Tutorial on Over-Time Networks

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Future Help / Questions

ORA Google Group

https://groups.google.com/forum/#!forum/ORA-google-group

This group is to support the sharing of information about network science, and the network science tools ORA (PRO or LITE), NetMapper, SM-deidentifer, AutoMap and Construct. All members should feel free to post and answer questions.

You can request membership in this Google Group by sending e-mail to:

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Over 700 Members who can and do help answer questions from new members

Outline of Tutorial

- Network Representation for Dynamic Networks
  - Using ORA as a example vehicle
- Over-Time Network Stability vs. Change
  - How networks change over time
- Measures on Network Structures that vary over time
  - How to analyze Networks that change over time to get measures
  - Change Detection on Network measures
- Tracking Changes in Geo-Temporal Network Structures
  - How to analyze Networks that change over time and space

CASOS

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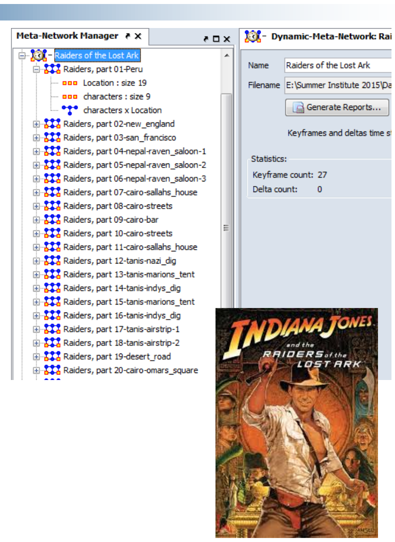
Start with an Example

- This dataset is a mapping of the 1981 movie "Raiders of the Lost Ark"
- It is a dynamic meta-network containing 27 different time periods
- Each time period contains the same 19 locations and 9 characters
- Each differs from another in two ways
  - The links present/not present
  - The timestamp



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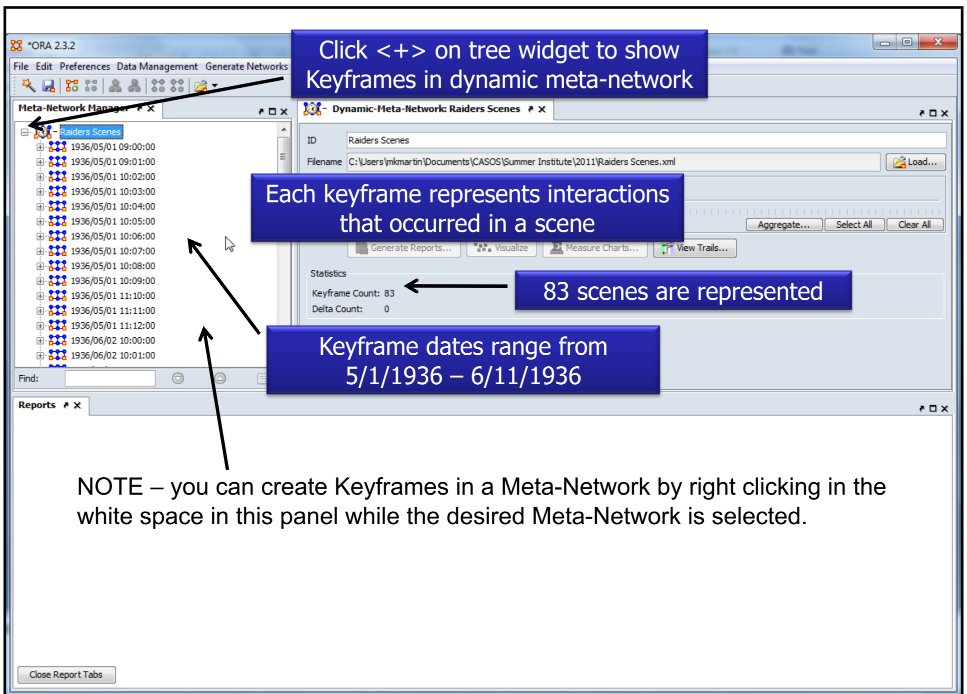
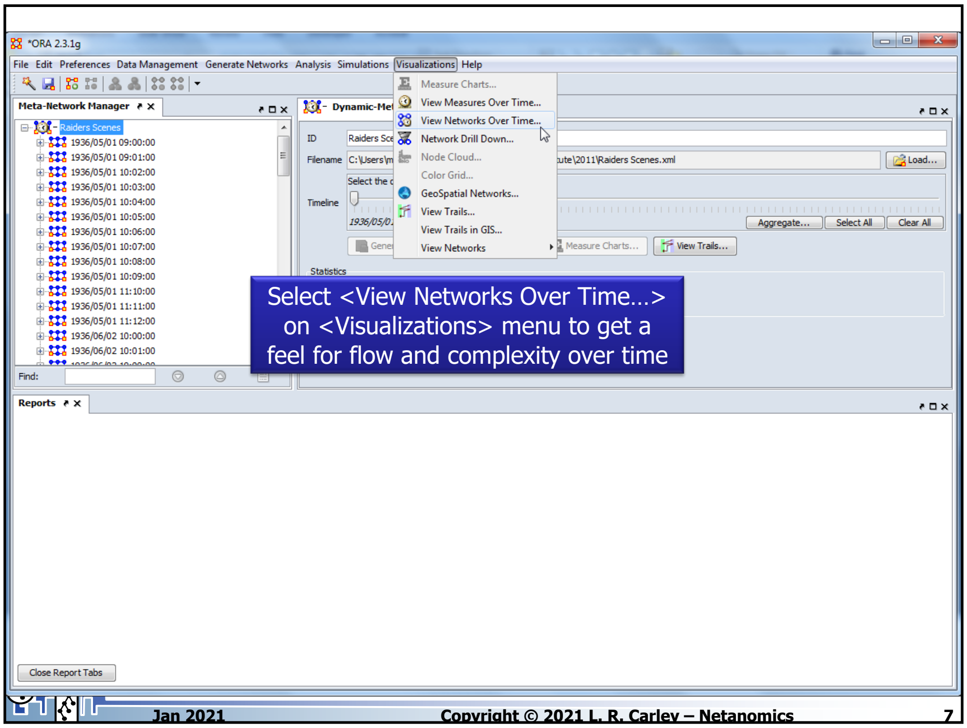
Raiders of the Lost Ark (1981)

- Movie
  - Set in 1936.
  - Archeologist Indiana Jones is hired by the US government to find the Ark of the Covenant before the Nazis.
    - The Nazis have hired Rene Belloq to do their bidding.
    - Indy partners with Marion Ravenwood.
  - Indy is 2nd most popular film hero according to American Film Institute.
- Data
  - Relational data based on draft script of Raiders
  - Relations coded among characters, resources, knowledge, locations per scene.
  - Incomplete w/minimal task representation




*ORA 2.3.1g
File Edit Preferences Data Management Generate Networks Analysis Simulations Visualizations Help
Measure Charts...
View Measures Over Time...
View Networks Over Time...
Network Drill Down...
Node Cloud...
Color Grid...
GeoSpatial Networks...
View Trails...
View Trails in GIS...
View Networks
Meta-Network Manager
Raiders Scenes
Reports
Close Report Tabs
Select <View Networks Over Time...> on <Visualizations> menu to get a feel for flow and complexity over time
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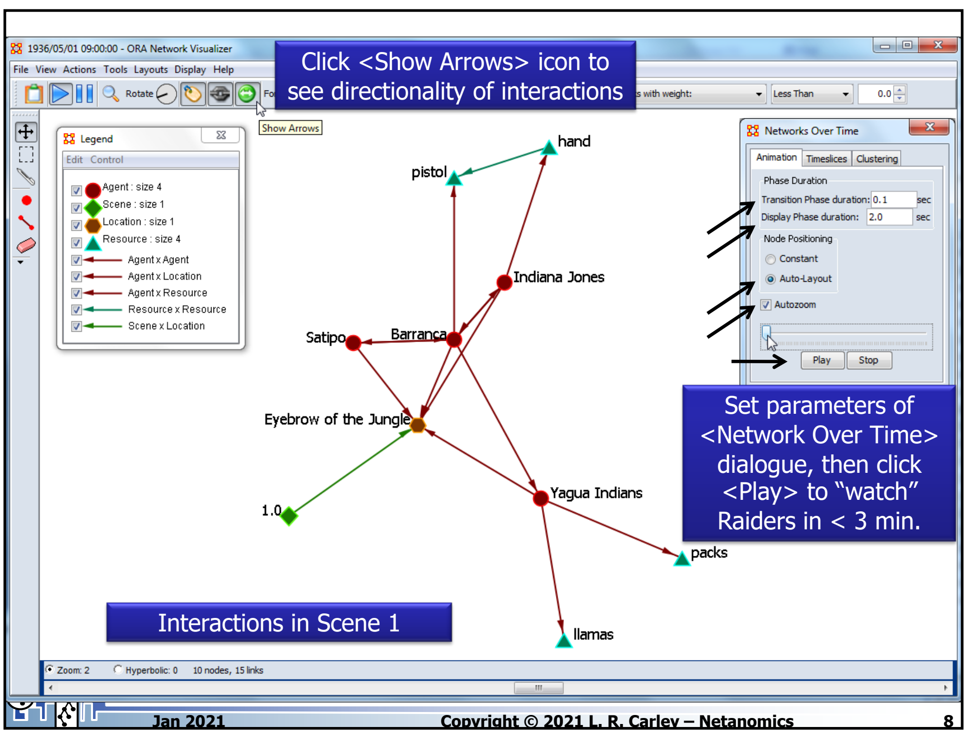
1936/05/01 09:00:00 - ORA Network Visualizer
File View Actions Tools Layouts Display Help
Click <Show Arrows> icon to see directionality of interactions
Show Arrows
Legend
Agent : size 4
Scene : size 1
Location : size 1
Resource : size 4
Agent x Agent
Agent x Location
Agent x Resource
Resource x Resource
Scene x Location
hand
pistol
Indiana Jones
Satipo
Barranca
Eyebrow of the Jungle
1.0
Yagua Indians
packs
llamas
Networks Over Time
Animation
Timeslices
Clustering
Phase Duration
Transition Phase duration: 0.1 sec
Display Phase duration: 2.0 sec
Node Positioning
Constant
Auto-Layout
Autozoom
Play
Stop
Set parameters of <Network Over Time> dialogue, then click <Play> to "watch" Raiders in < 3 min.
Interactions in Scene 1
Zoom: 2
Hyperbolic: 0
10 nodes, 15 links
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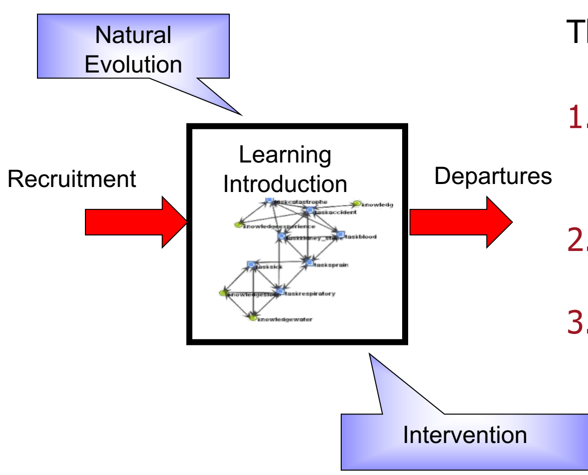
What Have We Learned?

