Inverted Indexing

for Text Retrieval

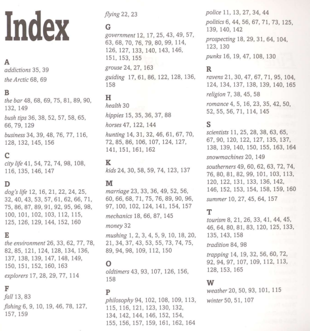
Three components of the web search problem

- Gathering web content
  - Web crawling
- Construction of the inverted index
  - Indexing
- Ranking documents given a query
  - Retrieval

- First two steps are typically carried out off-line
- The retrieval step needs to be operated in real time

What is inverted index?

- First, what is index?



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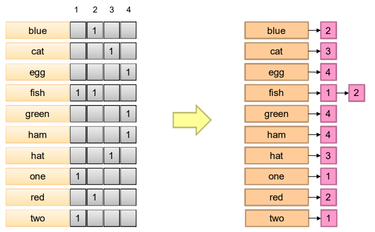
Example of inverted index

Doc 1 one fish, two fish

Doc 2 red fish, blue fish

Doc 3 cat in the hat

Doc 4 green eggs and ham

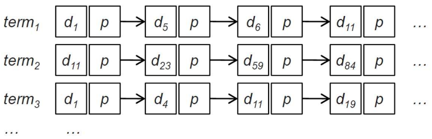


	1	2	3	4
blue		1		
cat			1	
egg				1
fish	1	1		
green				1
ham				1
hat			1	
one	1			
red		1		
two	1			

blue → 2
cat → 3
egg → 4
fish → 1 → 2
green → 4
ham → 4
hat → 3
one → 1
red → 2
two → 1

More abstract view of inverted index

terms **postings**



$term_1$: d_1 p → d_5 p → d_6 p → d_{11} p …

$term_2$: d_{11} p → d_{23} p → d_{59} p → d_{84} p …

$term_3$: d_1 p → d_4 p → d_{11} p → d_{19} p …

… …

- An inverted index consists of posting lists
- A posting list is comprised of individual postings
  - Each posting consists of a document id and a payload
    - Payload example: the occurrence frequency of the term in the corresponding document
  - Generally, postings are sorted by document id

Baseline implementation of inverted indexing

```
class Mapper
    procedure Map(docid $n$, doc $d$)
        $H \leftarrow$ new AssociativeArray
        for all term $t \in$ doc $d$ do
            $H\{t\} \leftarrow H\{t\} + 1$
        for all term $t \in H$ do
            Emit(term $t$, posting $\langle n, H\{t\}\rangle$)
```

```
class Reducer
    procedure Reduce(term $t$, postings $[\langle n_1, f_1\rangle, \langle n_2, f_2\rangle \ldots]$)
        $P \leftarrow$ new List
        for all posting $\langle a, f\rangle \in$ postings $[\langle n_1, f_1\rangle, \langle n_2, f_2\rangle \ldots]$ do
            $P$.Add($\langle a, f\rangle$)
        $P$.Sort()
        Emit(term $t$, postings $P$)
```

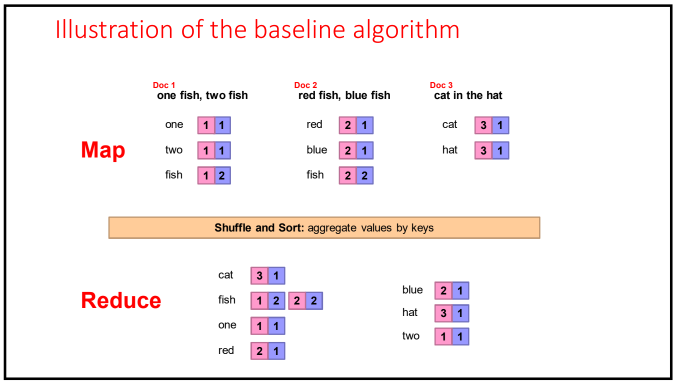


Illustration of the baseline algorithm

Map

Doc 1
one fish, two fish

one 1 1
two 1 1
fish 1 2

Doc 2
red fish, blue fish

red 2 1
blue 2 1
fish 2 2

Doc 3
cat in the hat

cat 3 1
hat 3 1

Shuffle and Sort: aggregate values by keys

Reduce

cat 3 1
fish 1 2 2 2
one 1 1
red 2 1

blue 2 1
hat 3 1
two 1 1

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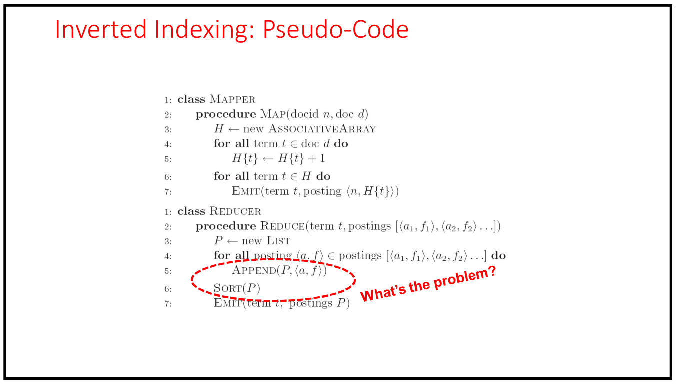

