GOOGLE SEARCH ENGINE SIMULATOR USING RED BLACK TREES

Programming Assignment 3

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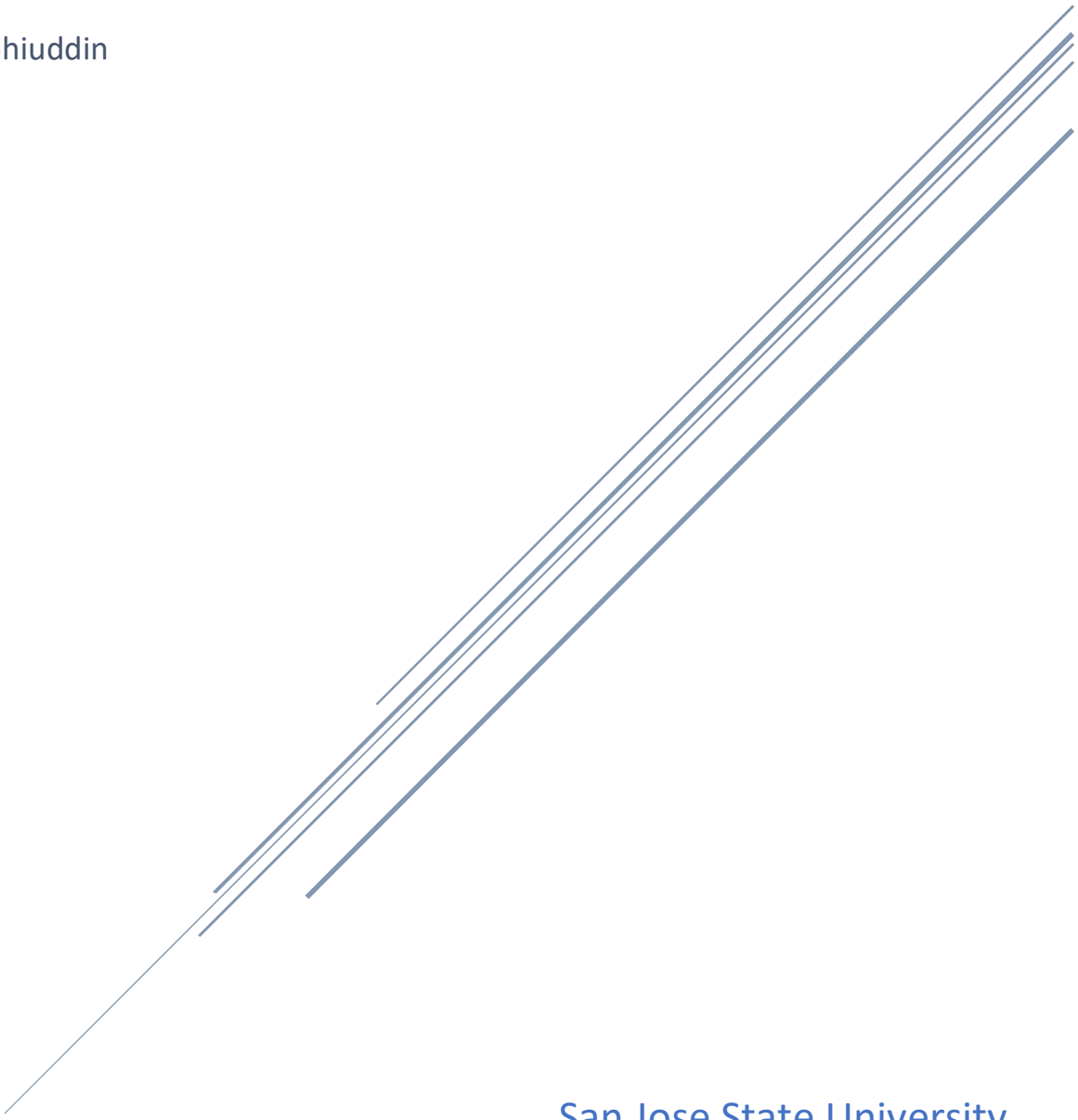

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How to Run Application

1. Unzip application
2. Open a terminal or console window
3. Change directories to the bin folder of the unzipped project
4. Execute java -jar BuildApp.jar
5. Try all options to view complete functionality of application

Implementation Overview

The Google Search Engine Simulator allows a user to conduct a search of a term they desire with five main sub functions. Once the search is submitted, a list of about 30 results are displayed to the user along with options on what to do next. These options include:

1. View results from Red Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search

The Simulator consists of six java classes and one interface: RBTree, Node, FunnyCrawler, BuildApp, WebPageURL, and Rank Interface.

The BuildApp class uses all classes (RBTree, Node, FunnyCrawler, BuildApp, and WebPageURL).

RBTree Node uses Rank Interface for its rank object and Color Enum to hold its color instance.

Test Cases

1. View search results from Red Black Tree Inorder Walk

Enter a search term: red black trees
Your term 'red black trees' found 39 results

Rank	Total Score	Index	Color	URL
39	8	34	RED	http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2
38	14	8	BLACK	https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYh
37	14	21	RED	https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvV
36	16	23	RED	http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwo
35	17	2	BLACK	https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x9
34	18	3	BLACK	https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
33	20	16	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVE
32	20	22	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou
31	20	29	RED	https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg
30	21	5	RED	https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&u
29	21	14	RED	https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&
28	21	27	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXI
27	21	37	RED	https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVa
26	22	9	RED	https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulb
25	22	30	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiDM
24	23	17	BLACK	https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXk
23	24	12	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vc
22	24	33	BLACK	https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6
21	25	26	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEy
20	25	31	BLACK	https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg
19	25	35	RED	http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqE
18	26	6	RED	https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvV
17	29	13	BLACK	https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92
16	29	19	RED	http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krk
15	30	1	BLACK	https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-h
14	30	32	RED	https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
13	30	36	BLACK	https://www.sciencedirect.com/science/article/pii/S0020019014001124&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghcMAO&usg=AOvVaw1l-
12	30	38	RED	https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJ0ZM
11	32	15	RED	http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDk
10	32	18	BLACK	http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
9	34	11	BLACK	https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw
8	34	20	RED	https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=
7	35	4	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNIVhQs
6	35	7	RED	https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg
5	36	10	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4
4	38	25	BLACK	https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-
3	40	24	RED	http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
2	41	28	BLACK	https://en.wikipedia.org/wiki/Robert_Sedgewick_(computer_scientist)&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILCgBMAQ&usg=AOvVaw2HH
1	46	39	RED	https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8lFYxymeilJ-RAOfu

Figure 1: Search results from “red black trees”

