School of Information
University of Michigan

SI 508/708 CS 608
Network visualization & GUESS

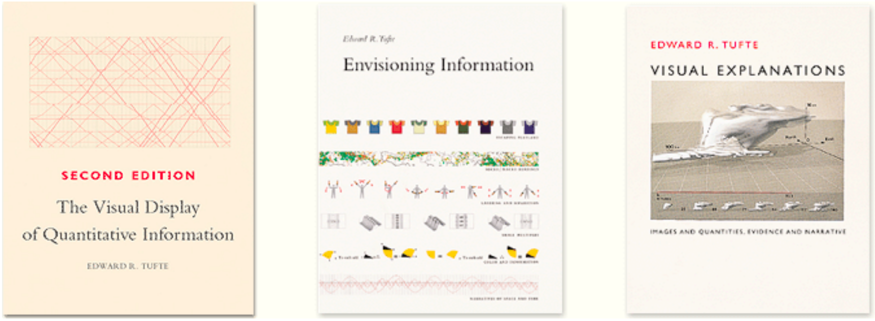
Outline

- Visualization
  - General tips for effective visualizations
  - Visualizing networks
    - layout algorithms
    - options for large networks
    - longitudinal data
    - visualization software besides Pajek & GUESS
- Exploratory data analysis
  - GUESS – the graph exploration system

Tips for effective visualizations

- *"The success of a visualization is based on deep knowledge and care about the substance, and the quality, relevance and integrity of the content.“ (Tufte, 1983)*
  - know thy network!

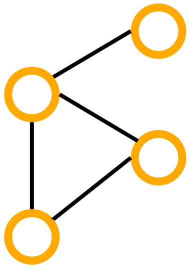
- **Five Principles in the Theory of Graphic Display**
  - Above all else show the data.
  - Maximize the data-ink ratio, within reason.
  - Erase non-data ink, within reason.
  - Erase redundant data-ink.
  - Revise and edit.



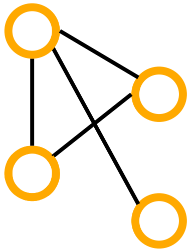
Source: http://www.edwardtufte.com/tufte/

Aesthetic criteria for network visualizations

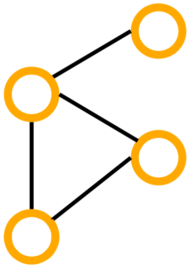
- minimize edge crossings



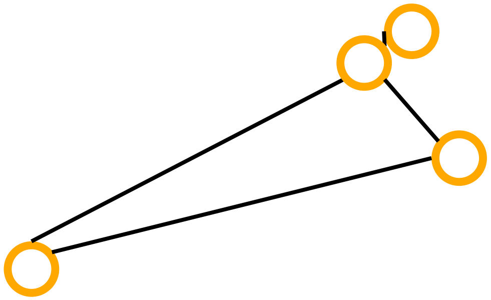
better than



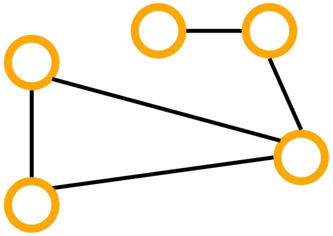
- uniform edge lengths
  - (connected nodes close together but not too close)



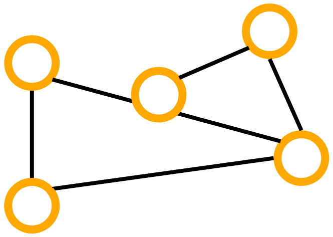
better than



- don’t allow nodes to overlap with edges that are not incident on them

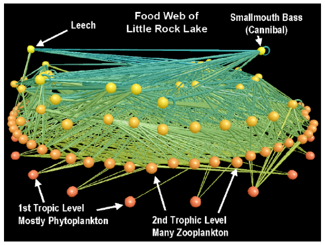


better than



Cool looking visualizations are not always most informative

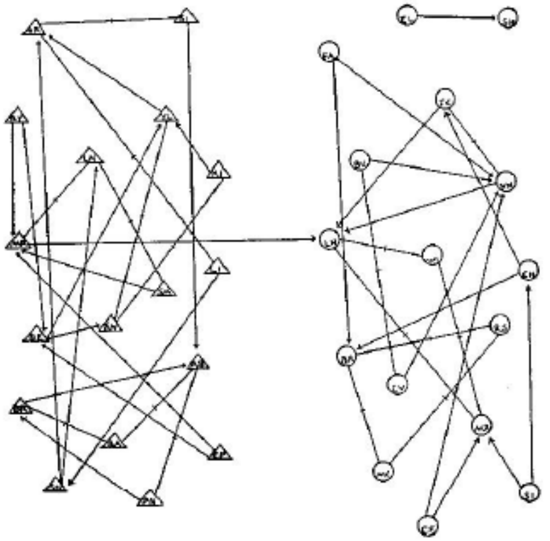
http://ridge.icu.ac.jp/gen-ed/ecosystem-jpgs/food-web.jpg



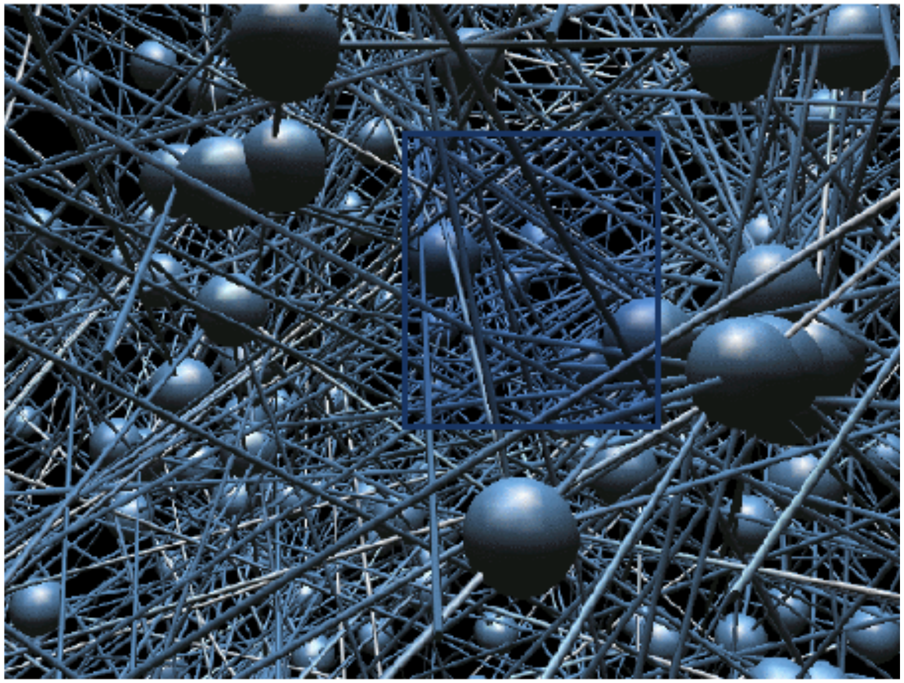
http://news.bbc.co.uk/2/hi/science/nature/2288621.stm

slide adapted from Katy Borner

Viewing a subset of the network and highlighting node attributes through shape and color enhances understanding



An Attraction Network in a Fourth Grade Class
(Moreno, ‘Who shall survive?’, 1934).

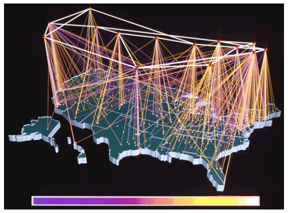


Alden Klovdahl: The core (n~ 450) of a social network of over 5,000 urban residents in Canberra, Australia

http://arts.anu.edu.au/sss/Klovdahl.asp

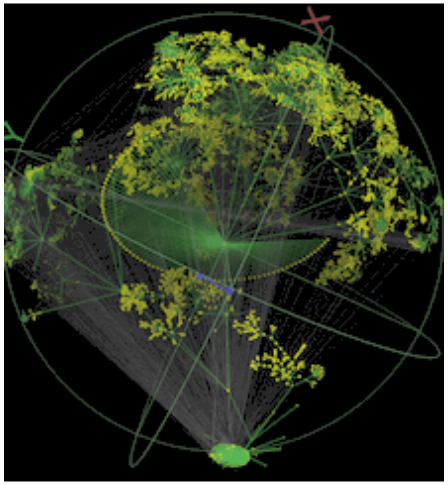
slide adapted from Katy Borner

Overlaying a network on geographical context



byte traffic into the ANS/NSFnet T1 backbone for the month of September, 1991. Cox & Patterson, NCSA.

http://www.nsf.gov/news/news_summ.jsp?cntn_id=110776

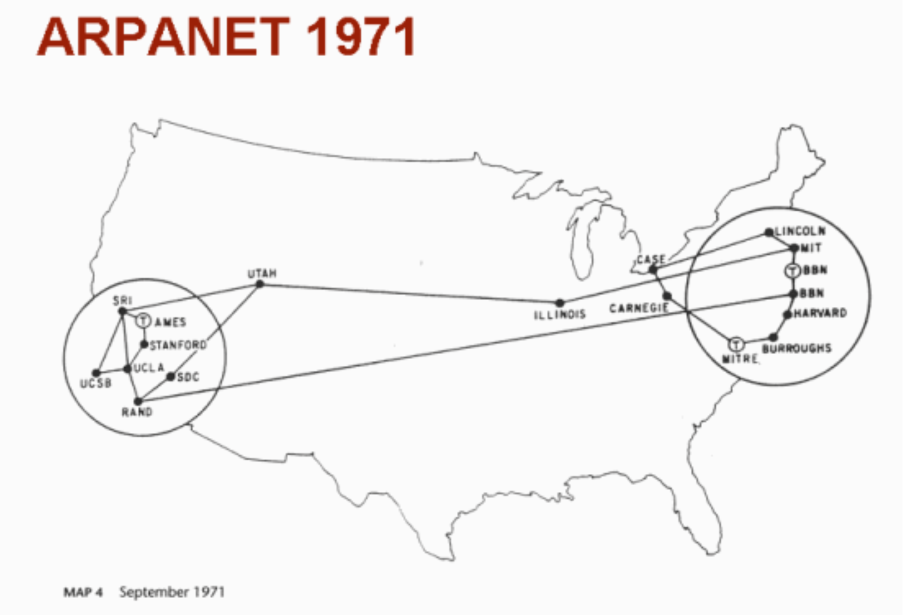


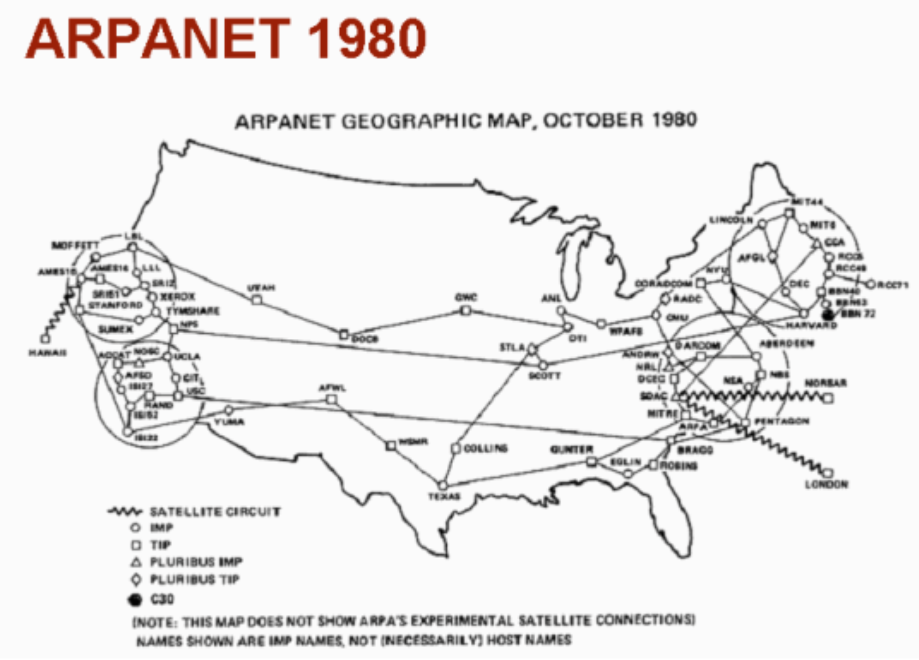
Walrus images of Skitter internet mapping data

Walrus is available under GPL

http://www.caida.org/tools/visualization/walrus/gallery1/

Longitudinal comparison





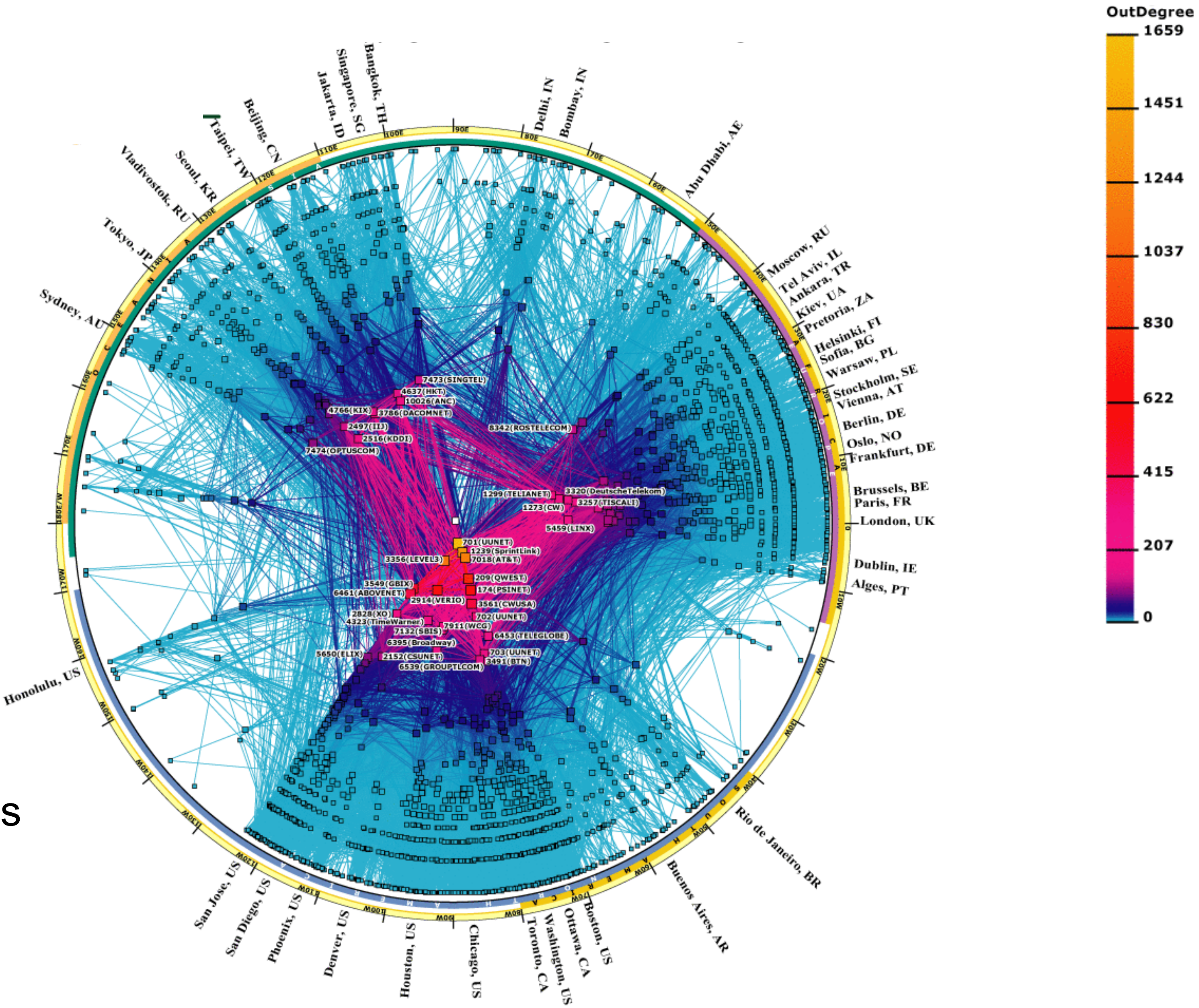
(NOTE: THIS MAP DOES NOT SHOW ARPA'S EXPERIMENTAL SATELLITE CONNECTIONS)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Sources:
1971 - "Casting the Net", page 64;
1980 - http://mappa.mundi.net/maps/maps_001/
http://personalpages.manchester.ac.uk/staff/m.dodge/cybergeography/atlas/historical.html

