



Problems with the Predecessor

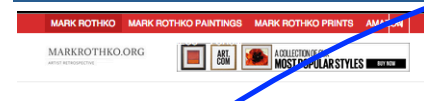
Mid '90's: “popularity”-based, search engines ranked results in terms of how many times each link was clicked.

- Positive feedback loop for top-ranked sites
- Waiting time for a significant number of clicks

Reformulation as a network problem

→ use the link structure of the internet itself to predict behavior

www.markrothko.org



MoMA is the Museum of Modern Art in New York, United States and it is an important institution of original and contemporary art. It is a place where you can find the most important art of the 20th century and what else you might find in this internationally respected Museum of art. The collection of Rothko ensures that each of the paintings at MoMA are frequently in demand by other galleries and museums, meaning that...



From September 20, 2014 through to January 18, 2015 you can visit an important exhibition of original and contemporary art. It is a place where you can find the most important art of the 20th century and what else you might find in this internationally respected Museum of art. The collection of Rothko ensures that each of the paintings at MoMA are frequently in demand by other galleries and museums, meaning that...



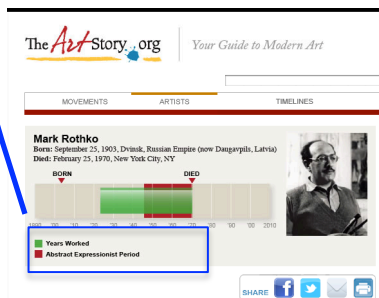
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www.nga.gov/rothko/



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www.theartstory.org/rothko



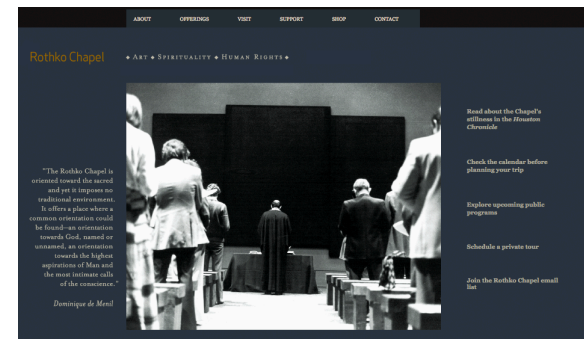
Mark Rothko
Born: September 25, 1903, Dvinsk, Russian Empire (now Daugavpils, Latvia)
Died: February 25, 1970, New York City, NY



Years Worked
Abstract Expressionist Period

"If you are only moved by color relationships, you are missing the point. I am interested in expressing the big emotions - tragedy, ecstasy, doom."

www.rothkochapel.org



"The Rothko Chapel is oriented toward the sacred and yet is impregnated with a human orientation. It offers a place where a common orientation could be found, an orientation towards God, toward the sacred, an orientation towards the highest aspirations of Man and the most intimate calls of the conscience."

Dominique de Mendonça

http://en.wikipedia.org/wiki/Mark_Rothko



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Mark Rothko

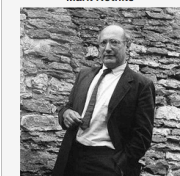
From Wikipedia, the free encyclopedia

Mark Rothko (Latvian: *Mārkuss Rotkovičs*, Russian: *Марк Ротко*; born *Міркус Яковлевич Роткович*; **Marcus Yakovlevich Rothkowitz**; September 25, 1903 – February 25, 1970) was an American painter of Russian Jewish descent. He is generally identified as an Abstract Expressionist. With Jackson Pollock and Willem de Kooning, he is one of the most famous postwar American artists.

