

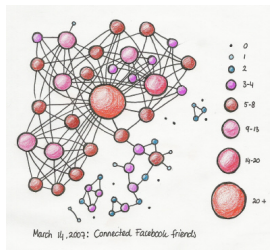
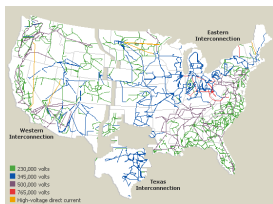
1 - Introduction to NetworkX

Drew Conway and Aric Hagberg

June 29, 2010

Vast amounts of data are being generated and collected

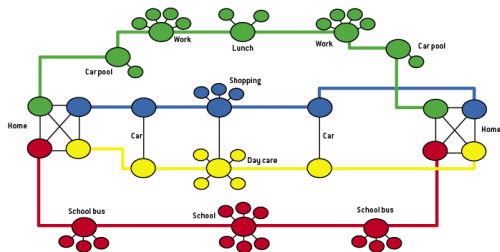
- ▶ Sociology: WWW, email, social networking
- ▶ Technology: Internet, telecommunications, power grid
- ▶ Biology: protein interactions, genetic regulatory networks, epidemiology



Need theory, analysis, models

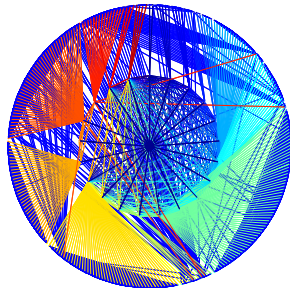
Example: social networks and epidemics

Understand epidemic outbreak of diseases through modeling
Build social networks from detailed census data
Run dynamic models for smallpox, SARS, flu, etc.



Building a social network

Goal: find a good intervention strategy
NISAC: EpiSimS



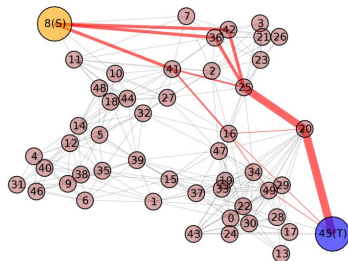
Social network of one person

Example: interdiction

Problem: smuggling of nuclear material in transportation network



Detector at border crossing



Find best set of roads (edges) to monitor (cut) with limited budget



University libraries, journals, and aggregators collect journal usage data through web portals

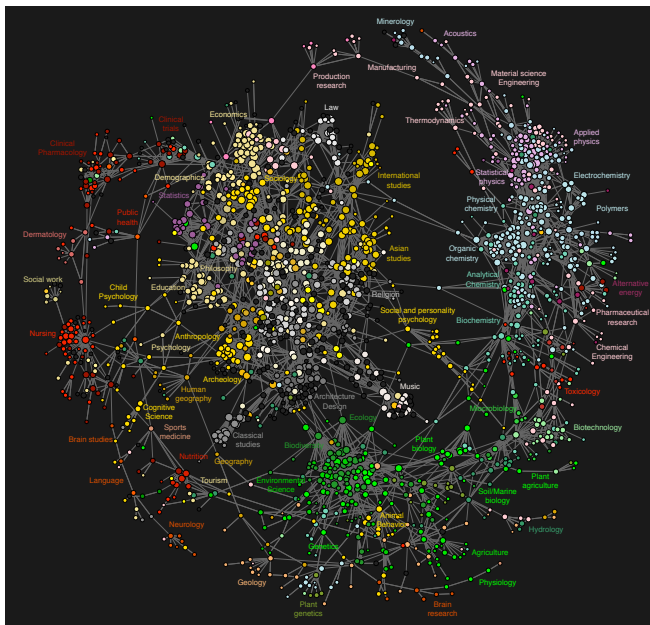
MESUR project is analyzing about 1 billion usage events

Build network from user click streams

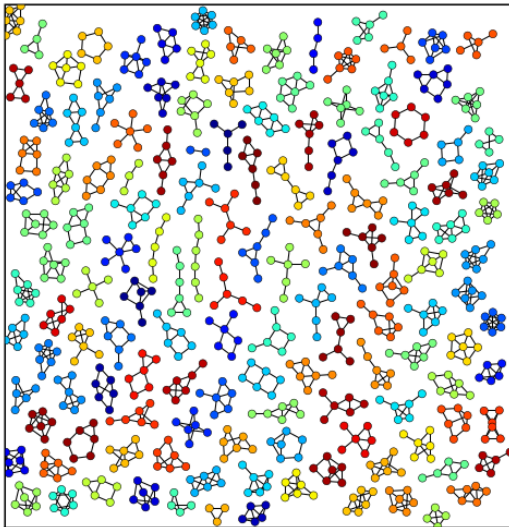
- ▶ Do scholars read and cite journals in the same way?
- ▶ Can new trends in research (new field, interdisciplinary) be spotted?
- ▶ Which journals are most important according to usage?

Johan Bollen, Los Alamos

Example: journal usage network



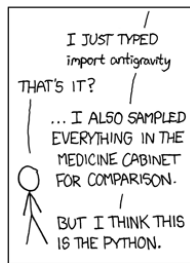
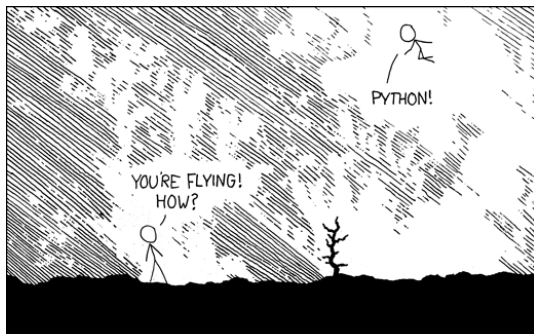
NetworkX project: goals and features



Goals: Why we started project

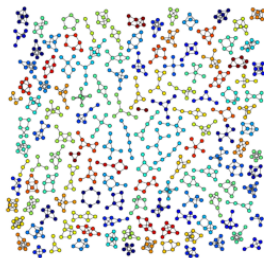
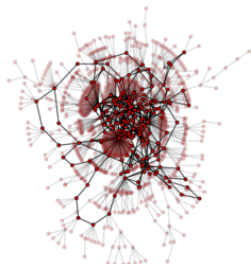
We needed:

- ▶ Tool to study the structure and dynamics of social, biological, and infrastructure networks
 - ▶ Ease-of-use and rapid development in a collaborative, multidisciplinary environment
 - ▶ Open-source tool base that can easily grow in a multidisciplinary environment with non-expert users and developers
 - ▶ An easy interface to existing code bases written in C, C++, and FORTRAN
 - ▶ To painlessly slurp in large nonstandard data sets
-
- ▶ No existing API or graph implementation that was suitable
 - ▶ Inspired by Guido van Rossum's 1998 Python graph representation essay
 - ▶ First public release in April 2005



Features: NetworkX in one slide

- ▶ Python language package for exploration and analysis of networks and network algorithms
- ▶ Data structures for representing many types of networks, or graphs, (simple graphs, directed graphs, and graphs with parallel edges and self loops)
- ▶ Nodes can be any (hashable) Python object
- ▶ Edges can contain arbitrary data
- ▶ Flexibility ideal for representing networks found in many different fields
- ▶ Many unit and functional tests
- ▶ Online up-to-date documentation



NetworkX defines no custom node objects or edge objects

- ▶ “node-centric” view of network
- ▶ Nodes: whatever you put in (hashable)
- ▶ Edges: tuples with optional edge data (stored in dictionary)
- ▶ Edge data is arbitrary and users can define custom node types

NetworkX is all Python

(Other projects use custom compiled code and Python: Boost Graph, igraph, Graphviz)

- ▶ Focus on computational network modeling not software tool development
- ▶ Move fast to design new algorithms or models

Feature: Simple use, adding nodes

Start Python

Import NetworkX using “nx” as a short name

```
>>> import networkx as nx
```

The basic *Graph* class is used to hold the network information.
Nodes can be added as follows:

```
>>> G=nx.Graph()  
>>> G.add_node(1) # integer  
>>> G.add_node('a') # string  
>>> print G.nodes()  
['a', 1]
```

Feature: nodes can be “anything”

Nodes can be any hashable object such as strings, numbers, files, functions, and more

```
>>> import math
>>> G.add_node(math.cos) # cosine function
>>> fh=open('tmp.txt','w')
>>> G.add_node(fh) # file handle
>>> print G.nodes()
[<built-in function cos>,
 <open file 'tmp.txt', mode 'w' at 0x30dc38>]
```

Feature: edges are just pairs of nodes

Edges, or links, between nodes are represented as tuples of nodes. They can be added simply

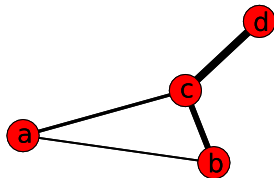
```
>>> G.add_edge(1, 'a')
>>> G.add_edge('b', math.cos)
>>> print G.edges()
[('b', <built-in function cos>), ('a', 1)]
```

If the nodes do not already exist they are automatically added to the graph.

Feature: Edge can hold arbitrary data

Any Python object is allowed as edge data (e.g. number, string, image, file, ip address)
Edge data assigned and stored in a Python dictionary (default empty).

Use Dijkstra's algorithm to find the shortest path:



```
>>> G=nx.Graph()  
>>> G.add_edge('a','b',weight=0.3)  
>>> G.add_edge('b','c',weight=0.5)  
>>> G.add_edge('a','c',weight=2.0)  
>>> G.add_edge('c','d',weight=1.0)  
>>> print nx.shortest_path(G,'a','d')  
['a', 'c', 'd']  
>>> print nx.shortest_path(G,'a','d',weighted=True)  
['a', 'b', 'c', 'd']
```

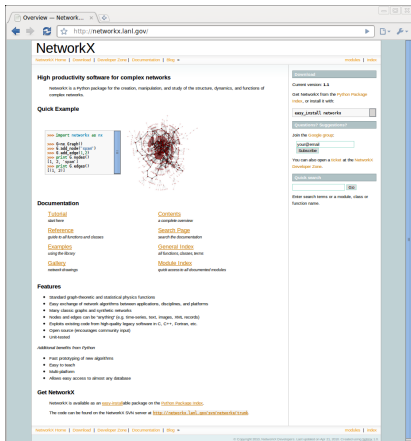
NetworkX has many tests that can be run by users

```
>>> import networkx
>>> networkx.test(verbosity=2)
...
Doctest: networkx.utils ... ok
Conversion from digraph to array to digraph. ... ok
Conversion from digraph to matrix to digraph. ... ok
Conversion from graph to array to graph. ... ok
Conversion from graph to matrix to graph. ... ok
Conversion from weighted digraph to array to weighted digraph. ... ok
...
Conversion from non-square array. ... ok
Conversion from digraph to sparse matrix to digraph. ... ok
Conversion from graph to sparse matrix to graph. ... ok
Conversion from weighted digraph to sparse matrix to weighted digraph. ... ok
Conversion from weighted graph to sparse matrix to weighted graph. ... ok
Conversion from graph to sparse matrix to graph with nodelist. ... ok
Conversion from non-square sparse array. ... ok
Doctest: networkx ... ok

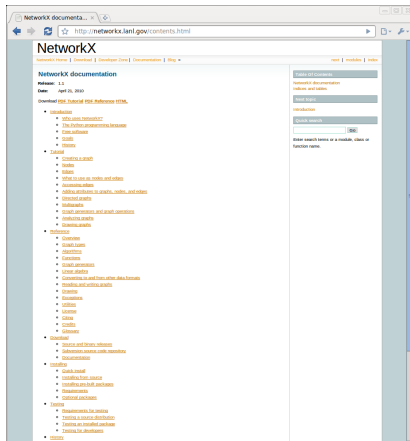
-----
Ran 855 tests in 4.334s

OK
```


Feature: Online, up-to-date documentation



The screenshot shows the NetworkX homepage at <http://networkx.lanl.gov/>. The page has a header with navigation links: [NetworkX Home](#), [Download](#), [Developer Zone](#), [Documentation](#), and [Blog](#). Below the header, there's a section titled "High productivity software for complex networks" with a brief description. A "Quick Example" section shows a code snippet for creating a graph and a corresponding network visualization. The "Documentation" section lists links for [Tutorial](#), [Reference](#), [Examples](#), and [Gallery](#). A "Features" section lists key capabilities like graph-theoretic and statistical physics functions, fast algorithms, and easy-to-use interfaces. A "Get NetworkX" section provides instructions on installing the software via a pip package or from source code. The right sidebar contains a "Download" section with links for the current version (1.5) and a "Developer Zone" section with a "Join the Google group" link and a "Quick search" bar.



The screenshot shows the NetworkX documentation page at <http://networkx.lanl.gov/contents.html>. The page has a header with navigation links: [NetworkX Home](#), [Download](#), [Developer Zone](#), [Documentation](#), and [Blog](#). Below the header, there's a section titled "NetworkX documentation" with a "Release: 1.5" and a "Date: April 18, 2010". A "Download" link points to the [pip, setuptools, and reference HTML](#). The main content area is a table of contents listing various topics:

- Introduction**
 - [What is NetworkX?](#)
 - [The NetworkX parameters, functions, and classes](#)
 - [Quick start](#)
 - [Tutorial](#)
- Tutorial**
 - [Creating a graph](#)
 - [Paths](#)
 - [Shortest paths](#)
 - [Shortest paths with weights and other attributes](#)
 - [NetworkX classes](#)
 - [Advanced algorithms in graphs, nodes, and edges](#)
 - [Directed graphs](#)
 - [Multigraphs](#)
 - [Graph operations and graph algorithms](#)
 - [NetworkX graphs](#)
 - [Graphs, nodes, and edges](#)
- Reference**
 - [Classes](#)
 - [Graph types](#)
 - [Algorithms](#)
 - [Functions](#)
 - [Graph operations](#)
 - [Link classes](#)
 - [Converting to and from other data formats](#)
 - [Reading and writing graphs](#)
 - [Graphs](#)
 - [Classes](#)
 - [Generators](#)
- Developer**
 - [Python and C++ interfaces](#)
 - [Subversion version control repository](#)
 - [Documentation](#)
- Example**
 - [Quick example](#)
 - [NetworkX Data Analysis](#)
 - [NetworkX in Python and C++](#)
 - [NetworkX in C++](#)
 - [NetworkX in C++](#)
- Index**
 - [Index](#)
 - [Index](#)
 - [Index](#)
 - [Index](#)

Python is easy to write and read

Breadth First Search

```
from collections import deque

def breadth_first_search(g, source):
    queue = deque([(None, source)])
    enqueued = set([source])
    while queue:
        parent, n = queue.popleft()
        yield parent, n
        new = set(g[n]) - enqueued
        enqueued |= new
        queue.extend([(n, child) for child in new])
```

Credit: Matteo Dell'Amico

Directed Scale-Free Graphs

Béla Bollobás*

Christian Borgs†

Jennifer Chayes‡

Oliver Riordan§

2 The model

We consider a directed graph which grows by adding single edges at discrete time steps. At each such step a vertex may or may not also be added. For simplicity we allow multiple edges and loops. More precisely, let α , β , γ , δ_{in} and δ_{out} be non-negative real numbers, with $\alpha + \beta + \gamma = 1$. Let G_0 be any fixed initial directed graph, for example a single vertex without edges, and let t_0 be the number of edges of G_0 . (Depending on the parameters, we may have to assume $t_0 \geq 1$ for the first few steps of our process to make sense.) We set $G(t_0) = G_0$, so at time t the graph $G(t)$ has exactly t edges, and a random number $n(t)$ of vertices. In what follows, to choose a vertex v of $G(t)$ according to $d_{out} + \delta_{out}$ means to choose v so that $\Pr(v = v_i)$ is proportional to $d_{out}(v_i) + \delta_{out}$, i.e., so that $\Pr(v = v_i) = (d_{out}(v_i) + \delta_{out}) / (t + \delta_{out}n(t))$. To choose v according to $d_{in} + \delta_{in}$ means to choose v so that $\Pr(v = v_i) = (d_{in}(v_i) + \delta_{in}) / (t + \delta_{in}n(t))$. Here $d_{out}(v_i)$ and $d_{in}(v_i)$ are the out-degree and in-degree of v_i , measured in the graph $G(t)$.

For $t \geq t_0$ we form $G(t+1)$ from $G(t)$ according the following rules:

(A) With probability α , add a new vertex v together with an edge from v to an existing vertex w , where w is chosen according to $d_{in} + \delta_{in}$.

(B) With probability β , add an edge from an existing vertex v to an existing vertex w , where v and w are chosen independently, v according to $d_{out} + \delta_{out}$, and w according to $d_{in} + \delta_{in}$.

(C) With probability γ , add a new vertex w and an edge from an existing vertex v to w , where v is chosen according to $d_{out} + \delta_{out}$.

Feature: Compact code - building new generators

```
import bisect
import random
from networkx import MultiDiGraph

def scale_free_graph(n, alpha=0.41,beta=0.54,delta_in=0.2,delta_out=0):
    def _choose_node(G,distribution,delta):
        cumsum=0.0
        psum=float(sum(distribution.values()))+float(delta)*len(distribution)
        r=random.random()
        for i in range(0,len(distribution)):
            cumsum+=(distribution[i]+delta)/psum
            if r < cumsum:
                break
        return i

    G=MultiDiGraph()
    G.add_edges_from([(0,1),(1,2),(2,0)])
    gamma=1-alpha-beta

    while len(G)<n:
        r = random.random()
        if r < alpha:
            v = len(G)
            w = _choose_node(G, G.in_degree(with_labels=True),delta_in)
        elif r < alpha+beta:
            v = _choose_node(G, G.out_degree(with_labels=True),delta_out)
            w = _choose_node(G, G.in_degree(with_labels=True),delta_in)
        else:
            v = _choose_node(G, G.out_degree(with_labels=True),delta_out)
            w = len(G)
        G.add_edge(v,w)
    return G
```

Feature: leveraging libraries

Use well-tested numerical and statistical libraries

E.g. convert Graphs to and from NumPy (and SciPy sparse) matrices

Example: Find eigenvalue spectrum of the graph Laplacian

```
>>> L=nx.laplacian(G)
>>> print L # a NumPy matrix
[[ 1. -1.  0.  0.  0.  0.]
 [-1.  2. -1.  0.  0.  0.]
 [ 0. -1.  2. -1.  0.  0.]
 [ 0.  0. -1.  2. -1.  0.]
 [ 0.  0.  0. -1.  2. -1.]
 [ 0.  0.  0.  0. -1.  1.]]
>>> import numpy.linalg
>>> print numpy.linalg.eigvals(L)
[ 3.7321e+00  3.0000e+00  2.0000e+00
 1.0000e+00 -4.0235e-17  2.6795e-01]
```

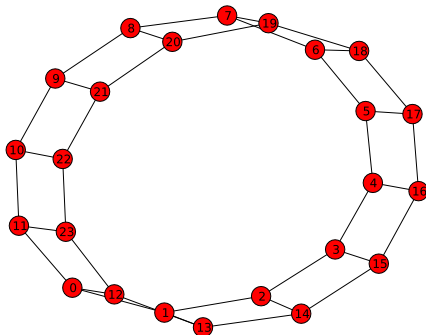


Feature: drawing

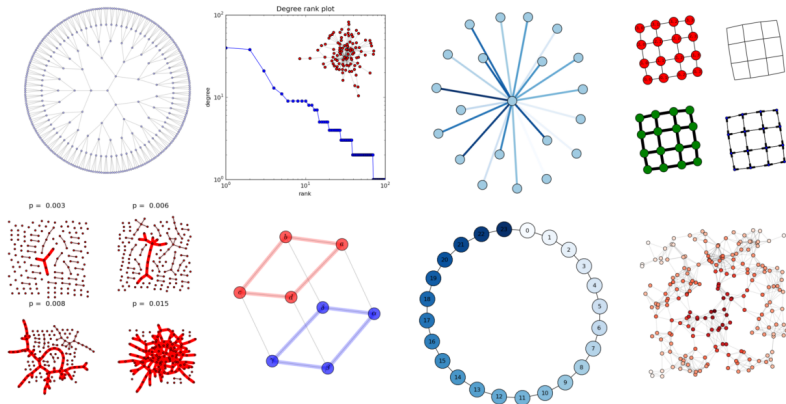
Built-in interface to Matplotlib plotting package

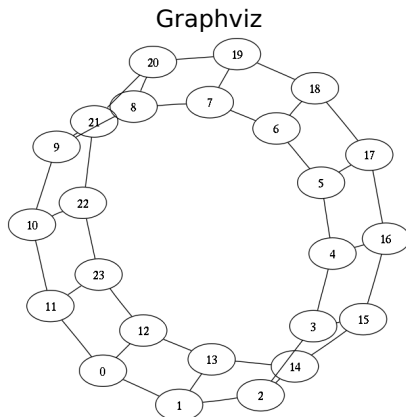
Node positioning algorithms based on force-directed, spectral, and geometric methods

```
>>> G = nx.circular_ladder_graph(12)
>>> nx.draw(G) # Matplotlib under the hood
```



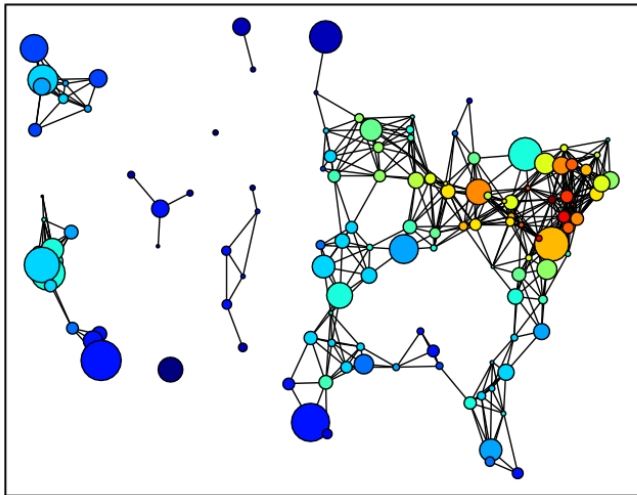
Drawing with Matplotlib





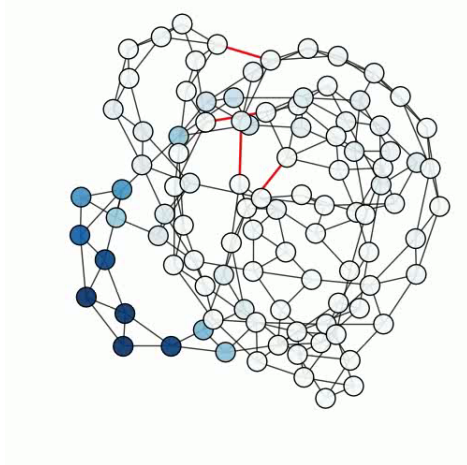
Output to: dot, GML, LEDA, edge list, adjacency list, YAML, sparsegraph6, GraphML

Where is NetworkX being used?



Los Alamos: Synchronization of networks of oscillators

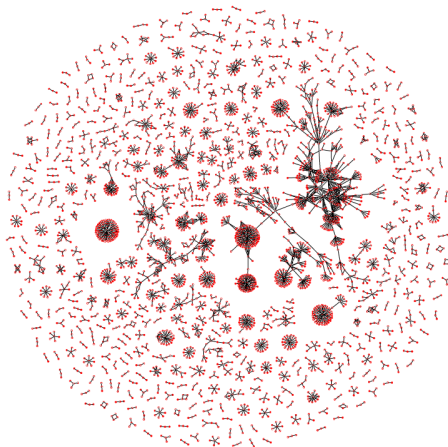
Adding red edges allows network to synchronize.
Edges found by studying network Laplacian spectrum.



Aric Hagberg and Daniel A. Schult, "Rewiring networks for synchronization", Chaos, 2008

I

NFO/SOCI 485 Computational Methods for Complex Networks
(Gueorgi Kossinets)
Physics 7682 / Computing & Information Sciences 6229
(Chris Myers)



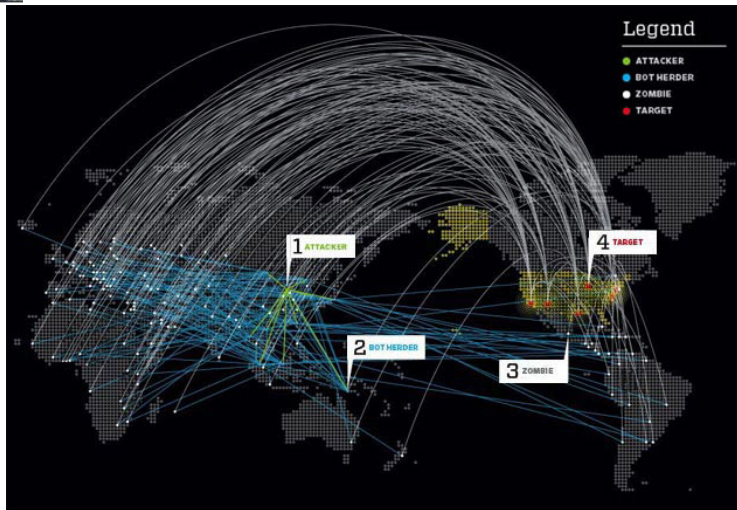
"Reality mining" (Nathan Eagle)



Inferring social network structure using cell phone data
e.g. 1.2M phone users in Rwanda



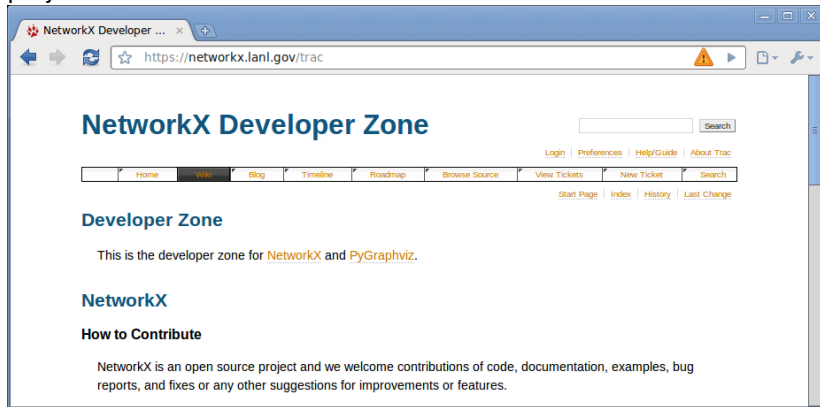
Fighting cybercrime: botnets, spam, phishing



`http://networkx.lanl.gov/`

Currently at version networkx-1.1

Active development: community driven, community supported project.



We hope you will contribute (after class is fine).