- Circular layout
- IPv4 internet graph

- AS-level internet map

- copyright UC Regents 2004



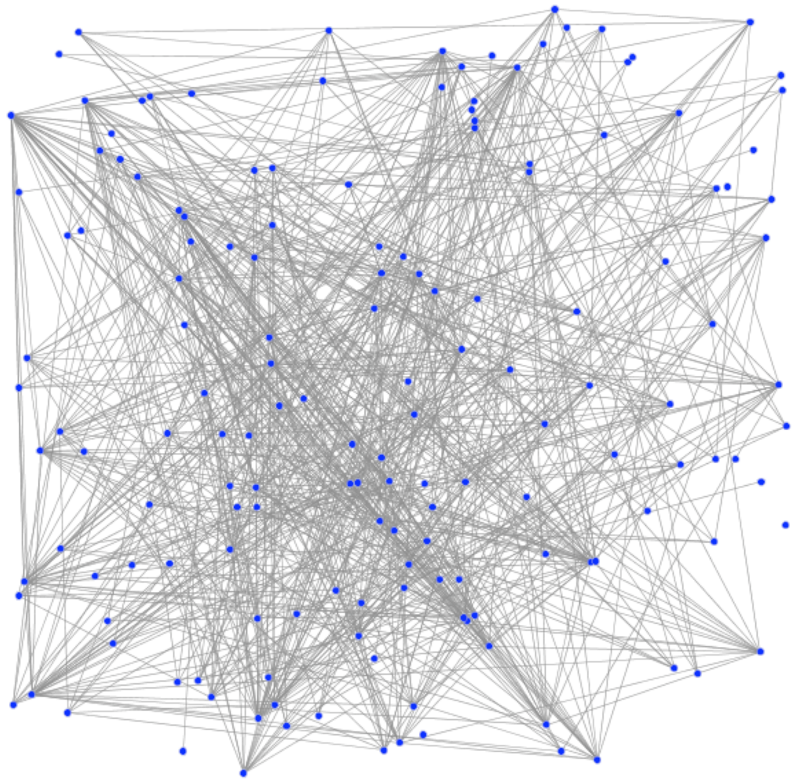
Source: http://www.caida.org/research/topology/as_core_network/

What counts in a network visualization

- Use of color
  - Internet nodes were colored by outdegree
  - Edges colored by degree of endpoints
- Use of meaningful coordinates
  - Polar coordinates
    - r – nodes with higher degree closer in
      - throws leaf nodes toward the outer edge of the graph
    - or distance from the most central node
    - position along ring denotes geographical longitude
- Use of different sizes
  - nodes sized by degree
- What else is left?
  - node shape
  - edge thickness

Random Layout

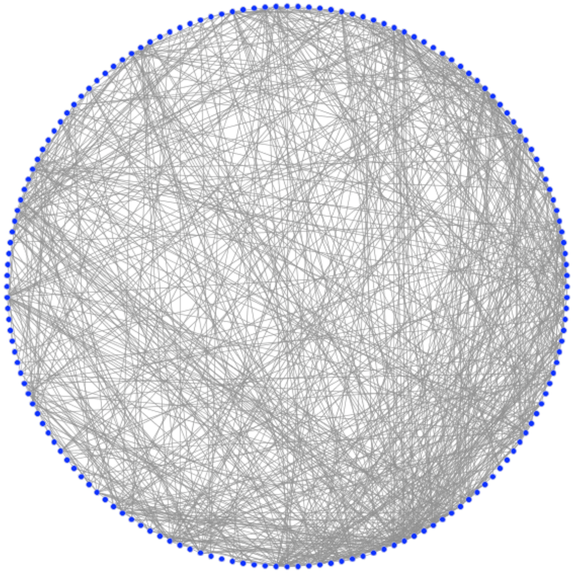
- Choose x & y coordinates at random
  - advantage: very fast
  - disadvantage: impossible to interpret



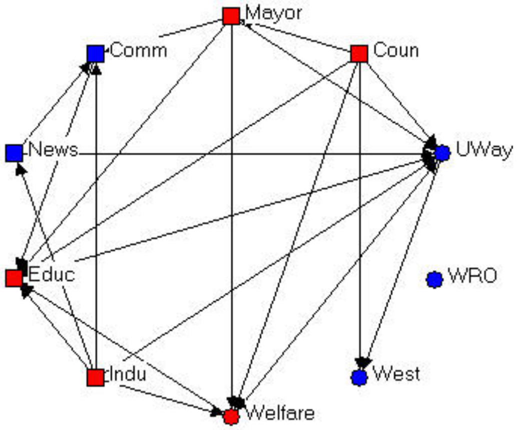
layout in *GUESS*

Circular layout

- Layout nodes along a circle and draw in all edges between them
- Advantages
  - Circular coordinates can represent a property of the data (e.g. latitude or ‘age’)
  - Very fast
- Disadvantages
  - difficult to interpret for large networks
    - many overlapping edges
    - many long edges (connected nodes need not be close together)
    - clusters hard to identify

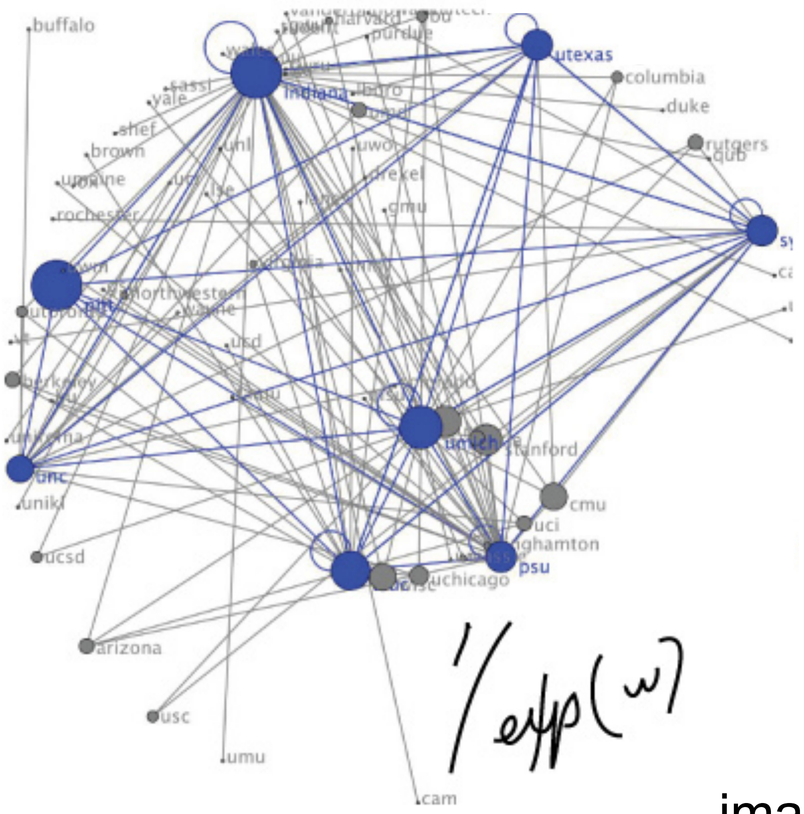


layout in *GUESS*



Circular layout in GUESS

- circleLayout(edge_weight, center_node)



$1/\exp(w)$

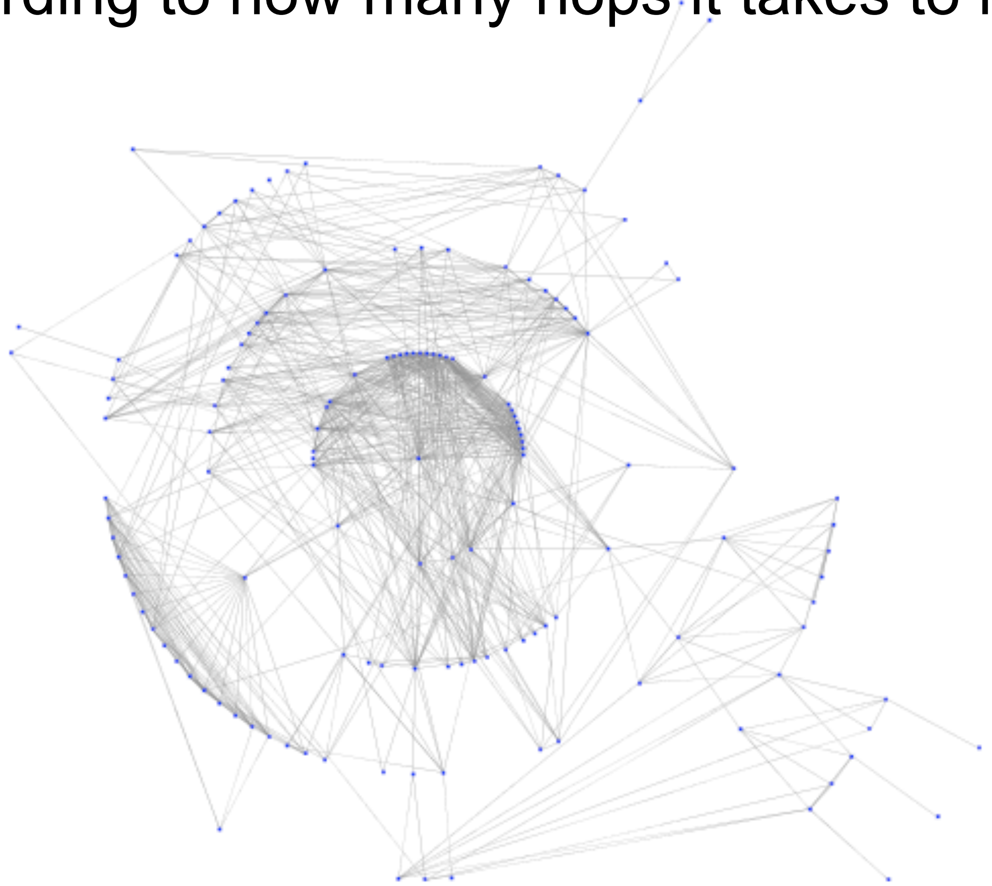
- Place all nodes on a circle
- Place center node in the middle
- Place center node's neighbors in a circle around at a radius depending on the weight of the edge

image: Andrea Wiggins

http://www.andreawiggins.com/work.html

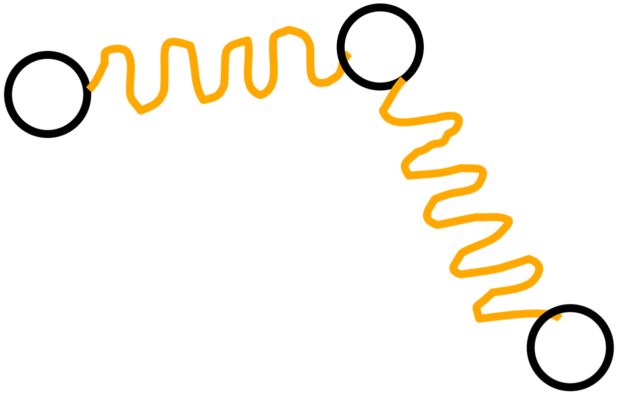
Radial Layout

- Start with one node, draw all other nodes in circular layers according to how many hops it takes to reach them

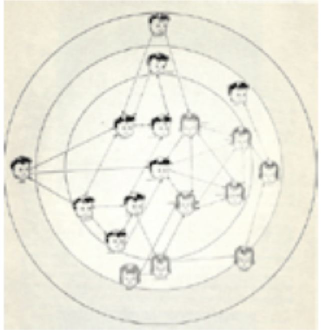


Spring embedding algorithms

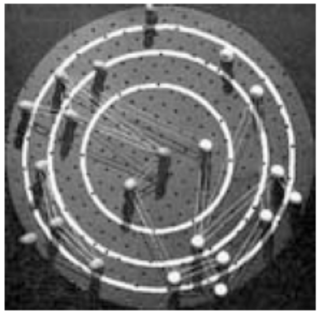
- Two parts
  - Force (or energy) model that quantifies the quality of drawing
  - Optimization algorithm that computes a network configuration that is locally optimal with respect to this algorithm
- Final layout depends on starting positions
  - Simulated annealing introduces randomness to help the algorithm find global minima
- At equilibrium, the force on each vertex is 0



“manual” spring layouts



Grant's Drawing of a Target Sociogram of a First Grade Class (from Northway, 1952).



McKenzie's Target Sociogram Board (from Northway, 1952).

Pegs and rubber bands used to determine an individual’s location in the sociogram.

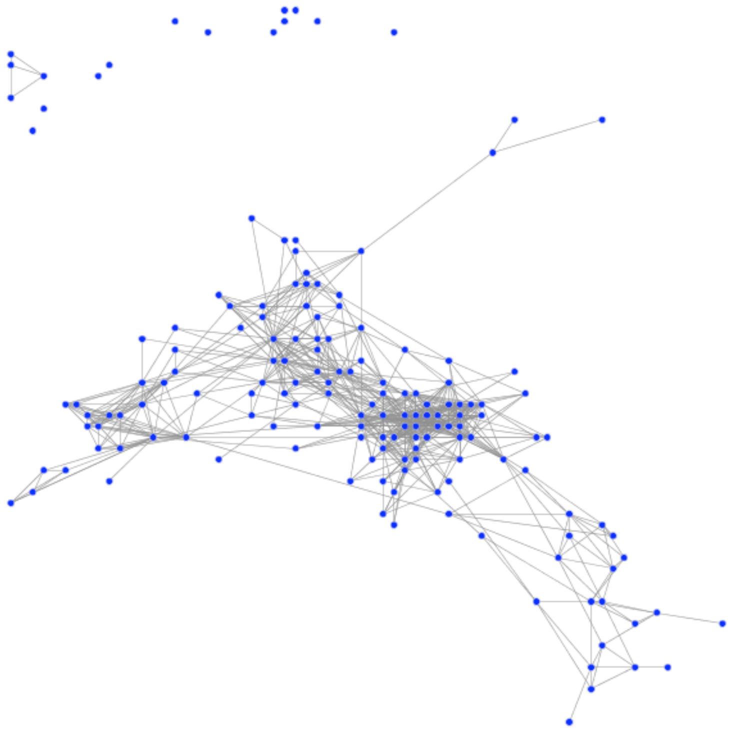
computerized spring layouts

- Iterative procedure
- At each time step, allow springs to expand or contract toward a neutral position

```
select optimal edge length  (node distance)   k
repeat
    for each node  v  do
        for each pair of nodes  (u, v)
        compute repulsive force              $f_r(u,v) = - c•$
         for each edge  e = (u,v)
        compute attractive force    $f_a(u,v) = c•$
    sum all force vectors  $F(v) = \sum f_r(u,v) + \sum f_a(u,v)$
    move  node  v  according to F(v)
until  DONE
```