- Indy is an important character, given a variety of relevant measures
  - Indy ranked in top 3 in 94% of measures calculated
  - Marion Ravenwood, Sallah, & Rene Belloq are also important (i.e., top-ranked in a high percentage of measures)
  - German Agents, while identified as important, is an entity that represents various extras who wore Nazi uniforms in bit parts
- Knowing of the Well of Souls & the Ark of the Covenant is important
- The Ark of the Covenant is the most important resource in the movie
- The Raven Saloon & Tanis Ruins are important locations

Changes in Networks over Time

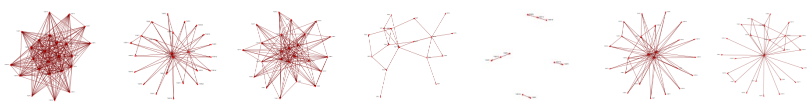


Three Ways to Study Dynamics

1. Comparison over past times
   - Look at real data
2. Immediate Impact
   - Comparative statics
3. Near Term Impact
   - Utilizes simulation - DyNet

Longitudinal (Over Time) Networks

- Consider watching communications on a network, such as email. Mark a link between agents if communicated.



- Has this organization changed significantly?
- Has it evolved?
- Have people changed their position in the network?

One Issue: the node set

- Over time the set of nodes change
- What should you do?
  - Compare just nodes present in all time periods
    - For core group – how has it changed
  - Create a master network of all nodes
    - How has the flux altered the groups
  - Use whatever nodes are available
    - What are the natural dynamics
  - Note – choice changes many measures that are scaled by size
- No single right answer
  - Right answer depends on what you want to know
  - Often try two different approaches and see how much they differ

Taxonomy of Change in Network Data

- Stability: Relationships remain the same over time.
  - But will still have significant "random" variations with time
- Evolution: Interaction among agents cause the relationships to change over time.
  - Normal state of affairs with humans beings as agents
  - Still has "random" variations as well
- Shock: Change is exogenous to the social group.
  - This is crucial for many real world applications
- Mutation: A shock stimulates evolutionary behavior.
  - This is longer term response of organization to changing environment

Models Used to Classify "Change"

- Stability: LPM , ERGM, repeated measures
  - LPM is Link Probability Model
  - ERGMs are Exponential Random Graph Models
- Evolution: SIENA, multi-agent simulation (CONSTRUCT), or both
- Shock: Change detection in real-world applications
  Multi-agent simulation for experimentation
- Mutation: Change detection coupled with SIENA for real world applications
  Multi-agent simulation for experimentation

Dynamic Analysis Techniques

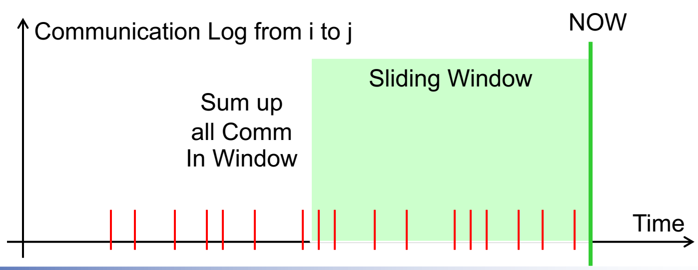
- Visualization
- Comparative Statics – Immediate Impact
- Longitudinal Networks and Change
  - Stability, Evolution, Shock, Mutation
- QAP (Quadratic Assignment Procedure) and MRQAP (Multiple Regression QAP), Longitudinal QAP
- Statistical Models of Networks
  - Link Probability Model (LPM) for Stability
  - Actor-Oriented Models for Evolution
  - Multi-Agent Simulation for Evolution, Shock, and Mutation
- Exponential Random Graph Models
- SIENA
- Statistical Process Control
- Network Change Detection
- Fourier Analysis
- Simulation (Agent-Based Dynamic Network)

Critical Issue: Slicing and Dicing

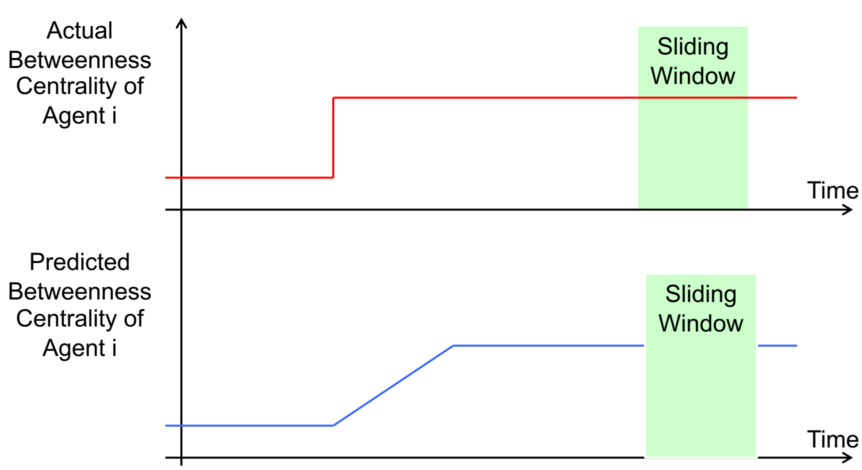
- Approach 1: Cumulative network
  - Each time period is all prior links plus new
  - Good for data where links don't go away – e.g., citation networks
- Approach 2: Divide based on external shock
  - Number of time windows depends on external events e.g., before and after a referendum
  - Good for data where there is a major known change
- Approach 3: Divide into uniform periods
  - Number of time windows depends on collection and time slice
  - Good for large data and for doing periodicity studies
- Approach 4: Streaming
  - Only show most recent data using some moving average
  - Good when data too large to be stored – least developed

Sliding Window for Over-Time Links

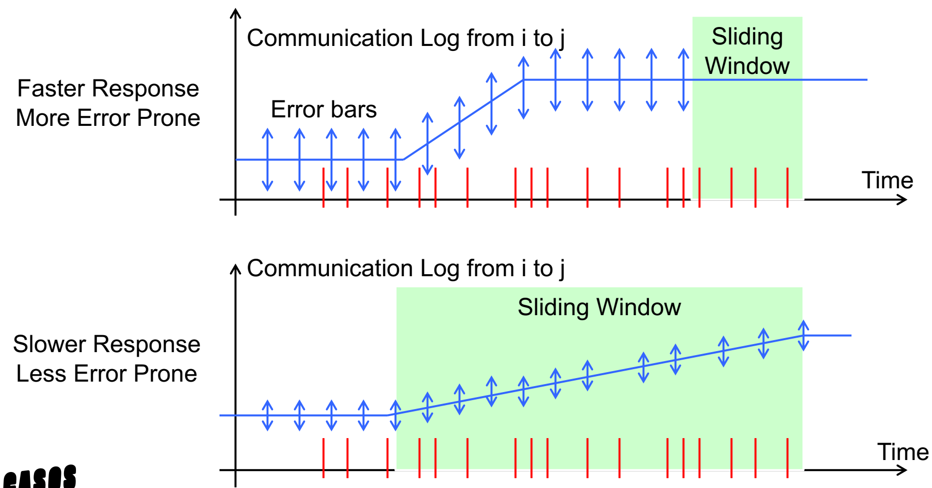
- Estimator for Link Weight (a.k.a. Link Cost)
  - Add up # of Communication Events between x & y in window
  - Take reciprocal. If # is 0, there is no Link between that pair
  - Then move window forward by a time step and repeat
  - Alternatives possible:
    - Incorporate duration of communication
    - Weight different communications channels differently



Smoothing Effect of Sliding Window

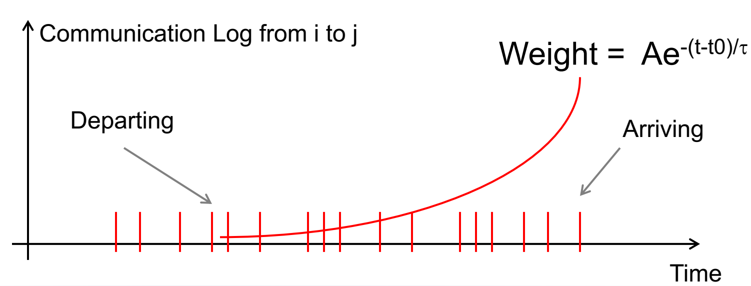


Adjusting Window Size



Mathematically Better Window

- Improved tradeoff between smoothing and averaging
  - Mathematically, Exponentially Weighted Moving Average (EWMA)
    - Considers all past known events in estimating current network
    - Old events receive smaller and smaller weighting
    - New events receive highest weighting
    - Exponential time constant – τ – sets how quickly past attenuates vs. how much averaging reduces variance of network



Incremental Sliding Window

- Sliding Window is Synergistic with Incremental Analysis
  - As window moves forward in time
    - New events "arrive" and must be processed
    - Old events "fall out" of trailing edge of window and must be processed
    - BUT – all of the data in middle of window remains unchanged
    - Incremental algorithms fast because only small part of data changes

Communications as a Proxy

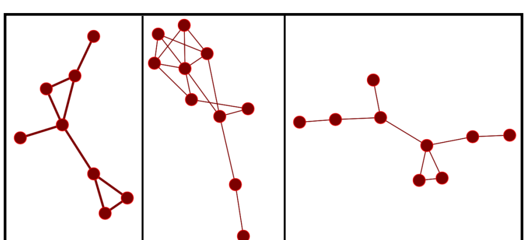
- "Ideal approach" – directly sample network each time period
  - E.g., have every member of society fill out survey every time period
  - Limited to very small societies and really motivated subjects
- Or, tracking changes over time using communications data
  - Communication is "proxy" for a network tie
  - Tracking large amounts of communication data gives approximate picture of the underlying social network structure
  - Can use it to find Key Entities and other Network measures
- Communication log data available from many sources
  - Cell Phone Service Providers – call logs, txt msg logs
  - E-mail Data logs – available within organizations
  - Software: Twitter, Facebook, FourSquare, etc.
  - Hardware: building sensors, cell phone sensors, RFID Tags, GPS, etc.

