT - ▲Radiology Contrast							
▼0000552 CREAT - Radiology Contrast														▲CREAT - ▲Radiology Contrast				
▼0000553 CREAT-H CREAT - Radiology Contrast																	▲CREAT-H ▲CREAT - ▲Radiology Contrast	
▼0000554 CREAT - CREAT-L Radiology Contrast																	▲CREAT - ▲CREAT-L ▲Radiology Contrast	
▼0000555 CREAT-H Radiology Contrast																	▲CREAT-H ▲Radiology Contrast	
▼0000556																		

ARF Controls

Preferences

Align by...

No alignment

Rank by...

☒ name
 ☐ #/times
 Radiology Contrast (3598)

Filter by...

☒ nothing
 ☐ #/times
 1 CREAT-H (1190)
 CREAT- (2346)
 Radiology Contrast (3598)
 CREAT-H (1190)

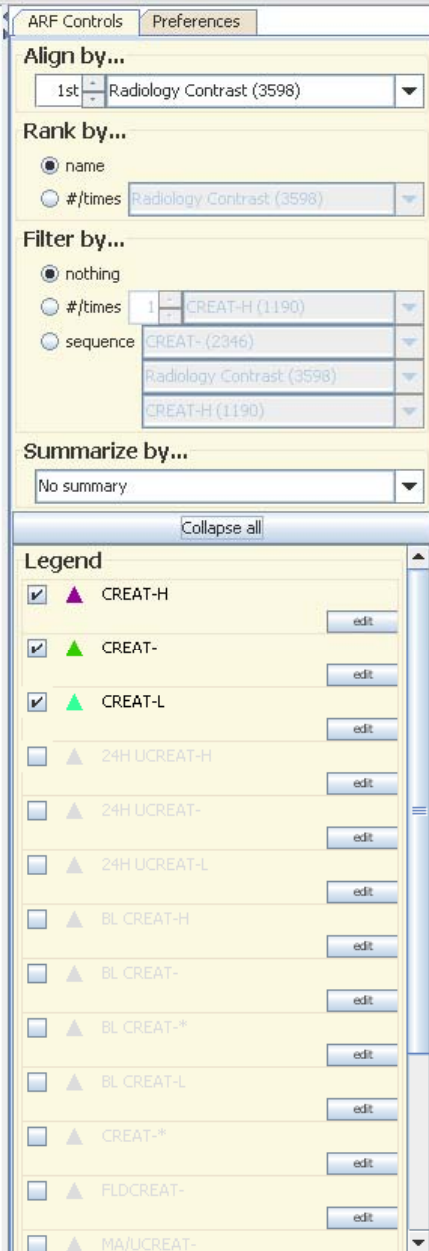
Summarize by...

No summary

Collapse all

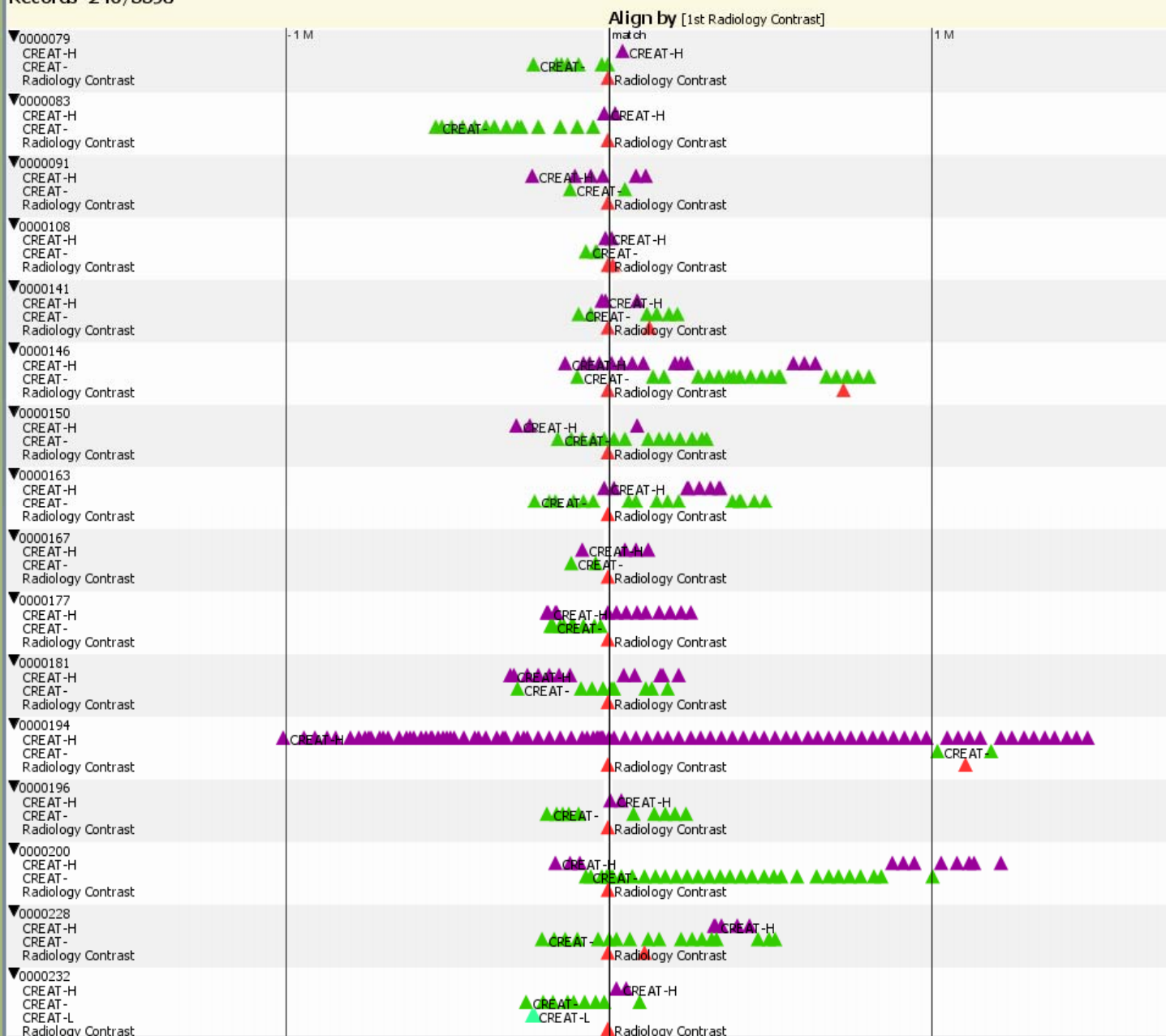
Legend

☒ ▲ CREAT-H
 ☒ ▲ CREAT-
 ☒ ▲ CREAT-L
 ☐ ▲ 24H UCREAT-H
 ☐ ▲ 24H UCREAT-
 ☐ ▲ 24H UCREAT-L
 ☐ ▲ BL CREAT-H
 ☐ ▲ BL CREAT-
 ☐ ▲ BL CREAT-\*
 ☐ ▲ BL CREAT-L
 ☐ ▲ CREAT-\*
 ☐ ▲ FLDCREAT-
 ☐ ▲ MA/UCREAT-





Records 240/3598



ARF Controls Preferences

Align by...

1st Radiology Contrast (3598)

Rank by...

☒ name

☐ #/times Radiology Contrast (3598)

Filter by...

