Information Retrieval – Part 2

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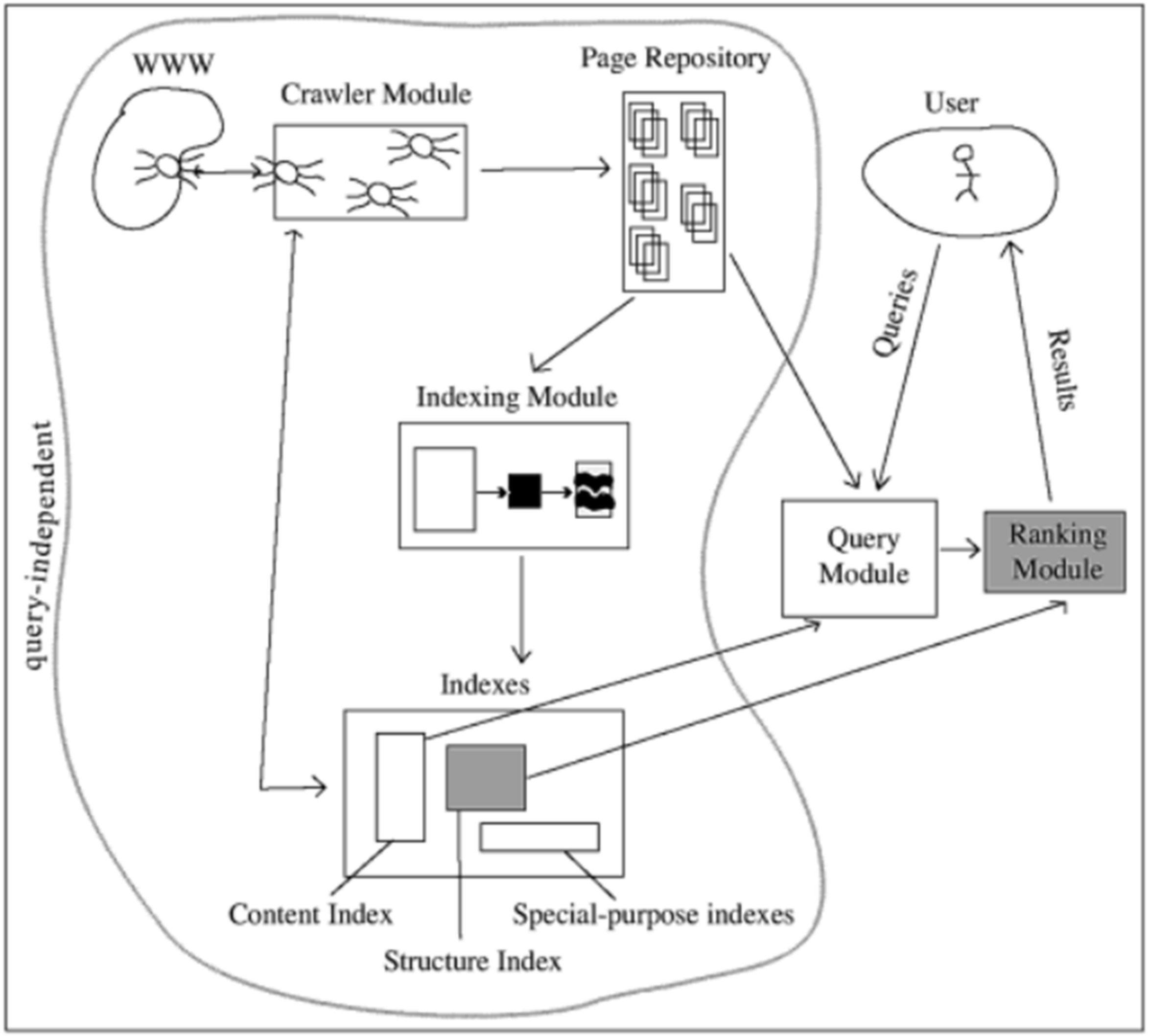
Borges' *Library of Babel*

"…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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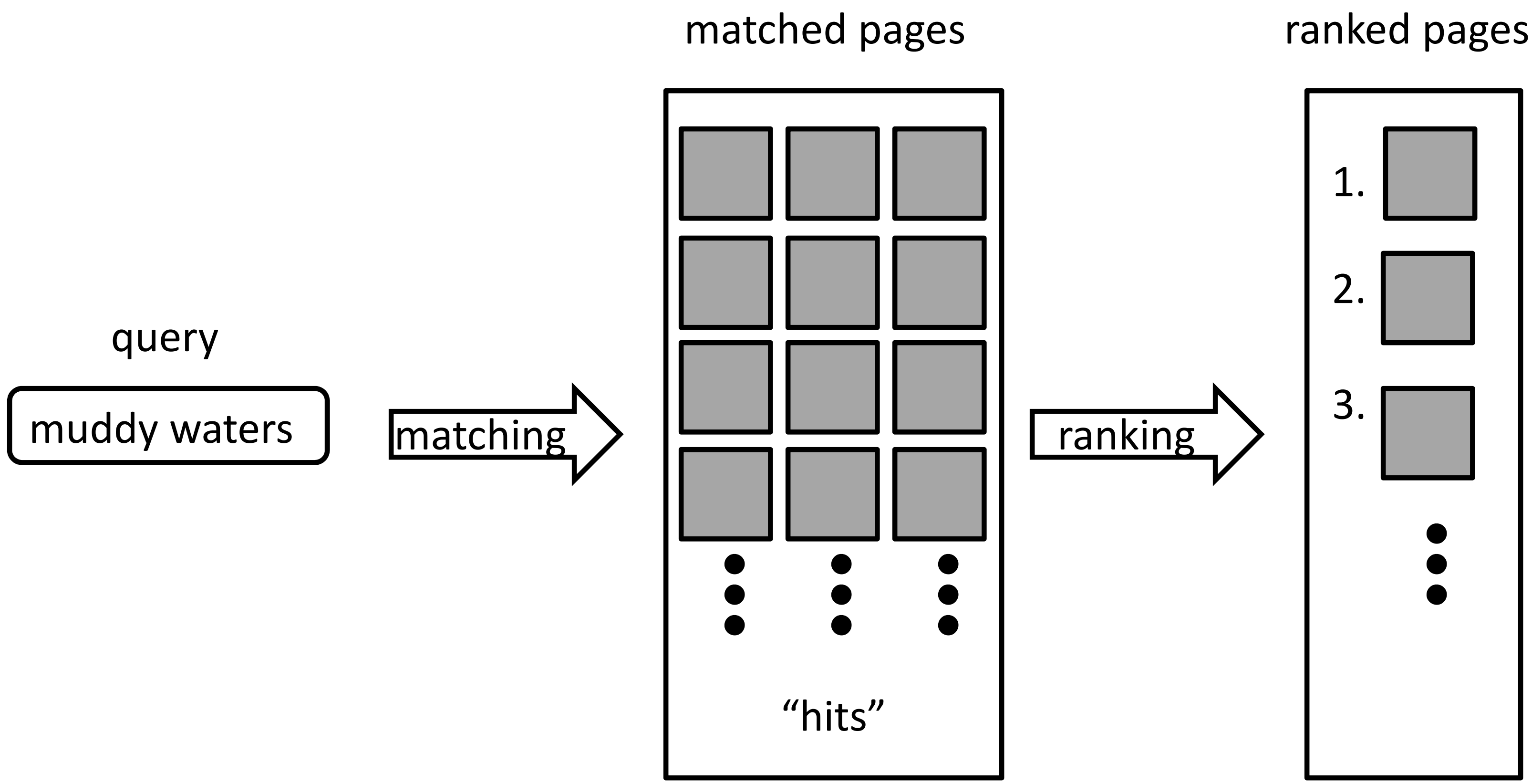
Efficient matching
is only one half the story.

The other grand challenge
is how to *<u>rank</u>* 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

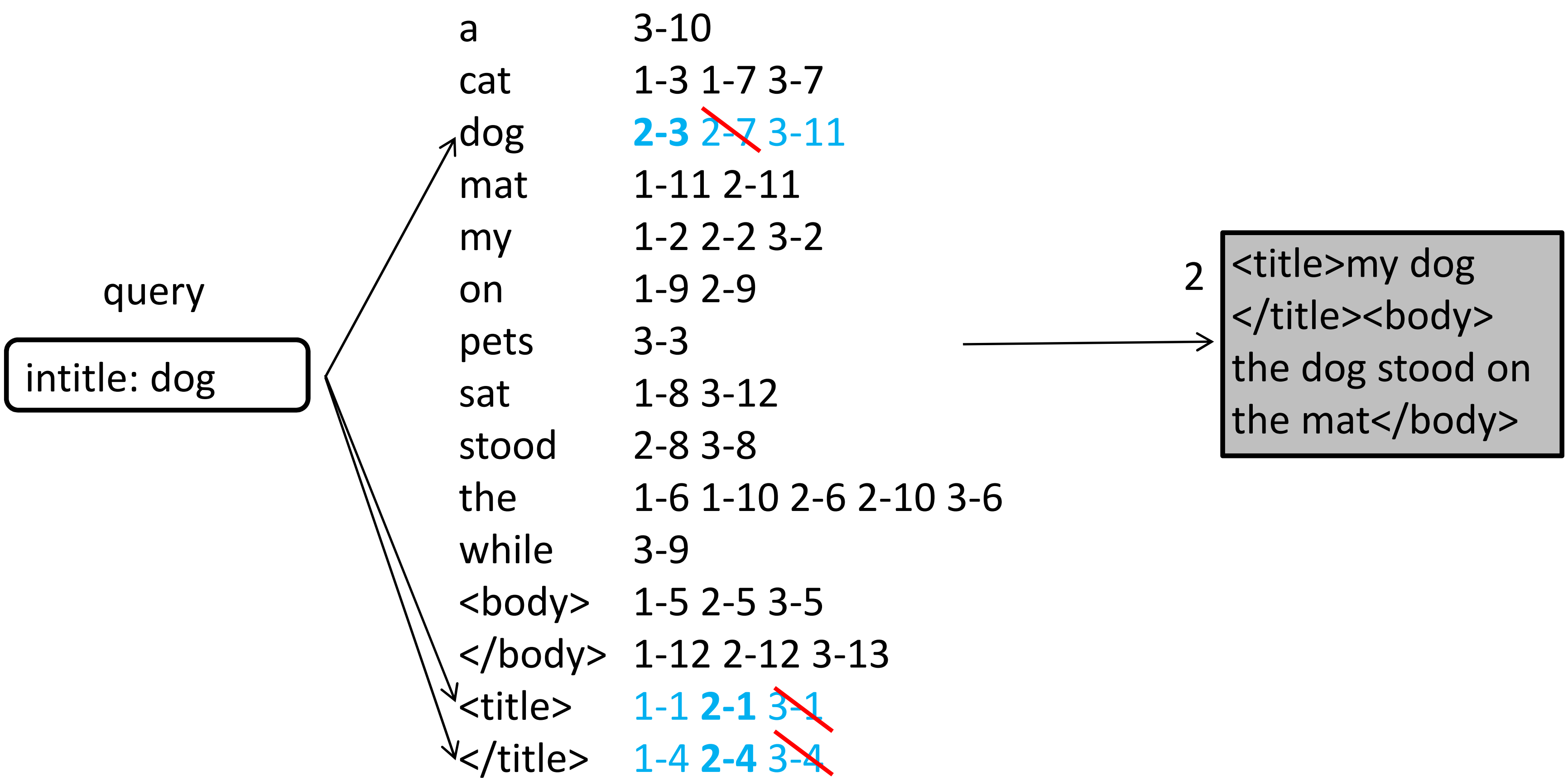
1 <title>my cat </title> <body> the cat sat on the mat </body>