Inverted Indexing: Pseudo-Code

```
class $\textsc{Mapper}$
    procedure $\textsc{Map}$(docid $n$, doc $d$)
        $H \leftarrow$ new $\textsc{AssociativeArray}$
        for all term $t \in$ doc $d$ do
            $H\{t\} \leftarrow H\{t\} + 1$
        for all term $t \in H$ do
            $\textsc{Emit}$(term $t$, posting $\langle n, H\{t\}\rangle$)

class $\textsc{Reducer}$
    procedure $\textsc{Reduce}$(term $t$, postings $[\langle a_1, f_1\rangle, \langle a_2, f_2\rangle \ldots]$)
        $P \leftarrow$ new $\textsc{List}$
        for all posting $\langle a, f\rangle \in$ postings $[\langle a_1, f_1\rangle, \langle a_2, f_2\rangle \ldots]$ do
            $\textsc{Append}(P, \langle a, f\rangle)$
        $\textsc{Sort}(P)$
        $\textsc{Emit}$(term $t$, postings $P$)
```

What's the problem?

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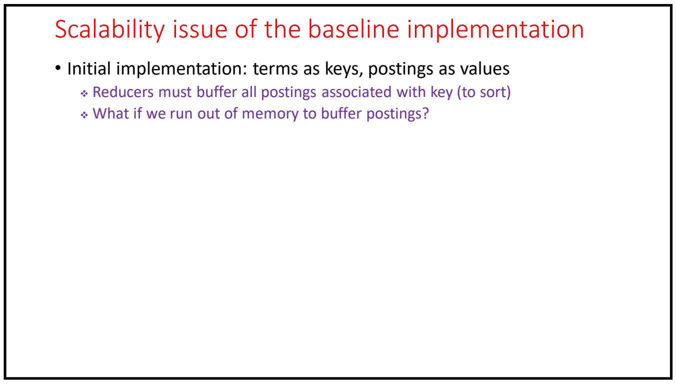

Scalability issue of the baseline implementation

- Initial implementation: terms as keys, postings as values
  - Reducers must buffer all postings associated with key (to sort)
  - What if we run out of memory to buffer postings?

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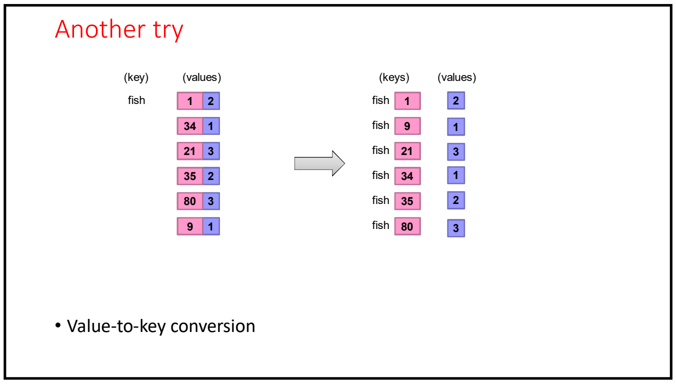

Another try

(key)	(values)
fish	1 2
	34 1
	21 3
	35 2
	80 3
	9 1

(keys)		(values)
fish	1	2
fish	9	1
fish	21	3
fish	34	1
fish	35	2
fish	80	3

- Value-to-key conversion

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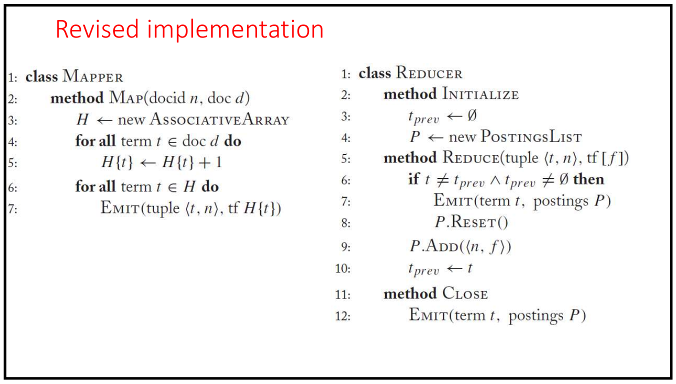

Revised implementation

```
class $\textsc{Mapper}$
    method $\textsc{Map}$(docid $n$, doc $d$)
        $H \leftarrow$ new $\textsc{AssociativeArray}$
        for all term $t \in$ doc $d$ do
            $H\{t\} \leftarrow H\{t\} + 1$
        for all term $t \in H$ do
            $\textsc{Emit}$(tuple $\langle t, n\rangle$, tf $H\{t\}$)
```

```
class $\textsc{Reducer}$
    method $\textsc{Initialize}$
        $t_{prev} \leftarrow \emptyset$
        $P \leftarrow$ new $\textsc{PostingsList}$
    method $\textsc{Reduce}$(tuple $\langle t, n\rangle$, tf $[f]$)
        if $t \neq t_{prev} \wedge t_{prev} \neq \emptyset$ then
            $\textsc{Emit}$(term $t$, postings $P$)
            $P.\textsc{Reset}()$
        $P.\textsc{Add}(\langle n, f\rangle)$
        $t_{prev} \leftarrow t$
    method $\textsc{Close}$
        $\textsc{Emit}$(term $t$, postings $P$)
```

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