☐ nothing

☐ #/times 1 CREAT-H (1190)

☒ sequence CREAT- (2346)

Radiology Contrast (3598)

CREAT-H (1190)

Summarize by...

No summary

Collapse all

Legend

☒ CREAT-H edit

☒ CREAT- edit

☒ CREAT-L edit

☐ 24H UCREAT-H edit

☐ 24H UCREAT- edit

☐ 24H UCREAT-L edit

☐ BL CREAT-H edit

☐ BL CREAT- edit

☐ BL CREAT-\* edit

☐ BL CREAT-L edit

☐ CREAT-\* edit

☐ FLD CREAT- edit

☐ MA/UCREAT- edit

HCIL UNIVERSITY OF MARYLAND

Copyright 2007  
HCIL UMD



Records 240/3598



ARF Controls

Preferences

Align by...

1st Radiology Contrast (3598)

Rank by...

☒ name
 ☐ #/times Radiology Contrast (3598)

Filter by...

☐ nothing
 ☐ #/times 1 CREAT-H (1190)
 ☒ sequence CREAT- (2346)
 Radiology Contrast (3598)
 CREAT-H (1190)

Summarize by...

No summary

Expand all

Legend

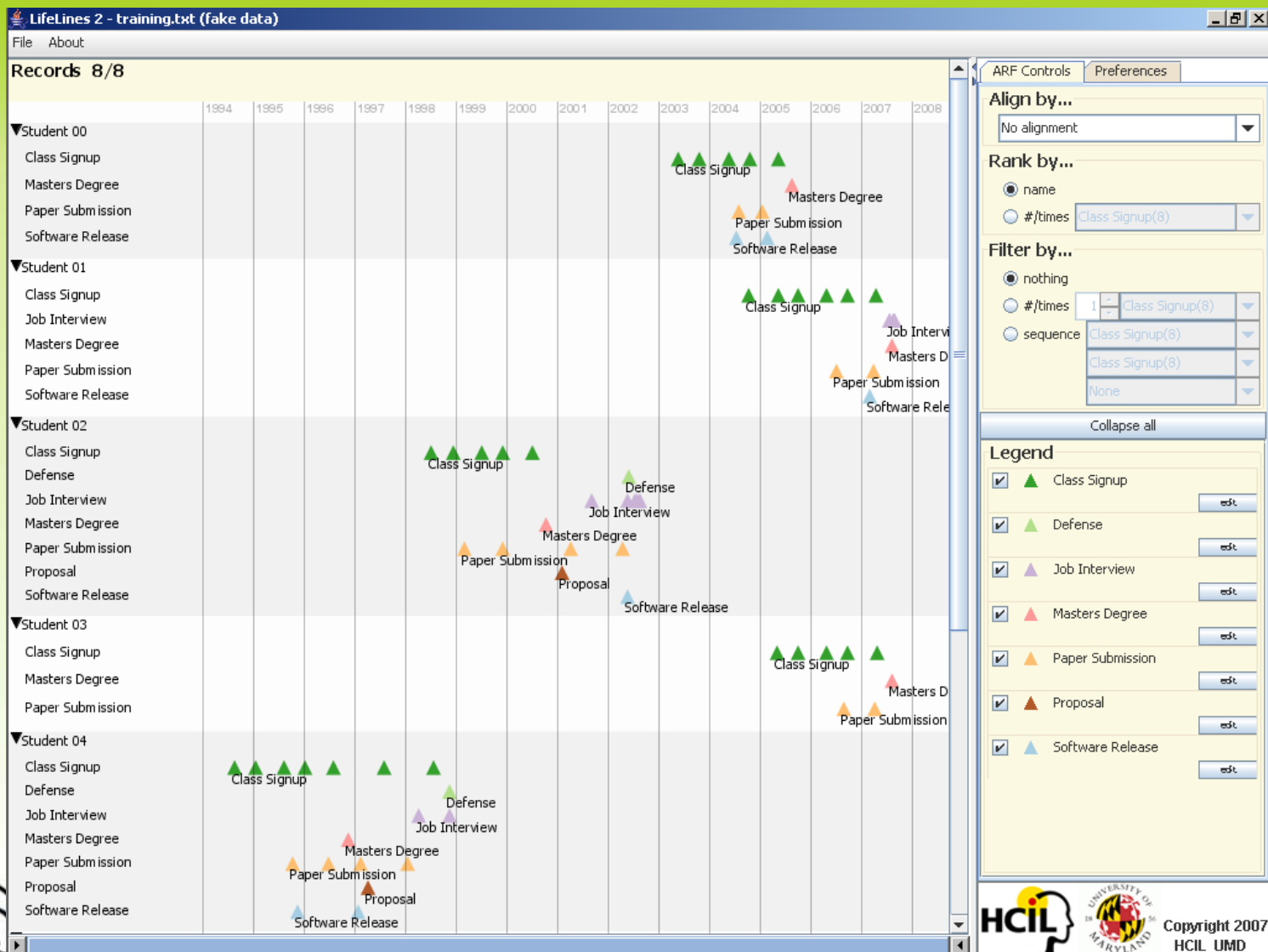
☒ CREAT-H
 ☒ CREAT-
 ☒ CREAT-L
 ☐ 24H UCREAT-H
 ☐ 24H UCREAT-
 ☐ 24H UCREAT-L
 ☐ BL CREAT-H
 ☐ BL CREAT-
 ☐ BL CREAT-\*
 ☐ BL CREAT-L
 ☐ CREAT-\*
 ☐ FLDCREAT-
 ☐ MA/UCREAT-

# Qualitative Evaluation Results

- Visual representation and ARF easily understood
    - Readily apply without training
  - 2/4 participants saw immediate utility in their own medical research
- 
- IV alters perception, interpretation of data
  - IV can be confusing
    - Did not trust how intervals are assigned
    - Interpreted the interval literally
  - Feedback on improving ARF