Communications Log Data

- Data on who you talk to over monitored means, but NOT what you say (decreased privacy concerns relative to full text monitoring)
- Researchers often only have access to logs from 1 or 2 communications channels – not all possible channels
  - Missing data is substantial
- Communication event is taken as a proxy for a link
  - But this may not always be the case; e.g., calling a wrong #

Dynamic Metrics on Over-Time Data

- *Identifying central nodes in a network*



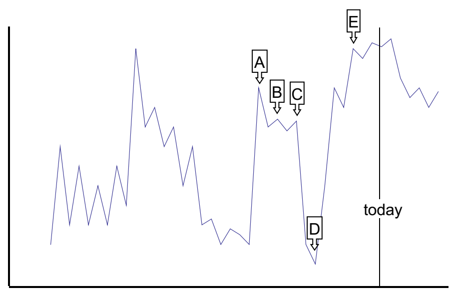
T_1 T_2 T_3

Dynamically Changing Network Structure!!!

Focus on calculating measures for each network
Then evaluate how measures change over time

Changes in Network Data Measures

- Various measures of a network are calculated for a window of network data at a multiple points in time
- Change detection: quickly determine *that* a change occurs.
- Change point identification: *when* did the change occur.



Change Detection

- Goal: Rapidly detect that a change has occurred
- Detect *shocks*, not evolutionary changes
  - Evolutionary change: change due to interaction among actors in a network
    - Example: change of interaction patterns over time among new students as they get to know each other
  - Shock: change reason is exogenous to the network
    - Example: change of interaction patterns among students after they graduate
  - Another way to say it: detect "fast" change not "slow" change
- Another goal is to identify *change point*
  - Likely time when change occurred
  - Limits the scope of explanation for network change

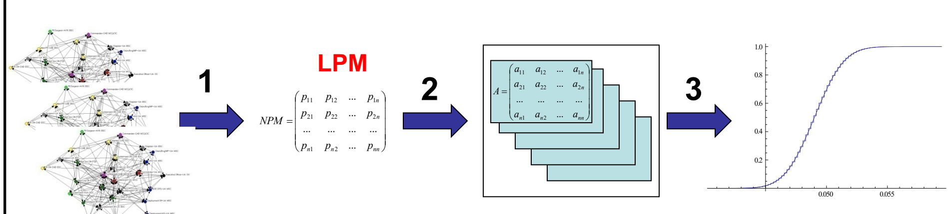
Statistical Process Control (SPC)

- Change detection can be based on SPC
- What is Statistical Process Control?
  - Used in manufacturing to maintain quality control
  - Monitors a process to detect potential changes
  - Calculates a statistic from observed measurements of a process and compares it to a decision interval
  - If the statistic exceeds the decision interval, it is said to "signal", that a potential change may have occurred
  - A quality engineer will then begin to search for the specific cause of change

Statistical Models of Networks

Link Probability Model (LPM) for Stability

- LPM is a model for a network in *Stability*
- The probability that an email is sent from *i* to *j* within some period of time *t* is: $$p = \int_0^t f_{ij}(x \mid \theta_{ij})dx$$
  - (p, as a function of t, is a CDF: f is the PDF that best fits cell ij in an NPM)
- LPM can be used to simulate stable longitudinal networks



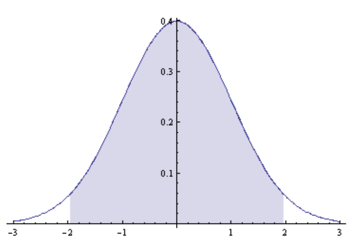
Statistical Models of Networks
Link Probability Model (LPM) for Stability

LPM simulated networks are compared to empirical networks and are shown to represent the network well.

M	*8*		*N*	*60000*			
e_mean	**e_stdev**		**s_mean**	**s_stdev**		**t-val**	**p**
409.2857	38.5604		358.0939	12.77466		3.754923	0.00
365.8571	18.2978		320.0974	12.7394		7.073195	0.00
365.8571	29.04266		320.1638	12.79331		4.449958	0.00
377.8571	38.24669		330.6744	12.77289		3.489244	0.00
375.2857	36.10039		328.3765	12.79551		3.675254	0.00
349.8571	38.15944		306.0783	12.7845		3.244918	0.00
373.8571	48.45076		327.0728	12.82622		2.731135	0.01
362.4286	55.63529		317.1509	12.77754		2.301849	0.02

Probability Background

- Consider a normal distribution with μ=0 and σ=1.
- 95% of the time, observations are between ±1.9597
- When an observation occurs in the tail, we don't believe it and think that something unusual might be going on.



Statistical Process Control

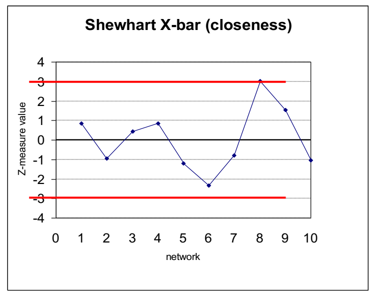
- Manufacturing processes are: stochastic, dependent, non-ergotic, complex, and involve human interaction.
- Shewhart (1927) X-bar Control Chart proposed to monitor change of any process
- Calculate Z_t transform value for each time-period, *t*.

$$Z_t = (x_t - \mu_0)/\sigma$$

- Calculate a control limit, *L*, based on risk for false alarm.

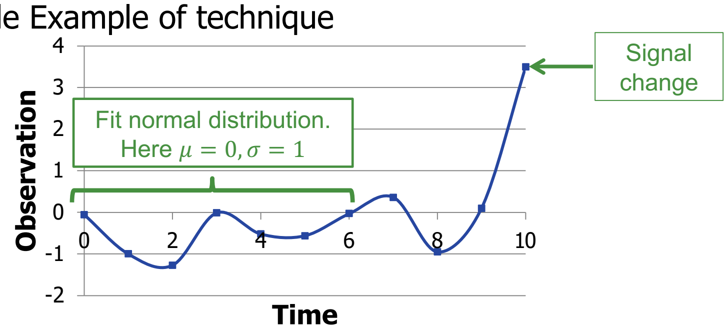
$$\int_L^{\infty} f(x)dx = \alpha$$

- Chart Signals when *Z* exceeds control limit, *L*.



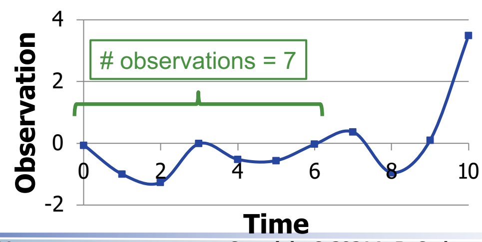
The Shewhart X-Bar Chart

- Overview
  - Fit normal distribution on "control period" (early observations)
    > assumed to represent the "normal state"
  - Signal change if a subsequent observation is outside confidence interval
- Simple Example of technique



The Shewhart X-Bar Chart

- Parameters
  - # observations used to fit distribution (the "normal" period)
  - False positive risk or decision interval
    - Trade-off between False positive risk & detection speed
- Assumption
  - Observations are normally distributed as independent random vars
    - Shewhart X-Bar chart used even when assumption is violated. However, false positive risk probability may be inaccurate



Statistical Process Control (cont.)

