Information Retrieval – Part 2

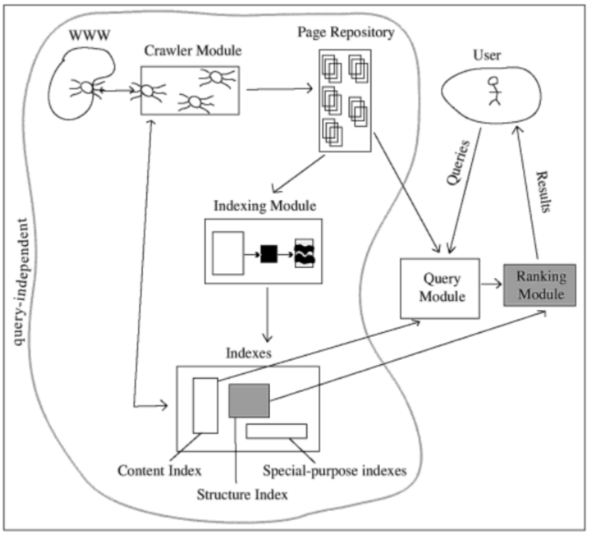
Deepak Kumar

Borges’ *Library of Babel*

“…each book contains four hundred ten pages; each page, forty lines; each line, approximately eighty black letters. There are also letters on the front cover of each book; these letters neither indicate nor prefigure what the pages inside will say.”

Q: How many books are in the library?
Q. How would you find what you’re looking for?

Elements of a Search Engine



Web Information Retrieval

- Search Engines
- Queries
  phrase queries
  structure queries (NEAR, intitle:, …)
- Matching
- Inverted Index
  page number
  location
- Ranking & Relevance
- Metadata

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- Queries
  phrase queries
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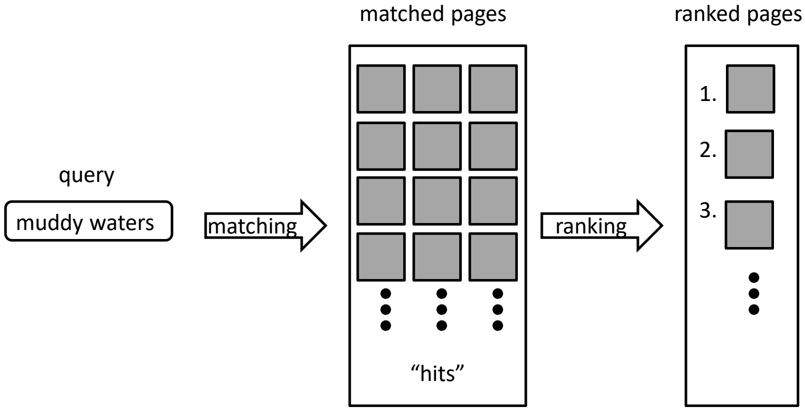
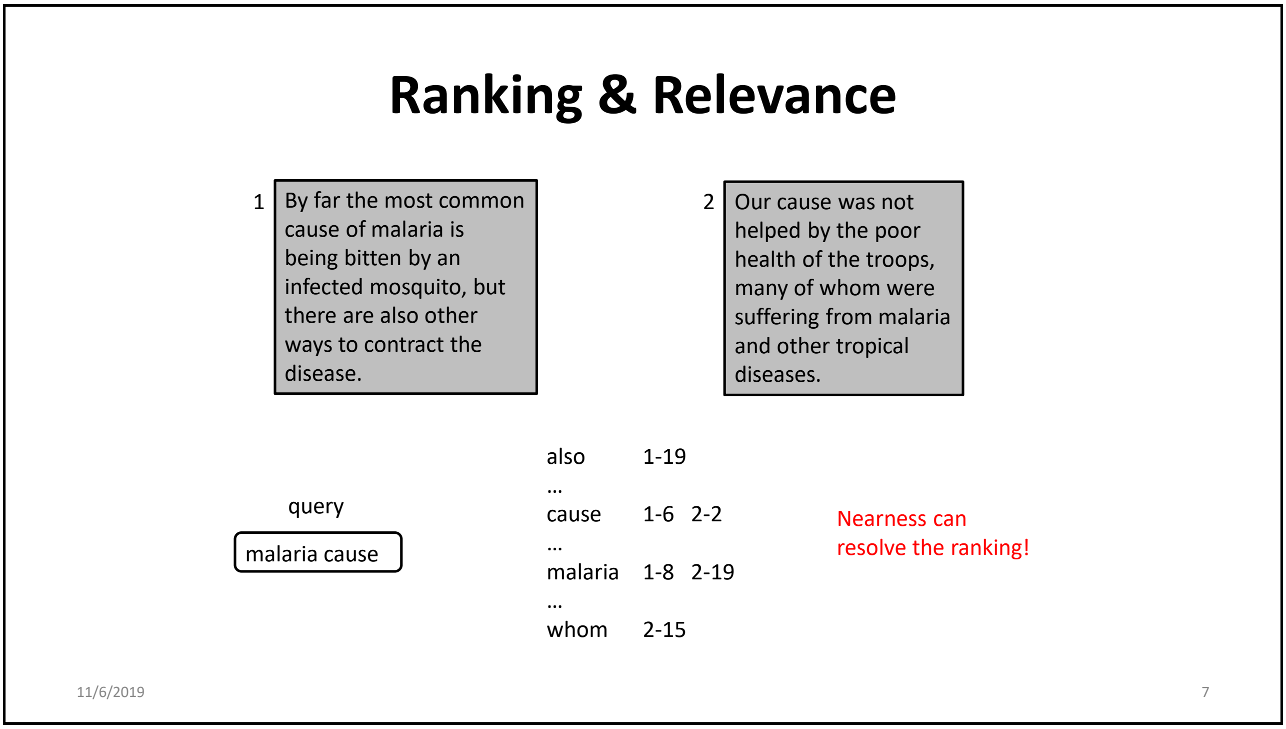
**Efficient matching
is only one half the story.**

**The other grand challenge
is how to *rank* the
matching pages**

Matching & Ranking





Ranking & Relevance

1 By far the most common cause of malaria is being bitten by an infected mosquito, but there are also other ways to contract the disease.