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- 1 Childhood
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 - 4.1 Inspiration from mythology
 - 4.2 Nietzsche's influence
 - 4.3 "Mythomorphic" abstractionism

Mark Rothko

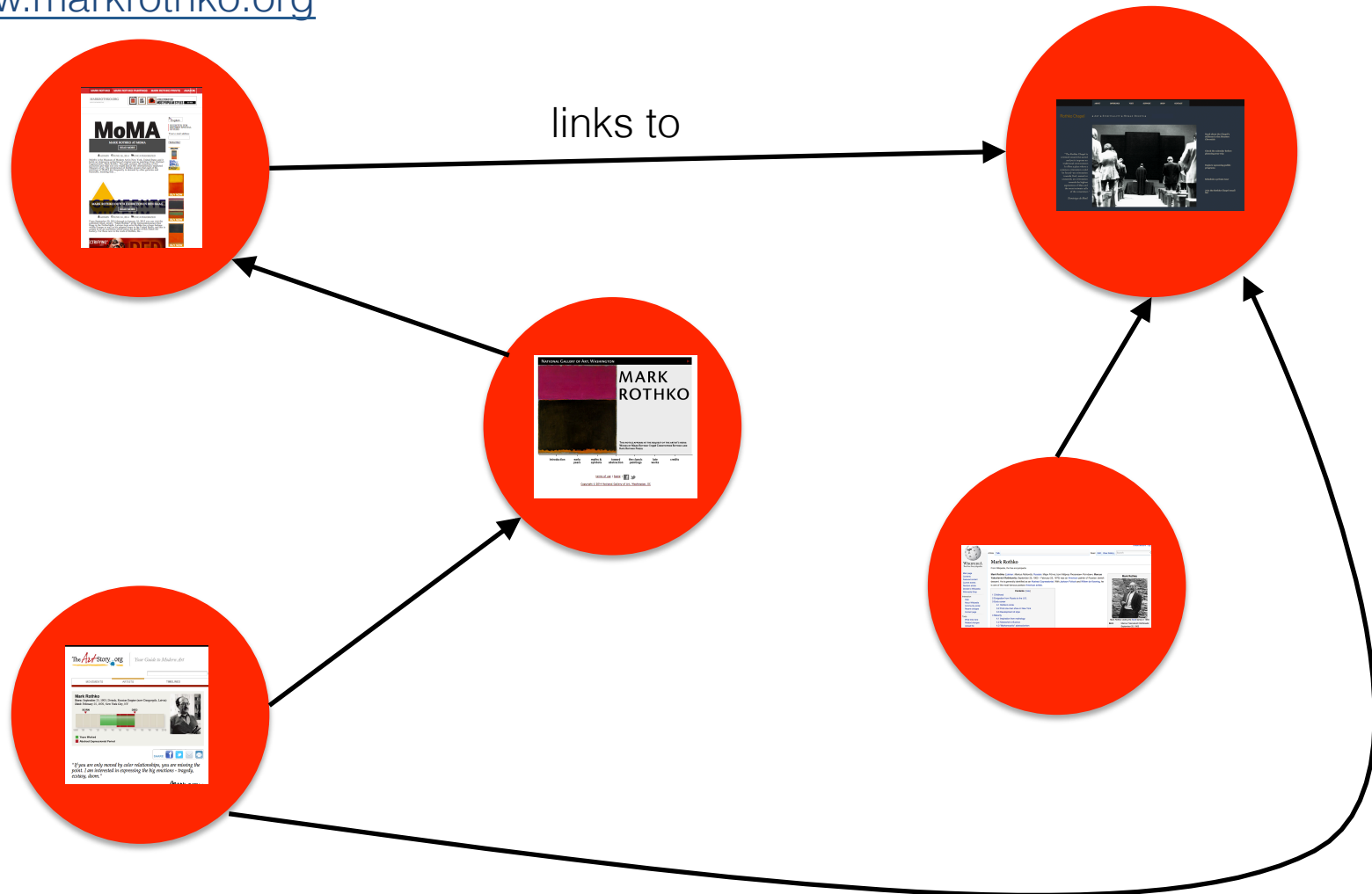


Mark Rothko visiting the Scott family in 1959
Born Marcus Yakovlevich Rothkowitz
September 25, 1903

