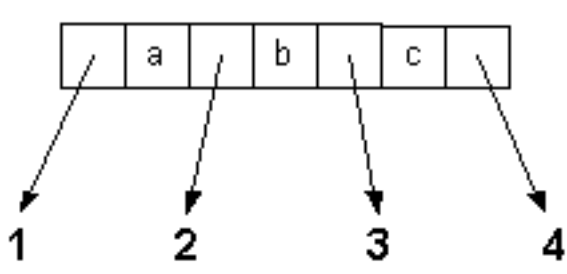
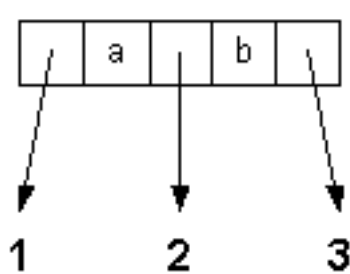
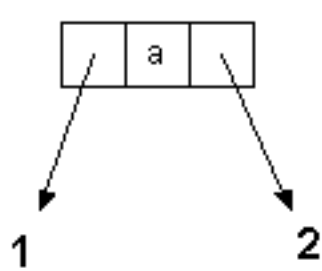


## Mapping 2-3-4 Trees into Red-Black Trees

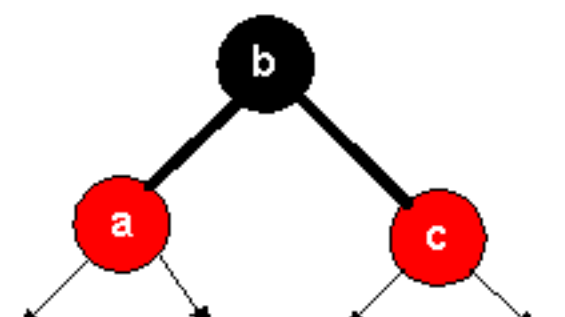
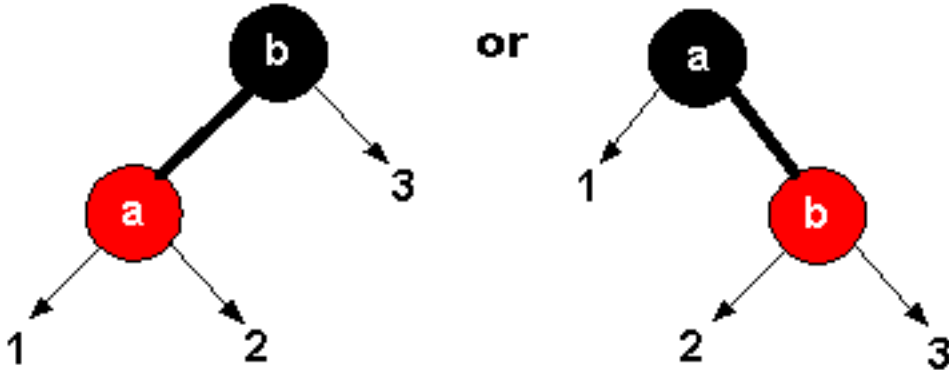
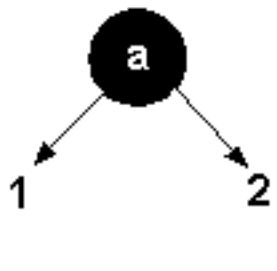
## Mapping 2-3-4 trees into Red-Black trees

- Since we're implementing 2-3-4 trees using binary trees, all nodes must be 2-nodes.
- This will inherently make the tree deeper, but the benefits outweigh this slight overhead.
- A 2-node requires one red/black node, a 3-node requires two red/black nodes, and a 4-node requires 3 red/black nodes.