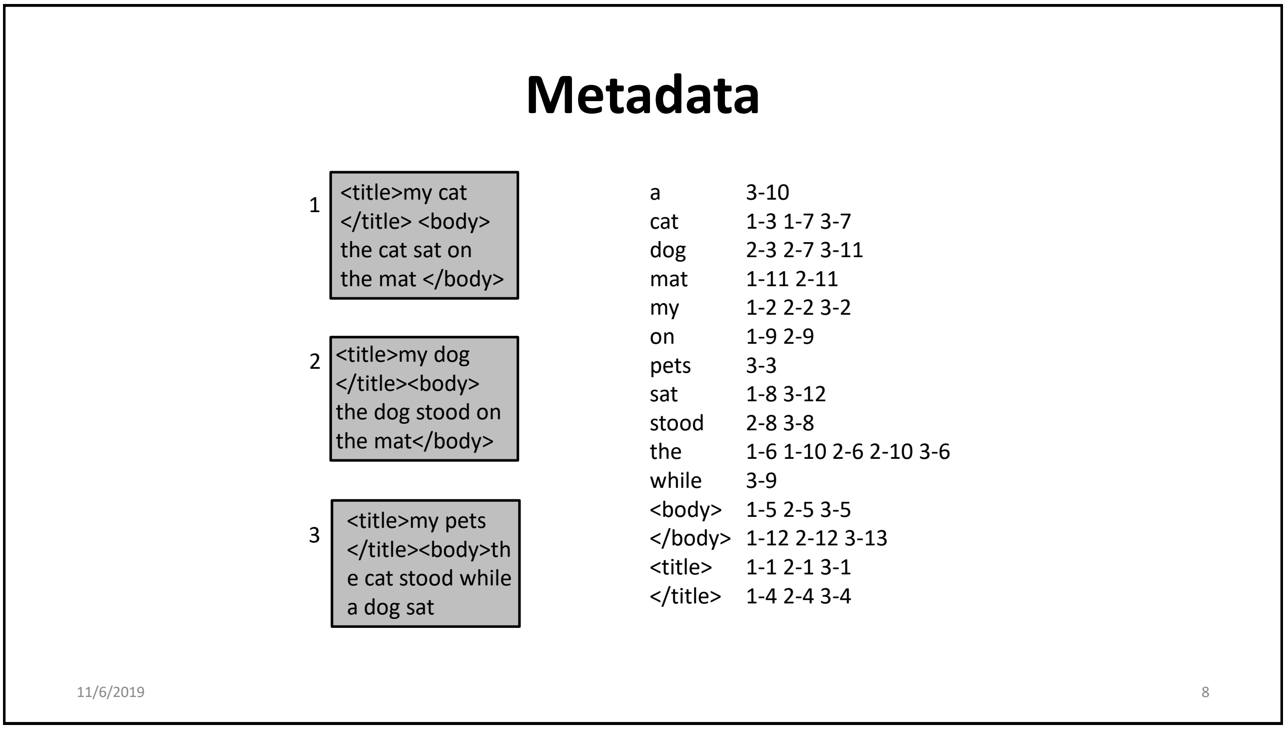
2 Our cause was not helped by the poor health of the troops, many of whom were suffering from malaria and other tropical diseases.

query

malaria cause

also	1-19	
…		
cause	1-6	2-2
…		
malaria	1-8	2-19
…		
whom	2-15	

Nearness can resolve the ranking!



Metadata

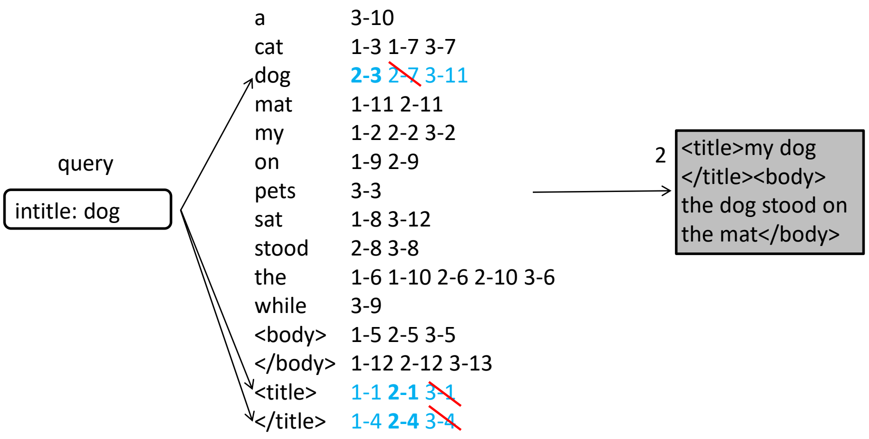
1 <title>my cat </title> <body> the cat sat on the mat </body>

2 <title>my dog </title><body> the dog stood on the mat</body>

3 <title>my pets </title><body>the cat stood while a dog sat

a	3-10
cat	1-3 1-7 3-7
dog	2-3 2-7 3-11
mat	1-11 2-11
my	1-2 2-2 3-2
on	1-9 2-9
pets	3-3
sat	1-8 3-12
stood	2-8 3-8
the	1-6 1-10 2-6 2-10 3-6
while	3-9
<body>	1-5 2-5 3-5
</body>	1-12 2-12 3-13
<title>	1-1 2-1 3-1
</title>	1-4 2-4 3-4

Structure Queries



query

intitle: dog

a	3-10
cat	1-3 1-7 3-7
dog	**2-3** ~~2-7~~ 3-11
mat	1-11 2-11
my	1-2 2-2 3-2
on	1-9 2-9
pets	3-3
sat	1-8 3-12
stood	2-8 3-8
the	1-6 1-10 2-6 2-10 3-6
while	3-9
<body>	1-5 2-5 3-5
</body>	1-12 2-12 3-13
<title>	1-1 **2-1** ~~3-1~~
</title>	1-4 **2-4** ~~3-4~~

2 <title>my dog </title><body> the dog stood on the mat</body>

Exploiting Link Structure

- ***PageRank*** exploits the structure of the web:

  Use of Hyperlinks to
  - count # of incoming links
  - Identifying web authority

- Use the above in determining ranking & relevance.

