CPE466
Lab3

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Abstract

When working with a graph of social data, where nodes represent actors and edges represent relationships, it can be useful to determine the most influential nodes. The PageRank algorithm provides a straightforward way to rank nodes based on their influence. We implemented the PageRank algorithm and observed its results on various datasets.

1   Introduction

The PageRank algorithm, developed by Larry Page and Sergey Brin, and initially used in what became the Google search engine, is a technique for calculating the importance of nodes in a graph. We wrote and tested an implementation of this algorithm to better understand how it works as well as observe its behavior on various datasets.

2   Implementation Overview

We implemented our reading and writing system in Python. We wrote the PageRank algorithm in c, and used Python's cffi library to interface between the two languages.

The ranking process starts by loading a given file into memory by parsing each line as an edge between two nodes. Each edge can have an optional weight. If the `--weighted` flag is specified, the weight is read from file. Otherwise each line is expected to be an edge between the left node pointing to the right node.

Our implementation computes the standard PageRank with options to customize its behavior:

`--help` — display all the below options and descriptions

`--dval <int>` — the d parameter of the PageRank algorithm; probability of following a link

`--epsilon <float>` — (per iteration) consider the algorithm to have converged if the maximum change in PageRank of each node in the graph is less than epsilon

`--maxiterations <int>` — the number of iterations the algorithm will run before before giving up and considering the graph converged

`--threads <int>` — the number of computation threads to use

`--batchsize <int>` — per iteration, each thread claims `batchsize` nodes at a time to compute PageRank for. Too small and the threads will spend all their time synchronizing around a mutex. Too large and all the threads may wait on one thread to finish so the algorithm can continue to the next iteration.

`--fmt string` — the data format; either csv (default) or snap

`--scale` — scale epsilon and the printed results by the size of the graph.

`--weighted` — specify if the graph includes weights per edge.

When the `--weighted` flag is enabled, our algorithm runs a modified version of PageRank which takes into account the weights of edges. The modified version computes PageRank such that the weight is the number of edges between the nodes. The result is that edges with higher weight indicate stronger relationships than edges with lower weights.

The in-memory representation of the graph, PageRank computation, and parallel execution all happen in C. In the parallelized PageRank computation, each thread asks the master thread for a block of nodes to work on. Each node has two page ranks—the page rank of the previous iteration and the page rank of this iteration. By having both page ranks, we were able to parallelize computation without forcing Nodes to be computed in a specific order.

The graph is composed of an array of Nodes, a c structure with six fields:

```
{
  unsigned int id;
  char active;
  double pageRank_a;
  double pageRank_b;
  int outDegree;
  struct LLNode *inNodes;
}
```

The PageRank fields allow us to switch between the page rank of the last iteration and this iteration. inNodes is a linked list of incoming edges. Each edge has a source node and weight.

Once the graph is built, many iterations of the PageRank are computed until the algorithm converges. On every iteration, worker threads calculate PageRank on blocks of nodes from the list of nodes that haven't been processed yet until there are no nodes left to process in the iteration.

For each node in the block, the current PageRank is read from either the `pageRank_a` or `pageRank_b` field and the new rank is written to the other. If the rank has changed more than the (configurable) epsilon, a flag is updated to inform the system that the algorithm has not converged. Once all the worker threads have completed their work,

if the "unconverged" flag is set, the master thread starts the workers again, this time telling them to read from the field they were just writing to and to write to the field they were reading from.

3 Results

In general, we ran all the computations with `--threads 8 --maxiterations 1000000 --epsilon 0.00000001 --batchsize 5000`. For the `LES-MISERABLES`, `NCAA-FOOTBALL`, and `SLASHDOT-ZOO-NOV6-2008` datasets, we also added the `--weighted` flag.

The results below include 3 columns each. The first column is the node name, the second the page rank, and the third the change in pagerank on the final iteration before convergence.

3.1 STATES

```
MA   1.462869437832707    8.532877876499256e-09
PA   1.3524810393473186   7.338763104158819e-09
NY   1.3271898437852825   7.786156441813574e-09
TN   1.3246348667661838   5.411682039990762e-09
KY   1.2686518916839202   5.653326071164422e-09
VA   1.2149463457633922   5.519433868284018e-09
ID   1.1957384420210948   2.7722326170764866e-09
MO   1.1940810483446511   4.389067234655819e-09
AR   1.1802419201439789   4.378786742920138e-09
MD   1.1208570953850048   5.514879698742536e-09
GA   1.1115358233807457   3.888831097420553e-09
OK   1.100494937600193    3.6911694187291566e-09
NV   1.0631327348400668   2.5448008283968093e-09
TX   1.0454328357344842   3.6191985172684404e-09
NH   1.0356269847111486   5.2541955161689025e-09
OH   1.0345121503002406   4.7246054291072426e-09
WV   1.03418223392241     5.0745513693883915e-09
UT   0.9466970183172859   2.3233356211127543e-09
CO   0.9221848584696164   2.5064941441832467e-09
WY   0.9209460697948871   2.126906983868082e-09
OR   0.9207126832348004   2.0249385501713846e-09
NB   0.9198421526448283   2.550868544171081e-09
VT   0.9177377192802924   5.087968588113334e-09
SD   0.9152833803384534   2.0886851276324947e-09
IA   0.9032036994941208   2.6370548106280367e-09
CT   0.9024186330227187   5.056845046869096e-09
IL   0.8984584669948867   3.2521053558443036e-09
AL   0.8842034295692448   3.0377084528354636e-09
NC   0.8748931952085944   3.2286413126358937e-09
AZ   0.8727433468843778   2.167064097613469e-09
```

```
MS   0.8498202476500514    3.0223309965826672e-09
NM   0.8441587411421481    2.5198917605329108e-09
IN   0.8211997493904607    3.248204309691527e-09
NJ   0.7806691722936716    4.087988367956763e-09
WI   0.7768374932182449    2.376985327318115e-09
DE   0.7533367824707436    3.743891394819565e-09
MT   0.7484861114120919    1.597971061029213e-09
MN   0.7416542967907246    1.8177874136493521e-09
LA   0.7199422168746245    2.4283349636666784e-09
CA   0.71184196999972      1.5833141221721636e-09
MI   0.6654499776068552    2.3875423339758672e-09
RI   0.6543730809046352    3.4413492888685226e-09
ND   0.5963199812693003    1.2216931459529956e-09
KS   0.5846674144855015    1.6070394147360556e-09
FL   0.5268543174515771    1.5614288507992402e-09
SC   0.5248758926093655    1.6097755940747138e-09
WA   0.5150477236506844    9.847204648916197e-10
DC   0.5126631034791487    2.0536867345599674e-09
ME   0.44342764417947      1.7767023095804912e-09
NE   0.15000000000000002   0.0
```