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



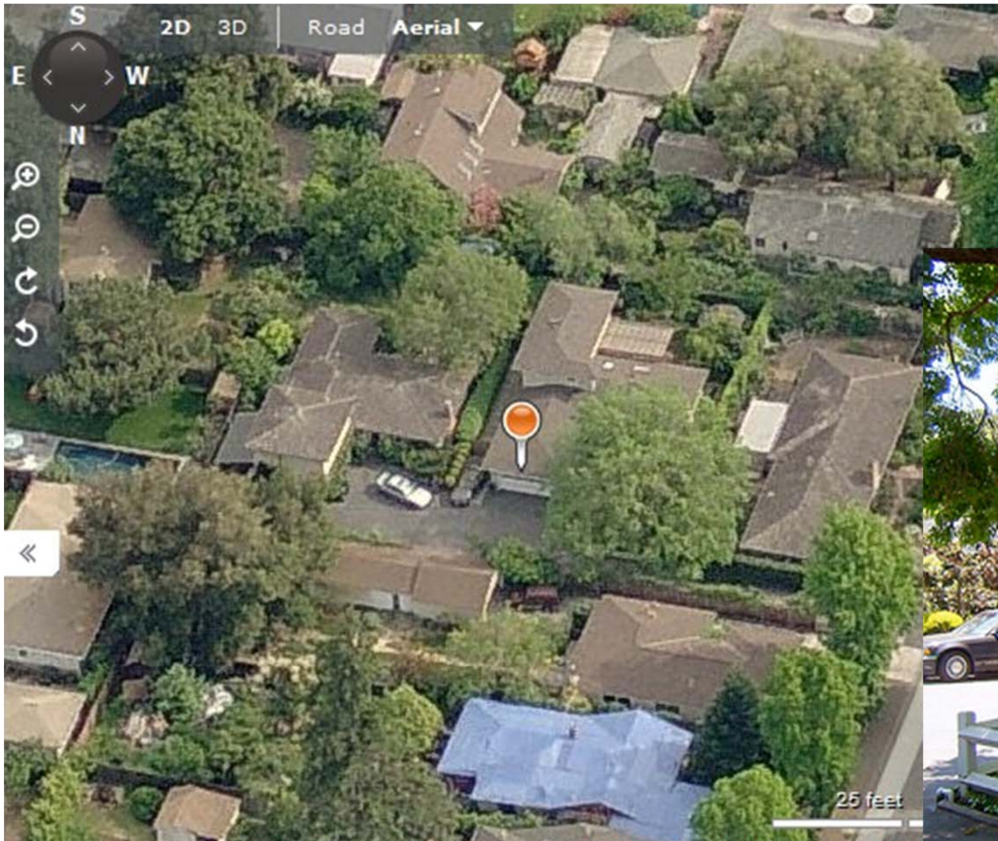
Exploiting Link Structure

- ***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



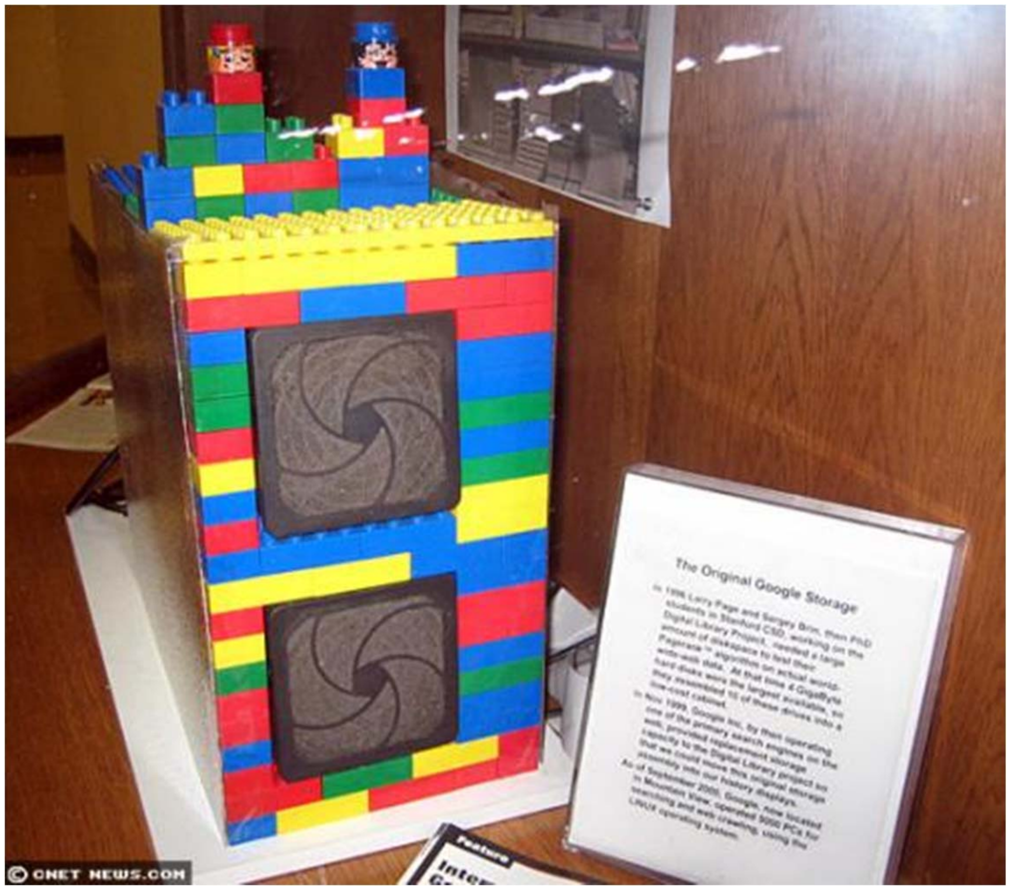
Garage at 232 Santa Margarita, Menlo Park, CA

Google 1.0 (1998)

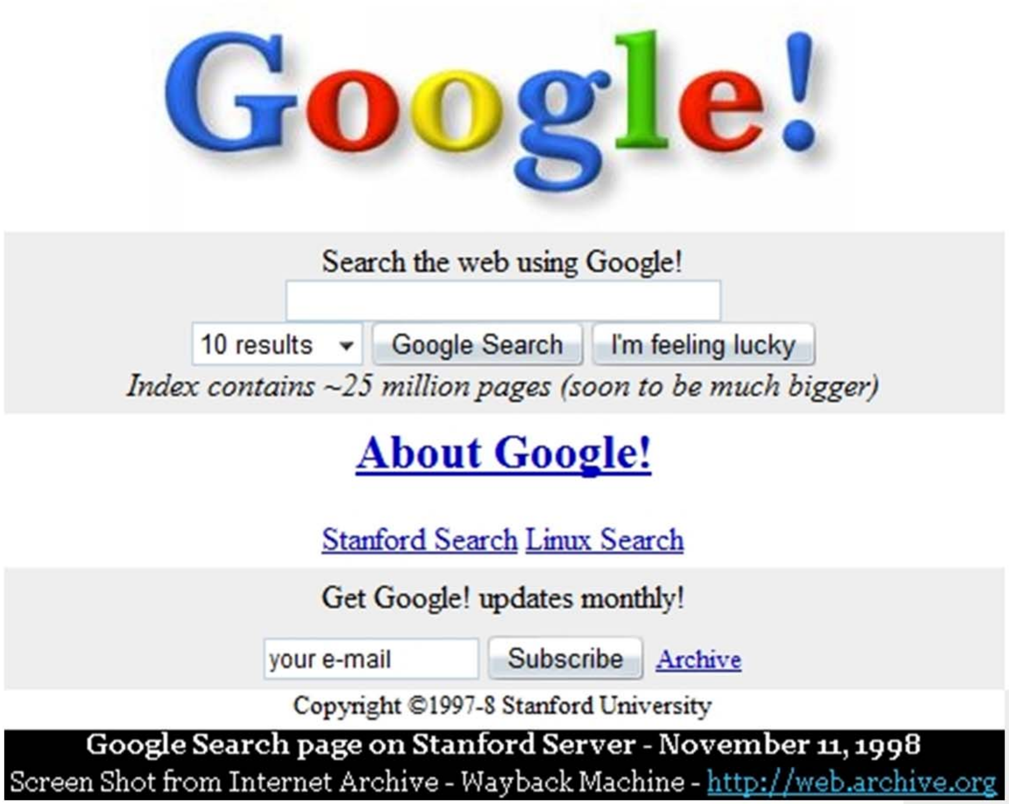
2-proc Pentium II 300mhz, 512mb, five 9gb drives
2-proc Pentium II 300mhz, 512mb, four 9gb drives
4-proc PPC 604 333mhz, 512mb, eight 9gb drives
2-proc UltraSparc II 200mhz, 256mb, three 9gb drives, six 4gb drives
Disk expansion, eight 9gb drives
Disk expansion, ten 9gb drives