The Garage

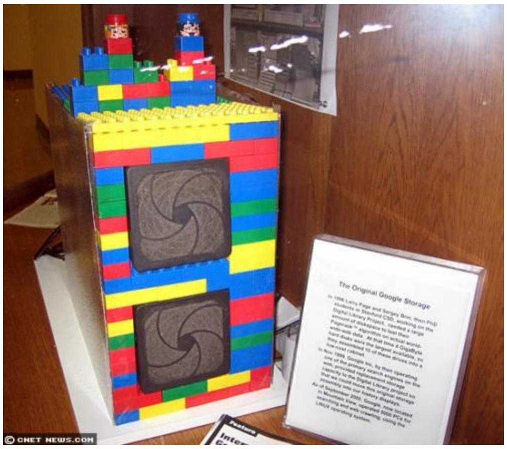
Garage at 232 Santa Margarita, Menlo Park, CA

Google 1.0 (1998)

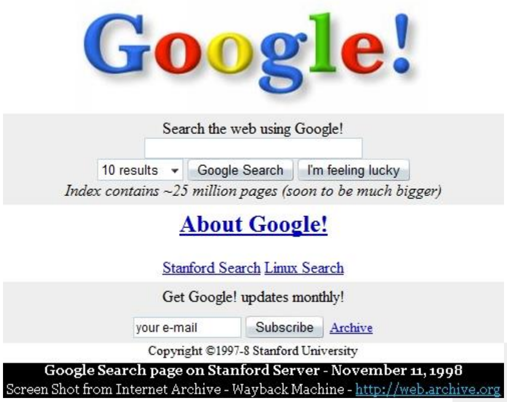
2-proc Pentium II 300mhz, 512mb, five 9gb drives
2-proc Pentium II 300mhz, 512mb, four 9gb drives
4-proc PPC 604 333mhz, 512mb, eight 9gb drives
2-proc UltraSparc II 200mhz, 256mb, three 9gb drives, six 4gb drives
Disk expansion, eight 9gb drives
Disk expansion, ten 9gb drives

That's a total of:
1792 megabytes of memory
366 gigabytes of disk storage
2933 megahertz in **10** CPUs

The Disk Storage



Google 1.0 (1998)



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10 results ▾ | Google Search | I'm feeling lucky

Index contains ~25 million pages (soon to be much bigger)

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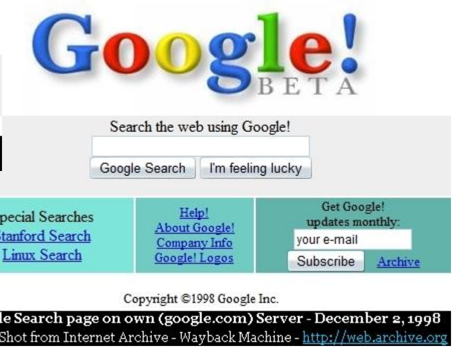

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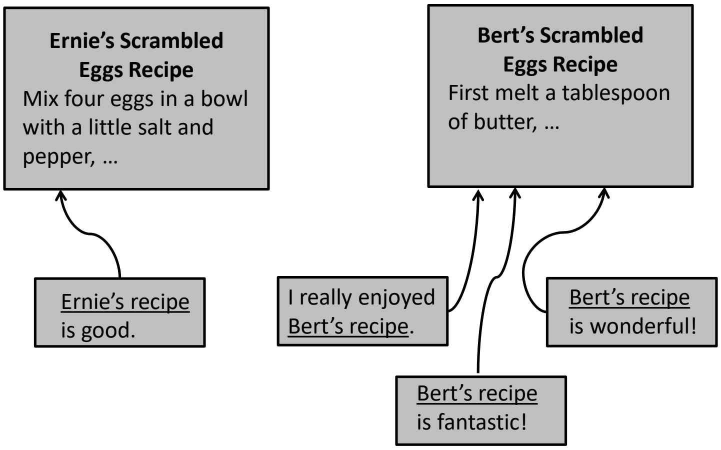
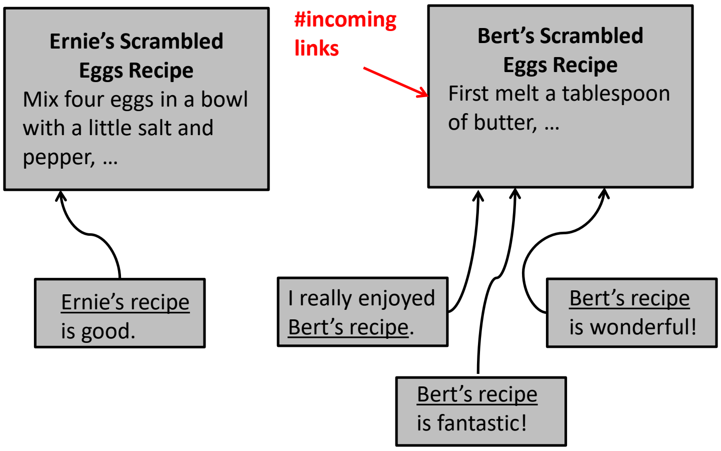
Hyperlinks


Ernie's Scrambled Eggs Recipe
Mix four eggs in a bowl with a little salt and pepper, …
Bert's Scrambled Eggs Recipe
First melt a tablespoon of butter, …
Ernie's recipe is good.
I really enjoyed Bert's recipe.
Bert's recipe is wonderful!
Bert's recipe is fantastic!

11/6/2019 15

Hyperlinks: # Incoming Links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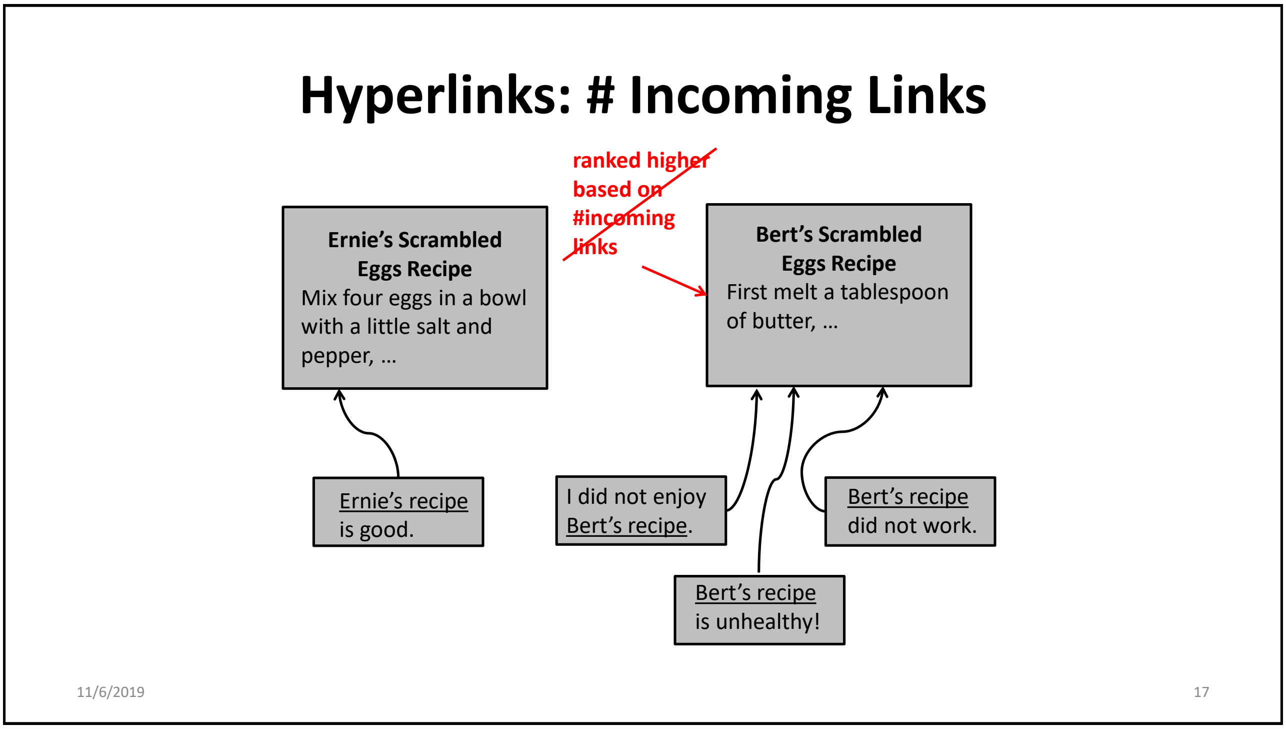
ranked higher based on #incoming links