- Newer approaches detect change in fewer observations subject to the same rate of false positives.
- Scan Statistic (Fisher, 1934)
- Exponentially Weighted Moving Average (EWMA) (Roberts, 1959)
  - Good at detecting small changes in mean over time
  - Performs well on time series with closely spaced data samples

$$w_t = \lambda \bar{x}_t + (1-\lambda) w_{t-1} \qquad \mu_0 \pm L\sigma_{\bar{x}} \left(\frac{\lambda}{2-\lambda} \left[1 - (1-\lambda)^{2T} \right] \right)^{1/2},$$

- Cumulative-Sum (CUSUM) Control Chart (Page, 1961)
  - Good at detecting small changes in mean over time
  - Built-in change point detection
  - Two Charts (To Detect Increase and Decrease)

$$C_t^+ = \max\{0,\ Z_t - k + C_{t-1}^+\} \qquad C_t^- = \max\{0,\ -Z_t - k + C_{t-1}^-\}$$

Cumulative Sum (CUMSUM)

- Cumulative-Sum Control Chart
  - Good at detecting small changes in mean over time
  - Built-in change point detection
- Calculate Z_t transform for each time-period, t

$$Z_t = (x_t - \mu_0)/\sigma$$

- Two Charts (To Detect Increase and Decrease)

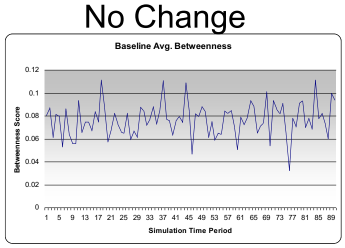
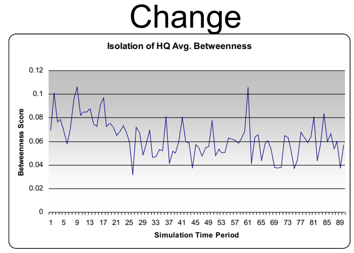
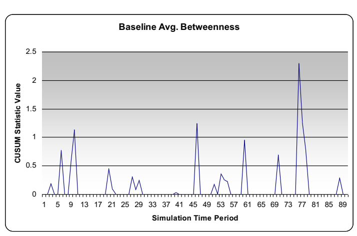
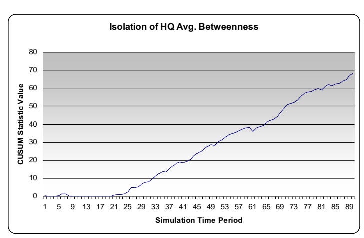
$$C_t^+ = \max\{0,\ Z_t - \frac{\delta}{2} + C_{t-1}^+\}$$

- Chart Signals when C^+ or C^- statistic exceeds decision interval

$$C_t^- = \max\{0,\ -Z_t - \frac{\delta}{2} + C_{t-1}^-\}$$

- Sensitivity in CUSUM due to discrete integration of error

Comparison of Change Detection Approaches

	No Change	Change
Over-Time Meas		
CUSUM Statistic		

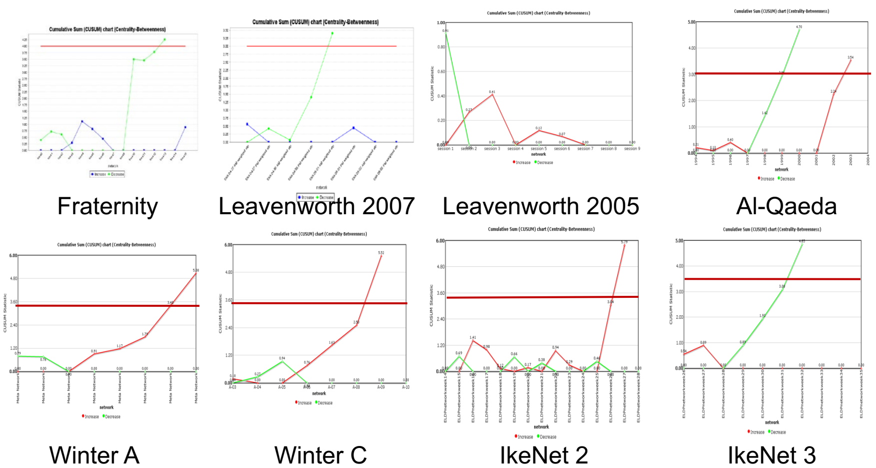
Comparison of Change Detection Approaches

	CUSUM $k = 0.5$	EWMA $r = 0.1$	EWMA $r = 0.2$	EWMA $r = 0.3$	Scan Statistic
Average Betweenness	9.32	8.24	10.16	11.52	6.76
Maximum Betweenness	14.36	14.72	15.72	17.08	13.24
Std Dev. Betweenness	16.44	16.24	16.92	18.52	15.24
Average Closeness	10.68	9.08	13.60	17.52	10.48
Maximum Closeness	8.76	6.00	10.60	37.96	8.64
Std Deviation Closeness	34.48	34.72	34.52	35.68	27.08
Average Eigenvector	31.28	31.28	31.28	31.28	24.00
Minimum Eigenvector	14.36	14.36	14.28	15.56	14.88
Maximum Eigenvector	5.24	5.40	5.80	7.52	4.00
Std. Dev Eigenvector	5.92	4.88	6.40	6.96	3.64

Network Change Detection: Analysis of Real World Data

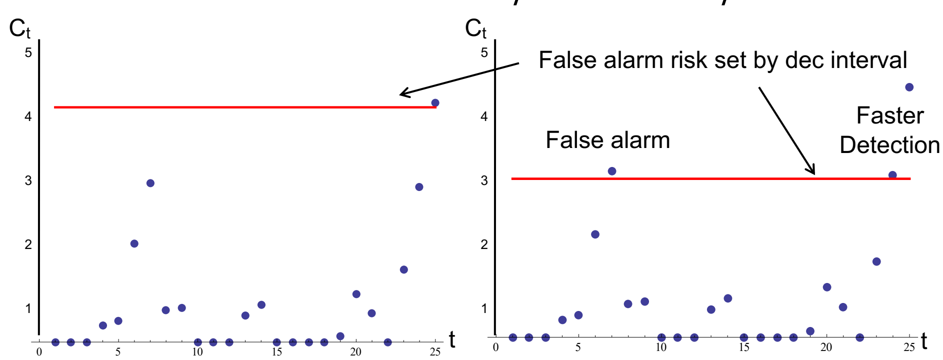
	# Nodes	Time Periods	Method of Collection	Type of Relation	Design	Known Change
Fraternity	17	15	Survey	Ranking	Fixed	Yes
Leav 07	68	8	Survey	Rating	Free	Yes
Leav 05	158	9	Survey	Rating	Free	None
Al-Qaeda	62-260	17	Text	Rating	Free	Yes
Winter C	22	9	Observation & Survey	Rating	Fixed	Yes
Winter A	28	9	Observation & Survey	Rating	Fixed	Yes
IkeNet 2	22	46	Email	Count Msg	Free	Yes
IkeNet 3	68	121	Email	Count Msg	Free	Yes

Network Change Detection: Analysis of Real World Data



Summary of Change Detection Across Data Sets

There is a trade-off between false positive and rapid detection



Low risk of false alarm
Longer to detect change

High risk of false alarm
Faster to detect change

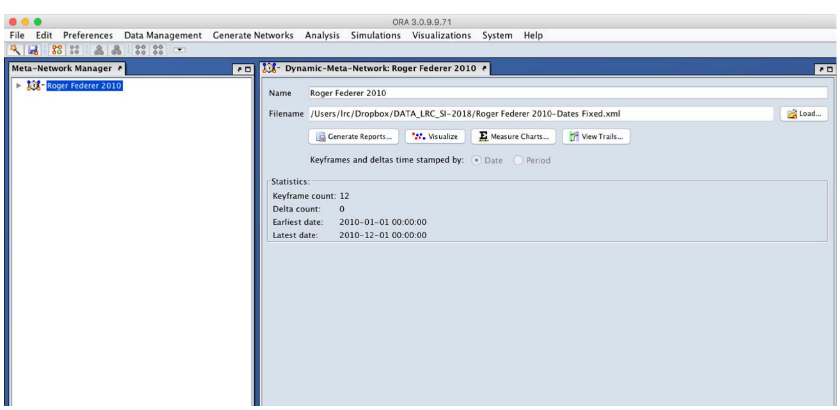
Summary of Change Detection Across Data Sets

Too little risk may prevent change detection all together

Data	Change	α = 0.05	α = 0.02	α = 0.01	α = 0.005	α = 0.001
Fraternity	8	10	10	10	13	Never
Leav 07	3	5	5	5	Never	Never
Leav 05	None	No F.A.	No F.A.	No F.A.	No F.A.	No F.A.
Al-Qaeda	1997	1999	1999	2000	2000	Never
Winter C	May	Sept	Sept	Oct	Oct	Never
Winter A	May	Aug	Sept	Sept	Sept	Oct
IkeNet 2	25	26	26	27	27	27
IkeNet 3	14	15	18	19	19	20

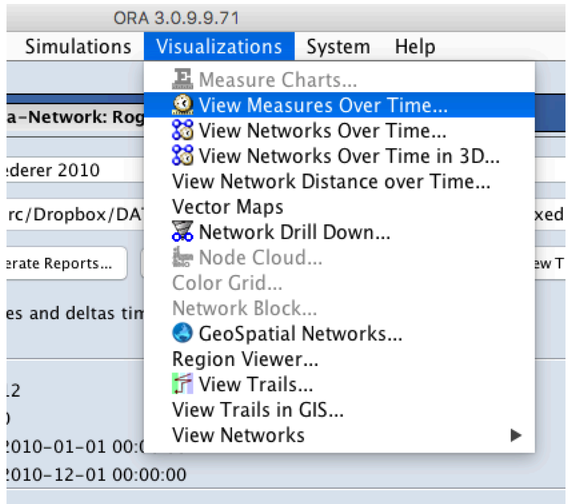
Change Detection Hands-On

- Based on Roger Federer 2010 data

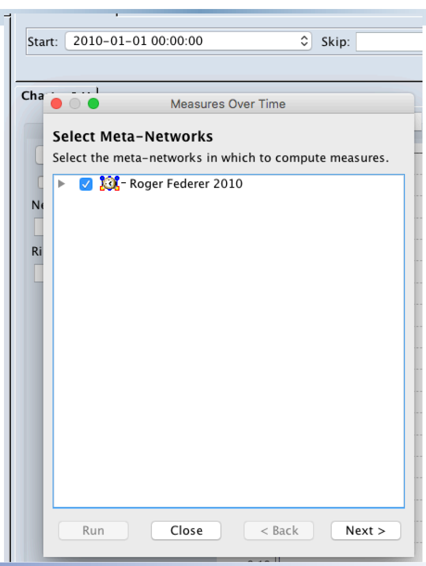


Change Detection Hands-On

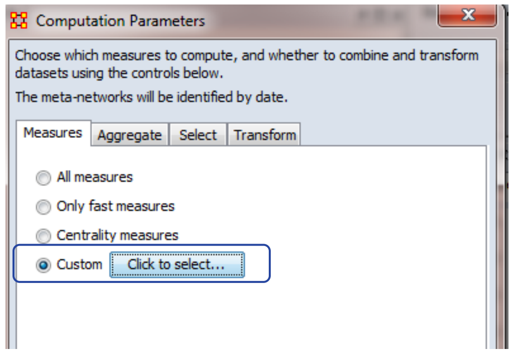
- Analysis uses over-time changes in "measures" based on the network data