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

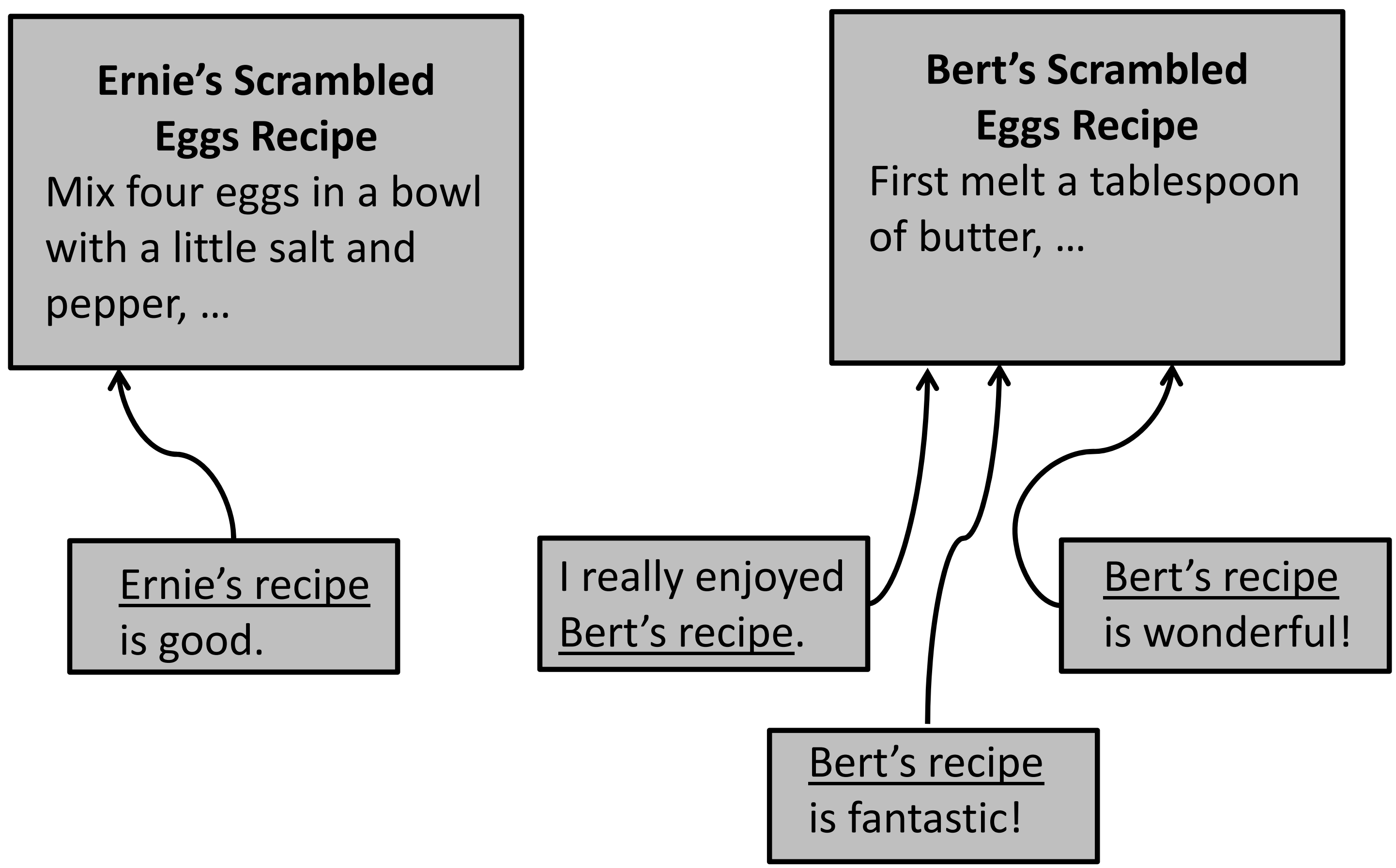
The Disk Storage



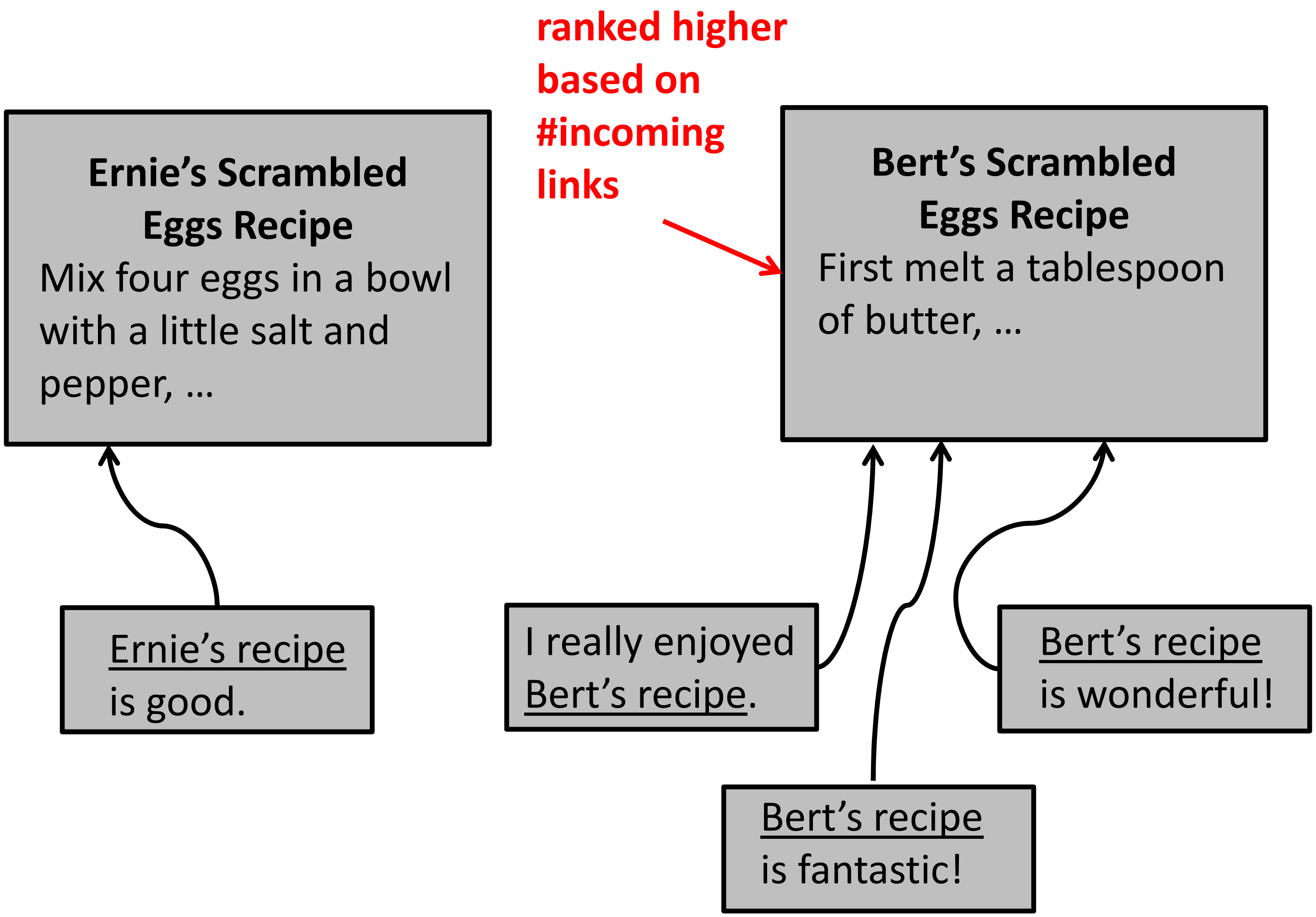
Google 1.0 (1998)



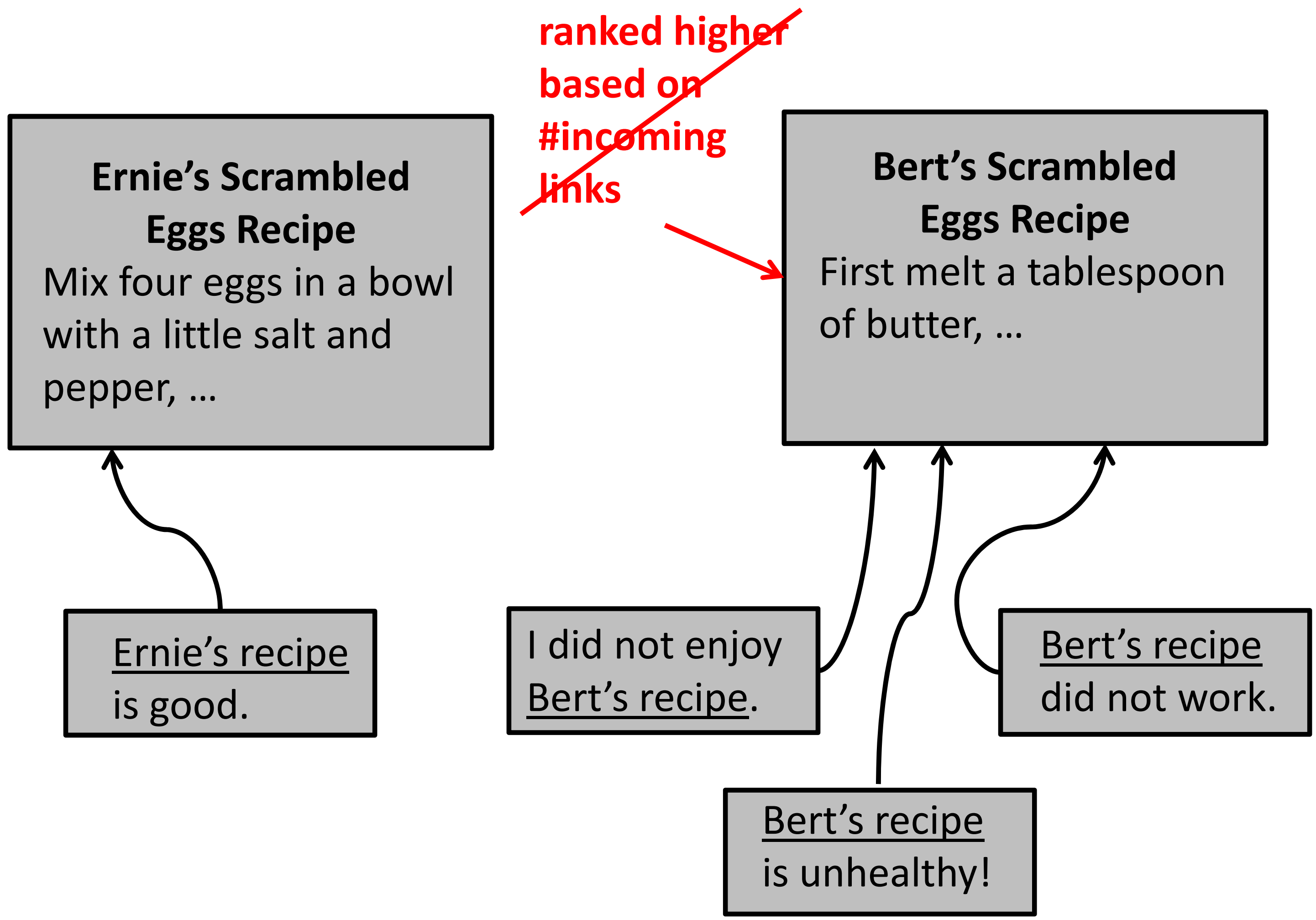
Hyperlinks


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!

