A Visual Interface for Multivariate Temporal Data: Finding Patterns of Events across Multiple Histories

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Time is Pervasive!

- Stock market trades
- Web log URLs
- Medical histories
- Crime/terror activities
- Maintenance records
Temporal Data: TimeSearcher 1.3

- Time series
  - Stocks
  - Weather
  - Genes
- User-specified patterns
- Rapid search
Temporal Data: TimeSearcher 2.0

- Long Time series (>10,000 time points)
- Multiple variables
- Controlled precision in match (Linear, offset, noise, amplitude)

www.cs.umd.edu/hcil/timesearcher
KNAVE: Clinical Patient Data

Distributed Knowledge-Based Abstraction, Visualization, and Exploration of Time-Oriented Clinical Data

(Shahar, 1998)
LifeLines: Visualizing Personal Histories

(Plaisant et al., CHI 1997)
Finding Patterns in Temporal Events

• Types of Time Data
  • Ordinal Values (e.g., TimeSearcher)
  • Categorical Events & Intervals (e.g., LifeLines)
  • Categorical Events

• Goal: Find Temporal Patterns Across Millions of Records
  • SQL makes it very difficult to specify
  • Temporal SQL helps only a little
Comparison with SQL

SELECT P.*
FROM Person P, Event E1, Event E2, Event E3, Event E4

WHERE P.PID = E1.PID
AND P.PID = E2.PID
AND P.PID = E3.PID
AND P.PID = E4.PID
AND E1.type = "Medication"
AND E1.class = "Anti Depressant"
AND E1.name = "Remeron"
AND E2.type = "Medication"
AND E2.class = "Anti Depressant"
AND E2.name = "Remeron"
AND E3.type = "Medication"
AND E3.class = "Anti Depressant"
AND E3.name = "Remeron"
AND E2.value > E1.value
AND E3.value >= E2.value
AND E2.date > E1.date
AND E3.date >= E2.date
AND E4.type = "Visit"
AND E4.class = "Hospital"
AND E4.name = "Emergency"
AND E4.value = "Heart Attack"
AND E4.date >= E3.date
AND 180 <= (E4.date – E3.date)
Temporal Patterns in Medical Histories

- **Reality**
  - Very large & complex data sets
  - Missing, uncertain, and redundant data

- **Tasks**
  - Alerts concerning patient status
  - Decision support for treatment decisions
  - Clinical research on outcomes
  - Identify groups of patients for testing
## Temporal Patterns in Medical Histories

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Visits and Hospitalizations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>Date</td>
<td>Doctor</td>
<td>Location</td>
<td>Reason</td>
</tr>
<tr>
<td>103</td>
<td>1/16/2004</td>
<td>Kakani, Indira</td>
<td>Clinic</td>
<td>Follow up</td>
</tr>
<tr>
<td>104</td>
<td>11/15/2003</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Follow up</td>
</tr>
<tr>
<td>105</td>
<td>10/15/2003</td>
<td>Carmichel, John</td>
<td>Hospital</td>
<td>Mastectomy</td>
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<tr>
<td>106</td>
<td>9/20/2003</td>
<td>Kakani, Indira</td>
<td>Hospital</td>
<td>Chemo treatment and</td>
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<tr>
<td>107</td>
<td>8/31/2003</td>
<td>Kakani, Indira</td>
<td>Hospital</td>
<td>mammogram</td>
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<td>108</td>
<td>8/15/2003</td>
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<td>Hospital</td>
<td>Chemo Treatment</td>
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<tr>
<td>109</td>
<td>7/31/2003</td>
<td>Kakani, Indira</td>
<td>Clinic</td>
<td>Chemo Treatment</td>
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<tr>
<td>110</td>
<td>6/15/2001</td>
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<td>Clinic</td>
<td>Felt lump during breast</td>
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<td>111</td>
<td>1/12/2000</td>
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<td>exam</td>
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<td>112</td>
<td>5/11/1999</td>
<td>Whitter, Herbert</td>
<td>Clinic</td>
<td>Annual exam</td>
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<td>113</td>
<td>9/29/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Annual exam</td>
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<tr>
<td>114</td>
<td>8/17/1997</td>
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<td>Hospital</td>
<td>Allergies kicking in</td>
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<td>115</td>
<td>8/15/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Followup</td>
</tr>
<tr>
<td>116</td>
<td>8/8/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>St. Thomas: Baby arrived</td>
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<tr>
<td>117</td>
<td>8/1/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Final?? prenatal visit</td>
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<tr>
<td>118</td>
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<td>Checkup</td>
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<tr>
<td>119</td>
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<td>reg checkup</td>
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<tr>
<td>120</td>
<td>6/21/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Beginning every two weeks</td>
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<td>121</td>
<td>6/1/1997</td>
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<td>regular checkup</td>
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<td>Jones, Sam</td>
<td>Office</td>
<td>Standard checkup</td>
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<td>Office</td>
<td>Ultrasound Followup</td>
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<td>124</td>
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<td>Kakani, Indira</td>
<td>Office</td>
<td>Check on high fever</td>
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<tr>
<td>125</td>
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<td>Office</td>
<td>Regular checkup</td>
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<tr>
<td>126</td>
<td>1/15/1997</td>
<td>Kakani, Indira</td>
<td>Office</td>
<td>Visit for ultrasound</td>
</tr>
</tbody>
</table>