Select The Metanetwork

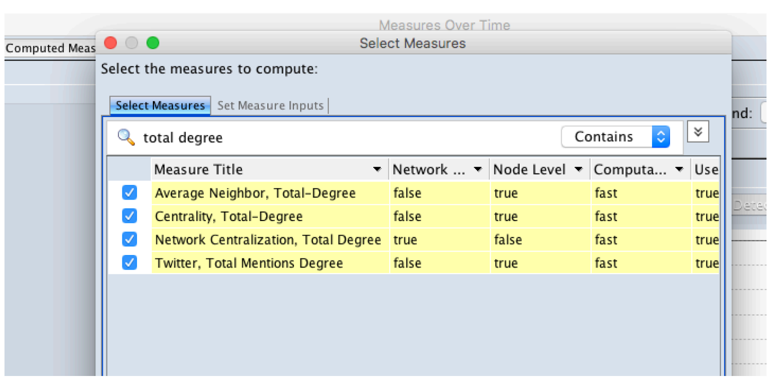


Custom Measure Selection

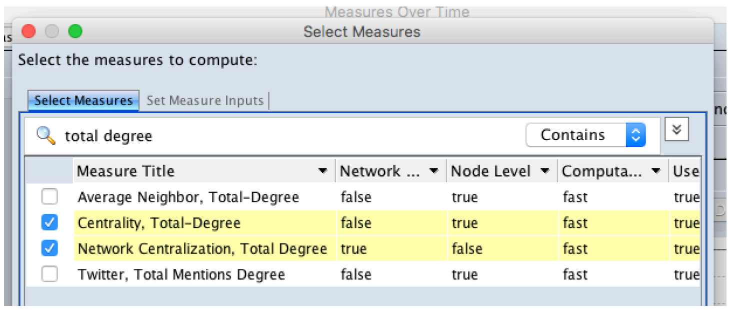


Use Search to Find Measure

Hint: Click Select Box at bottom to deselect all measure,
Then use search to find the ones you want



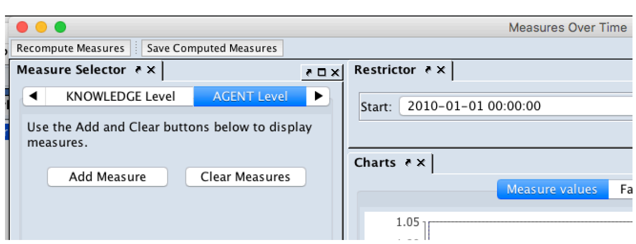
Two measures selected to run



Add Measure – Agent Based Measure – select “Centrality, Total Degree”

Now Select Display

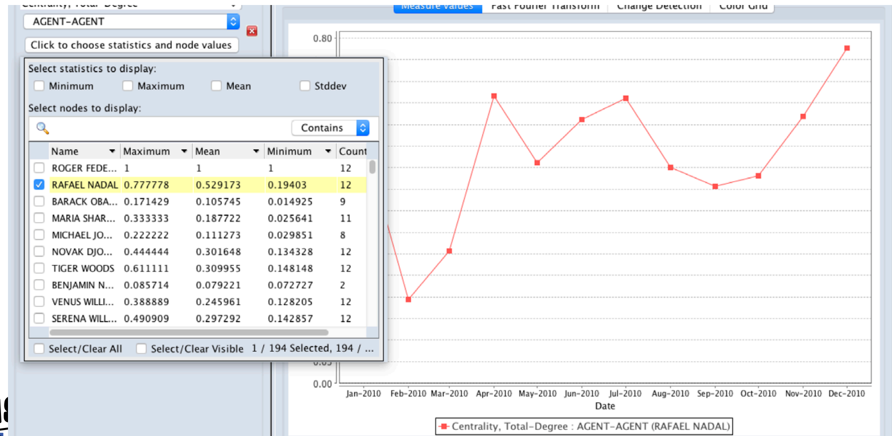
First step is to select type of variables to display
– AGENT Level in this case



Then click on “Add Measure” to add a new plot line

Select Agent for Measure

Click on the “Click to choose ….” button
and select second agent for analysis (Federer is always primary)



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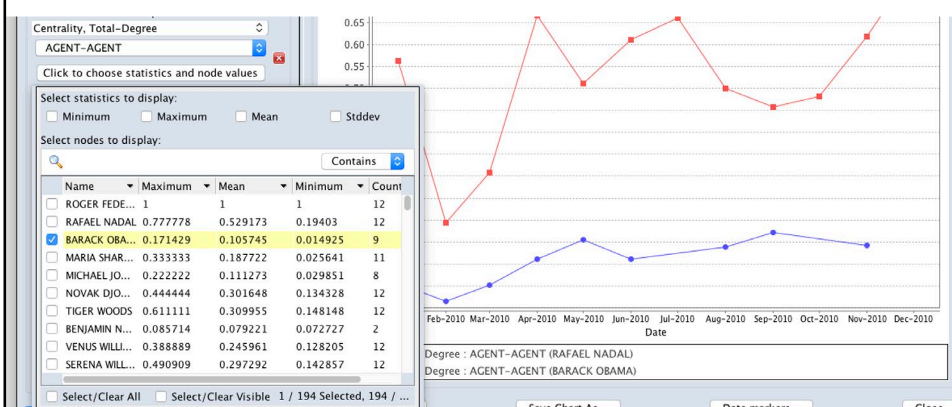
Add Another Agent Measure Plot

Click on Add a Measure button again to add another line



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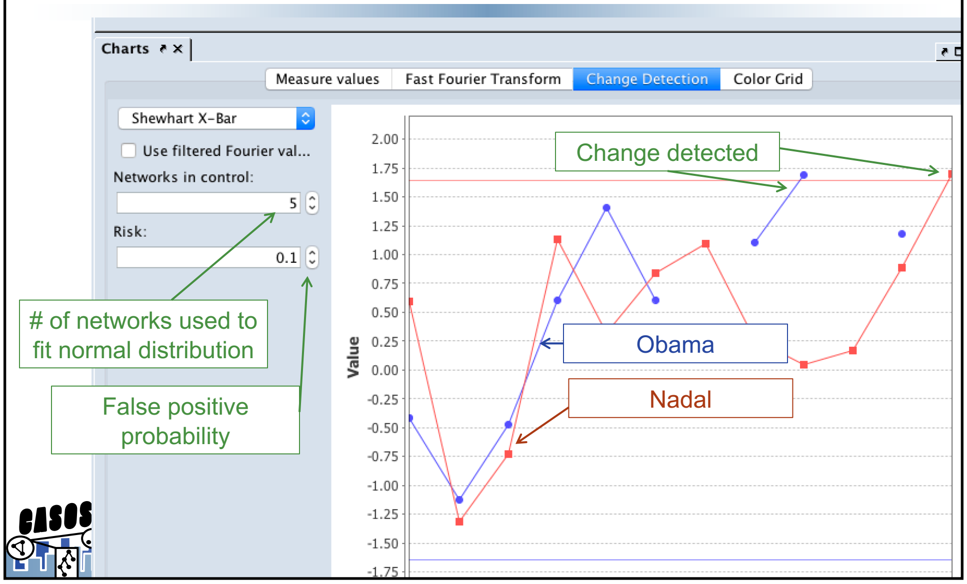
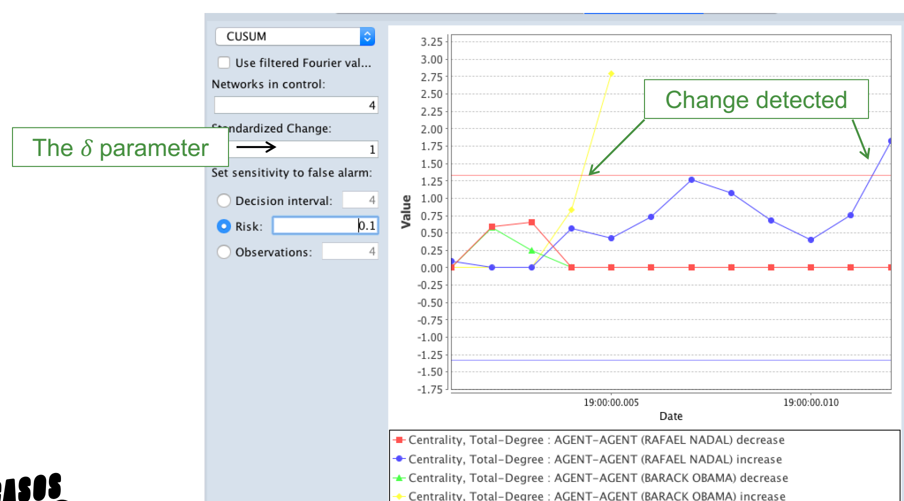
Change Detection Hands-On
The Shewhart X-Bar Chart



Change Detection Hands-On
CUMSUM Method

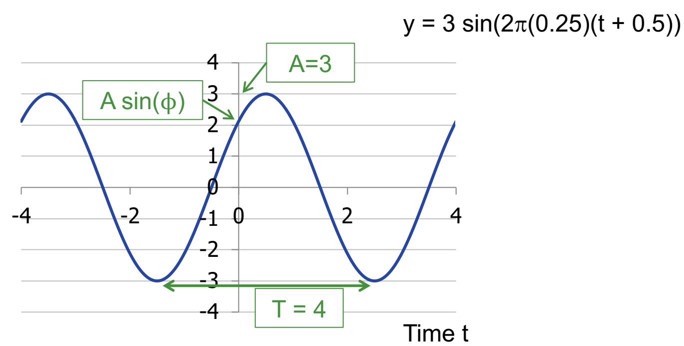


Fast Fourier Transform (FFT)

- Goal: detect periodicity in over-time data
- Examples
  - Weekly periodicity in email data
  - Time of the day effects
- Fourier's theorem
  - Any time signal can be represented by a sum of sinusoidal functions with different frequencies, amplitudes and phase shifts
- Fourier transform finds sinusoids that decompose a signal
  - Analogy: given a dish, find the ingredients
  - Sinusoids have the advantage that they are orthogonal