11/6/2019 16



Hyperlinks: # Incoming Links

~~ranked higher based on #incoming links~~

Ernie's Scrambled Eggs Recipe
Mix four eggs in a bowl with a little salt and pepper, …

Bert's Scrambled Eggs Recipe
First melt a tablespoon of butter, …

Ernie's recipe is good.

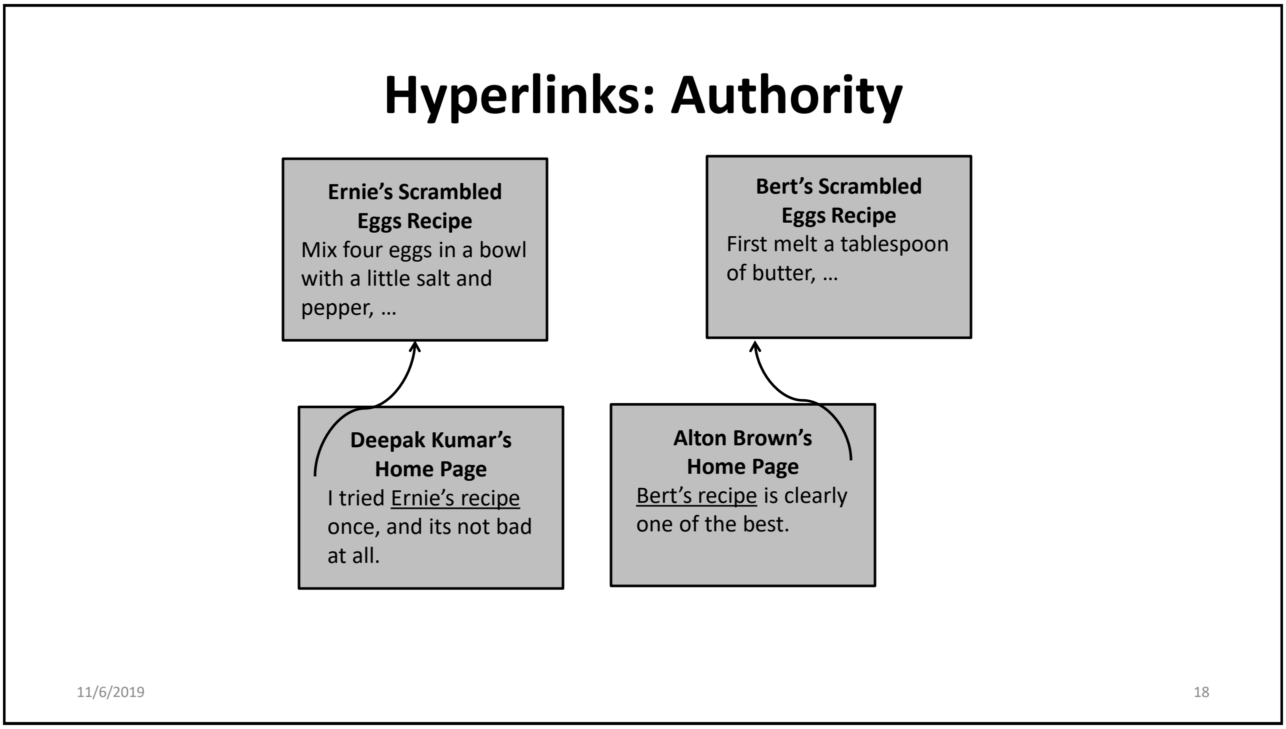
I did not enjoy Bert's recipe.

Bert's recipe did not work.

Bert's recipe is unhealthy!

11/6/2019

17



Hyperlinks: Authority

Ernie's Scrambled Eggs Recipe
Mix four eggs in a bowl with a little salt and pepper, …

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First melt a tablespoon of butter, …

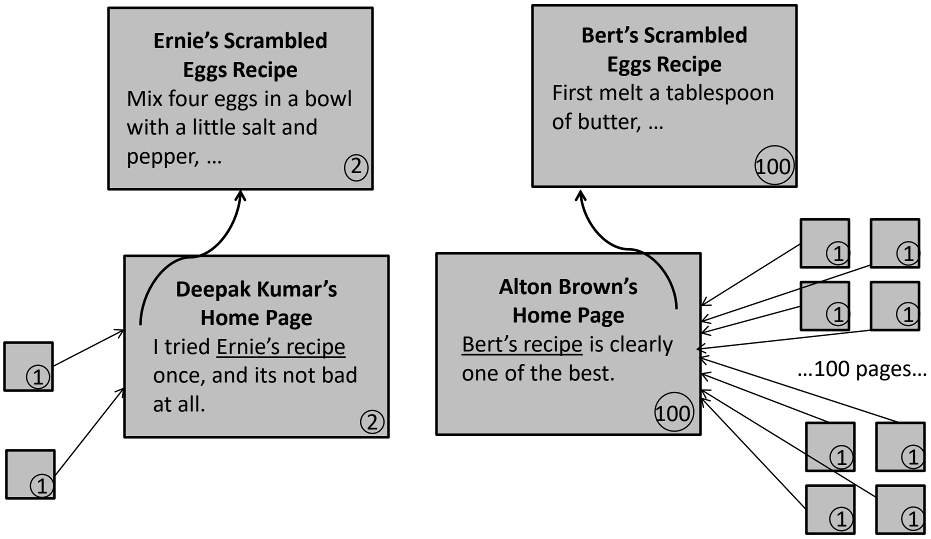
Deepak Kumar's Home Page
I tried Ernie's recipe once, and its not bad at all.