## 2-3-4 Nodes

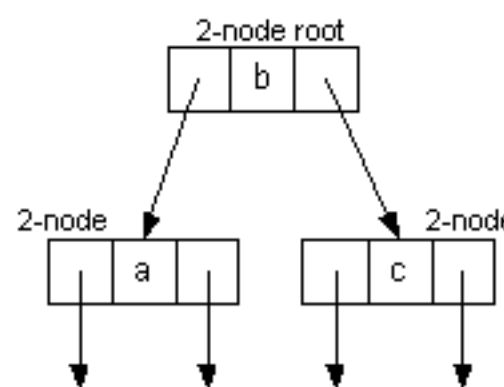
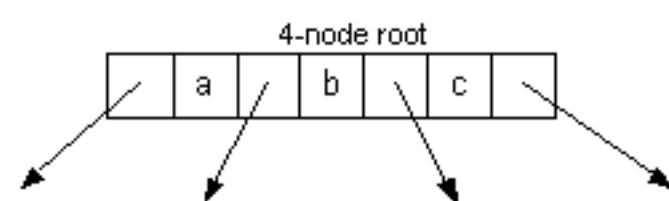
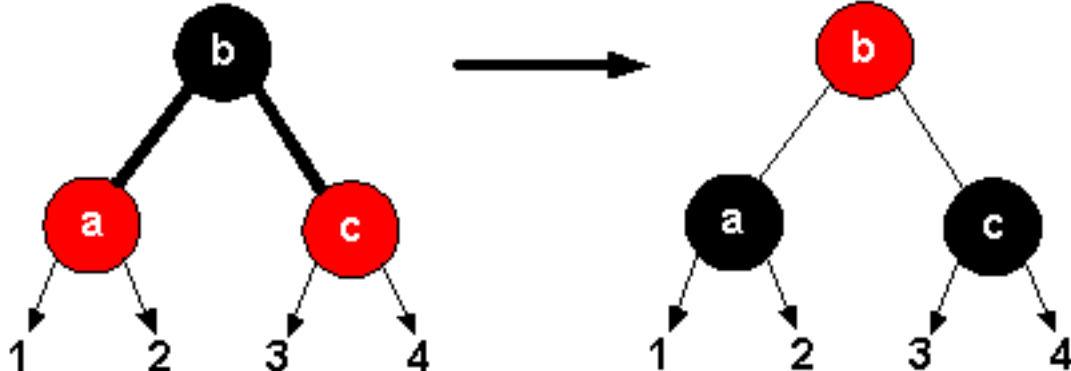


## Red-Black Nodes



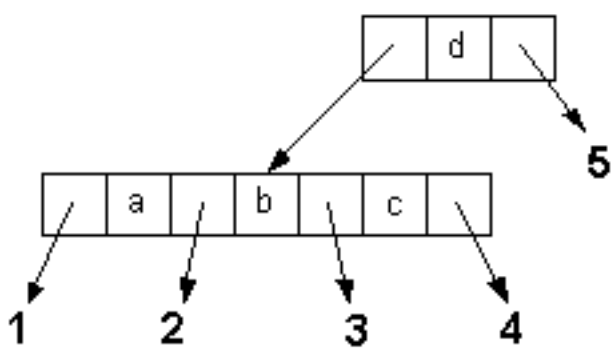
- Splitting a 4-node (implemented in a Red-Black tree) is trivial:

### Splitting a 4-node

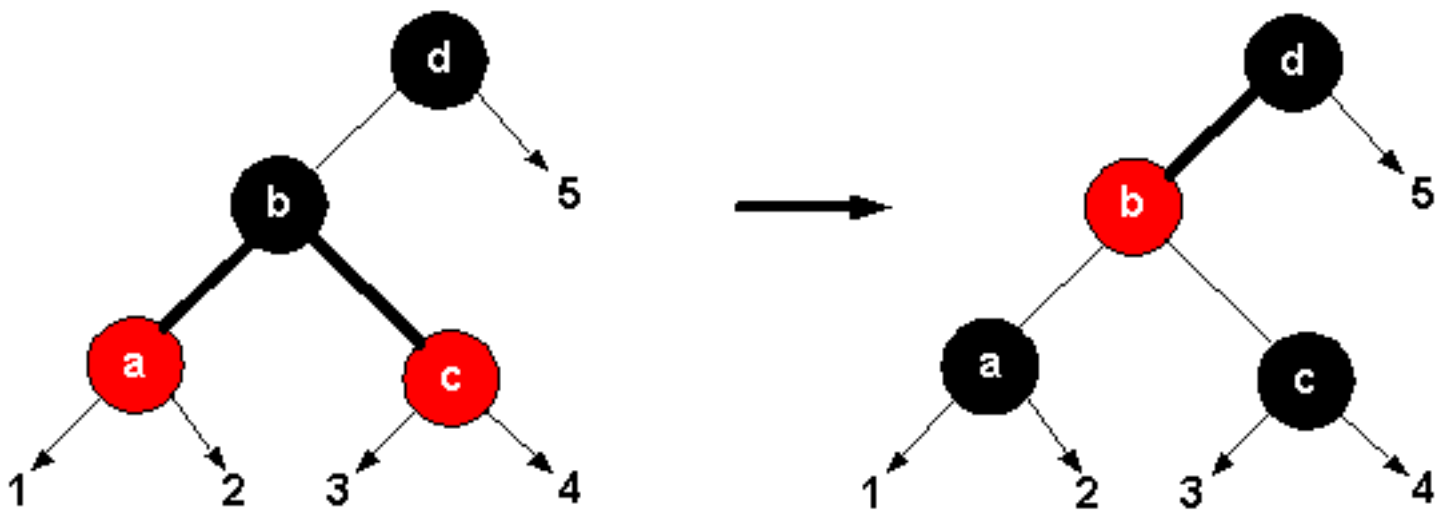


### Splitting a 4-node connected to a 2-node

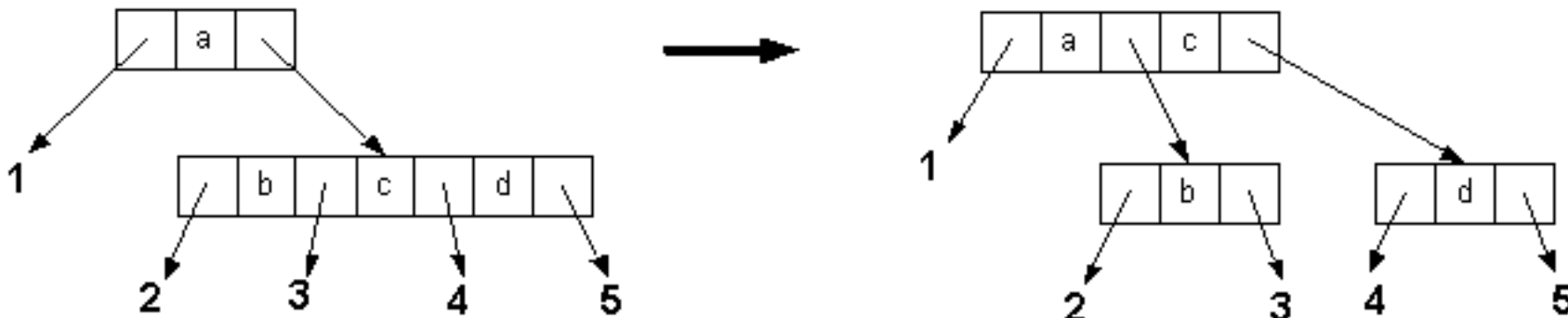
Orientation #1 (2-3-4 tree):



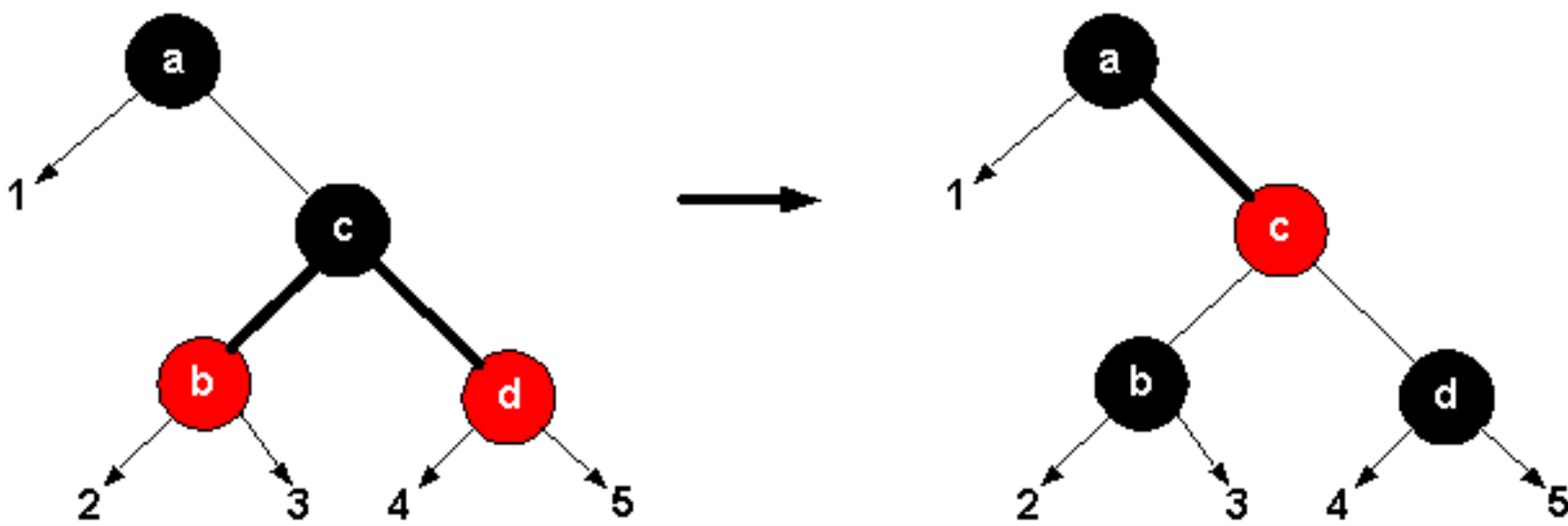
Orientation #1 (Red-Black tree):



