NAME : - Jinggui Tan & Siddhant Barua
CWID :- 10427381 & 10439929

Assignment 4 Report

For random array as input

Red-Black Trees

- *Input Size : 50000*

    Duplicate : (3+2+1+1+2+0+1+1+0+0) 1.1

    Case 1 : (25721 + 25626 + 25659 + 25562+ 25663 + 25690+ 25541 + 25682 + 50000 + 25643) 28078.7

    Case 2 : (9674 + 9707 + 9577 + 9658 + 9707 + 9821 + 9584 + 9774 + 9711 + 9692) 9690.5

    Case 3 : (19377 + 19431 + 19410 + 19313 + 19318 + 19273 + 19398 + 19379 + 19555 + 19385) 19383.9

    Left Rotate : (14595 + 14572 + 14427 + 14530 + 14492 + 14585 + 14433 + 14595 + 14517 + 14550) 14529.6

    Right Rotate : (14519 + 14625 + 14589 + 14464 + 14554 + 14488 + 14526 + 14529 + 14690 +14464) 14544.8

    Time : (21 + 32 + 31 + 21 + 30 + 29 + 36 + 29 + 30 + 30) 28.9

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- *Input Size : 100000*

  Duplicate : (1 + 2 + 2 + 1 + 3 + 0 + 2 + 4 + 3 + 4) 2.2

  Case 1 : (51229 + 51351 + 51114 + 51521 + 51372 + 51322 + 51315 + 51361 + 51305 + 51348) 51323.8

  Case 2 : (19299 + 19374 + 19346 + 19475 + 19599 + 19168 + 19512 +19422 + 19389 + 19238) 19382.2

  Case 3 : (38613 +38671 + 38943 + 38973 + 38552 + 38982 + 38936 + 38885 + 38796 + 38802) 38815.3

  Left Rotate : (28867 + 28963 + 29077 + 29211 + 29335 + 28902 + 29220 + 29352 + 29117 + 28929) 29097.3

  Right Rotate : (28922 + 28943 + 29013 + 29265 + 28818 + 29246 + 29200 + 29154 +29207 + 29234) 29100.2

  Time : (59 + 61 + 61 + 60 + 63 + 63 + 64 + 61 + 62 + 57) 61.1

- *Input Size : 250000*

  Duplicate : (15 + 10 + 14 + 17 + 10 + 12 + 16 + 15 + 8 + 19) 13.6

  Case 1 : (128241 + 128333 + 128381 + 128390 + 128387 + 128392 + 128388 + 128371 + 128379 + 128303) 128356.5

  Case 2 : (48426 + 48332 + 48690 + 48803 + 48651 + 48559 + 48682 + 48661 + 48118 + 48589) 48551.1

  Case 3 : (97243 + 96934 + 97195 + 97182 + 97098 + 97544 + 97079 + 97228 + 97358 + 97161) 97202.2

  Left Rotate : (72919 + 72731 + 73026 + 73035 + 73112 + 72767 + 72911 + 72888 + 72345 + 73035) 72876.9

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Right Rotate : (72797 + 72707 + 72968 + 72953 + 72890 + 72847 + 72892 + 72959 + 72668 + 72651) 72833.2

Time : (147 + 141 + 149 + 146 + 149 + 140 + 147 + 143 + 149 + 142) 145.3

- *Input Size : 500000*

  Duplicate : (58 + 57 + 64 + 57 + 61 + 52 + 70 + 61 + 68 + 46) 59.4

  Case 1 : (256915 + 256802 + 256322 + 256975 + 256909 + 256737 + 256825 + 257219 + 256822 + 256828) 256835.4

  Case 2 : (97214 + 97563 + 97126 + 96999 + 96797 + 97084 + 96818 + 96995 + 97036 + 97013) 97064.5

  Case 3 : (194263 + 194237 + 194445 + 194167 + 194050 + 193958 + 194193 + 193937 + 194659 + 194297) 194220.6

  Left Rotate : (145704 + 146263 + 145378 + 145658 + 145468 + 145758 + 145365 + 145672 + 145463 + 145747) 145647.6

  Right Rotate : (145529 + 145810 + 145768 + 145620 + 145376 + 145287 + 145534 + 145685 + 145959 + 145807) 145637.5

  Time : (355 + 373 + 328 + 328 + 320 + 325 + 324 + 339 + 322 + 318) 333.2

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- *Input Size : 1000000*

    Duplicate : (253 + 243 + 255 + 216 + 237 + 243 + 214 + 226 + 232 + 253) 237.2

    Case 1 : (513191 + 513487 + 513093 + 513347 + 513180 + 513270 + 513131 + 513363 + 513115 + 513422) 513259.9

