Lab 6 - PageRank

From Wikipedia:

"""

PageRank is an algorithm used by Google Search to rank websites in their search engine results. PageRank was named after Larry Page, one of the founders of Google. PageRank is a way of measuring the importance of website pages. According to Google:

```
PageRank works by counting the number and quality of links to a page to
determine a rough estimate of how important the website is. The underlying
assumption is that more important websites are likely to receive more links
from other websites.
```

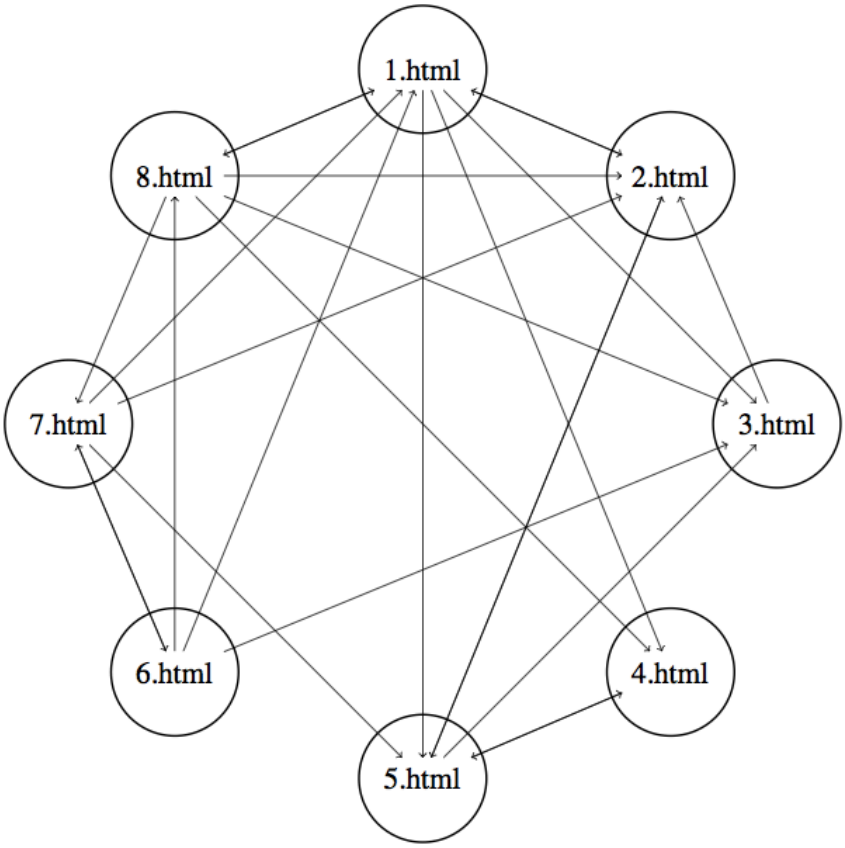
"""

There are four common frameworks by which academics view Google's PageRank algorithm. The first looks the social impact, both positive and negative, of immediate access to previously unimaginable knowledge through one centralized terminal. The second, and most mathematical, sees PageRank as a computation of the Singular Value Decomposition (SVD (http://en.wikipedia.org/wiki/Singular_value_decomposition)) of the adjacency matrix of the graph formed by the internet, with particular emphasis paid the the first few singular vectors. The third, and most far reaching practical, technical implication of Google's work, is the implementation of algorithms and computation at enormous scale. Much of the computing infrastructure which operates at a global scale deployed today can trace its origins to Google's need to perform SVD on an object as enormous as the Internet. Finally, a more intuitive way to look at the PageRank algorithm is through the lens of a web crawler (or many web crawler) acting as an agent (or agents) in a Markov Chain the size of the web. We will investigate this viewpoint.

This crawler is searching for an approximate "invariant" distribution (why does a true invariant distribution almost certainly not exist?) and will rank pages based on their "probability" in this generated distribution. In order to do so, our crawler chooses to follow a link uniformly at random from the page it is on in order to arrive at a new page, keeping tally of how many times it has visited each page. If this crawler runs for a really, really long time, the fraction of time it has spent on each webpage will be approximately the probability of being on that page (assuming we account for pathologies in the Markov chain which we will discuss soon). We then rank pages in decreasing order of probability.