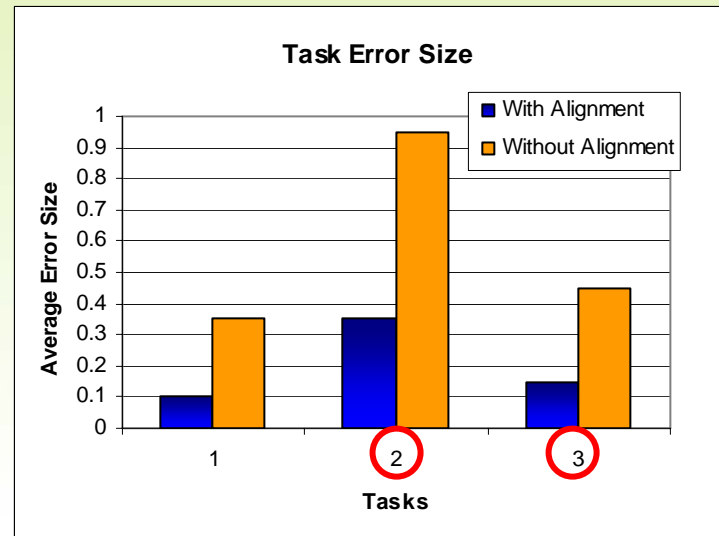
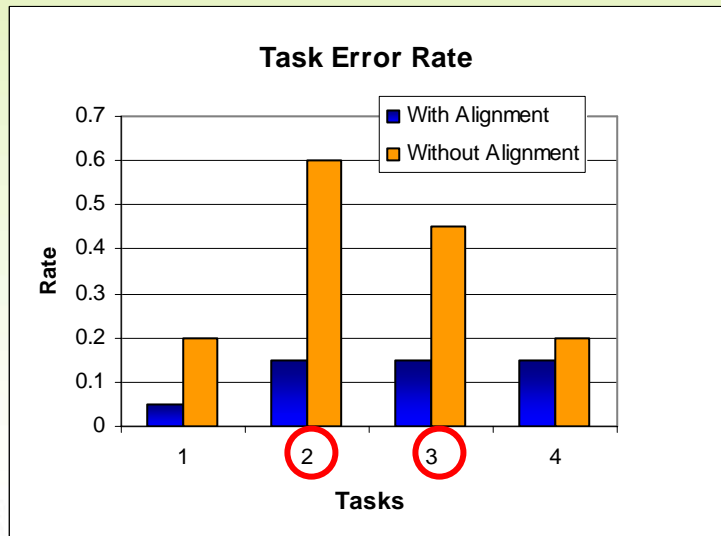
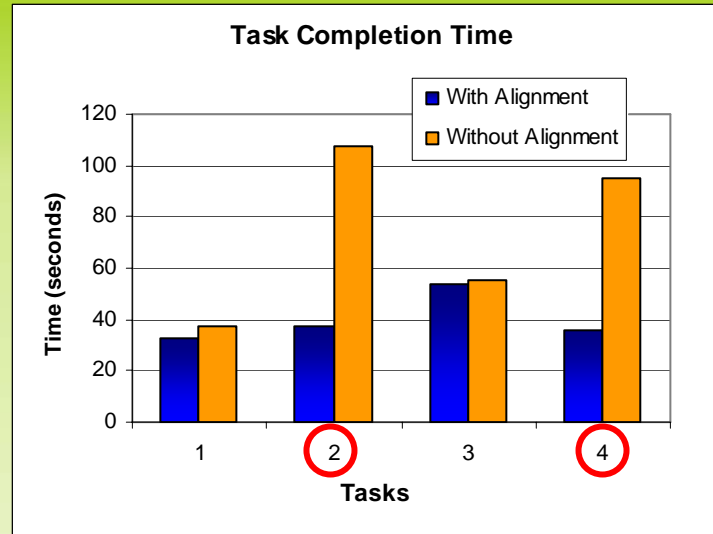


# Quant. Evaluation Sample Data

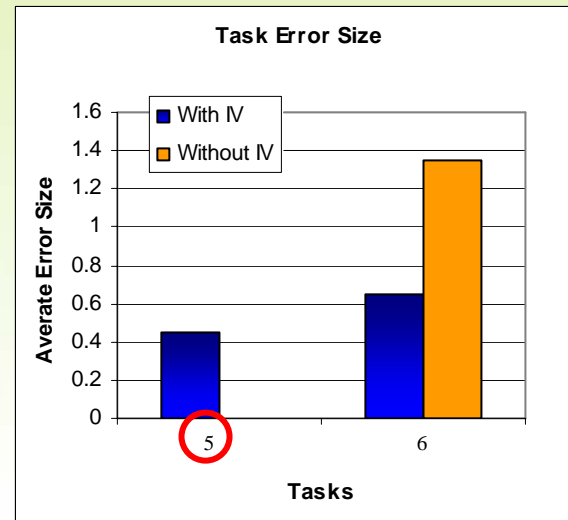
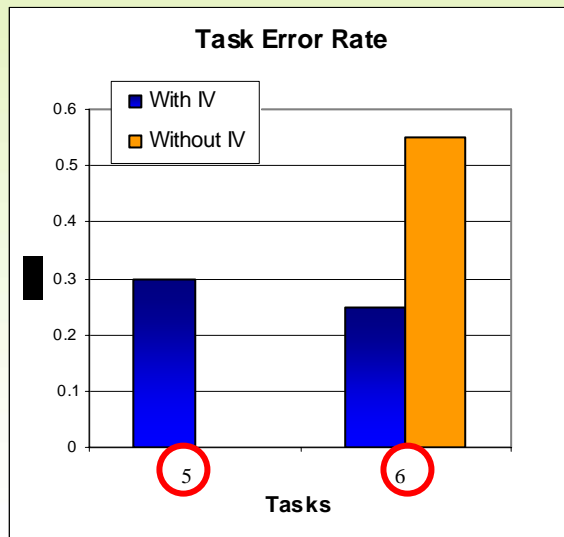
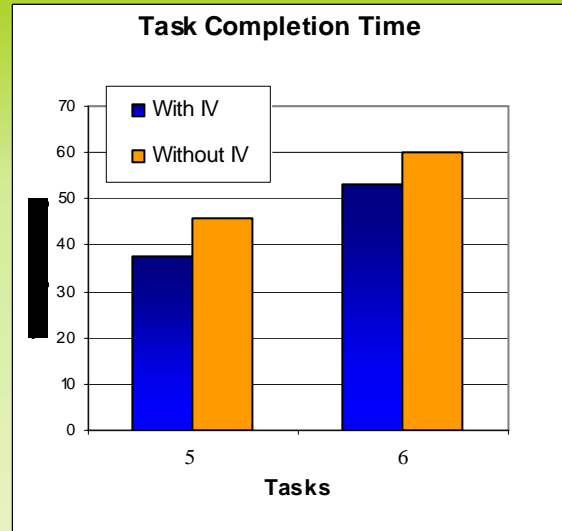


[Back to Evaluations](#)

# (Alignment vs. No Alignment)



# (IV vs. no IV)



# Quantitative Evaluation Tasks

- **Task 1:** How many students submitted a paper within 1 month after proposal? (5 records)
- **Task 2:** How many students submitted a paper within 1 month after proposal? (20 records)
- **Task 3:** How many students published at least 3 papers between proposal and defense?
- **Task 4:** What occurred most often within a month of a student's 1<sup>st</sup> paper submission?

For interval of validity

- **Task 5:** Assuming a class lasts 3 months, how many students proposed while they were taking a class?
- **Task 6:** Assuming a class lasts 3 months, and it takes 2 months to prepare for proposal, how many students were preparing for proposal while taking a class?