    Case 2 : (193855 + 93607 + 193869 + 194358 + 193952 + 194062 + 194008 + 194470 + 194529 + 194529) 184123.9

    Case 3 : (388374 + 388633 + 388677 + 388459 + 388916 + 388399 + 389155 + 388470 + 387964 + 388659) 388570.6

    Left Rotate : (291331 + 290692 + 291666 + 291647 + 290999 + 290973 + 291706 + 292003 + 292072 + 291230) 291431.9

    Right Rotate : (291673 + 291090 + 291144 + 290761 + 292005 + 291352 + 291866 + 290673 + 290879 + 291183) 291262.6

    Time : (893 + 653 + 871 + 728 + 726 + 604 + 733 + 620 + 757 + 675) 726

- *Input Size : 2500000*

    Duplicate : (1504 + 1438 + 1494 + 1534 + 1411 + 1438 + 1451 + 1363 + 1448 + 1455) 1453.6

    Case 1 : (1283038 + 727546 + 1282335 + 1282827 + 1282801 + 1282412 + 1282901 + 1283417 + 1283346 + 1283308)

    Case 2 : (485439 + 484287 + 485912 + 485472 + 485515 + 484965 + 485508 + 484599 + 485179 + 485718) 1227393.1

    Case 3 : (970102 + 970023 + 971587 + 970057 + 971821 + 970832 + 970650 + 970551 + 970030 + 970881) 970653.4

    Left Rotate : (728208 + 727869 + 728232 + 728182 + 727634 + 727786 + 728769 + 727225 + 728481 + 727546) 727993.2

    Right Rotate : (728274 + 728285 + 727431 + 728560 + 728011 + 728531 + 727841 + 727710 + 727299 + 728056) 727999.8

    Time : (2910 + 2953 + 3181 + 2945 + 2237 + 2919 + 2195 + 2560 + 2278 + 2215) 2639.3

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- *Input Size : 5000000*

  Duplicate : (5930+5809+5816+5828+5736+5817+5901+5876+5738+5817) 5826.8

  Case 1 :
  (2564575+2562639+2564897+2564845+2564298+2564208+2563391+2564219+2565146+2564086) 2564230.4

  Case 2 :
  (970161+969562+968848+969423+968846+968391+969016+970980+970207+970141) 969557.5

  Case 3 :
  (1940099+1940463+1941222+1938633+1939838+1939160+1938560+1940079+1940708+1940133) 1939889.5

  Left Rotate :
  (1455465+1454814+1453926+1454179+1453396+1453941+1453811+1456427+1455814+1454742) 1454651.5

  Right Rotate :
  (1455498+1454856+1455775+1453838+1454288+1454610+1453804+1455001+1455456+1454829) 1454795.5

  Time : (5442+6473+6980+6872+6184+6442+5981+7567+6779+5925) 6464.5

Binary Search Trees

- *Input Size : 50000*

  Duplicate : (0 + 0 + 1 + 1 + 0 + 2 + 1 + 1 + 2 + 3) 1.1
  Time : (20 + 23 + 26 + 21 + 22 + 27 + 22 + 24 + 26 + 30) 24.1

- *Input Size : 100000*

  Duplicate : (1 + 2 + 2 + 1 + 3 + 0 + 2 + 4 + 3 + 4) 2.2
  Time : (56 + 54 + 62 + 59 + 59 + 58 + 60 + 46 + 49 + 46) 54.9

- *Input Size : 250000*

  Duplicate : (15 + 10 + 14 + 17 + 10 + 12 + 16 + 15 + 8 + 19) 13.6
  Time : (137 + 137 + 145 + 147 + 144 + 150 + 138 + 150 + 150 + 133) 143.1

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- *Input Size : 500000*

  Duplicate : (58 + 57 + 64 + 57 + 61 + 52 + 70 + 61 + 68 + 46) 59.4
  Time : (404 + 321 + 313 + 314 + 320 + 300 + 317 + 256 + 366 + 299) 321

- *Input Size : 1000000*

  Duplicate : (253 + 243 + 255 + 216 + 237 + 243 + 214 + 226 + 232 + 253) 237.2
  Time : (657 + 765 + 635 + 644 + 624 + 639 + 608 + 677 + 667 + 744) 666

- *Input Size : 2500000*

  Duplicate : (1504 + 1438 + 1494 + 1534 + 1411 + 1438 + 1451 + 1363 + 1448 + 1455) 1453.6
  Time : (2230 + 2287 + 2231 + 3018 + 2596 + 2283 + 2510 + 3291 + 2604 + 2754) 2580.4

For sorted array as input

Red-Black Trees

- *Input Size : 50000*

  Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 1 : (49966 + 49966 + 49966 + 49966 + 49966 + 49966 + 49966 + 49966 + 49966 + 49966) 49966

  Case 2 : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 3 : (49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971) 49971

  Left Rotate : (49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971 + 49971) 49971

Right Rotate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Time : (28 + 29 + 27 + 28 + 28 + 27 + 28 + 28 + 28 + 27) 27.8

- *Input Size : 100000*

  Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 1 : (99964+99964+ 99964+99964+ 99964+99964+ 99964+99964+ 99964+99964) 99964

  Case 2 : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 3 : (99969+99969+99969+99969+99969+99969+99969+99969+99969+99969) 99969

  Left Rotate : (99969+99969+99969+99969+99969+99969+99969+99969+99969+99969) 99969

  Right Rotate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Time : (56 + 56 + 55 + 58 + 49 + 56 + 42 + 56 + 55 + 56) 53.9

- *Input Size : 250000*

  Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 1 : (249961+249961+249961+249961+249961+249961+249961+249961+249961+249961) 249961

  Case 2 : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

  Case 3 : (249967+249967+249967+249967+249967+249967+249967+249967+249967+249967) 249967

  Left Rotate : (249967+249967+249967+249967+249967+249967+249967+249967+249967+249967) 249967

  Right Rotate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Time : (133 + 133 + 132 + 131 + 124 + 131 + 81 + 124 + 127 + 125) 124.1

- *Input Size : 500000*

    Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

    Case 1 : (499959+ 499959+499959+499959) 499959

    Case 2 : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

    Case 3 : (499965+499965+499965+499965) 499965

    Left Rotate : (499965+499965+499965+499965) 499965

    Right Rotate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

    Time : (276 + 280 + 274 + 285) 278.75

Binary Search Trees

- *Input Size : 50000*

    Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)
    Time : (6091 + 6078 + 6055 + 6085 + 6020 + 6023 + 6030 + 6352 + 6147 + 6057) 6093.8

- *Input Size : 100000*

    Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)
    Time : (23816 + 23679 + 25454 + 26107 + 25799 + 24826 + 23497 + 23705 + 23941 + 23599) 24442.3

- *Input Size : 250000*

    Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)
    Time : (149431 + 153164 + 152413 + 149090 + 150635 + 151442 + 157266 + 158648 + 160080 + 149907) 153207.6

- *Input Size : 500000*

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Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Time : (682598 + 719484 + 666545) 689542.3

- *Input Size : 1000000*

Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Time : (Takes too long i.e. more than 10 mins)

For reverse-sorted array as input

Red-Black Trees

- *Input Size : 50000*

Duplicate : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Case 1 : (49966+49966+49966+49966+49966+49966+49966+49966+49966+49966) 49966

Case 2 : (0 + 0 + 0+ 0+ 0 + 0 + 0 + 0 + 0 + 0)

Case 3 : (49971+49971+49971+49971+49971+49971+49971+49971+49971+49971) 49971

Left Rotate : (0+0+0+0+0+0+0+0+0+0)

Right Rotate : (49971+49971+49971+49971+49971+49971+49971+49971+49971) 49971

Time : (26+26+26+27+26+28+25+27+27+25) 26.3

- *Input Size : 100000*

Duplicate : (0+0+0+0+0+0+0+0+0+0)

Case 1 : (99964+99964+99964+99964+99964+99964+99964+99964+99964+99964) 99964

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Case 2 : (0+0+0+0+0+0+0+0+0+0)

*Case 3 : (99969+99969+99969+99969+99969+99969+99969+99969+99969+99969)
99969*

Left Rotate : (0+0+0+0+0+0+0+0+0+0)

*Right Rotate:(99969+99969+99969+99969+99969+99969+99969+99969+99969+99969)
99969*

Time : (52+52+44+54+49+52+46+55+52+52) 50.8

- *Input Size : 250000*

    Duplicate : (0+0+0+0+0+0+0+0+0+0)

    *Case 1 :
    (249961+249961+249961+249961+249961+249961+249961+249961+249961+249961) 249961*

    Case 2 : (0+0+0+0+0+0+0+0+0+0)

    *Case 3 :
    (249967+249967+249967+249967+249967+249967+249967+249967+249967+249967) 249967*

    Left Rotate : (0+0+0+0+0+0+0+0+0+0)