Spring layout algorithms: Fruchterman and Reingold

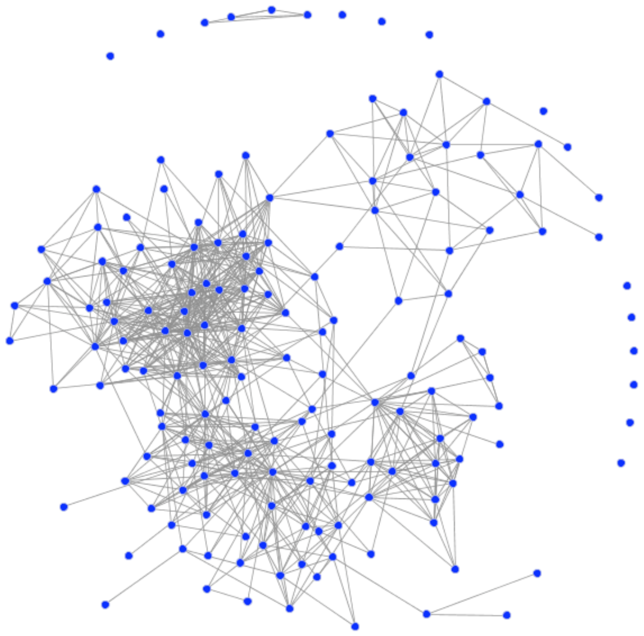
- Model roughly corresponds to electrostatic attraction between connected nodes
- Use adjacency matrix directly
- Iterative optimization
  - at each step, every node reacts to the pulls and pushes of the springs that tie it to all the other nodes
- Can be slow as the network grows



layout in *GUESS*

Spring layout algorithms: Kamada Kawai

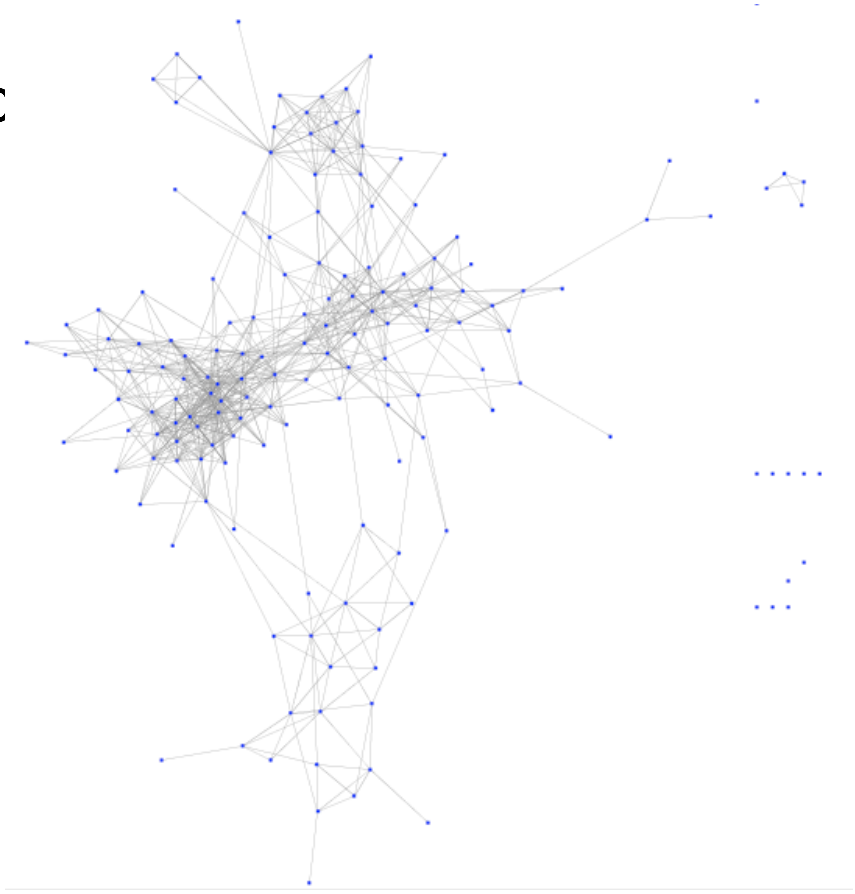
- All nodes are connected by springs with a resting length proportional to the length of the shortest path between them
- Need to calculate all pairs shortest paths first
- Iterative optimization
- Advantage: can be used on edge- weighted graphs
- Can be slow as the network grows



layout in *GUESS*

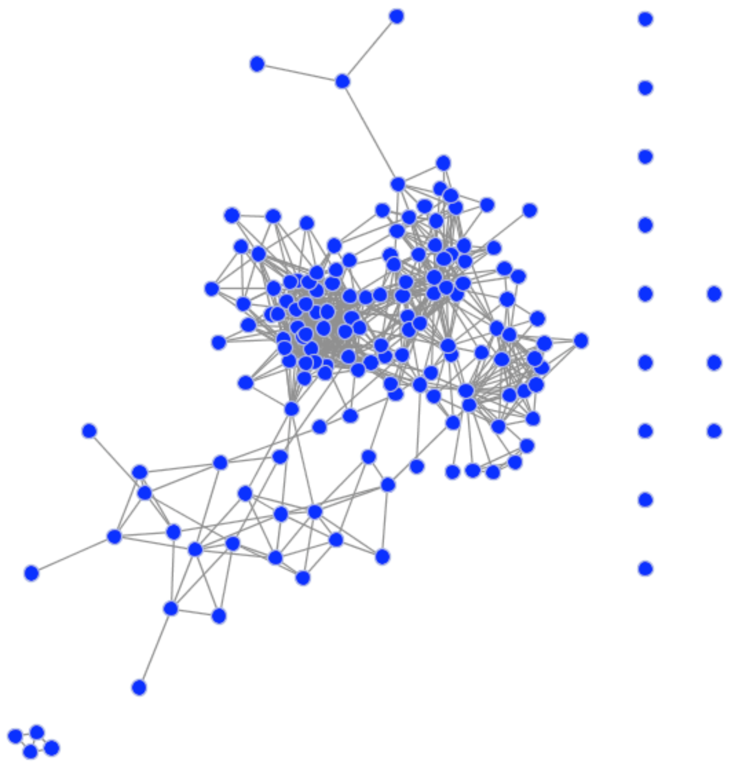
Spring layout algorithms: GraphOpt

- Another physics approach with springs and electrostatic charges
- Iterative optimization
- Layering:
  - nodes assigned 'layers' based on relative positions
  - hide nodes in lower layers
  - lay out higher level nodes
- Advantage: can be used on somewhat larger graphs
- Can be slow as the network grows



layout in *GUESS*

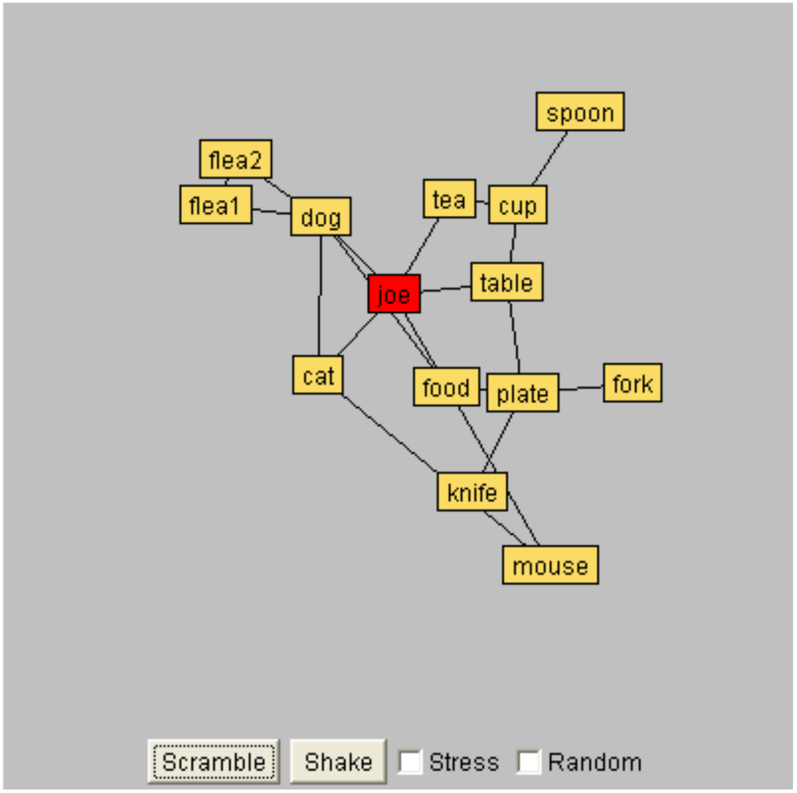
There are many variations on spring layout algorithms...



Spring() layout in *GUESS*

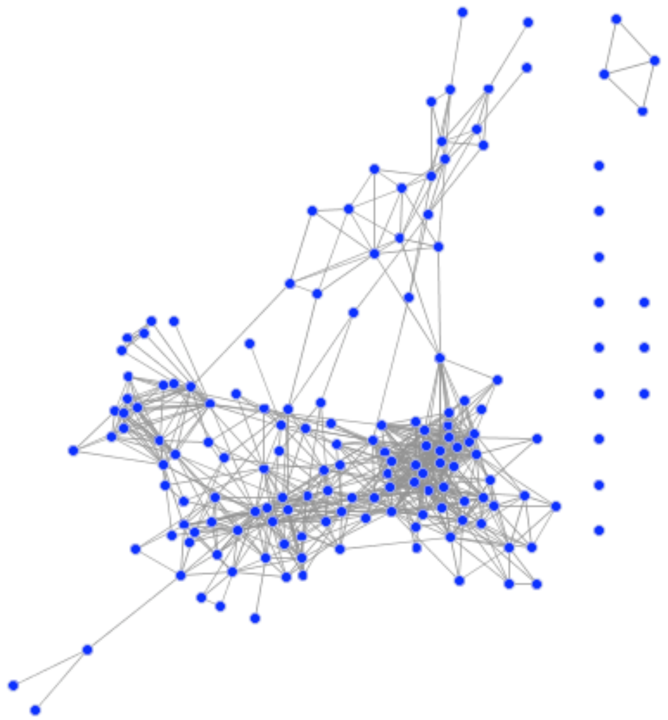
Java applet demo of a spring layout

- http://java.sun.com/applets/jdk/1.4/demo/applets/GraphLayout/example1.html



GEM (graph embedding) Layout

- Embedding algorithm with speed & layout optimizations
- Significantly faster than KK or FR
- In GUESS, you can lay out 1,000 – 10,000 node graphs, depending on the edge density



layout in *GUESS*

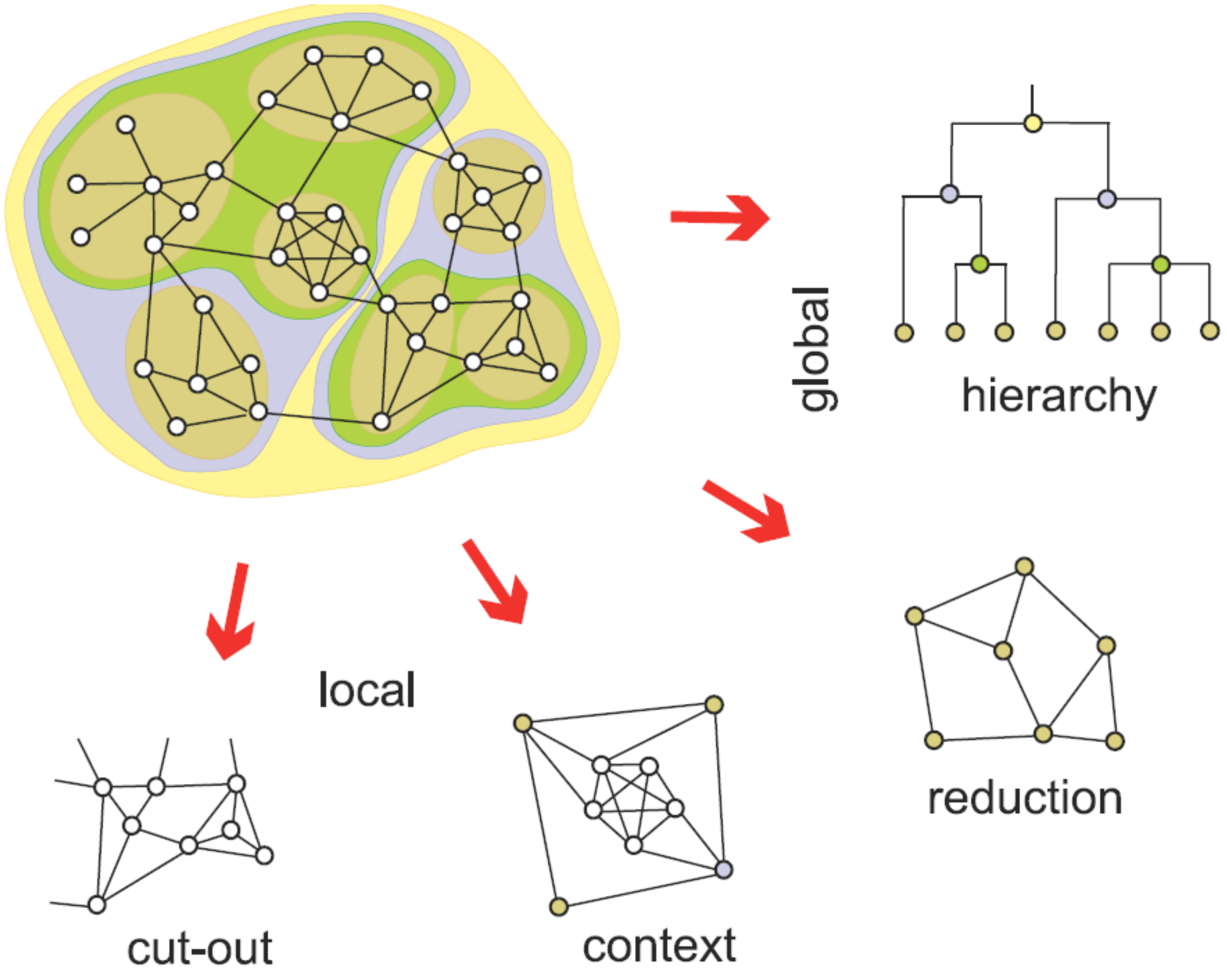
Multidimensional scaling concept

- Metric MDS gives an exact solution based on a Singular Value Decomposition of the input matrix.
- Input matrix can be the all pairs shortest path or another ‘distance matrix’
- Usually the data is plotted according to the eigenvectors corresponding to the two largest eigenvalues

Strategies for visualizing large graphs

- Reduce the number of nodes and edges
  - introduce thresholds
    - only authors who have written at least x papers
    - only edges with weight > y
    - only nodes with degree > z (e.g. removing leaf nodes)
  - show minimum spanning trees
    - can visualize all the nodes with a subset of the edges
  - use pathfinder network scaling (http://iv.slis.indiana.edu/sw/pfnet.html)
    - triangle inequality to eliminate redundant or counter-intuitive links
    - remaining edges are more representative of internode relationships than minimum spanning trees
  - collapse nodes into clusters
    - show multiple nodes as a single node
    - display connections between clusters
    - e.g. displaying the internet graph on the autonomous system level rather than the individual router level

From the Pajek manual:
approaches to deal with large networks



global

hierarchy

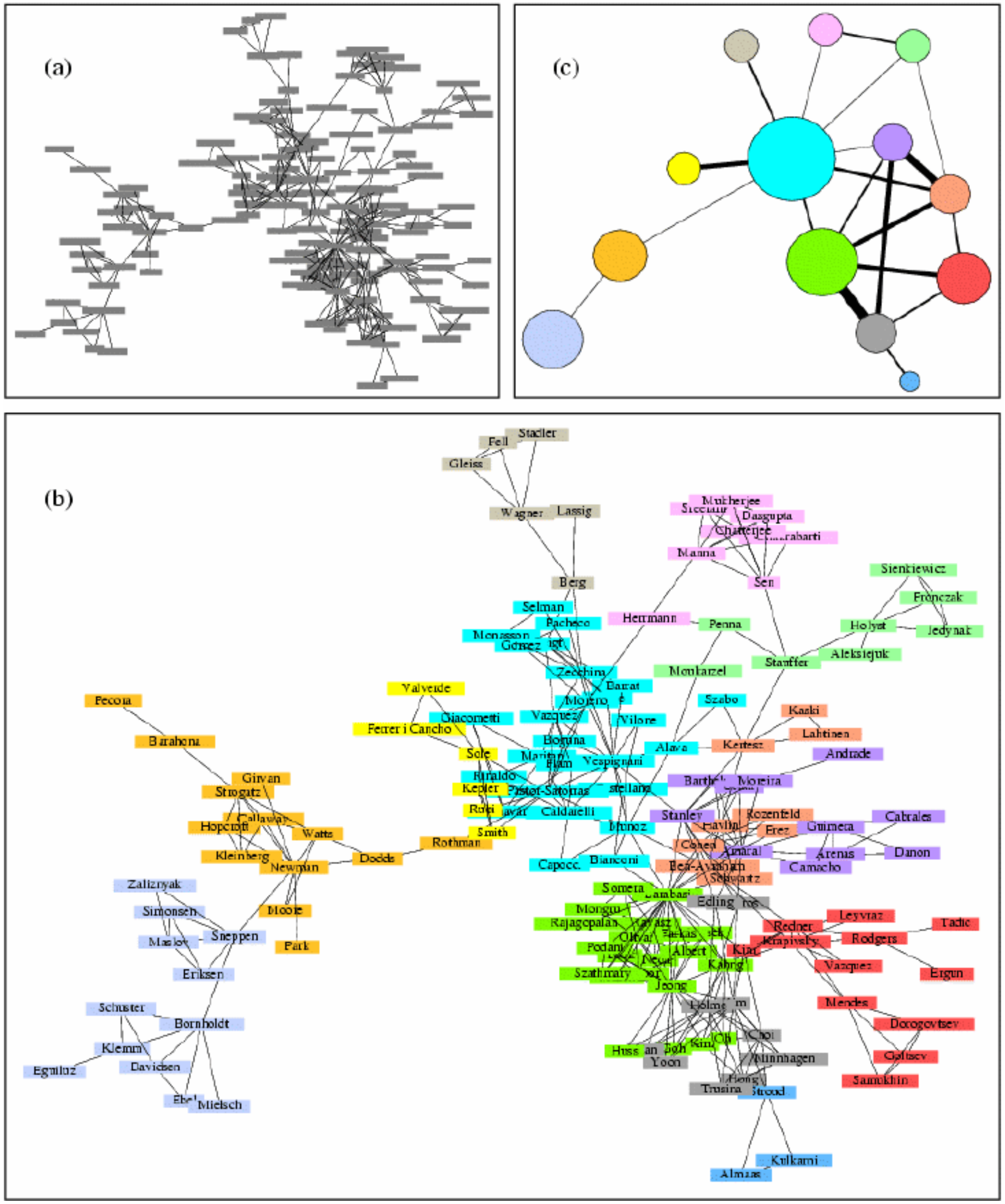
reduction

local

cut-out

context

Source: Pajek, http://vlado.fmf.uni-lj.si/pub/networks/pajek/ - free for noncommercial use