[Back to Evaluations](#)

LifeLine 8/97 9/97 10/97 11/97 12/97 1/98 2/98 3/98 4/98

▼ Problems

Severe headache

Seizure

Smoker

Thoracic outlet syndrome

Depression

▼ Allergies

asa - rash

codeine - angioedema

penicillin - anaphylaxis

toradol - angioedema

▼ Diagnosis

Migraine

Depressive disorder

Smoker

Seizure disorder

Possible irritable bowel syndrome

▼ Complaints

Headache

Migraine

Headache

Migraine

Left Lower Quadrant pain

Constipation

▼ Lab-Path

Dilantin(Phenytoin)

Liver profile

► Imaging

▼ Medications

Athenolol

Prochlorperazine

Butalbital/apap/caffeine tab

Chloral hydrate

Dilantin

Paxil

Propanolol

Promethazine HCL

Chloral hydrate

Dilantin

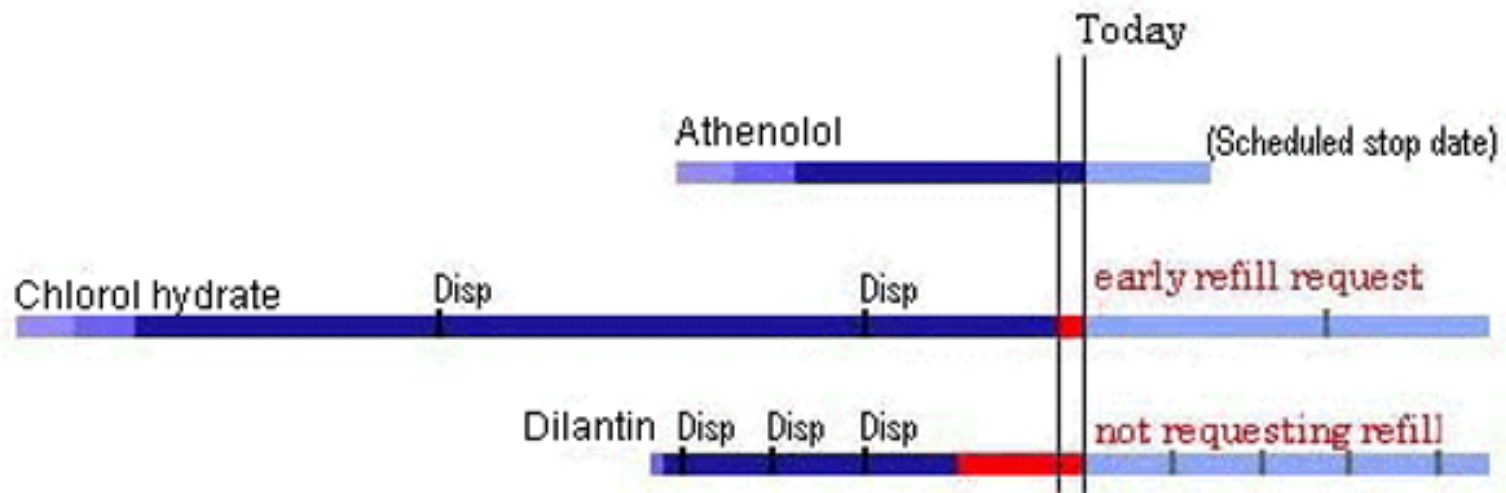
Meperidine

Nortriptyline HCL

Meperidine



# Medications examples



Aleve (thickness for dosage)

A horizontal bar with a light blue segment on the left and a dark blue segment on the right. The dark blue segment is thicker than the light blue segment.

# Summarization

- Important issue because of large time range
- Recursive aggregation mechanism  
(set of events) --- (summary event)

Propanolol	Propanolol	Athenolol	Propanolol
■	■	■	■
	Prochlorperazine	Prochlorperazine	Promethazine HCL
	■	■	■ ■ ■ ■

Betablocker

Phenothiazine

# i2b2 CRC Navigator in Exploration Mode

Shawn Murphy

Status: ● Log out Help

- Concept trees Find
- Demographics
  - Diagnoses
    - Circulatory system
    - Conditions in the perinatal period
    - Congenital anomalies
    - Digestive system
    - Endocrine disorders
    - Events of pregnancy
    - Genitourinary system
    - Hematologic diseases
    - Infectious and parasitic diseases
    - Injury and poisoning
    - Mental Disorders
    - Metabolic and immunity disorders
    - Musculoskeletal and connective tissue
    - Neoplasms
    - Neurologic Disorders
    - Nutritional deficiencies
    - Respiratory system
      - Acute respiratory infections
      - Chronic obstructive diseases
        - Adult bronchiectasis
        - Asthma
        - Bronchiectasis
        - Bronchiectasis NOS
        - Bronchiolitis
        - Bronchitis NOS
        - Bronchitis, not specified as acute or chronic
        - COPD
        - Chronic obstructive lung disease

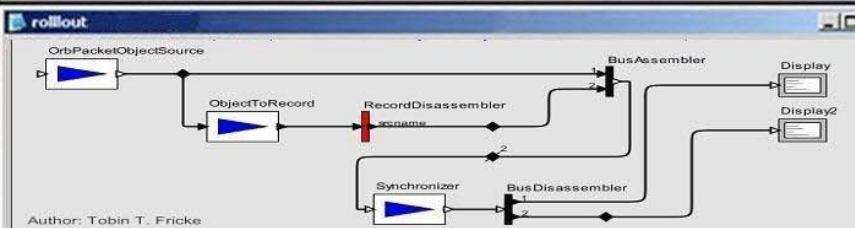
- Patient Sets & Previous Queries
- Digestive System, BWVH on 08/21/06
    - 01/01/06 - 34 Patients
    - 01/02/06 - 78 Patients
    - 01/23/06 - 4 Patients
      - John Smith
      - William Carter
      - Sarah Ahern
      - Rebecca Lynn
  - Circulatory System on 07/22/06
    - 01/01/06 - 34 Patients
    - 01/01/06 - 34 Patients
    - 04/718/06 - 49 Patients
    - 08/29/06 - 3 Patients
    - 08/01/06 - 9 Patients
      - Mike Li
      - David Johnes

Group 1			Group 2			Group 3		
Dates	Occurs 1x	Exclude	Dates	Occurs 1x	Exclude	Dates	Occurs 1x	Exclude
	<input checked="" type="checkbox"/>	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>
Bronchodilators			Prednisolone					
			Prednisone					
			and					
						Add Group		