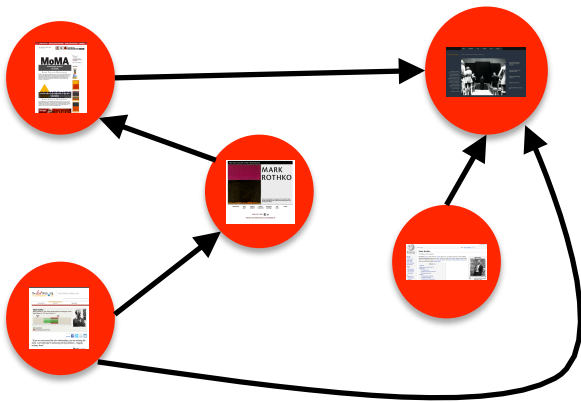
Reformulation as a network problem

www.markrothko.org

www.rothkochapel.org



Reformulation as a network problem



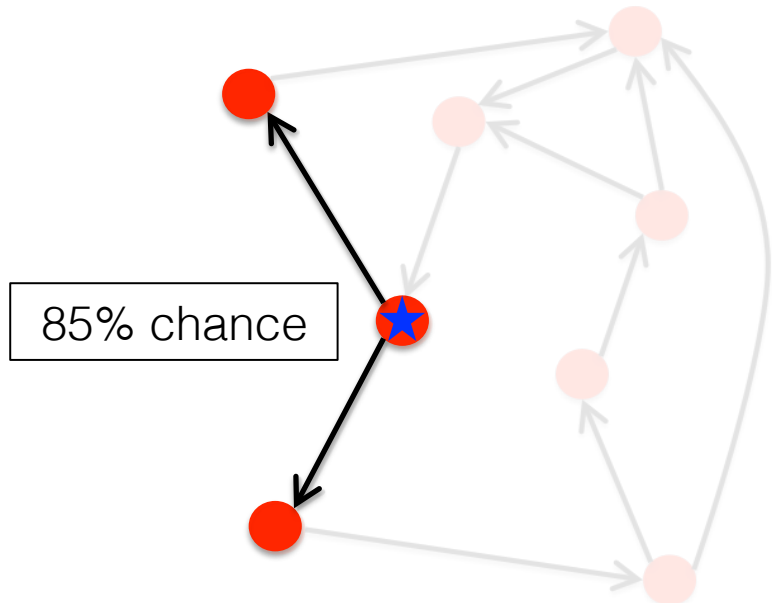
- Each webpage occupies a node on a graph
- Edges of graph represent links from one page to another
- The graph is *directed*, where there is an arrow pointing from node i to node j if node i links to node j .
- A “small” site could be highly ranked if it has a lot of important sites linking to it

PageRank Algorithm

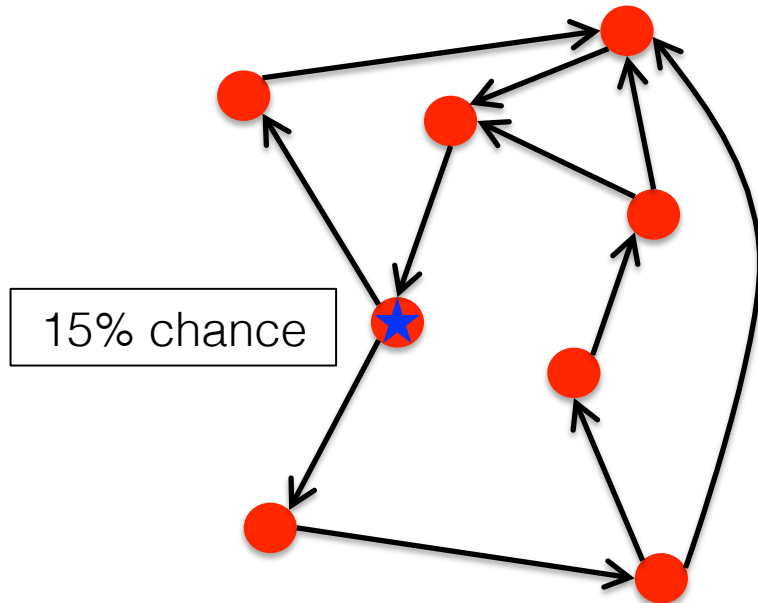
Once the network is constructed, we can simulate the “walk” of a web user across the graph and determine how many visits each page will receive, *based on its position on this graph*.

The number of visits gives us the page rank.

