Name: _____

Today's Date: _____

Today's Goals

- Explain how 2-3-4 and Red-Black trees maintain balance
- Reflect on the first half of the semester – and prepare for the 2nd half!

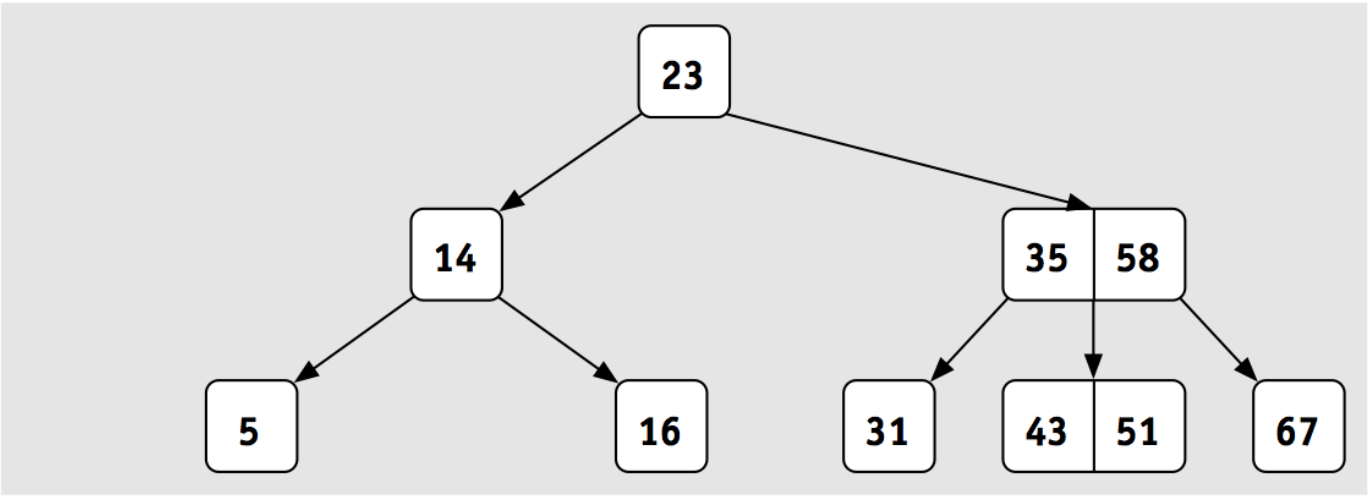
Today's Question(s)

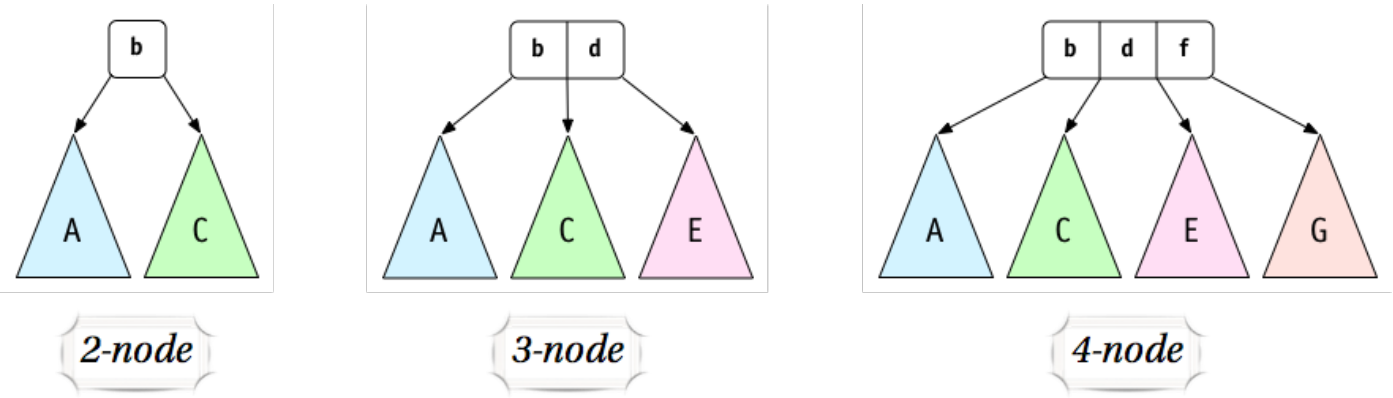
Why do we want our trees to be *balanced*?

Lingering Questions

2-3-4 Tree

Key idea: Keep all leaves at same height by allowing a node to store more than one key.





2-3-4 trees: insertion

Always keep the leaves at the same level

Top-down insert-at-leaves (balance as you go):

- If we pass a 4 node on the way down:
- If leaf is a 2 node:
- If leaf is a 3 node:
- If leaf is a 4 node:

There's also a bottom-up version that rebalances after insert.