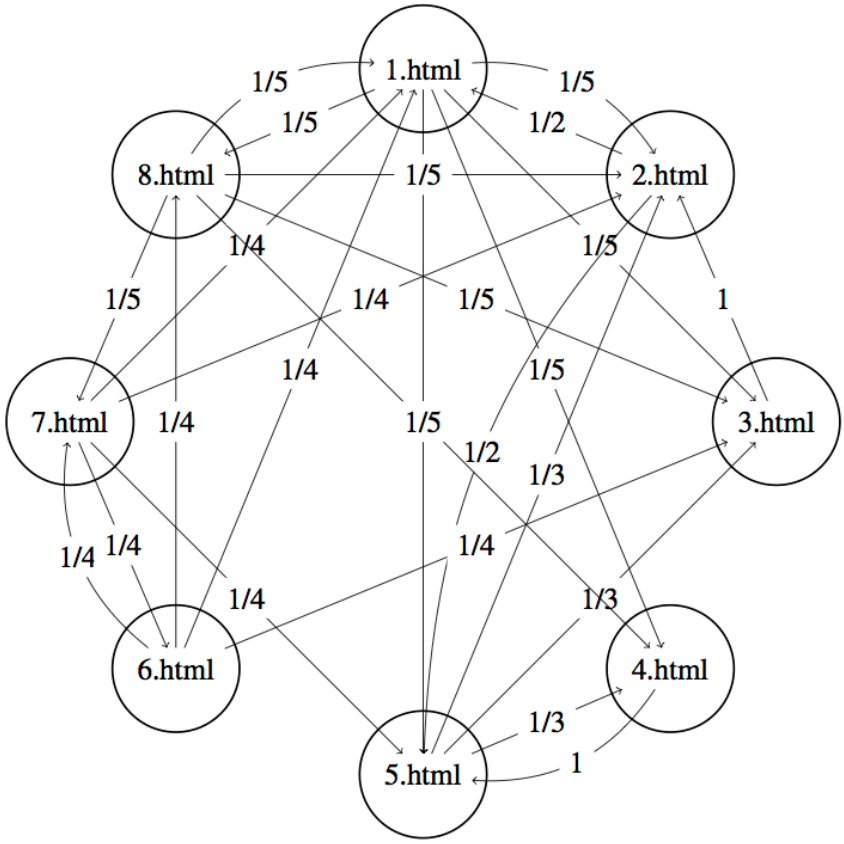
Alright, great! Let's do stuff. First, visit the following webpage, and see how many web pages can be reached by clicking the links on each page. http://www.eecs.berkeley.edu/~kw1jjang/ee126/1.html

There are total of \(8\) pages, and they are connected as follows.



Since we choose a link at uniform from each page, the probability of going between pages \(x\) and \(y\) is \(\Large \frac{\text{# of pages from x to y}}{\text{# of pages leaving x}}\)

Thus the Markov chain generated by the web pages above is



and the transition matrix of the Markov chain is

\[\left(\begin{array}{cccccccc} 0 & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & 0 & 0 & \frac{1}{5} \\ \frac{1}{2} & 0 & 0 & 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & 0 & 0 & 0 & 0 \\ \frac{1}{4} & 0 & \frac{1}{4} & 0 & 0 & 0 & 0 & \frac{1}{4} & \frac{1}{4} \\ \frac{1}{4} & \frac{1}{4} & 0 & 0 & \frac{1}{4} & \frac{1}{4} & 0 & 0 \\ \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & 0 & 0 & \frac{1}{5} & 0 \end{array} \right) \]

$$1. Find the steady-state (invariant/stationary) distribution \(\pi\) of the Markov chain above. How do you know that it exists? The Markov matrix is copied in code below. This might make your computation easier, but you can solve this in any way you wish.

(Note: don't forget about the difference between right and left eigenvectors)

In [13]:
```
import numpy as np
from __future__ import division

P = np.matrix([[0, 1/5, 1/5, 1/5, 1/5, 0, 0, 1/5],[1/2, 0, 0, 0, 1/2, 0, 0, 0]
```

```
,[0, 1, 0, 0, 0, 0, 0, 0],[0, 0, 0, 0, 1, 0, 0, 0], \
               [0, 1/3, 1/3, 1/3, 0, 0, 0, 0],[1/4,0,1/4,0,0,0,1/4,1/4],[1/4,
1/4, 0, 0, 1/4, 1/4, 0, 0],[1/5, 1/5, 1/5, 1/5, 0, 0, 1/5, 0]])

P_transpose = P.T

print P
```

```
[[ 0.          0.2         0.2         0.2         0.2         0.          0.
   0.2       ]
 [ 0.5         0.          0.          0.          0.5         0.          0.
   0.        ]
 [ 0.          1.          0.          0.          0.          0.          0.
   0.        ]
 [ 0.          0.          0.          0.          1.          0.          0.
   0.        ]
 [ 0.          0.33333333  0.33333333  0.33333333  0.          0.          0.
   0.        ]
 [ 0.25        0.          0.25        0.          0.          0.          0.2
5
   0.25      ]
 [ 0.25        0.25        0.          0.          0.25        0.25        0.
   0.        ]
 [ 0.2         0.2         0.2         0.2         0.          0.          0.2
   0.        ]]
```

In []:
```
# Solution Here
```

Simulation time!