Reset Run Query

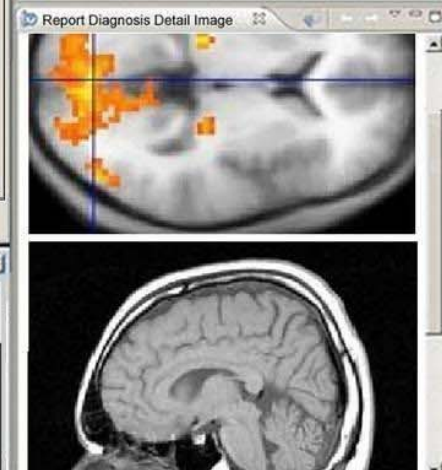


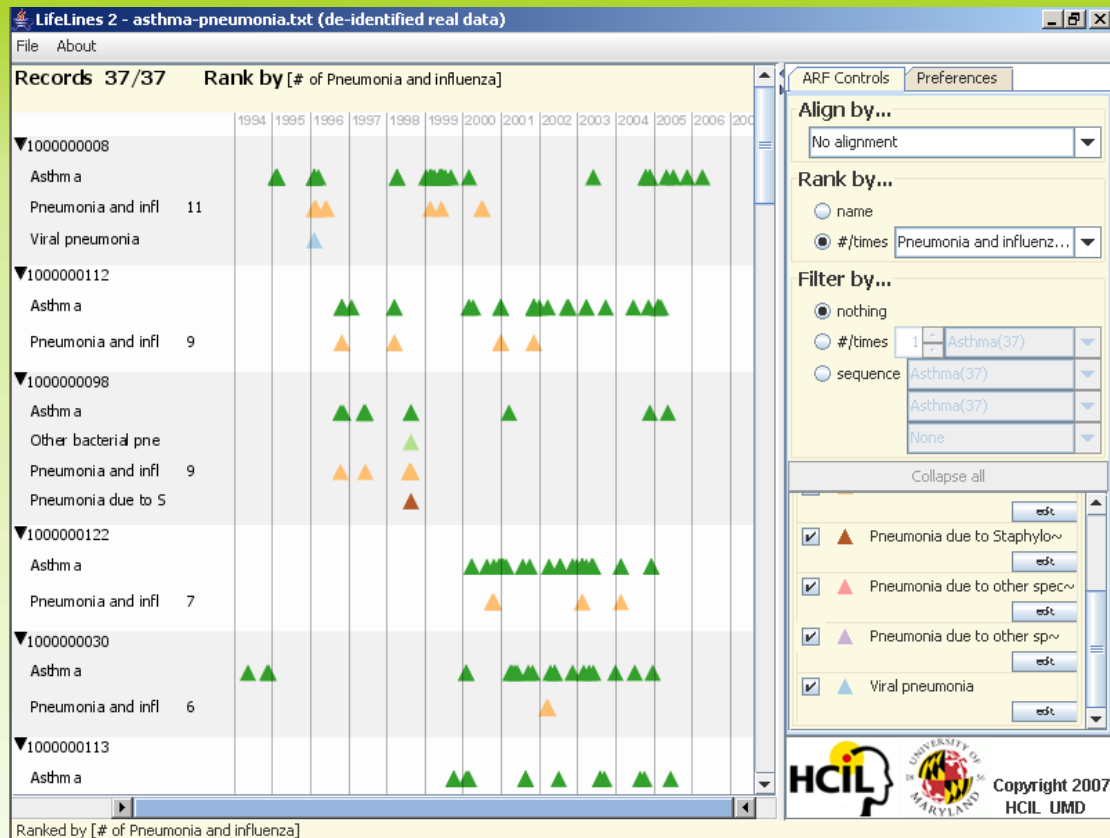
Patient Set: Patient Set - 3884 Patients <<< start: 0 Increment: 10 >>>

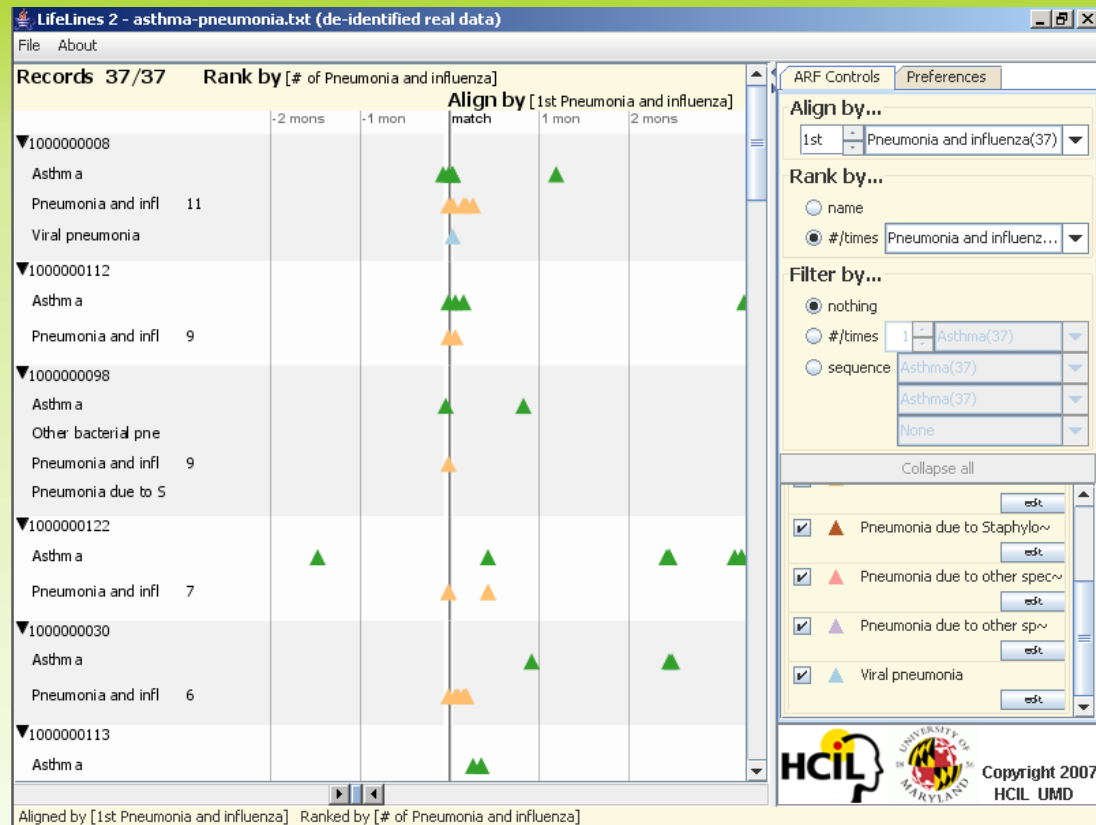


- Help
- Related Topics
- About Outline
    - View to show the outline (if applicable) of a resource being edited.
    - Views
    - Outline view
  - Dynamic Help
    - Search results:
      - Using the Java browsing perspective
      - Outline view
      - Searching the workspace
      - Opening a Java editor
- Go To:
- All Topics
  - Search
  - Bookmarks

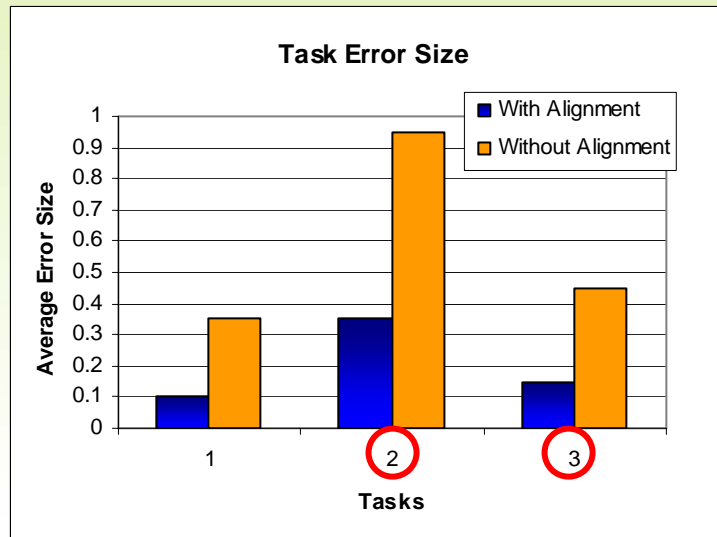
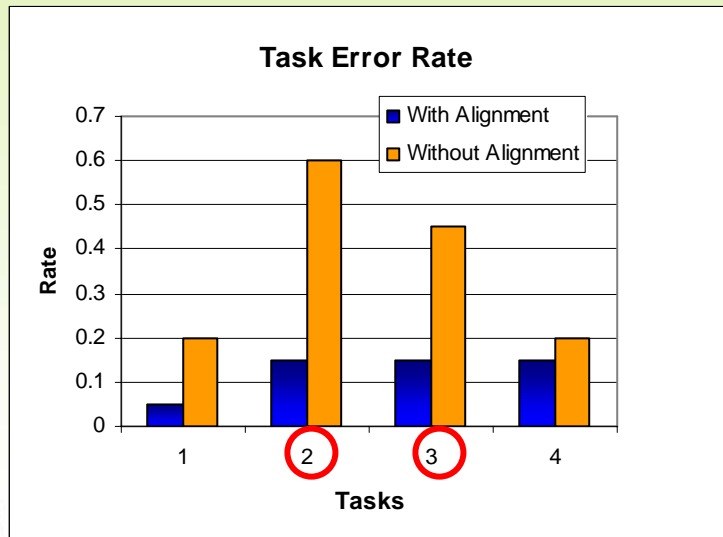
- Patient Schedule
- John Smith
- 03/01/2006 11:00 am - 12:00 am
    - REG - Medical Walk in
    - Murphy, Shawn Norman, M.D.
    - Visit Type: REG
  - 11/01/2006 1:00 pm - 2:00 pm
    - Search results:
      - Dermatology
      - Gordon, Susan Ruth, M.D.
      - Visit Type: REG