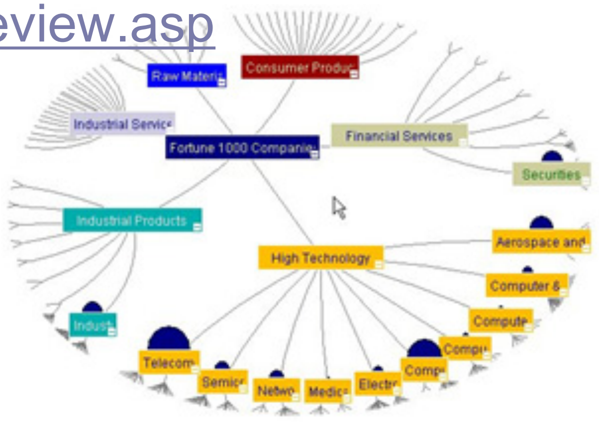
Example of coarsening network structure

- Newman & Girvan 2004
- co-authorship network of physicists writing papers on networks
- clustering algorithm identifies different subcommunities
- each node is a community – size represents number of authors
- each edge thickness represents the number of co-author pairs between communities

Source: Finding and Evaluating Community Structure in Netowrks, M. E. J. Newman and M. Girvan, http://link.aps.org/doi/10.1103/PhysRevE.69.026113 DOI: 10.1103/PhysRevE.69.026113

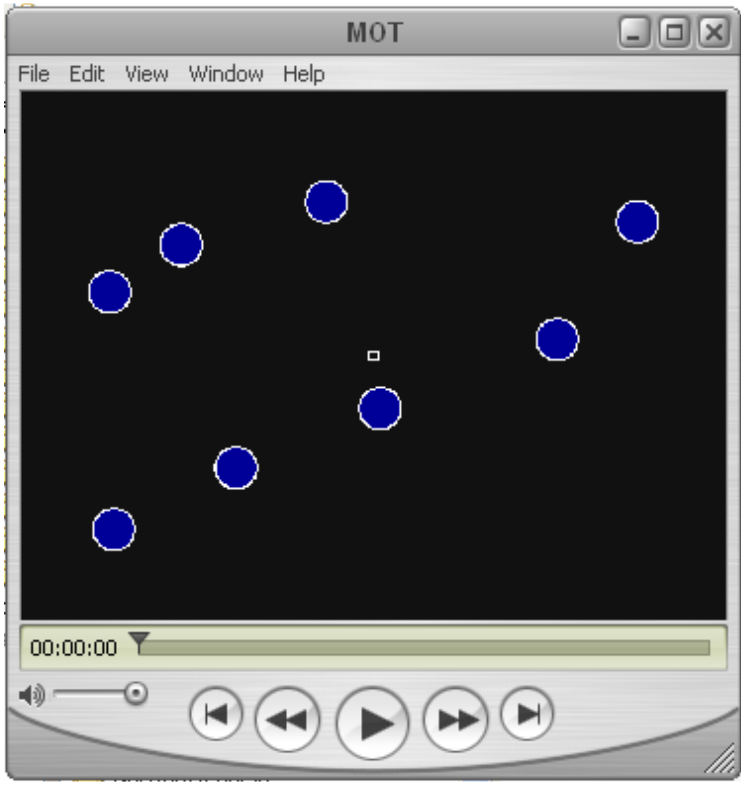
Zoomable interfaces

- GUESS lays out networks on an infinite plane that one can zoom in and out of (demo)
- hyperbolic browser (InXight demo): http://www.inxight.com/VizServerDemos/demo/orgchart.html
  - map a hyperbolic plane onto a circular layout
  - in a hyperbolic plane each child node gets as much space as its parent
  - focus of hyperbolic plane is displayed in the middle of a unit circle
  - rest fades off-perspective toward the edge of the disk
  - in the browser, change focus by clicking on node to bring it to the center
  - good for visualizing large hierarchies
  - another demo with Lexis-Nexis: http://www.lexisnexis.com/startree/interactiveview.asp

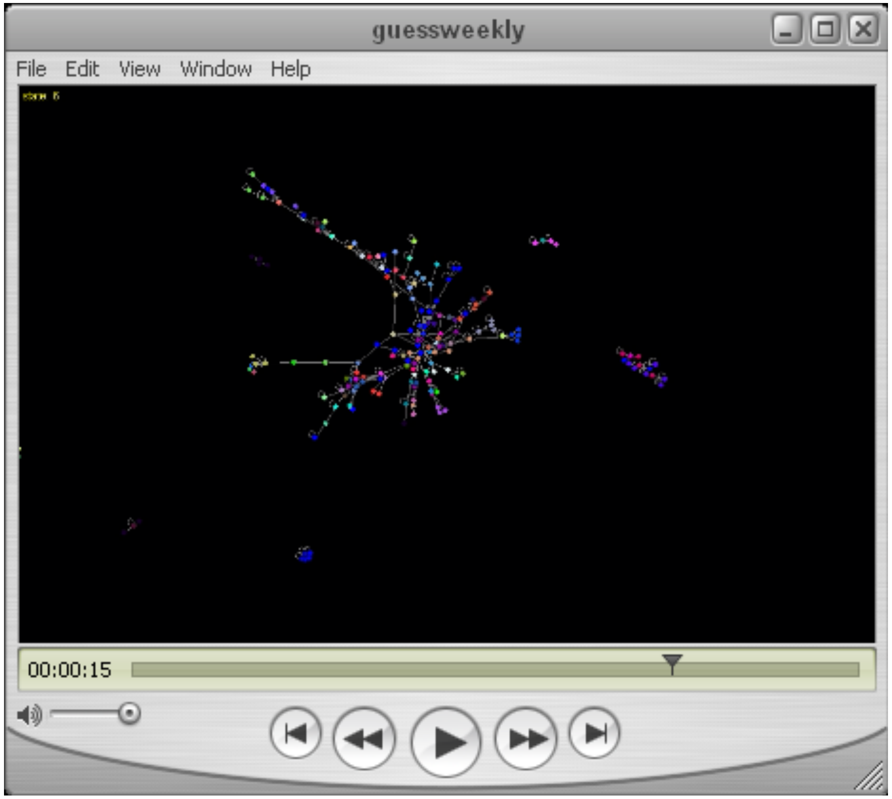


Displaying longitudinal data through animation

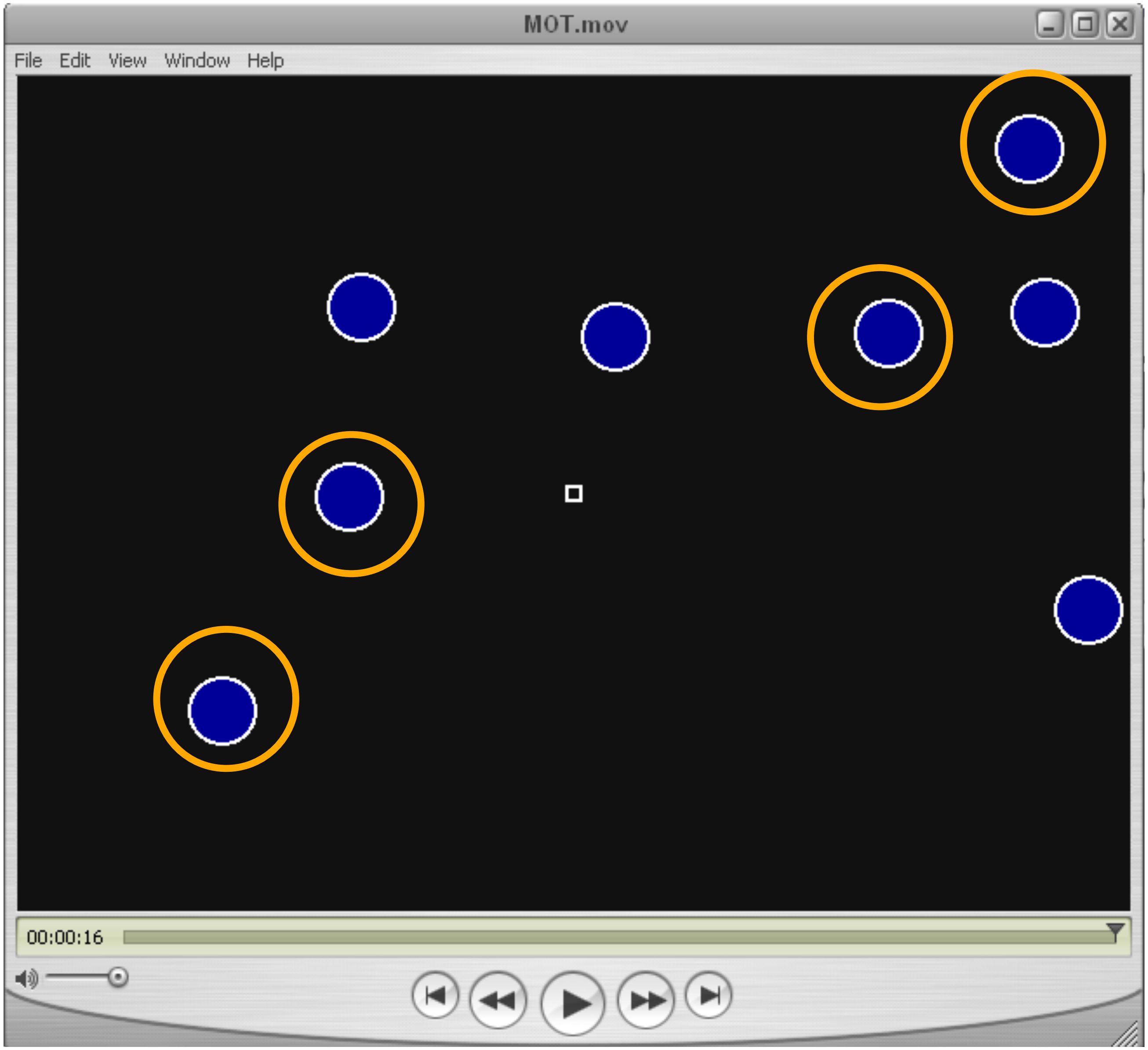
- Nodes should move little between different timepoints to make it easier to track them
- Most people can track 3-7 objects simultaneously (your network can have hundreds or more)