Alton Brown's Home Page
Bert's recipe is clearly one of the best.

11/6/2019

18

Hyperlinks: Authority



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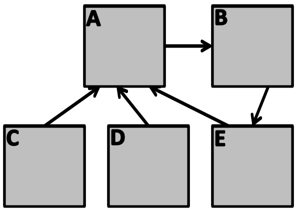
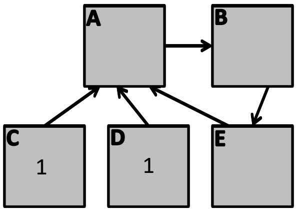
…100 pages…

Cycles



Computing Authority Scores



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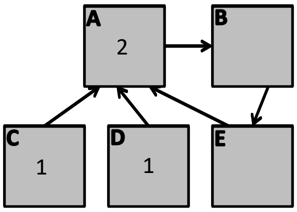
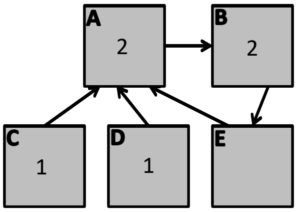


Computing Authority Scores



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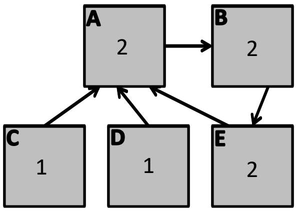

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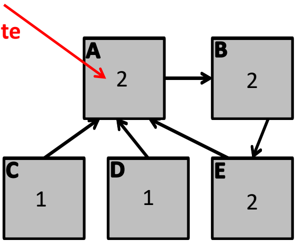
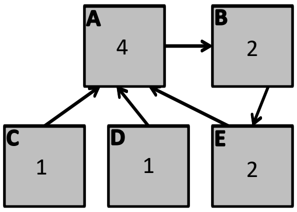
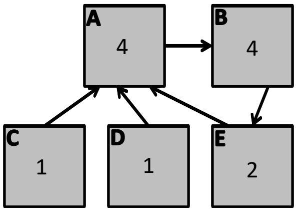


score for A
is out of date

Computing Authority Scores



Computing Authority Scores



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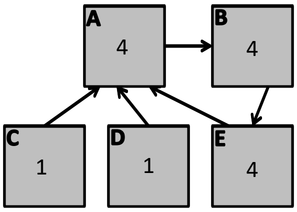

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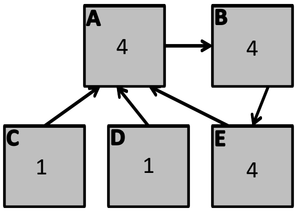
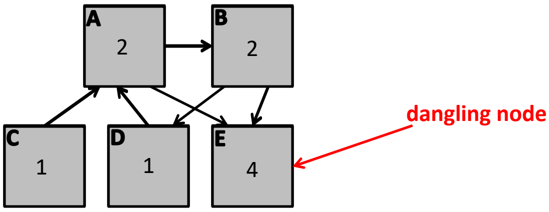
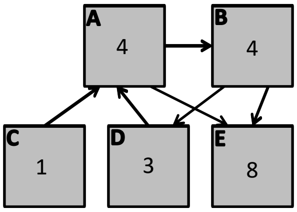


and so on…stuck in an infinite loop….