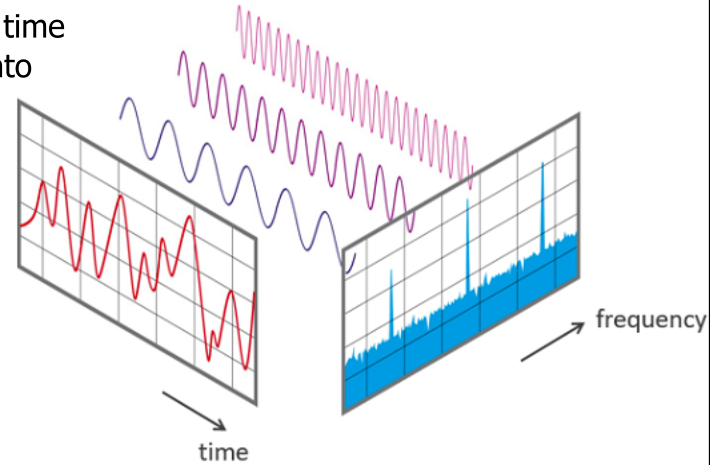
Sinusoidal Function

- A sinusoidal function $y = A\sin(2\pi f t + \phi)$ has
  - A amplitude
  - f frequency $\left(T = \frac{1}{f}\right.$ is the period)
  - ϕ phase



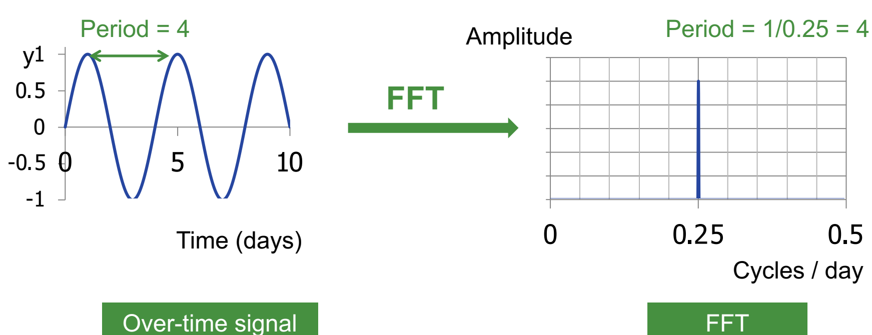
Frequency Domain: The FFT

- Fast Fourier Transform (FFT)
- Decompose time waveform into sum of sinewaves



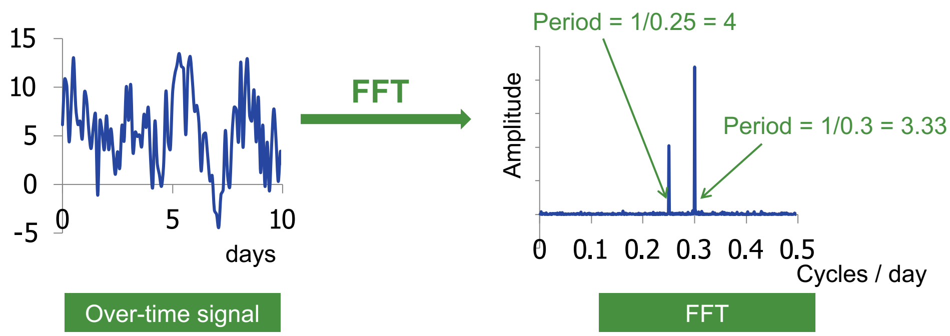
FFT Example: Sum of Sinusoids

- Fast Fourier transform of sinusoidal function is a spike at the sinusoidal frequency
- Example $y = sin(2\,\pi\,0.25\,t)$



FFT Example 2

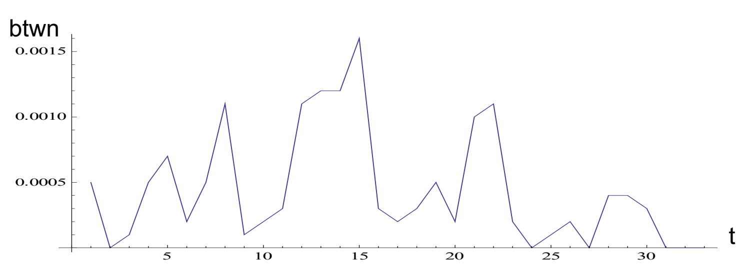
- FFT finds periodicities that may be unclear in over-time signal



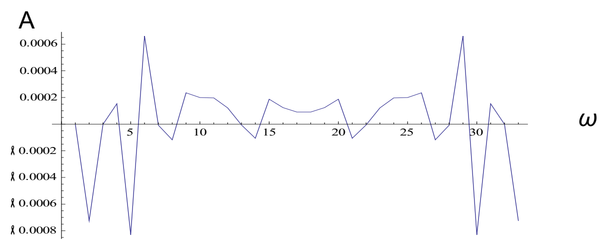
Hidden "recipe": over – time signal computed as
y(t) = 2 sin(2 pi 0.25 t) + 3 sin(2 pi 0.3 t + 0.2) + noise

Fourier Analysis Example 3

- 24 cadets in a regimental chain of command agreed to have their email monitored to form a social network data set known as IkeNet3.
- The betweenness was calculated based on the e-mail communications observations over the first month in their duty positions.



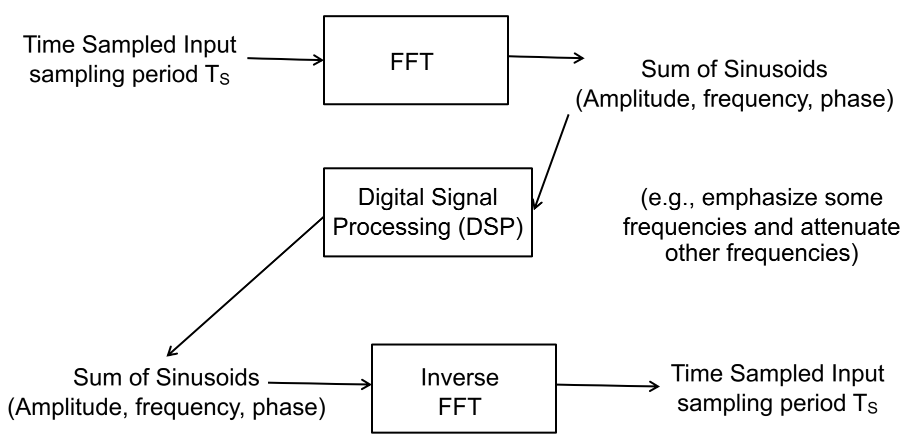
Fourier Analysis – Example 3



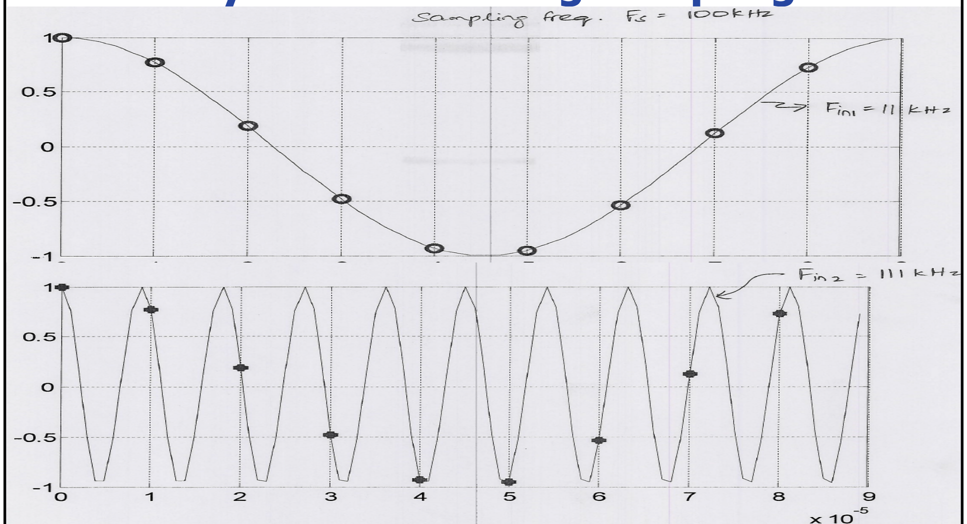
Fourier transform
Symmetric around the midpoint
3 main components (in terms of magnitude)

That is why we typically only display from origin up to midpoint

Digital Signal Processing

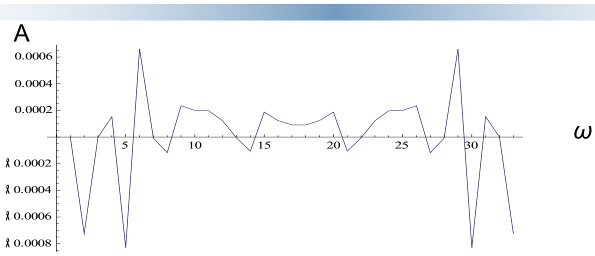


One Key Issue: Aliasing Sampling Limits



If we want DSP to work unambiguously, we choose to limit maximum input frequency to ≤ 1 / (2 T_S) = F_S / 2 = “Nyquist Frequency”

Digital Signal Processing



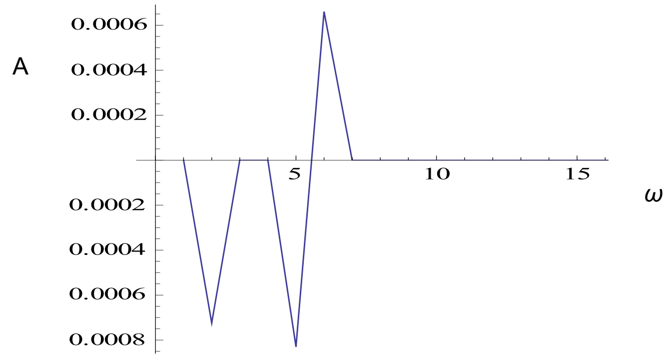
Fourier transform
Symmetric around the midpoint
3 main components (in terms of magnitude)

That is why we typically only display from origin up to midpoint

How do we use this?