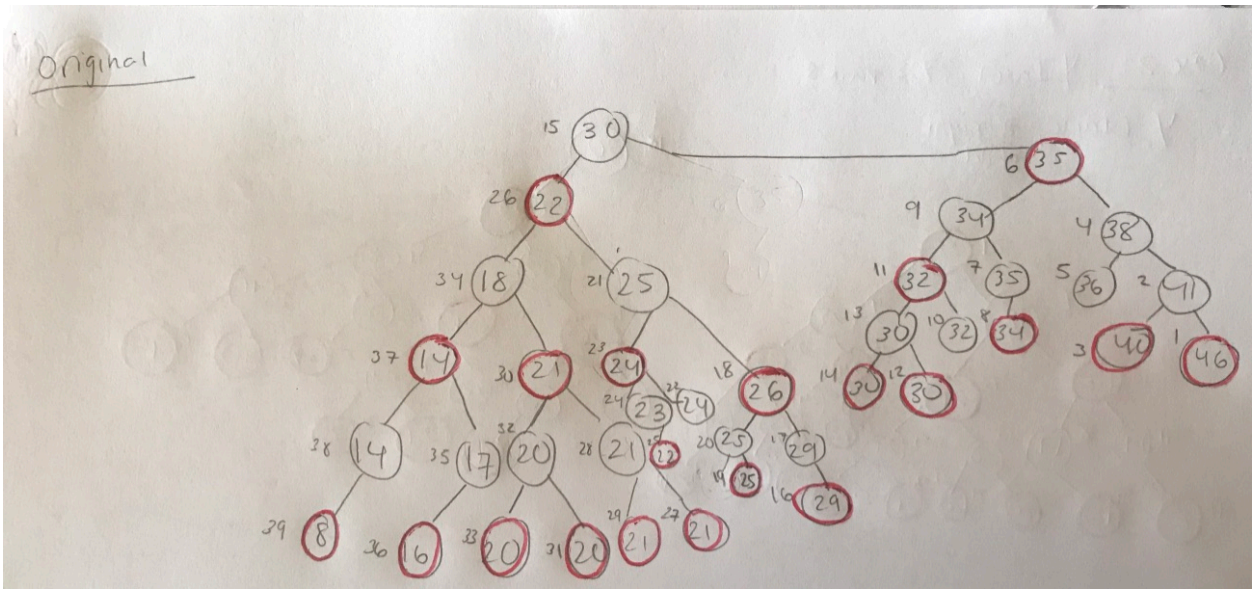

Figure 2: Drawing of search results

2. Search for a specific page rank

```
Enter a search term: google
Your term 'google' found 38 results


Rank  Total Score  Index  Color  URL
38    4            13     BLACK  https://www.google.com/docs/about/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAIIDAC&usg=AOvVaw09gYZdlwkNXddTRwWX0kMe
37    11           32     RED    https://www.android.com/tv/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghUMBA&usg=AOvVaw2X-M12EhgNxf9EEKIxzspO
36    17           15     RED    https://translate.google.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAIHjAE&usg=AOvVaw0nW5I9FZ7qjblO92_RwSOS
35    19           10     BLACK  https://classroom.google.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAIJDAD&usg=AOvVaw2IWsy4GSU-waTQPI7m-hmg
34    19           18     RED    https://www.google.com/drive/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAIHDAB&usg=AOvVaw3jLIhMLv3rivoqD4oMC6gA
33    20           12     BLACK  https://www.x.company/glass/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgg4MAs&usg=AOvVaw0-ya6YBaOetDbJrH_uyEXq
32    21           28     RED    https://www.blog.google/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghfMBI&usg=AOvVaw27XDuXjj9sHShaWjXtJ44U
31    23           17     BLACK  https://www.google.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFggVMAA&usg=AOvVaw3xZ2_X8Psw6G-ISA70Hr8V
30    23           20     RED    https://en.wikipedia.org/wiki/Google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQmhMI1wEoADAI&usg=AOvVaw14WBM8XiT-EOrAMfm0NIJS
29    24           25     RED    https://www.blog.google/technology/safety-security/project-strobe/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghkMBM&usg=AOvVaw085Etw4l_fGWIl5Pmr7JR5
28    24           30     BLACK  https://ai.google/research/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghJMA4&usg=AOvVaw1qRqce-YKcPgMEQ8p6Ne7i
27    25           2      RED    https://www.youtube.com/Google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiGATAZ&usg=AOvVaw2S5HxUY7aFZAD02IONAnpk
26    26           3      RED    https://www.blog.google/products/project-fi/bringing-google-fi-more-people-android-and-ios/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiiATAe&usg=AOvVaw1EhSpiejdkrwJS
25    26           11     BLACK  https://techspective.net/2018/03/14/5-ways-the-google-logo-has-changed-over-its-20-year-history/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQndQBCNEBMCM&usg=AOvVa
24    26           24     RED    https://github.com/google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiuATAg&usg=AOvVaw1N2FXBDMBEqnwP9Evgtk8N
23    26           27     RED    https://waymo.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiQATAb&usg=AOvVaw37MvZvrmY1A0Fxyx6keUpp
22    28           31     BLACK  https://domains.google/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghOMA8&usg=AOvVaw1O2D8AtGyeWR-5ncGHa40d
21    29           33     RED    https://www.thinkwithgoogle.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghDMA0&usg=AOvVaw0VC-rQzyZ-xB7MW8rEPJst
20    30           6      BLACK  https://www.blog.google/products/project-fi/bringing-google-fi-more-people-android-and-ios/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQqQIILjAI&usg=AOvVaw2k6qRCQBV2z
19    30           14     RED    https://techcrunch.com/2018/11/29/google-assistant-please-thank-you-santa/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgioATAf&usg=AOvVaw2FZVGCdMQjerTxwqtFVGLA
18    30           22     BLACK  https://www.facebook.com/Google/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgi0ATAh&usg=AOvVaw2VUaWIlNCeYWQxN3u9SM-9
17    30           38     RED    https://www.blog.google/outreach-initiatives/public-policy/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghwMBU&usg=AOvVaw1p5eP6dFGz_XtyducU2Cw4
16    31           4      RED    https://www.cnbc.com/2018/11/29/google-worker-strike-discussions-on-project-dragonfly-censored-search.html&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgh1MBY&usg=AO
15    32           21     BLACK  https://abc.xyz/investor/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgi5ATAi&usg=AOvVaw21HtAR2CNYLMI-xq60WMN9
14    34           1      BLACK  https://twitter.com/google%3Flang%3Den&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgg9MAw&usg=AOvVaw2PaKZu99F7AJDtWZ2BG0uS
13    34           8      BLACK  https://www.theverge.com/2018/11/30/18118711/google-strike-project-dragonfly-fundraising&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQqQIILDAH&usg=AOvVaw2cADuOQK3
12    34           16     BLACK  https://www.theverge.com/2018/11/30/18118691/google-dragonfly-employee-activism-listserv-union-strike&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQqQIIMDAJ&usg=AOvV
11    34           26     RED    https://safety.google/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiLATAa&usg=AOvVaw3w0dJX-sX-TufmQpwXVpJs
10    35           9      BLACK  https://www.blog.google/products/assistant/7-ways-google-assistant-can-help-you-survive-holidays/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghqMBQ&usg=AOvVaw3vKL9
9     36           23     RED    https://www.google.com/videohp%3Fhl%3DEN&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAIIjAF&usg=AOvVaw1xUTqrQOZDeQWbU_H9fFI-
8     39           35     BLACK  https://news.google.com/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQjBAJjAG&usg=AOvVaw3bfaKLEHuMWt85oo_v7VvS
7     40           34     RED    https://www.google.org/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFggyMAo&usg=AOvVaw0o5blz6YdGXCtWxjeGpc4s
6     41           19     RED    https://www.linkedin.com/company/google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFghaMBE&usg=AOvVaw2aTC2O20u3hxg7KyVgNybm
5     41           37     BLACK  https://en.wikipedia.org/wiki/Google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgh7MBc&usg=AOvVaw2tcwOxBg3BsfXzq8YtWSza
4     43           36     RED    https://www.theverge.com/2018/11/30/18118711/google-strike-project-dragonfly-fundraising&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQpwIIKg&usg=AOvVaw1_qOM_tK-ARRH
3     44           5      BLACK  https://www.theverge.com/2018/11/29/18117520/google-tablet-android-chrome-os-pixel-slate-failure&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiWATAc&usg=AOvVaw2HC
2     44           29     RED    https://design.google/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgiBATAY&usg=AOvVaw0U5-lCuCharuVRUSABbzEM
1     47           7      BLACK  https://www.google.es/&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQFgicATAd&usg=AOvVaw231X4N4p7ulkoREuDpzZ-U
```

Figure 3: Search results from “google”

```
Option: 2
Which Rank item would you like to display?
There are currently 38URLs

Search URL Rank: 30


Rank  Total Score  Index  Color  URL
30    23           20     RED    https://en.wikipedia.org/wiki/Google&sa=U&ved=0ahUKEwil5qXm-fzeAhWmCjQIHRQcBjcQmhMI1wEoADAI&usg=AOvVaw14WBM8XiT-EOrAMfm0NIJS
```

