Blame Trees

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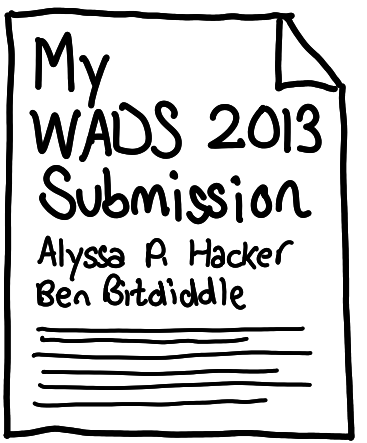
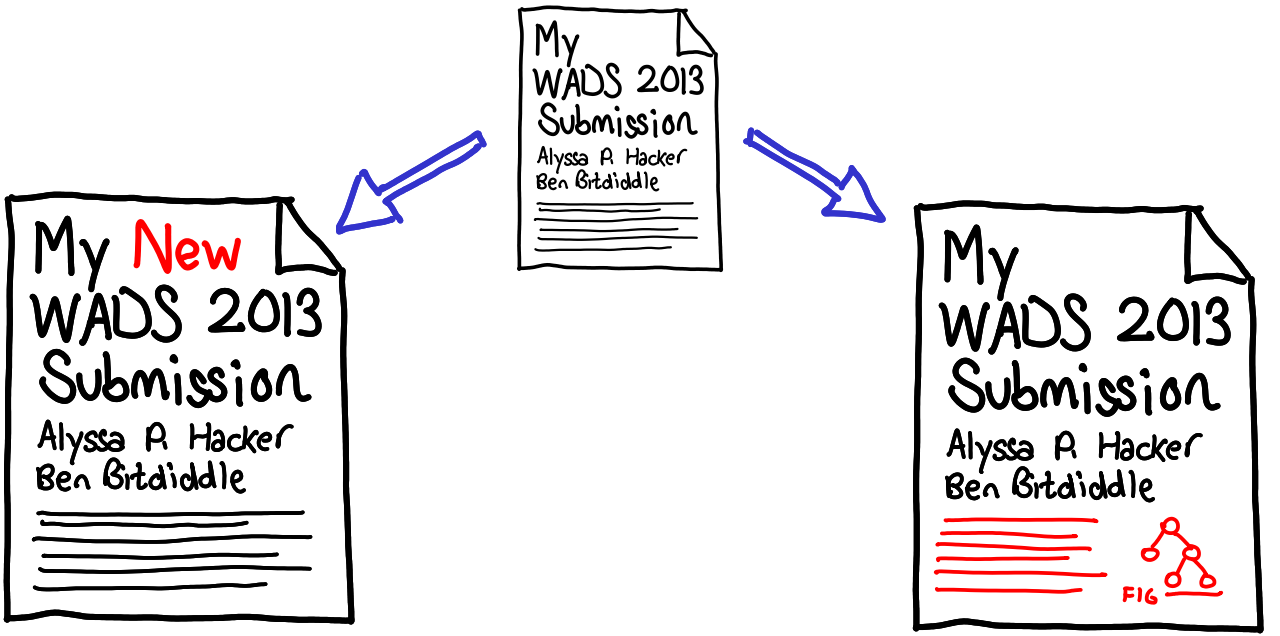
WADS 2013

Document Merge
in Version Control Systems



Document Merge
in Version Control Systems



Document Merge
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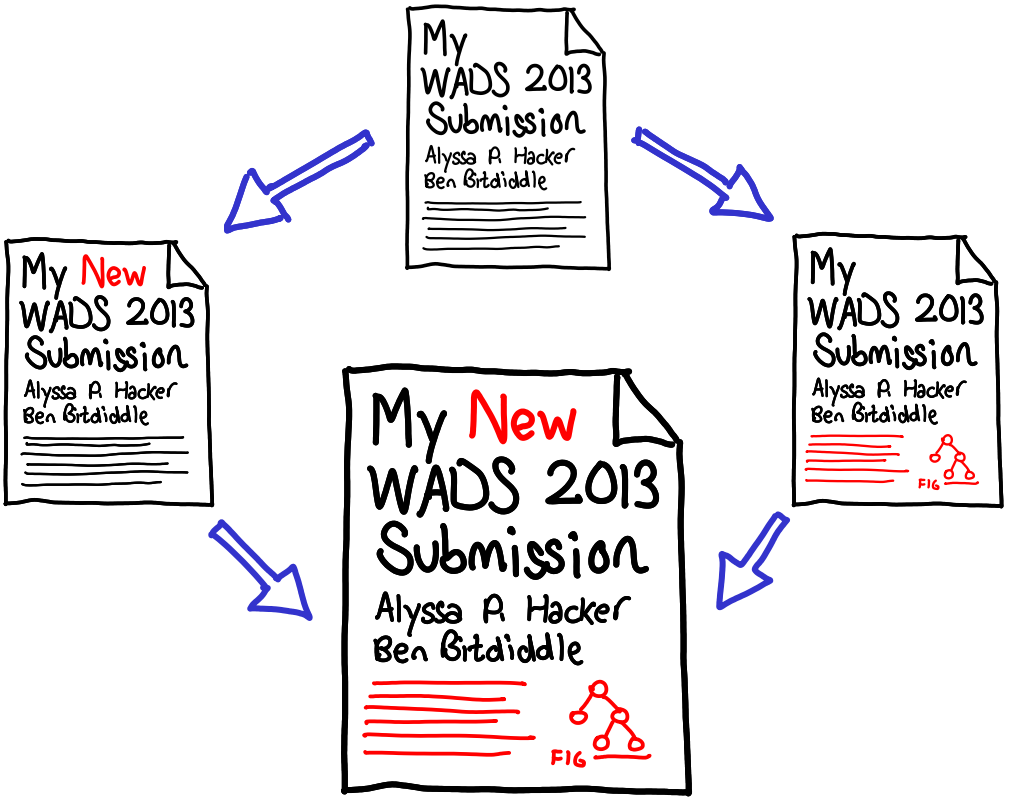

Document Merge
in Version Control Systems

Blame trees are a functional* data structure which can be merged efficiently.

* implies confluently persistent

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Document Merge
in Version Control Systems

Blame trees are a functional* data structure which can be merged efficiently.

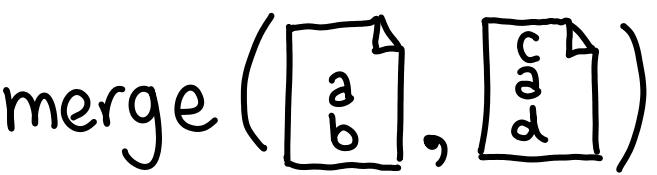
?

Git, Mercurial, SVN, Perforce, Darcs, Bazaar, CVS, RCS, Bitkeeper, Monotone, Fossil, Veracity ...

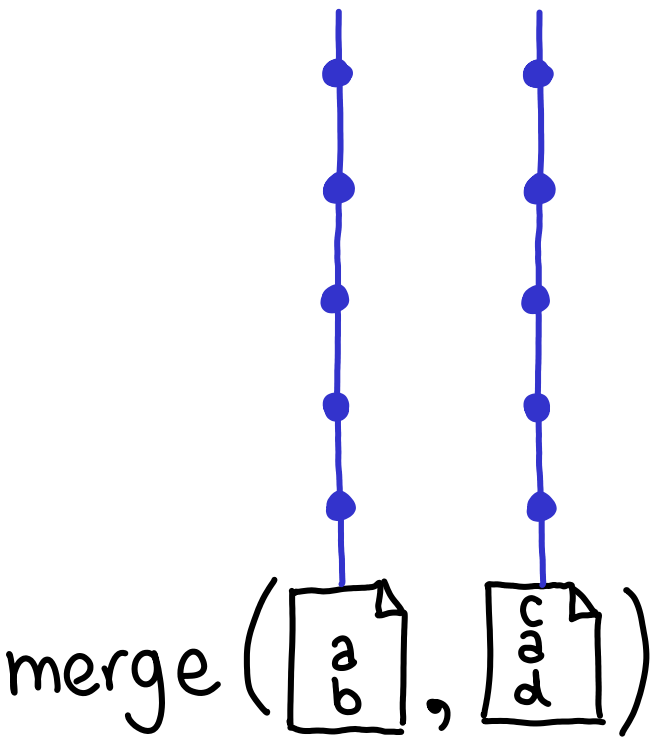
* implies confluently persistent

Let's look at this from an algorithms & data structures perspective

three-way recursive merge [Git]



three-way recursive merge [Git]



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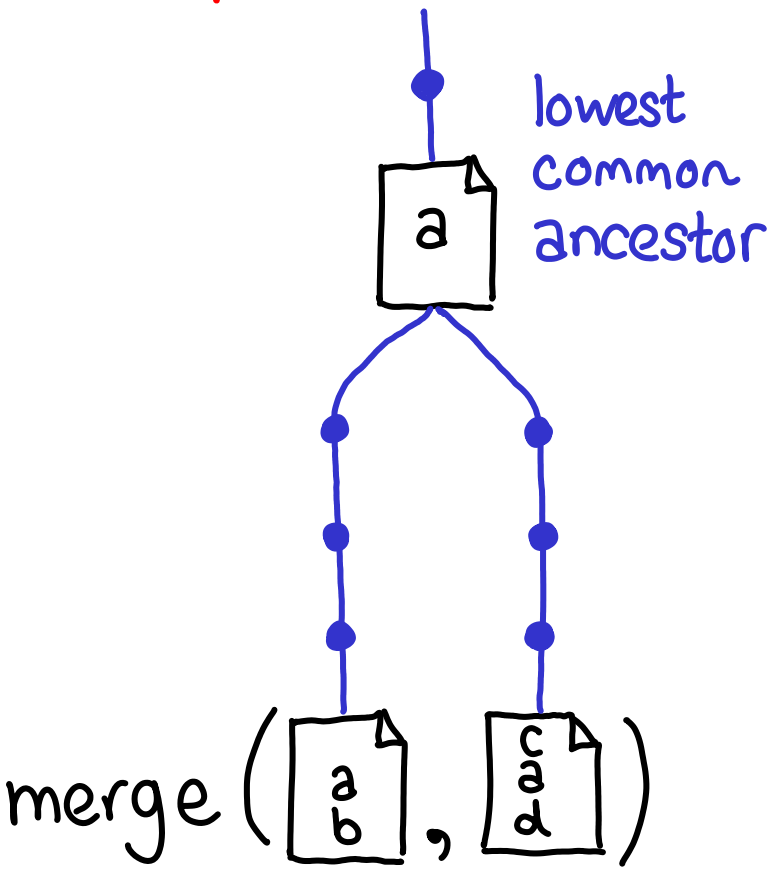

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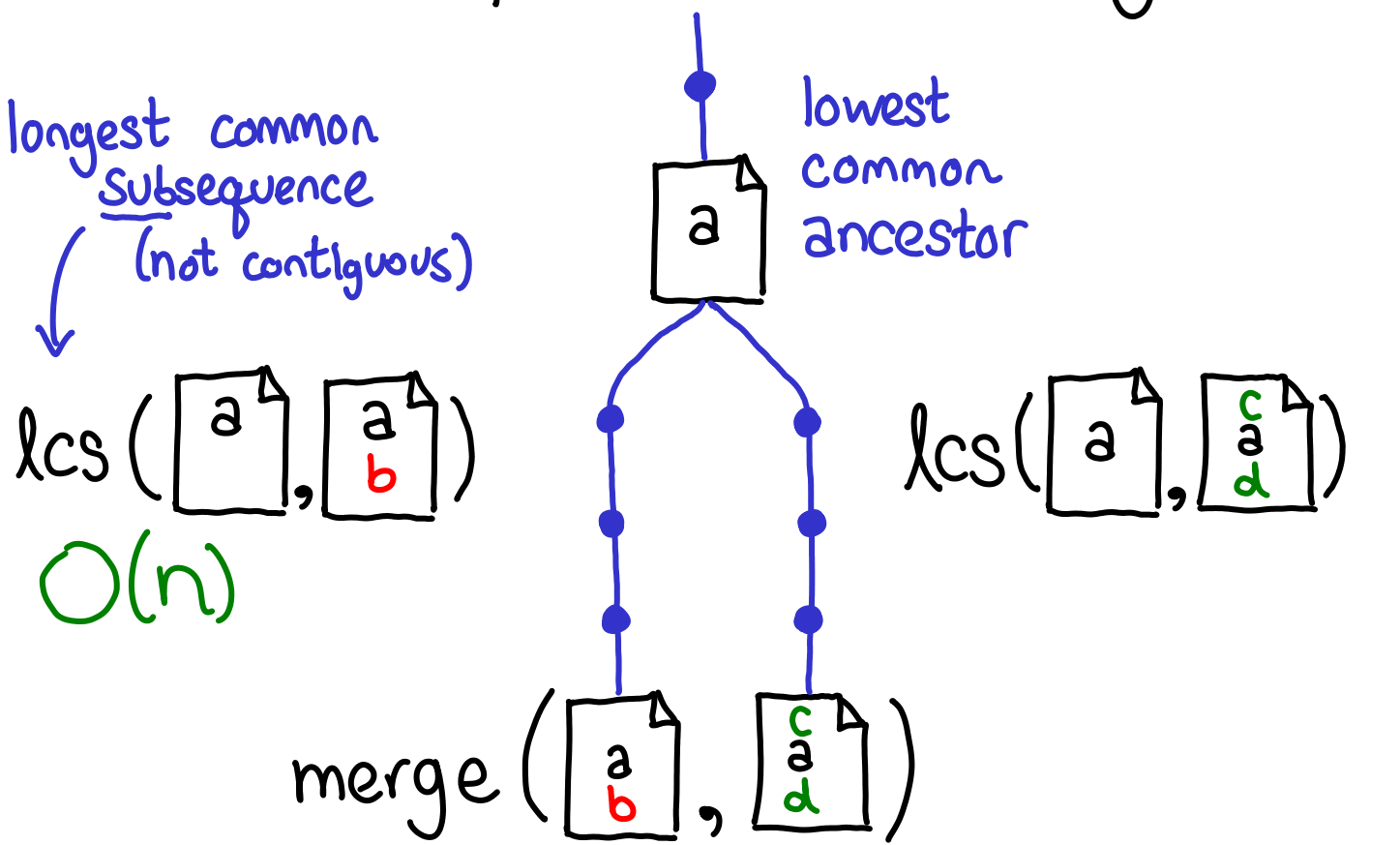