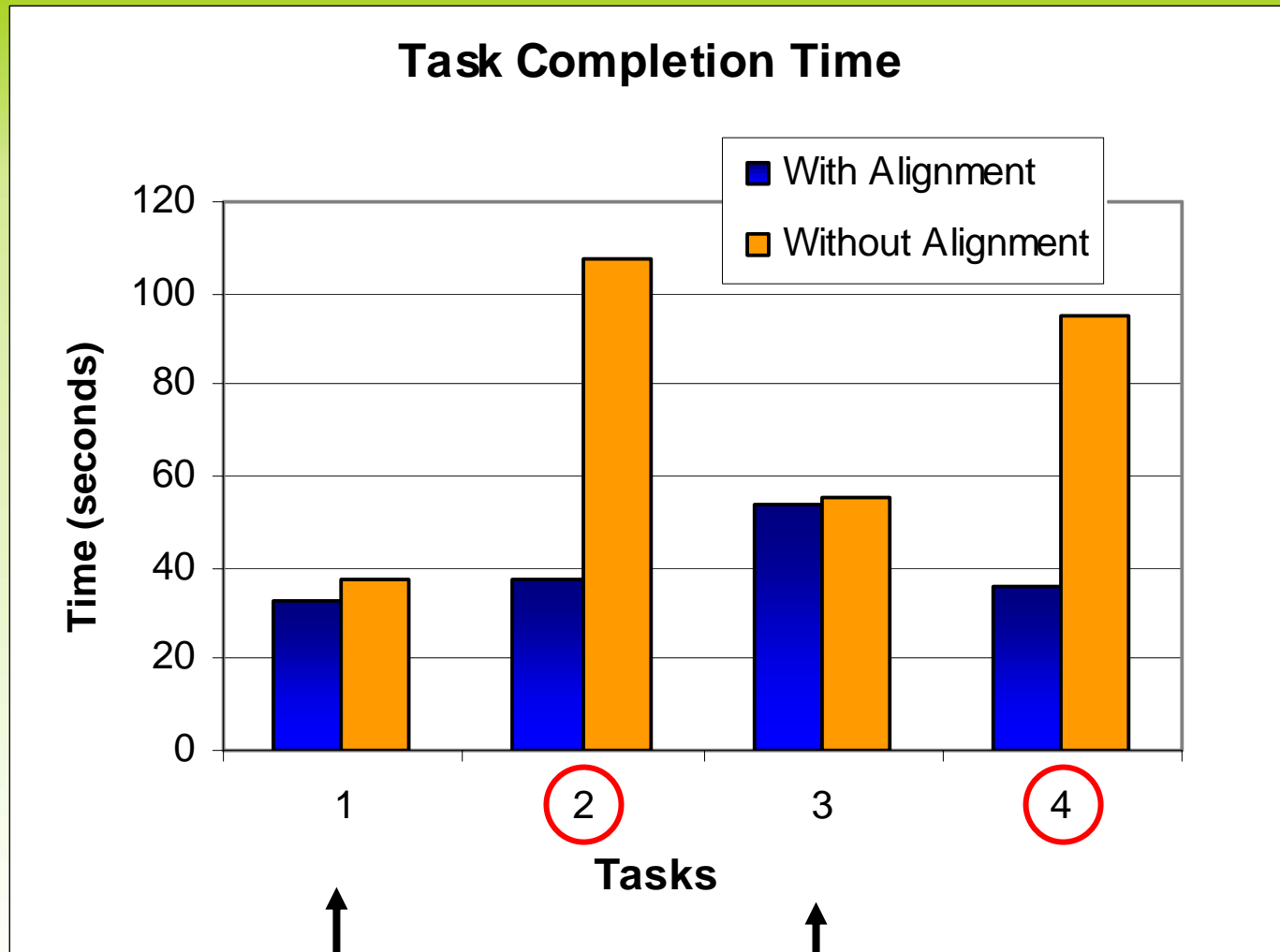




# Also fewer, smaller errors With alignment



# Task completion time



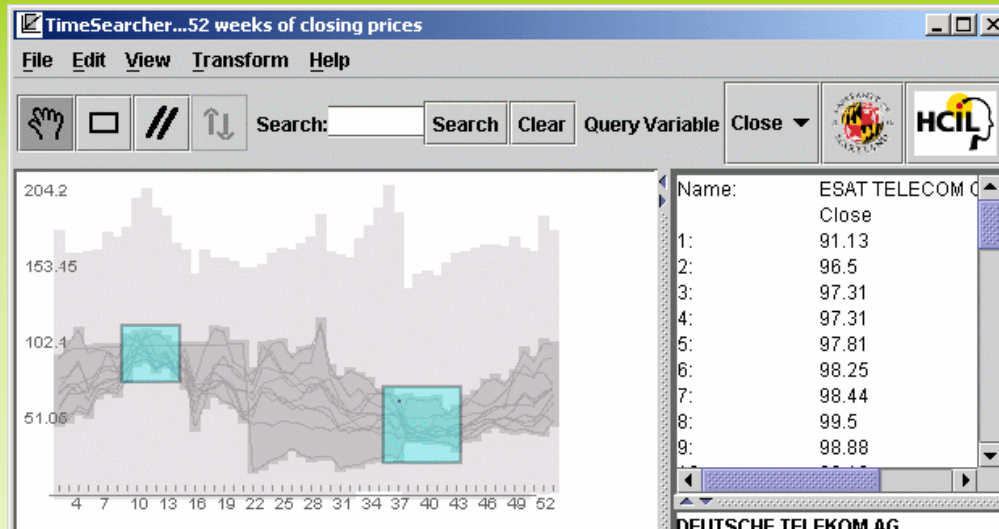
Not really useful if data fit in one screen