Figure 4: Searching for Rank 30 brings the correct URL

3. Insert a URL (based on Total Score) into search results (RBT)

Case 1: Uncle Y is Red (Insert 31 – Rank 5)

```
Option: 3
Enter a URL that starts with http:// or https://
URL: http://rabia.com
Total Score of URL: 31

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1


Rank  Total Score  Index  Color  URL
40    8            34     RED    http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMCFho6Je41CPtR
39    14           8      BLACK  https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5tHKen3rR5dxOt
38    14           21     RED    https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0cmKqrdANHXP
37    16           23     RED    http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4onWrbLxuRGlgF
36    17           2      BLACK  https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93wKu7lnufb3Em5U
35    18           3      BLACK  https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
34    20           16     RED    https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6MMjgCgO_APqZ
33    20           22     BLACK  https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O71KhGrDe0M1a
32    20           29     RED    https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AOvVaw3GDq_qO
31    21           5      RED    https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=AOvVaw0baKcl
30    21           14     RED    https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&usg=AOvVaw1WJbv
29    21           27     BLACK  https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXIP2p6Oyv
28    21           37     RED    https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2HQpmU9G8lRrx
27    22           9      RED    https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulbFCeVWu2IK
26    22           30     RED    https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1lG_fUnJiDMIk8z55GWfnZ
25    23           17     BLACK  https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMK
24    24           12     RED    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8cGa89z7R1K8jW
23    24           33     BLACK  https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw0BBF6OFmyVFOqpcPL67
22    25           26     BLACK  https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWjeSShmnONO
21    25           31     BLACK  https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AOvVaw1xsS2t7y
20    25           35     RED    http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLIqEUbkFjWgk6t_33X1
19    26           6      RED    https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILjDMAQ&usg=AOvVaw1h_6pewe_4arpp
18    29           13     BLACK  https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ7WTHbA2ojTyd
17    29           19     RED    http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krkX4NtHDEHhkGskV
16    30           1      BLACK  https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-hTsntaV7EU4t
15    30           32     BLACK  https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrIXnVI92
14    30           36     RED    https://www.sciencedirect.com/science/article/pii/S0020019014001124&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghcMA0&usg=AOvVaw1l-2JgeLKWcBGZvJGA
13    30           38     BLACK  https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJOZMD9l
12    31           39     RED    http://rabia.com
11    32           15     BLACK  http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVThb289r6aWTaKDKe
10    32           18     BLACK  http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
9     34           11     RED    https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30mGsBMqr7rXQLW
8     34           20     RED    https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AOvVaw0YQSX9aS
7     35           4      BLACK  https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNlVhQsRZQGKT1LW0k
6     35           7      RED    https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AOvVaw3ykqPAoY
5     36           10     BLACK  https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggIMAQ&usg=AOvVaw2B1E7yn4j4NgmrCEYHXNEU
4     38           25     BLACK  https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
3     40           24     RED    http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgIgATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
2     41           28     BLACK  https://en.wikipedia.org/wiki/Robert_Sedgewick_(computer_scientist)&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILCgBMAQ&usg=AOvVaw2HhxPG9Tb_v4j1WWD
1     46           39     RED    https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8lFYxvmeiLJ-RAQfu
```

Figure 5: Inserting URL with total score of 31 into tree from Figure 1 and 2

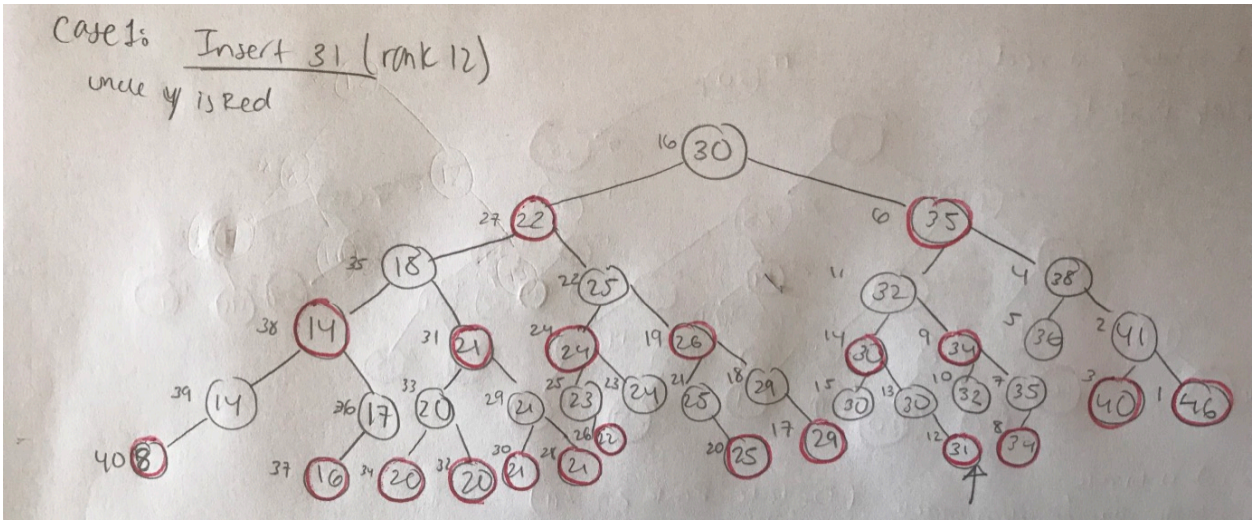

Figure 6: Drawing of tree after insertion

Case 2: Y Black, Z right child (Insert 37)

```
Option: 3
Enter a URL that starts with http:// or https://
URL: http://thirtyseven.com
Total Score of URL: 37

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1
```

Rank	Total Score	Index	Color	URL
42	8	34	RED	http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMCFho6Je41CPtR
41	14	8	BLACK	https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5tHKen3rR5dxOt
40	14	21	RED	https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0cmKqrdANHXP
39	16	23	RED	http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4onWrbLxuRGlgF
38	17	2	BLACK	https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93wKu7lnufb3Em5U
37	18	3	BLACK	https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
36	20	16	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6MMjgCgO_APqZ
35	20	22	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O71KhGrDe0M1a
34	20	29	RED	https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AOvVaw3GDq_q0
33	21	5	RED	https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=AOvVaw0baKcv
32	21	14	RED	https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&usg=AOvVaw1WJbv
31	21	27	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIlNzAG&usg=AOvVaw0zx0mrdgXtw_VXlP2p6Oyv
30	21	37	RED	https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2HQpmU9G8lRrx
29	22	9	RED	https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulbFCeVWu2lK
28	22	30	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiDMlk8z55GWfnZ
27	23	17	BLACK	https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMK
26	24	12	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8cGa89z7R1K8jW
25	24	33	BLACK	https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6OFmyVF0qpcPL67
24	25	26	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWjeS5hmnONO
23	25	31	BLACK	https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AOvVaw1xsS2t7y
22	25	35	RED	http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqEUbkFjWgk6t_33X1
21	26	6	RED	https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvVaw1h_6pewe_4arpp
20	29	13	BLACK	https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ7WTHbA2ojTyd
19	29	19	RED	http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krkX4NtHDEHhkGskV
18	30	1	BLACK	https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-hTsntaV7EU4t
17	30	32	BLACK	https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
16	30	36	RED	https://www.sciencedirect.com/science/article/pii/S0020019014001124&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghcMA0&usg=AOvVaw1I-2JgeLKWcBGZvJGA
15	30	38	BLACK	https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJ0ZMD9I
14	31	39	RED	http://rabia.com
13	32	15	BLACK	http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDKe
12	32	18	BLACK	http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JlRN
11	34	11	RED	https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30mGsBMqr7rXQL
10	34	20	RED	https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AOvVaw0YQSX9a
9	34	40	BLACK	http://thirtyfour.com
8	35	4	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNIVhQsRZQGKT1LW0k
7	35	7	RED	https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AOvVaw3ykqPAoY
6	36	10	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4NgmrCEYHXNEU
5	37	41	RED	http://thirtyseven.com
4	38	25	BLACK	https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
3	40	24	RED	http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
2	41	28	BLACK	https://en.wikipedia.org/wiki/Robert_Sedgewick_(computer_scientist)&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILCgBMAQ&usg=AOvVaw2HhxPG9Tb_v4j1WWD
1	46	39	RED	https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8lFYxymeiIJ-RAOfu