Advantages of 2-3-4 Trees

- Leaves are always ...
- Every node is always ...
- Worst case for insert and lookup is ...

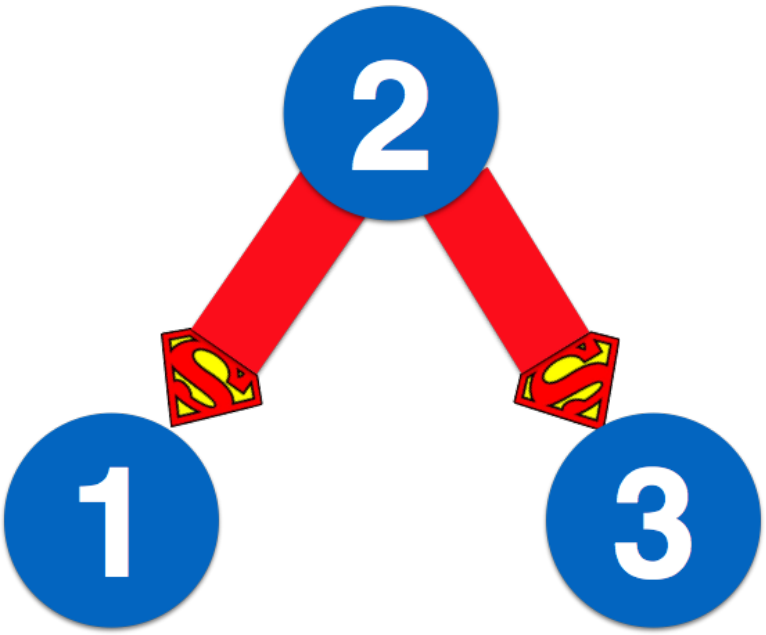
Disadvantages of 2-3-4 Trees

-
-
-

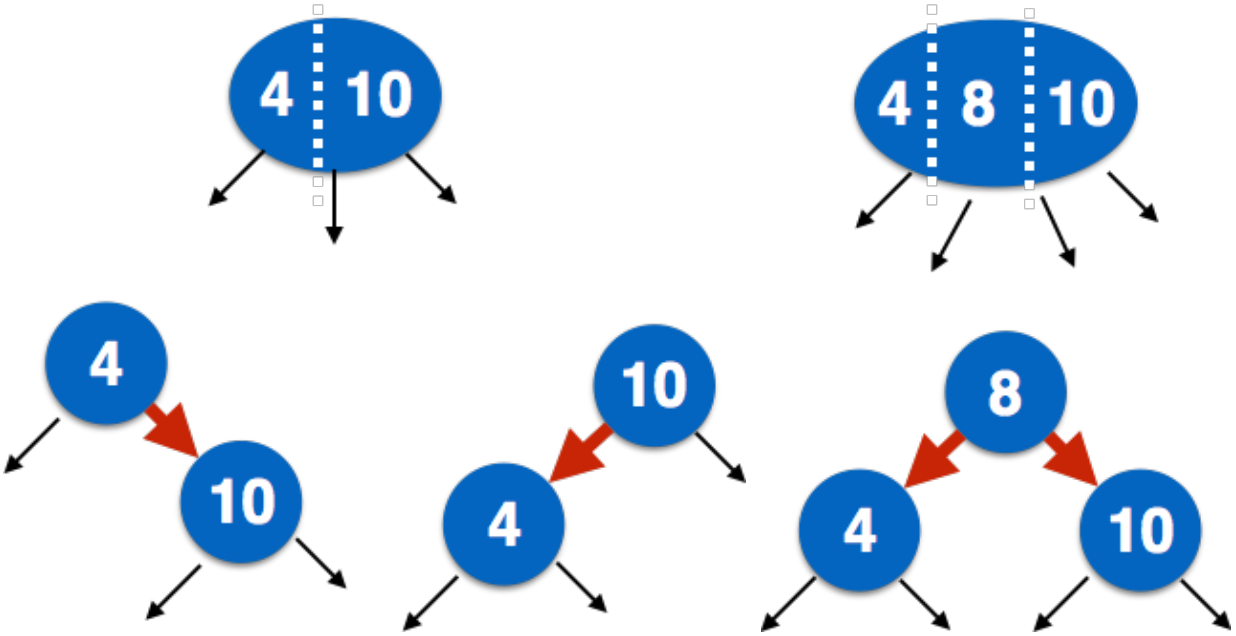
Your Turn: 2-3-4 Trees

In groups: Starting from an empty tree, draw what you get when you insert the month and day of each of your birthdays into a 2-3-4 Tree.