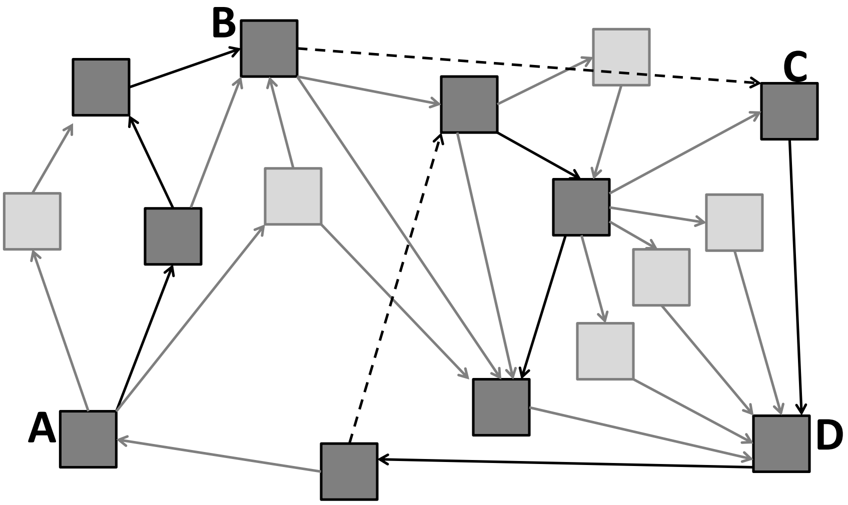
Sinks



Sinks

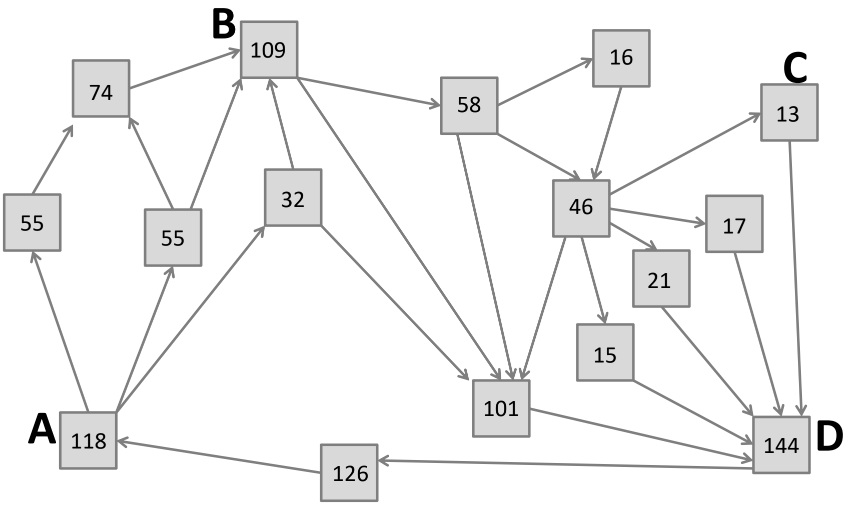


The Random Surfer



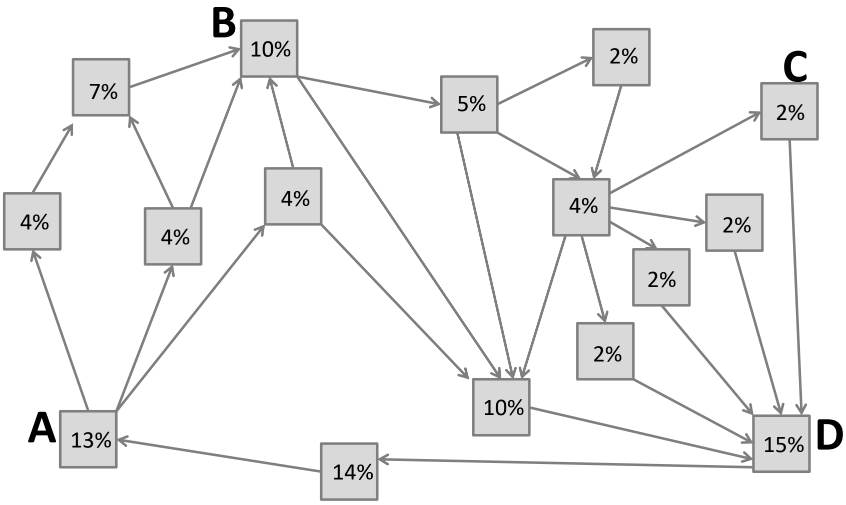
restart probability = 15%

The Random Surfer



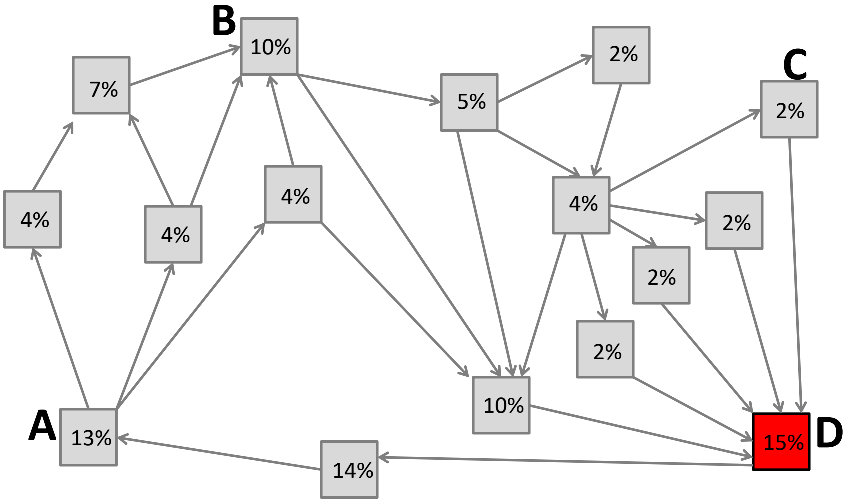
after 1000 page visits

The Random Surfer



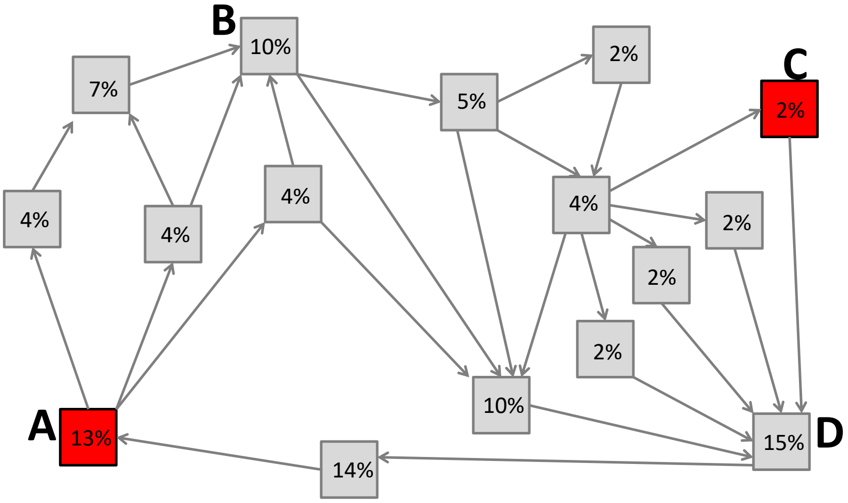
after 1 million page visits

The Random Surfer



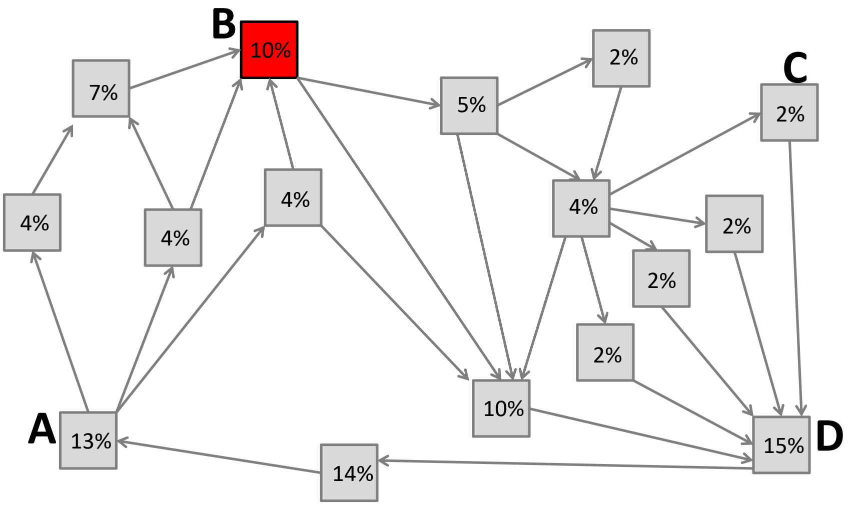
pages with many incoming links get high ranking