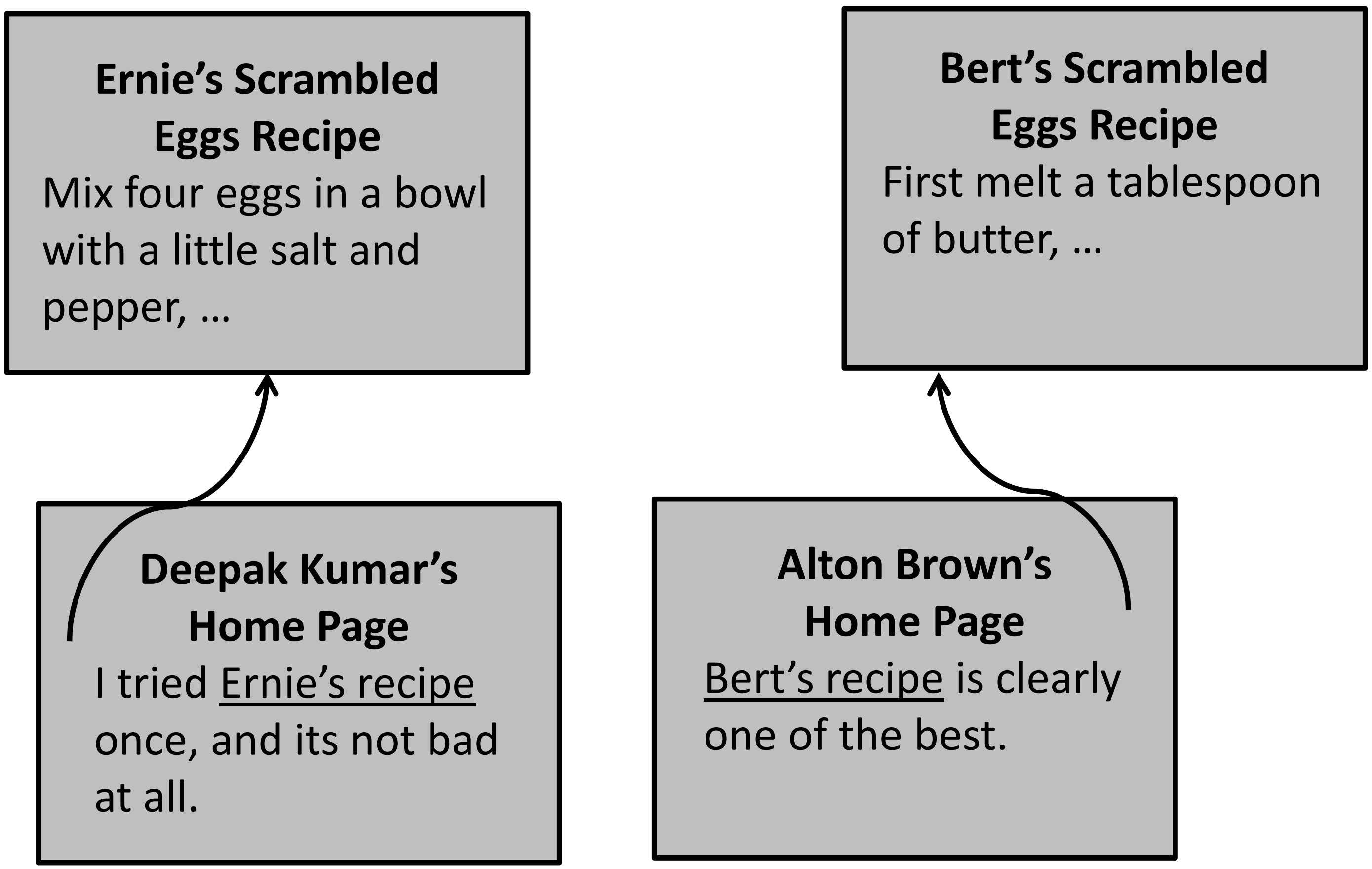
Hyperlinks: # Incoming Links



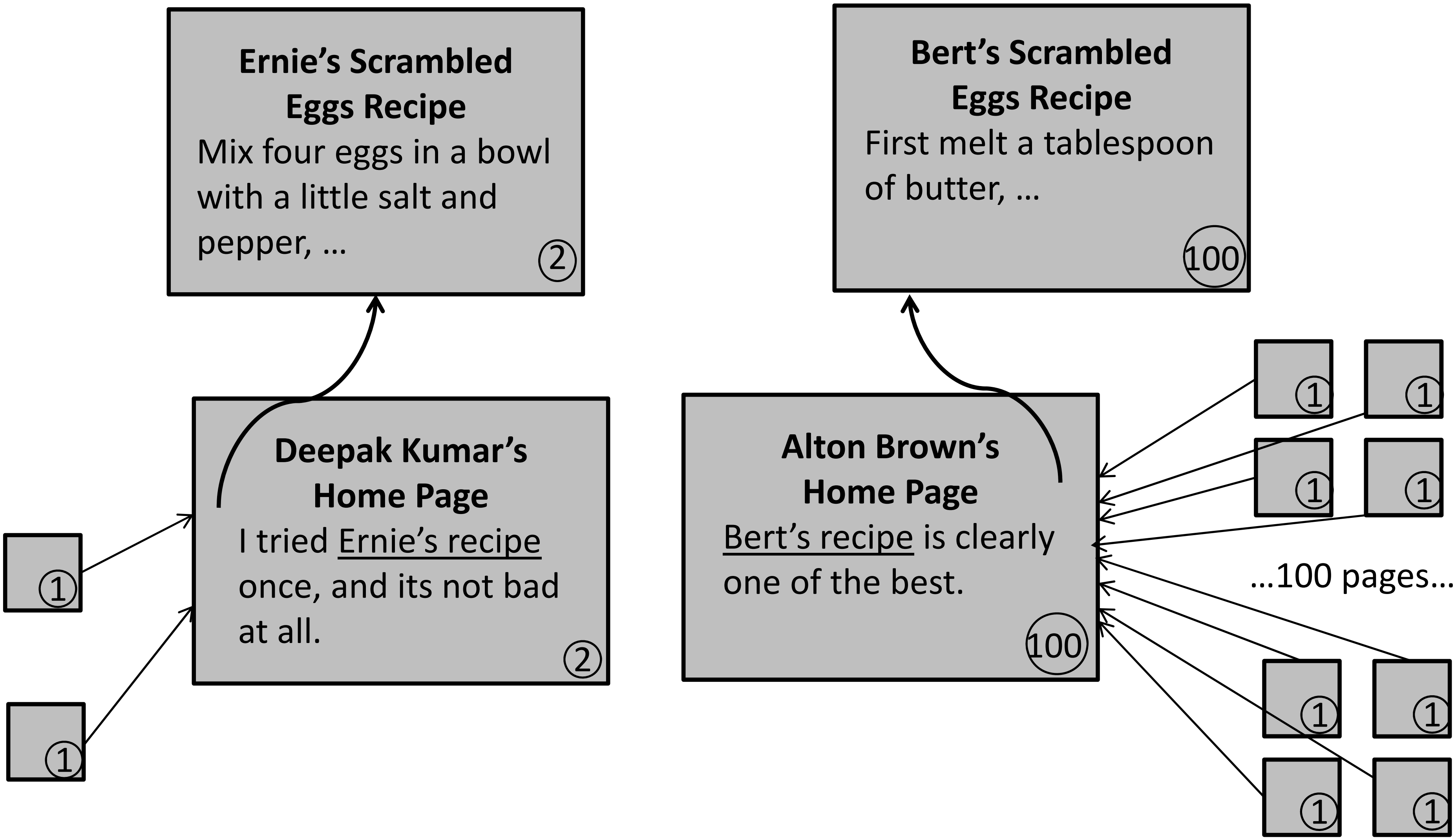
Hyperlinks: # Incoming Links



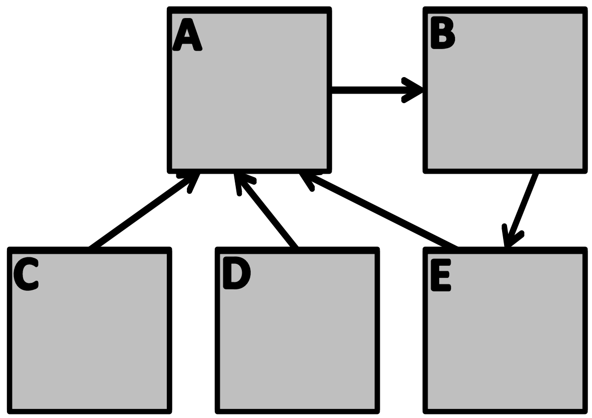
Hyperlinks: Authority



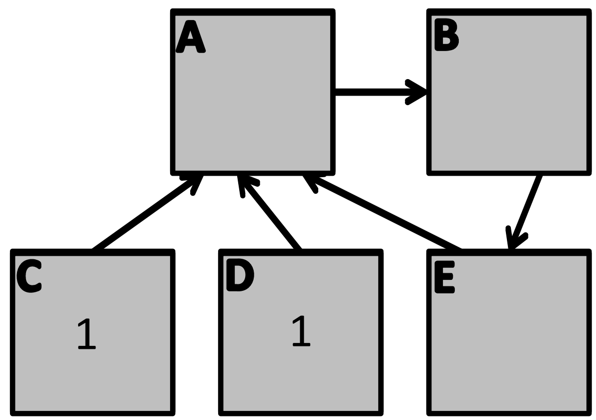
Hyperlinks: Authority



Cycles



Computing Authority Scores



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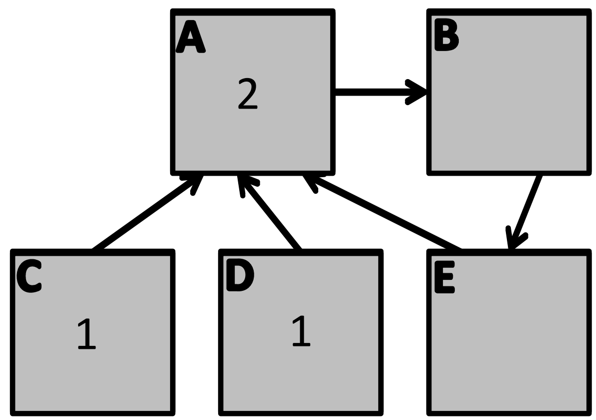

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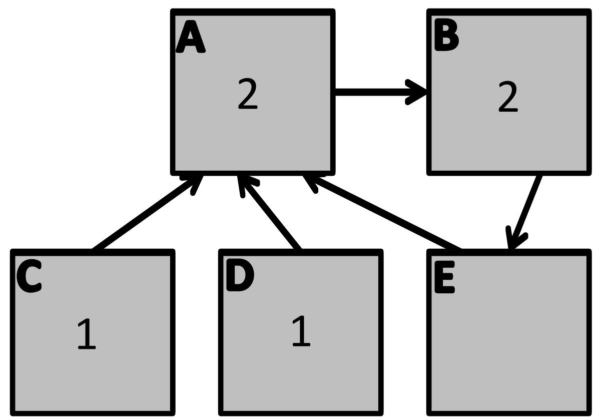

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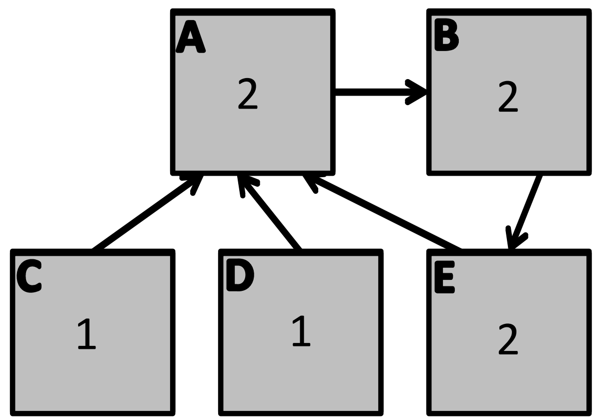