http://ruccs.rutgers.edu/finstlab/motMovies/mot.mov

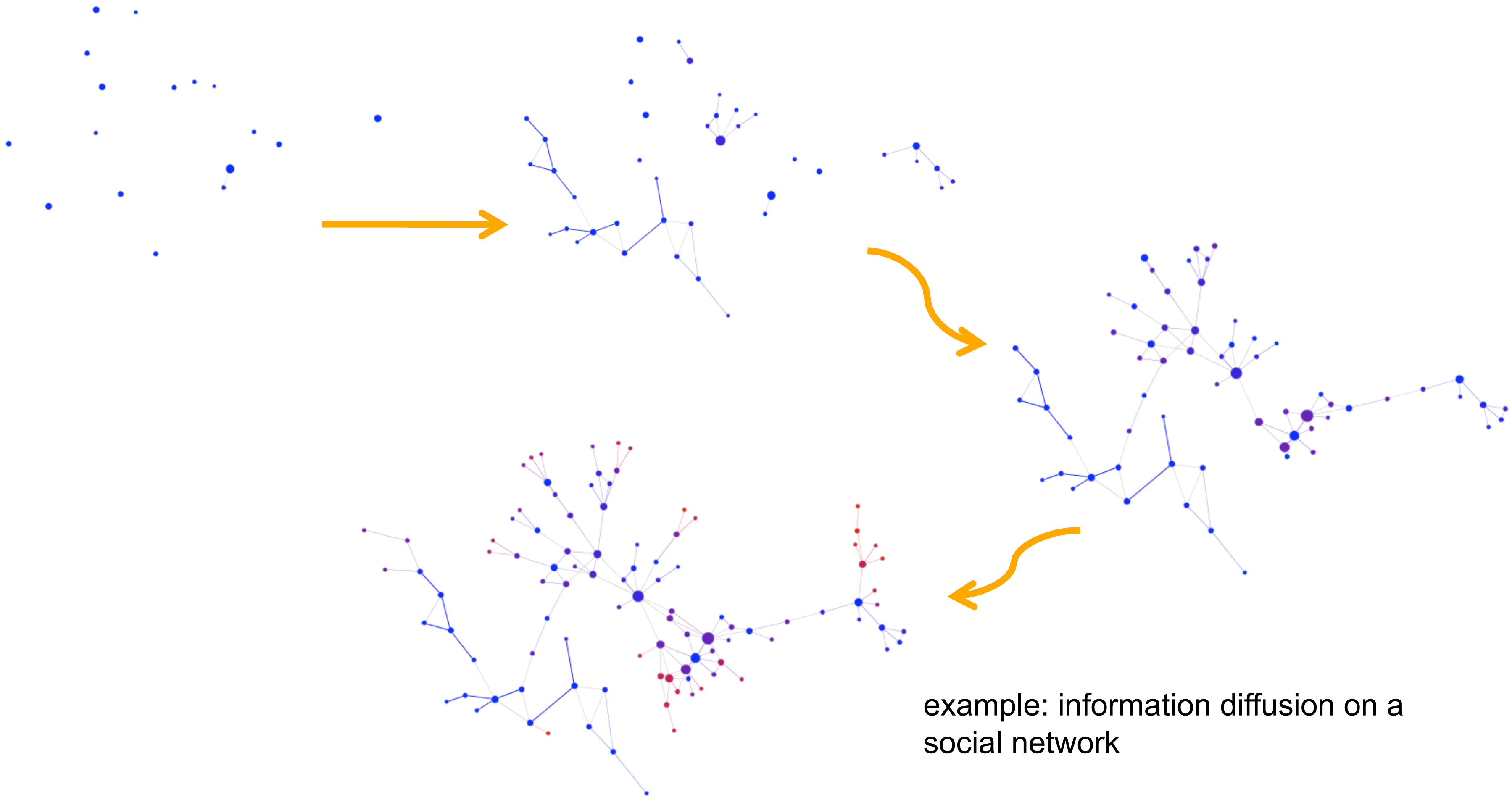


http://graphexploration.cond.org/sample.mov


MOT.mov
File
Edit
View
Window
Help
00:00:16

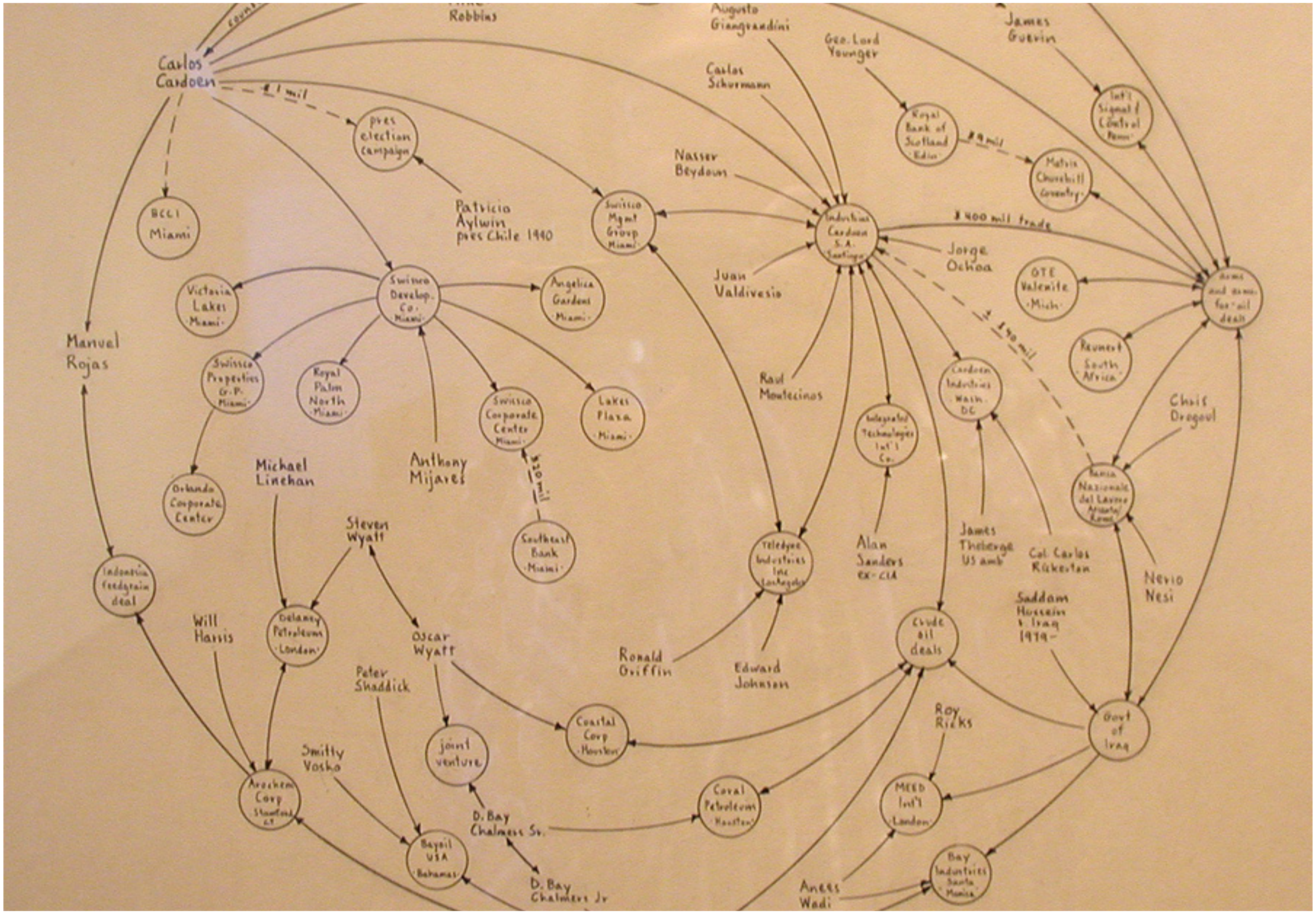
graphs over time

- consider keeping nodes in the same place, but having them appear/ disappear….

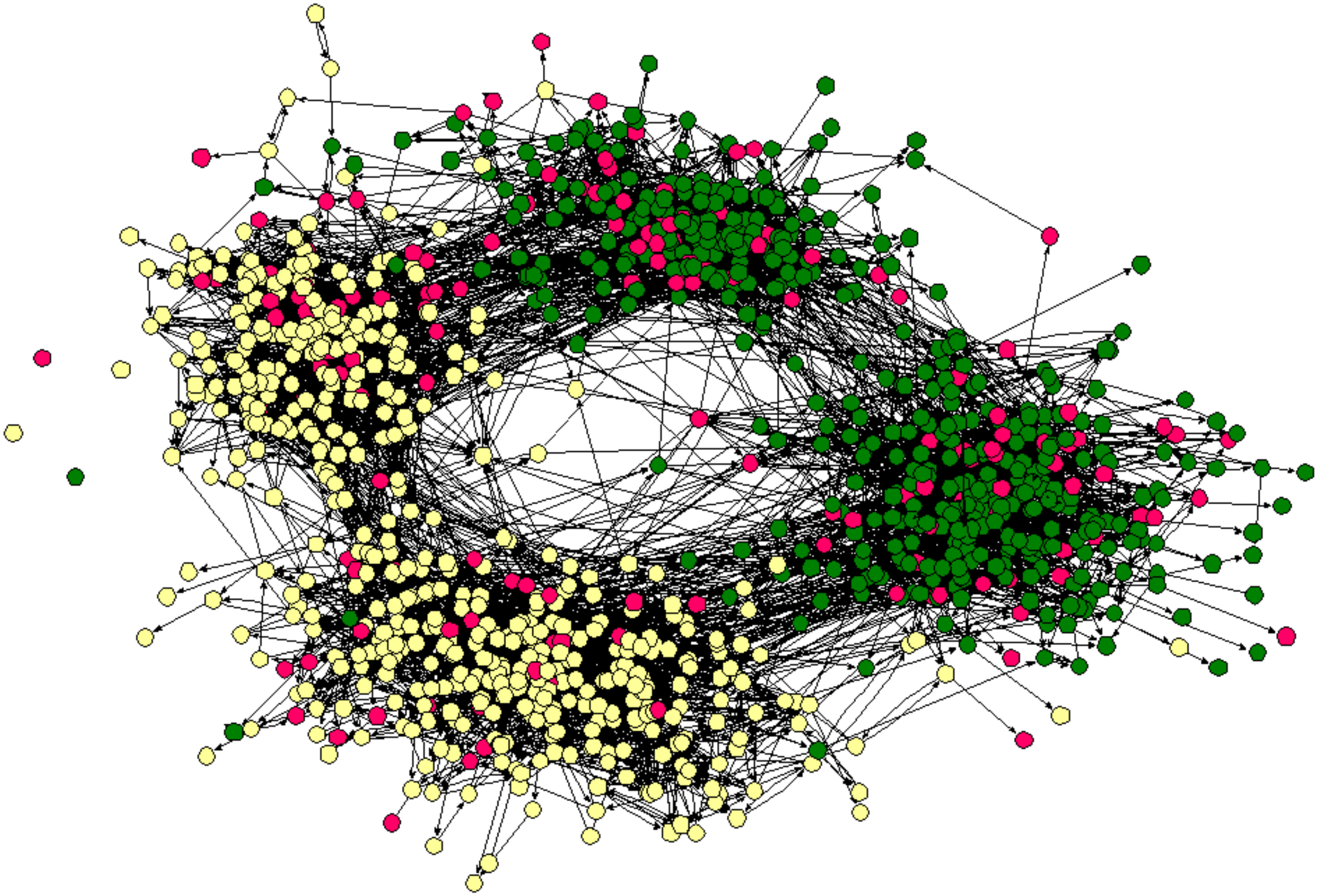


example: information diffusion on a social network

Mark Lombadi’s (hand-drawn) networks

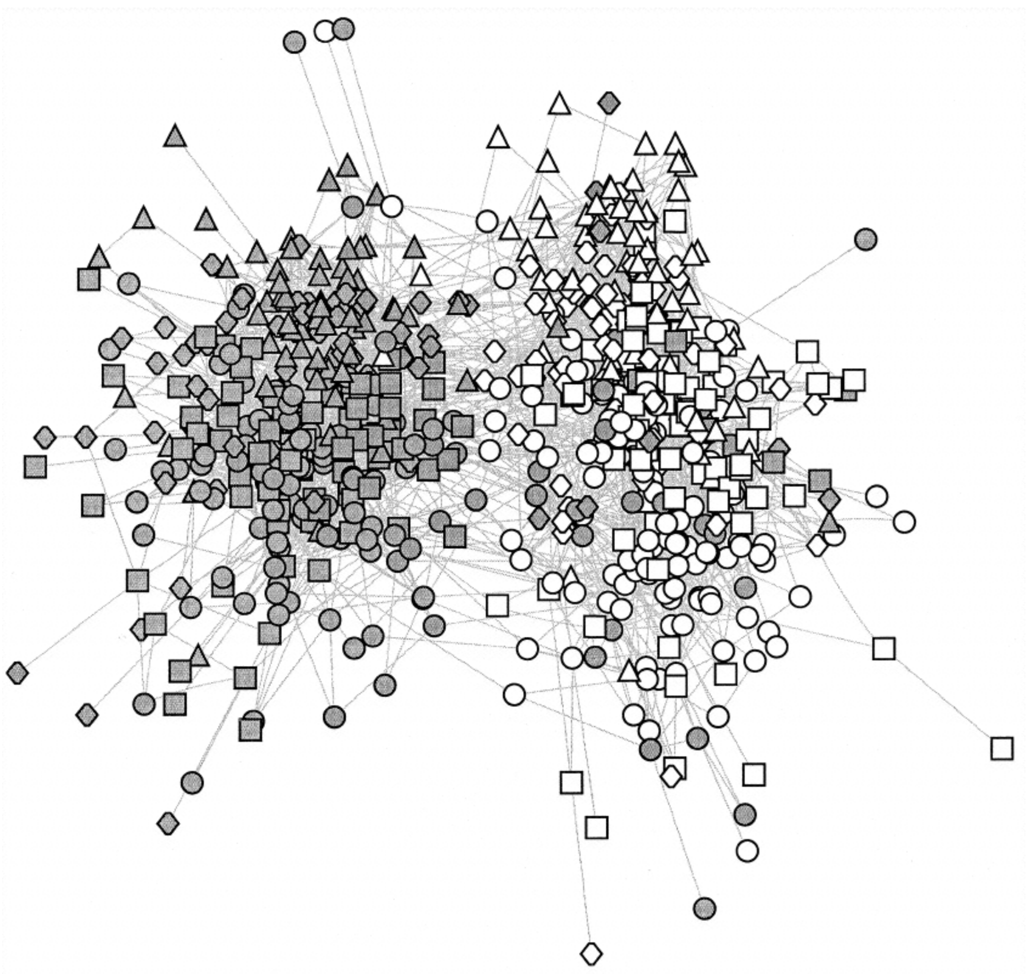


What else could be added to this visualization?



source: James Moody, **Race, School Integration, and Friendship Segregation in America**
AJS Volume 107 Number 3 (November 2001): 679–716

What else could be added to this visualization?



○ 9th

□ 10th

⬡ 11th

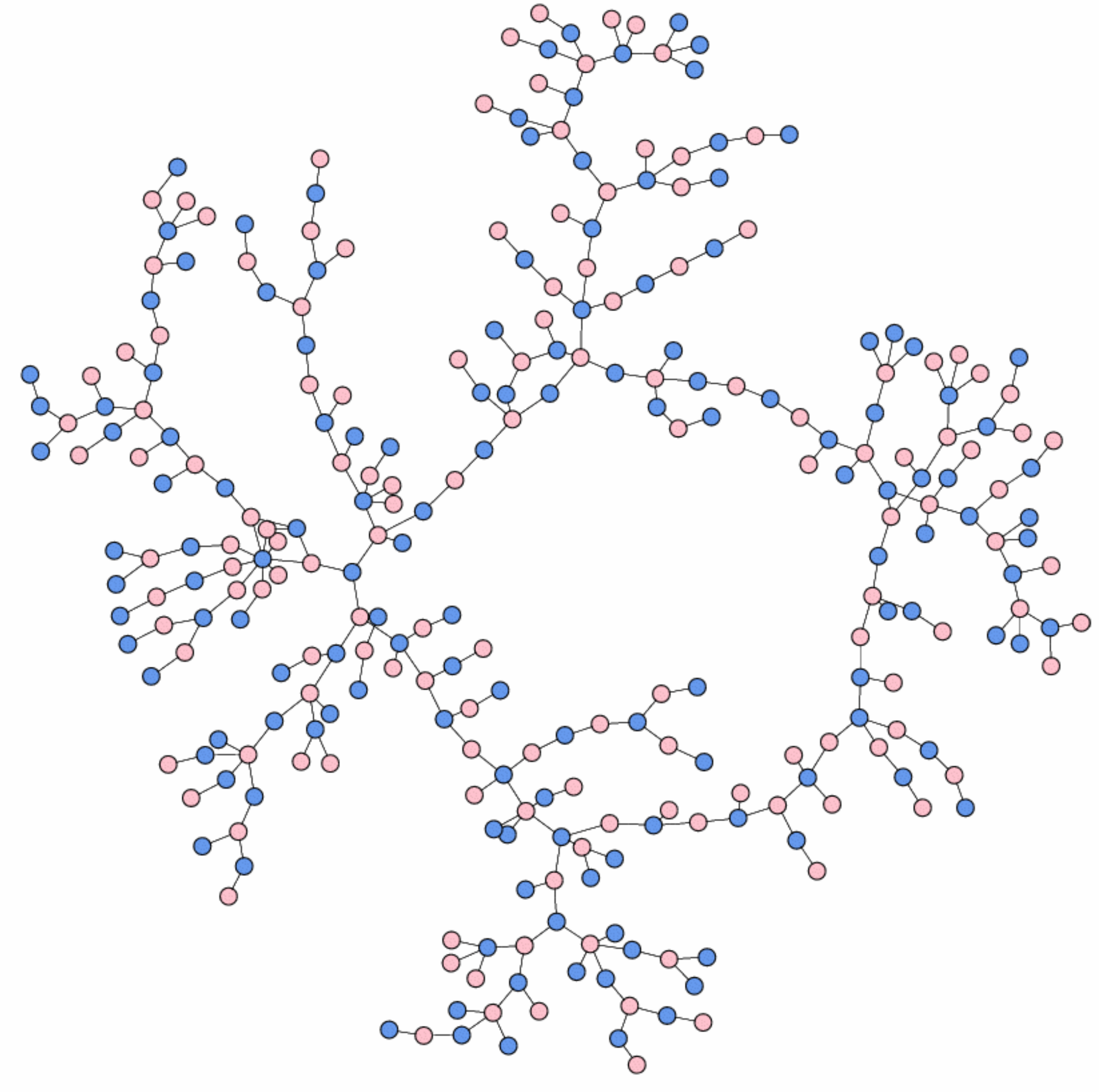
△ 12th

□ white

■ non-white

source: James Moody, **Race, School Integration, and Friendship Segregation in America**
AJS Volume 107 Number 3 (November 2001): 679–716

Visualizing attributes (gender)



High school dating: Data drawn from Peter S. Bearman, James Moody, and Katherine Stovel, Chains of affection: The structure of adolescent romantic and sexual networks, *American Journal of Sociology* **110**, 44-91 (2004).