3.2 NCAA-FOOTBALL

We observered that the NCAA data set is troublesome to run as unweighted because the nodes are in the opposite order from the other datasets. Typically edges in the dataset run from left (source) to right (destination), but for PageRank to do anything meaningful with this dataset, the edges must run from right to left. This is because the left team is always the winning team, and thus there should be an edge connecting from losing team (right) to winning team (left) to represent the winning team gaining prestige from the losing team. Our program only provides meaningful results for this dataset if the `--weighted` flag is provided, in which case the edges are flipped to go from right to left due to the weighting of edges.

Mississippi	15.35711933877105	6.565710225503452e-09
Florida	15.120842239804153	5.958453064280889e-09
USC	9.709094062122265	8.673411308612877e-09
Oregon State	9.138868090363559	9.268392678341009e-09
Oklahoma	9.093401455685925	2.0352699109382755e-09
Texas Tech	6.933583512895485	1.3122560954537121e-09
South Carolina	6.186403273609781	2.8357764469966185e-09
Texas	5.771265700405203	1.2049815728554236e-09
Alabama	5.289853932502011	2.11207079603426e-09
Penn State	5.107477363379916	4.5762501149626544e-09
Vanderbilt	4.91241475509652	2.353541389554792e-09
Utah	4.589133042096809	1.7619420089598492e-09
Oregon	3.959113846990245	4.055958388593517e-09
Wake Forest	3.4167626140316907	1.518014255963429e-09
North Carolina State	3.032703633203939	7.923217221206258e-10
North Carolina	2.9538761491670127	6.973040513058582e-10
Virginia	2.8493836410031554	5.648575808481215e-10
TCU	2.8280597269404333	8.340812832074995e-10
Clemson	2.821228451582217	7.64319538215652e-10
Florida State	2.812912146215853	9.765833107466815e-10
Richmond	2.5124588409373794	1.572353358625378e-14
West Virginia	2.4976151735654684	1.7437398747155441e-10
Maryland	2.453766427549545	1.178236914284314e-09
Houston	2.396438567629544	1.7840993266071692e-10
LSU	2.346431884334138	4.135507318536735e-10
Duke	2.30562119705057	2.6866265809277756e-10
East Carolina	2.2321091986673487	2.525521111684803e-10
Weber State	2.193510984452151	3.180442020855878e-14
Georgia	2.1863942302007753	7.924707383366592e-10
Iowa	2.1831728243586492	9.233255583718236e-10
James Madison	2.128782927459705	5.0029425047171117e-14
Tulsa	2.1149560628489588	1.2653477918234124e-10
Montana	2.085060469571556	2.394265341543189e-14
Villanova	2.0777466616365063	1.139956185003399e-13

Ohio State	1.9451531483953115	5.106610620475571e-10
Rutgers	1.9222801960052662	3.638868789623828e-10
Georgia Tech	1.8968545355050521	3.867424644421469e-10
Boston College	1.8681267894126905	5.814044558294373e-10
Virginia Tech	1.8415554064606094	4.987176088766532e-10
Appalachian State	1.8242011043800201	0.0
Missouri	1.7670485311870654	1.626449461222812e-10
Boise State	1.7002205378957824	5.518713715180201e-10
Northwestern	1.6778533619258764	4.676507653345041e-10
Pittsburgh	1.5091825498165916	3.0892062172216406e-10
Oklahoma State	1.4936791322886462	1.0240791027682494e-10
Brown	1.4652285727750236	0.0
California	1.4472830308458573	1.1958478079304724e-09
South Florida	1.4306961347508518	2.52333589786935e-10
Connecticut	1.4294029846875864	2.237816182359964e-10
Brigham Young	1.3266992194196499	4.9976179444799484e-11
Miami (FL)	1.3159810118670185	3.2672823821466856e-10
Cincinnati	1.262196466866521	1.6483373346809493e-10
Michigan State	1.240934792324587	3.983605476737262e-10
Jacksonville	1.2029922142886587	0.0
Northern Iowa	1.184674785228468	1.8582357874663558e-14
Harvard	1.1761728795184991	0.0
Dayton	1.17132536726602455	0.0
Stanford	1.1329183472889885	1.1167182317750601e-09
Massachusetts	1.1326416303038789	0.0
Lafayette	1.1252191538695084	0.0
Rice	1.1202755174006902	7.798890526433677e-11
Albany	1.1112746522993475	0.0
South Carolina State	1.0704075410768772	0.0
Nevada	1.0416114046960527	2.1988468337785783e-11
Grambling State	1.0332130612004637	0.0
Tennessee	1.0066108109068825	3.9442448265814e-10
Central Arkansas	0.989009647450989	0.0
Hawaii	0.9405369871334621	5.933132457558443e-12
Rhode Island	0.9401492340320694	0.0
New Hampshire	0.937074042183389	1.5455518809215363e-13
Southern Miss	0.9352815534342132	8.705638120110049e-11
Cal Poly	0.9107993093752099	2.3406623861355058e-14
Arizona	0.8991217056106117	4.3395308874094596e-10
Delaware	0.893092987972269	0.0
Navy	0.8584636405949517	2.541105277586997e-10
Liberty	0.8568766385836117	0.0
Marshall	0.8442358052571748	6.044948222538871e-11
Central Connecticut State	0.8397495121899511	0.0