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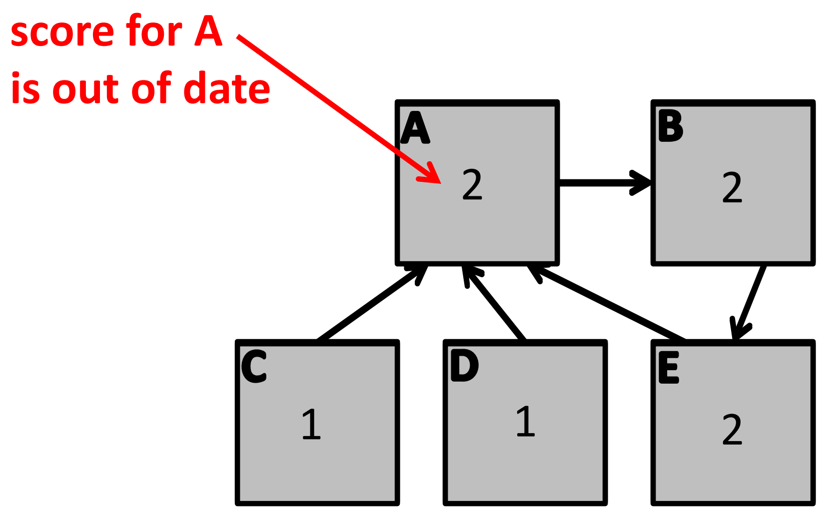
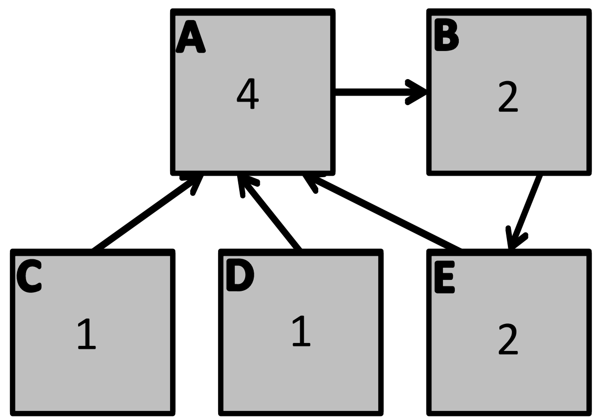


Computing Authority Scores



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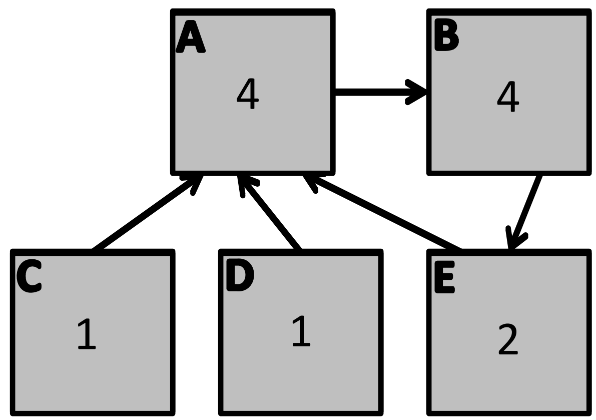
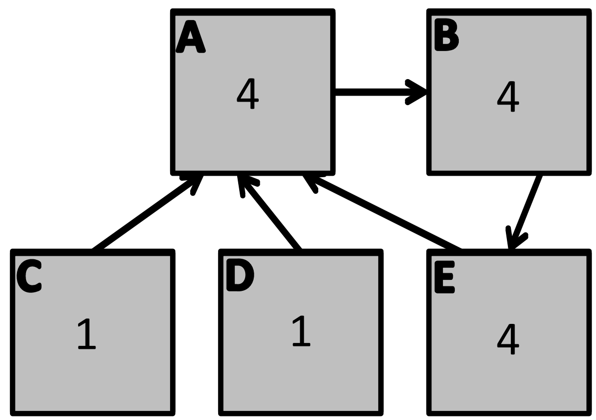
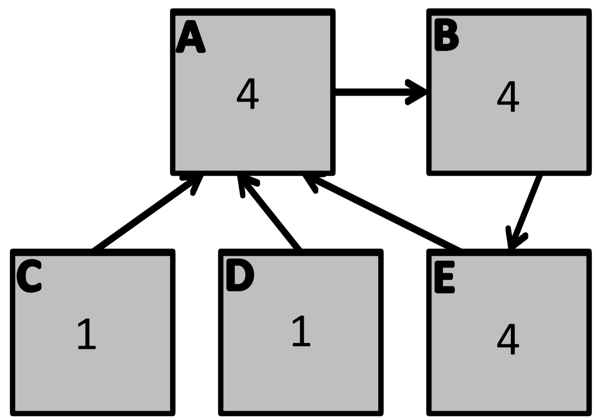


Computing Authority Scores

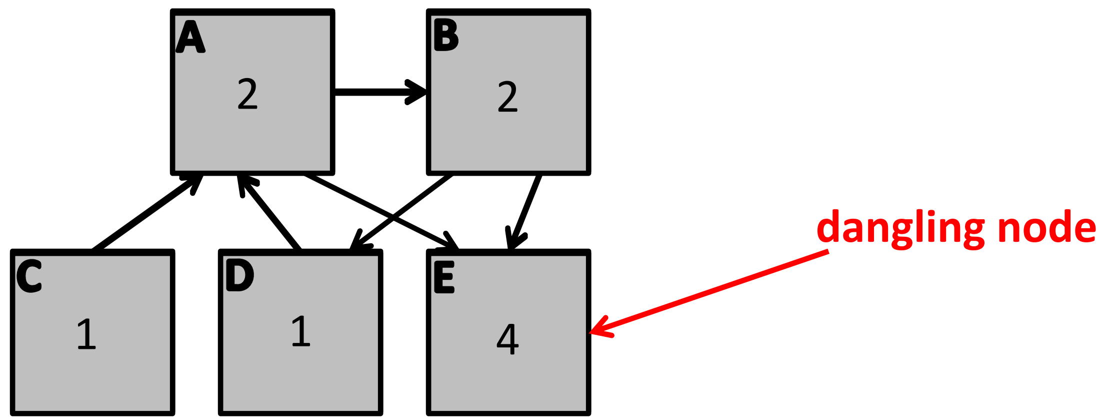


Computing Authority Scores

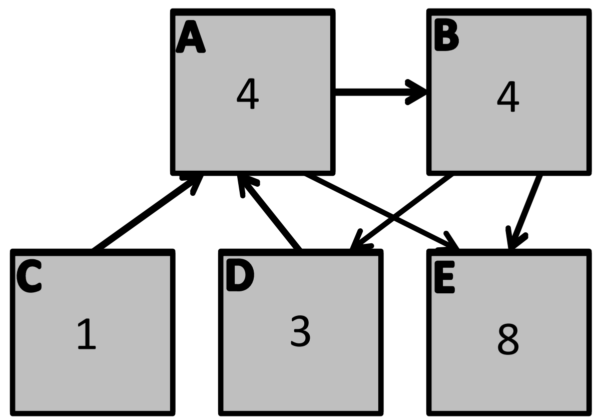


and so on…stuck in an infinite loop….