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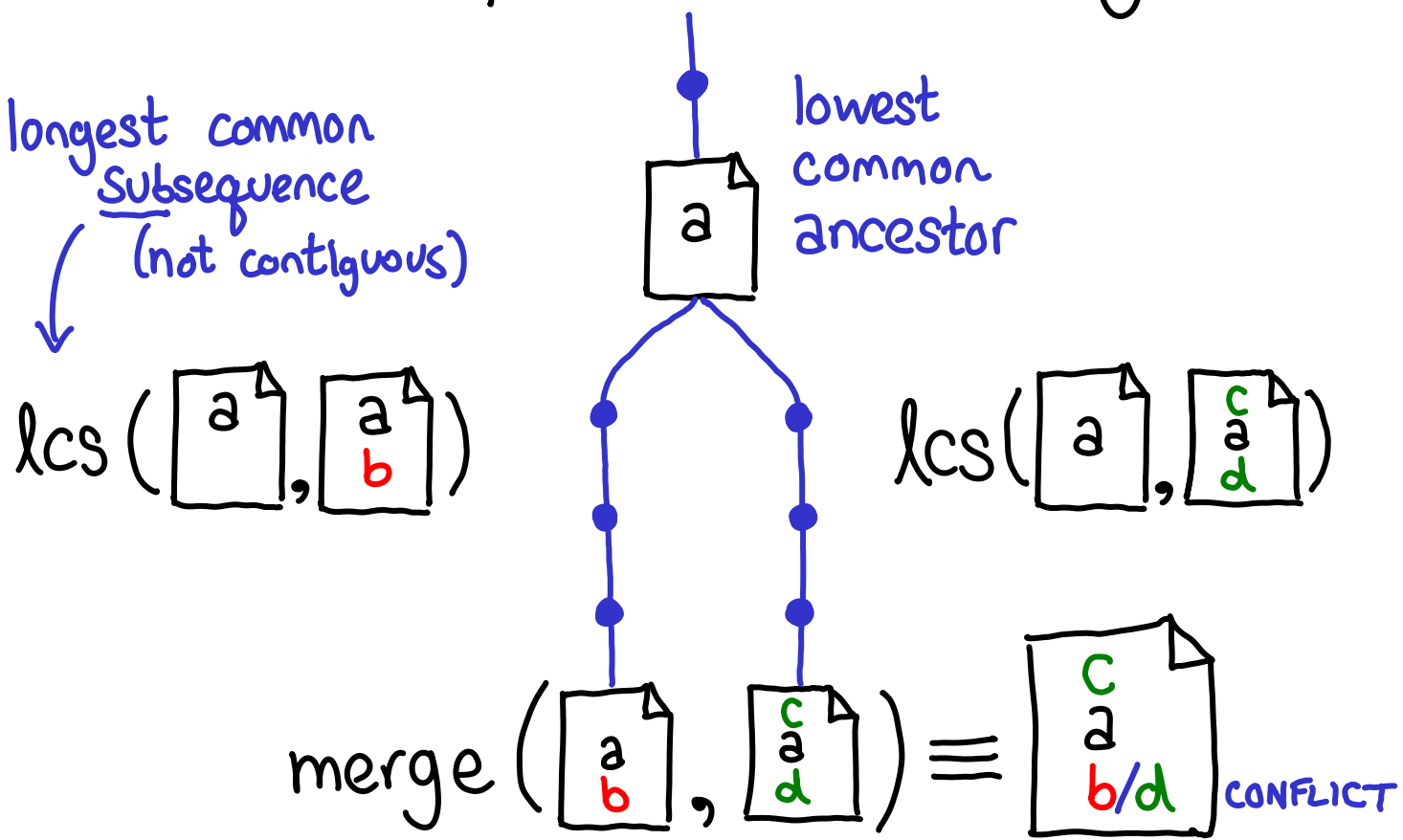
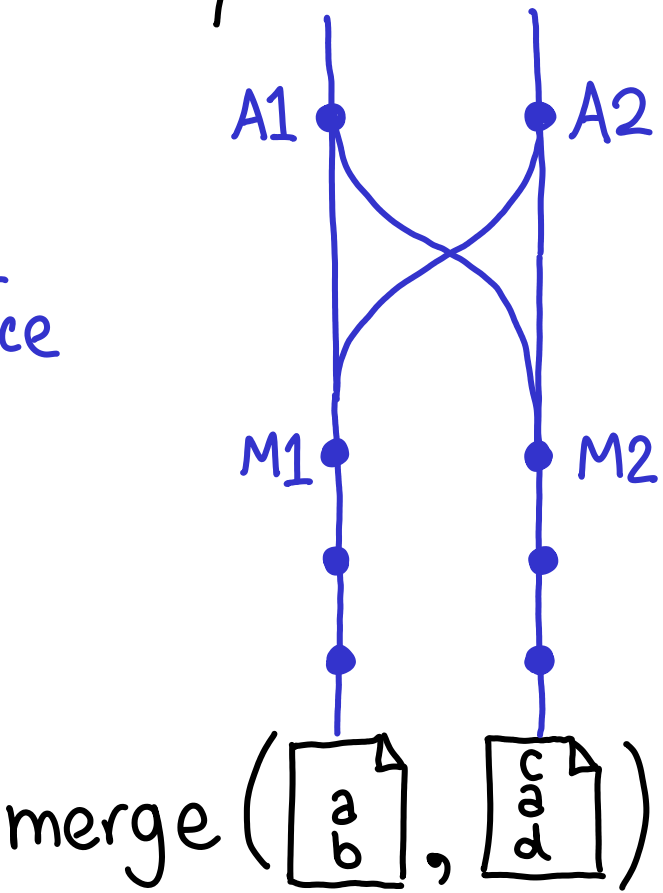
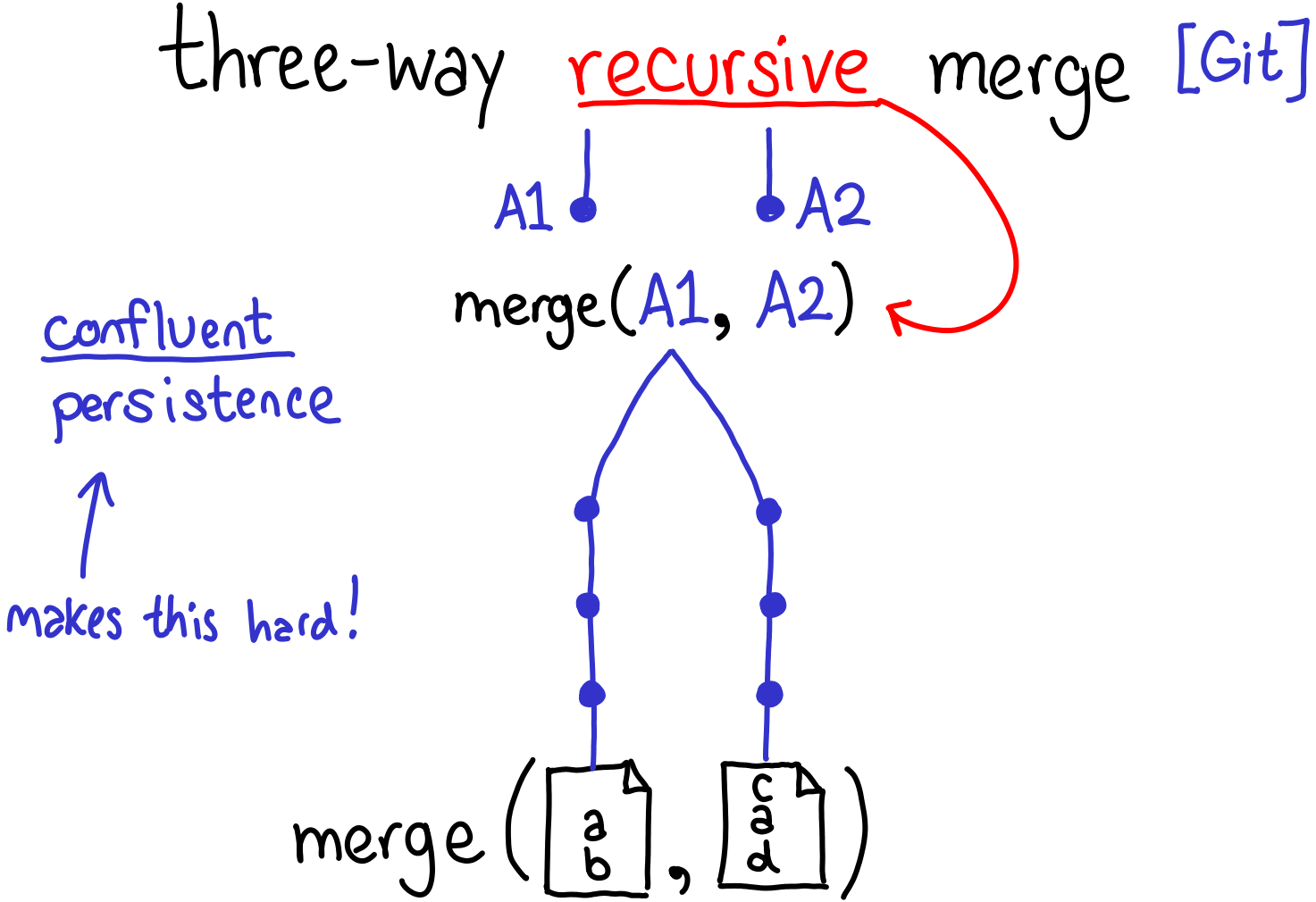


three-way recursive merge [Git]

confluent persistence




three-way recursive merge [Git]
A1
A2
merge(A1, A2)
confluent persistence
makes this hard!
merge
a
b
c
a
d

three-way recursive merge [Git]

requires $O(nk)$ time and the entire history of a document

(where k is the number of recursive calls — usually $k=1$)

three-way recursive merge [Git]

requires $O(nk)$ time and the entire history of a document

(where k is the number of recursive calls — usually $k=1$)

not too bad in practice, but...

three-way recursive merge [Git]

- it's not asymptotically optimal
  should be cheaper when documents similar
- can be a problem with large documents
  both merge & history is expensive
- may be inflexible
  my way (lcs) or the high way!

blame trees

merge requires $O(\sum_{S \in \text{shared regions}} \log|S| + \text{conflicts})$ time

using a structured document representation

(with $O(\log n)$ update/delete/insert)

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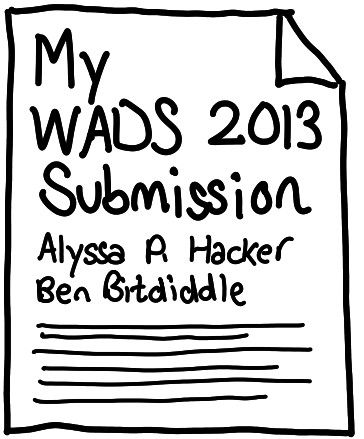
Abstract the Problem



sequence of characters

model of VCS merge

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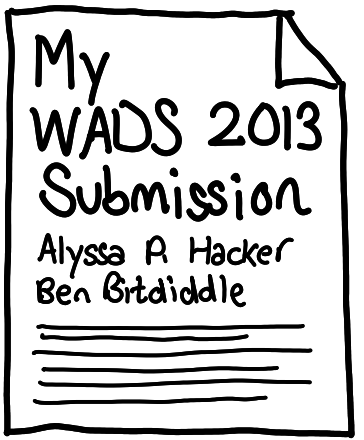
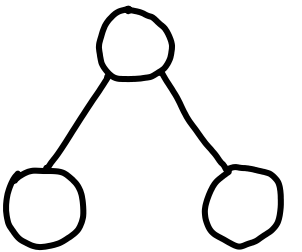




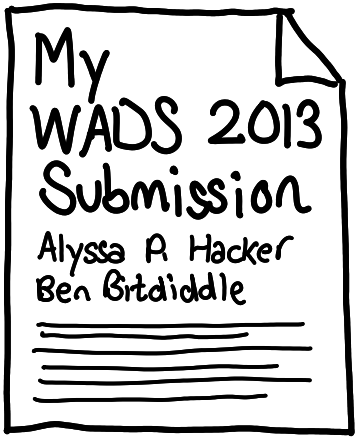
sequence of characters

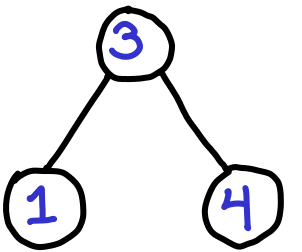
model of VCS merge

sorted associative map

Abstract the Problem

[Dietz '87]