**Tasks:**
- Alerts concerning patient status
- Decision support for treatment decisions
- Clinical research on outcomes
- Identify groups of patients for testing
Finding Patterns in Temporal Events

- Imagine simple table

<table>
<thead>
<tr>
<th>P-ID</th>
<th>Age</th>
<th>Gender</th>
<th>Date</th>
<th>Source</th>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/6/2005</td>
<td>Test</td>
<td>WBC</td>
<td>12</td>
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<tr>
<td>183</td>
<td>67</td>
<td>F</td>
<td>5/7/2005</td>
<td>ER</td>
<td>Symptom</td>
<td>Chest Pain</td>
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<tr>
<td>183</td>
<td>67</td>
<td>F</td>
<td>5/8/2005</td>
<td>Test</td>
<td>WBC</td>
<td>23</td>
</tr>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/12/2005</td>
<td>Medication</td>
<td>Tylenol</td>
<td>325mg</td>
</tr>
<tr>
<td>259</td>
<td>71</td>
<td>F</td>
<td>5/12/2005</td>
<td>Test</td>
<td>HDL</td>
<td>55</td>
</tr>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/14/2005</td>
<td>Test</td>
<td>WBC</td>
<td>19</td>
</tr>
</tbody>
</table>
Finding Patterns in Temporal Events

- Imagine an even simpler table

<table>
<thead>
<tr>
<th>P-ID</th>
<th>Age</th>
<th>Gender</th>
<th>Date</th>
<th>Source</th>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/6/2005</td>
<td>Test</td>
<td>WBC</td>
<td>12</td>
</tr>
<tr>
<td>183</td>
<td>67</td>
<td>F</td>
<td>5/7/2005</td>
<td>Test</td>
<td>WBC</td>
<td>14</td>
</tr>
<tr>
<td>183</td>
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<td>F</td>
<td>5/8/2005</td>
<td>Test</td>
<td>WBC</td>
<td>23</td>
</tr>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/12/2005</td>
<td>Test</td>
<td>RBC</td>
<td>4</td>
</tr>
<tr>
<td>259</td>
<td>71</td>
<td>F</td>
<td>5/12/2005</td>
<td>Test</td>
<td>HDL</td>
<td>55</td>
</tr>
<tr>
<td>174</td>
<td>73</td>
<td>M</td>
<td>5/14/2005</td>
<td>Test</td>
<td>WBC</td>
<td>19</td>
</tr>
</tbody>
</table>
Demo
Simple Search: Event (E)

- No TimeSpan

Find patients who had cholesterol test above 200
Simple Search: Two Events (E)

• No TimeSpan

Find patients who had cholesterol test above 200

And White Blood Cell above 10
Events with Fixed Time (E-FT)

- **Fixed TimeSpan length**

Find patients who had cholesterol test above 200 and White Blood Cell above 10 exactly 1 day later.
Events with Variable Time (E-VT)

- Variable TimeSpan length

Find patients who had cholesterol test above 200 and White Blood Cell above 10 with 0 to 7 days later.
Trends with Event Sets E*WC

- Sets of Events behave as single Events
- Adds Window and Cardinality constraints

Find patients with 3-8 WBC tests at 15-29, during a 6 day period
This pattern specifies any patient who received increasing dosages of Remeron followed by a heart attack within 180 days (along with the events constituting the temporal pattern match).
The results show five matches of people who received increasing dosages of Remeron followed by a heart attack within 180 days.
Current work