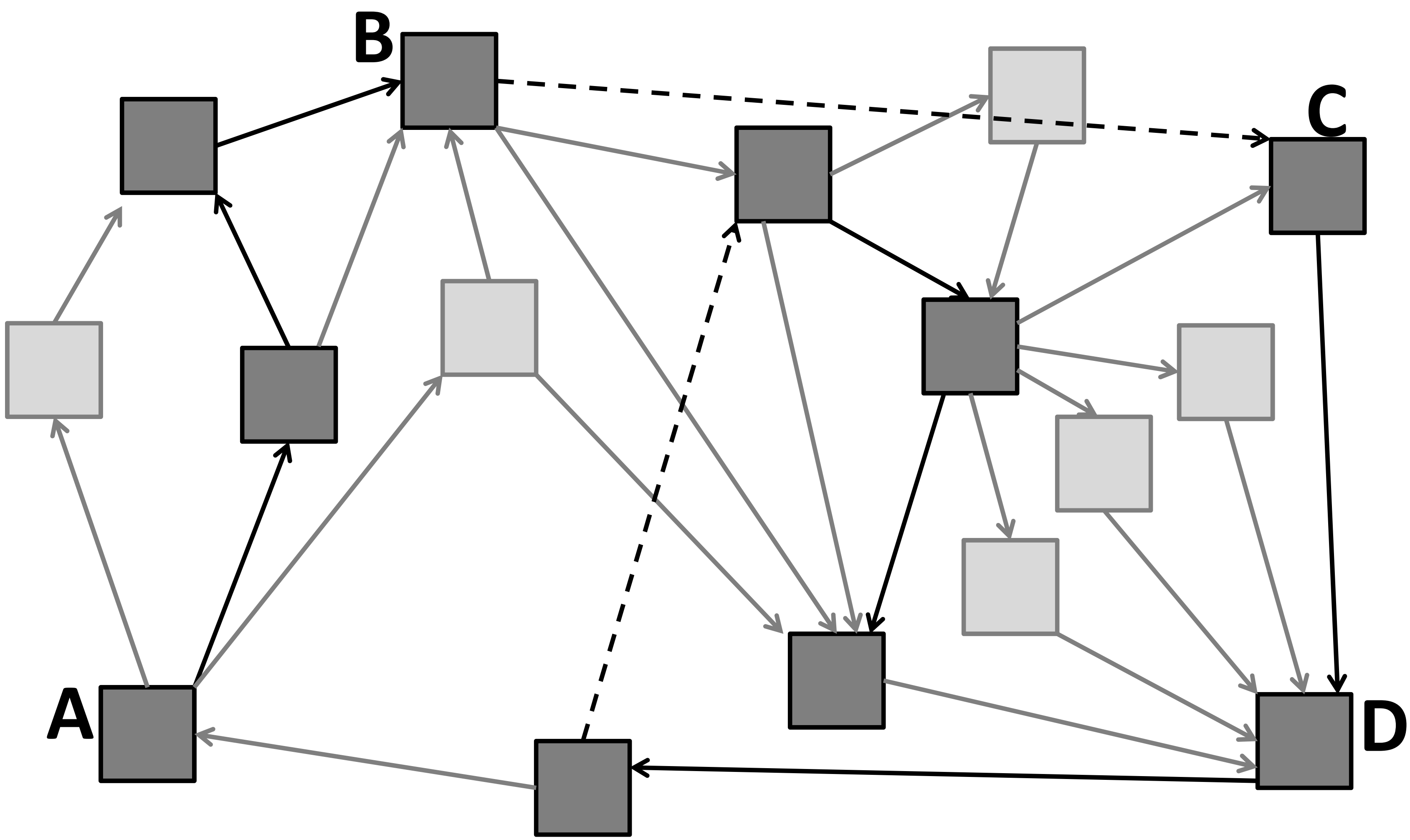
Sinks



Sinks

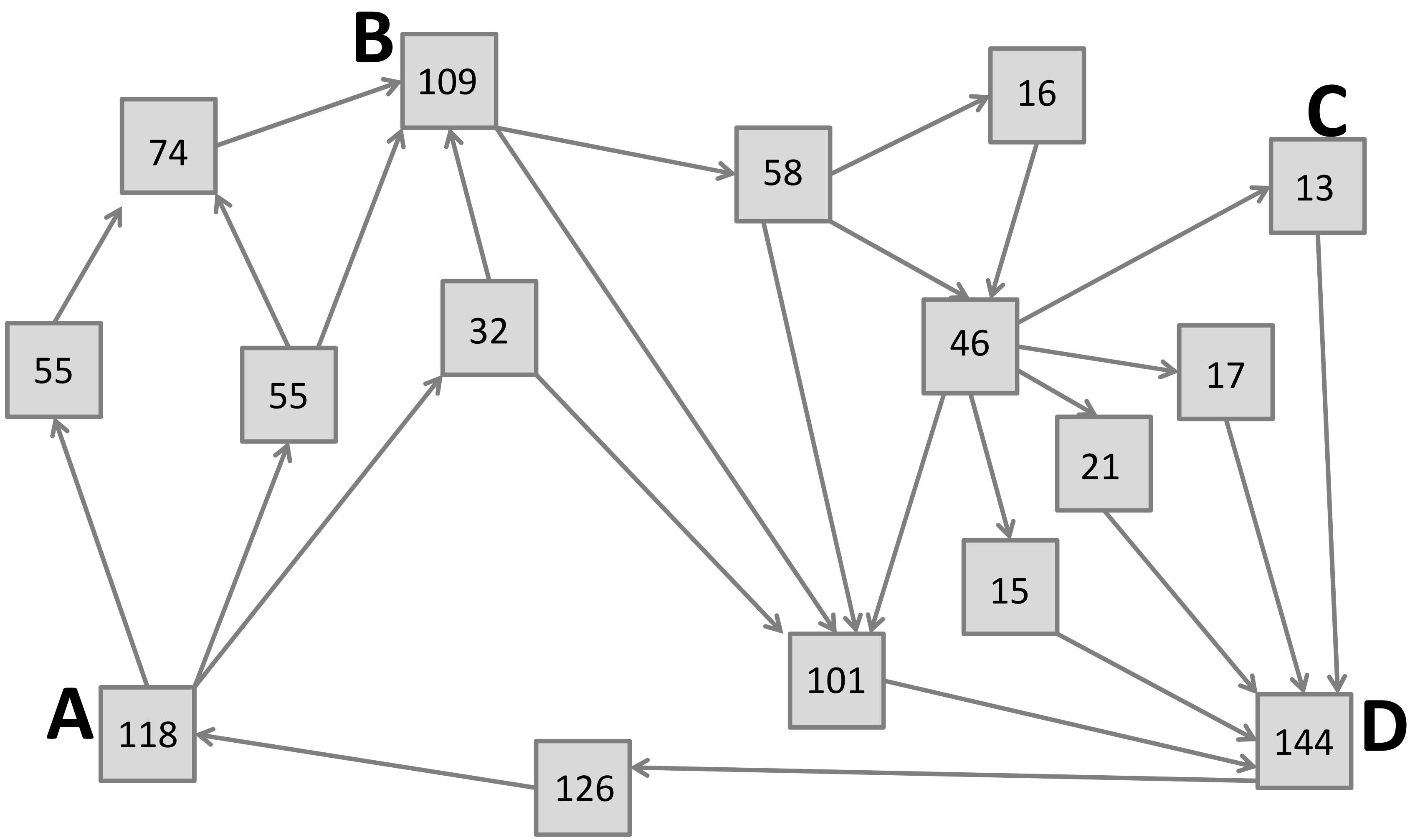


The Random Surfer



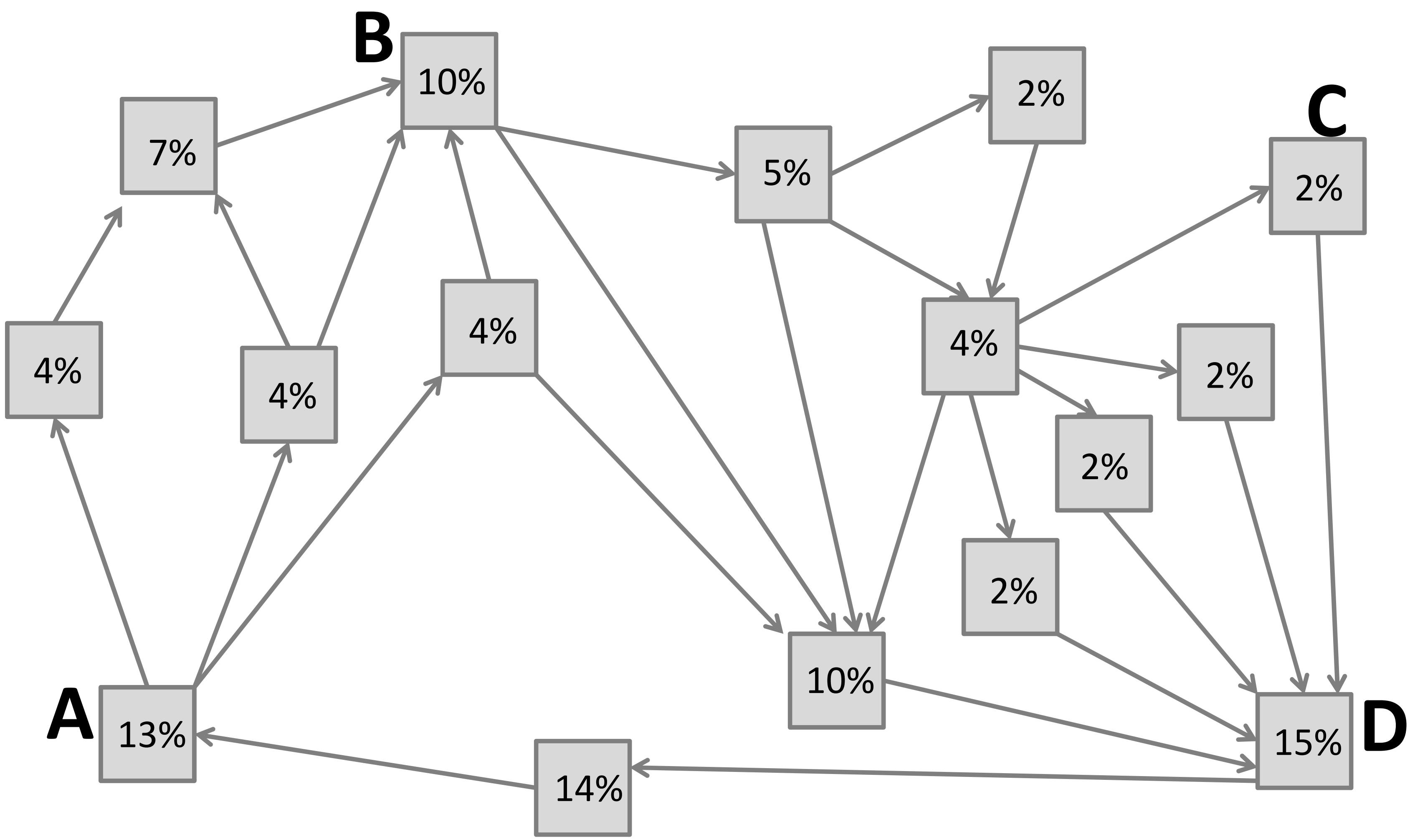
restart probability = 15%

The Random Surfer



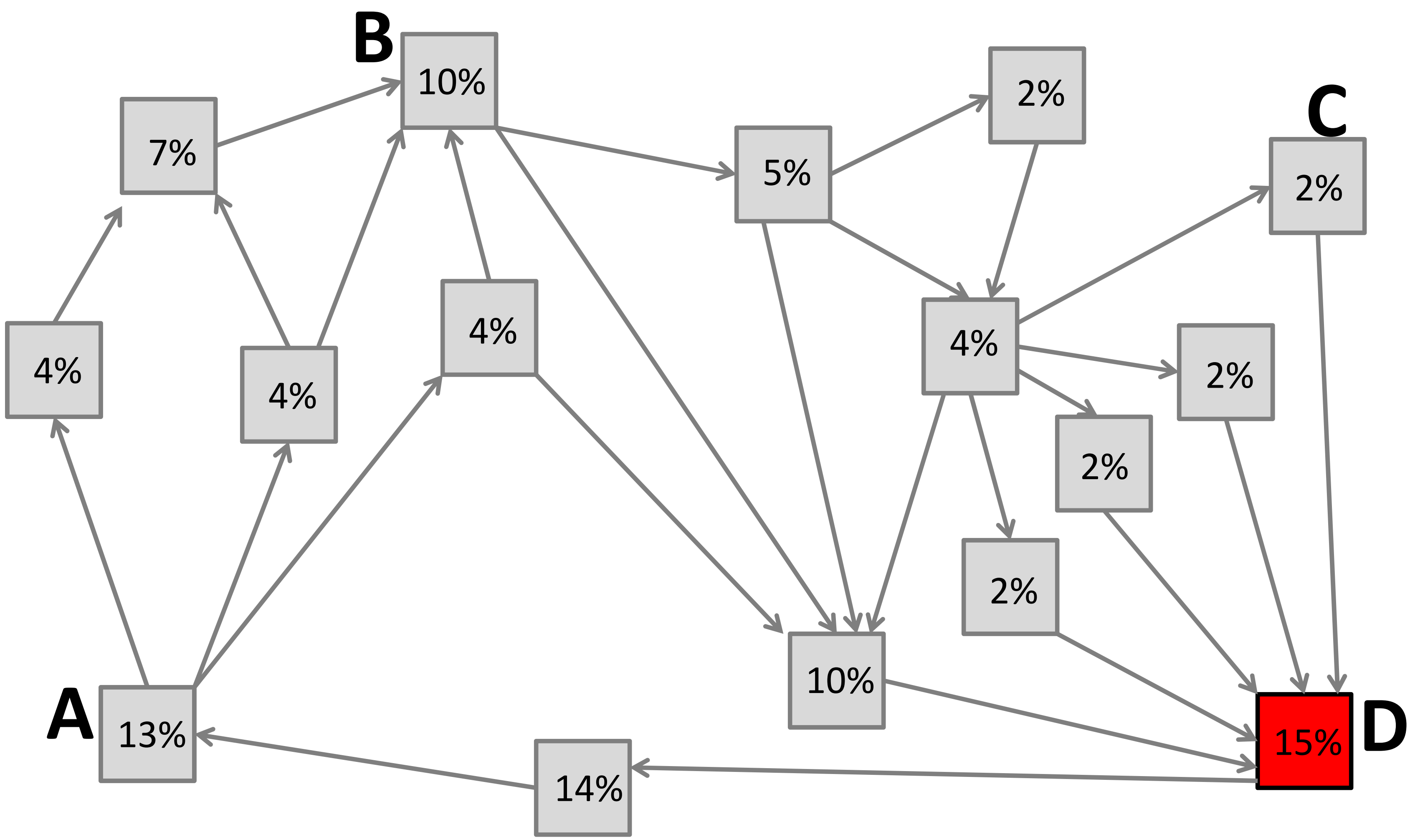
after 1000 page visits

The Random Surfer



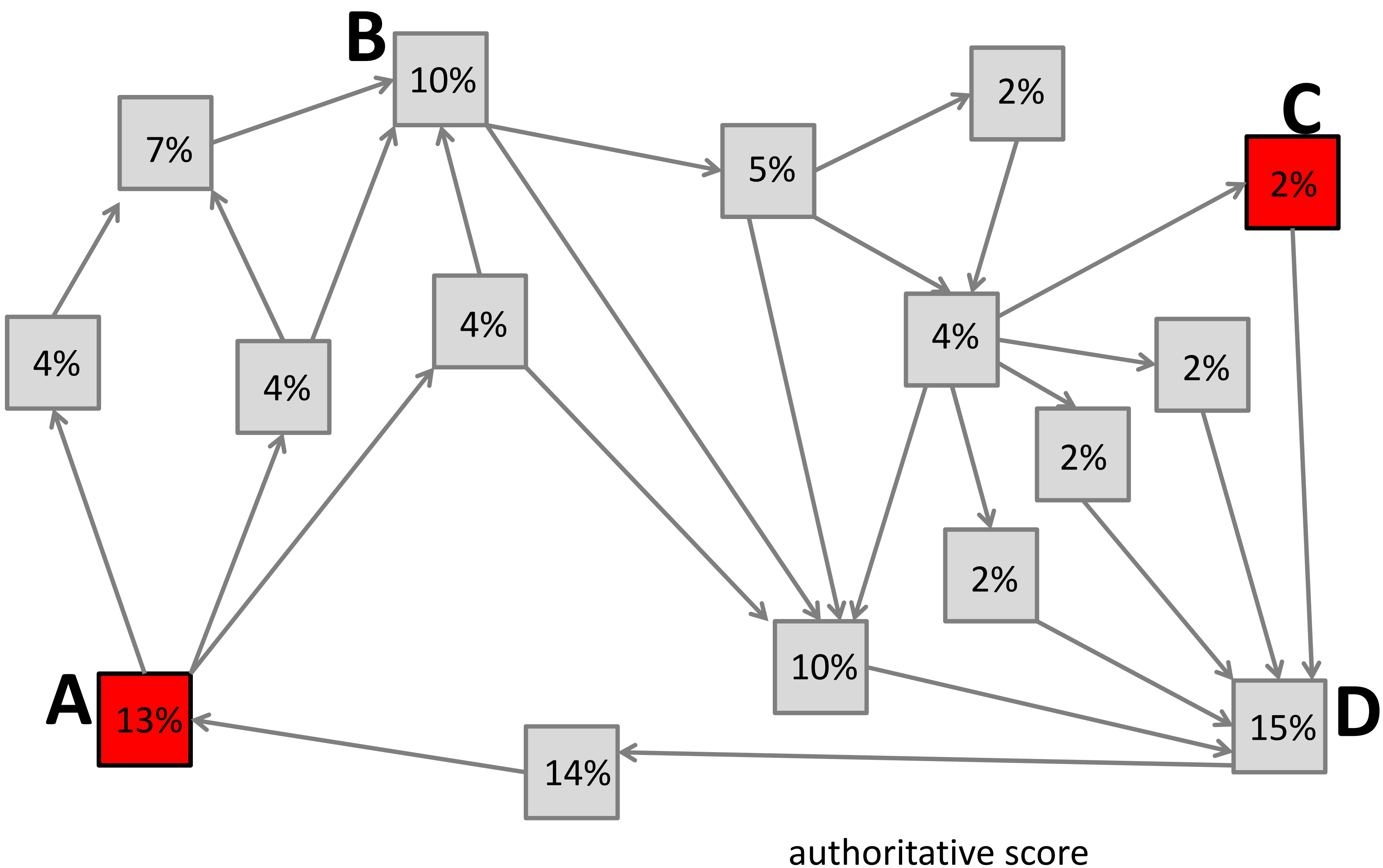
after 1 million page visits

The Random Surfer

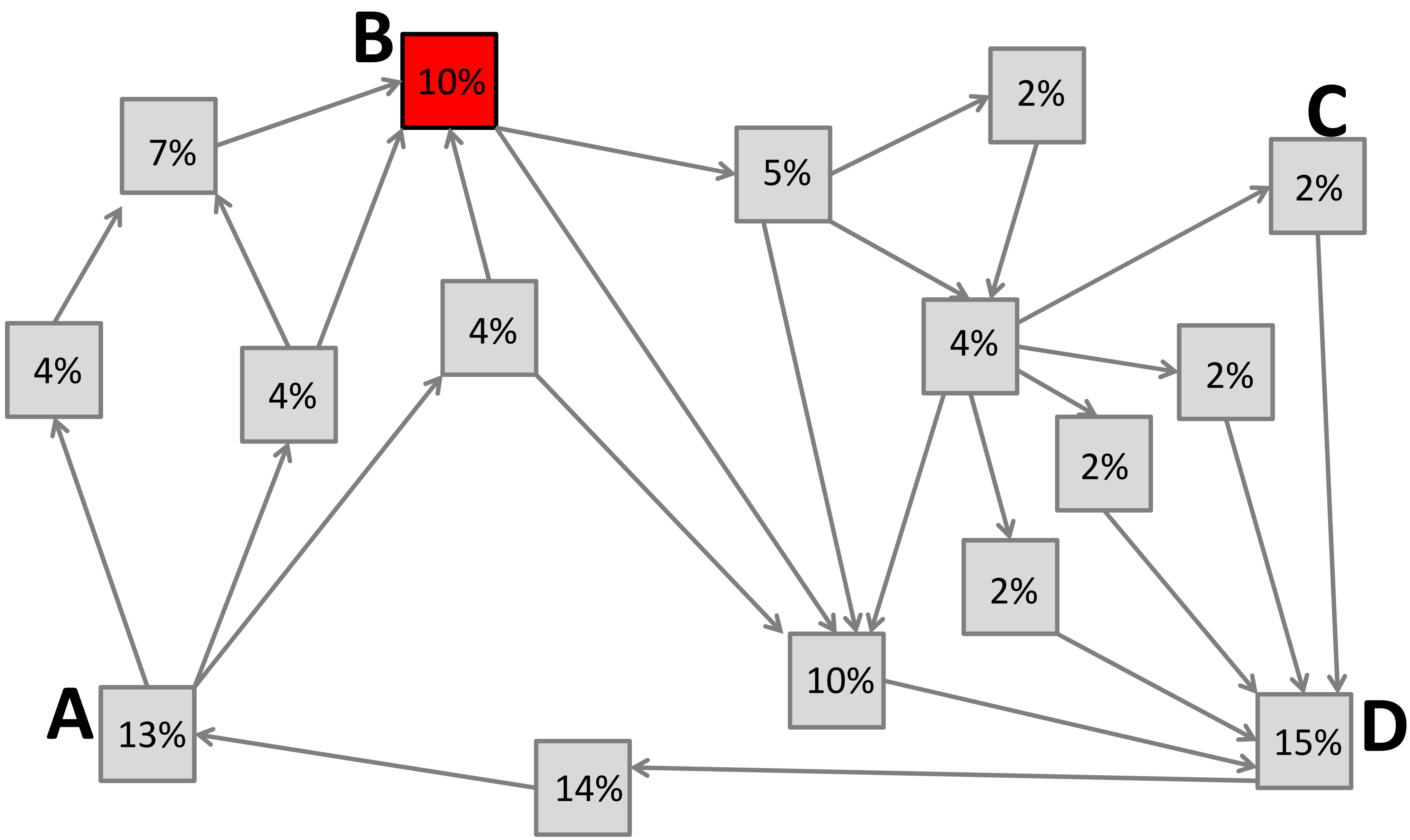


pages with many incoming links get high ranking

The Random Surfer

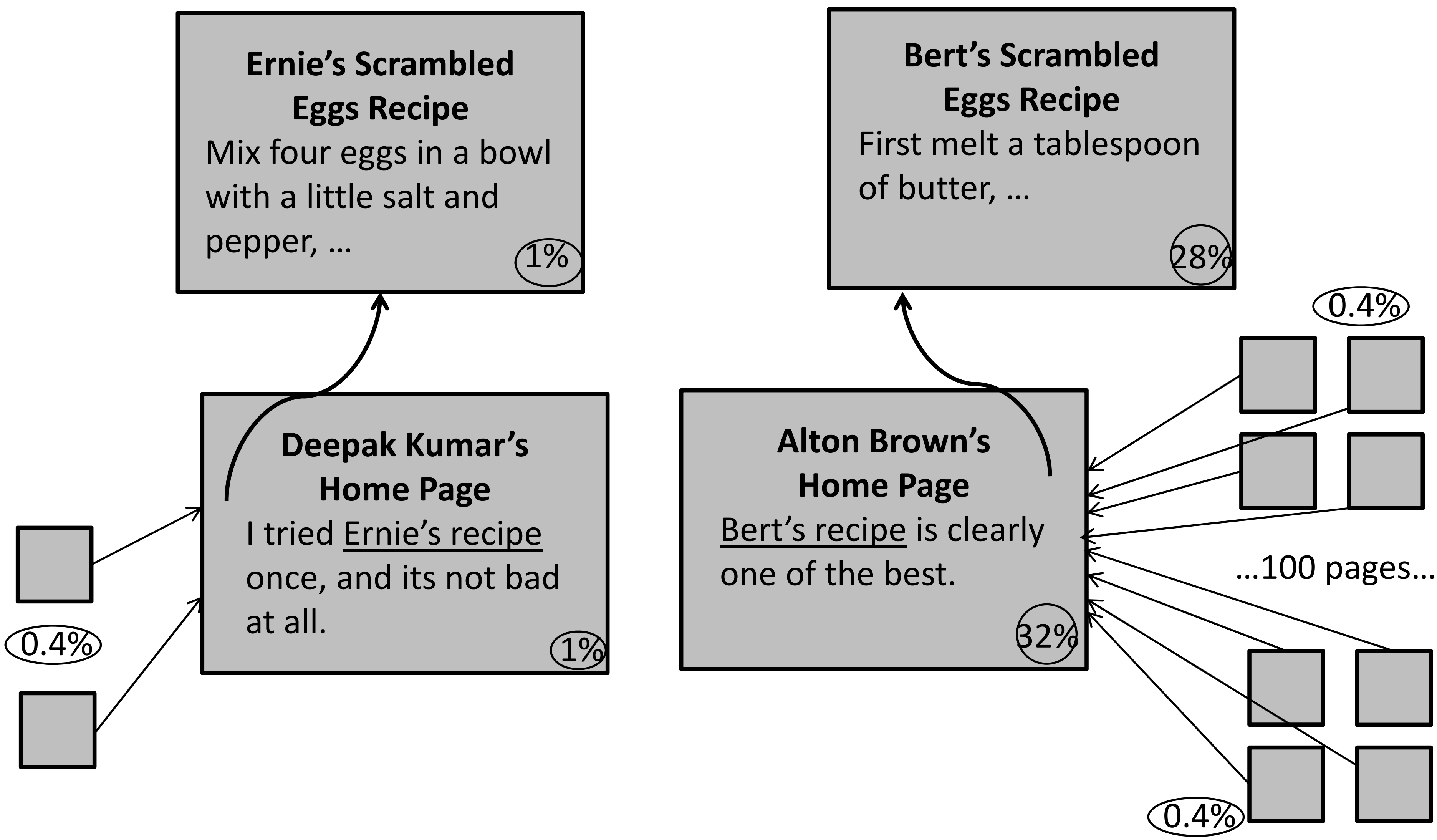


The Random Surfer

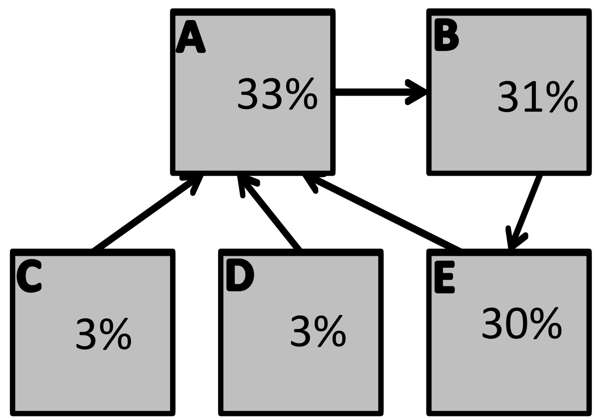


#links+authoritative score

The Random Surfer



The Random Surfer