or if still learning i.e. best strategy not immediate



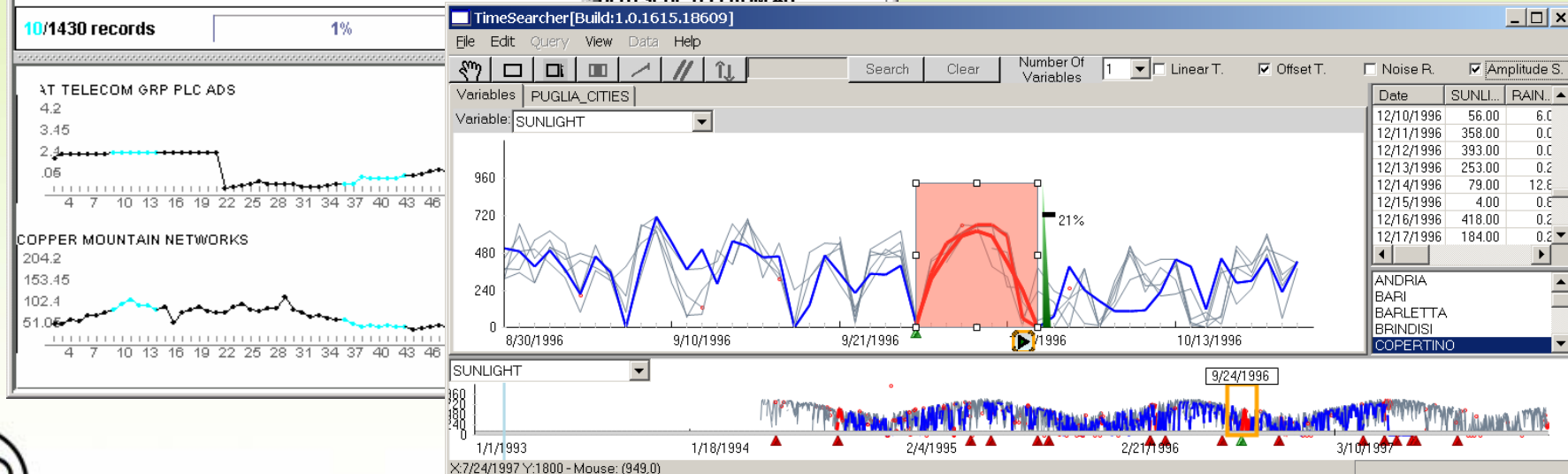
# TimeSearcher

## Dynamic queries on numerical temporal data



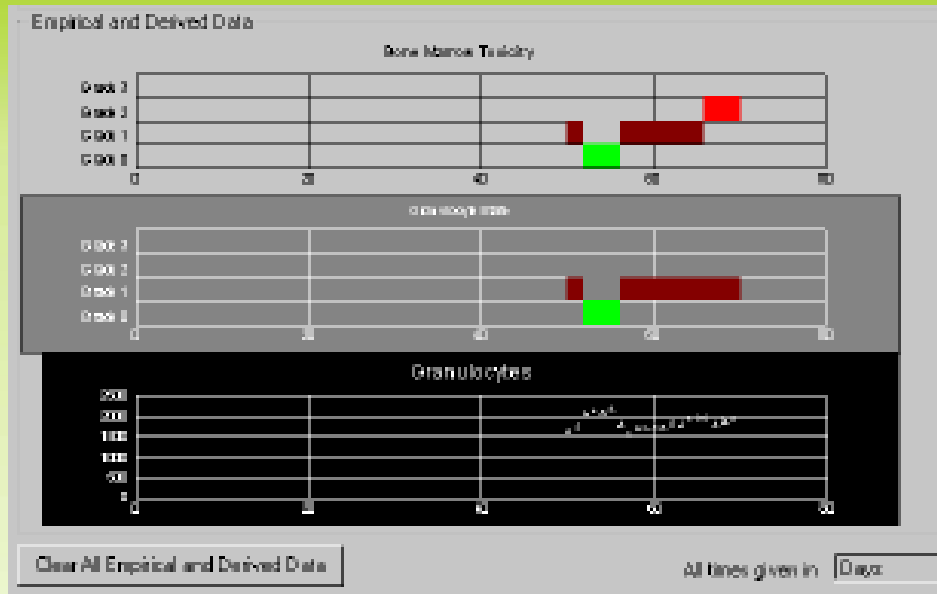
Hochheiser Infovis04

Buono VDA05



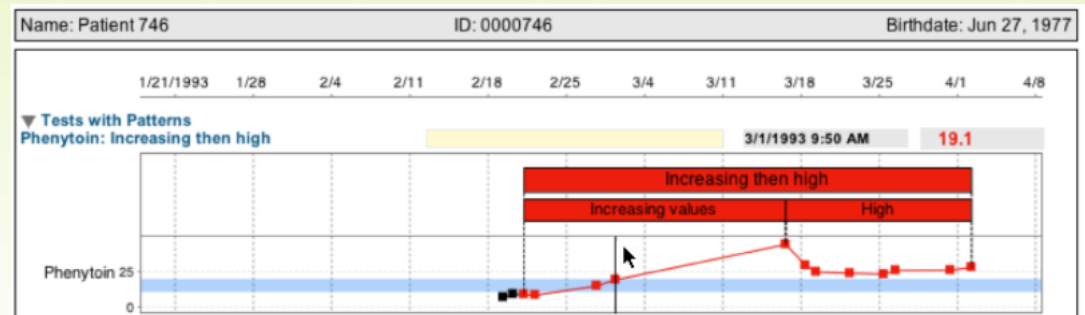
# Specification of temporal abstractions

## To reason/query with them



Post 2007

Shahar 1999



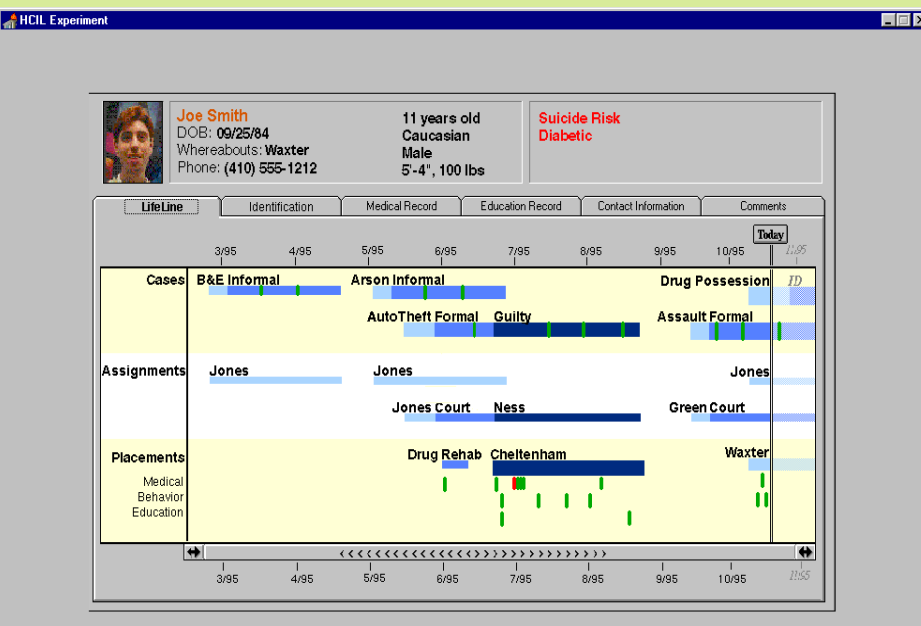
No focus on interaction

# Combine alignment with PatternFinder **Collaboration with Washington Hospital Center** (original developers of Azyxxi, now **Microsoft Amalga**)

- Connected to real time database
- Search UI was designed to match style of existing search interface
- Alignment integrated
- Put on desk of first users soon



# Measured benefits over tabular display



**Joe Smith**  
DOB: 09/25/84  
Whereabouts: Waxter  
Phone: (410) 555-1212

11 years old  
Caucasian  
Male  
5'-4", 100 lbs

**Suicide Risk**  
**Diabetic**

**Reviews**

Case	Review Date
1	3/15/95
1	4/2/95
2	5/26/95
2	6/8/95
3	6/15/95
3	7/13/95
3	7/29/95
3	8/14/95
5	9/22/95
5	10/10/95
5	10/19/95