Source: Finding and Evaluating Community Structure in Netowrks, M. E. J. Newman and M. Girvan, http://link.aps.org/doi/10.1103/PhysRevE.69.026113 DOI: 10.1103/PhysRevE.69.026113

School of Information
University of Michigan

GUESS
The Graph Exploration System

Eytan Adar

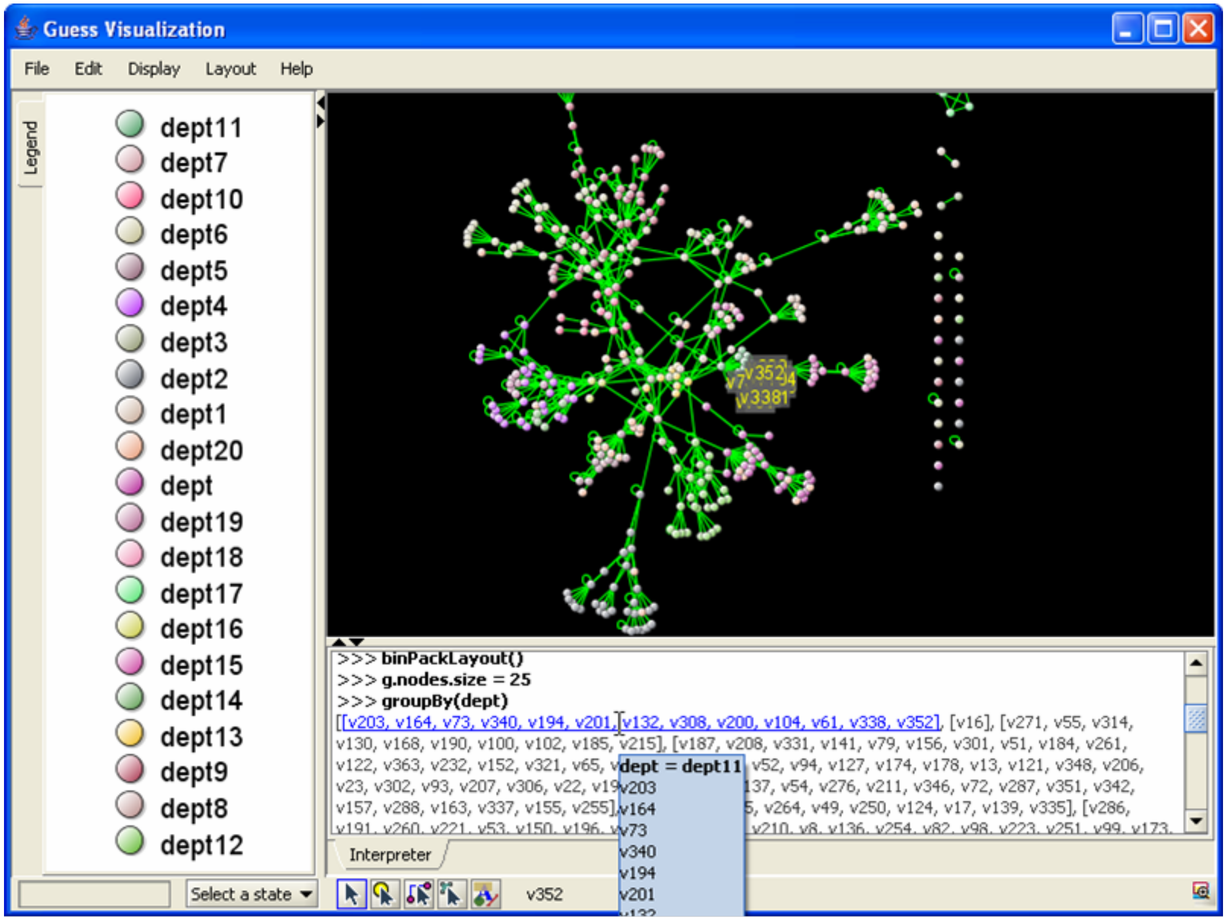
November 23, 2005

Design requirements

- Deal with different kinds of networks
    - But not by abstracting everything to a matrix
        - Nodes and edges have properties!
- Exploratory tool
    - Tolerate mistakes made in exploration
- Ability to easily do standard analysis
- Ability to add new analysis routines
- Scriptable
- Compile into application/applet
- Flexible front/back ends

- guess.bat (windows)
- guess.sh (Mac)

Screenshot



```
>>> binPackLayout()
>>> g.nodes.size = 25
>>> groupBy(dept)
[[v203, v164, v73, v340, v194, v201, v132, v308, v200, v104, v61, v338, v352], [v16], [v271, v55, v314,
v130, v168, v190, v100, v102, v185, v215], [v187, v208, v331, v141, v79, v156, v301, v51, v184, v261,
v122, v363, v232, v152, v321, v65, v                 v52, v94, v127, v174, v178, v13, v121, v348, v206,
v23, v302, v93, v207, v306, v22, v19               137, v54, v276, v211, v346, v72, v287, v351, v342,
v157, v288, v163, v337, v155, v255],               5, v264, v49, v250, v124, v17, v139, v335], [v286,
v191, v260, v221, v53, v150, v196, v               v210, v8, v136, v254, v82, v98, v223, v251, v99, v173,
```

GUESS

- “Gython”
  - Python + graph data structures + operators + query language
- Better (expandable/separable) architecture
  - Back-end storage abstracted
  - Front-end visualization abstracted
    - Prefuse
    - Touchgraph
    - Still have one main “zoomable” front end
      - The most complete

Query language built in

- Nodes and Edges have properties
  - The usual types (text, numbers, Booleans)
- Can use these to manipulate the display
  - (dept == ‘Human Resources’).color = blue
  - (freq > 10).width = 4
  - (cell_location == ‘wall’) & (expression_levels > 100)
  - (name like ‘Bob%’)

Getting data in

- GUESS lets you define your own properties

```
nodedef> name, country VARCHAR
N1,”US”
N2,”France”
edgedef> node1,node2, delay INT default 5
N1,N2,20
```

Visual properties built in…

- GUESS knows about visual properties
  - Nodes
    - location, color, size, shape, label, etc.
  - Edges
    - width, color, etc.
- (Non-visual) properties generated dynamically
  - e.g. indegree, pagerank, betweeenness
- Everything accessed same way
  - v3.color v3.dept v3.indegree

Visual shortcuts

- Lots of syntactic sugar to do certain things
  - Color each department differently
    - colorize(dept)
  - Color each edge by frequency from red to blue
    - colorize(freq,red,blue)

- Can group and sort by properties
  - depts = groupBy(dept)
  - freqs = sortBy(freq)
  - whatever = groupAndSortBy(…)

Built in functions

- Layouts
- Clustering algorithms
- Shortest path/Flow algorithms
- Centrality measures
- Graph statistics
- Plots and charts

- Can even connect to R for more

Connect interpreter to display

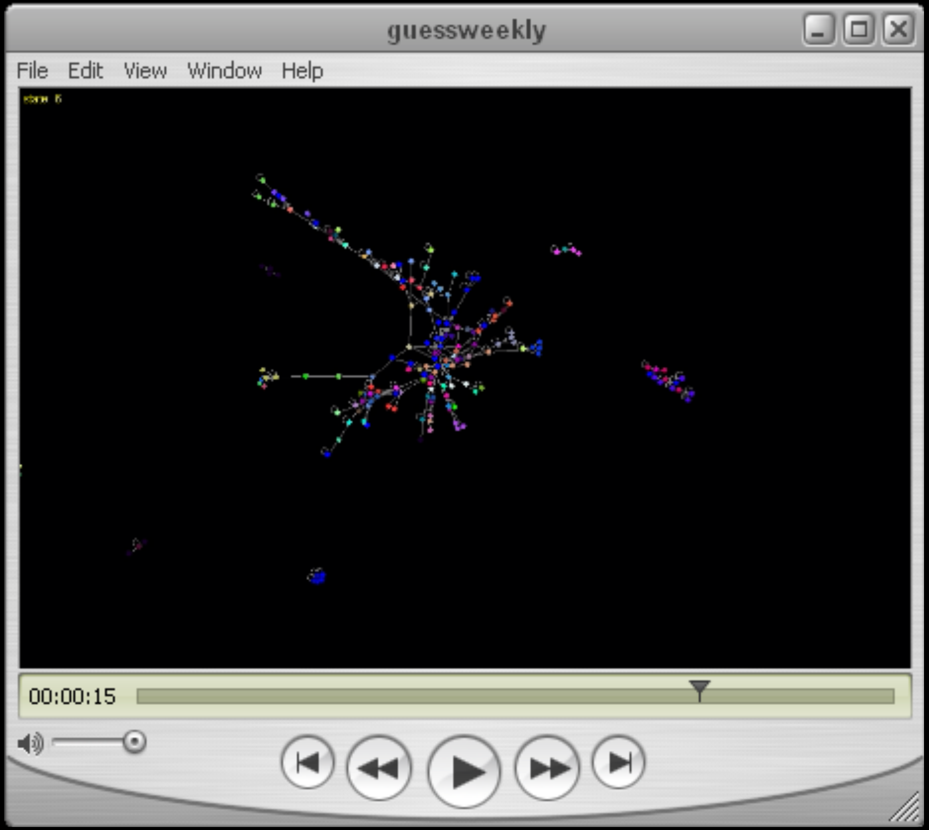
- Unique feature of GUESS
- Mouse motion over text results in highlighting of graph/ visualization structures
- [[v4,v5],[v6,v7,v8]]

States and Time

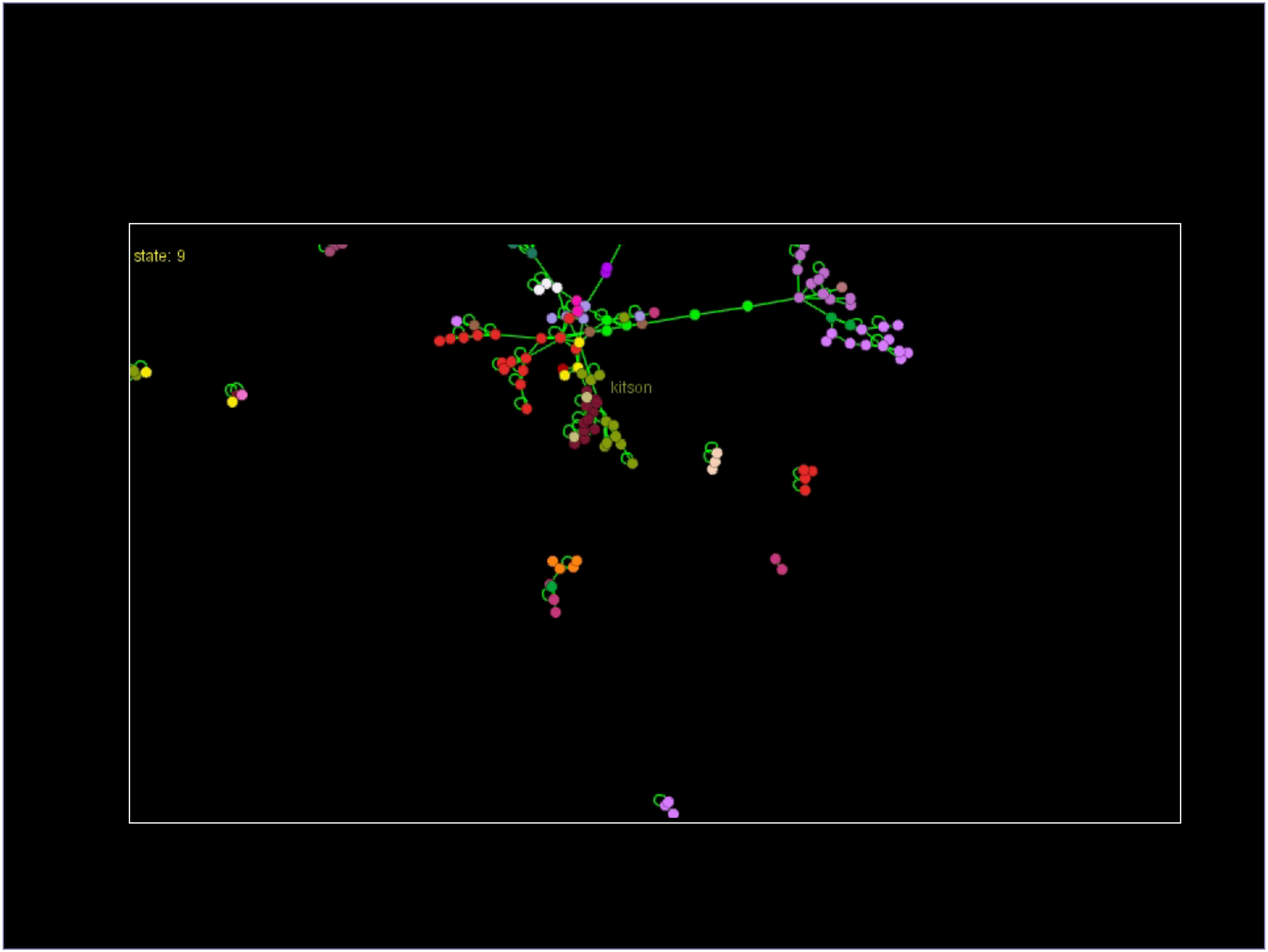
- As if graphs weren’t complicated enough…
  - Time is a critical dimension
  - Graphs and properties change
  - We want to visualize them
- And users in an exploratory mode want undo
- Kill two birds with one stone…

States and Time

- Basics through simple commands
  - ss(‘state name’)
  - ls(‘state name’)
- Queries work between states
  - v44[‘q105’].dept
  - freq[2005] > freq[2003]
- Morphing
  - morph(‘state name’,time)
  - output as movie
  - Camera tracking (in Zoomgraph and soon in GUESS)
- Also… “range” fields
  - “1,5-100,102-105”
  - Node rcontains (5,10)
  - Node rexact (102-105)



guessweekly
File Edit View Window Help
00:00:15


state: 9
kitson

Extending GUESS

- Write your own routines/programs
- Change mouseover/click behavior
  - E.g. pop up a web page
- Control remotely or through Java
- Add “dockable” widgets
- Replace front end
- Compile into applet

Simple Example: Skitter

$$\textbf{radius} = 1 - \log\left(\frac{\text{outdegree(AS)} + 1}{\text{maximum.outdegree} + 1}\right)$$

$$\theta = \left(\begin{array}{c}\text{longitude of the AS headquarters}\\ \text{in whois records}\end{array}\right)$$

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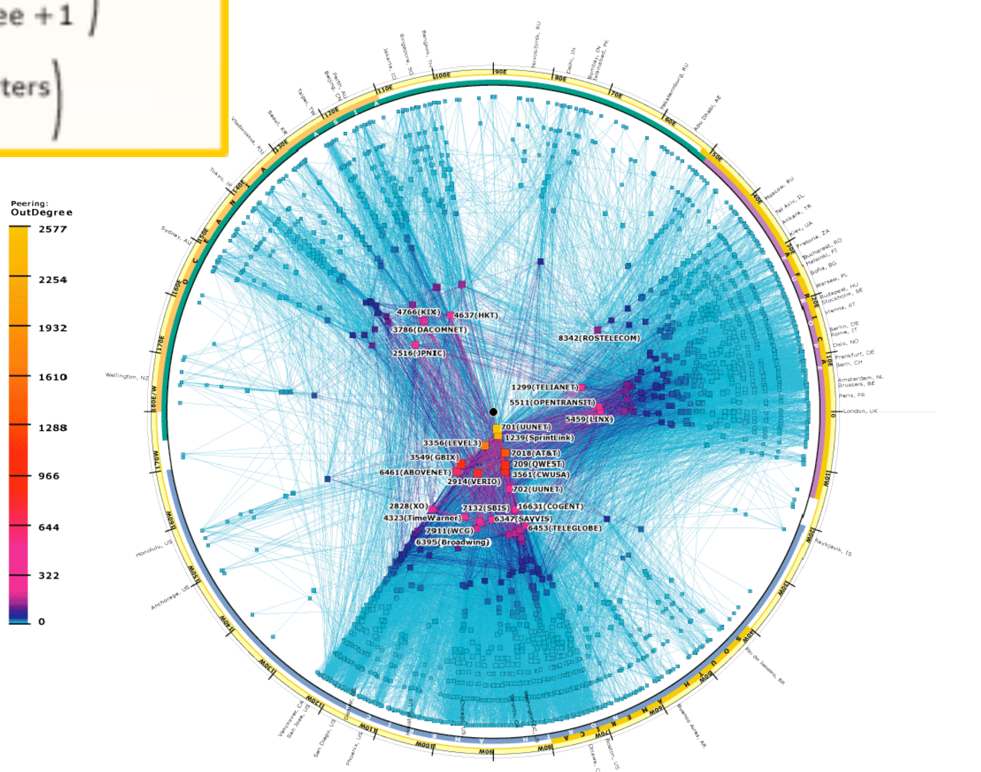


cooperative association for internet data analysis ○ san diego supercomputer center ○ university of california, san diego