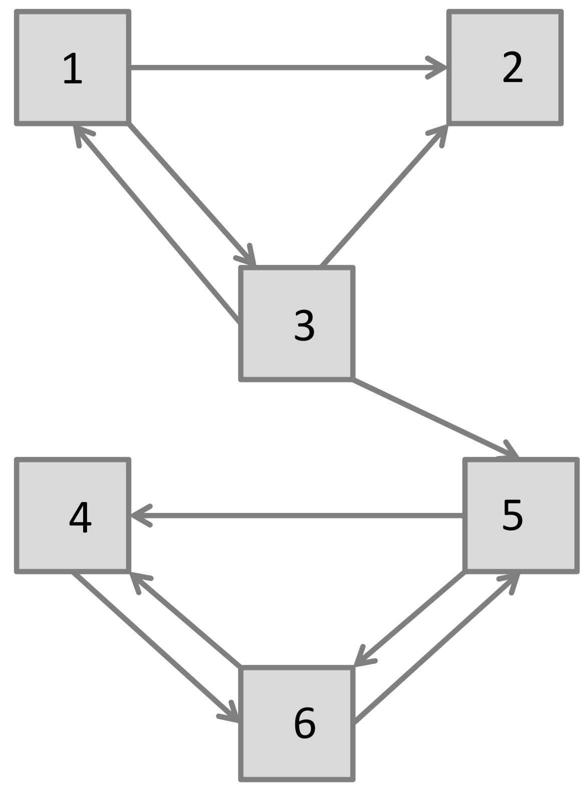
Formalizing PageRank

- 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, $r(P_i)$

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

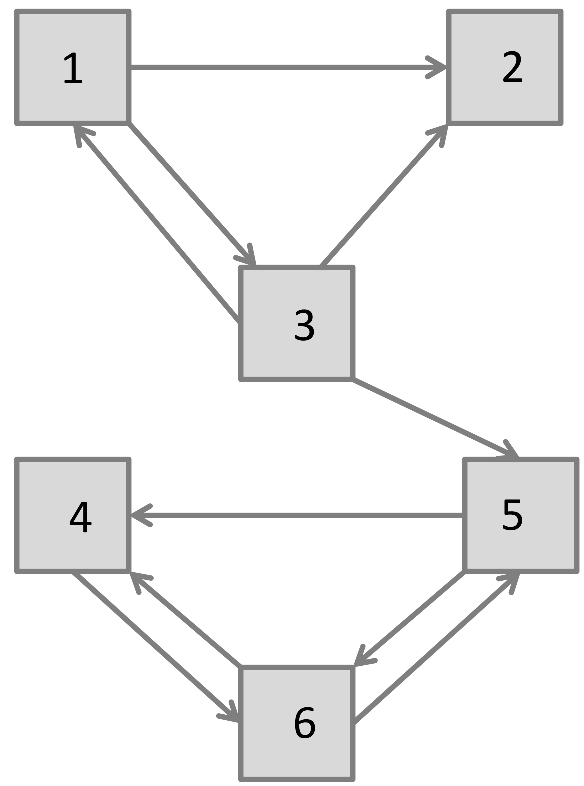
Computing PageRank

- $r(P_1) = r(P_3)$
- 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

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

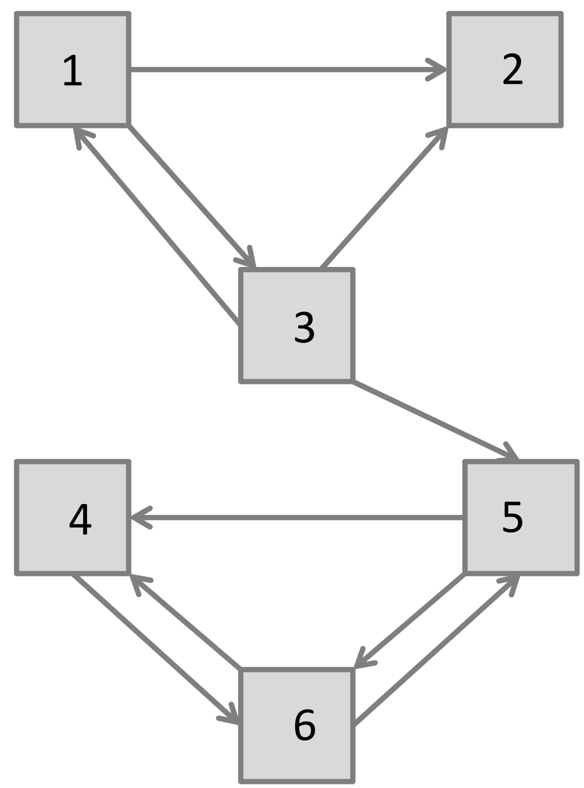


$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$

Computing PageRank

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

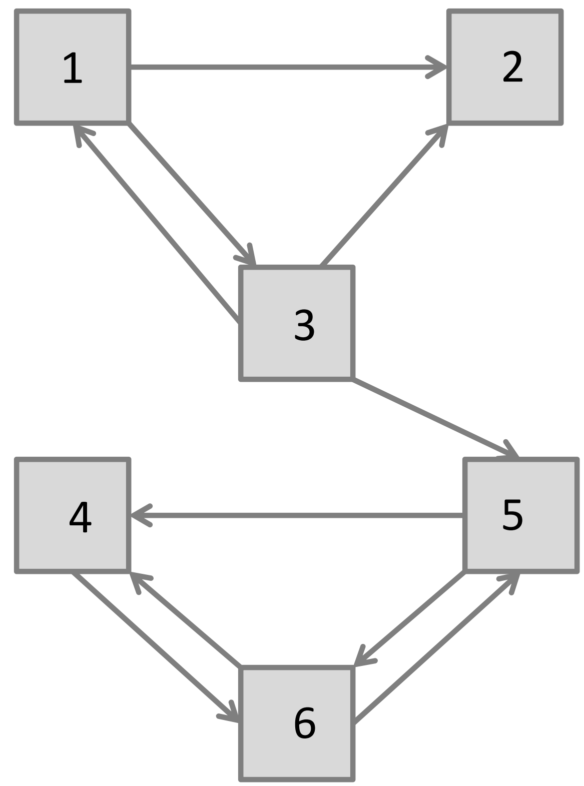
$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$



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