3.3 KARATE

34	3.431252149966154	8.707609577829345e-09
1	3.2979076567614305	8.195399414656634e-09
33	2.4375696493652135	6.146548853225298e-09
3	1.940669293582341	5.122124044354415e-09
2	1.7978153919561228	4.609911521957777e-09
32	1.2633749429357202	3.0732737188454706e-09
4	1.2192351473227652	3.073274190690256e-09
24	1.0717654878943703	2.5610611964488328e-09
9	1.012045892241893	2.5610617862548146e-09
14	1.0042394946523805	2.561061904216011e-09
6	0.9897792474544365	2.048849971625355e-09
7	0.9897792474544365	2.048849971625355e-09
30	0.8938102700237597	2.0488492638581768e-09
28	0.8717520828066848	2.0488492638581768e-09
31	0.8360652668415772	2.0488492638581768e-09
8	0.8326768875894534	2.048849617741766e-09
11	0.747250371688433	1.5366375671899135e-09
5	0.747250371688433	1.5366375671899135e-09
25	0.716585132305966	1.5366369773839317e-09
26	0.7142107027051523	1.5366369773839317e-09
20	0.6665576263645843	1.536637095345128e-09
29	0.6654976130625588	1.5366369773839317e-09
17	0.5706561792973743	1.024425162754472e-09
27	0.5114972890075956	1.0244244549872938e-09
13	0.49792632259874825	1.024424808870883e-09
18	0.49499501930165707	1.024424808870883e-09
22	0.49499501930165707	1.024424808870883e-09
15	0.49422379012424933	1.0244245729484902e-09
16	0.49422379012424933	1.0244245729484902e-09
19	0.49422379012424933	1.0244245729484902e-09
21	0.49422379012424933	1.0244245729484902e-09
23	0.49422379012424933	1.0244245729484902e-09
10	0.48651949658204574	1.0244246909096866e-09
12	0.32520134383007043	5.122124044354415e-10

3.4 DOLPHINS

```
       Grin  1.9929584993071667    9.35167862592401e-09
        Jet  1.967144665571631     7.040288171888953e-09
    Trigger  1.9405600839191688    7.792422068719773e-09
        Web  1.865912985987976     7.0405458685307565e-09
        SN4  1.8522709448116916    8.572964761699442e-09
     Topless  1.8298805734742087   8.57237666268551e-09
      Scabs  1.7622302792686884    7.7927987188197771e-09
   Patchback  1.640430072175734    7.0131839918774475e-09
    Gallatin  1.6217262752147679   6.259463475322136e-09
  Beescratch  1.5283444092422989   6.251719669725375e-09
     Kringel  1.5277369287435327   7.01561124472061e-09
       SN63  1.4842331174368502    6.2342287790451145e-09
     Feather  1.4544256882987086   5.477406223031167e-09
        SN9  1.3619146564136206    6.2369371750525815e-09
     Stripes  1.3448497261403864   5.454560920992169e-09
     Upbang  1.3423543472968191    5.473508507547464e-09
      SN100  1.2780301140466968    5.460063970397222e-09
       DN21  1.2433249899836387    4.694479728561962e-09
    Haecksel  1.232751011081599    5.455429517853272e-09
       Jonah  1.2025241103754618   5.454888742095765e-09
       TR99  1.1923805400446332    5.4553137909807425e-09
       SN96  1.092356294750833     4.677576721789922e-09
       TR77  1.0750500910429874    4.678380571832008e-09
     Number1  1.0620656262882313   3.908881406056164e-09
      Double  1.0600946257920347   4.677003895281473e-09
        Beak  1.051854260449204    4.676884296506145e-09
      MN105  1.0502173585938894    4.675476644733223e-09
       MN83  1.0481568452060985    4.675490411498728e-09
        Hook  1.0308625908146938   4.6758578120531524e-09
       SN90  1.0005291265651786    3.910992668609836e-09
    Shmuddel  0.9870360026167347   3.896236201728076e-09
       DN63  0.9698678669312149    3.905049943131456e-09
          PL  0.9487298836526632   3.901697090413769e-09
        Fish  0.9367206252329705   3.8972852722807226e-09
       Oscar  0.9204357707648877   3.900529281508636e-09
         Zap  0.9156110167179048   3.8974218644072245e-09
       DN16  0.8945389354882448    3.130139578089164e-09
      Bumper  0.8269609263282902   3.1175270698291513e-09
  Ripplefluke  0.8251379772904986  2.347968319771354e-09
        Knit  0.801548379168406    3.124906701457153e-09
     Thumper  0.7955113488599097   3.117281204001454e-09
      TSN103  0.7485005988393056   3.1173072317924877e-09
         Mus  0.7132618077079809   2.3460650644402392e-09
       Notch  0.6950285934747813   2.3454552397494943e-09
```

```
   Zipfel  0.6844298328220967   2.3378478111735213e-09
     MN60  0.6115368386324737   2.3384745216625813e-09
      CCL  0.5970018365426253   2.3381971428482196e-09
     TR88  0.5503584689495779   1.558313426214264e-09
    TR120  0.5472055290102805   1.5582967555216598e-09
     Wave  0.5162272293753949   1.5651356113921544e-09
    TSN83  0.5072249656728637   1.5584277548996717e-09
     SN89  0.4814144850067452   1.5623700510419836e-09
      Vau  0.46463880001109403  1.5585150340419185e-09
      Zig  0.38378909290038365  7.827573138274868e-10
     MN23  0.33578588441684903  7.823388256666952e-10
    Quasi  0.33578588441684903  7.823388256666952e-10
     TR82  0.3262251146783684   7.823686715840994e-10
    Cross  0.31494760647077347  7.792029070585738e-10
     Five  0.31494760647077347  7.792029070585738e-10
 Whitetip  0.30769976806527854  7.79240873216569e-10
     SMN5  0.30492950615424086  7.792034448228513e-10
     Fork  0.2997895730754506   7.792421100744074e-10
```