**Cases**

Case	Received	Alleged Offense	Severity	Intake Decision	Decision Date	Court Finding	Court Date	Closed
1	2/20/95	B&E	4	Informal	3/3/95	NA		4/22/95
2	5/4/95	Arson	6	Informal	5/11/95	NA		6/29/95
3	5/19/95	Auto Theft	6	Formal	5/28/95	Guilty	6/20/95	8/22/95
4	9/14/95	Assault	8	Formal	9/20/95	NA		
5	10/12/95	Drug Possession	7					

**Assignments**

Case	Worker	Type	Start	Finish
1	Jones	Intake	2/20/95	4/22/95
2	Jones	Intake	5/4/95	6/29/95
3	Jones	Intake	5/19/95	5/28/95
3	Court	Court	5/28/95	6/20/95
3	Ness	Probation	6/28/95	8/22/95
4	Green	Intake	9/14/95	9/20/95
4	Court	Court	9/20/95	
5	Jones	Intake	10/12/95	

**Leaves**

Type	Placement	Severity	Date(s)
Medical	Drug Rehab	Normal	5/28/95
	Cheltenham	Normal	6/20/95
	Cheltenham	Critical	7/2/95
	Cheltenham	Normal	7/3/95
	Cheltenham	Normal	7/4/95
	Cheltenham	Normal	7/5/95
Behavior	Cheltenham	Normal	8/6/95
	Cheltenham	Normal	8/6/95
	Waxter	Normal	10/13/95
	Cheltenham	Normal	6/22/95
	Cheltenham	Normal	7/11/95
	Cheltenham	Normal	7/27/95
Education	Cheltenham	Normal	8/2/95
	Waxter	Normal	10/11/95
	Waxter	Normal	10/15/95
	Cheltenham	Normal	6/22/95

**Placements**

Case	Placement	Type	Start	Finish
3	Drug Rehab	Program	5/28/95	6/9/95
3	Cheltenham	Committed	6/20/95	8/22/95
5	Waxter	Detention	10/10/95	



# PatternFinder

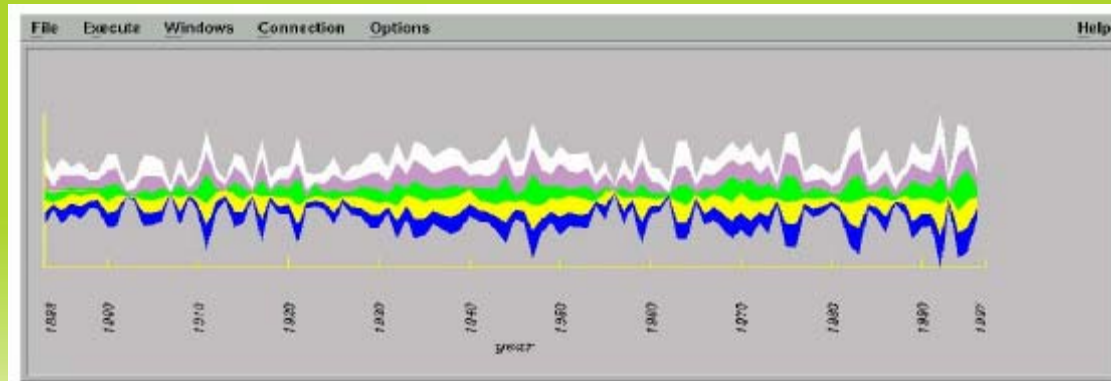
Specification of complex temporal queries on

The screenshot shows the TempViz PatternFinder interface. On the left, the 'Person/People' panel includes fields for Name, Age (4 to 78), Gender (Female and Male checked), and a 'People Selected: 6 of 950' status. The main area contains two event boxes. 'Event Box 1' is configured with Type 'Medications', Level 1 'Medications', Level 2 'Anti Depressan', and Level 3 'Remeron'. It has a value range of 4 to 126 and a span of 363 days. 'Event Box 2' is configured with Type 'Visit', Level 1 'Visit', Level 2 'Hospital', and Level 3 'Emergency'. It has a value range of -122 to 122 and a span of 180 days. A blue arrow indicates a temporal relationship between the two events. The bottom of the interface shows the date range from 01-Jan-2005 to 30-Dec-2005 and a 'Run Query' button.

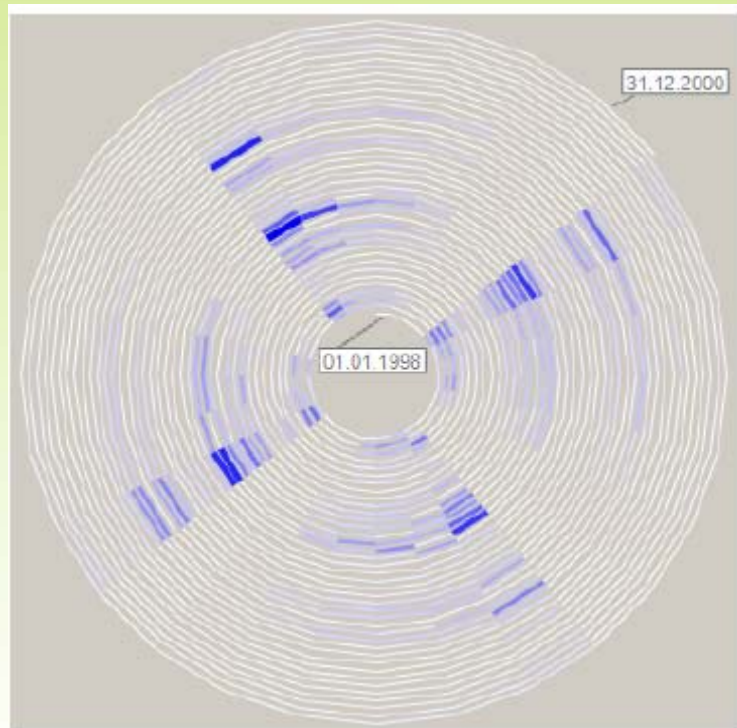
[Fails et al. VAST06]

Patients with increasing dosages of Remeron followed by a heart attack within 180 days

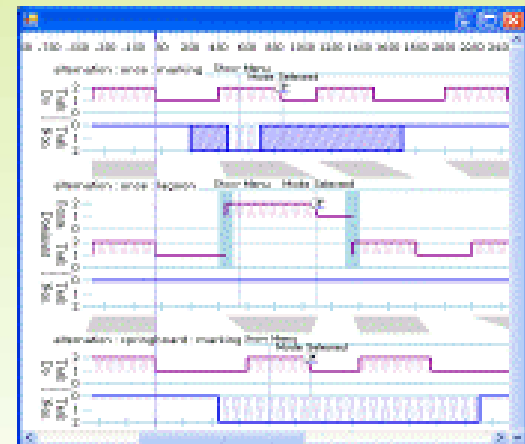




**ThemeRiver (Havre, Infovis00)**



**Spiral Graph: Weber 01 (based on Carlis UIST 89)**  
Periodic data



**Experiscope**  
**(Guimbretiere, CHI07)**  
One of many example of manual alignment