The Random Surfer



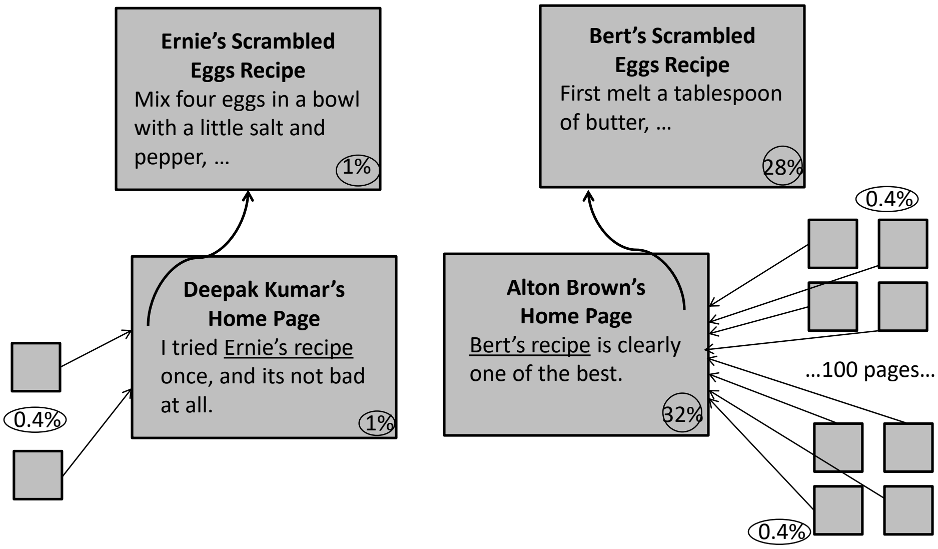
authoritative score

The Random Surfer



#links+authoritative score

The Random Surfer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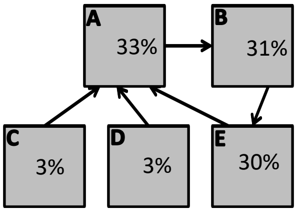


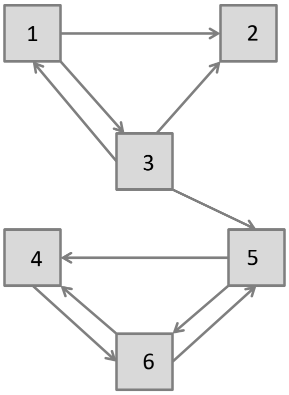
Formalizing PageRank

- Given a web page, P_i
- Set of pages pointing into P_i, B_{P_i}
- Number of outgoing links from page P_j, $|P_j|$
- PageRank of a page, $r(P_i)$

$$r(P_i) = \sum_{P_j \in B_{P_i}} \frac{r(P_j)}{|P_j|}$$

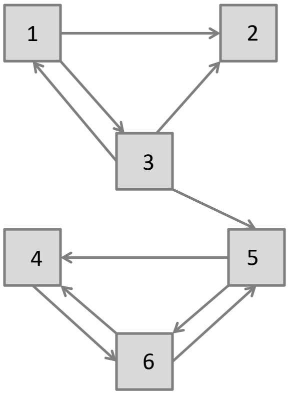
Computing PageRank

- $r(P_1) = r(P_3)$
- But, $r(P_3)$ is unknown
- To start, assume all pages have rank $\frac{1}{n}$ $(n\ =\ 6)$
- $\therefore r(P_1) = \frac{1}{6}$



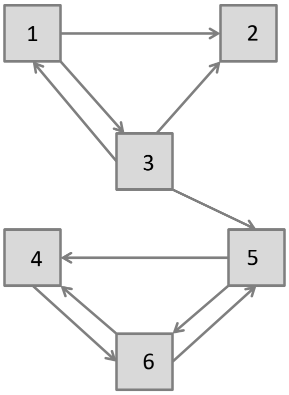
Computing PageRank

$$r_0(P_1) = 1/6$$
$$r_0(P_2) = 1/6$$
$$r_0(P_3) = 1/6$$
$$r_0(P_4) = 1/6$$
$$r_0(P_5) = 1/6$$
$$r_0(P_6) = 1/6$$



Computing PageRank

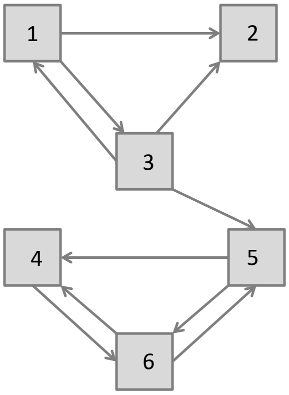
$r_1(P_1) = 1/18$
$r_1(P_2) = 5/36$
$r_1(P_3) = 1/12$
$r_1(P_4) = 1/4$
$r_1(P_5) = 5/36$
$r_1(P_6) = 1/6$



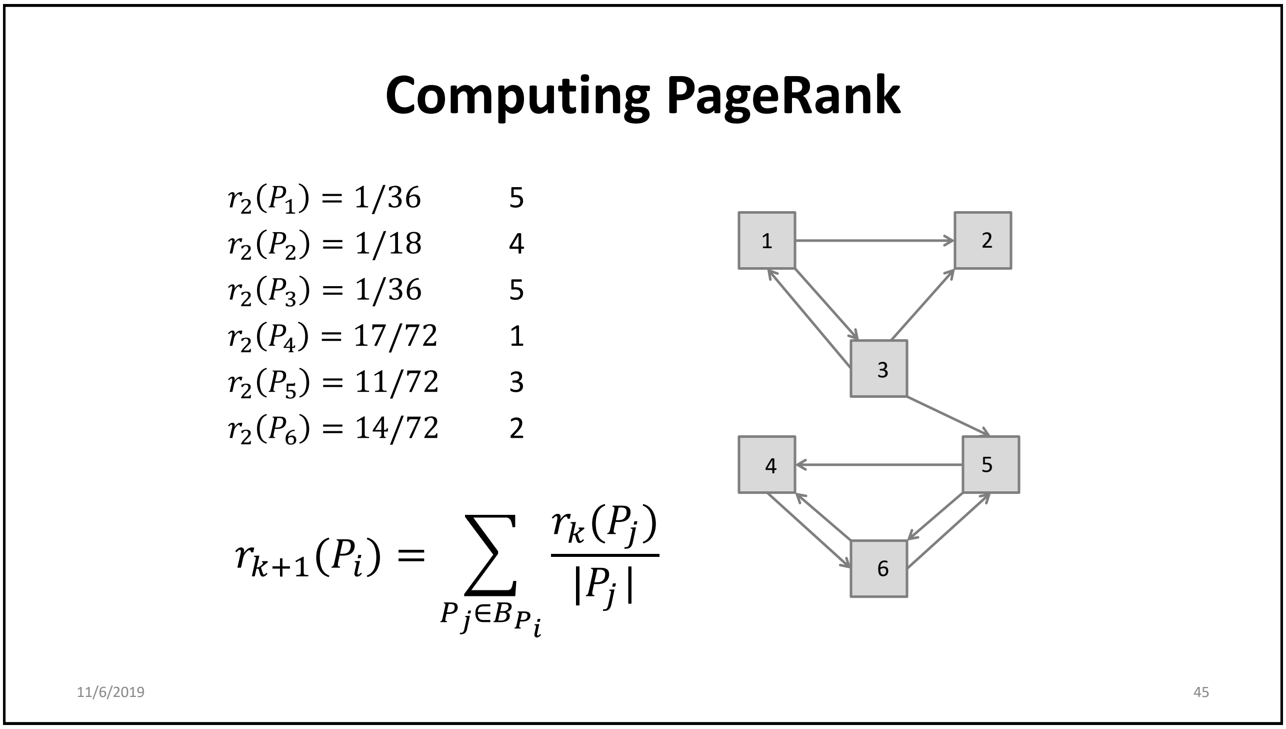
$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$