Orientation #2 (2-3-4 tree):



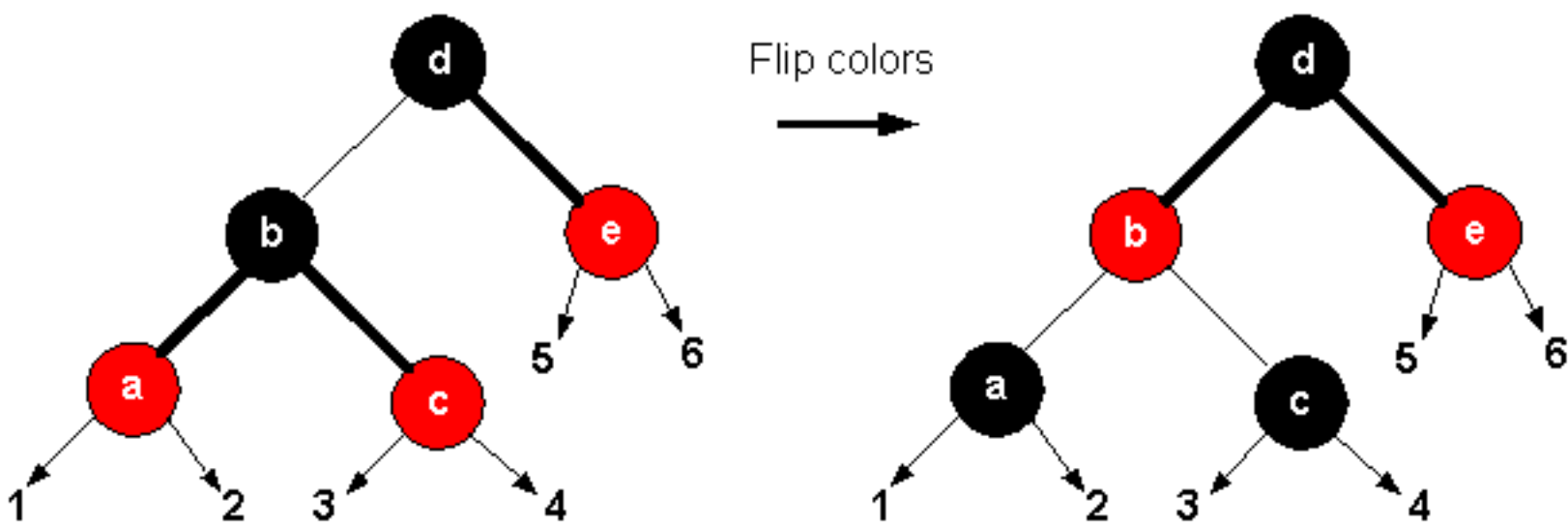
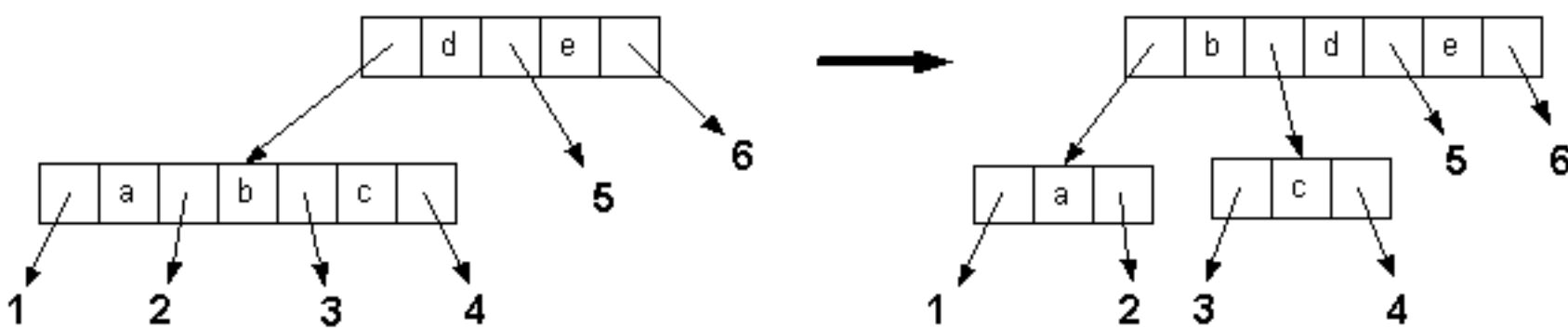
### Orientation #2 (Red-Black tree):