9500 gilman drive, mc0505 ○ la jolla, ca 92093-0505 ○ tel. 858-534-5000 ○ http://www.caida.org/

caida
www.caida.org

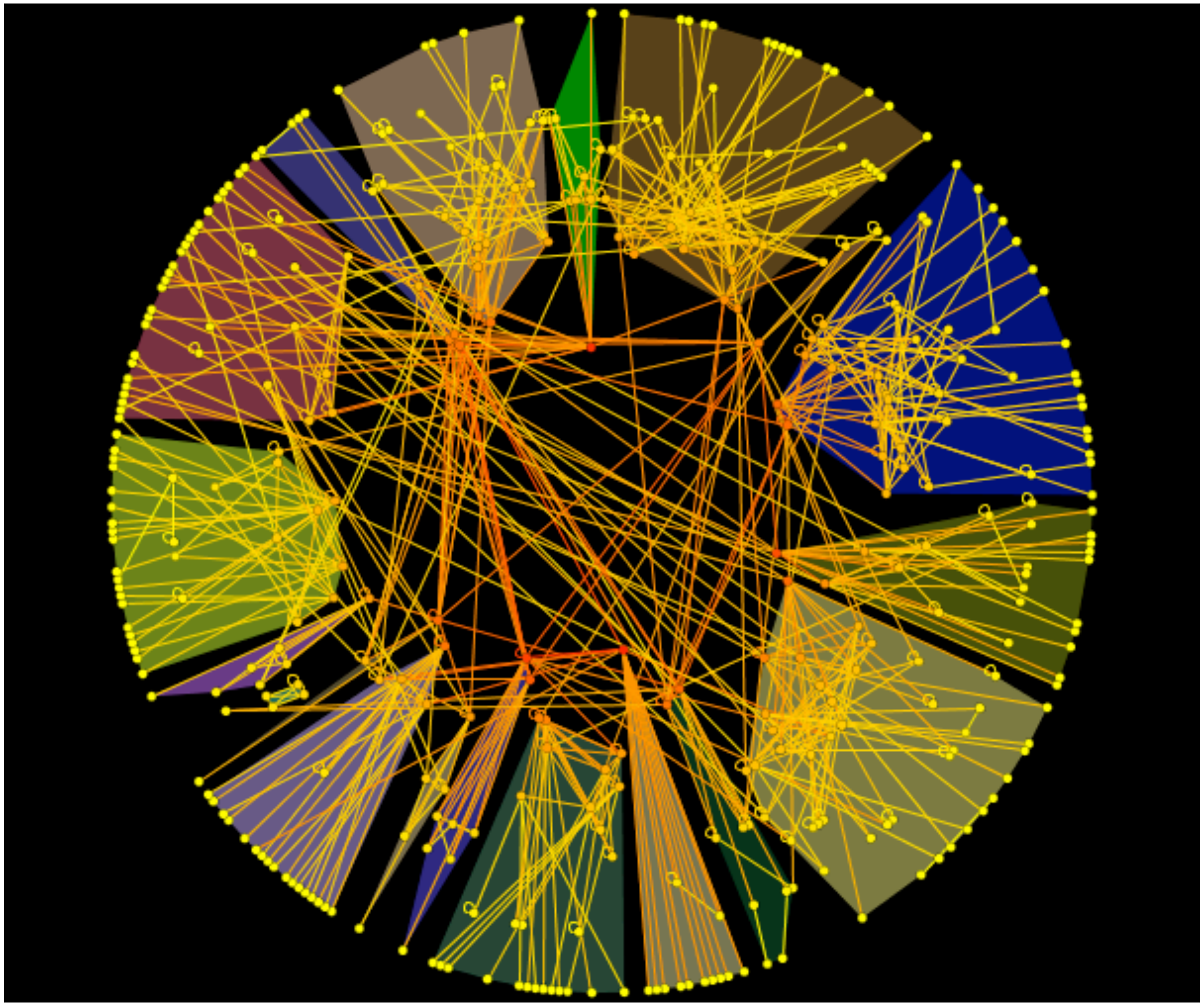
CAIDA is a program of the University of California's San Diego Supercomputer Center (UCSD/SDSC)
CAIDA's topology mapping projects are supported by DARPA, NCS, NSF, WIDE and CAIDA members

Source: http://www.caida.org/research/topology/as_core_network/

Skitter

```
def skitter(_field):
    _maxangle = 2 * Math.PI
    _ordering = sortBy(_field)
    _increment = _maxangle / len(_ordering)
    _curangle = 0
    g.nodes[0].outdegree
    _maxdeg = outdegree.max + 1.0
    for _n in _ordering:
        _radius = 1 - Math.log((_n.outdegree + 1.0) / _maxdeg)
        _radius = _radius * 500.0
        _x = 500.0 + _radius * Math.cos(_curangle)
        _y = 500.0 + _radius * Math.sin(_curangle)
        _n.setX(_x)
        _n.setY(_y)
        _curangle += _increment
```

Skitter



Modify the interface

```
import …
class dockexample1(com.hp.hpl.guess.ui.DockableAdapter):

    def __init__(self):
        testButton = JButton("center")
        action = lambda event: center()
        testButton.actionPerformed = action
        self.add(testButton)

    def getTitle(self):
        return("dockexample1")
```

Modify the interface

```
def sc(self,evt):
        val = self.testSlider.getValue()
        g.nodes.visible = 1
        (freq < val).visible = 0
        (freq >= val).visible = 1
        self.hideDisconnectedNodes()
        self.label.setText("Frequency threshold ("+str(val)+")")
```

Modify the interface

```
import …
class dockexample2(com.hp.hpl.guess.ui.DockableAdapter):

        testSlider = JSlider()
        label = JLabel("Frequency threshold (0)   ")

        def __init__(self):
                self.testSlider.setMinimum(freq.min)
                …
                self.testSlider.setValue(freq.min)  # default value

                self.testSlider.mouseReleased = self.sc
                self.add(self.label)
                self.add(self.testSlider)
                ui.dock(self)
```

Modify the interface

```
def hideDisconnectedNodes(self):
    toHide = []
    for nod in g.nodes:     # for all nodes
        vis = 0     # default to invisble
        for ed in nod.getOutEdges():
            if (ed.visible == 1):
                vis = 1
                break
        if (vis == 0):  # should we hide the node?
            toHide += [nod]
    # hide all the nodes we put in our list
    toHide.visible = 0
```

Compiling and distributing…

- Users build applets/applications
  - Network simulation
  - Political blogs
  - Neuroscience and sewer/water lines

- Discussion group:
  - Guess-discuss on google groups

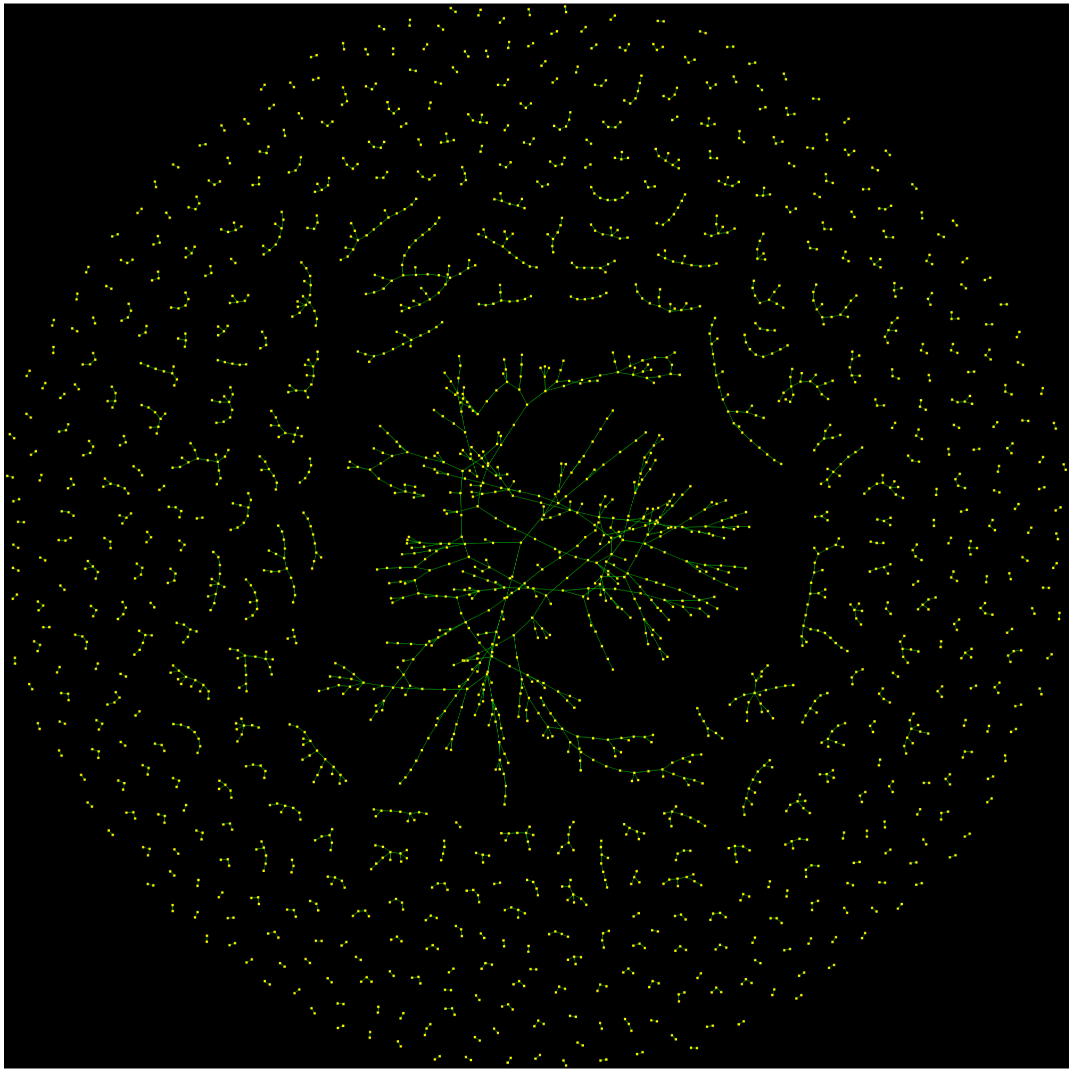
Front end flexibility

- Can replace the visualization
  - Eytan likes Piccolo
  - But…
    - Prefuse
    - Touchgraph
    - JUNG
    - and soon Wilma (3D)
  - Are also available

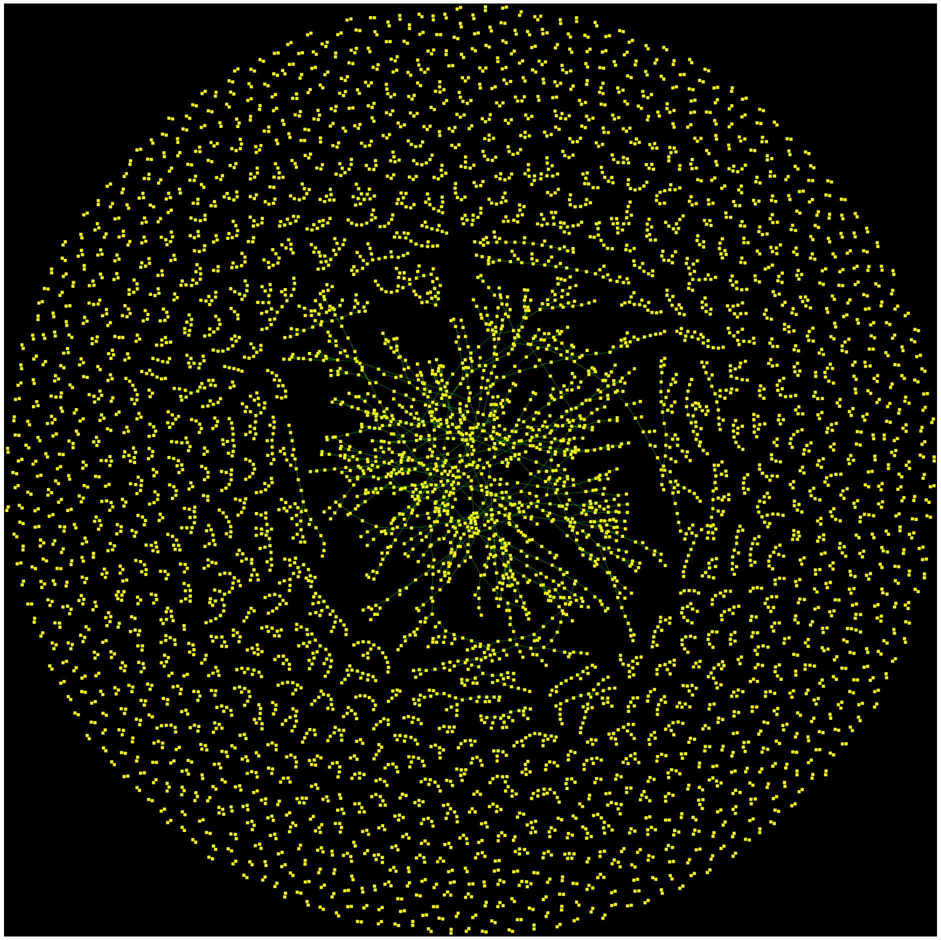
Scaling…

- Not bad…
  - Graphics will slow you down
  - Algorithms are pretty fast
- You can…
  - Load up a big dataset
  - Do a faster layout (gemLayout())
  - Go to lunch
  - Play with graph