Figure 7: Insert URL with score 37 into results from Figure 1

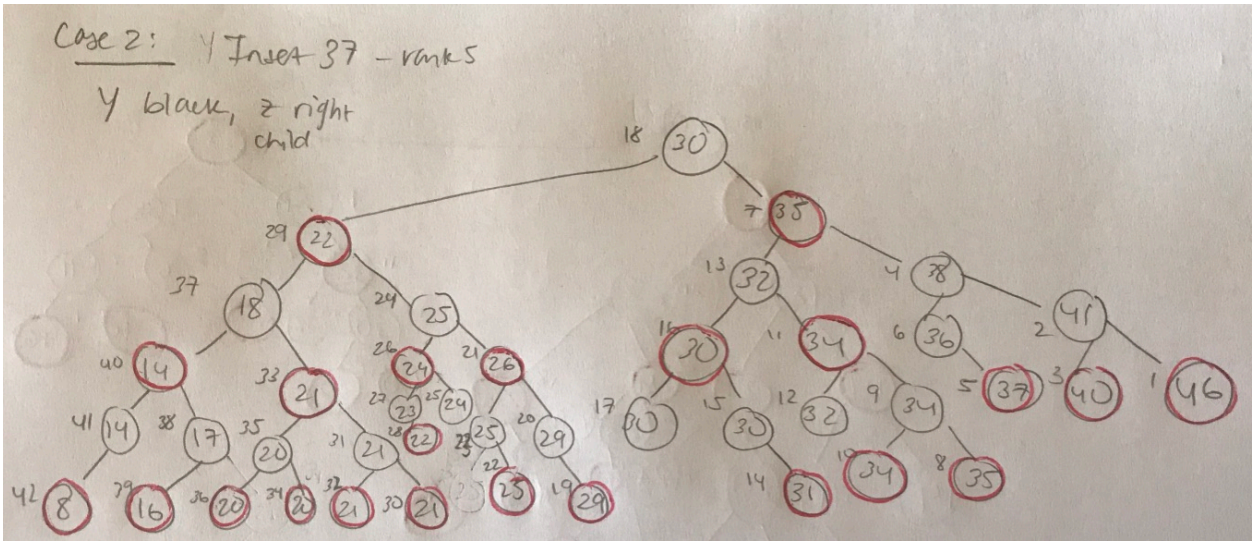

Figure 8: Draw tree from Figure 7 after insertion of 37

Case 3: Y Black, Z left child (Insert 34 – Rank 4)

```
Option: 3
Enter a URL that starts with http:// or https://
URL: http://thirtyfive.com
Total Score of URL: 35

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1


Rank  Total Score  Index  Color  URL
41    8            34     RED    http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMCFho6Je41CPt
40    14           8      BLACK    https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5tHKen3rR5dxO
39    14           21     RED      https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0cmKqrdANHX
38    16           23     RED      http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4onWrbLxuRGlg
37    17           2      BLACK    https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93wKu7lnufb3EmE
36    18           3      BLACK    https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
35    20           16     RED      https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6MMjgCgO_APq
34    20           22     BLACK      https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O71KhGrDe0M1
33    20           29     RED      https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AOvVaw3GDq_q
32    21           5      RED    https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=AOvVaw0baKc
31    21           14     RED      https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&usg=AOvVaw1WJE
30    21           27     BLACK      https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXlP2p6Oyv
29    21           37     RED      https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2HQpmU9G8IRr
28    22           9      RED    https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulbFCeVWu2IK
27    22           30     RED      https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiDMIk8z55GWfnZ
26    23           17     BLACK      https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMK
25    24           12     RED      https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8cGa89z7R1K8j
24    24           33     BLACK      https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6OFmyVF0qpcPL6
23    25           26     BLACK      https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWjeS5hmnONO
22    25           31     BLACK      https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AOvVaw1xsS2t7
21    25           35     RED      http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqEUbkFjWgk6t_33X
20    26           6      RED    https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvVaw1h_6pewe_4arp
19    29           13     BLACK      https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ7WTHbA2ojTy
18    29           19     RED      http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krkX4NtHDEHhkGsk
17    30           1      BLACK      https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-hTsntaV7EU4t
16    30           32     BLACK      https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
15    30           36     RED      https://www.sciencedirect.com/science/article/pii/S0020019014001124&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghcMA0&usg=AOvVaw1l-2JgeLKWcBGZvJG
14    30           38     BLACK      https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJOZMD9I
13    31           39     RED      http://rabia.com
12    32           15     BLACK      http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDKe
11    32           18     BLACK      http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
10    34           11     RED      https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30mGsBMqr7rXQ
9     34           20     RED      https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AOvVaw0YQSX9a
8     35           4      BLACK    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNlVhQsRZQGKT1LW0k
7     35           7      RED    https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AOvVaw3ykqPAo
6     35           40     RED      http://thirtyfive.com
5     36           10     BLACK      https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4NgmrCEYHXNEU
4     38           25     BLACK      https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
3     40           24     RED      http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
2     41           28     BLACK      https://en.wikipedia.org/wiki/Robert_Sedgewick_(computer_scientist)&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILCgBMAQ&usg=AOvVaw2HhxPG9Tb_v4j1WW
1     46           39     RED      https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8lFYxymeiIJ-RAOfu
```

Figure 9: Insert URL with score 35 into results from Figure 1

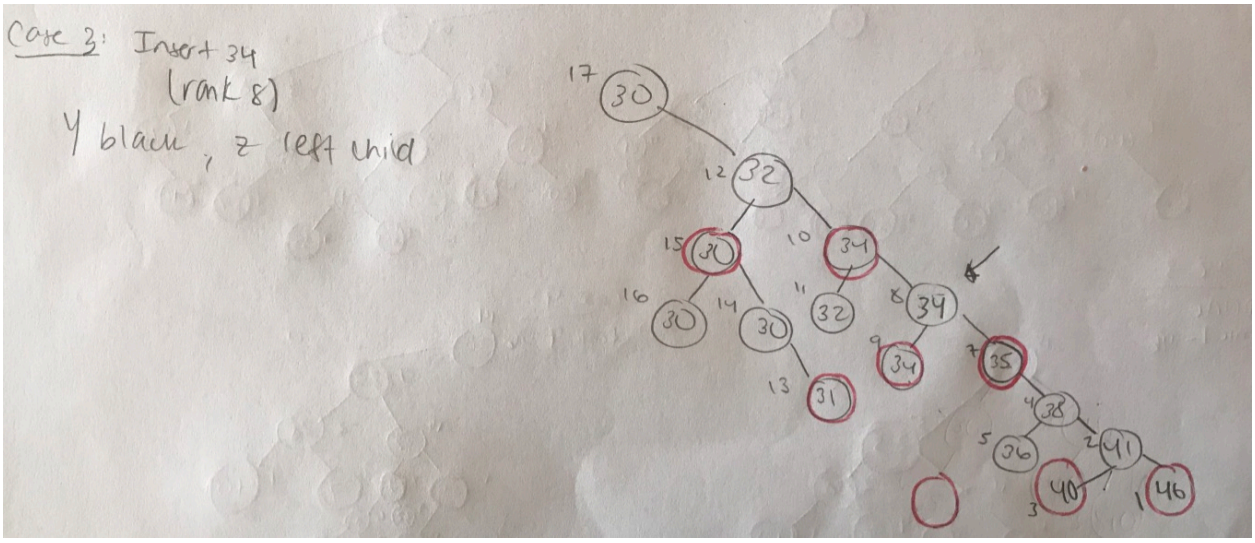

Figure 10: Drawing of tree after insertion from Figure 9

4. Delete a URL (based on Page Rank) from search results (RBT)

Case 1: X sibling W is Red

```
Which Rank item would you like to delete?
There are currently 42 URLs

Delete URL Rank: 16
Rank item 16 was deleted

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1
```

Rank	Total Score	Index	Color	URL
41	8	34	RED	http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMCFho6Je41CPtRXiPAC
40	14	8	BLACK	https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5tHKen3rR5dxOt
39	14	21	RED	https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0cmKqrdANHXPaiiJ-2
38	16	23	RED	http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4onWrbLxuRGlgFO
37	17	2	BLACK	https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93wKu7lnufb3Em5LNlnT
36	18	3	BLACK	https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
35	20	16	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6MMjgCgO_APqZbN
34	20	22	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O71KhGrDe0M1auBJG
33	20	29	RED	https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AOvVaw3GDq_q0FsgpE
32	21	5	RED	https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=AOvVaw0baKclvNQ0
31	21	14	RED	https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&usg=AOvVaw1WJbwn1Hy
30	21	27	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXIP2p6Oyv
29	21	37	RED	https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2HQpmU9G8lRrxTyPZS
28	22	9	RED	https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulbFCeVWu2IK
27	22	30	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiDMlk8z55GWfnZ
26	23	17	BLACK	https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC
25	24	12	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8cGa89z7R1K8jW
24	24	33	BLACK	https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6OFmyVF0qpcPL678q8
23	25	26	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWjeS5hmnONO
22	25	31	BLACK	https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AOvVaw1xsS2t7yHjUiq
21	25	35	RED	http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqEUbkFjWgk6t_33X1
20	26	6	RED	https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvVaw1h_6pewe_4arppKJdX
19	29	13	BLACK	https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ7WTHbA2ojTydyjBm
18	29	19	RED	http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1rkX4NtHDEHhkGskVFFep
17	30	1	BLACK	https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgIHcI5B-hTsntaV7EU4t
16	30	32	BLACK	https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
15	30	38	RED	https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJ0ZMD9I
14	31	39	RED	http://rabia.com
13	32	15	BLACK	http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDKe
12	32	18	BLACK	http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JlRN
11	34	11	RED	https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30mGsBMqr7rXQLWCv2
10	34	20	RED	https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AOvVaw0YQSX9aS1Zi4
9	34	40	BLACK	http://thirtyfour.com
8	35	4	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNlVhQsRZQGKT1LW0k
7	35	7	RED	https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AOvVaw3ykqPAoYCySg
6	36	10	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4NgmrCEYHXNEU
5	37	41	RED	http://thirtyseven.com
4	38	25	BLACK	https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
3	40	24	RED	http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
2	41	28	BLACK	https://en.wikipedia.org/wiki/Robert_Sedgewick_(computer_scientist)&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILCgBMAQ&usg=AOvVaw2HhxPG9Tb_v4j1WWDAN4H
1	46	39	RED	https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8lFYxymeiIJ-RAOfu