3.5 LES-MISERABLES

Valjean	7.665974282581213	9.349708741598906e-09
Marius	3.9784442848480737	6.154232121309555e-09
Myriel	3.020831596182633	1.8344405538876785e-09
Cosette	2.8420371738890955	4.023922938346108e-09
Enjolras	2.8194934790338655	5.384945372423344e-09
Thenardier	2.7475371663125885	3.6096958469164497e-09
Courfeyrac	2.5409217654001015	4.970718280993686e-09
Gavroche	2.179302801471389	3.313812536875904e-09
Fantine	2.0915902723875295	2.781246382938668e-09
Javert	2.0653543190409005	2.7812416640571325e-09
Combeferre	2.0505992845473897	4.023914287063293e-09
Bossuet	2.0170107783106874	3.9055639516720475e-09
MmeThenardier	1.543019540501597	2.011961993493225e-09
MmeMagloire	1.5040372211824298	1.1243338226586685e-09
Gillenormand	1.4095121514104394	1.7160836644943e-09
Joly	1.3606420733536875	2.5445336527922524e-09
MlleBaptistine	1.340072283463428	1.0059829629472522e-09
MlleGillenormand	1.284394920231858	1.3610323961604776e-09
Bahorel	1.2668098475120204	2.307832982009761e-09
Babet	1.20889623728762	1.5977341155833102e-09
Feuilly	1.1930561303835443	2.2486579453941807e-09
Gueulemer	1.1309018254952004	1.479383255871894e-09
Favourite	1.0882621697317887	1.5385631424490523e-09
Tholomyes	1.0832720590924592	1.538562880288967e-09
Dahlia	1.0516761942505566	1.4793877125933441e-09
Blacheville	1.0497067947878496	1.4793878436733868e-09
Zephine	1.0152931576783895	1.4202121516575933e-09
Fameuil	1.0133335333371034	1.420212282737636e-09
Listolier	1.0133335333371034	1.420212282737636e-09
Fauchelevent	0.9821008205449455	8.284549693395732e-10
Claquesous	0.9218615685465926	1.1835066309135236e-09
Eponine	0.8888680673937737	1.1243308078176875e-09
Champmathieu	0.8725420804446677	8.284556247397865e-10
Judge	0.8725420804446677	8.284556247397865e-10
Mabeuf	0.7479938707725754	9.468034696102218e-10
Brevet	0.7199645908653883	6.509293351726619e-10
Chenildieu	0.7199645908653883	6.509293351726619e-10
Cochepaille	0.7199645908653883	6.509293351726619e-10
Bamatabois	0.686464745492754	6.509294662527046e-10
Prouvaire	0.6628773407226528	1.124328710537005e-09
Brujon	0.6498670995283629	7.692791462437371e-10
Montparnasse	0.613588917267272	7.101039785481142e-10
Grantaire	0.5969920877885561	9.468032074501365e-10
Simplice	0.560678554303123	4.734030456055374e-10

MmeBurgon	0.4526771542650991	1.7752563416691125e-10
Child1	0.44113756371784485	2.9587610063819964e-10
Child2	0.44113756371784485	2.9587610063819964e-10
MotherInnocent	0.3701236501425086	2.3670158834279004e-10
LtGillenormand	0.35428842037522523	2.958764938783276e-10
MmeHucheloup	0.3473245692455373	4.1422643602944537e-10
Woman2	0.3466006196624297	2.958767560384129e-10
Pontmercy	0.34644228707568325	1.775260274070392e-10
Anzelma	0.34467649694148567	2.958767560384129e-10
Count	0.31565850678683643	1.18350990791459e-10
Perpetue	0.3069708252242483	1.7752635510714584e-10
Toussaint	0.29964408261173453	2.367014572627474e-10
MmePontmercy	0.29562541669535625	1.1835059755133104e-10
Jondrette	0.2782585269914792	5.917516769562287e-11
Woman1	0.2698341542021101	1.7752609294706054e-10
Gribier	0.26925509953700244	1.1835076140138436e-10
MotherPlutarch	0.26921152300348244	1.7752563416691125e-10
Marguerite	0.2668942659078705	1.7752625679711385e-10
Champtercier	0.2328292533934182	5.91754953957295e-11
CountessDeLo	0.2328292533934182	5.91754953957295e-11
Cravatte	0.2328292533934182	5.91754953957295e-11
Geborand	0.2328292533934182	5.91754953957295e-11
Napoleon	0.2328292533934182	5.91754953957295e-11
OldMan	0.2328292533934182	5.91754953957295e-11
Magnon	0.2298887756084548	1.1835069586136303e-10
BaronessT	0.22382941827015396	1.1835059755133104e-10
MlleVaubois	0.19746676874087837	5.917529877566552e-11
Gervais	0.19124100083700493	5.917533154567618e-11
Isabeau	0.19124100083700493	5.917533154567618e-11
Labarre	0.19124100083700493	5.917533154567618e-11
MmeDeR	0.19124100083700493	5.917533154567618e-11
Scaufflaire	0.19124100083700493	5.917533154567618e-11
Boulatruelle	0.18828535390651577	5.917536431568685e-11

3.6 POLITICAL-BLOGS

155	14.33699779725792	3.184952301893418e-13
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1051	10.087984834737082	2.526728826168778e-13
855	9.981406373574437	1.5287771049088406e-13
641	9.934803171129245	2.484262795476866e-13
1153	8.717819558526761	1.985286934846897e-13
963	8.55903698255803	9.236361675490912e-14
729	8.426207150886063	2.3993307340930414e-13
1245	7.139541800692389	1.613709166292665e-13
798	6.8826107180770135	1.5818596432737309e-13
323	6.801816765155126	1.794189796733292e-13
1112	6.774591406277854	1.5606266279277747e-13
1461	5.732336246128715	1.5818596432737309e-13
1306	5.593177860657325	1.411995520506082e-13
1463	5.455375831744107	1.603092658619687e-13
1179	5.399673672205255	1.3907625051601258e-13
1041	5.3512669970315105	1.242131397738433e-13
1437	5.14921968532767	8.493206138382448e-14
535	4.977002837558232	1.42261202817906e-13
990	4.815735281748969	1.0298012442788718e-13
180	4.448210464984683	1.263364413084389e-13
642	4.398969659166724	1.1731240978640756e-13
756	4.295354297845709	1.2739809207573671e-13
301	4.2541475426620625	9.501774367315363e-14
1067	4.197743464155556	8.015463293098435e-14
514	4.137358998413356	9.979517212599376e-14
1086	4.113180247127488	9.395609290585583e-14
297	4.054437672216793	1.242131397738433e-13
1479	3.7657376444950272	7.590802986179312e-14
1159	3.748716989993412	9.474158176731029e-09
1270	3.7056030170656253	8.068545831463325e-14
1293	3.6732015873850075	2.1747491307788636e-09
878	3.6319732780646445	7.803133139638874e-14
1101	3.5288412705640257	7.272307755989971e-14
741	3.518217362190016	6.688399833976177e-14
1317	3.4947051844589176	8.97094898366646e-14
493	3.393371316388047	9.236361675490912e-14
434	3.3206570101794446	6.635317295611287e-14
170	3.242613610184056	5.573666528313481e-14
547	3.1862649750377168	9.236361675490912e-14
1209	3.1600574346778956	7.643885524544203e-14
1055	3.0906695204010255	6.316822065421945e-14
623	3.0681589939065135	8.387041061652667e-14
150	3.0436171130787604	9.395609290585583e-14