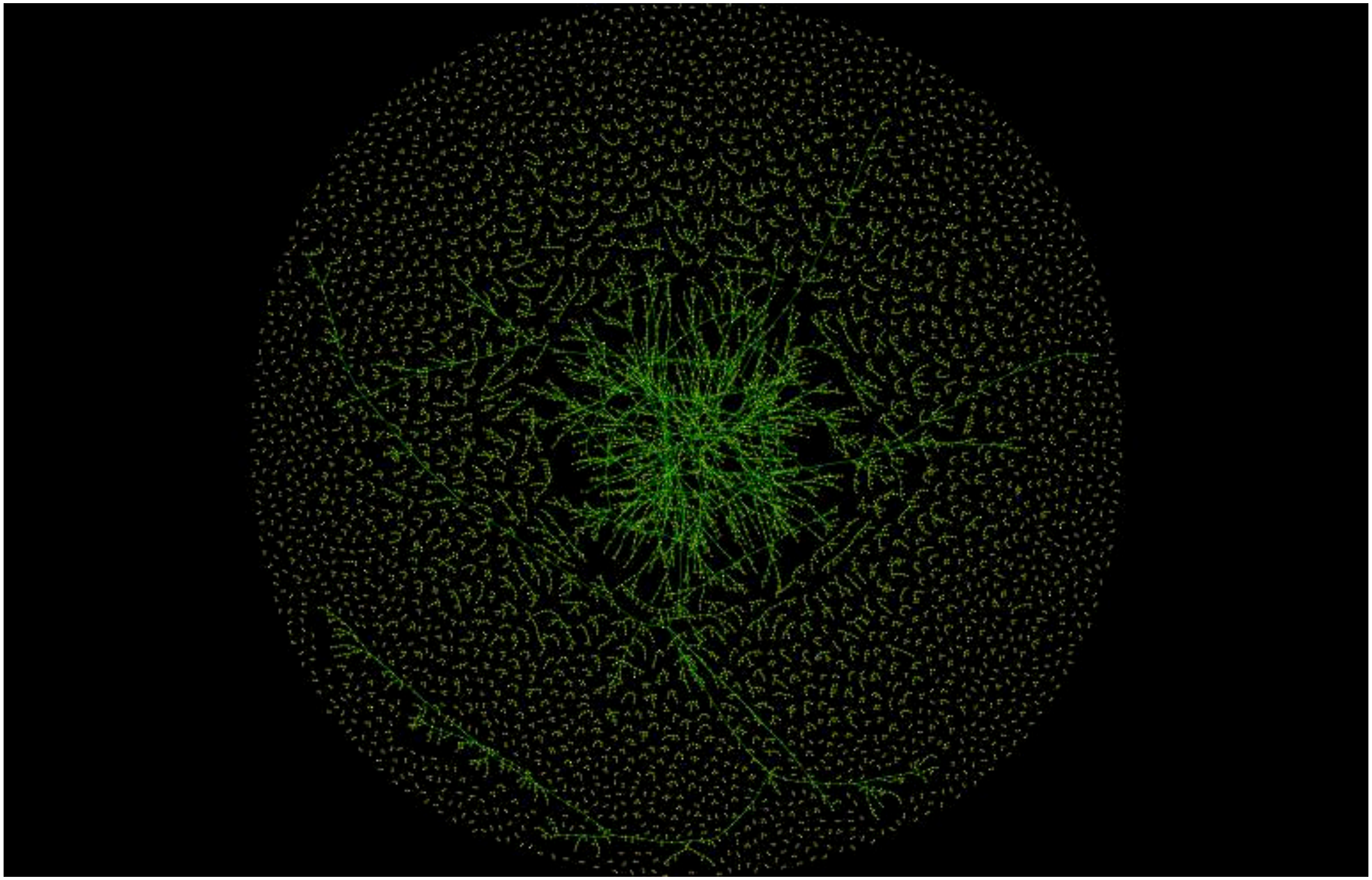
~2000



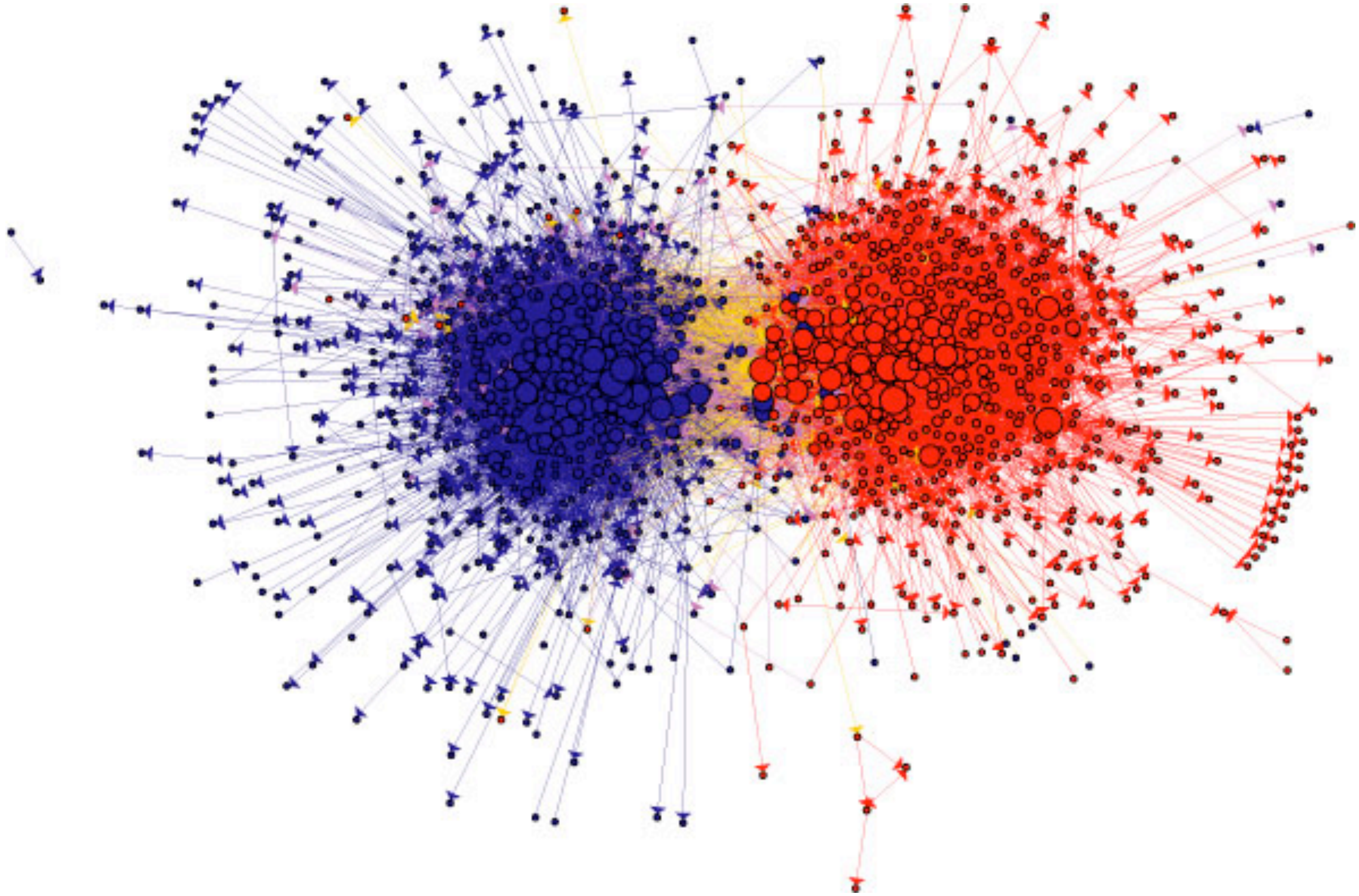
~6000 nodes



~12000 nodes

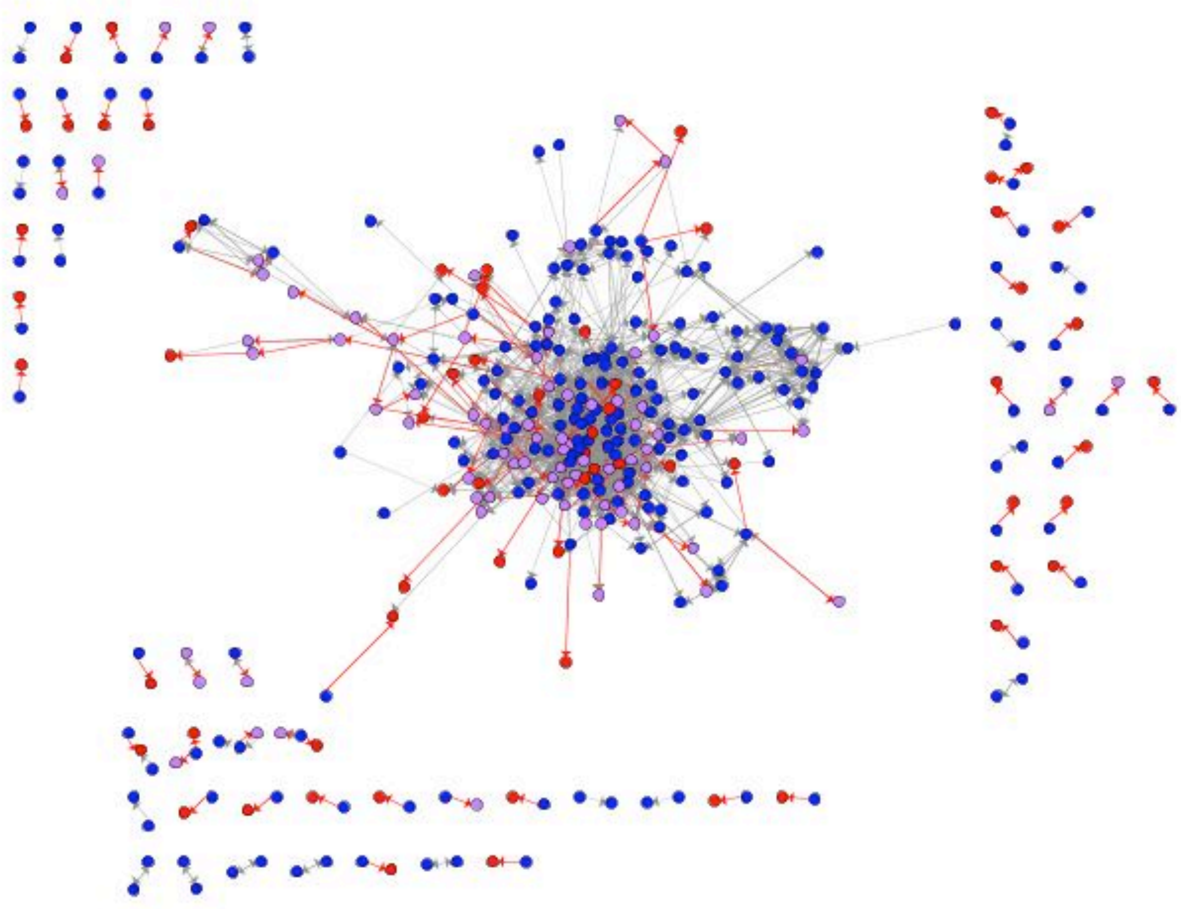


Politics and Blogs



source: Adamic and Glance, The political blogosphere and the 2004 US election: divided they blog, Proceedings of LinkKDD, Chicago, IL, p.36-43, 2005.

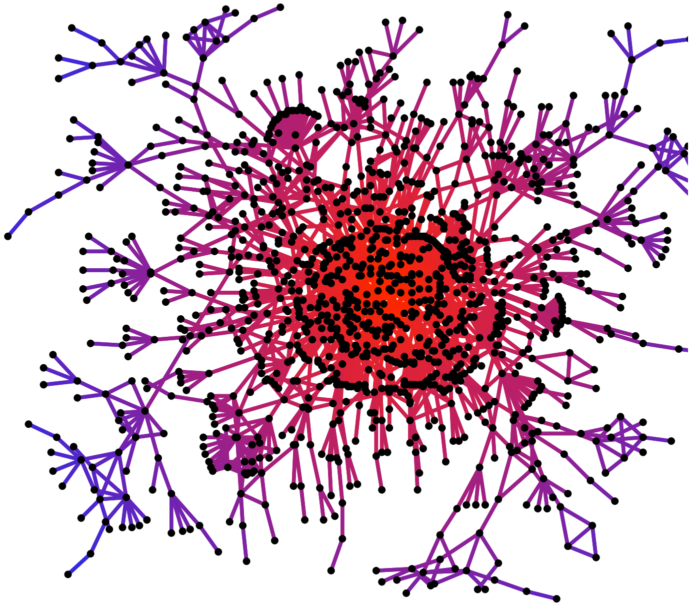
Viral marketing



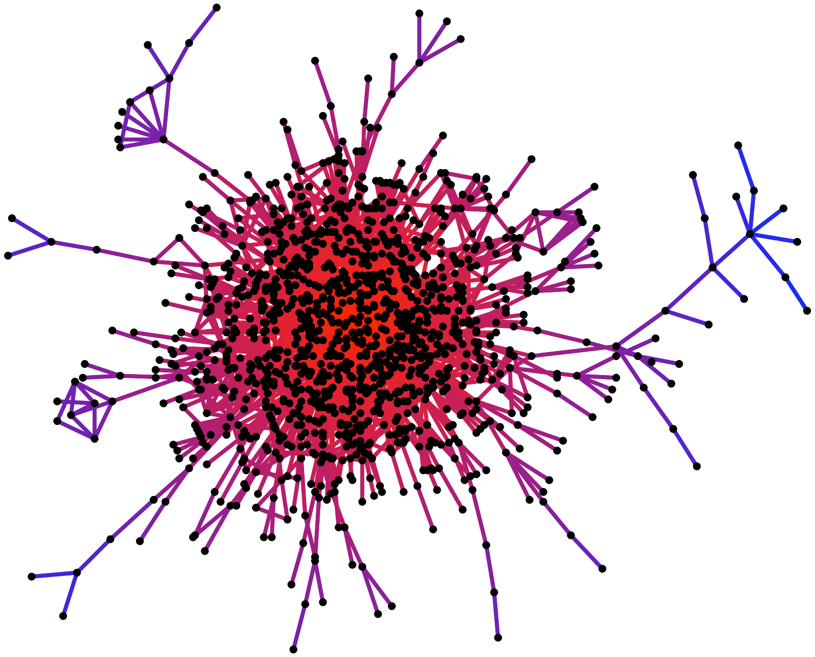
based on data from: Leskovec et al., The political blogosphere and the 2004 US election: divided they blog, Proceedings of LinkKDD, Chicago, IL, p.36-43, 2005.

Social groups

Stanford personal homepages, ca. 1999

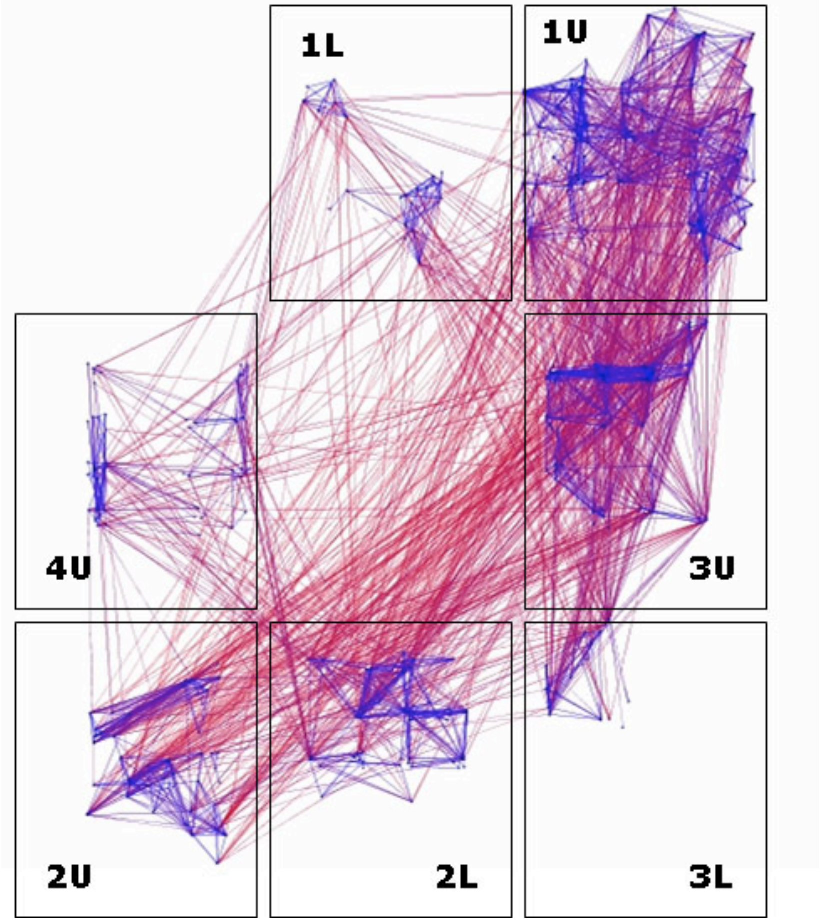


MIT personal homepages, ca. 1999



source: Adamic and Adar, **Friends and neighbors on the web**, Social Networks, 25(3), p.211-230, 2003.

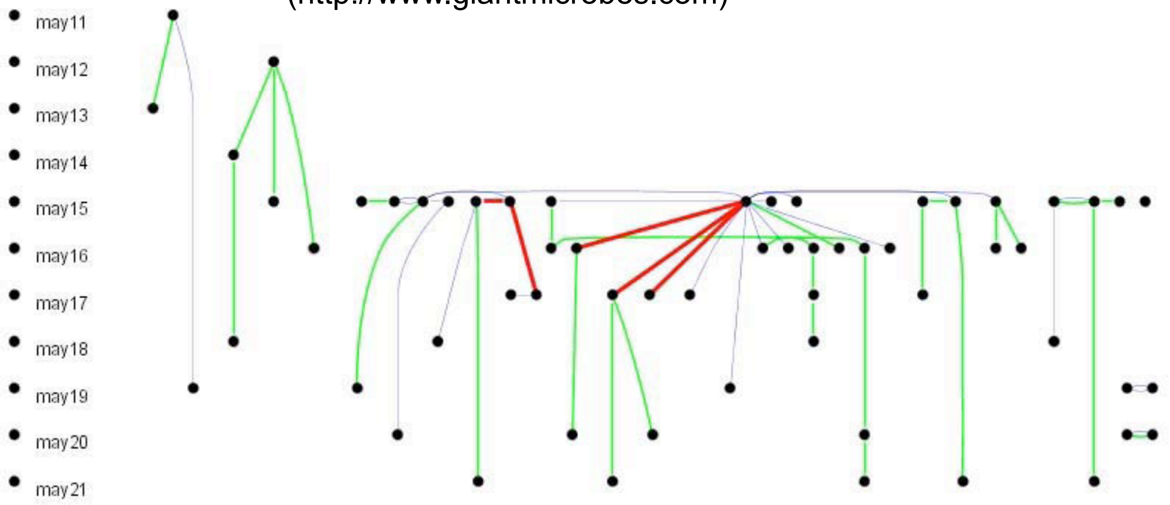
Email communications



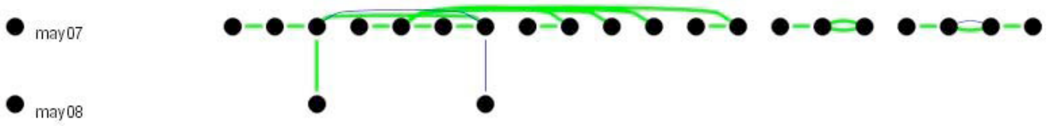
source: Adamic and Adar, How to search a social network, Social Networks, 27(3), p.187-203, 2005.

Information Flow

Giant Microbes
(http://www.giantmicrobes.com)



CNN story on Walmart
(http://money.cnn.com/2003/05/06/news/companies/walmart_mags/index.htm)



source: Adar and Adamic, Tracking information epidemics in blogspace, Proceedings of Web Intelligence 2005, p.207-214.

Summary… (end Eytan's slides)

- Exploratory data analysis
- Free (GPL)
  - http://www.graphexploration.org

lab

- discover the citation patterns between political blogs using Guess