Work with Washington Hospital Center
  - Developing taxonomy of simple queries
  - Designing interface to fit in Azyxxi
  - Implementing simple searches

Lab value [HGB] is high, then decreases >1.5
Lab value [Platelets] is high in a patient on heparin, then decreases > 20%

Patient seen at ER & discharged, then returns to ER within 14 days
Patient seen at ER & discharged, then returns to ER within 14 days & condition = [dead]
Diverse Applications

Maintenance log
Replace battery, repair generator, repair starter,…

Web log analysis
Browse books, Checkout, Help, Leave Website

Terror/criminal behavior
Withdraw funds, buy weapon, purchase tickets…

TV viewing (in 30 min segments)
NBC, ABC, ABC, ABC, CBS, CBS
Contributions: Queries for temporal events

- Taxonomy of queries
- Visual specification
- Visualization of results: ball & chain view
Contributions: Queries for temporal events

- Taxonomy of queries
- Visual specification
- Visualization of results: ball & chain view
- Reformulation of relational completeness
- Facilitate medical treatment & research
<table>
<thead>
<tr>
<th>Pattern</th>
<th>Restrictions</th>
<th>Example</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E</strong> Events Only</td>
<td><strong>Event</strong>: Specify all non-temporal attributes of one or more events.</td>
<td>Find patients who have had at least 2 emergency doctor visits.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TimeSpan</strong>: No span. Left to right ordering implicitly denotes “any time later”.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E–FT Fixed TimeSpans</td>
<td><strong>Event</strong>: Specify all non-temporal attributes of two or more events.</td>
<td>Find patients whose cholesterol was above 240 but two weeks later was below 200.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TimeSpan</strong>: Relative TimeSpan of fixed size.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E–VT Variable TimeSpans</td>
<td><strong>Events</strong>: Same as E–FT.</td>
<td>Find patients whose cholesterol was above 240 but fell below 200 within 2 months.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>TimeSpan</strong>: Relative TimeSpan of variable size.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Taxonomy Table (2 of 2)

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Restrictions</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E^e–VT</strong>&lt;br&gt;Variable Events&lt;br&gt;Variable TimeSpans</td>
<td><strong>Event</strong>: Specify a <em>subset</em> of non-temporal attributes of one or more events.&lt;br&gt;<strong>TimeSpan</strong>: Same as E–VT</td>
<td><img src="image1.png" alt="Example Image" /> Find patients who had an emergency doctor’s visit followed by a hospitalization within a week.</td>
</tr>
<tr>
<td><strong>E^wc–VT</strong>&lt;br&gt;Linked EventSet and Event</td>
<td><strong>Event</strong>: Specify a subset of non-temporal attributes of one or more event <em>sets</em>. The elements of an event set are defined by a relative time <em>window</em> during which all events in the set must occur, as well as <em>cardinality</em> - the number of events that must occur within the window.&lt;br&gt;<strong>TimeSpan</strong>: Same as E–VT.</td>
<td><img src="image2.png" alt="Example Image" /> Find patients who had 3 or more hospitalizations within two months followed by a heart attack hospitalization within a month.</td>
</tr>
<tr>
<td><strong>f(E^wc)–VT</strong>&lt;br&gt;EventSet</td>
<td><strong>Event</strong>: Same as E^wc–VT plus a functional condition that must hold across all members of the set.&lt;br&gt;<strong>TimeSpan</strong>: Same as E–VT</td>
<td><img src="image3.png" alt="Example Image" /> Find patients whose cholesterol increased by at least 20 points each reading for 3 months.</td>
</tr>
</tbody>
</table>
Current work

Query 1: Fixed patient values and fixed dates
Low HGB followed by higher HGB after 9/22/2006
Filter1: HGB < 150  Date < 9/22/2006
Filter2: HGB > 160  Date > 9/22/2006

Query 2: Fixed patient values and relative dates
Low HGB followed by higher HGB After the first reading.
Filter1: HGB < 150  Date < 9/22/2006
Filter2: HGB > 160  Date AFTER F1.Date

Query 3: Relative patient values and relative dates
Low HGB followed by HGB 5 points higher, After the first reading.
Filter1: HGB < 150  Date < 9/22/2006
Filter2: HGB > F1.HGB+5  Date AFTER F1.Date