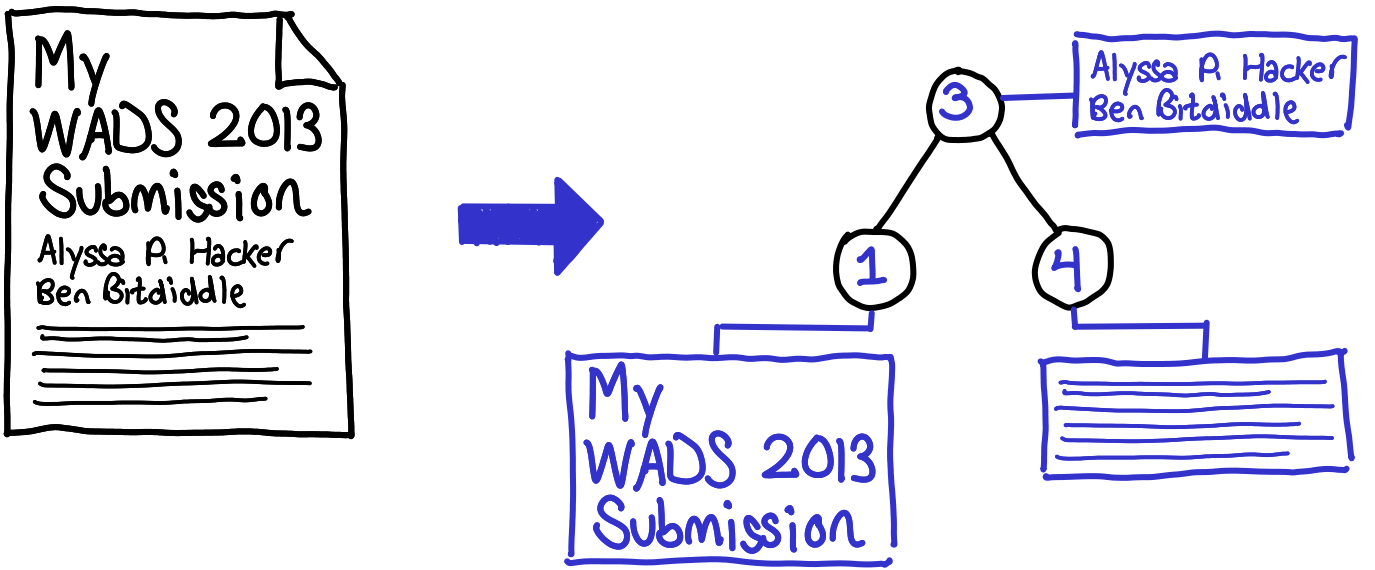


$$between(k_1, k_2) = k_{12} \text{ s.t. } k_1 < k_{12} \wedge k_{12} < k_2$$

sequence of characters
model of VCS merge

sorted associative map
keys: line "number"

Abstract the Problem



sequence of characters
model of VCS merge

sorted associative map
keys: line "number"
values: fragments of document

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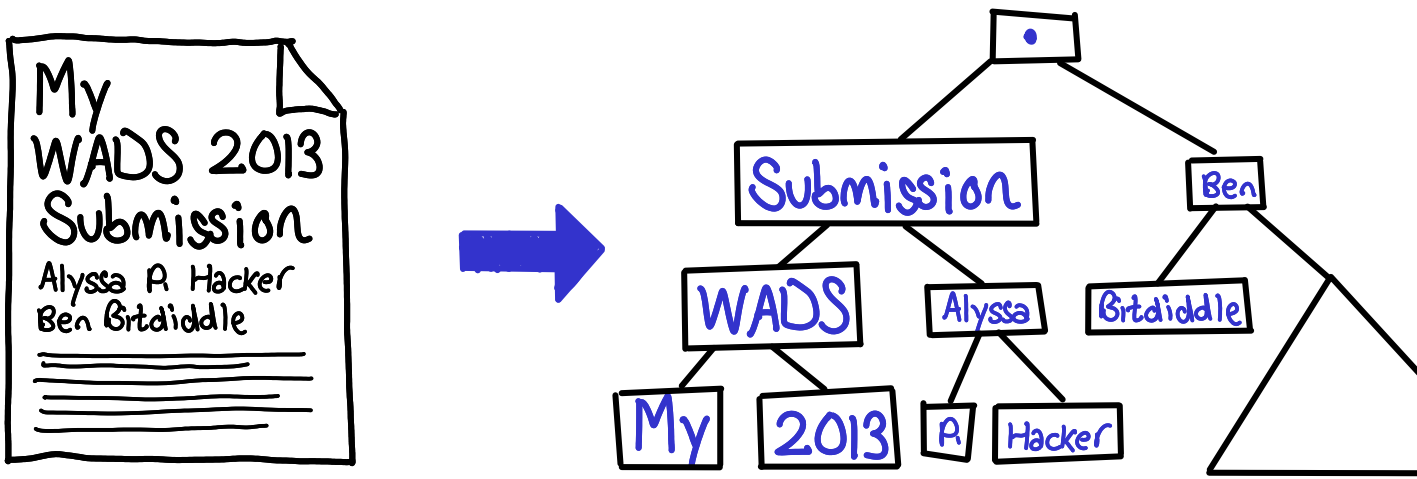


sequence of characters
model of VCS merge

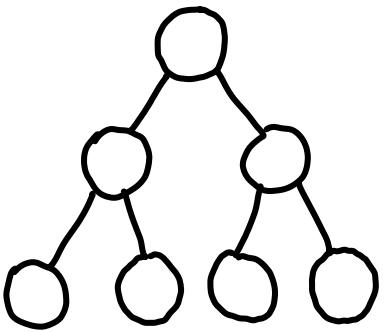
sorted associative map
keys: word "number"
values: fragments of document

Abstract the Problem

functional
data structure

⇓

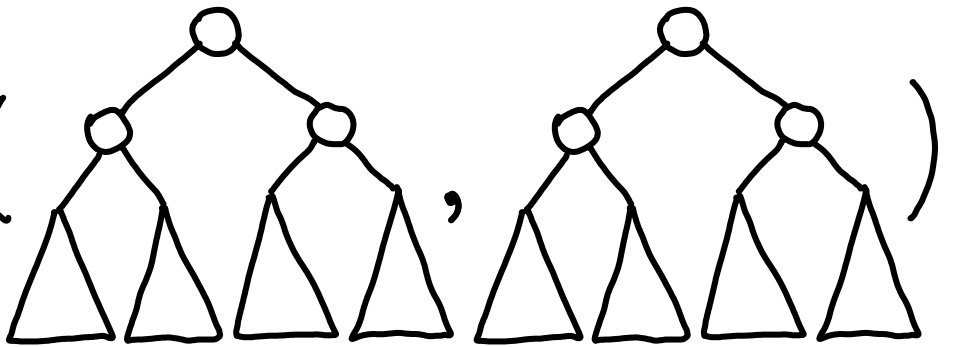
confluently
persistent



```
data Tree = Node  key
                  value
                  left
                  right

          | Leaf
```

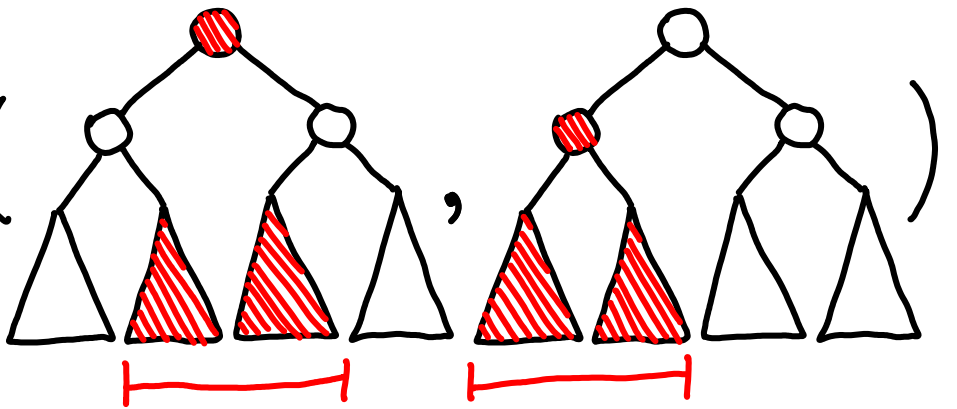
Our Result

merge()

$$O\left(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|\right)$$

shared

Our Result

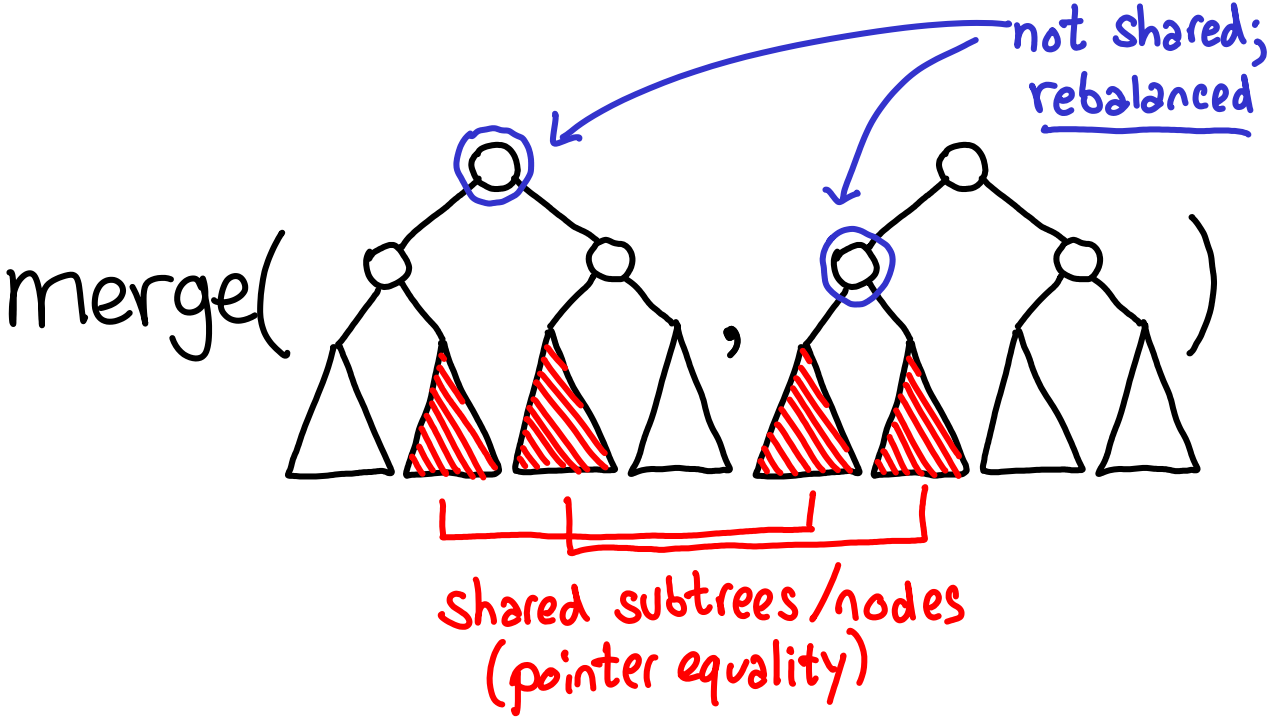
merge()

shared regions
(same keys and values)

$$O\left(R\left(\text{non-shared nodes}\right) + \sum_{S \in \text{shared regions}} \log |S|\right)$$