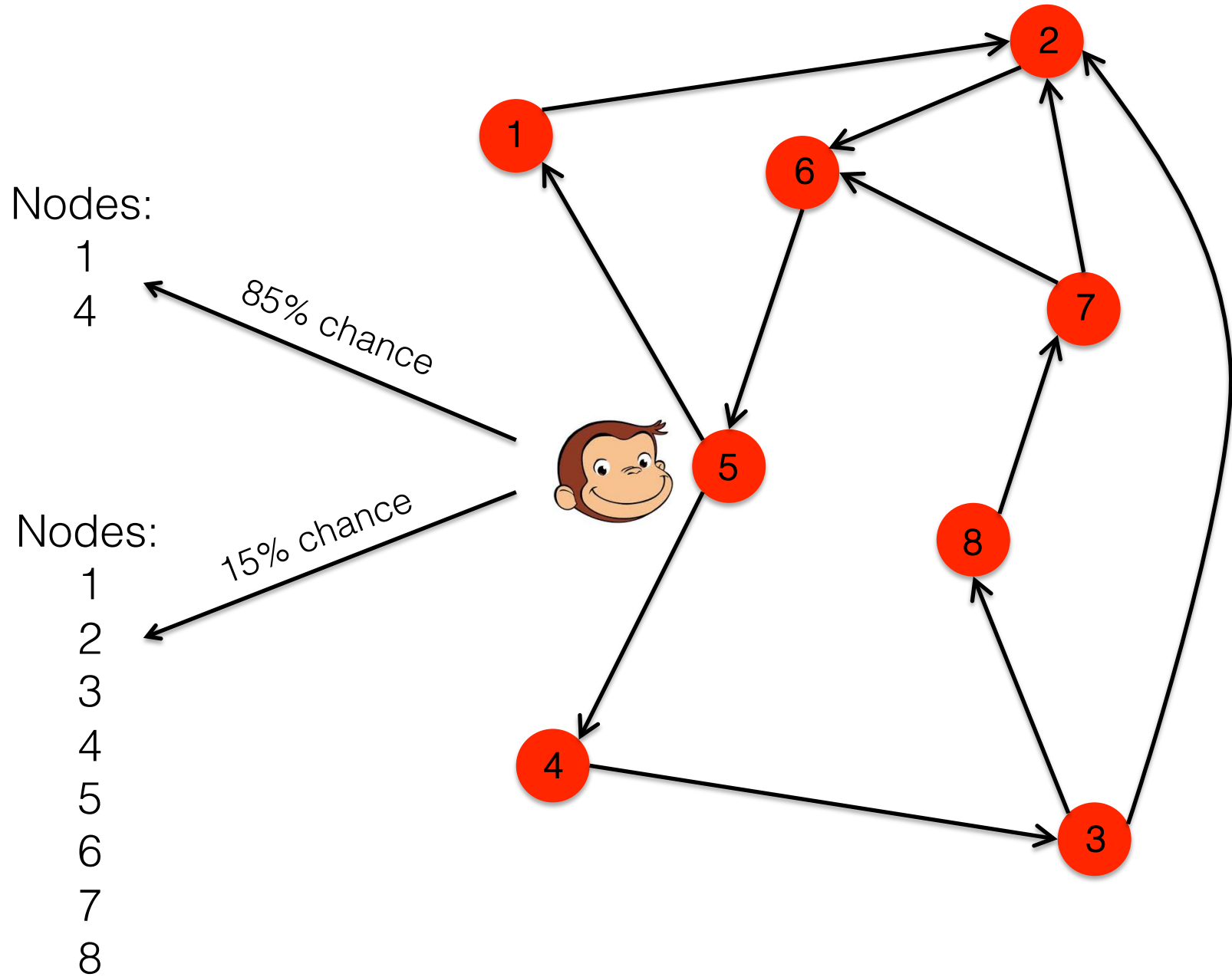
At any give node, there are two possibilities for behavior, each with a set probability of occurrence.