One possible approach – big peaks are periodic “background”

Filtering



e.g., identify 3 main (high magnitude) components
keep them and remove FFT components
at all other frequencies

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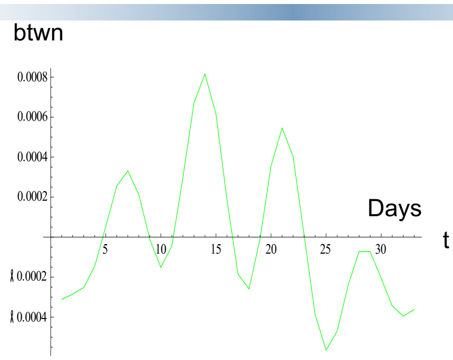
Inverse Fast Fourier Transform



This is the inverse Fourier transform of just the 3
selected components, which are then reconverted to time waveform

There is a weekly, two week and three week cycle

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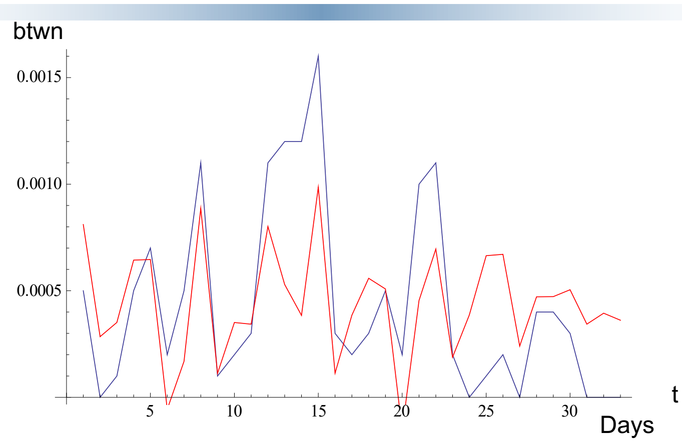
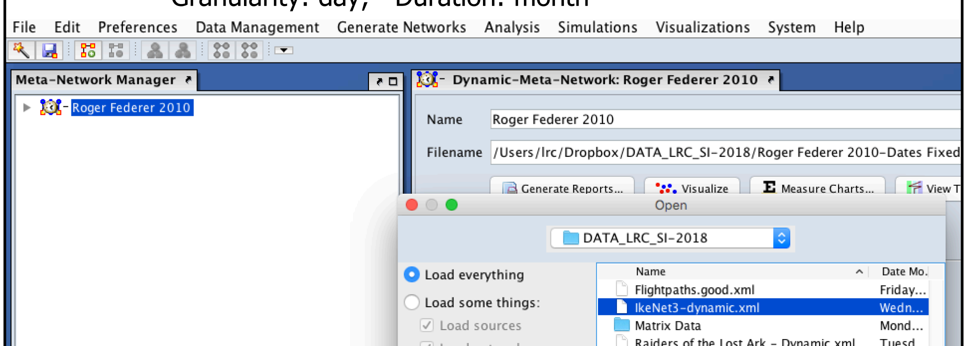
Anomaly Detection



The filtered pattern has been subtracted from the original
The red is what is left – the anomalies

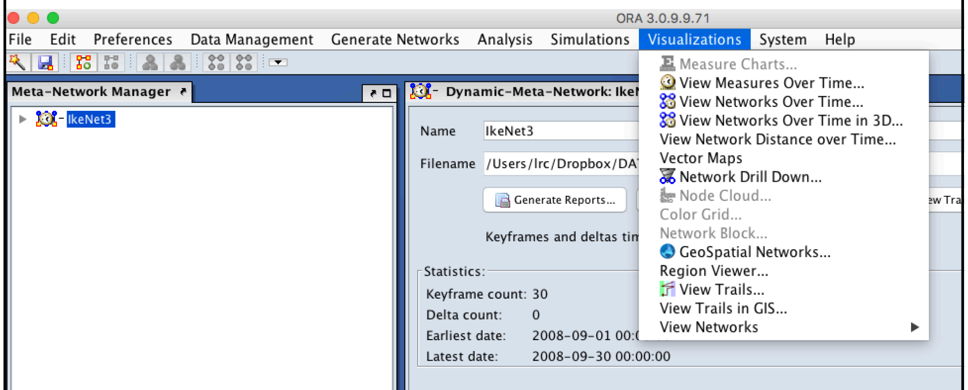
FFT Example Hands-On

- IkeNet data (IkeNet3-dynamic.xml)
  - Email exchange data among mid-career officers in a one-year graduate program at Columbia University
  - Granularity: day; Duration: month

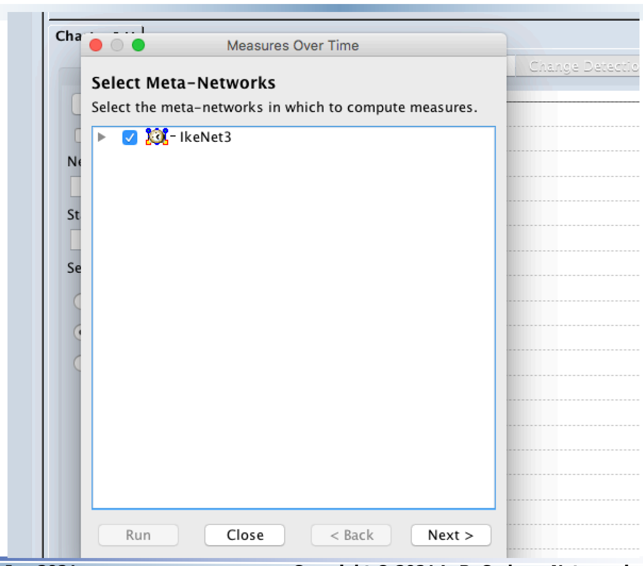


Over Time Measures

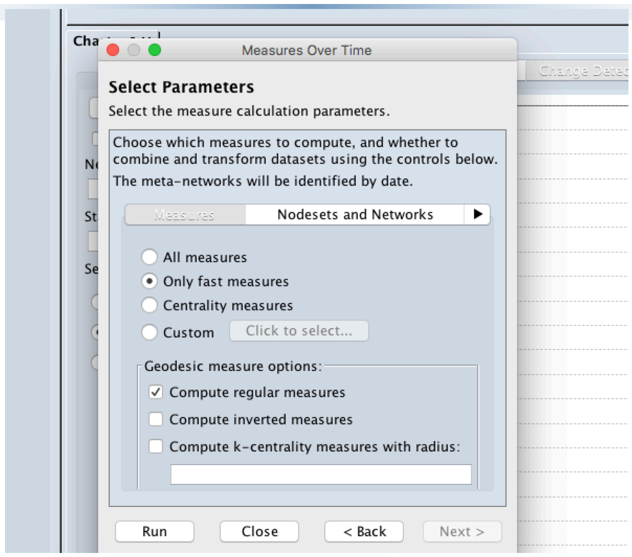
Again View Measures Over Time



Selecting MetaNetwork



Selecting Measures



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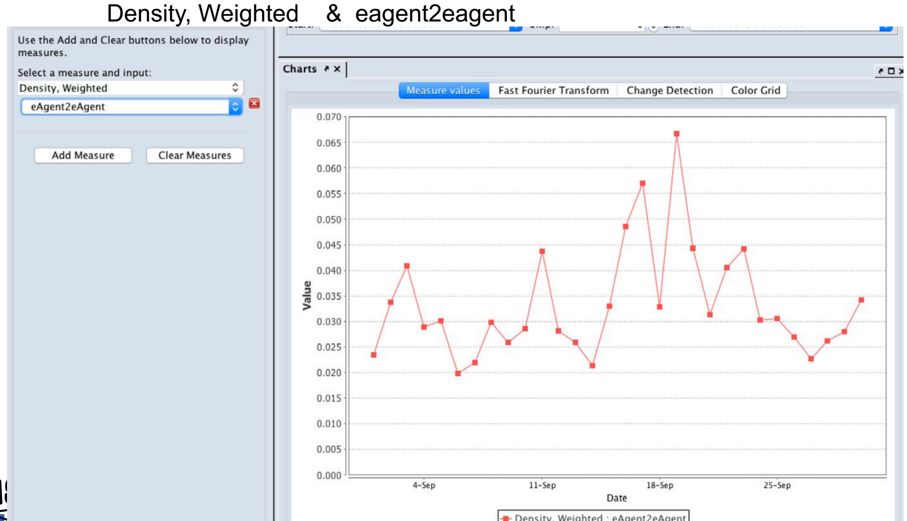
Selecting Measures to Plot

Density, Weighted & eagent2eagent



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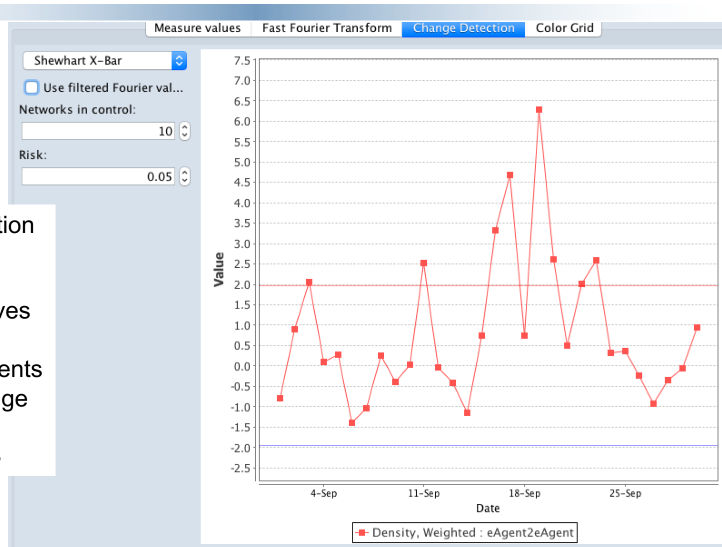
Run Shewhart to Detect Change