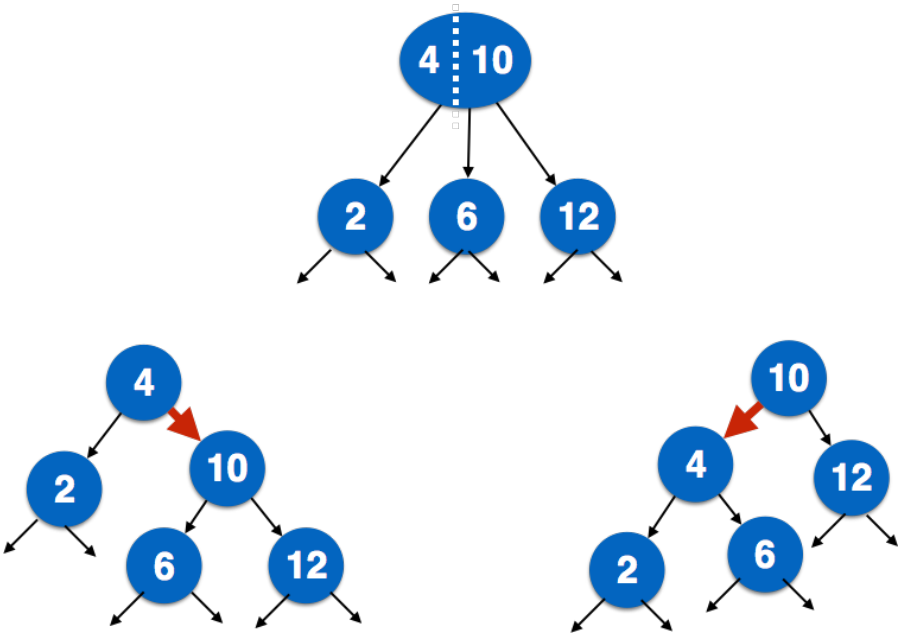
Super Links!



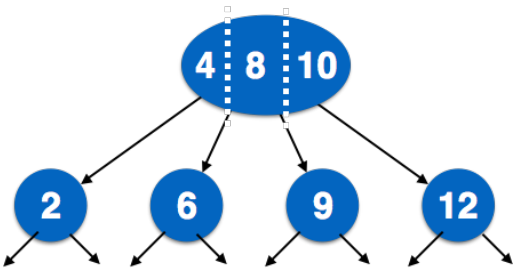
Expanding 3- and 4-Nodes

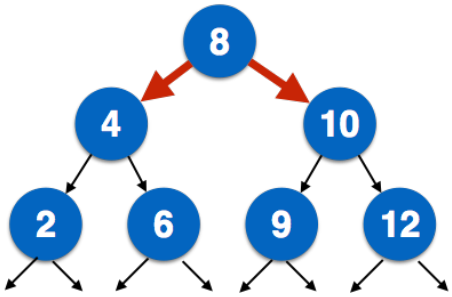


Expanded 3 node in context. . .



Expanded 4 node in context. . .