Move along directed edges to a node linked to current node



Move randomly to any node in network, including current node



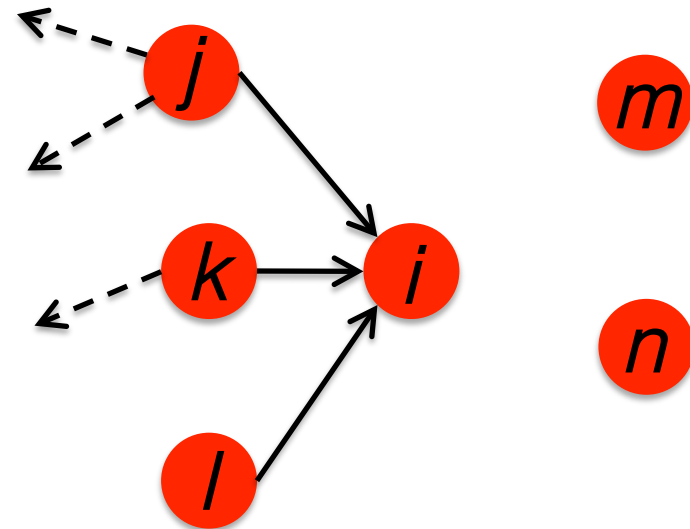
Running through the simulation of user navigation enough times for a significant ranking system would be very computationally intensive.

So...we are going to model the process using matrices to speed things up.

For each node, as its *rank*, we seek the proportion of visits to that node out of the network.

Let's start with the probability that we arrived at node i at a particular step.

We can either arrive at node i from a node that is connected to it (nodes j , k , l), or from any random node in the network.



Probabilities of each way to arrive at node i , given that you start at another node

$$j \rightarrow i \quad .85 \cdot (1/d_j) + .15/n \quad (d_j = \text{degree of node } j = 3, \quad n = \text{total nodes} = 6)$$

$$k \rightarrow i \quad .85 \cdot (1/d_k) + .15/n$$

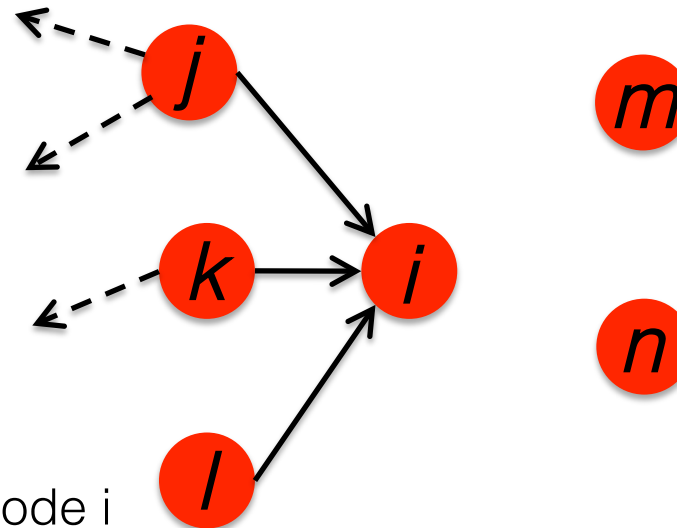
$$l \rightarrow i \quad .85 \cdot (1/d_l) + .15/n$$

$$m \rightarrow i \quad ?$$

$$n \rightarrow i \quad ?$$

$$i \rightarrow i \quad ?$$

We can either arrive at node i from a node that is connected to it (nodes j , k , l), or from any random node in the network.



Probabilities of each way to arrive at node i

$j \rightarrow i$ $.85*(1/d_j) + .15/n$ (d_j = degree of node $j = 3$, n = total nodes = 6)

$k \rightarrow i$ $.85*(1/d_k) + .15/n$

$l \rightarrow i$ $.85*(1/d_l) + .15/n$

$m \rightarrow i$ $.15/n$

$n \rightarrow i$ $.15/n$

$i \rightarrow i$ $.15/n$

Importantly, we are doing this *recursively*, so the probability of going from $j \rightarrow i$ depends on the probability we were at j to begin with.

$$P(i) = P(j \rightarrow i)P(j) + P(k \rightarrow i)P(k) + P(l \rightarrow i)P(l) + P(m \rightarrow i)P(m) + P(n \rightarrow i)P(n) + P(i \rightarrow i)P(i)$$