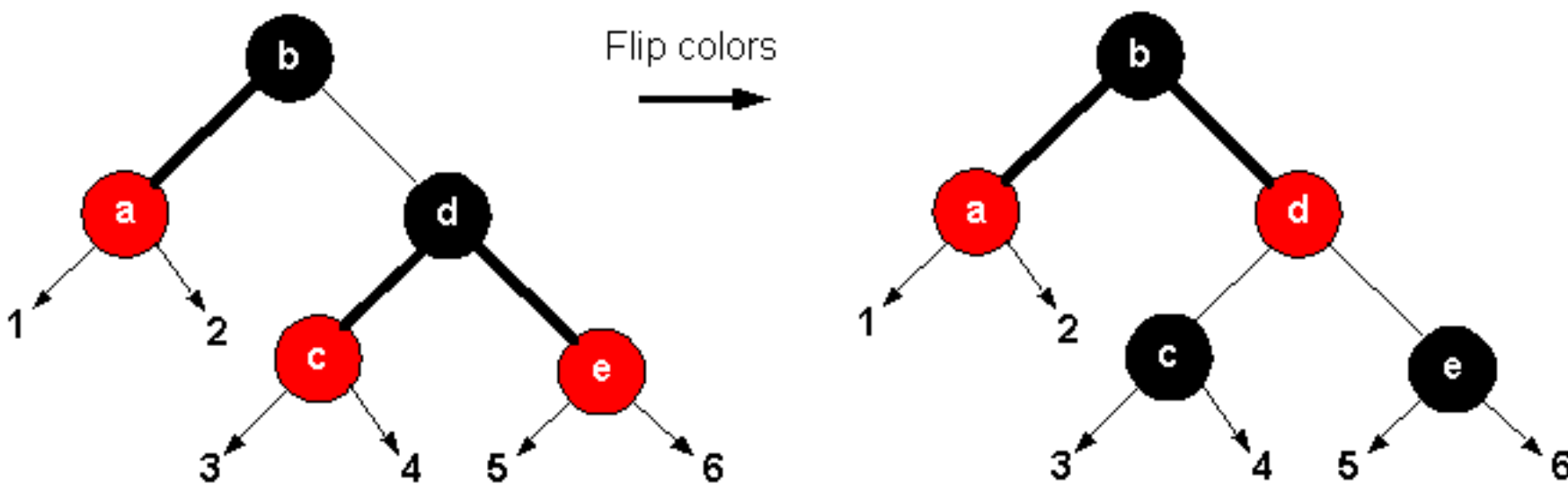
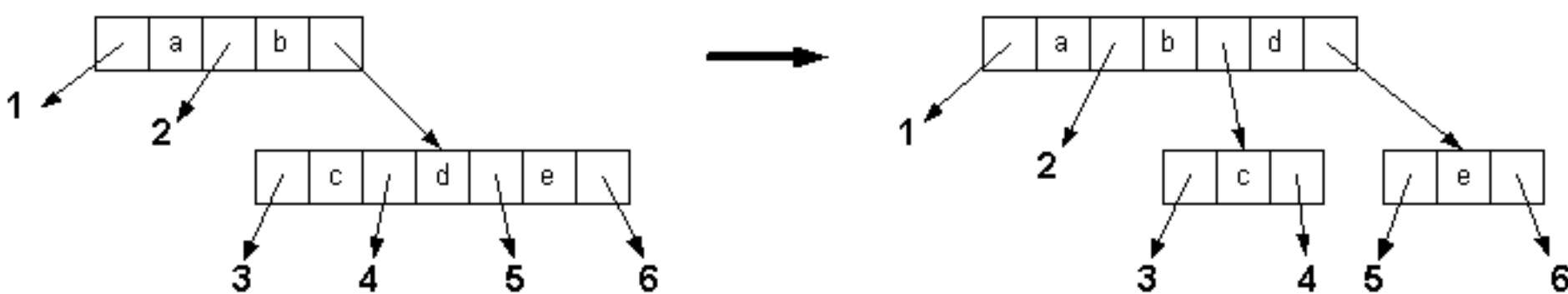
### Splitting a 4-node connected to a 3-node

## 2-3-4 Trees

Orientation #1:



### Orientation #2:



### Orientation #3:

