CSE 564
Visualization and Visual Analytics
Time Varying and Streaming Data

Klaus Mueller
Computer Science Department
Stony Brook University
<table>
<thead>
<tr>
<th>Lecture</th>
<th>Topic</th>
<th>Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Intro, schedule, and logistics</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Applications of visual analytics, basic tasks, data types</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Introduction to D3, basic vis techniques for non-spatial data</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Data assimilation and preparation</td>
<td>Project #1 out</td>
</tr>
<tr>
<td>5</td>
<td>Bias in visualization</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Data reduction and dimension reduction</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Visual perception and cognition</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Visual design and aesthetics</td>
<td>Project #1 due/Project #2 out</td>
</tr>
<tr>
<td>9</td>
<td>High-dimensional data vis. &amp; dimensionality reduction</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Visual design and aesthetics</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Cluster analysis and dimension reduction</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Cluster analysis and dimension reduction</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Cluster analysis and dimension reduction</td>
<td>Project #2 due</td>
</tr>
<tr>
<td>14</td>
<td>Foundations of scientific and medical visualization</td>
<td>Project #3 out</td>
</tr>
<tr>
<td>15</td>
<td>Computer graphics and volume rendering</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Scientific and medical visualization</td>
<td>Project #3 due/Final project proposal call</td>
</tr>
<tr>
<td>17</td>
<td>Illustrative rendering</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Principles of interaction</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Visual analytics and the visual sense making process</td>
<td>Final project proposal due</td>
</tr>
<tr>
<td>20</td>
<td>Midterm #1</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Midterm discussion</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Tasks, VA design and evaluation with user studies</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td><strong>Visualization of time-varying, time-series &amp; streaming data</strong></td>
<td>Final project prelim report due</td>
</tr>
<tr>
<td>24</td>
<td>Visualization of geospatial data</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Visualization of graphs and hierarchies</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Memorable vis., visual embellishments, infographics</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Midterm #2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final project presentations</td>
<td>Final Project slides, video, report due</td>
</tr>
</tbody>
</table>
Wednesday 28 April 1999; Posted: 11:33 p.m. EDT (03:33 GMT): Another robbery occurred in southwestern Ontario today, making this the fourth robbery in the past few months. Delaware Bank in Brantford was robbed by three masked individuals who stole $150,000 in currency and several unknown items from the bank’s vault. The bank robbery occurred at 2:30, lasting all of five minutes and injuring eight people. All injured parties were taken to the local hospital where one died on arrival. Two people were released and the remaining people are in intensive care. This robbery is similar to a crime spree that started on the Chinese New Year. The first robbery occurred in the morning at Allegiant Bank in Richmond Hill, with the robbers taking more than $100,000 in currency. The second robbery occurred about two weeks later at Banner Bank in Ajax and was caught on tape. The robbers arrived just as the bank opened, riding in a white van and wearing black ski masks and black outfits, and carrying automatic machine guns. During the first three minutes, the robbers instructed all of the patrons to face the wall and place their hands on their heads. While two of the robbers watched the patrons, the other robber took the bank manager and instructed him to open the vault. Other video captured the movement in the vault. The vault was opened about five minutes after the robbers arrived. The safe was blown two minutes later, and the robber removed only two safety deposit boxes and placed them in a bag. He then continued to club the manager and was back upstairs, yelling instructions to his buddies as they left the bank, not more than 20 minutes after they arrived. What was unusual was that no alarms were sounded. The third robbery happened at night at Carter Bank in Brampton, with only nearby homeowners mentioning that they do not remember hearing the bank alarm, only dogs barking for a while....
Why are temporal relationships difficult to discern?
Temporal relationships can be difficult to discern because

- temporal ordering can be hard to determine
- event may occur in spatially disjoint locations
- what came before what – cause and effect
- what time shifts are acceptable/plausible?

To understand temporal relationships, an analyst:

- might need to reread the paragraph many times
- needs to cognitively make inferences between pieces of information

Visualization is key to externalize these relationships

- put it all out on “paper” and reason with it
What actually is time?

- how can one work with the metaphor of time’s flow?
- what is the proper formalism that captures the time’s special role in reasoning

The time variable is different than the other variables

- people consider it as an independent quantity
- can’t go back in time
- our perception is that we have no control over it
- time is an ever-present thread that can help tie events together
Calendars and time have reference frames

- Gregorian, Greenwich, EDT

Time is also often used in relative terms:

- “today”, “yesterday”, “fortnight”, “before Tuesday”, …
- must normalize different reference systems into a common framework
- but it might be unknown what reference system was used individually
- “This robbery is similar to a crime spree that started on the Chinese New Year …” – when is Chinese New Year?
- causes ambiguities, uncertainties, biases, conflicts
Bank Robbery Example (from Kuchar et al. IEEE CG&A May/June 2006)

1st robbery: Allegiant Bank; morning; started on Chinese New Year; 16 Feb., 1999

2nd robbery: Banner Bank; 2 weeks later

3rd robbery: Carter Bank; night

Robbery today (28 Apr.) at 2:30: duration 5 min.
Often asked questions:

- when was something greatest/least?
- is there a pattern?
- are two series similar?
- does a data element exist at time t, and when?
- how long does a data element exist and how often?
- how fast are data elements changing
- in what order do they appear?
- do data elements exist together?

Different types of time series data:

- discrete vs. interval
- linear vs. cyclic
- ordinal vs. continuous
- ordered vs. branching vs. time with multiple perspectives
Traditional Time Series Visualizations

NVIDIA stock vs. NASDAQ (from yahoo! finance)
Fun one... (found in J. Stasko lecture)
A few good visualization metaphors for time
  • there are quite a few of them…
River widens or narrows to depict changes in the collective strength of selected themes in the underlying documents. Individual themes are represented as colored "currents" flowing within the river.

Example shown here: newspaper themes around the Cuban Missile crisis

Summer blockbusters and holiday hits make up the bulk of box office revenue each year, while contenders for the Oscars tend to attract smaller audiences that build over time. Here's a look at how movies have fared at the box office, after adjusting for inflation.

Each shape shows how one film did at the box office.

Height shows weekly box office revenue

Width shows longevity

The area of the shape (and its color) corresponds to the film's total domestic gross, through Feb. 21

Sources: Baseline StudioSystems, Box Office Mojo

Mathew Bloch, Lee Byron, Shan Carter and Amanda Cox
How Different Groups Spend Their Day
The American Time Use Survey asks thousands of American residents to recall every minute of a day. Here is how people over age 15 spent their time in 2008. Related article

Everyone
Sleeping, eating, working and watching television take up about two-thirds of the average day.

<table>
<thead>
<tr>
<th></th>
<th>Everyone</th>
<th>Employed</th>
<th>White</th>
<th>Age 15-24</th>
<th>H.S. grads</th>
<th>No children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stacked Area Charts
New! Try the NameMapper to see where your favorite names are being used, and Namipedia for full info on every name.
Question

Can you tell me who is who?

- I tell you all the names there are and the age of each person
- can you assign them? (hint: use the Name Voyager)
Medical data are often displayed along time

- natural to humans
- progression of disease
- appearance of symptoms
- time course of treatment and outcome
- but also time signals (ECG, blood pressure, etc.)

A popular example is Lifelines and Lifelines2

- Shneiderman and Plaisant et al.
LifeLines: Patient-Centric
Goals:

• bring out temporal categorical patterns across multiple records
• categorical event data such as complaints, diagnoses, treatments
• play important roles in health providers decision making

Features

• allows users to manipulate multiple records simultaneously
• understand relative temporal relationships across records
• 3 operators: align, rank, filter
• temporal summaries allow multiple groups of records to be compared
Deal with different levels of detail

- illustrative abstraction
- overview + detail
- used here for medical data
Cyclic Patterns

Time data are often cyclic

- Spiral displays are good to bring out cyclic patterns
- One period per loop (for example, a year)

![linear layout](image1)
![radial layout](image2)
![sunshine pattern](image3)

Weber et al., 2001

Figure 2. An indented spiral, with spokes, showing monthly consumption percentages for Baphia Capparidifolia during the period 1980 – 1988.
Cyclic Patterns

May have to play around to discover the cycles

from J. Stasko, lecture notes
OculusInfo Geotime application

• events are represented in an X,Y,T coordinate space
• the X,Y plane shows geography
• the vertical T axis represents time
• events animate in time vertically through the 3-D space as the time slider bar is moved.

http://www.oculusinfo.com/SoftwareProducts/GeoTime.html
Geotime
As complexity increases, interaction capabilities are key

- show more context of what else was going on at that time
- likely have to abstract some of the information
- allow several different levels of detail at once
- allow drill-down for details
- use dashboard design with many linked information displays

Example: Computer system management

- LiveRAC system (McLachlan et al.)
- next two slides
Figure 3. LiveRAC shows a full day of system management time-series data using a reorderable matrix of area-aware charts. Over 4000 devices are shown in rows, with 11 columns representing groups of monitored parameters. (a): The user has sorted by the maximum value in the CPU column. The first several dozen rows have been stretched to show sparklines for the devices, with the top 13 enlarged enough to display text labels. The time period of business hours has been selected, showing the increase in the In pkts parameter for many devices. (b): The top three rows have been further enlarged to show fully detailed charts in the CPU column and partially detailed ones in Swap and two other columns. The time marker (vertical black line on each chart) indicates the start of anomalous activity in several of spire’s parameters. Below the labeled rows, we see many blocks at the lowest semantic zoom level, and further below we see a compressed region of highly saturated blocks that aggregate information from many charts.
Quick Preview on Future Lectures

Stuff that might come in handy for your final project:

- maps
- hierarchies
Maps

Choropleth maps

- use them whenever your data have a geospatial component
- uses a shapefile format for storing location, geo-shape, and attributes of geographic features
- use [leaflet.js](https://leafletjs.com) which is an open-source JavaScript library
Hierarchies: Sunburst Diagram

Complete hierarchy sunburst

Incomplete hierarchy sunburst
Hierarchies: Tree Diagram

Horizontal tree diagram
Chord Diagrams

Can show flows among a set of entities

Examples:

• refugees: the number of people migrating from one country to another
• economics of trade: relationships among countries or blocks
• consumer loyalty, such as folks switching from one brand to another

Chord diagram
Chord Diagrams with Hierarchical Edge Bundling

Visualize adjacency relations between entities in a hierarchy

- bundle the adjacency edges together
- decreases the clutter usually observed in complex networks

Hierarchical edge bundling
Time series data with no end…
Types of Streaming data

Transaction streams
  • credit card, point-of-sale transaction
  • at a supermarket, or online purchase of an item

Web click-streams

Social streams
  • online social networks such as Twitter
  • speed and volume of the stream typically scale super-linearly with the number of actors

Network streams
  • communication networks contain large volumes of traffic streams
  • often mined for intrusions, outliers, or other unusual activity
Challenges (1)

One-pass constraint

- data is generated continuously and rapidly
- it is assumed that the data can be processed only once
- archival for future processing is not possible
- prevents use of iterative mining or model building algorithms that require multiple passes over the data

Concept drift, concept evolution, feature evolution

- data may evolve over time
- various statistical properties, such as correlations between attributes, correlations between attributes and class labels, and cluster distributions may change over time
Concept Drift

Current hyperplane

Previous hyperplane

A data chunk

Negative instance •

Positive instance ○

Instances victim of concept-drift ○

Latifur Khan, et al. IBM
Classification rules:

R1. if \((x > x_1 \text{ and } y < y_2)\) or \((x < x_1 \text{ and } y < y_1)\) then class = +

R2. if \((x > x_1 \text{ and } y > y_2)\) or \((x < x_1 \text{ and } y > y_1)\) then class = -

Existing classification models misclassify novel class instances

Latifur Khan, et al. IBM
CluStream Clustering

The concept drift in an evolving data stream changes the clusters significantly over time

- need a clustering algorithm that can deal with this
- CluStream is such an algorithm

CluStream’s online microclustering clustering stage

- processes the stream in real time to continuously maintain summarized but detailed (micro-)cluster statistics of the stream