shared

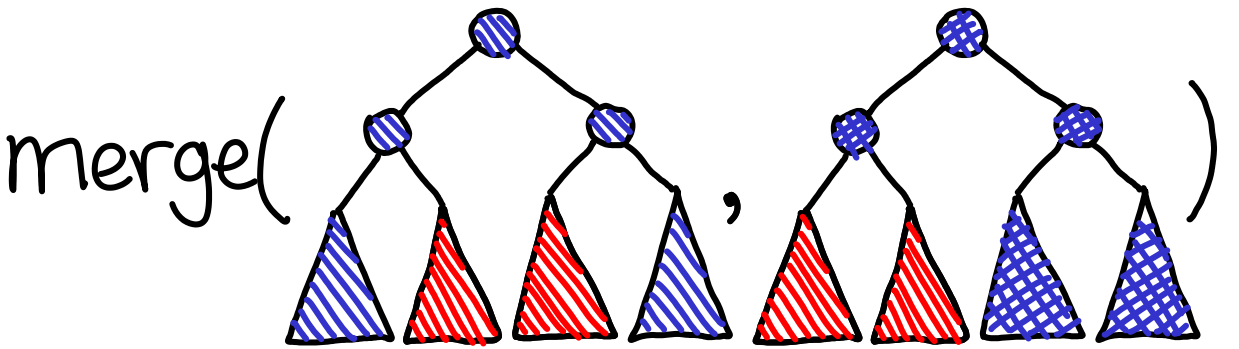
Our Result



$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|)$$

shared
unshared

Our Result

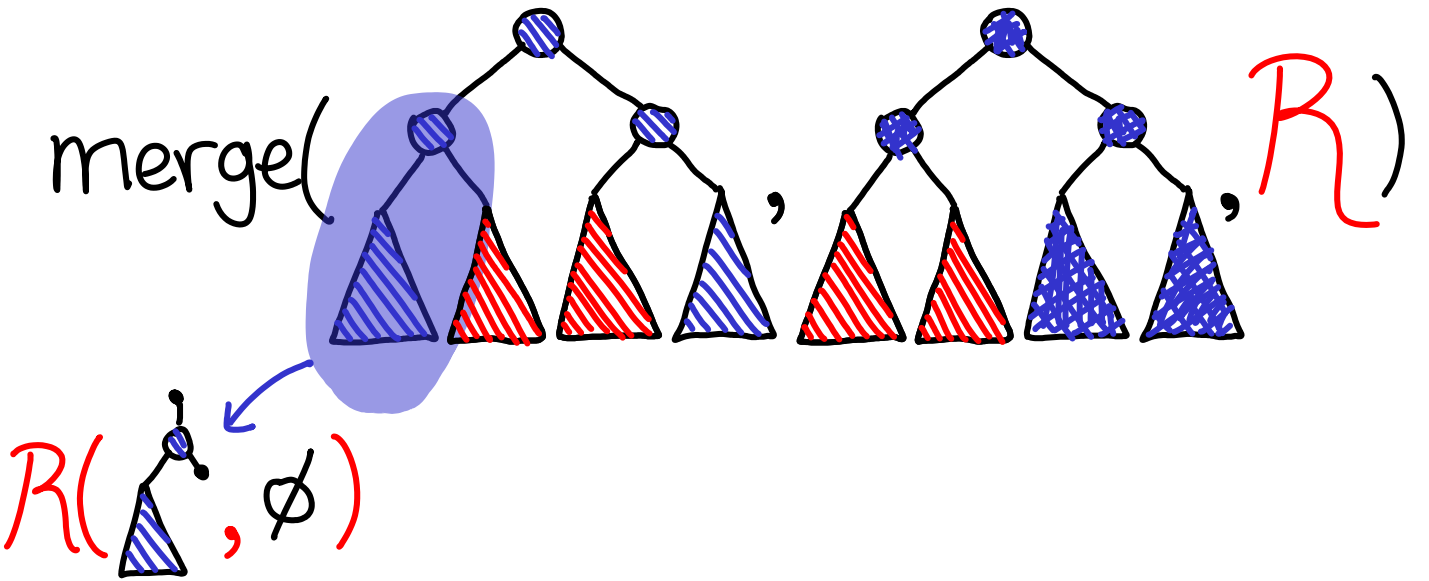


non-shared subtrees/nodes

$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|)$$

shared
unshared

Our Result

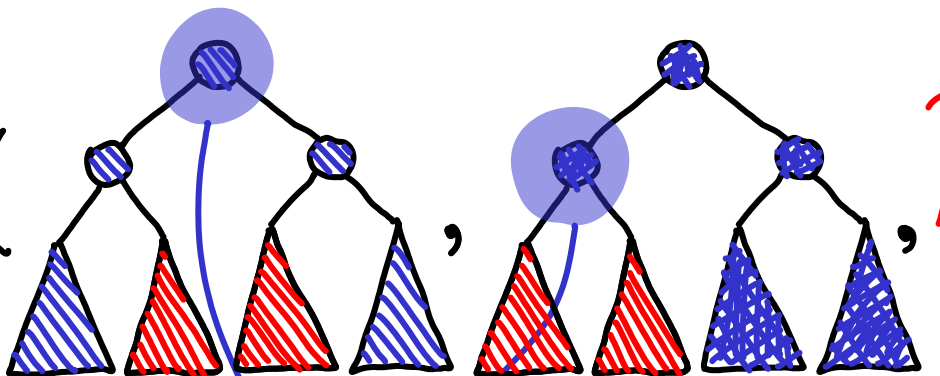


$$O\left(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|\right)$$

shared
unshared

Our Result

merge(, , R)



$R(\ ,\emptyset)$

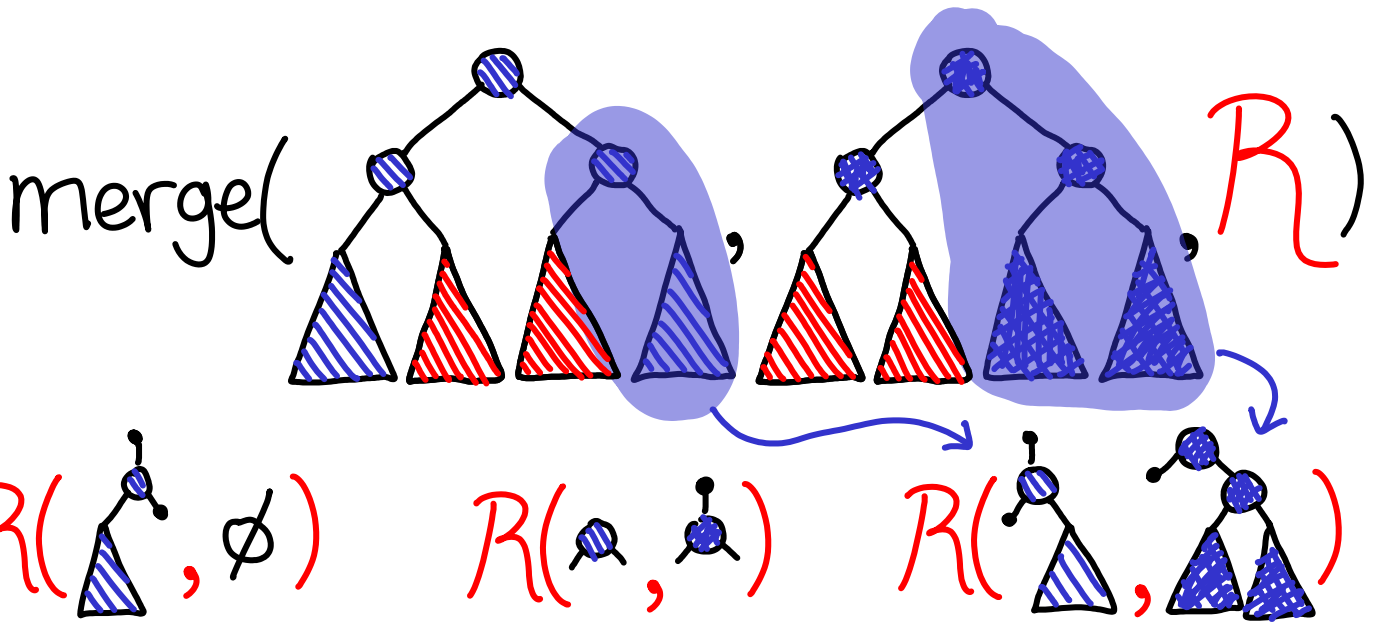
$R(\ ,\ )$

(can optimize)

$$O\left(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|\right)$$

shared
unshared

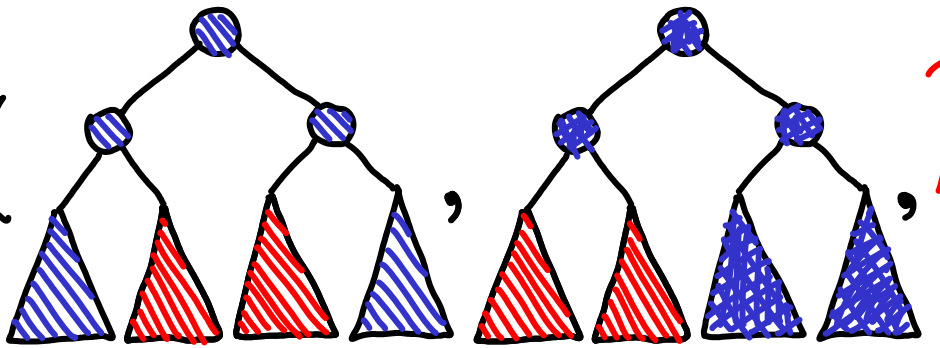
Our Result



$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|)$$

shared
unshared

Our Result

merge( , R)

Ω(non-shared nodes)

$$O\left(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|\right)$$

blame trees

require $O(\sum_{S \in \text{shared regions}} \log|S| + \text{conflicts})$ time

using a structured document representation

how?

The key idea is to annotate all subtrees with their last update revision (blame). The primary technical difficulty is efficiently identifying shared subtrees.

Blame

```
d1a89f24 (Edward Z. Yang  2012-11-30 12:16:35 -0800   1) \documentcl
^1e00c69 (Edward Z. Yang  2012-11-28 10:41:07 -0800   2)
d1a89f24 (Edward Z. Yang  2012-11-30 12:16:35 -0800   3) \title{Blam
0178feba (Edward Z. Yang  2013-05-03 14:39:26 -0700   4) \author{Eri
fd01474f (Erik Demaine    2013-02-24 21:04:55 -0500   5) \institute{
^1e00c69 (Edward Z. Yang  2012-11-28 10:41:07 -0800   6)
^1e00c69 (Edward Z. Yang  2012-11-28 10:41:07 -0800   7) \usepackage
d1a89f24 (Edward Z. Yang  2012-11-30 12:16:35 -0800   8) \usepackage
eb146b8a (Edward Z. Yang  2013-01-15 20:50:55 -0800   9) \usepackage
4e1a0491 (Erik Demaine    2013-02-24 21:22:45 -0500  10) \usepackage
^1e00c69 (Edward Z. Yang  2012-11-28 10:41:07 -0800  11)
d1a89f24 (Edward Z. Yang  2012-11-30 12:16:35 -0800  12) \newcommand
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7b24b512 (Edward Z. Yang  2012-12-13 13:04:13 -0800  14) %\newcomman
7b24b512 (Edward Z. Yang  2012-12-13 13:04:13 -0800  15) %\algloopde
7b24b512 (Edward Z. Yang  2012-12-13 13:04:13 -0800  16)
38ec8c67 (Erik Demaine    2013-02-24 22:35:40 -0500  17) % Put figur
38ec8c67 (Erik Demaine    2013-02-24 22:35:40 -0500  18) \def\textfr
38ec8c67 (Erik Demaine    2013-02-24 22:35:40 -0500  19) \def\topfra
38ec8c67 (Erik Demaine    2013-02-24 22:35:40 -0500  20) \def\dbltop
```

Blame

content

```
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revision annotation

Blame

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```
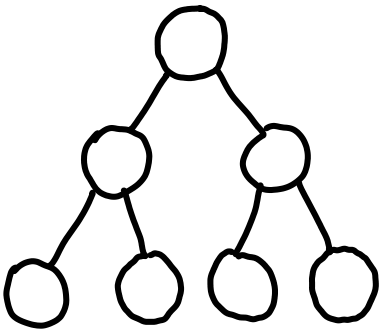

Idea: Record Blame

(don't compute it!)



```
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                  value
                  left
                  right
          | Leaf
```

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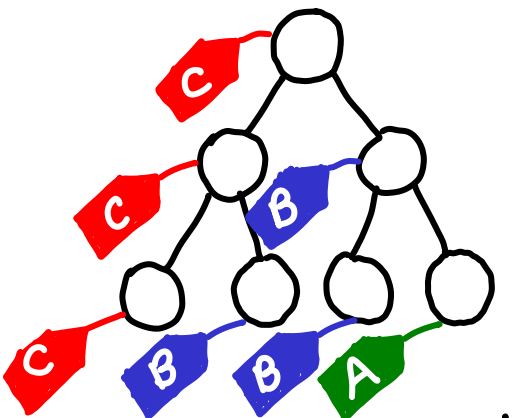


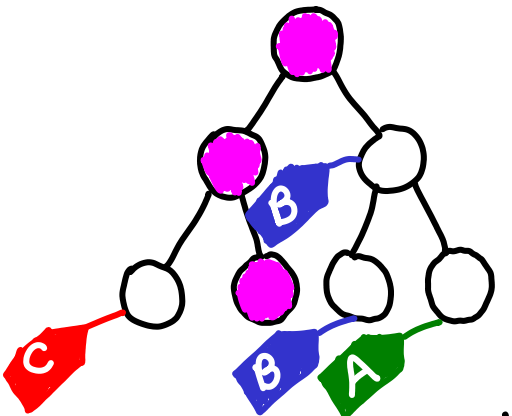
data Tree = Node key
value
revision
left
right
| Leaf

Idea: Record Blame

(don't compute it!)

path copying

[Oka'99]



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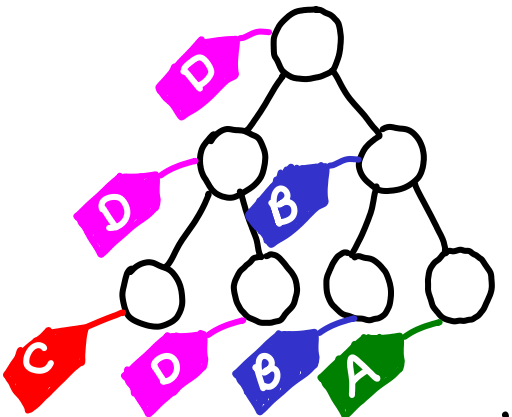

data Tree = Node key value revision left right | Leaf

Key invariant

$$key_1 = key_2 \land rev_1 = rev_2 \iff tree_1 = tree_2$$

Algorithm

1. Traverse tree, identifying shared regions.
2. Split tree at region boundaries.
3. Perform conflict resolution on unshared regions.
4. Merge trees back together.

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$\sum_{\text{seregions}} \log|s|$

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4. Merge trees back together. $\sum_{\text{seregions}} \log|s|$

Algorithm

1. Traverse tree, identifying shared regions.	???
2. Split tree at region boundaries.	$\sum_{\text{seregions}} \log\|s\|$
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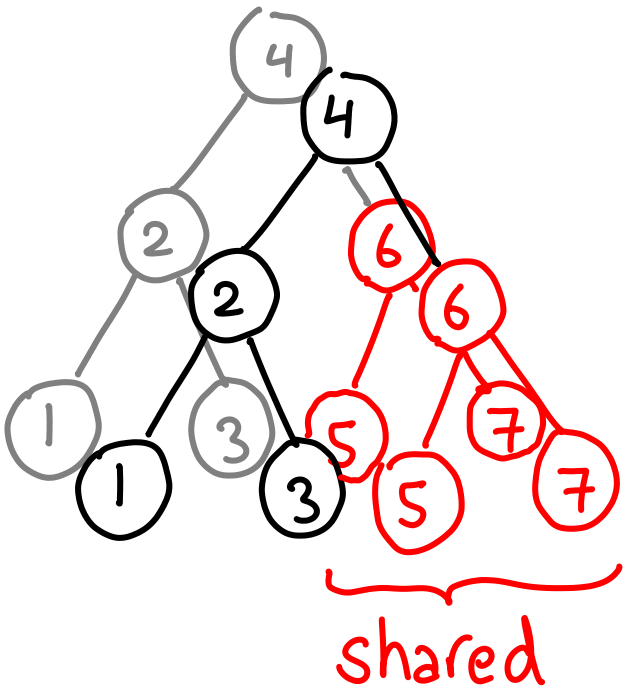
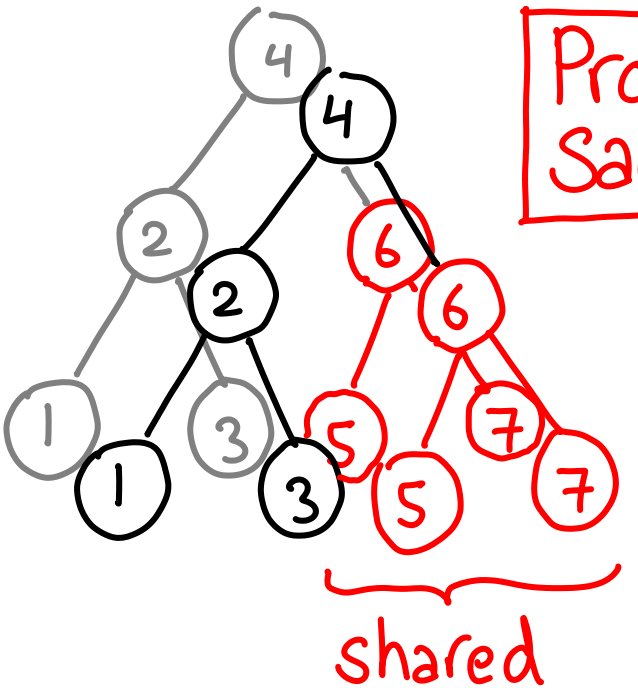
Traversal: Solution 1 (naïve)



XXXXGGG
YYYYGGG

$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|)$$

Traversal: Solution 1 (naïve)



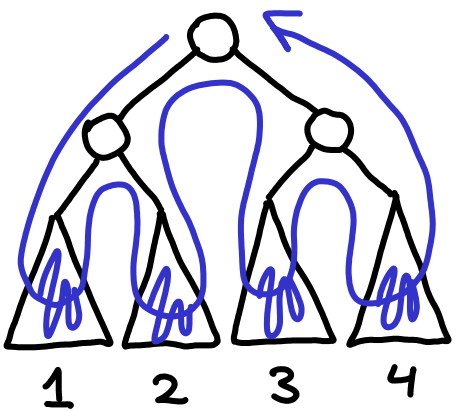
Problem: Requires Same Structure

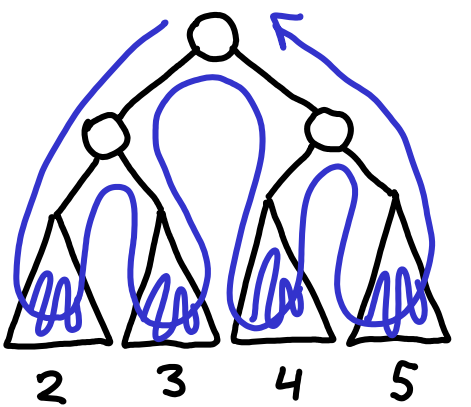
XXXXGGG
YYYYGGG

$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log |S|)$$

Traversal: Solution 2 (in-order)

f(left)
visit
f(right)



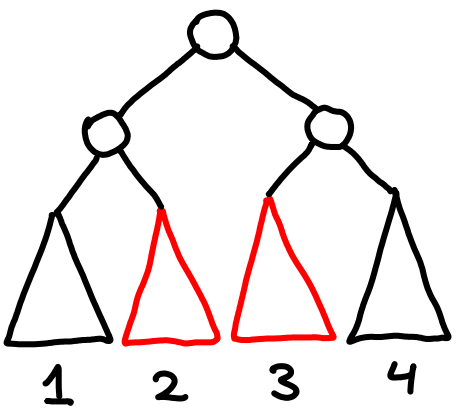


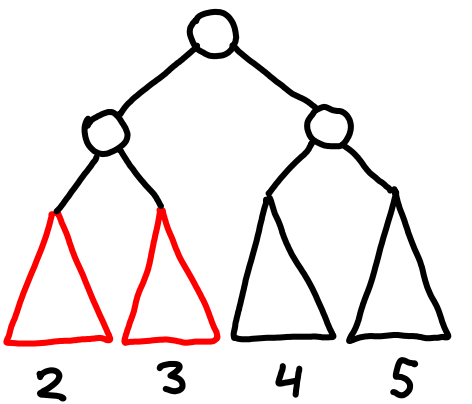
$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} |S|)$

Traversal: Solution 2 (in-order)

Short-circuited

```
f(left)
visit
if(!shared)
    f(right)
```





Traversal: Solution 2 (in-order)

Short-circuited

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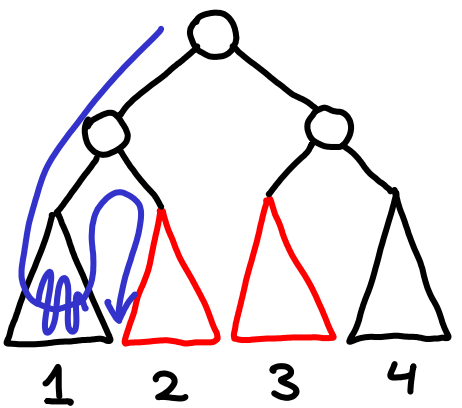

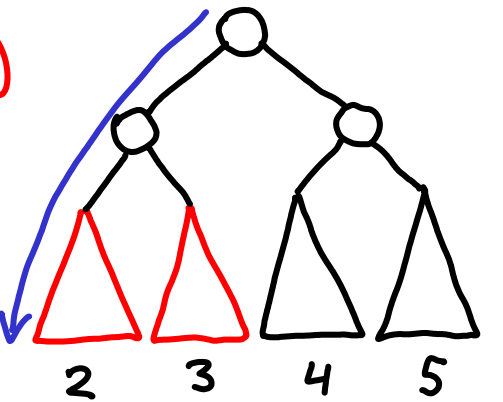

Traversal: Solution 2 (in-order)

Short-circuited

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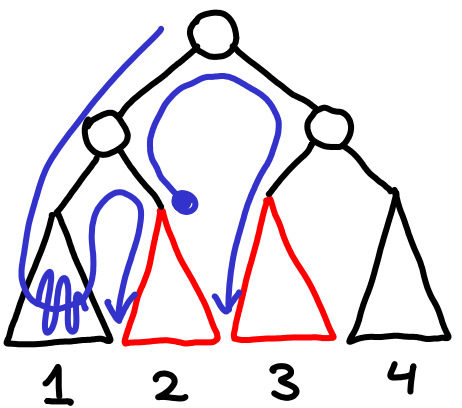
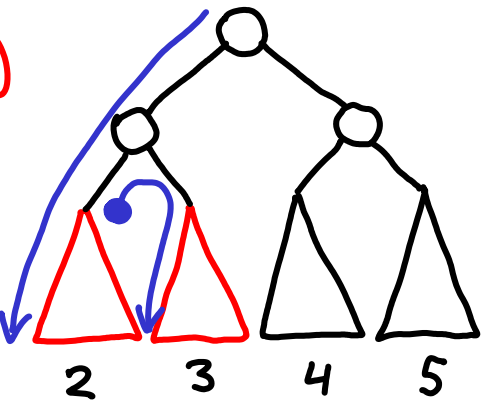
visit
if(!shared)
    f(right)
```





Traversal: Solution 2 (in-order)

Short-circuited

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f(left)
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if(!shared)
    f(right)
```
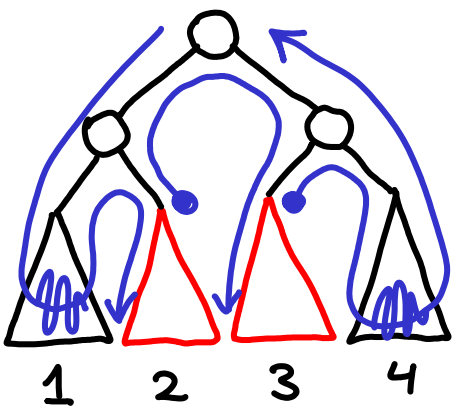
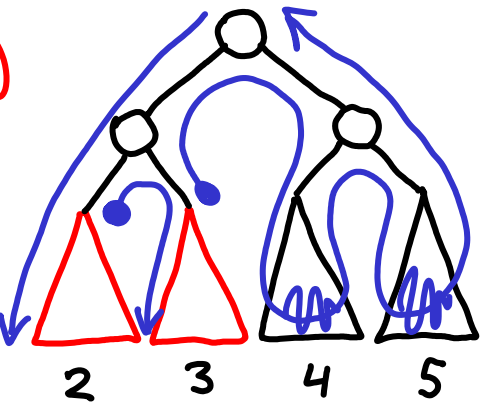
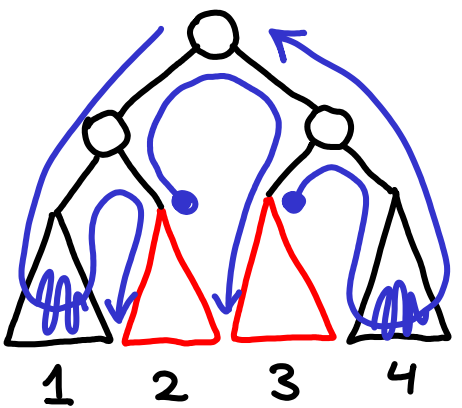



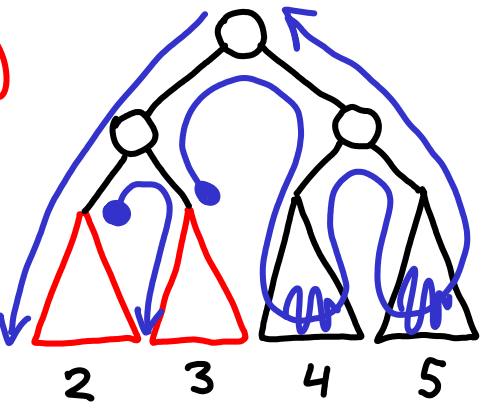


Traversal: Solution 2 (in-order)

Short-circuited

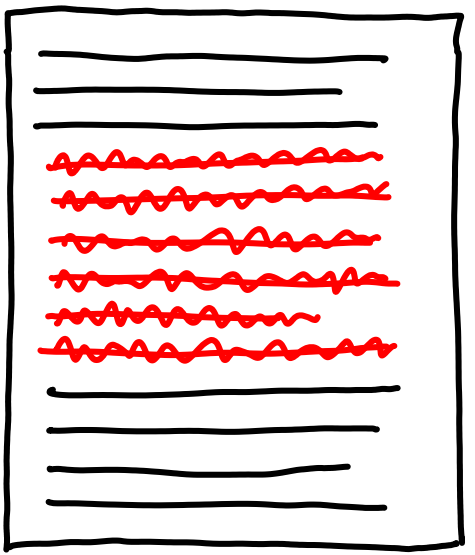
```
f(left)
visit
if(!shared)
    f(right)
```

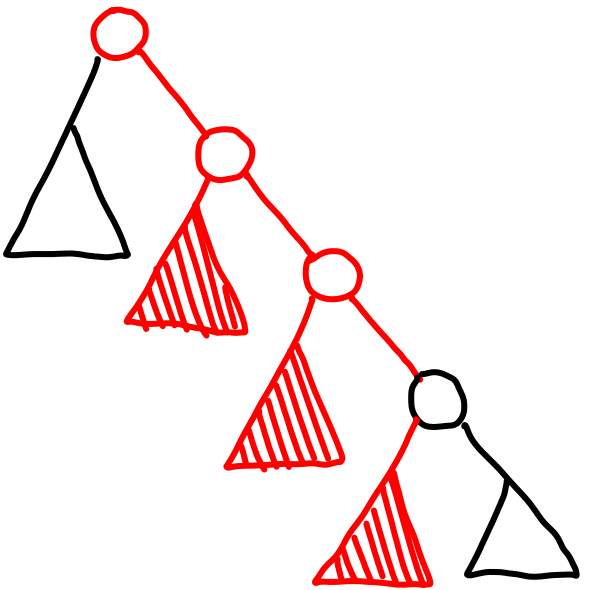




$$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared regions}} \log^2 |S|)$$

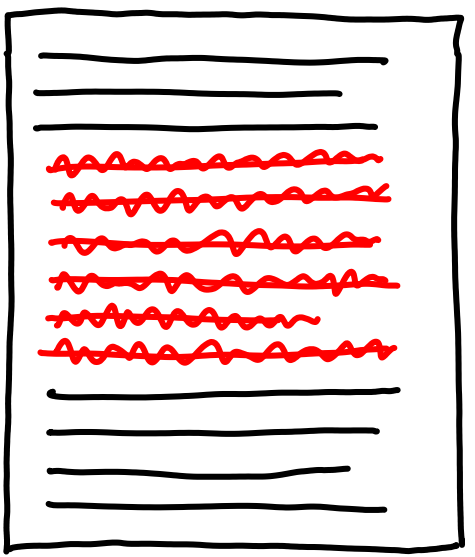
Why $\log^2(|S|)$?

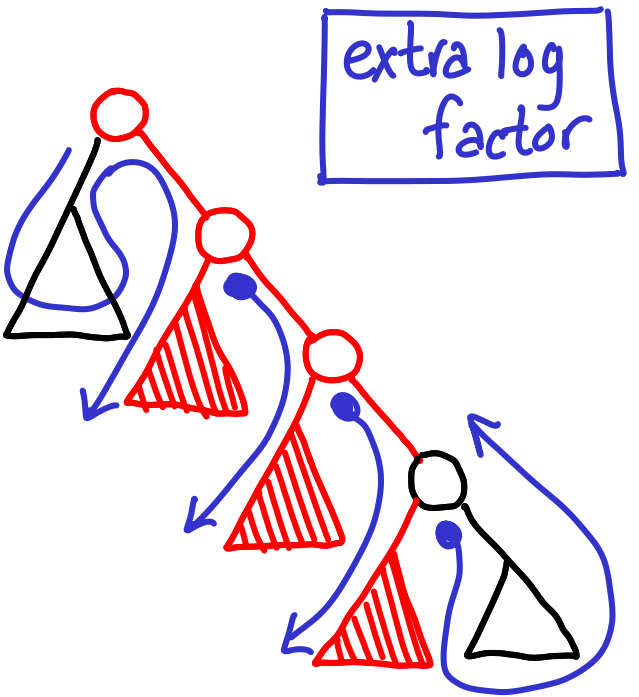




shared subregion $\neq$ shared subtree

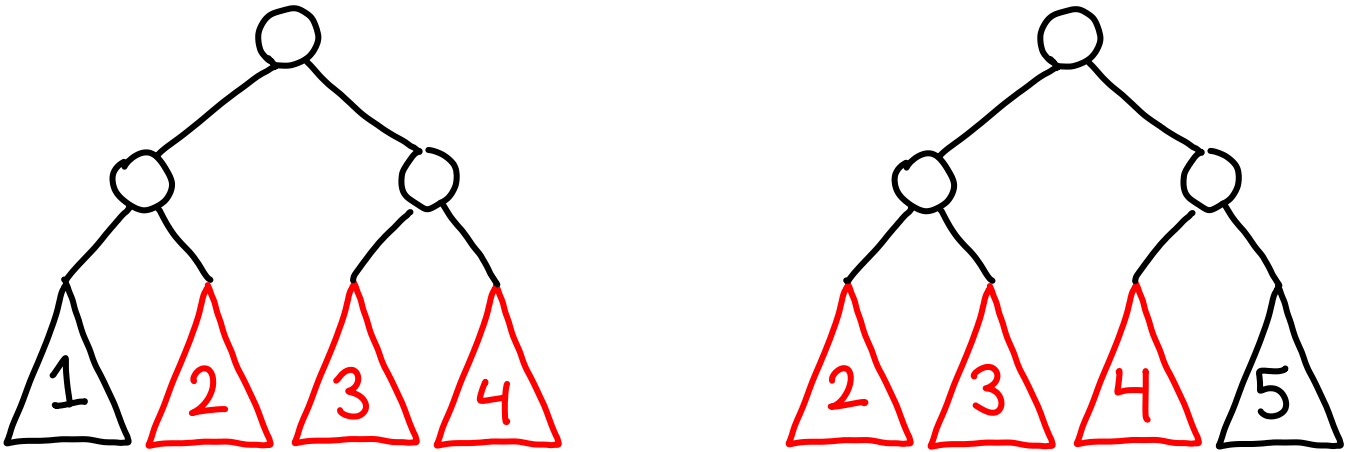
Why $\log^2(|S|)$?





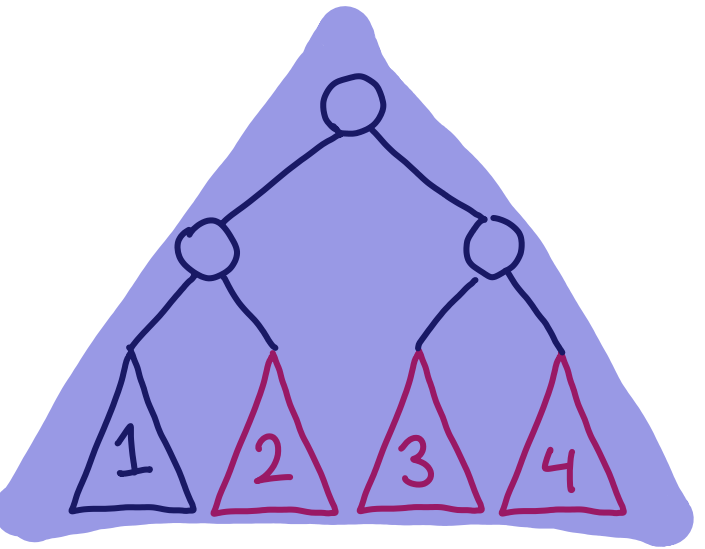
shared subregion $\neq$ shared subtree

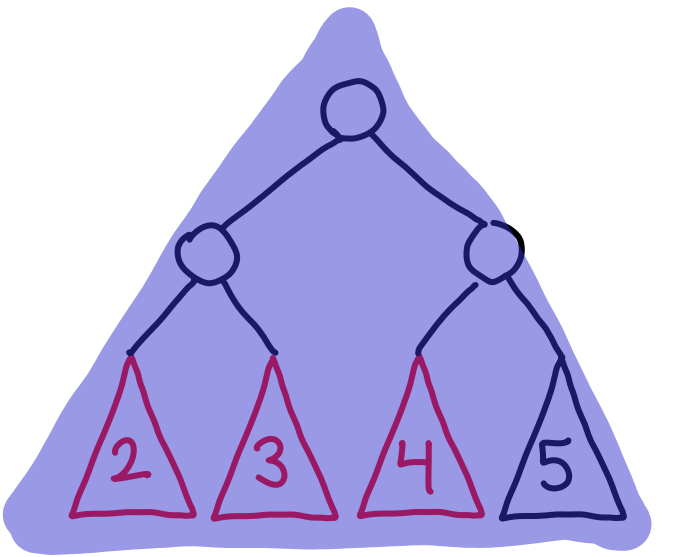
Traversal: Solution 3 (level-order)

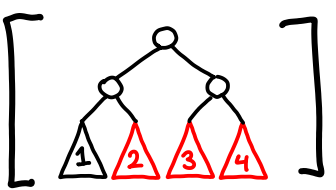


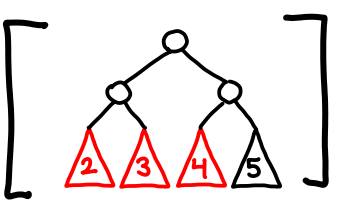
traverse by level

Traversal: Solution 3 (level-order)

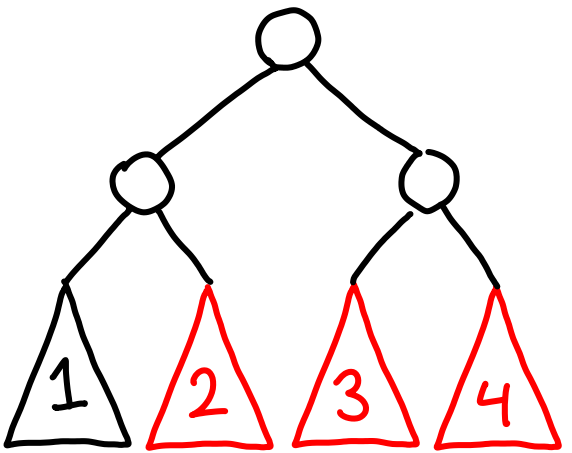


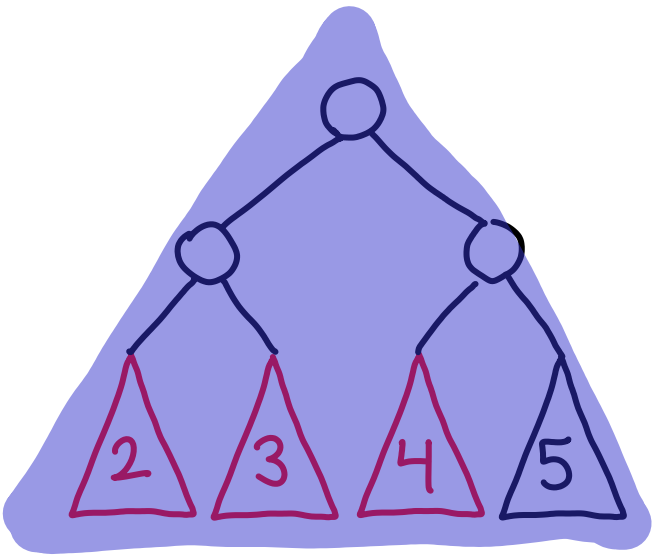


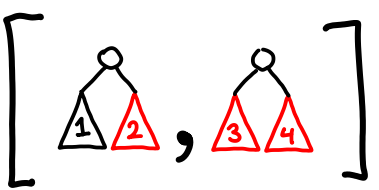


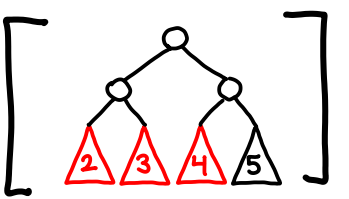


Traversal: Solution 3 (level-order)