210	3.0435498401993644	8.440123600017557e-14
233	3.023817872868067	8.387041061652667e-14
1330	3.0017206413198743	6.263739527057055e-14
826	2.9256100782515313	6.953812525800629e-14
72	2.886079876855764	8.758618830206899e-14
1122	2.877991307409817	4.830510991205017e-14
405	2.8674145217942875	8.811701368571789e-14
687	2.860498314932836	6.741482372341068e-14
644	2.826315868075746	8.440123600017557e-14
483	2.8178652501205574	6.688399833976177e-14
1429	2.744201461170769	6.953812525800629e-14
979	2.735060586782139	1.2208983823924768e-14
810	2.7312306945747866	6.476069680516616e-14
363	2.6913423111480643	6.263739527057055e-14
23	2.6779599334346527	6.582234757246397e-14
1000	2.643102841625095	2.654126918244515e-14
564	2.629553622272874	4.299685607556114e-14
996	2.5963292882014124	1.4863110742169283e-14
154	2.534250639211949	7.272307755989971e-14
664	2.486883344567851	6.263739527057055e-14
563	2.4860813152821635	7.484637909449532e-14
726	2.4762255139664013	7.431555371084642e-14
119	2.460446482354251	5.149006221394359e-14
490	2.4569603408457006	6.794564910705958e-14
754	2.3878328076880426	6.768023641523513e-14
27	2.365240392802229	6.157574450327274e-14
1478	2.364075495070288	5.945244296867713e-14
1232	2.3587577778094406	4.246603069191224e-14
885	2.3429319588230095	5.6002077974959263e-14
99	2.3225964553217477	6.874188718253293e-14
892	2.2721653642530053	4.9101347987523525e-14
189	2.2518814020358473	5.679831605043262e-14
396	2.2169682022957056	7.139601410077745e-14
172	2.188909270445399	4.618180837745456e-14

3.7   WIKI-VOTE

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5003  0.15000000000000005   0.0
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   4  0.0                    0.0
   5  0.0                    0.0
   6  0.0                    0.0
   7  0.0                    0.0
   8  0.0                    0.0
   9  0.0                    0.0
  10  0.0                    0.0
  11  0.0                    0.0
  12  0.0                    0.0
  13  0.0                    0.0
  14  0.0                    0.0
  15  0.0                    0.0
  16  0.0                    0.0
  17  0.0                    0.0
  18  0.0                    0.0
  19  0.0                    0.0
  20  0.0                    0.0
  21  0.0                    0.0
  22  0.0                    0.0
  23  0.0                    0.0
  24  0.0                    0.0
  25  0.0                    0.0
  26  0.0                    0.0
  27  0.0                    0.0
  28  0.0                    0.0
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  31  0.0                    0.0
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  35  0.0                    0.0
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  37  0.0                    0.0
  38  0.0                    0.0
  39  0.0                    0.0
  40  0.0                    0.0
  41  0.0                    0.0
  42  0.0                    0.0
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44	0.0	0.0
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48	0.0	0.0
49	0.0	0.0
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71	0.0	0.0
72	0.0	0.0
73	0.0	0.0
74	0.0	0.0
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76	0.0	0.0
77	0.0	0.0
78	0.0	0.0

3.8 P2P-GNUTELLA05

1676	2.2893265367796816	7.560402784075396e-09
1020	2.240373415862026	6.81349165445027e-09
386	2.138792620761244	6.110298507401232e-09
222	2.1180519569822533	6.3256778824348145e-09
227	2.0587734835409996	6.5616636834306755e-09
388	2.0344465307066235	7.574853081641995e-09
389	2.024772893513499	5.9593097177877e-09
688	1.9477121729740716	5.576120157084995e-09
226	1.9082240861923279	3.921205384970362e-09
842	1.904361909873529	4.6871135955220584e-09
876	1.885077537266172	3.6379314065858835e-09
223	1.7619395981362695	4.412674230842243e-09
31	1.7526146249801846	4.819592279740534e-09
391	1.7334015959971365	4.460240782722287e-09
279	1.6981482948855464	4.645029894197964e-09
271	1.6915315316046862	4.177984873321959e-09
225	1.6806709214711981	4.311810352991205e-09
277	1.67759388087549	4.3874095278606355e-09
274	1.6599153060982188	5.686661924339531e-09
272	1.6437288434471098	4.899689564393916e-09
887	1.6308898565685914	3.969222227371422e-09
278	1.6155748528672476	3.8994859405849965e-09
229	1.6115493615515435	3.5972532446836188e-09
679	1.5637113772513052	8.401457241491092e-09
47	1.5298408381363586	3.0593776207603167e-09
541	1.5194170263877123	3.5748396623545148e-09
221	1.5058003195374967	2.70813758717443e-09
230	1.5006714397834382	3.012961251856478e-09
385	1.477224924222306	4.072401097224808e-09
821	1.4513677589396554	3.845710270849664e-09
276	1.449331734188012	3.2717061456397946e-09
999	1.4320025712942697	4.445151494613352e-09
275	1.4088966117021486	3.4819167705341103e-09
48	1.3139562158038485	2.7530081504398285e-09
693	1.3035151934269713	3.1491669413245132e-09
387	1.3021227929078505	2.015752371715019e-09
392	1.2393473079910415	3.590918246890347e-09
224	1.2360209957823751	3.307949257612755e-09
1297	1.1794871777896727	3.1238696294446852e-09
1086	1.1794491635990842	3.404541849339523e-09
672	1.1794262921180951	1.9933704391988938e-09
3079	1.1775428848530465	4.1954596461985134e-09
324	1.1492150929282114	6.7619969291912024e-09
1929	1.1186290279487607	1.0686823100720597e-09