CluStream’s offline macroclustering stage

- further summarizes these detailed clusters
- provides the user with a more concise understanding of the clusters over different time horizons and levels of temporal granularity.
There are k microclusters

- a new data point either needs to be absorbed by a microcluster, or it needs to be put in a cluster of its own

Algorithm

- determine distance of the new data point to all current microcluster centroids
- assign the point to the closest cluster and update the statistics
- if the point does not fall within the maximum boundary of any microcluster create a new microcluster
- to create this new microcluster, the number of other microclusters must be reduced by 1 to free memory availability
- achieve this by either deleting an old microcluster or merging two of the older clusters
- decide by examining the staleness (using the time stamp statistics) of the different clusters, and the number of points in them
- determine whether one of them is “sufficiently” stale to merit removal
- if no microcluster is stale, then a merging of the two microclusters is initiated
Assume for now we have
- two attributes (burglary, theft)
- both observed over time

Can visualize
- but each point is a time series!
**Similarity Measures**

Needed it for clustering
- recall Euclidean, correlation, cosine distances

- similarity of two states
- similarity of two crimes
- similarity of two crimes in a given state over time
- similarity of two states for a given crime over time

![Excel Table]

- State: CALIFORNIA, MICHIGAN, TENNESSEE, MISSOURI, MARYLAND, ALABAMA, OHIO, ILLINOIS, ARKANSAS, CALIFORNIA, WISCONSIN
- Crime: Burglary, Larceny-theft, Motor Vehicle Theft, Arson, Violent

- Time series:
  - Euclidean
  - Correlation
  - Cosine

- Similarity measures for crime trends and state comparisons.
What can be clustered with these measures?
- crimes (averaged over time)
- states (averaged over time)
- crimes in a given state (taking time series into account)
- states for a given crime (taking time series into account)

Can we get more inclusive?
- cluster crimes but including the time series characteristics
- cluster states but including the time series characteristics

Capture more information about their time series when you compare two data points
- compute the similarity of two crimes by summing the times-series similarities for each state
- compute the similarity of two states by summing the times-series similarities for each crime
**In Practice**

**Time-series aware similarity (distance) $S_{tsa}$ for a pair of states**

for a given pair of states $i, j$

for each crime $c$

compute the time series similarity $\rightarrow \text{sim}_t(c)$

sum all $\text{sim}_t(c)$ $\rightarrow S_{tsa}(i,j)$

$S_{tsa}$ for a pair of crimes

for each pair of crimes $i, j$

for each state $s$

compute the time series similarity $\rightarrow \text{sim}_t(s)$

sum all $\text{sim}_t(s)$ $\rightarrow S_{tsa}(i,j)$

If the time series are aligned for all states then the $S_{tsa}$ will be high and the two crimes have very similar time behaviors nationwide.

similarity could be some measure of correlation of the two time series vectors
The time series might not be aligned
  - one crime might cause another
  - can apply dynamic time warping (see next)

You may (also) have a geospatial component in your data
  - can use them as a regular attribute (encoded by an ID)
  - can you make them more continuous and linearly ordered?
  - use a space filling curve (see next)

You may want to just keep time instances as separate entities
  - that will work too
  - then you might discover clusters that are sensitive to time
  - or you can see how the years relate to another along a trajectory
  - as a general rule, when you visualize multivariate data first decide what you will put into the rectangular data matrix (samples, attributes)
Standard pairwise distance

$$\text{Dist}(X, Y) = \left( \sum_{i=1}^{n} |x_i - y_i|^p \right)^{1/p}$$

Shortcomings:
- designed for time series of equal length
- cannot address distortions on the temporal (contextual) attributes
Can better accommodate local mismatches

Three constraints

- no skipping of beginning or ends of either sequence
- continuity – no jumps
- monotonicity – can’t go back in time
DTW – Find The Minimum Cost Path

Euclidian

DTW
DTW – Find The Minimum Cost Path

DTW

Compute using dynamic programming

Available in python
Convert a geographical map into a grid map

Linearize using a space-filling curve (Hilbert curve)