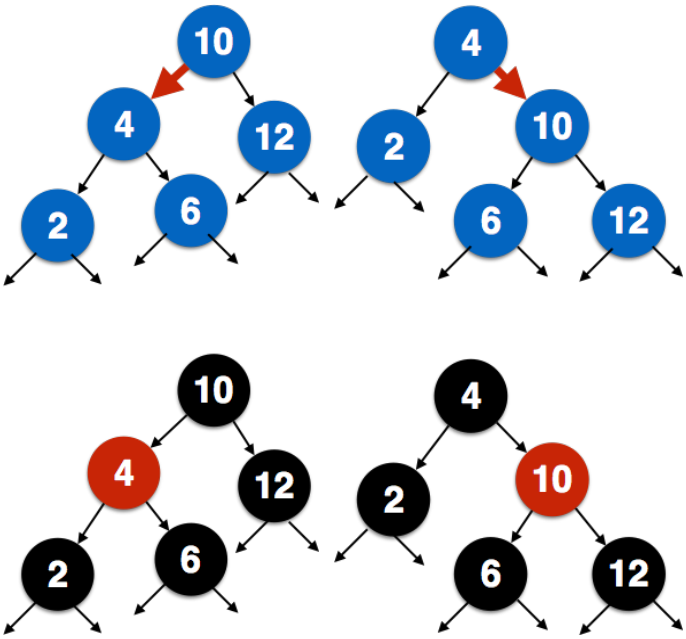


Shifting Labels to Nodes

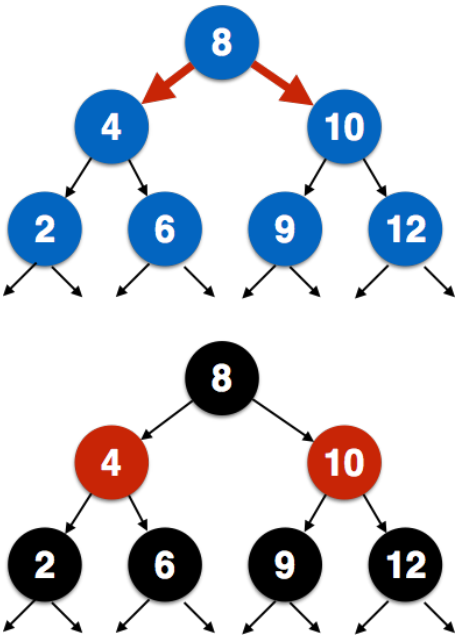
Each node has exactly one incoming edge.

Idea:

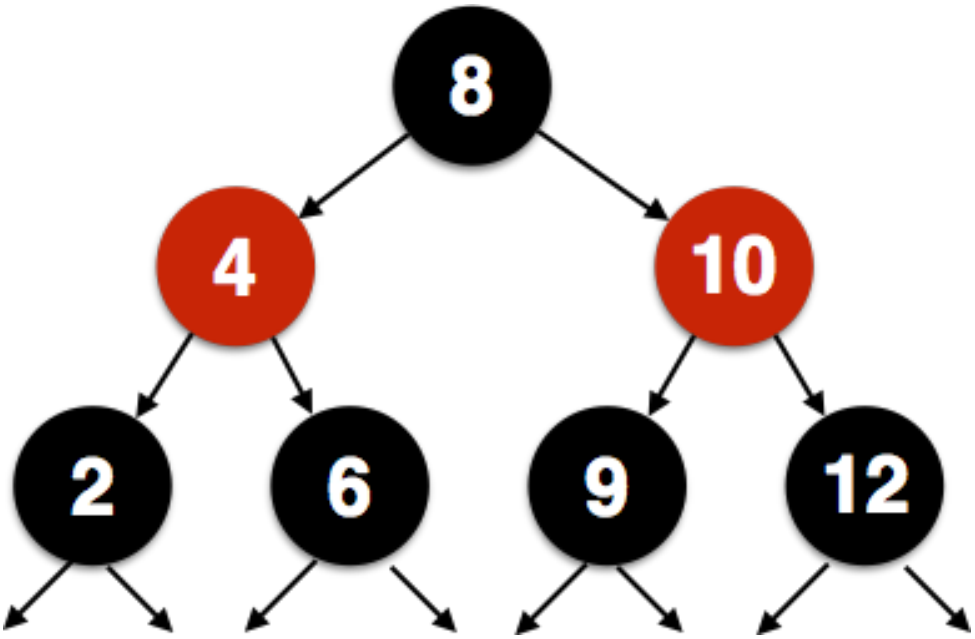
Color-filled 3-Node



Color-filled 4 node



Red-Black Trees



Red-Black Trees Defined Directly

"A red-black BST is a binary search tree in which each node is marked to be either red or black, with the additional restriction that no two red nodes appear consecutively on any path from an external link to the root." –Sedgewick

Word of Warning!

It's easy to write convoluted, messy, confusing, scary Red-Black Tree implementations!

When coding, think about what's going on. Draw diagrams. Refer back to the 2-3-4 implementation.

Advantages of Red-Black Trees

- All the advantages of 2-3-4 Trees
- Only one node type, so easier to implement

Disadvantages of Red-Black Trees

- Can be messy if you don't draw diagrams and think about the 2-3-4 equivalents during implementation.
- Rotations trickier conceptually than 2-3-4 tree operations.

Applet demo

This is the first semester that CS70 has used Docker. This change allows students to work on their own machines, instead of doing their work on the CS70 server. In deciding whether to continue this change in future semesters, what would you like us to know?

This is the first semester that CS70 has used Gradescope. This change allows students to see the results of all tests when they submit, and to re-submit their assignment as many times as they like before the deadline. In deciding whether to continue this change in future semesters, what would you like us to know?

The first 4 homework assignments this semester (Memes, Embroidery, Animation, Train) were all new this semester. In deciding whether to continue using these assignments in future semesters, what would you like us to know?

CS70 offers a variety of ways to get help. Please let us know how often you use each of the following:

- Grutoring hours: _____
- Office hours: _____
- Piazza: _____
- Other (please specify): _____

(This form continues on the other side. . .)

How have you found the *pace* of CS70 so far this semester? (1 = way too slow, 3 = just right, 5 = way too fast)

What is one thing that is working *well* for you so far this semester?

What is one thing we can do to best support your learning in the second half of the semester?

What is one thing you can do to best support your learning in the second half of the semester?

Anything else you'd like us to know?