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 841    1.1057127375099973    2.8950932722112896e-09
 393    1.08567333461649      2.6031748187713317e-09
 854    1.0796166578472766    3.9467713606035435e-09
1277    1.0776368151783953    2.1235105139409422e-09
1364    1.030844342478635     1.8446468890407925e-09
1363    1.00538449710153      2.4205922027800263e-09
4057    0.9866747875433236    7.398758797196991e-10
3078    0.9517566467689746    1.4378665887603524e-09
 509    0.9504009135742617    3.4826287714404772e-09
1198    0.9439041569478117    1.974531127794596e-09
1066    0.9313014791567222    2.343502369673558e-09
 737    0.922454596788743     2.7646899285703724e-09
 343    0.9132010887367421    1.3391939809154728e-09
 150    0.9131330665111644    2.6780836920379907e-09
 273    0.9073946195264616    2.403937327899539e-09
3543    0.8995086569579138    5.79753913165738e-09
1226    0.8799836979378771    1.6582739681739699e-09
1110    0.856436106875459     2.169562430452904e-09
1019    0.8512918063068826    2.7047219249714833e-09
1681    0.848400275094165     1.822665014956145e-09
1673    0.8400244878117635    1.5361333836623036e-09
2022    0.8383550513985313    1.237224997094593e-09
 919    0.8193813604823968    1.7721610247518373e-09
  20    0.8146287750490356    3.5149324407828236e-09
 207    0.8083117069761213    2.0664203654956713e-09
1069    0.7935331416940903    1.888987917367073e-09
1606    0.7933599866802549    1.7895494799566314e-09
 686    0.7686380958611426    4.456031117824801e-10
2817    0.7641364087091898    1.2102333412495041e-09
5356    0.763303465491071     6.210160860488541e-10
 485    0.7576452485444095    1.3570317675560412e-09
 459    0.7407995694035123    9.867169671389994e-10
1465    0.7388891000571138    1.414725660161013e-09
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3.9 SLASHDOT-ZOO-NOV6-2008

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   57   29.460257181044028    0.0
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 1981   28.233941822149216    0.0
 1240   28.150536496422063    4.1931519020876884e-15
 1116   27.96799282036949     0.0
 6487   27.3996761970114      0.0
   34   26.887991365658717    0.0
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11241   25.717756150265114    0.0
 1397   25.27464343714724     0.0
 1491   25.14467273185559     0.0
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 6246   23.672777601701213    4.1931519020876884e-15
  165   23.65712952278909     0.0
34901   23.522797957525352    0.0
 1832   23.369585879760272    8.386303804175377e-15
 2300   23.030805172384813    0.0
   53   22.97484430595397     0.0
 3335   22.83488601106818     0.0
   15   22.68140662007755     0.0
28908   22.5395413126905      0.0
31774   22.00475438736104     0.0
 1070   21.806715285179646    0.0
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 1381   21.31434939699602     0.0
 8601   21.301007543341253    0.0
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33861   19.869971360062845    0.0
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 1159   18.399771797906332   0.0
16375   18.257125878704166   0.0
 3124   18.22737206020321    0.0
10668   18.199043012571455   0.0
16297   18.086027960929012   0.0
 7516   17.708156375205355   0.0
 7497   17.570923429870398   0.0
 2310   17.494885339780645   0.0
 1455   17.42198223529526    0.0
 1794   17.233309375915496   0.0
 4149   16.99290531631894    8.70735038298277e-09
23929   16.828576544225758   0.0
 4720   16.79481105724953    0.0
 2329   16.78193840935214    0.0
  736   16.70489263768596    0.0
 2980   16.67105444618503    0.0
 2956   16.591055399095655   0.0
  618   16.541307520639705   0.0
  443   16.48377199402765    0.0
 2233   16.292837851448297   0.0
25592   16.0839917856796     0.0
 1222   15.998913316705309   0.0
10404   15.982406609985187   0.0
 3393   15.93389830347012    0.0
49423   15.89361378099691    2.0965759510438442e-15
  723   15.840286390091912   0.0
  950   15.741026537243867   0.0
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3.10 AMAZON-MAY03