    *Right Rotate :
    (249967+249967+249967+249967+249967+249967+249967+249967+249967+249967) 249967*

    Time : (124+109+124+125+118+122+121+123+118+119) 120.3

- *Input Size : 500000*

    Duplicate : (0+0+0+0+0+0+0+0+0+0)

    *Case 1 :
    (499959+499959+499959+499959+499959+499959+499959+499959+499959+499959) 499959*

    Case 2 : (0+0+0+0+0+0+0+0+0+0)

Case 3 :
(499965+499965+499965+499965+499965+499965+499965+499965+499965+499965) 499969

Left Rotate : (0+0+0+0+0+0+0+0+0)

Right Rotate :
(499965+499965+499965+499965+499965+499965+499965+499965+499965+499965) 499965

Time : (276 + 280 + 274 + 285 +276 + 280 + 274 + 285 + 276 + 280) 278.75

Binary Search Trees

- *Input Size : 50000*

  Duplicate : (0)
  Time : (5777+6032+6747+6003+6502+5995+5766+5757+5769+6294) 6064.2

- *Input Size : 100000*

  Duplicate : (0)
  Time : (22710+22486+22758+23564+24905+22919+23048+23249+23693+22809)
  23214.1

- *Input Size : 250000*

  Duplicate : (0)
  Time :
  (143618+151751+152648+144119+149557+144178+143691+142571+144527+144294)
  146095.4

- *Input Size : 500000*

  Duplicate : (0)
  Time : (674401+648221+700070) 674230.7
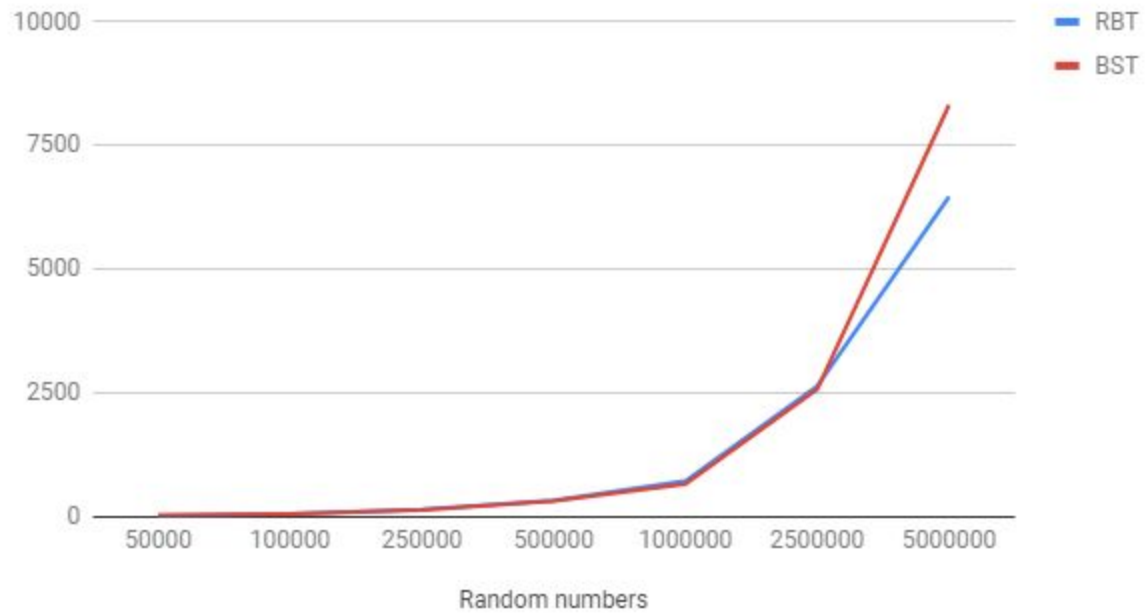
- *Input Size : 1000000*

  Duplicate : (0)
  Time : (Takes too long i.e. more than 10 mins)