Figure 11: Delete URL Rank 16 from results of Figure 9

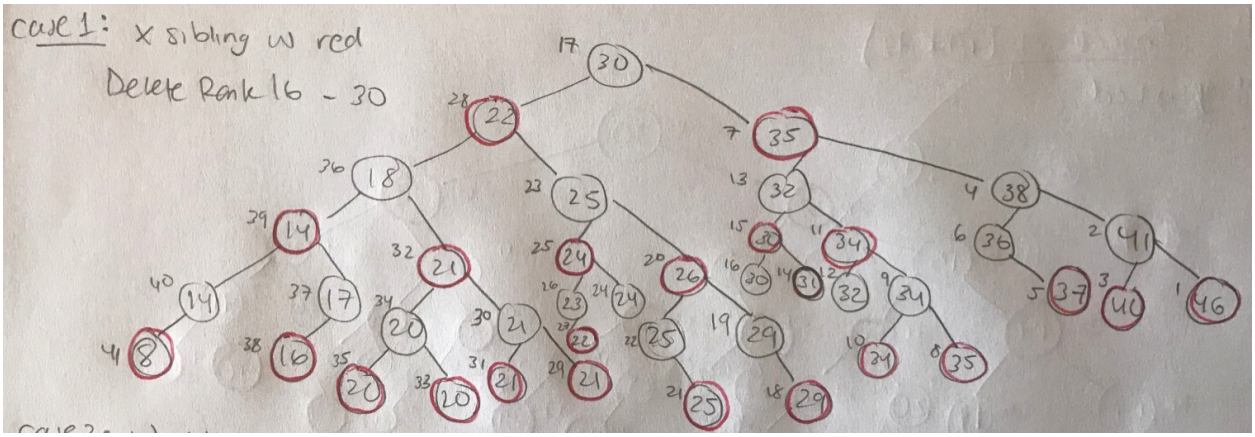

Figure 12: Drawing of tree after deletion from Figure 11

Case 2: W is black, both W's children are black

```
Option: 4
Which Rank item would you like to delete?
There are currently 41 URLs

Delete URL Rank: 2
Rank item 2 was deleted

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1

Rank  Total Score  Index  Color  URL
40    8            34     RED    http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMC
39    14           8      BLACK    https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5t
38    14           21     RED    https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0
37    16           23     RED    http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4
36    17           2      BLACK    https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93w
35    18           3      BLACK    https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
34    20           16     RED    https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6N
33    20           22     BLACK    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O7
32    20           29     RED    https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AO
31    21           5      RED    https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=
30    21           14     RED    https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc&usg=
29    21           27     BLACK    https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXIP2p
28    21           37     RED    https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2
27    22           9      RED    https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNulbFC
26    22           30     RED    https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiDMIk8
25    23           17     BLACK    https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0
24    24           12     RED    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8c
23    24           33     BLACK    https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6OFr
22    25           26     BLACK    https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWje
21    25           31     BLACK    https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AO
20    25           35     RED    http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqEUbk
19    26           6      RED    https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvVaw1
18    29           13     BLACK    https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ
17    29           19     RED    http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krkX4
16    30           1      BLACK    https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-hTsn
15    30           32     BLACK    https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
14    30           38     RED    https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJ0ZMD9
13    31           39     RED    http://rabia.com
12    32           15     BLACK    http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDKe
11    32           18     BLACK    http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
10    34           11     RED    https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30m
9     34           20     RED    https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AO
8     34           40     BLACK    http://thirtyfour.com
7     35           4      RED    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNIVhQsRZQ
6     35           7      RED    https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AO
5     36           10     BLACK    https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4Ngn
4     37           41     RED    http://thirtyseven.com
3     38           25     BLACK    https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
2     40           24     RED    http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA
1     46           39     BLACK    https://brilliant.org/wiki/red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiPATAX&usg=AOvVaw1ZKwJ8IFYxymeiIJ-RAOfu
```

Figure 13: Delete URL Rank 2 from results shown in Figure 11

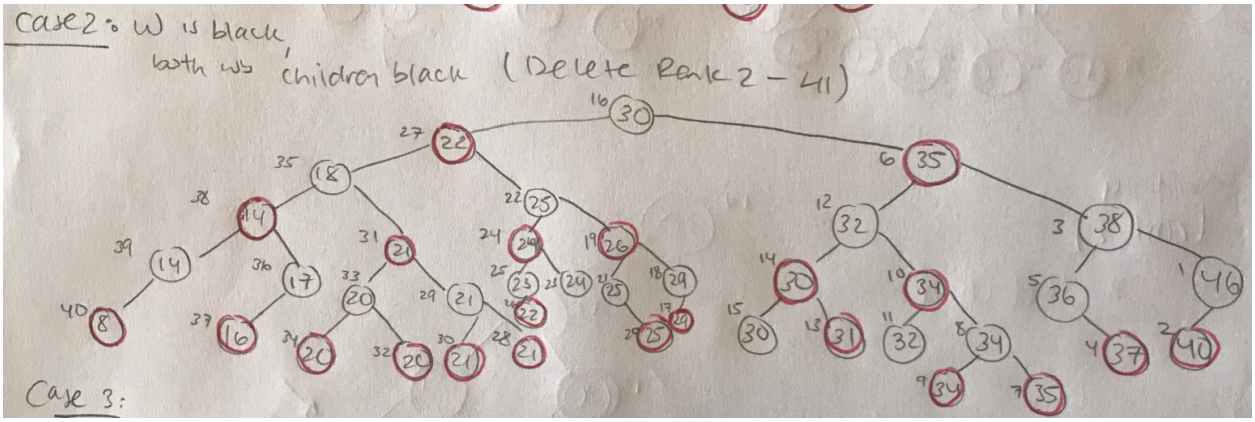

Figure 14: Draw tree resulting from deletion in Figure 13

Case 3: W is black, W's left child is Red, W's right child is black

```
Option: 4
Which Rank item would you like to delete?
There are currently 40 URLs

Delete URL Rank: 1
Rank item 1 was deleted

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1
```

Rank	Total Score	Index	Color	URL
39	8	34	RED	http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw2fMCFho6Je41C
38	14	8	BLACK	https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmYhp5tHKen3rR5dx
37	14	21	RED	https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AOvVaw0cmKqrdANH
36	16	23	RED	http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVwqm4onWrbLxuRG
35	17	2	BLACK	https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1x93wKu7lnufb3Er
34	18	3	BLACK	https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
33	20	16	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelVEE6MMjgCgO_AF
32	20	22	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0aou1O71KhGrDeOM
31	20	29	RED	https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&usg=AOvVaw3GDq
30	21	5	RED	https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM&usg=AOvVaw0ba
29	21	14	RED	https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggGMAc&usg=AOvVaw1W
28	21	27	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VXIP2p6Oyv
27	21	37	RED	https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvVaw2HQpmU9G8I
26	22	9	RED	https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNuIbFCeVWu2IK
25	22	30	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1G_fUnJiDMlk8z55GWfnZ
24	23	17	BLACK	https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5Y
23	24	12	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5Vci8cGa89z7R1K
22	24	33	BLACK	https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08BF6OFmyVF0qpcPU
21	25	26	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NLEyWjeS5hmnONO
20	25	31	BLACK	https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&usg=AOvVaw1xsS2
19	25	35	RED	http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLlqEUbkFjWgk6t_33
18	26	6	RED	https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOvVaw1h_6pewe_4a
17	29	13	BLACK	https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1u92QZ7WTHbA2oj
16	29	19	RED	http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1krkX4NtHDEHhkGs
15	30	1	BLACK	https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B-hTsntaV7EU4t
14	30	32	BLACK	https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVI92
13	30	38	RED	https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJ0ZMD9I
12	31	39	RED	http://rabia.com
11	32	15	BLACK	http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTaKDKe
10	32	18	BLACK	http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
9	34	11	RED	https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw30mGsBMqr7rX
8	34	20	RED	https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&usg=AOvVaw0YQSX
7	34	40	BLACK	http://thirtyfour.com
6	35	4	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNlVhQsRZQGKT1LW0k
5	35	7	RED	https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&usg=AOvVaw3ykqP
4	36	10	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgglMAQ&usg=AOvVaw2B1E7yn4j4NgmrCEYHXNE
3	37	41	RED	http://thirtyseven.com
2	38	25	BLACK	https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS-z
1	40	24	RED	http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA

Figure 15: Delete URL Rank 1 from tree shown in Figure 13

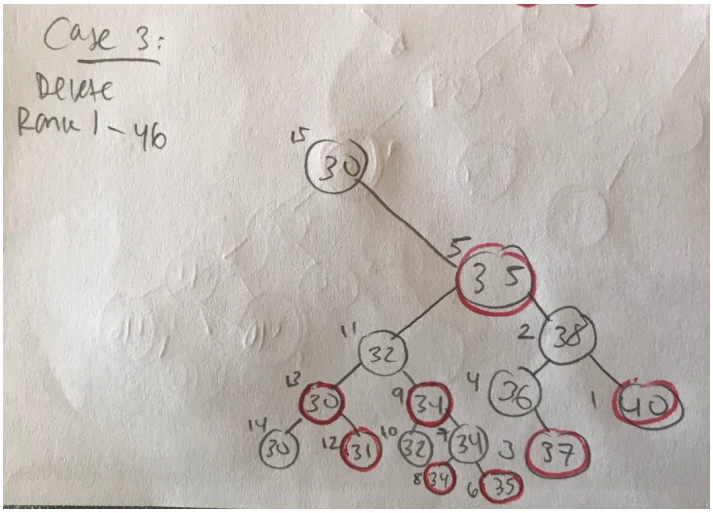

Figure 16: Drawing of tree after deletion from results shown in Figure 15

Case 4: W is black, W's right child is Red

```
Option: 4
Which Rank item would you like to delete?
There are currently 39 URLs

Delete URL Rank: 4
Rank item 4 was deleted

What would you like to do next?
1. View results from Red-Black Tree Inorder Walk
2. Search for a specific page rank
3. Insert a URL (based on Total Score) into search results (RBT)
4. Delete a URL (based on Page Rank) from search results (RBT)
5. Run another search
0. Quit

Option: 1
```

Rank	Total Score	Index	Color	URL
38	8	34	RED	http://www.eternallyconfuzzled.com/tuts/datastructures/jsw_tut_rbtree.aspx&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghWMAw&usg=AOvVaw
37	14	8	BLACK	https://www.d.umn.edu/~gshute/ds/binary-tree/red-black-tree.xhtml&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgisATAc&usg=AOvVaw3FlAmY
36	14	21	RED	https://www.sanfoundry.com/data-structure-questions-answers-red-black-tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgimATAb&usg=AO
35	16	23	RED	http://staff.ustc.edu.cn/~csli/graduate/algorithms/book6/chap14.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghgMA8&usg=AOvVaw0QJVv
34	17	2	BLACK	https://www.sciencedirect.com/science/article/pii/S0743731512002912&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgheMA4&usg=AOvVaw1
33	18	3	BLACK	https://en.wikipedia.org/wiki/Rudolf_Bayer&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIIKygAMAQ&usg=AOvVaw3DBZB_eDU91tA2J62FzrFD
32	20	16	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQndQBCNkBMCE&usg=AOvVaw2gelV
31	20	22	BLACK	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQmhMI3gEoADAj&usg=AOvVaw0ao
30	20	29	RED	https://cs.stackexchange.com/questions/62626/why-is-this-not-a-valid-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiyATAd&us
29	21	5	RED	https://github.com/raywenderlich/swift-algorithm-club/tree/master/Red-Black%2520Tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh4MBM8
28	21	14	RED	https://towardsdatascience.com/red-black-binary-tree-maintaining-balance-e342f5aa6f5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgg6MAc
27	21	27	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQtwIINzAG&usg=AOvVaw0zx0mrdgXtw_VX
26	21	37	RED	https://www.usna.edu/Users/cs/crabbe/SI321/current/red-black/red-black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghsMBE&usg=AOvV
25	22	9	RED	https://www.cs.usfca.edu/~galles/visualization/RedBlack.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghLMAo&usg=AOvVaw3RCsCGKmxNu
24	22	30	RED	https://www.cs.auckland.ac.nz/software/AlgAnim/red_black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggwMAU&usg=AOvVaw1IG_fUnJiD
23	23	17	BLACK	https://www.topcoder.com/community/competitive-programming/tutorials/an-introduction-to-binary-search-and-red-black-trees/&sa=U&ved=0ahUKEwiX
22	24	12	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQqoUBCBkwAA&usg=AOvVaw0UYr5
21	24	33	BLACK	https://www.geeksforgeeks.org/red-black-tree-set-1-introduction-2/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgggMAM&usg=AOvVaw08B
20	25	26	BLACK	https://www.youtube.com/watch%3Fv%3DqvZGUFHWChY&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQuAIIODAGUAE&usg=AOvVaw2RGDI3_NL
19	25	31	BLACK	https://en.wikipedia.org/wiki/2%25E2%2580%25933%25E2%2580%25934_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILSgCMAQ&us
18	25	35	RED	http://www.eecs.umich.edu/courses/eecs380/ALG/niemann/s_rbt.htm&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiVATAY&usg=AOvVaw1VeLIc
17	26	6	RED	https://en.wikipedia.org/wiki/Left-leaning_red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQ0gIILigDMAQ&usg=AOv
16	29	13	BLACK	https://pages.cs.wisc.edu/~deppeler/cs400/readings/Red-Black-Trees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghGMAk&usg=AOvVaw1uS
15	29	19	RED	http://www.dgp.toronto.edu/people/JamesStewart/378notes/16redBlack/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgh-MBQ&usg=AOvVaw1k
14	30	1	BLACK	https://www.radford.edu/nokie/classes/360/trees.red.black.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgjCATAg&usg=AOvVaw0qgiHci5B
13	30	32	BLACK	https://abhiroop.github.io/Haskell-Red-Black-Tree/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghmMBA&usg=AOvVaw17Ptyyqu2-E_9jrlXnVlS
12	30	38	RED	https://www.cs.princeton.edu/~rs/talks/LLRB/LLRB.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi3ATAe&usg=AOvVaw0f8bncUzQtkyyTdJOZ
11	31	39	RED	http://rabia.com
10	32	15	BLACK	http://mathworld.wolfram.com/Red-BlackTree.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiaATAZ&usg=AOvVaw2wPqtVTHb289r6aWTa
9	32	18	BLACK	http://cs.lmu.edu/~ray/notes/redblacktrees/&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghyMBI&usg=AOvVaw3h53TBOYU9vWR2cgQ2JIRN
8	34	11	RED	https://docs.racket-lang.org/functional-data-structures/Red-Black_Trees.html&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgi8ATAf&usg=AOvVaw
7	34	20	RED	https://www.cs.utexas.edu/~scottm/cs314/handouts/slides/Topic23RedBlackTrees.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiJATAW&us
6	34	40	BLACK	http://thirtyfour.com
5	35	4	RED	https://en.wikipedia.org/wiki/Red%25E2%2580%2593black_tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFggcMAI&usg=AOvVaw0Y2VjNlVhQs
4	35	7	RED	https://medium.com/basecs/painting-nodes-black-with-red-black-trees-60eacb2be9a5&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFghAMAg&us
3	37	41	RED	http://thirtyseven.com
2	38	25	BLACK	https://www.quora.com/What-is-a-red-black-tree&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgiEATAV&usg=AOvVaw0EXGjneAoqATSbL5MOCS
1	40	24	RED	http://software.ucv.ro/~mburicea/lab8ASD.pdf&sa=U&ved=0ahUKEwiXkrfj0vveAhVH5YMKHcKqC2kQFgigATAa&usg=AOvVaw1X34LdtdTwUaXdA3KcANfA