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89	528.5222626364349	1.6352735979566213e-09
590	421.90888647403875	6.643126639928332e-09
972	409.18910845420345	6.9472663576791716e-09
976	346.73222708041595	5.842213522417455e-09
974	338.6719026659883	5.735066318547644e-09
975	315.9810062972935	4.852358386625566e-09
978	310.40205320693224	5.789685150574264e-09
120	300.9645296713251	1.083836888293721e-09
977	294.1891785060802	2.4860908926123415e-09
634	293.0907416674093	1.2088197205370466e-09
2612	284.5788411482681	2.259476113153358e-10
598	258.37578707111254	4.107798738314794e-09
597	229.10405836748188	4.289668774273142e-09
585	222.55394269295974	3.2519109657673517e-09
162	217.58581615239285	9.726421976857802e-10
596	196.76295115957225	3.2463512312369547e-09
4455	194.42224538692096	1.6463485891411722e-10
88	182.5561379271678	4.686411430362275e-10
44	181.57380030527216	2.8921739027125415e-10
1196	179.52262153854943	7.011492410974318e-10
4458	177.2546526741898	1.4497563761463328e-10
594	168.2561672704969	1.8831265633217215e-09
39	165.32884408968872	2.693802574667975e-10
605	160.1030534057475	6.045210549591312e-10
4460	159.7738614479099	1.3185466412289626e-10
157	157.9981693995838	6.854040729073474e-10
587	155.39664082423286	1.9953220061451338e-09
2611	147.38878431304138	1.524479208234869e-10
4461	142.35946519520397	1.2544984994387887e-10
158	137.56438513727457	6.318971877868063e-10
4454	133.40736402931233	1.2436014197592105e-10
4459	133.2539728294955	1.0401151359466787e-10
578	132.7170256286018	1.77066425324085e-09
2264	127.42698648324547	4.5894496601521506e-10
1850	123.89846430478401	2.4318723614719095e-09
10999	123.67204398597042	4.385518597577187e-11
121	123.23159679276976	3.9260621359851755e-10
7241	122.59315750621981	9.046800027862067e-11
592	117.42039787601209	1.8858174748344336e-09
2613	113.14565863364423	1.3201033668974738e-10
8548	111.03206149853379	1.2073519506210217e-10

```
   37    110.01223372090521    1.0292180562671005e-10
  582    109.61694137312938    4.776923908517139e-11
12642    106.92753755279169    7.447820376919878e-11
  830    106.77973053757106    3.357634877597382e-10
22508    105.56234001708219    1.1722144283889124e-10
 8934    103.91208882968714    7.712463740566777e-11
   53    103.05807572554949    1.2831867296156374e-10
11040    101.15753552269229    1.2077967293834535e-10
21043     97.49686648660163    9.689505339575966e-11
32614     95.49776840943298    2.3842365560154677e-10
 7247     94.40204380103415    9.115740736038991e-11
  693     91.73770436300572    3.81620178166453e-10
  337     91.39855054802138    4.691303996749024e-10
11042     89.72910205586447    1.0542368616538872e-10
 7239     89.5122611193318     8.258429671451767e-11
32613     89.05438247456333    2.2232266440151693e-10
 2263     87.6485373442334     3.6723158520178545e-10
 7682     87.35425495554905    5.862184088850642e-11
 4457     86.64086278623058    7.551231439185263e-11
 9004     86.16283303072106    6.600516834487369e-11
   90     85.56141086360624    1.968146023760553e-10
32909     85.184860213762      2.0297478823573523e-10
10046     84.32964830780134    8.976747372779065e-11
 1843     83.39010155880555    2.9544429294529884e-11
 3267     83.01213978203126    1.6750256998489602e-09
15270     82.32737542181037    4.043150145195337e-10
 2227     81.27302023769413    1.0347333129212544e-09
 9396     80.891617107875      5.852176566695927e-11
   79     80.52338926609832    1.0952677024882174e-10
  338     79.67307249044859    4.2734343494443827e-10
 1197     79.63386782509026    2.438499565032143e-10
 1303     78.8762986525977     2.8807208495799236e-10
 3828     78.59693665630384    6.275828337912182e-11
11944     78.47041058424688    2.4388331491039666e-10
```

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8737	667.7378481886446	1.379633589987904e-10
2914	588.7797064482876	1.0150161412053865e-10
18964	411.6788387359599	1.004504647186431e-10
1220	356.109611293974	7.653681582551943e-11
2409	336.32739348103115	8.336928693784048e-11
10029	327.42383243387826	1.5116842336010319e-10
214538	303.35145321800434	7.686530001361179e-11
7343	286.89309737449344	5.695915821521489e-11
39295	270.0845662115683	6.297041885730504e-11
38283	269.0910138021256	9.039884856301694e-11
18963	268.7649320414745	1.632894899007112e-10
40509	239.19028450395749	3.5443443895165436e-11
1918	236.0082507540417	3.081181684306319e-11
4494	235.22733404137333	4.621772526459478e-11
3407	227.19445495384923	2.5654615090013166e-11
214406	223.48878544091485	9.952972353942022e-09
56913	220.85722026121175	5.544813094999004e-11
39633	218.738612486407	3.44908397496976e-11
1772	212.27053645376893	3.994367727203074e-11
503	210.9315239444211	2.985921269759535e-11
1689	204.68175142268694	6.218205680588338e-11
33515	195.08870669755345	5.682776453997795e-11
96144	191.7101060443912	9.670574497439022e-11
16624	187.9257211584422	2.4242133081216026e-11
58404	186.77091266451208	5.061941338503238e-11
110250	183.49879858424552	5.691087103956531e-09
25184	183.14503913687037	4.089628141749858e-11
7327	178.2286440713265	3.304550932209122e-11
33498	177.12688587372614	4.5166575862699235e-11
44070	173.50275537203285	9.795398488914118e-11
1776	171.71004752647855	8.365703908660939e-09
1110	170.60079933735867	3.738150060491035e-11
46505	163.16071519336802	3.343969034780205e-11
1113	162.6235509413837	3.360393244184823e-11
27653	162.2201157217	4.536366637555465e-11
37981	160.58699830193586	3.895822470775367e-11
92995	157.59504838390677	9.897228587222749e-11
19388	155.48484142567406	4.043640355416928e-11
8686	155.47650487669006	7.679960317599332e-11
48538	154.2127017791379	2.7789762312613493e-11
3394	151.37928532170267	3.468793026255301e-11
12633	150.86896753030257	3.790707530585812e-11
113192	147.76629209551362	3.2946964065663515e-11

39394	147.74572167349524	5.544041157156987e-09
8859	146.4331004647933	2.7280611821070338e-11
12647	144.81390595605876	3.0828241052467805e-11
23273	142.7294147051526	7.970668824061069e-11
8514	139.440600234099	1.520881790867618e-11
1797	137.86586383858918	2.930078957783834e-11
7246	137.0951457941474	2.0973715409697063e-11
214467	136.3143994044115	1.3574609072916697e-09
67238	134.95262727585433	3.4819323937789956e-11
5249	134.90022470440644	3.0516181073780065e-11
16621	134.59986534536029	3.018769688568771e-11
95183	134.3809867705237	8.085638289893394e-11
62339	133.6899133868269	1.841153874257667e-11
96803	132.31960322408557	9.053024223825389e-11
8401	131.7659767593551	1.2564520194532696e-11
23508	131.75341919467348	2.5211161436088482e-11
354856	131.62154136426352	3.2782721971617336e-11
39240	131.283446599754	7.675033054777946e-11
6962	130.4373353959775	3.191223887317259e-11
3685	129.8097731411169	1.5405908421531594e-11
529482	129.68725200970928	3.225714727066956e-11
42911	127.67588790734249	2.6984976051787216e-11
10002	127.13125774861679	7.717735999229953e-11
6304	125.23724619567312	2.5211161436088482e-11
363255	124.51623069116299	3.132096733460634e-11
214451	124.42222962757778	3.6878427070846903e-09
38698	123.41768398010547	1.832941769555358e-11
96805	123.16048071368671	7.64218463596871e-11
93045	122.8695916287649	6.894883108058596e-11
937828	122.22342197226614	3.0039879001046146e-11
39243	121.739917145619	6.203423892124182e-11
94936	121.66725467390764	7.44837896499422e-11
828954	121.5152794060673	2.979351585997688e-11
11860	118.85443242984827	2.4472072012880677e-11
1366	117.8350587355705	2.961284955652608e-11