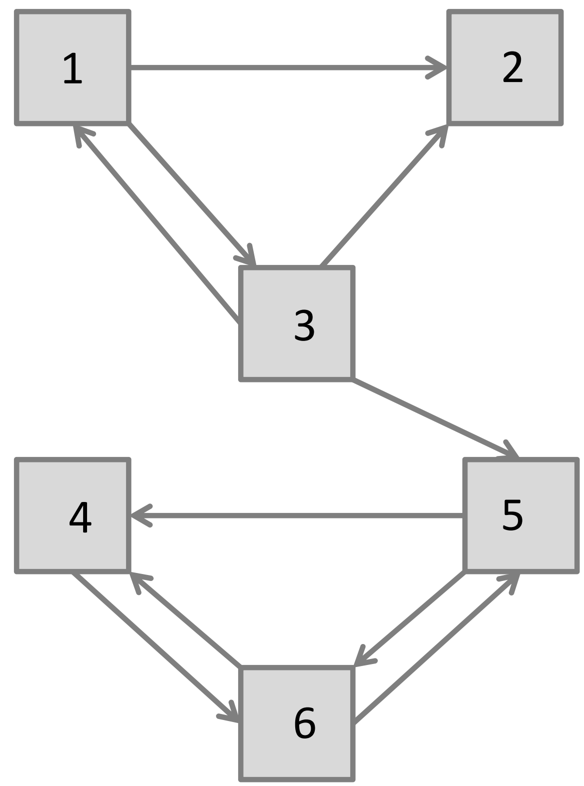
$r_2(P_3) = 1/36$ 5

$r_2(P_4) = 17/72$ 1

$r_2(P_5) = 11/72$ 3

$r_2(P_6) = 14/72$ 2

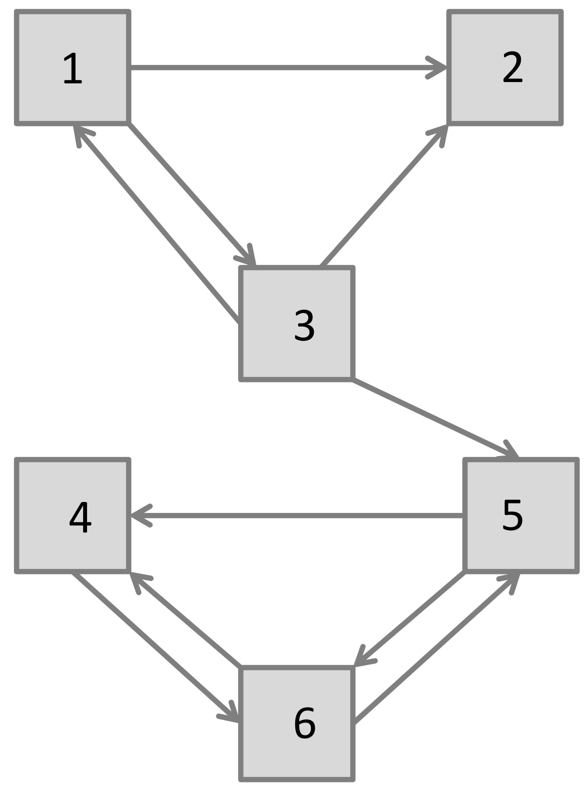
$$r_{k+1}(P_i) = \sum_{P_j \in B_{P_i}} \frac{r_k(P_j)}{|P_j|}$$



Matrix Representation

- Adjacency Matrix

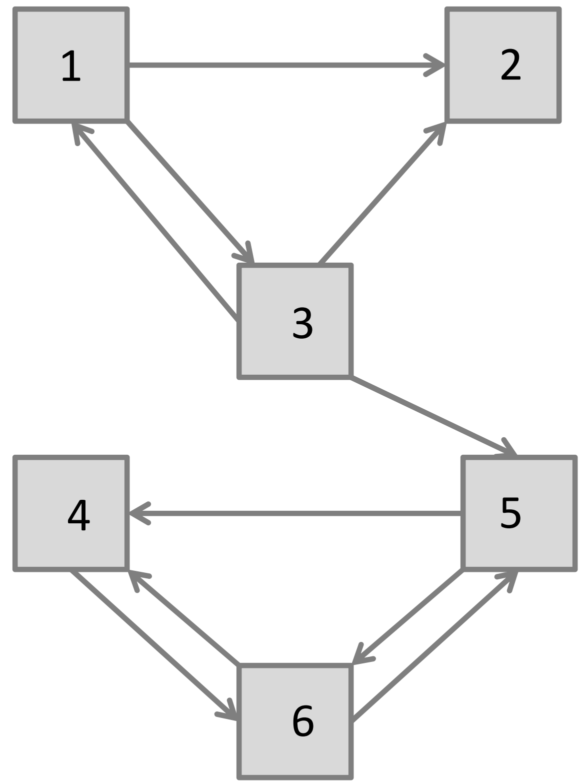
$$A = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 &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



Matrix Representation

- Hyperlink Matrix, H

	1	2	3	4	5	6
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



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

  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.