Figure 17: Delete Rank 4 from results shown in Figure 15

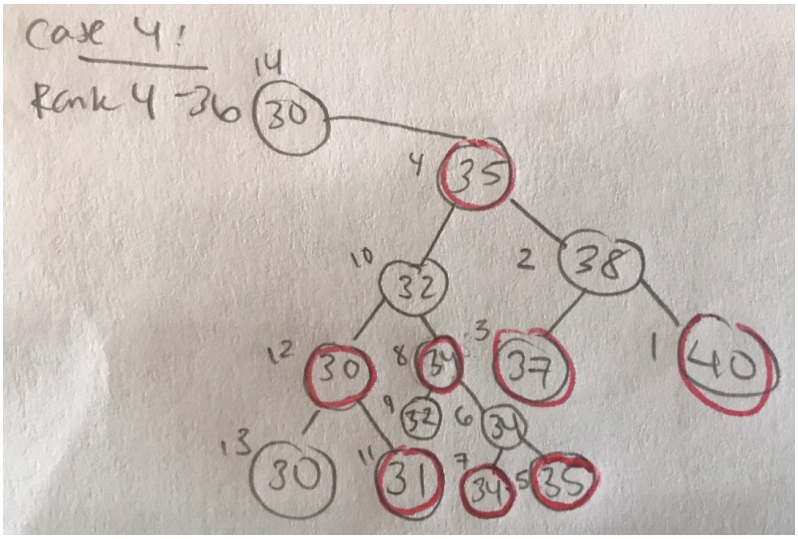

Figure 18: Draw resulting tree from deletion in Figure 17

Classes and Methods

RBTree Class

The purpose of the RBTree class is to provide functionality for searching an ArrayList of objects of type Rank. RBTree implements Binary Search Tree required methods as well as Red-Black Tree required methods to color each node and satisfy the Red-Black Tree properties. Instead of being dependent on integers, nodes are filled with Rank objects and have a Color object.

Variables

- **root** – private Node that holds pointer to the top of the Red-Black Tree
- **nil** – public static Node that points to nil black node of Red-Black Tree

Methods

- **public RBTree**() – Constructor of Red-Black Tree
  - Input – None
  - Output – None
  - Algorithm – Creates Red-Black Tree where root points to nil.
  - Complexity – O(1)
- **public Node getRoot**() – Retrieves root of tree.
  - Input – None
  - Output – Node of root of RBT
  - Algorithm – Returns the root of tree.
  - Complexity – O(1)
- **public void inorderTreeWalk**(Node node) – RBT in order walk that prints smallest to largest by going through the left side of tree first, then right side
  - Input – Node of tree
  - Output – None
  - Algorithm – Recursive function that iterates to left side of tree first, then right in order to print in order of smallest to largest node.
  - Complexity – O(n)
- **public Node treeMinimum**(Node node) - RBT smallest node in tree
  - Input – Node of tree
  - Output – Smallest node in tree
  - Algorithm – Iterates through tree to keep going left till node has no left child.
  - Complexity – O(h)
- **public Node treeMaximum**(Node node) - RBT largest node in tree
  - Input – Node of tree
  - Output – largest node in tree
  - Algorithm – Iterates through tree to keep going right till node has no right child.
  - Complexity – O(h)
- **public void leftRotate**(Node node) – Rotates left around a given node
  - Input – Node of tree

    - Output – None.
    - Algorithm – Move the given node around left.
    - Complexity – O(1)
- **public void rightRotate**(Node node) – Rotates right around a given node
    - Input – Node of tree
    - Output – None.
    - Algorithm – Move the given node around right.
    - Complexity – O(1)
- **public void RBTreeInsert(**Node newNode) - Inserts a new node into RBT while maintaining RBT properties using Insert Fixup. Updates ranking of each node.
    - Input – new Node want to insert into tree
    - Output – None
    - Algorithm – Iterate through tree to find where to place new node while maintaining RBT properties. Then call RBInsertFixup() to ensure RBT properties satisfied and updateRanking() on tree.
    - Complexity – O(lg n)
- **public void RBInsertFixup(**Node newNode) - Fixes the RB Tree to ensure it maintains all RB Tree properties after insertion.
    - Input – new Node that was inserted and needs color fixing
    - Output – None
    - Algorithm – Iterate through tree to with the four cases of insertion to fix the coloring of the tree. Set root of tree to black.
    - Complexity – O(lg n)
- **public void RBTransplant**(Node u, Node v) - Transplant subtrees of two given nodes
    - Input – Two nodes whose subtrees will be transplanted
    - Output – None
    - Algorithm – Switch u and v's subtrees.
    - Complexity – O(2)
- **public void RBTreeDelete**(Node delete) - Deletes a given node from RBT while maintaining RBT properties using Delete Fixup. Updates ranking of each node.
    - Input – Node want to delete
    - Output – None
    - Algorithm – Check if node has a left child, right child, or both and based on that transplant the delete node with the left, right, or minimum node's subtree. Then call RBDeleteFixup() to ensure RBT properties satisfied and updateRanking() on tree.
    - Complexity – O(lg n)
- **public void RBDeleteFixup**(Node delete) - Fixes the RB Tree to ensure it maintains all RB Tree properties after deletion.
    - Input – Node that needs recoloring

    - Output – None
    - Algorithm – Iterate through tree to with the four cases of deletion to fix the coloring of the tree. Set root of tree to black.
    - Complexity – O(lg n)
- **private int size**(Node subtree) – Finds and returns the size of a given Node's subtree
    - Input – Node who's subtree's size want to get
    - Output – size of tree (int)
    - Algorithm – Recursively return current node (size 1) + size of left subtree + size of right subtree
    - Complexity – O(n)
- **public int getSize**() – Retrieves size of entire tree
    - Input – None
    - Output – size of tree from root
    - Algorithm – Calls size(RBT.root)
    - Complexity – O(n)
- **public void updateRanking**() – Search for rankings 0 to size of tree and set ranking of Rank object
    - Input – None
    - Output – None
    - Algorithm – Iterates through size of tree and searches for a specific rank, then sets the found object's rank as long as object is not null or nil.
    - Complexity – O(n)
- **public Node search**(int k)– Search for the node at a specific ranking
    - Input – integer of ranking
    - Output – Node found at ranking
    - Algorithm – Checks input to ensure is in the tree, then calls select helper function to retrieve Node.
    - Complexity – O(n)
- **public Node select**(Node x, int k)– Get k'th largest node in tree
    - Input – integer of ranking, Node of root
    - Output – Node found at ranking
    - Algorithm – Iterate through left and right subtrees based on if k is less than or greater than size of subtree.
    - Complexity – O(n)

Color Enum

The purpose of this Enum is to define the colors a Node can be (Black or Red)

Values

- **BLACK**
- **RED**

Node Class

The purpose of this class is to encase the Rank object and hold Node attributes for the Red-Black Tree.

Variables

- **Key** – Rank object
- **Parent** – Node pointer to parent
- **Left** – Node pointer to left child
- **Right** – Node pointer to right child
- **Color** – Color enum instance to hold color of node (either RED or BLACK)

Methods

- **public Node**(Rank obj) – Construct node with Rank object
  - Input – Rank object
  - Output – None
  - Algorithm – Set Rank object to key. Parent, left, and right are set to null.
  - Complexity – O(1)
- **public Node**(Color c) – Construct node with Color object
  - Input – Color object
  - Output – None
  - Algorithm – Set Color object to color instance in node. Parent, left, and right are set to nil.
  - Complexity – O(1)
- **public int compareTo**(Node o) – Compare two nodes by comparing their Rank
  - Input – Node object
  - Output – integer showing less than, greater than, or equal to
  - Algorithm – Compare keys of both nodes.
  - Complexity – O(1)

FunnyCrawler Class

The purpose of the FunnyCrawler class is to take a search term and send a request to Google's search engine and return a unique set of results from that query.

** Source: http://www.mkyong.com/java/jsoup-send-search-query-to-google/ **

Variables

None

Methods

- **public** Set<String> **getDataFromGoogle**(String query) – Uses the entered query to send a request to Google and return a results set of links.
  - Input – query: String the user wants information on
  - Output – Set<String>: Set of unique URL strings that match the query
  - Algorithm – Uses a Jsoup http request protocol object to connect to Google and retrieve all href links

- Complexity – O(n)

Rank Interface

The purpose of the Rank interface is allow the HeapSort class to build and sort heaps of both WebPageURL and SearchTerms objects. This interface implements some basic methods that will be used in the two classes that implement the Rank interface.