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Performance

Random numbers
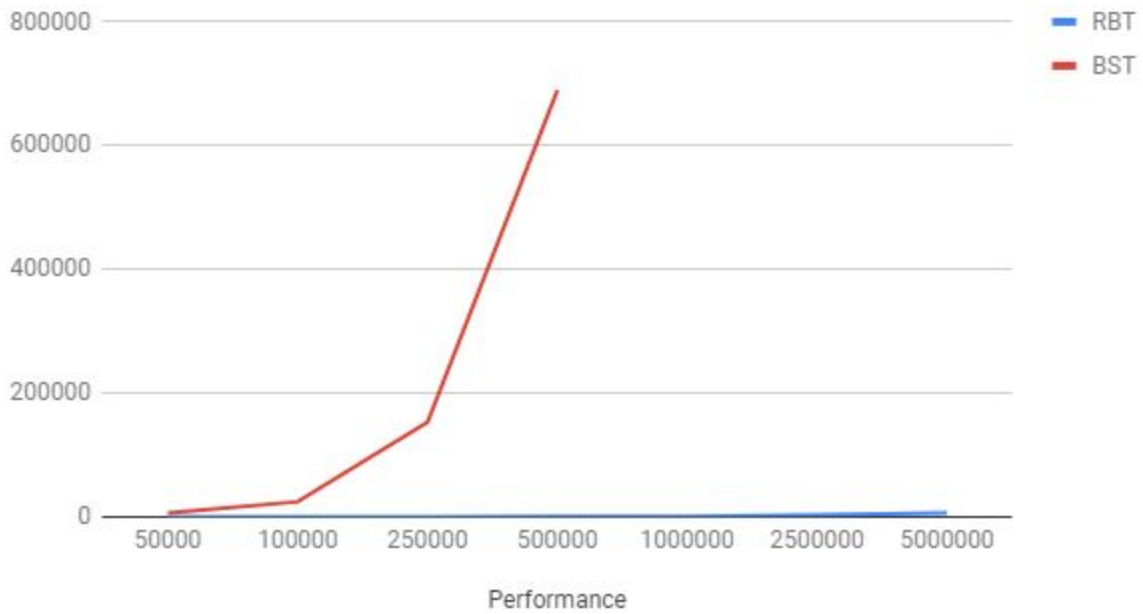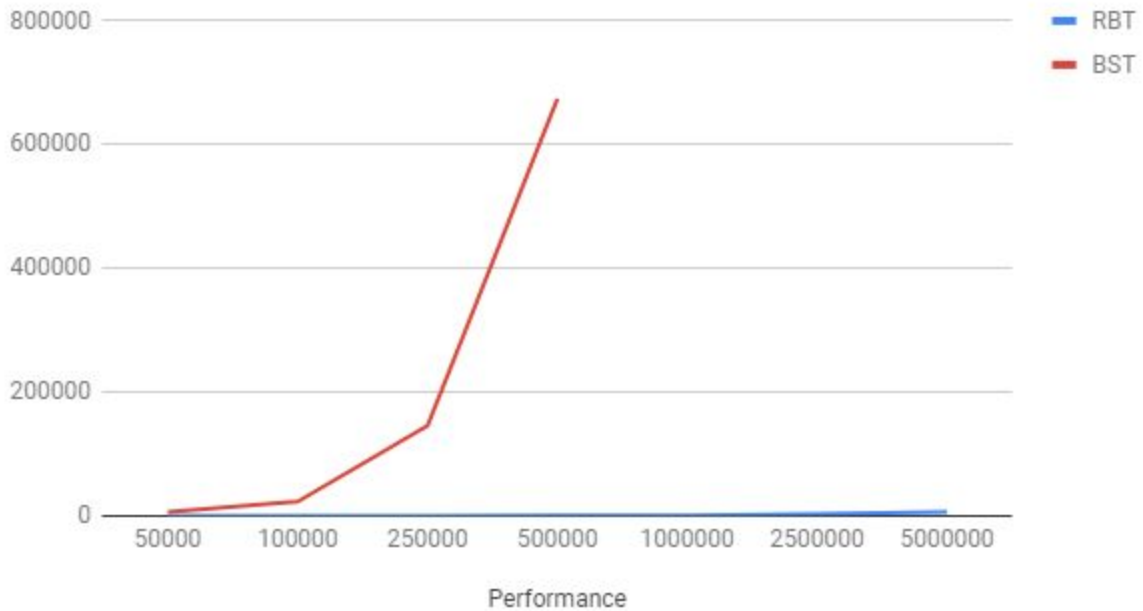
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RBT 和BST

RBT 和BST

*Sorted input (and reverse sorted) is the worst case for BST. In these 2 cases, the **height** of BST is almost the same as the input size which is n. The running time of program easily exceeds 10 minutes when the input size comes to 500000.*

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Assume the height of BST and RBT is k, the insertion and searching performance should be O(k). For the worst cases of BST (sorted and reverse sorted input), the height is equal to size n-1, which means the height k is O(n). So any insert and search in these 2 cases is O(n).
BST stays the same performance in any cases so the height would be always O(n). That's to say , the performance of BST would always be O(n).
But for random input, the difference between BST and RBT are is pretty small. Sometimes the BST can work even better because BST has no rotation steps to do.