We now want to empirically test what we solved above, by modeling a random user hopping along those webpages. We will start the user at "1.html," and behave as per the Markov chain above. In the code below, we simulate this and keep track of the average amount of time a user spends in each state. We will expect that after enough iterations, the fraction of time spent in each state should approach the stationary distribution.

We use the `parse_links()` method to parse all hyperlinks in a page. We use the library Beautiful Soup (http://www.crummy.com/software/BeautifulSoup/) in order to complete this portion of the lab in order to easiliy parse pages. Once you download the latest release, you must build and install setup.py. Alternatively, use pip or easy_install (help (http://www.crummy.com/software/BeautifulSoup/bs4/doc/)). You are welcome to use different/other tools in your own implementation.

In [2]:
```
import re
import sys
import urllib
```

```
import urlparse
import random
from bs4 import BeautifulSoup

#http://wolfprojects.altervista.org/articles/change-urllib-user-agent/
class MyOpener(urllib.FancyURLopener):
   version = 'Mozilla/5.0 (Windows; U; Windows NT 6.1; en-US; rv:1.9.2.15) Gec
ko/20110303 Firefox/3.6.15'

#This function will parse a url to give you the domain. Test it!
def domain(url):
    #urlparse breaks down the url passed it, and you split the hostname up
    #Ex: hostname="www.google.com" becomes ['www', 'google', 'com']
    hostname = urlparse.urlparse(url).hostname.split(".")
    hostname = ".".join(len(hostname[-2]) < 4 and hostname[-3:] or hostname[-2
:])
    return hostname

#This function will return all the urls on a page, and return the start url if
there is an error or no urls
def parse_links(url, url_start):
    url_list = []
    myopener = MyOpener()
    try:
        #open, read, and parse the text using beautiful soup
        page = myopener.open(url)
        text = page.read()
        page.close()
        soup = BeautifulSoup(text)

        #find all hyperlinks using beautiful soup
        for tag in soup.findAll('a', href=True):
            #concatenate the base url with the path from the hyperlink
            tmp = urlparse.urljoin(url, tag['href'])
            #we want to stay in the berkeley domain. This becomes more relevan
t later
            if domain(tmp).endswith('berkeley.edu'):
                url_list.append(tmp)
        if len(url_list) == 0:
            return [url_start]
        return url_list
    except:
        return [url_start]
```

In the following code block, we use the above functions to surf the web pages described by the Markov chain above. This code block may take a while to run. If it is taking more than a couple of minutes, maybe try reducing `num_of_visits`

In [10]:
```
import random

#the url we want to begin with
url_start = "http://www.eecs.berkeley.edu/~kw1jjang/ee126/1.html"
current_url = url_start

#parameter to set the number of transitions you make/different pages you visit
num_of_visits = 1000

#dictionary of pages visited so far
visit_history = {}

#initialize dictionary since we know exactly where we'll end up
for i in range(1, 9):
    page = "http://www.eecs.berkeley.edu/~kw1jjang/ee126/" + str(i) + ".html"
    visit_history[page] = 0

for i in range(num_of_visits):
#     print 'Visiting... ', current_url

    #incrementing the counts
    visit_history[current_url] += 1

    #parsing all the links on the page
    url_list = parse_links(current_url, url_start)

    #returning a random link to go to
    current_url = random.choice(url_list)
```

In []:
```
for i in range(1, 9):
    page = "http://www.eecs.berkeley.edu/~kw1jjang/ee126/" + str(i) + ".html"
    print 'Fraction of time staying on page %d is %f' % (i, double(visit_histo
ry[page])/num_of_visits)
```

Does this approximately match the invariant distribution you expected?

Generalizing to the Web

The toy websites given above conveniently form an irreducible Markov chain, but most of the web will not look like this. There will be fringes of the internet containing only self-loops, or some web pages which do not link to others at all. In order to account for such pathologies in the web, we need to make a more intelligent surfer. The simplest idea would be just to jump back to the starting page if there are no links found on the page you are on, and to always return to "good" starting spot with probability \(p\) on every page.

This is a very naive scheme, and there are many more intelligent methods by which you can sample from the distribution of the web, accounting for its pathologies and all. You might want to investigate some of these when working on your own mini-projects.

Ranking Berkeley Professors

The following code is an attempt to rank the Berkeley faculty based on a crawler which begins on the EECS research homepage.

In [4]:
```
url_start = "http://www.eecs.berkeley.edu/Research/Areas/"
current_url = url_start
num_of_visits = 1000
#List of professors obtained from the EECS page
profs = ['Abbeel','Agrawala','Alon','Anantharam','Arcak','Arias','Asanović','B
achrach','Bajcsy','Bodik','Bokor','Boser','Brewer','Canny','Chang-Hasnain','Cu
ller','Darrell','Demmel','Fearing','Fox','Franklin','Garcia','Goldberg','Hartm
ann','Harvey','Hellerstein','Javey','Joseph','Katz','Keutzer','Liu','Klein','K
ubiatowicz','Lee','Lustig','Maharbiz','Malik','Nguyen','Niknejad','Nikolic',"O
'Brien","Parekh','Patterson','Paxson','Pisano','Rabaey','Ramchandran','Roychow
dhury','Russell','Sahai','Salahuddin','Sanders','Sangiovanni-Vincentelli','Sas
try','Sen','Seshia','Shenker','Song','Song','Spanos','Stoica','Stojanovic','To
mlin','Tygar','Walrand','Wawrzynek','Wu','Yablonovitch','Yelick','Zakhor']
bad_urls = ['http://bgess.berkeley.edu/%7Ensbejr/index.html','http://superior.
berkeley.edu/Berkeley/Buildings/soda.html','http://physicalplant.berkeley.edu/
','http://www.eecs.berkeley.edu/Deptonly/Rosters/roster.room.cory.html',' http
://www.eecs.berkeley.edu/Resguide/admin.shtml#aliases','http://www.eecs.berkel
ey.edu/department/EECSbrochure/c1-s3.html']
# bad urls help take care of some pathologies that ruin our surfing
# you might have to be smart with try-catches depending on your application

#Creating a dictionary to keep track of how often we come across a professor
profdict = {}
for i in profs:
    profdict[i] = 0

for i in range(num_of_visits):
```

```
    if random.random() < 0.9: #follow a link!
        print  i , ' Visiting... ', current_url
        url_list = parse_links(current_url, url_start)
        current_url = random.choice(url_list)
        if current_url in bad_urls or "iris" in current_url or "Deptonly" in c
urrent_url: #dealing with more pathologies
            current_url = url_start
        myopener = MyOpener()
        page = myopener.open(current_url)
        text = page.read()
        page.close()
        #Figuring out which professor is mentioned on a page.
        for p in profs:
            profdict[p]+= 1 if " " + p + " " in text else 0 #can use regex re.
findall(i,text), but it's overkill
    else: #click 'home' button!
        current_url = url_start
```

```
0  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
1  Visiting...  http://www.eecs.berkeley.edu/XRG/IAB/
2  Visiting...  http://www.eecs.berkeley.edu/department/staff.shtml
4  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
5  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/OSNT/
6  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
9  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
10  Visiting...  http://www.eecs.berkeley.edu/
12  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
14  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
15  Visiting...  http://www.eecs.berkeley.edu/
16  Visiting...  http://www.eecs.berkeley.edu/Colloquium/
17  Visiting...  http://www.eecs.berkeley.edu/Rosters/roster.name.nostudentee.
html
18  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
19  Visiting...  http://www.eecs.berkeley.edu/deptinfo
20  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
21  Visiting...  http://www.cs.berkeley.edu/
22  Visiting...  http://www.eecs.berkeley.edu/department/emergency/sodaill.sht
ml
23  Visiting...  http://www.eecs.berkeley.edu/department/emergency/sodaill.sht
ml#finish
25  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
26  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/SEC/
27  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
28  Visiting...  http://www.eecs.berkeley.edu/Resguide/stud.shtml
29  Visiting...  http://www.eecs.berkeley.edu/Facilities
30  Visiting...  http://access-guide.berkeley.edu/evacuation-chairs
```

```
31  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
32  Visiting...  http://www.eecs.berkeley.edu/education/
33  Visiting...  http://www.eecs.berkeley.edu/department/officers.shtml
34  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
35  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/HCI/
36  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
37  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/
38  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/Centers/306.ht
ml
39  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
40  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/EDUC/
41  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
42  Visiting...  http://www.eecs.berkeley.edu/XRG/IAB/
43  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/
45  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
46  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/PHY/
47  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
49  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
50  Visiting...  http://www.eecs.berkeley.edu/Students/directories.shtml
51  Visiting...  http://www.eecs.berkeley.edu/XRG/conferences.shtml
52  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
53  Visiting...  http://www.eecs.berkeley.edu/Resguide/acad.shtml
54  Visiting...  http://www.eecs.berkeley.edu/AcadPers/leave_policies.shtml
55  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
56  Visiting...  http://www.eecs.berkeley.edu/Colloquium/
57  Visiting...  http://www.eecs.berkeley.edu/Colloquium/Archives/04-05/Spring
2005/
58  Visiting...  http://www.eecs.berkeley.edu/department/staffinfo.shtml
59  Visiting...  http://www.eecs.berkeley.edu/deptinfo/login.html?returnto=htt
p://www.eecs.berkeley.edu:80/Staff/
60  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
63  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
64  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/CIR/
65  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
66  Visiting...  http://www.eecs.berkeley.edu/education/
67  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/Centers/
69  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
70  Visiting...  http://www.eecs.berkeley.edu/department/Impact.shtml
71  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
72  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/AI/
73  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
74  Visiting...  http://www.eecs.berkeley.edu/
75  Visiting...  http://www.eecs.berkeley.edu/Facilities
76  Visiting...  http://public-safety.berkeley.edu/
77  Visiting...  http://public-safety.berkeley.edu/programs_and_services/index
```

```
.htm
79  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
80  Visiting...  http://www.eecs.berkeley.edu/Faculty/Lists/
83  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
84  Visiting...  http://www.eecs.berkeley.edu/Resguide/stud.shtml
86  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
87  Visiting...  http://www.eecs.berkeley.edu/department/OutreachPrograms.shtm
l
89  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
90  Visiting...  http://www.eecs.berkeley.edu/Prospective/ugrad.shtml
91  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
93  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
95  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
96  Visiting...  http://www.cs.berkeley.edu/
97  Visiting...  http://www.eecs.berkeley.edu/Directions/
98  Visiting...  http://www.eecs.berkeley.edu/Directions/#top
99  Visiting...  http://www.eecs.berkeley.edu/Resguide/admin.shtml
100  Visiting...  http://www.eecs.berkeley.edu/Resguide/acad.shtml#scheduling
101  Visiting...  http://www.eecs.berkeley.edu/GradAffairs/Faculty-Restricted/
gsi-hiring.shtml
102  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
103  Visiting...  http://www.eecs.berkeley.edu/
104  Visiting...  http://www.eecs.berkeley.edu/education/degrees.shtml
105  Visiting...  http://www.eecs.berkeley.edu/MEng/
106  Visiting...  http://www.eecs.berkeley.edu/MEng/prospective.shtml
107  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
108  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/toc.htm
l
109  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/c5-s1.h
tml
110  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/c3-s4.h
tml
111  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/toc.htm
l
112  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/c6-s4.h
tml
113  Visiting...  http://www.me.berkeley.edu/faculty/wright/
114  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
115  Visiting...  http://www.eecs.berkeley.edu/Faculty/Lists/
116  Visiting...  http://www.eecs.berkeley.edu/XRG/eecsgifts.shtml
117  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
118  Visiting...  http://www.eecs.berkeley.edu/XRG/conferences.shtml
119  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
120  Visiting...  http://coe.berkeley.edu/
121  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
```

```
122  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/INC/
123  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
124  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/DBMS/
125  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
126  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
128  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
129  Visiting...  http://www.eecs.berkeley.edu/Resguide/admin.shtml
130  Visiting...  http://www.eecs.berkeley.edu/Policies/
131  Visiting...  http://www.eecs.berkeley.edu/Policies/#workplace.faculty
132  Visiting...  http://www.eecs.berkeley.edu/Policies/#computer
133  Visiting...  http://teaching.berkeley.edu/campus-policies-regarding-teach
ing-and-learning
134  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
135  Visiting...  http://www.eecs.berkeley.edu/Prospective/ugrad.shtml
136  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
137  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/SP/
138  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
139  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/INC/
140  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
141  Visiting...  http://www.eecs.berkeley.edu/XRG/IAB/
142  Visiting...  http://www.eecs.berkeley.edu/news/
143  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
144  Visiting...  http://www.eecs.berkeley.edu/help
145  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
146  Visiting...  http://events.berkeley.edu/index.php/calendar/sn/eecs.html?v
iew=quick&timeframe=month&filter=Secondary%20Event%20Type&filtersel=32
147  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
149  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
150  Visiting...  http://www.eecs.berkeley.edu/department/Impact.shtml
151  Visiting...  http://www.eecs.berkeley.edu/XRG/eecsgifts.shtml
152  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
153  Visiting...  http://www.eecs.berkeley.edu/Visiting/Scholars/menu.shtml
154  Visiting...  http://www.eecs.berkeley.edu/XRG/eecsgifts.shtml
155  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
156  Visiting...  http://www.eecs.berkeley.edu/education/courses.shtml
157  Visiting...  http://www.eecs.berkeley.edu/
158  Visiting...  http://www.eecs.berkeley.edu/~larsrohr
159  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
160  Visiting...  http://www.eecs.berkeley.edu/Pubs/
161  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/
162  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/Areas/PHY.htm
l
163  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
164  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/Centers/
165  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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834 Visiting... http://www.eecs.berkeley.edu/Research/Areas/
835 Visiting... http://coe.berkeley.edu/
836 Visiting... http://www.eecs.berkeley.edu/Research/Areas/
837 Visiting... http://www.eecs.berkeley.edu/department/staff.shtml
839 Visiting... http://www.eecs.berkeley.edu/Research/Areas/
841 Visiting... http://www.eecs.berkeley.edu/Research/Areas/
842 Visiting... http://www.berkeley.edu/
843 Visiting... http://trsp.berkeley.edu/
844 Visiting... http://www.eecs.berkeley.edu/Research/Areas/
845 Visiting... http://www.eecs.berkeley.edu/deptinfo/login.html?returnto=ht
tp://www.eecs.berkeley.edu/Research/Areas/
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847 Visiting... http://www.eecs.berkeley.edu/Faculty/Lists/
848 Visiting... http://www.eecs.berkeley.edu/Resguide/stud.shtml
849 Visiting... http://www.eecs.berkeley.edu/XRG/
850 Visiting... http://www.eecs.berkeley.edu/Research/Areas/

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854  Visiting...  http://www.eecs.berkeley.edu/education/
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856  Visiting...  http://www.eecs.berkeley.edu/Students/
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858  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
859  Visiting...  http://www.erso.berkeley.edu/
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861  Visiting...  http://www.erso.berkeley.edu/misc/feedback.shtml
863  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
864  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/
865  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/Centers/312.h
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866  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
867  Visiting...  http://www.eecs.berkeley.edu/Resguide/stud.shtml
868  Visiting...  http://www.eecs.berkeley.edu/Gradnotes/section3.shtml#3.2
869  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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872  Visiting...  http://www.eecs.berkeley.edu/Includes/copyright.shtml
873  Visiting...  http://www.eecs.berkeley.edu/XRG/conferences.shtml
874  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
875  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
876  Visiting...  http://www.eecs.berkeley.edu/Pubs/
877  Visiting...  http://www.eecs.berkeley.edu/cal/
878  Visiting...  http://ciber.berkeley.edu/IGERT/?page_id=63
879  Visiting...  http://ciber.berkeley.edu/wp-content/uploads/2010/11/FrankFi
sh.pdf
881  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
882  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/EDUC/
883  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
884  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/MEMS/
886  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
887  Visiting...  http://www.eecs.berkeley.edu/Research/Projects/
888  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
889  Visiting...  http://www.eecs.berkeley.edu/Rosters/roster.name.nostudentee
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890  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
891  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/EDUC/
892  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
893  Visiting...  http://www.eecs.berkeley.edu/Rosters/roster.name.nostudentee
.html
894  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
895  Visiting...  http://coe.berkeley.edu/
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896  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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898  Visiting...  http://www.erso.berkeley.edu/misc/faq_000.shtml
899  Visiting...  http://www.erso.berkeley.edu/tools/tools_005c.shtml#8
900  Visiting...  http://bearbuy.is.berkeley.edu
901  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
902  Visiting...  http://events.berkeley.edu/index.php/calendar/sn/eecs.html?v
iew=quick&timeframe=month&filter=Secondary%20Event%20Type&filtersel=32
903  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
904  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/THY/
905  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
906  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/CIR/
907  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
909  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
910  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/AI/
911  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
912  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
913  Visiting...  http://www.eecs.berkeley.edu/department/OutreachPrograms.sht
ml
914  Visiting...  http://www.eecs.berkeley.edu/Diversity/
915  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
916  Visiting...  http://coe.berkeley.edu/
918  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
920  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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923  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
924  Visiting...  http://www.eecs.berkeley.edu/Students/directories.shtml
926  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
927  Visiting...  http://www.eecs.berkeley.edu/XRG/IAB/
928  Visiting...  http://www.eecs.berkeley.edu/XRG/eecsgifts.shtml
929  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
930  Visiting...  http://www.eecs.berkeley.edu/Faculty/Lists/
931  Visiting...  http://www.eecs.berkeley.edu/department/history.shtml
932  Visiting...  http://www.eecs.berkeley.edu/education/degrees.shtml
933  Visiting...  http://www.eecs.berkeley.edu/education/usli/
934  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
935  Visiting...  http://www.eecs.berkeley.edu/bears/
936  Visiting...  http://www.eecs.berkeley.edu/bears/
937  Visiting...  http://sdb.cs.berkeley.edu/wiki/index.php/Main_Page
938  Visiting...  http://sdb.cs.berkeley.edu/wiki/index.php/Main_Page
939  Visiting...  http://sdb.cs.berkeley.edu/wiki/index.php?title=Main_Page&ol
did=281
940  Visiting...  http://sdb.cs.berkeley.edu/wiki/index.php?title=Main_Page&ol
did=281#Weekly_Meetings
941  Visiting...  http://sdb.cs.berkeley.edu/wiki/index.php?title=Main_Page&di
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ff=prev&oldid=281
943  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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945  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
946  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/PHY/
947  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
948  Visiting...  http://www.eecs.berkeley.edu/department/
949  Visiting...  http://www.eecs.berkeley.edu/education/courses.shtml
950  Visiting...  http://www.eecs.berkeley.edu/XRG/
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952  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/PS/
953  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
954  Visiting...  http://www.eecs.berkeley.edu/education/degrees.shtml
955  Visiting...  http://www.eecs.berkeley.edu/GradAffairs/
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957  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/toc.htm
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958  Visiting...  http://www.eecs.berkeley.edu/department/EECSbrochure/c5-s2.h
tml
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961  Visiting...  http://www.eecs.berkeley.edu/Resguide/admin.shtml
962  Visiting...  http://www.eecs.berkeley.edu/Resguide/admin.shtml#top
963  Visiting...  http://www.eecs.berkeley.edu/Resguide/admin.shtml#top
964  Visiting...  http://police.berkeley.edu/programsandservices/lost-and-foun
d/index.html
965  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
966  Visiting...  http://www.eecs.berkeley.edu/Students/
967  Visiting...  http://www.eecs.berkeley.edu/department/history.shtml
968  Visiting...  http://www.eecs.berkeley.edu/Students/
969  Visiting...  http://www.eecs.berkeley.edu/education/degrees.shtml
970  Visiting...  http://coe.berkeley.edu/
971  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
972  Visiting...  http://www.eecs.berkeley.edu/education/usli/
973  Visiting...  http://www.berkeley.edu/
974  Visiting...  http://www.berkeley.edu/about/tour.shtml
975  Visiting...  http://www.berkeley.edu/about/ucsystem.shtml
976  Visiting...  http://www.berkeley.edu/about/trad.shtml
977  Visiting...  http://www.berkeley.edu/pubserv/
979  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
980  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/INC/
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984  Visiting...  http://www.eecs.berkeley.edu/Pubs/
985  Visiting...  http://www.eecs.berkeley.edu/XRG/entrepreneur.html
987  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
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989  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
990  Visiting...  http://www.eecs.berkeley.edu/education/degrees.shtml
991  Visiting...  http://www.eecs.berkeley.edu/alumni/lists.shtml
993  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
994  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/MEMS/
995  Visiting...  http://www.eecs.berkeley.edu/Research/Areas/
996  Visiting...  http://www.eecs.berkeley.edu/education/
997  Visiting...  http://www.eecs.berkeley.edu/Programs/Notes/newcurric-notes.
html
998  Visiting...  http://www.eecs.berkeley.edu/Programs/Notes/section5.shtml#5
.3
999  Visiting...  http://www.eecs.berkeley.edu/Programs/Notes/section5.shtml#t
op


Exception TypeError: "don't know how to handle UnicodeDecodeError in error cal
lback" in 'lxml.etree._BaseErrorLog._receive' ignored
Exception TypeError: "don't know how to handle UnicodeDecodeError in error cal
lback" in 'lxml.etree._BaseErrorLog._receive' ignored
```

In [5]:
```
prof_ranks = [pair[0] for pair in sorted(profdict.items(), key=lambda item: it
em[1], reverse=True)]
for i in range(len(prof_ranks)):
    print "%d: %s" % (i+1,prof_ranks[i])
```

```
1: Joseph
2: O'Brien
3: Sastry
4: Goldberg
5: Russell
6: Lee
7: Wu
8: Patterson
9: Katz
10: Fearing
11: Liu
12: Garcia
13: Malik
14: Javey
15: Boser
16: Song
17: Nguyen
18: Maharbiz
19: Bokor
20: Niknejad
21: Hellerstein
```

22: Stojanovic
23: Paxson
24: Klein
25: Culler
26: Rabaey
27: Chang-Hasnain
28: Parekh
29: Tomlin
30: Brewer
31: Salahuddin
32: Walrand
33: Yelick
34: Harvey
35: Zakhor
36: Fox
37: Shenker
38: Sangiovanni-Vincentelli
39: Anantharam
40: Arias
41: Seshia
42: Sanders
43: Ramchandran
44: Roychowdhury
45: Agrawala
46: Canny
47: Asanović
48: Arcak
49: Lustig
50: Nikolic
51: Keutzer
52: Kubiatowicz
53: Yablonovitch
54: Sahai
55: Alon
56: Demmel
57: Franklin
58: Bajcsy
59: Wawrzynek
60: Bachrach
61: Abbeel
62: Hartmann
63: Bodik
64: Darrell
65: Stoica
66: Spanos

67: Sen
68: Tygar
69: Pisano

Mini-project!

Hopefully this lab has given you a sense of some of the elements at play in ranking pages on the internet. The final portion of this lab is going to be a very open-ended mini-project. This project can be done in groups of up to four people.

Imagine it is the early 2000's, and almost all search engines on the web are essentially like the yellow pages, just made for the Internet. They are indexed manually, and results are often heavily influenced by relationships between advertisers and the search engine. For a quickly growing object the size of the Internet, such a naive form of indexing the web couldn't possibly be the best way of doing things.

You are a researcher who has developed some of the ideas behind using a web crawler to index the web more intelligently, and you have this dream where you might turn this into a multi-billion dollar company that knows way too much information about every internet user in the world. However, one of the great challenges of indexing the entire web is scale. The Internet is an enormous graph relative to the memory and computing power avaialable in even the supercomputers at the time. You want to convince your research advisor that your ideas have great merit, and that they deserve to be given the funding to test them at a legitimate scale. To that end, you want to put together a convincing demo for your research advisor that the potential of indexing the web in this way is enormous, and that it deserves further investigation. (For some background you might want to read this paper (http://infolab.stanford.edu/~backrub/google.html) to get a feel for where they were coming from when this all began).

Below are some default ideas for a demo you might want to implement, but you should feel free to be creative and come up with something else.

1. Improve on the algorithm to rank Professors in some way that makes it less naive and more effective
2. Rank popularity of fields of research based on which are recieving more attention in papers, awards, etc.
3. Do something interesting with Google Scholar citations (I know the idea of you being a researcher before Google doesn't make sense anymore if you do this, but whatever.)

Bonus points if you do something that makes fun of Stanford in some way.

You have two weeks to do this mini-project, so it will be due Thursday, October 25th. This project is not intended to be stressful, and is not intended to bring anybody's grade down too much. It is more of an opportunity for people who are more hands-on engineering oriented to get hacking using some of the ideas we've discussed in class so far and use them to do something neat. There is no requirement for how this project ought to be turned in (i.e. it doesn't have to be an iPython notebook like this and it doesn't have to be in Python at all), but be smart about how you message your project. You should turn in your code and a written component explaining your project and your results."

** Remember the constraints of time and memory when deciding what to do. The Internet is big. Do something manageable **

Be creative. Be ambitious. Have fun.

Extra credit: prove that finding the first left singular vector of the Markov matrix (generated as described above by picking links uniformly) is equivalent to finding the first left singular vector of the adjacency matrix of a graph. Argue that the crawling technique above will also arrive at the same distribution, assuming we avoid pathologies in the graph.

E.C. Solution