Run Change Detection
Shewhart
10 points for basis
0.05 for false positives

Lots of apparent events
That could be Change

All upward changes

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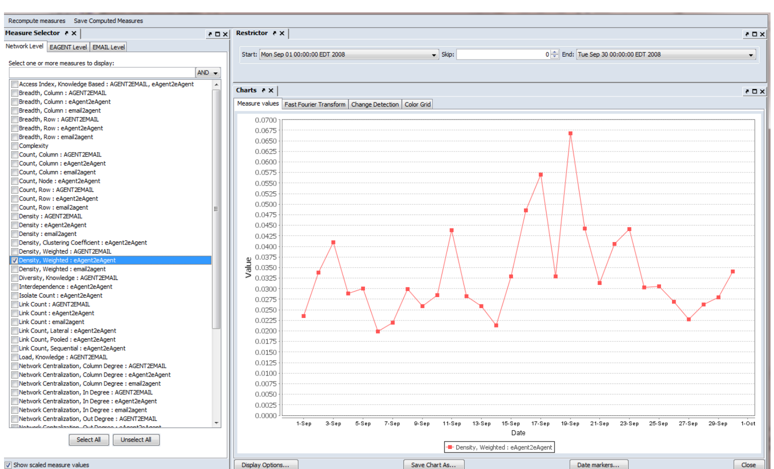
FFT Can Help with Periodic Patterns

Network Level / Density, Weighted / eAgent2eAgent



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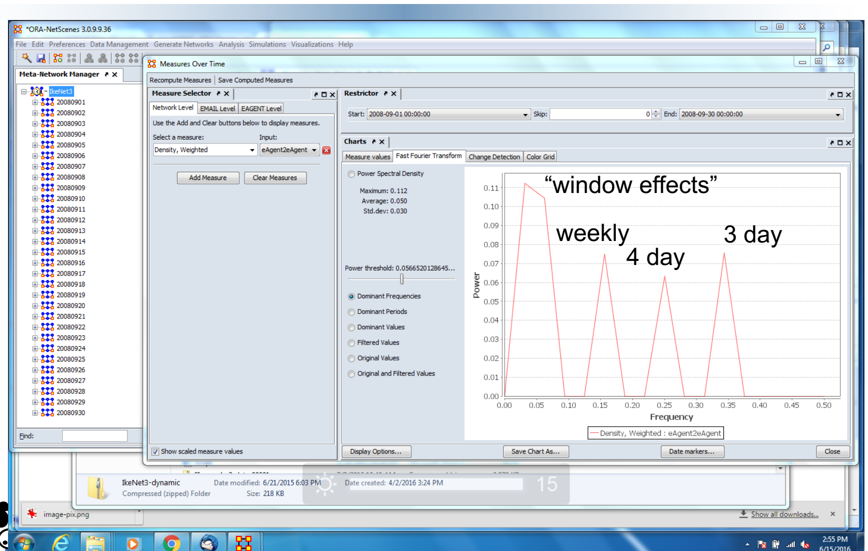
FFT Power Spectral Density

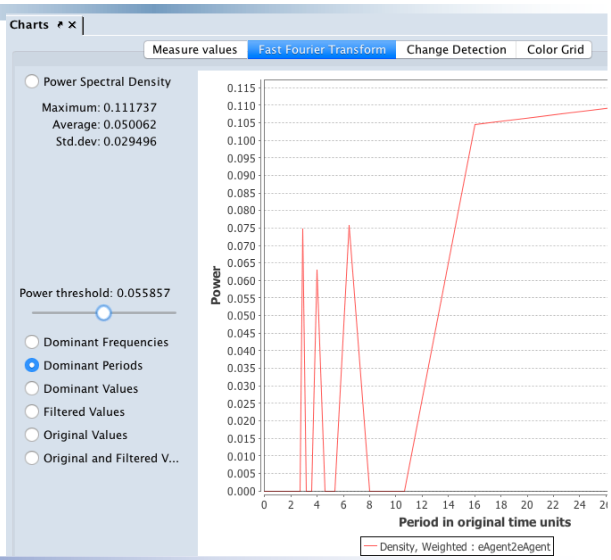


FFT Power vs. Period

Adjust Power Threshold to just select "background" periodic variations to be removed

NOTE – viewing the Dominant Periods is often more intuitive than PSD

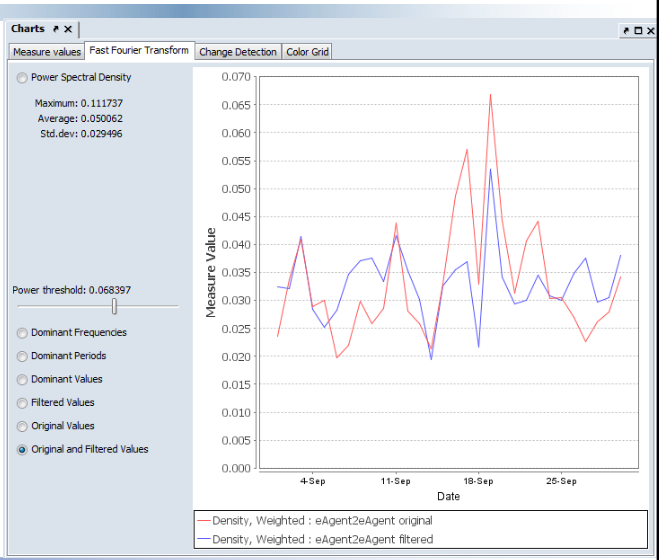
The long period values are artifact of finite length of data



Original vs. FFT subtracted data

Remaining FFT components are converted back to time values (inverse FFT) and subtracted

This removes some of the periodic patterns covering up the fundamental changes to be detected



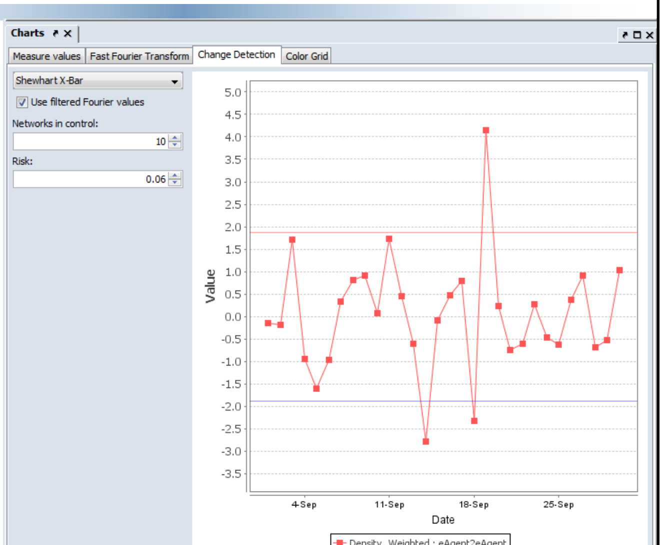
Shewhart on FFT subtracted data

Now use the Filtered Data

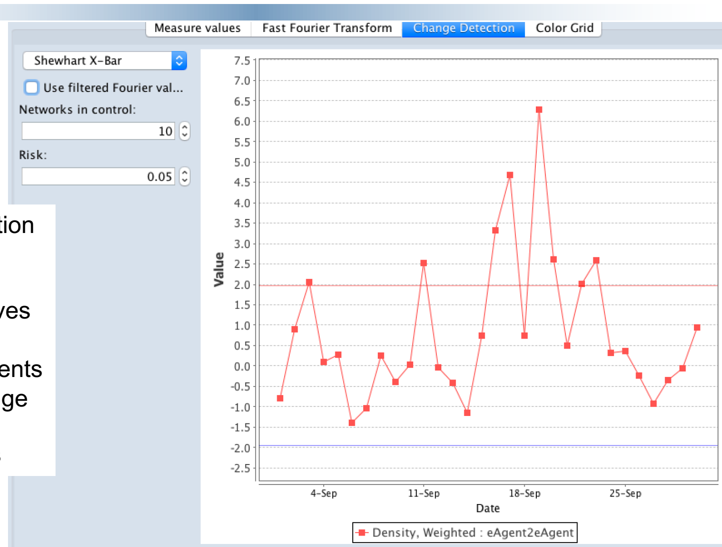
Run Change Detection Shewhart
10 points for basis
0.05 for false positives

Only 1 + event and 2 – events

Open Question – is this better than original or not?



Shewhart on original data



Run Change Detection
Shewhart
10 points for basis
0.05 for false positives

Lots of apparent events
That could be Change

All upward changes

Fourier Analysis to Handle Periodicity

- Fourier analysis can effectively identify periodic trends in longitudinal network data.
- Identification of periodic trends can allow the analyst to aggregate relational data over the period to remove over-time dependence.
- The inverse Fourier transform of the significant period can be used to subtract off periodicity from longitudinal network data measures over time.
- Further exploration of wavelets may produce greater insights in to network dynamics.

Scalability

- The change detection algorithm is linear, thus the time consuming part is calculating network measures.
- Networks with less than 20 nodes tend to have a higher variance in over time measures. When a link is added or removed, it affects (n-1)(n-2) triads.
- Requires at least 3 time periods: >2 to determine typical behavior and 1 to compare at each time point. In practice, 10+ network time points are preferred.
- No difference in number of required networks for each technique: CUSUM, EWMA, Scan Statistic, x-bar, etc.
- Wavelet/Fourier based approach needs many more time periods and complexity grows roughly as #T(log(#T))

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Limitations

- View findings on data with caution
- Slicing and dicing can distort conclusions
- Examine errors associated with technique through extensive simulations.
- Investigate more real world data sets.
- Investigate the degree to which network measures are correlated to understand the effects of compounding error.
- Investigate multi-dimensional network properties such as the cosine similarity between the triad census at different time periods.

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Summary

- Rapid change detection may allow an analyst to get inside a decision cycle and shape network evolution.
- Simulation is important for modeling longitudinal network behavior.
- Isolating when networks change enables more focused study on the causes of evolution, shock, and mutation, which may lead to future predictive analysis.
- Statistical process control is a useful tool for understanding social behavior.

Questions