Dataset	Execution Time (seconds)
amazon0505	40.117672
dolphins	0.0055940000000000002
karate	0.004950999999999997
lesmis	0.005074999999999996
NCAA_football	0.0063620000000000065
p2p-Gnutella05	0.017859999999999987
polblogs	0.04911300000000002
soc-LiveJournal1	1193.963033
soc-sign-Slashdot081106	2.74611
stateborders	0.004391999999999993
wiki-Vote	0.0008930000000000327

Table 12: Execution Times on Datasets

4   Overall Summary

Before implementing edge weights, page rank appeared to do decently on the graphs we manually tested. We created our own fakeball dataset, and analyzed carefully the results of the NCAA football dataset before and after weighting. As noted in the NCAA football section of Results, NCAA football was a bit troublesome to run unweighted.

Once we implemented edge weights, we noticed different rankings of the football teams, and the change in rankings seemed a bit more inline with the rankings from ESPN's 2008 data, though the rankings were far from perfect. We also compared the PageRank results with a ranking the teams by total score. Weighted PageRank matched much more closely to the teams sorted by total season score.

5   Performance Evaluation

All datasets were successfully executed in roughly 30 minutes (combined) on a 4-core hyperthreaded processor using 8 threads. The execution time for each dataset is provided in table 12. A visual representation is also included in fig. 1. Note that that on the graph, both the x and y axis are drawn in log10 so the outliers do not crowd out the trends. The visible trend on the graph suggests that the execution times increase roughly linearly as edge count increases to the max of our dataset.

6   Extra Credit

We added a weighted flag to our algorithm which takes into account a weight per edge when computing PageRank . We experimented with different ideas, but decided that simply using the weight as a multiplication factor for the importance of the edge would have the desired effect. We treated weights as edge counts. For instance, if the edge a->b had a weight of 7, we would compute page rank as if there were 7 edges from a to b. A weight of -7 would mean there were 7 edges in the opposite direction.
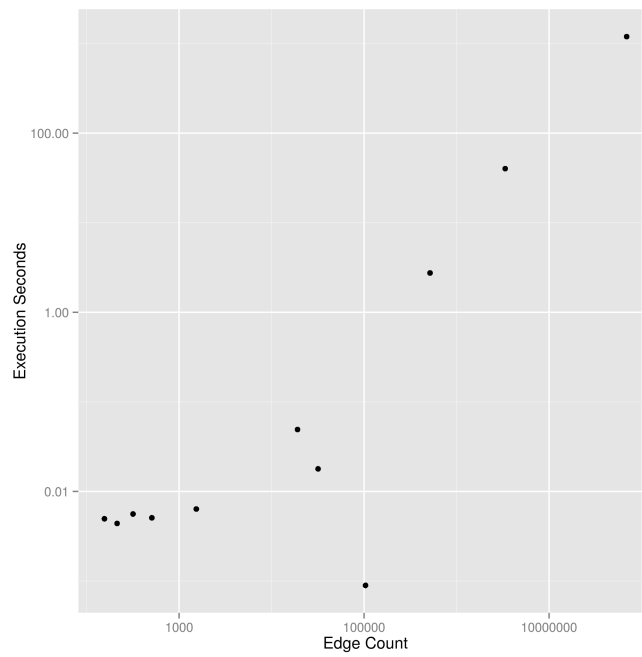
Figure 1: Graph of Execution Times on Datasets

Increasing the edges also involved increasing the node count. We discovered that PageRank would not converge unless we added an appropriate amount of fake nodes to the graph so that outdegree and other variables of the PageRank computation were accurate.

We used our weighted modification to the PageRank algorithm to compute PageRanks for the NCAA_football, lesmis, and SlashDot datasets.

The file `extra-credit.txt` contains the results of running our weighted PageRank using different d values. The top set of 25 teams is the actual rankings of teams from 2007 NCAA rankings, ESPN. The url to the actual rankings is included in the file. We found that changing the dval between 0.5, 0.9, and 0.97 had seemingly no significant impact on the amount of correct results found in the 25 nodes with the highest pagerank. Regardless of dval, PageRank resulted in typically 9 nodes correctly included in the top 25 results.

A   README

Team: Andrew Gilbert, Josh Terrell
   Important: Run everything from the project's root directory

A.1   Setup environment

```
pyvenv virtual
source virtual/bin/activate
pip install --upgrade -e .
```

A.2   Run all the tests

```
python3 -m unittest discover
```

A.3   Compute Page Rank

The ranker scripts assume the graph is directed.
   Correctly parsed formats include:
   SNAP (edges must be repeated if undirected) (weight is optional):

```
a b [weight]
```

CSVs, (edges must be repeated if undirected) (w_a and w_b are ignored unless `--weighted` flag is specified):

```
a,w_a,b,w_b
```

   To run:

```
ranker <filename.csv>            # unweighted
ranker <filename.csv> --weighted # weighted
ranker <filename.txt> --fmt=snap # option specifiying input file is snap format
```

   You can use `ranker --help` for more options such as setting the pagerank d parameter or tweaking parallel computation settings.

A.4 Deactivate environment

```
deactivate
```

A.5 (Optional) Manual Rebuild of Page Rank C-Implementation

```
python build_page_rank.py
```