Variables

None

Methods

- **public int getTotalScore**() – Retrieves total rank for WebPageURL or occurrence for SearchTerms
  - Input – None
  - Output – score (integer)
- **public int getIndex**() – Retrieves index for WebPageURL or occurrence for SearchTerms
  - Input – None
  - Output – score (integer)
- **public void setRanking**(int r) – Set ranking used for URL objects
  - Input – ranking integer
  - Output – None.
- **public int getRanking**() – Get ranking for URL objects
  - Input – None
  - Output – ranking integer
- **default public int compareTo**(Rank other) – Compare two rank objects by total score
  - Input – Rank object
  - Output – integer showing less than, greater than, or equal to
- **public void printAttributes**() – Prints attributes of object
  - Input – None
  - Output – None; Prints attributes to screen.
- **public** String **getName**() – Retrieve URL name or search term name
  - Input – None
  - Output – Name: String of either search term or URL
- **public void increase**(**int** value) – Increase value of object (either total rank or search occurrence)
  - Input – value: integer of how much want to increase object value by.
  - Output – None.

WebPageURL Class implements Rank

The purpose of the WebPageURL class is to store the URL string as well as four rankings of the site which include frequency the link has been visited, site age, how many times the link has been referenced, and amount of money paid to sponsor the site and bring it to the top of the search results. Also included are the original index and current ranking in terms of other URL objects.

Variables

- **frequency** – private integer variable of frequency a site is visited
- **siteAge** – private integer variable of age of the site
- **linkReference** – private integer variable of number of times site has been referenced on other webpages
- **moneyPaid** – private integer variable of amount of money paid to increase rank
- **URL** – private string variable of URL string
- **Index** – private integer that stores the original index the result query was received at.
- **Ranking** – private integer storing URL rank in relation to other URLs

Methods

- **public WebPageURL**() – Basic generic constructor that creates object without any input fields that assigns four minimum values for frequency, siteAge, linkReference, and moneyPaid. Used when creating space for a new node in HeapSort class.
    - Input – None
    - Output – None
    - Algorithm – Generates four minimum values for variables using Integer.*MIN_VALUE*
    - Complexity – O(1)
- **public WebPageURL**(String uRL, int index) – Constructor given URL that creates object and generates four random values for variables.
    - Input – uRL: String of url that is given by results of web crawler (FunnyCrawler)
    - Output – None
    - Algorithm – Uses Math.random() to generate four values for frequency, siteAge, linkReference, and moneyPaid.
    - Complexity – O(1)
- **public WebPageURL**(**int** key) – Constructor given key that is set to moneyPaid variable. Defaults to generic string for URL and assigns four random values.
    - Input – key: integer that is set to moneyPaid variable of object
    - Output – None
    - Algorithm - Uses Math.random() to generate three values for frequency, siteAge, linkReference but assigns key to moneyPaid.
    - Complexity – O(1)
- **public int getFrequency**() - Retrieves value of private frequency variable
    - Input – None

    - Output – frequency: integer that is of private frequency variable
    - Algorithm – returns frequency site shows up in searches
    - Complexity – O(1)
- **public int getSiteAge**() - Retrieves value of private siteAge variable
    - Input – None
    - Output – siteAge: integer that is of private siteAge variable
    - Algorithm – returns age of site
    - Complexity – O(1)
- **public int getLinkReference**() - Retrieves value of private linkReference variable
    - Input – None
    - Output – linkReference: integer that is of private linkReference variable
    - Algorithm – returns number of times link has been referenced
    - Complexity – O(1)
- **public int getMoneyPaid**() - Retrieves value of private moneyPaid variable
    - Input – None
    - Output – moneyPaid: integer that is of private moneyPaid variable
    - Algorithm – returns amount of money paid
    - Complexity – O(1)
- **public int getIndex**() - Retrieves value of private index variable
    - Input – None
    - Output – index: integer that is of private index variable
    - Algorithm – returns index
    - Complexity – O(1)
- **public void setRanking**(int r) – Sets private ranking variable
    - Input – r: integer to set ranking
    - Output – None
    - Algorithm – sets input r to ranking variable
    - Complexity – O(1)
- **public int getRanking**() - Retrieves value of private ranking variable
    - Input – None
    - Output – ranking: integer that is of private ranking variable
    - Algorithm – returns ranking
    - Complexity – O(1)
- **public void increase**(**int** value) – Increased value of money paid to value inputted
    - Input – value: integer of amount of money being paid
    - Output – None
    - Algorithm – Sets the inputted value to the moneyPaid variable
    - Complexity – O(1)
- **public int getTotalScore**() – retrieves page rank by summating frequency, siteAge, linkReference, and moneyPaid.

    - Input – None
    - Output – Rank: summation of four ranking variables
    - Algorithm – returns the sum of frequency, siteAge, linkReference, and moneyPaid.
    - Complexity – O(1)
- **public String getName**() - Retrieves value of private URL variable
    - Input – None
    - Output – URL: String that is of private URL variable
    - Algorithm – returns URL
    - Complexity – O(1)
- **public void printAttributes**() – Prints all attributes of object including page rank
    - Input – None
    - Output – None
    - Algorithm – Prints URL, frequency, siteAge, linkReference, moneyPaid, and page rank.
    - Complexity – O(1)

BuildApp Class

The purpose of the BuildApp class is to connect all elements of RBTree, WebPageURL, and FunnyCrawler to create a stable, clean interface for the user to complete any of the available functionality.

Variables

- **URLObjects** – ArrayList<Rank> Stores the complete list of search results from query
- **urlRBT** – RBT to manipulate search results

Methods

- **private** ArrayList<Rank> **search**(String search) – Private method to instantiate web crawler and retrieve complete set of results from query
    - Input – search: String the user has queried.
    - Output – ArrayList<Rank>: List of WebPageURL objects created from results.
    - Algorithm – Creates WebPageURL objects for every search result in the set returned from the web crawler.
    - Complexity – O(n)
- **public void enterSearch**(String searchTerm) – public method to retrieves search string from user, calls search and retrieves results, then builds RBT, and prints RBT to screen.
    - Input – searchTerm: String the user has queried.
    - Output – None.
    - Algorithm – Builds a RBT with ArrayList of URLs and prints to the screen.
    - Complexity – O(n lg n)
- **public void printHeader**() – Print header columns
    - Input – None

    - Output – None.
    - Algorithm – Print header columns.
    - Complexity – O(1)
- **public void userInterface**() – Holds all the options the user can do, validates user input, and calls respective methods of user's choice.
    - Input – None.
    - Output – None.
    - Algorithm – Displays options, asks user to pick, calls methods based on option choice and loops back until the user selects Quit.
    - Complexity – O(1)
- **public static void main**(String[] args) – Front point of the application
    - Input – None.
    - Output – None.
    - Algorithm – Instantiates BuildApp object and calls userInterface.
    - Complexity – O(1)

Problems Encountered During Implementation

One of the first problems I encountered was trying to figure out whether to create a NIL node or to just use null. I initially implemented all methods using null, however once I ran it, I would continuously get Null Pointer Exceptions. With no success in trying to debug, I decided to create a NIL node and it ended up solving quite a few problems as it could now hold a color (black).

This problem continued when implementing NIL in methods that checked for null, such as In order Walk, Tree Maximum, and Tree Minimum to name a few. I had to go back and change wherever null was mentioned to NIL, but also ensure that at no point were I to get a null value. In some cases, to prevent a null issue from arising, I decided to check for null or NIL.

Another major problem I encountered was not converting the pseudocode from the textbook properly, which caused tons of issues. I accidentally checked for "==" rather than "!=" in Insert Fixup which resulted in the tree being printed out of order and even printing duplicate elements. I didn't think to check whether my pseudocode conversion was correct and kept looking for bugs elsewhere, which ended up adding an additional day to complete the project.

The last issue I had was when trying to come up with the code for Rotate Right, as this pseudocode was not in the textbook. After a lot of trial and error, which included a lot of drawings on paper, I figured out how to rotate the tree right around a particular node.

Lessons Learned

The implementation of Red-Black Trees in use with a mock Google Search Engine taught me the importance of having a NIL node in the tree rather than pointing to an arbitrary null object. Pointing to null does not connect the tree in a way that satisfies Red-Black Tree properties.

Iterating through all the cases of Insert and Delete for Red-Black Trees was also a major lesson as there are eight cases that could possibly happen when trying to fix a tree following insertion or deletion. Going through the tree as it was printed helped me understand Red-Black Tree properties and solidified my understanding in how to build a tree using what is printed from In order traversal.

The final major lesson I learned was how to right rotate around a given node as the pseudocode was not given for this method. I had to use several drawings and attempts in order to understand where each of the elements go and where they point to.