Computing PageRank

$r_2(P_1) = 1/36$
$r_2(P_2) = 1/18$
$r_2(P_3) = 1/36$
$r_2(P_4) = 17/72$
$r_2(P_5) = 11/72$
$r_2(P_6) = 14/72$



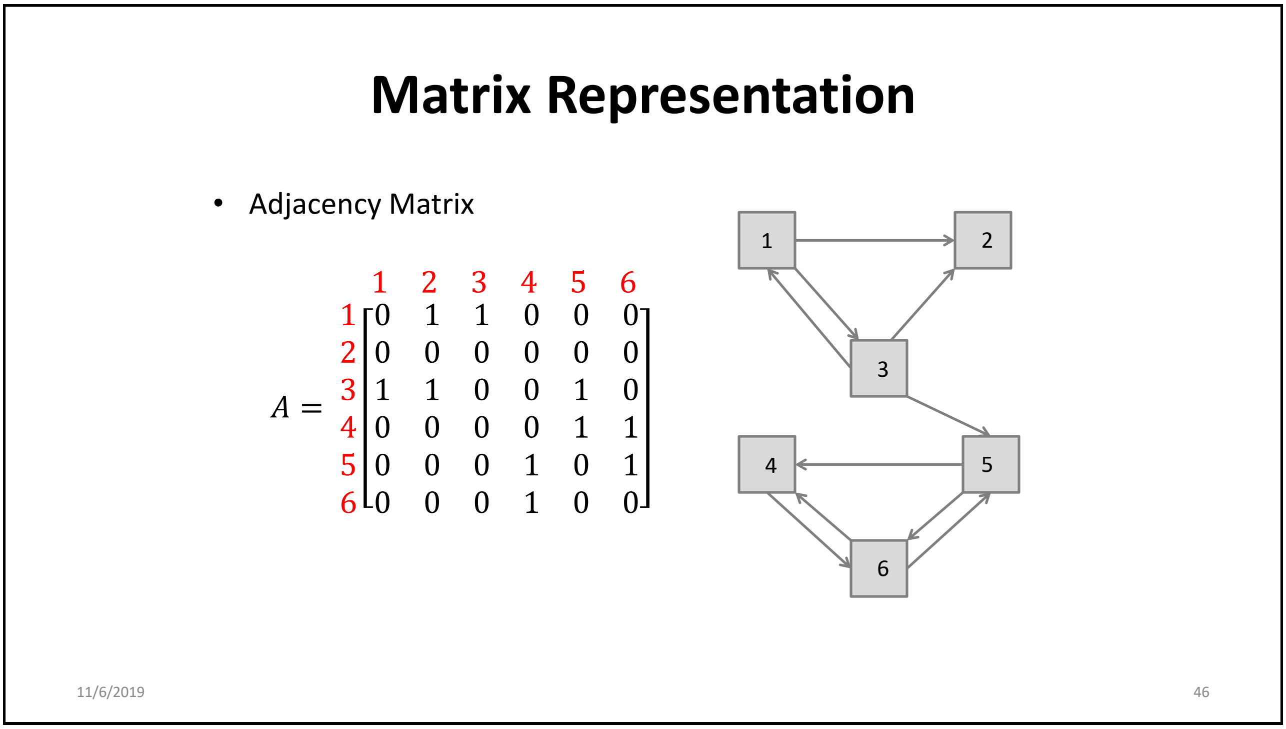
$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$



Computing PageRank

$r_2(P_1) = 1/36$	5
$r_2(P_2) = 1/18$	4
$r_2(P_3) = 1/36$	5
$r_2(P_4) = 17/72$	1
$r_2(P_5) = 11/72$	3
$r_2(P_6) = 14/72$	2

$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$



Matrix Representation

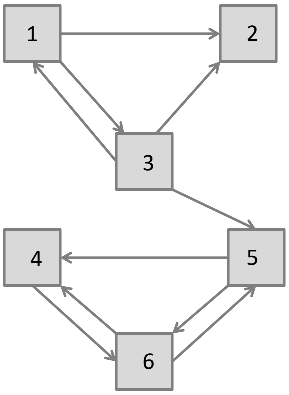
- Adjacency Matrix

$$A = \begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0 & 1 & 1 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 1 & 1 & 0 & 0 & 1 & 0 \\ 4 & 0 & 0 & 0 & 0 & 1 & 1 \\ 5 & 0 & 0 & 0 & 1 & 0 & 1 \\ 6 & 0 & 0 & 0 & 1 & 0 & 0 \end{array}$$

Matrix Representation

- Hyperlink Matrix, H

$$\begin{array}{c|cccccc} & 1 & 2 & 3 & 4 & 5 & 6 \\ \hline 1 & 0 & 1/2 & 1/2 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 3 & 1/3 & 1/3 & 0 & 0 & 1/3 & 0 \\ 4 & 0 & 0 & 0 & 0 & 1/2 & 1/2 \\ 5 & 0 & 0 & 0 & 1/2 & 0 & 1/2 \\ 6 & 0 & 0 & 0 & 1 & 0 & 0 \end{array}$$



- $\pi_{k+1}{}^{T} = \pi_{k}{}^{T}\, H$

  where $\pi_k{}^T$ is the k^{th} PageRank vector

The PageRank Equation

- $\pi^T = \pi^T(\alpha S + (1-\alpha)E)$

where
S is the stochastic H matrix
E is the teleportation matrix
α is the scaling parameter

- Certain stochastic conditions apply!

Google Data Center

References

- *Google's PageRank and Beyond*, Amy N. Langville and Carl D. Meyer, Princeton University Press, 2006.
- *Nine Algorithms That Changed The Future*, John MacCormick, Princeton University Press, 2012.
- *The Unimaginable Mathematics of Borges' Library of Babel*, William G. Bloch, Oxford University Press, 2008.