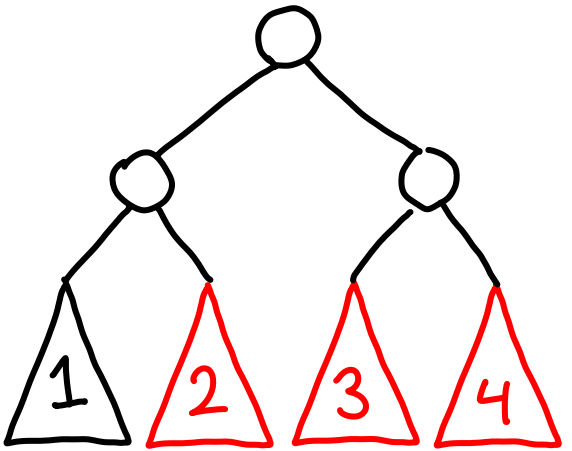


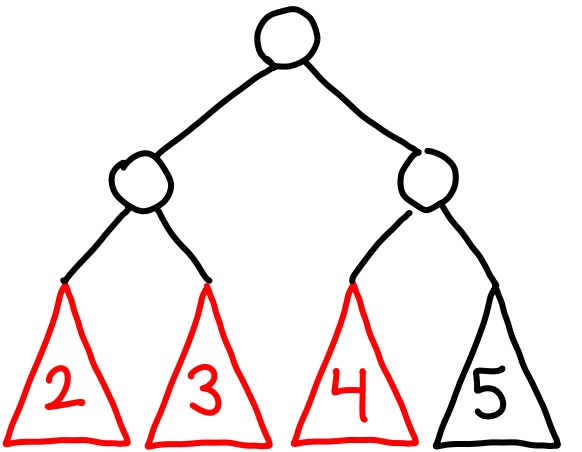


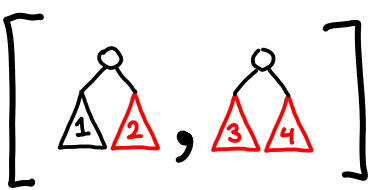


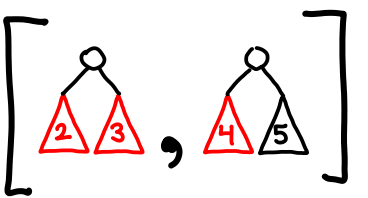


Traversal: Solution 3 (level-order)

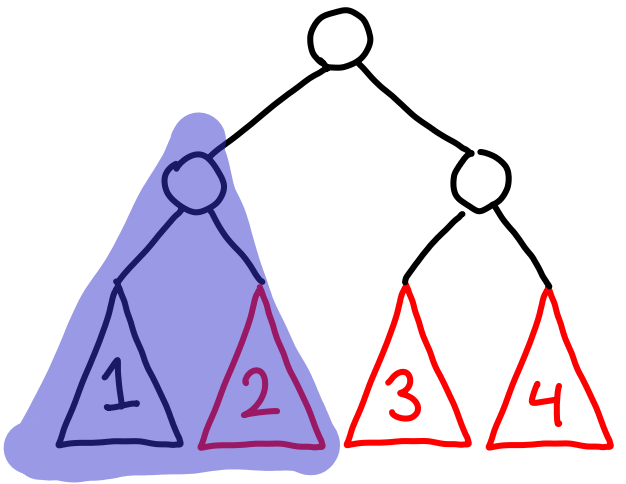


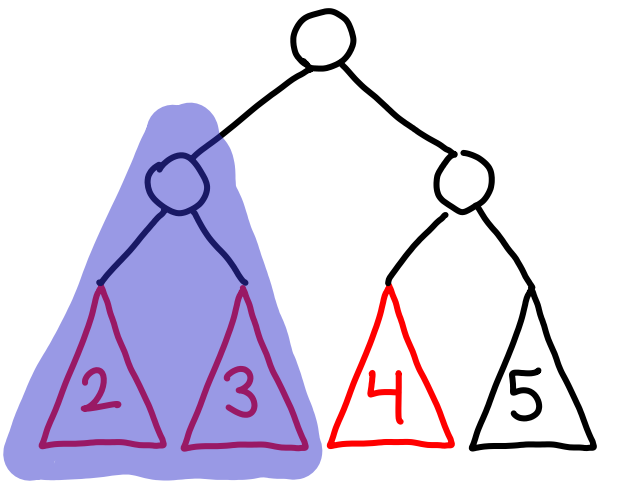


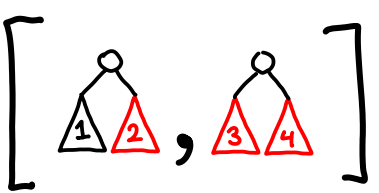


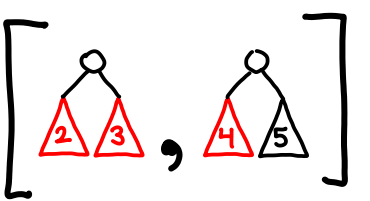


Traversal: Solution 3 (level-order)

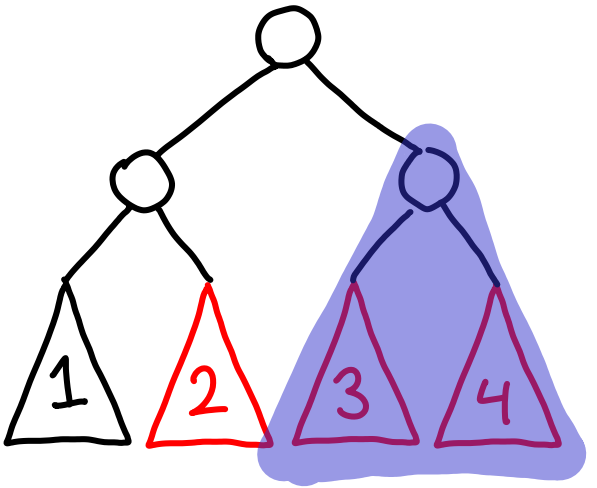


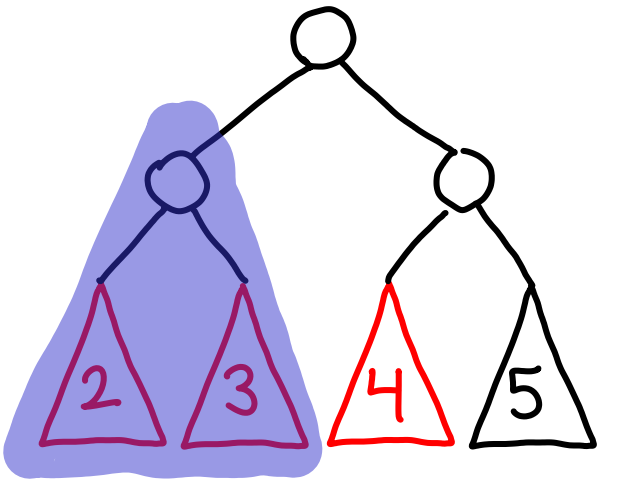


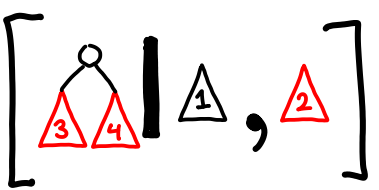


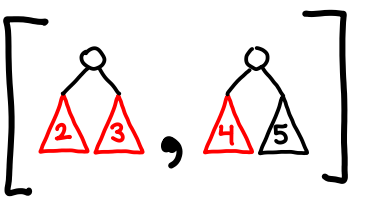


Traversal: Solution 3 (level-order)

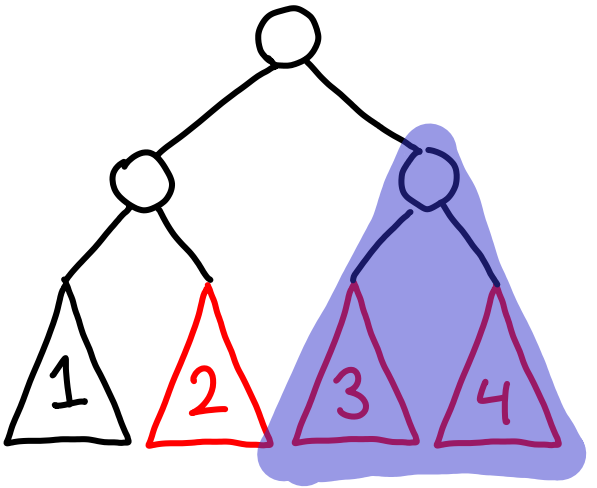


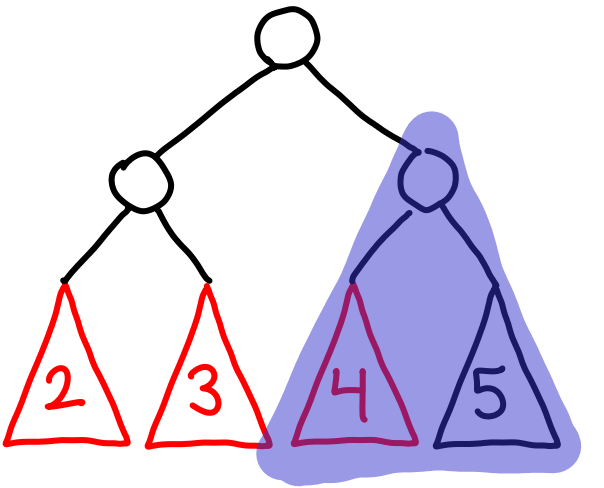


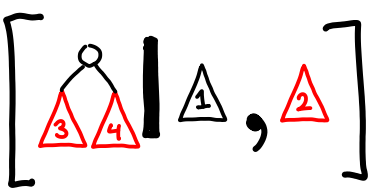


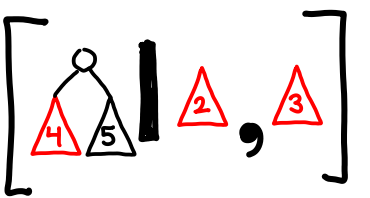


Traversal: Solution 3 (level-order)

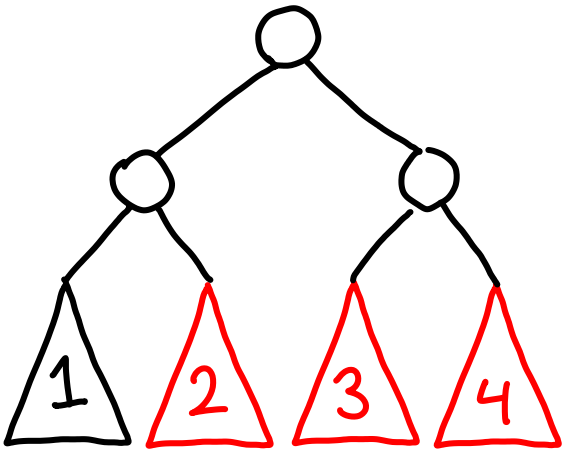


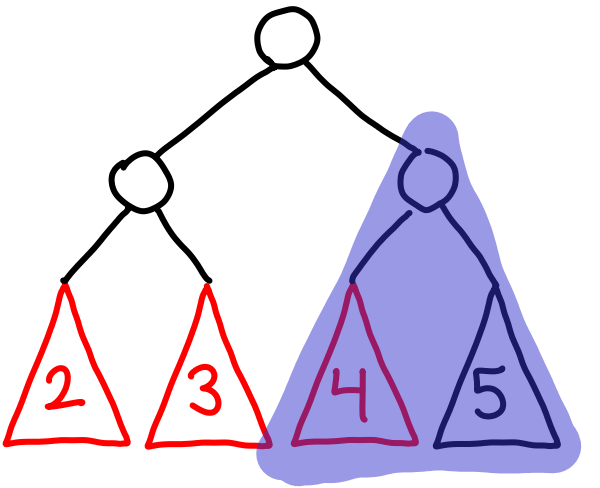


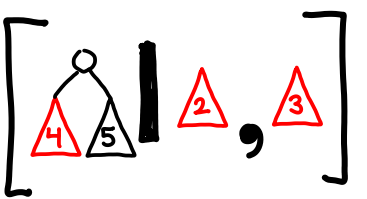




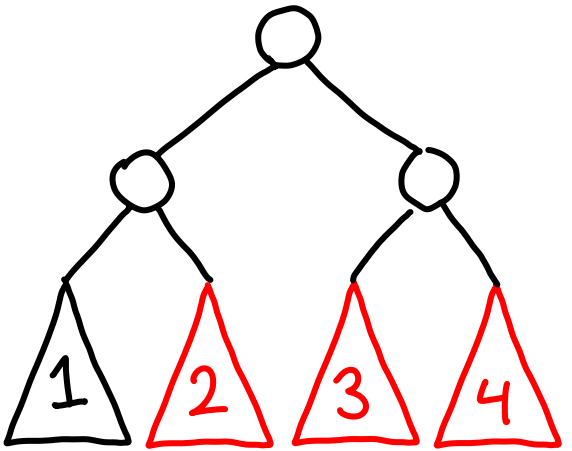
Traversal: Solution 3 (level-order)

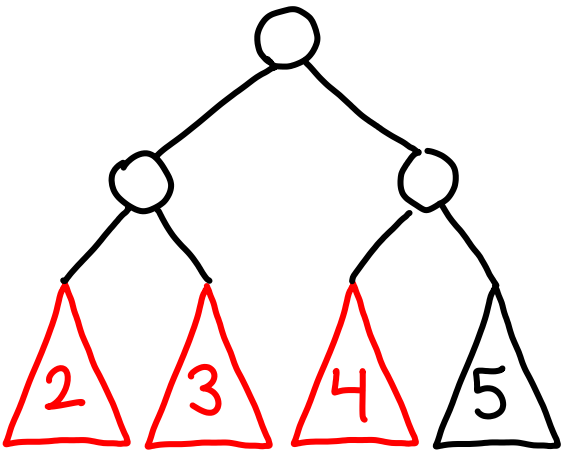


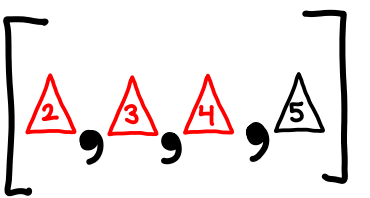




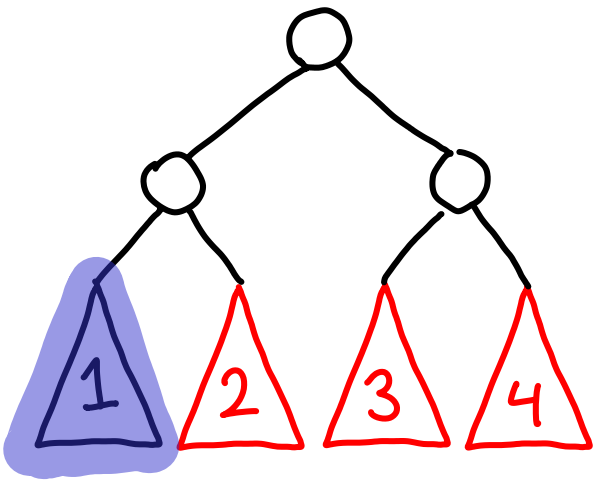
Traversal: Solution 3 (level-order)

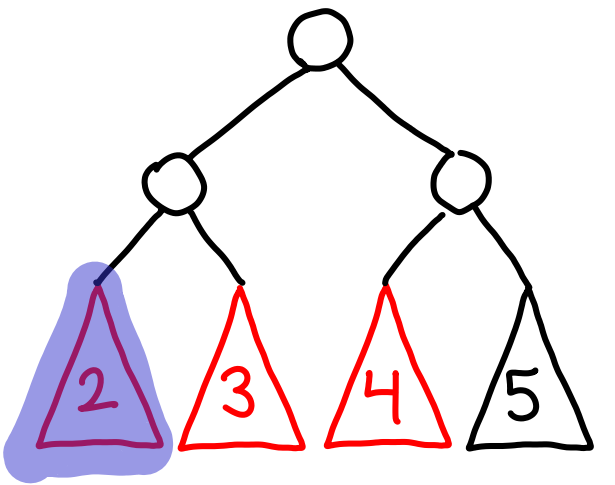


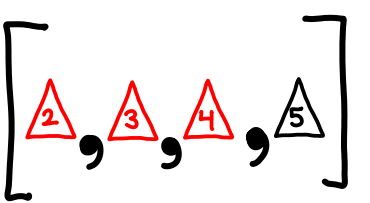