Constructing a Matrix Representation

$$P(j \rightarrow i)P(j) + P(k \rightarrow i)P(k) + P(l \rightarrow i)P(l) + P(m \rightarrow i)P(m) + P(n \rightarrow i)P(i) + P(i \rightarrow i)P(i) = P(i)$$

$$\begin{bmatrix} \dots \\ P(j \rightarrow i) & P(k \rightarrow i) & P(l \rightarrow i) & P(m \rightarrow i) & P(n \rightarrow i) & P(i \rightarrow i) \end{bmatrix} \begin{bmatrix} P(j) \\ P(k) \\ P(l) \\ P(m) \\ P(n) \\ P(i) \end{bmatrix} = \begin{bmatrix} P(j) \\ P(k) \\ P(l) \\ P(m) \\ P(n) \\ P(i) \end{bmatrix}$$

Constructing a Matrix Representation

R

$$\text{row } i \left[\begin{array}{cccccc} P(j \rightarrow i) & P(k \rightarrow i) & \dots & P(m \rightarrow i) & P(n \rightarrow i) & P(i \rightarrow i) \end{array} \right]$$

Construct a matrix \mathbf{R} s.t. $\mathbf{R}_{ij} = \begin{cases} \frac{0.85}{d_j} + \frac{0.15}{n} & \text{if } j \rightarrow i \\ \frac{0.15}{n} & \text{otherwise} \end{cases}$

Solving for “rank” p of each node

$$P(j \rightarrow i)P(j) + P(k \rightarrow i)P(k) + P(l \rightarrow i)P(l) + P(m \rightarrow i)P(m) + P(n \rightarrow i)P(i) + P(i \rightarrow i)P(i) = P(i)$$

$$\begin{bmatrix} \dots \\ P(j \rightarrow i) & P(k \rightarrow i) & P(l \rightarrow i) & P(m \rightarrow i) & P(n \rightarrow i) & P(i \rightarrow i) \end{bmatrix} \begin{bmatrix} P(j) \\ P(k) \\ P(l) \\ P(m) \\ P(n) \\ P(i) \end{bmatrix} = \begin{bmatrix} P(j) \\ P(k) \\ P(l) \\ P(m) \\ P(n) \\ P(i) \end{bmatrix}$$

$\mathbf{R} \qquad \mathbf{p} \qquad \mathbf{p}$

$$\mathbf{R}\mathbf{p} = \mathbf{p}$$

$$\mathbf{R}\mathbf{p} - \mathbf{p} = \mathbf{0}$$

$$\mathbf{R}\mathbf{p} - \mathbf{I}\mathbf{p} = \mathbf{0} \rightarrow (\mathbf{R} - \mathbf{I})\mathbf{p} = \mathbf{0}$$

We know \mathbf{R} and \mathbf{I} , so we can solve for \mathbf{p} using Gaussian elimination!

Solving for p using gauss

$$(R - I)p = 0$$

Problem: there is no unique solution (e.g. we could have $p = 0$).
Solution: Augment $(R-I)$ with a row of 1's at the bottom.

$$\left[\begin{array}{ccccccccc} & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ \hline 1 & 1 & 1 & 1 & 1 & 1 & \dots & & 1 \end{array} \right] p = \left[\begin{array}{c} 0 \\ \hline 1 \end{array} \right]$$

A z

Then run $p = \text{gauss}(A, z)$ to return the vector of ranks, p

This presentation is available at www.cogconfluence.com (under the CAAM 210, Fall '14 tab)

Project

Four functions:

pagerankdriver

- reads the .txt terrorist file into MATLAB
- calls pagerankmatrix on the edgelist E to create R
- calls gauss on “doctored” R to solve for p
- uses pagerank p to create a biograph with nodes colored/shaped based on rank

[p] = gauss(A,z)

- your own gaussian elimination code

[p] = trisolve(A,z)

- back-substitution to complete gauss, provided in notes

[R] = pagerankmatrix(E)

- your own code for creating R based on probabilities