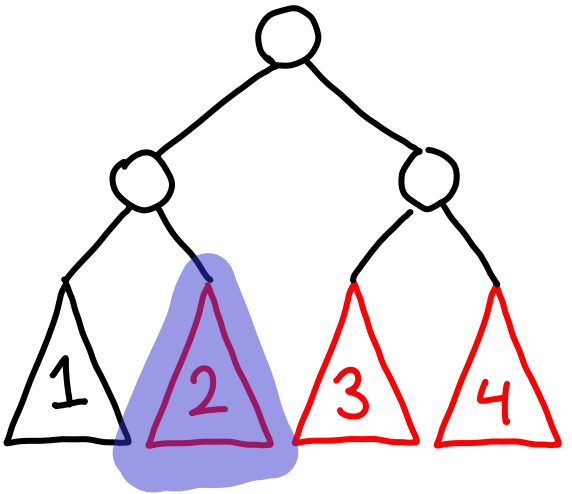
Traversal: Solution 3 (level-order)

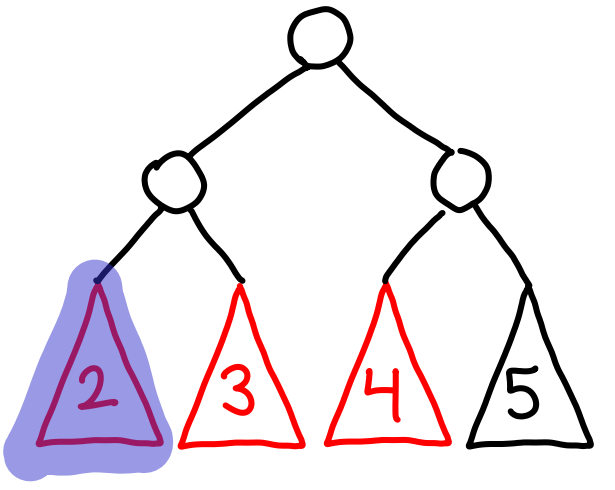


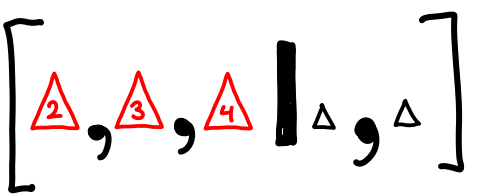


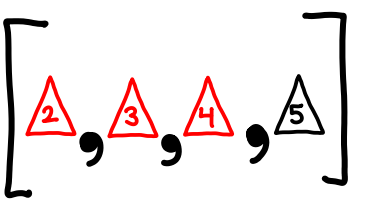


Traversal: Solution 3 (level-order)

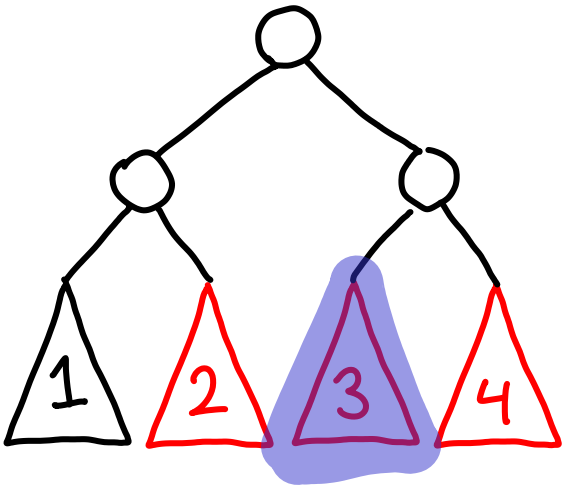


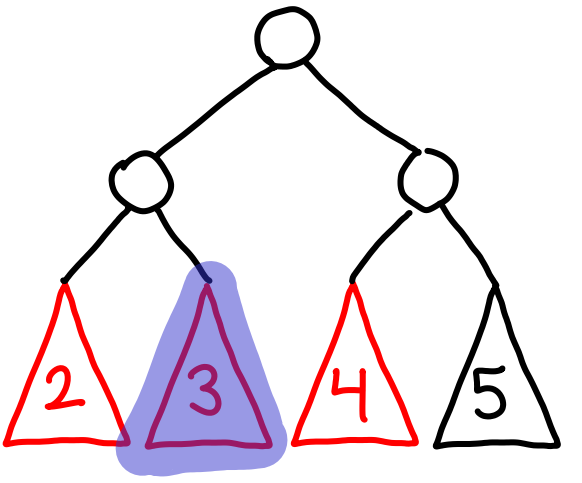


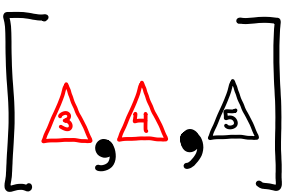




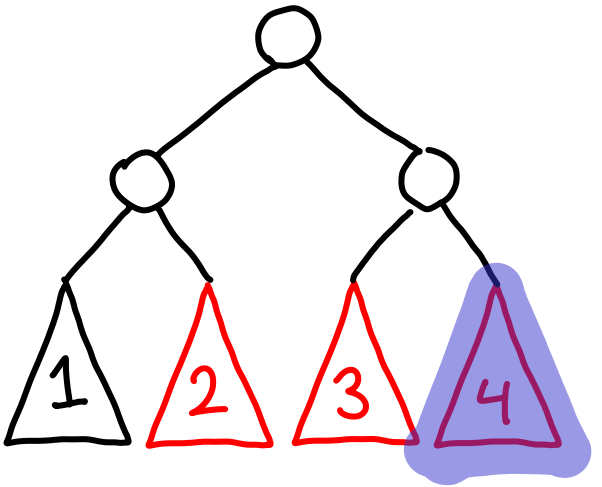
Traversal: Solution 3 (level-order)

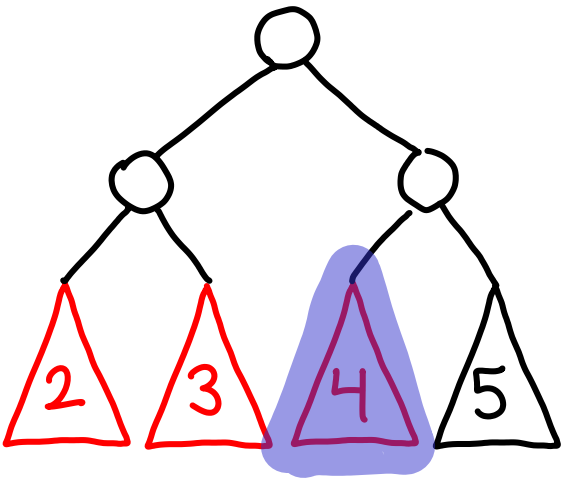






Traversal: Solution 3 (level-order)

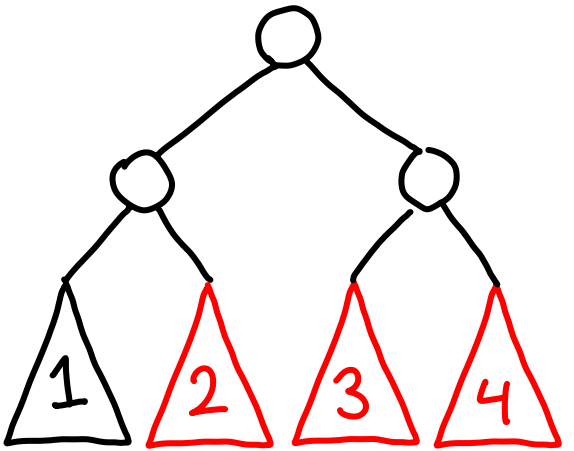


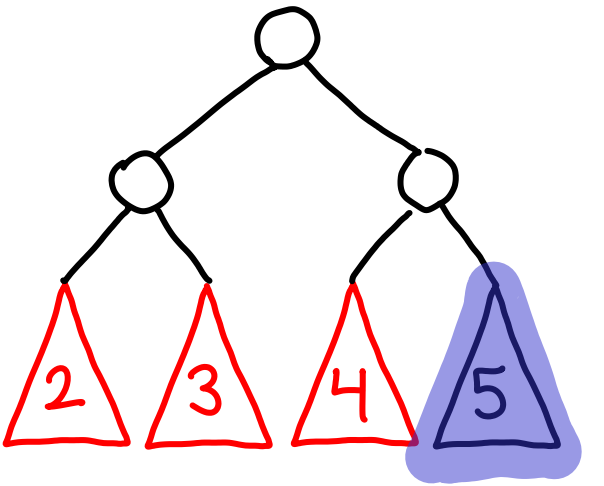


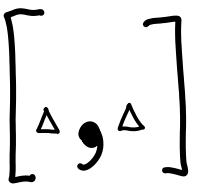
[4 | Δ , Δ]

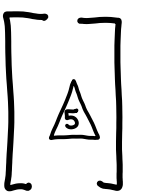
[4 , 5]

Traversal: Solution 3 (level-order)

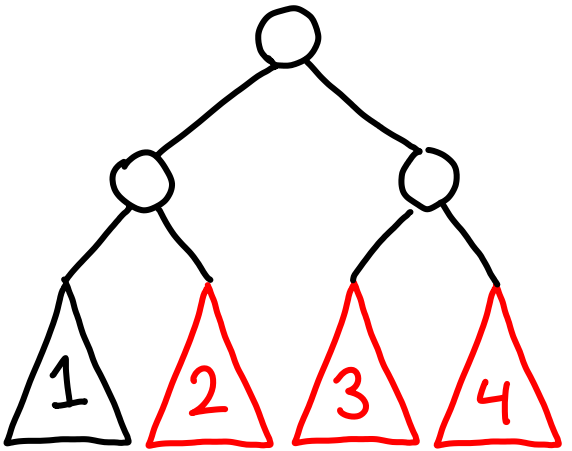


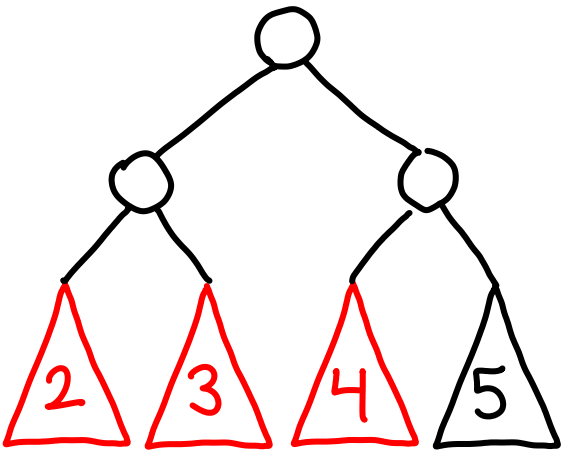


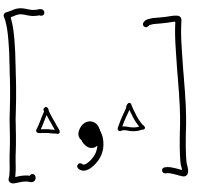


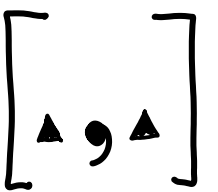


Traversal: Solution 3 (level-order)

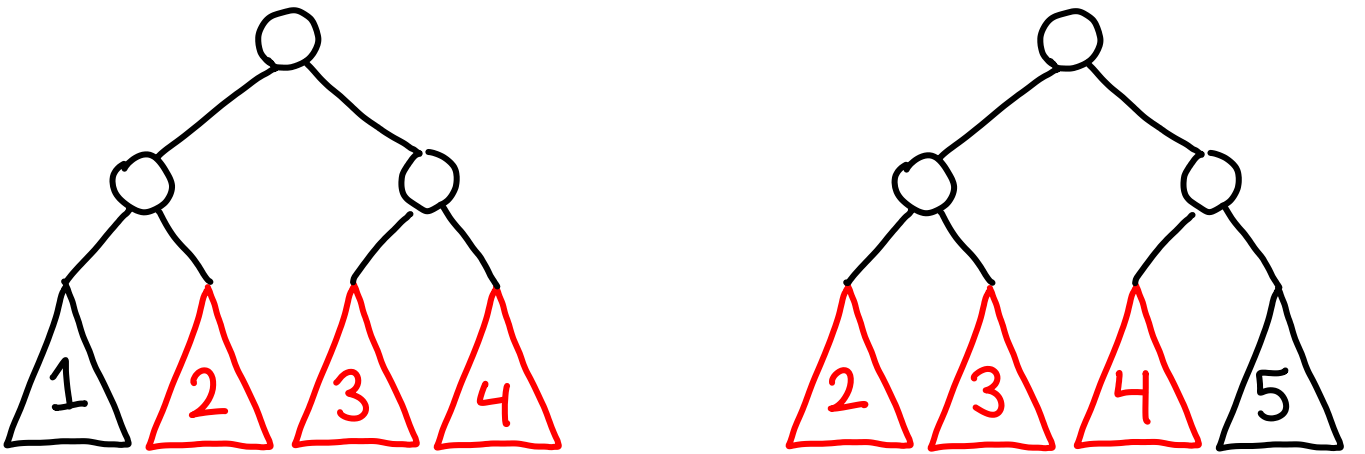








Traversal: Solution 3 (level-order)



$O(R(\text{non-shared nodes}) + \sum_{S \in \text{shared subtrees}} \log |S|)$ ✓

Conclusion

- Level-order works for red-black trees
- Bound matches optimal bound set by adaptive merging algorithms [CLP'93, DLM'00]
- Pesky constant factors.