

## REPORT : CS590-A hw-04

- n=50000  
d=0

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Blackheight |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|-------------|
| 1       | 355                        | 399                        | 1                                 | 1                                 | 25551          | 9604           | 19342          | 14463               | 14483                | 10          |
| 2       | 379                        | 407                        | 0                                 | 0                                 | 25616          | 9655           | 19546          | 14624               | 14577                | 10          |
| 3       | 355                        | 400                        | 0                                 | 0                                 | 25565          | 9707           | 19380          | 14526               | 14561                | 10          |
| 4       | 322                        | 386                        | 0                                 | 0                                 | 25702          | 9697           | 19353          | 14576               | 14474                | 10          |
| 5       | 370                        | 364                        | 0                                 | 0                                 | 25707          | 9622           | 19282          | 14455               | 14449                | 10          |
| 6       | 347                        | 382                        | 0                                 | 0                                 | 25668          | 9652           | 19328          | 14484               | 14496                | 10          |
| 7       | 314                        | 361                        | 0                                 | 0                                 | 25644          | 9669           | 19585          | 14588               | 14666                | 10          |
| 8       | 350                        | 425                        | 0                                 | 0                                 | 25642          | 9787           | 19417          | 14607               | 14610                | 10          |
| 9       | 349                        | 403                        | 1                                 | 1                                 | 25656          | 9821           | 19485          | 14627               | 14679                | 10          |
| 10      | 283                        | 338                        | 1                                 | 1                                 | 25755          | 9744           | 19266          | 14494               | 14546                | 10          |
| Average | 342.4                      | 386.5                      | 0.3                               | 0.3                               | 25650.6        | 9695.8         | 19398.4        | 145444              | 14554.1              | 10          |

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|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Blackheight |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|-------------|
| 1       | 6561                       | 393                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 2       | 6879                       | 412                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 3       | 7208                       | 386                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 4       | 7960                       | 412                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 5       | 6916                       | 363                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 6       | 6307                       | 378                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 7       | 7341                       | 370                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 8       | 6540                       | 404                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 9       | 6867                       | 374                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| 10      | 6769                       | 400                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |
| Average | 6934.8                     | 389.2                      | 0                                 | 0                                 | 49966          | 0              | 49971          | 49971               | 0                    | 15          |

- n=50000  
d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | 6146                       | 372                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 2       | 7020                       | 360                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 3       | 6097                       | 342                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 4       | 6949                       | 358                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 5       | 6047                       | 365                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 6       | 6446                       | 392                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 7       | 6169                       | 342                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 8       | 6315                       | 390                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 9       | 6306                       | 412                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| 10      | 6415                       | 393                        | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |
| Average | 6391                       | 372.6                      | 0                                 | 0                                 | 49966          | 0              | 49971          | 0                   | 49971                | 15           |

- n=70000  
d=0

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 423                        | 524                        | 1                                 | 1                                 | 35929          | 13589          | 27288          | 20412               | 20465                | 10                   |
| 2       | 466                        | 545                        | 0                                 | 0                                 | 35911          | 13764          | 27271          | 20472               | 20563                | 10                   |
| 3       | 563                        | 524                        | 1                                 | 1                                 | 35961          | 13658          | 27148          | 20270               | 20536                | 10                   |
| 4       | 485                        | 579                        | 2                                 | 2                                 | 35874          | 13717          | 27153          | 20398               | 20472                | 10                   |
| 5       | 405                        | 513                        | 1                                 | 1                                 | 36000          | 13583          | 27022          | 20309               | 20269                | 10                   |
| 6       | 409                        | 514                        | 3                                 | 3                                 | 35873          | 13501          | 27271          | 20324               | 20448                | 10                   |
| 7       | 514                        | 407                        | 2                                 | 2                                 | 35955          | 13500          | 27239          | 20396               | 20343                | 10                   |
| 8       | 617                        | 495                        | 3                                 | 3                                 | 35396          | 13642          | 27285          | 20323               | 20604                | 10                   |
| 9       | 405                        | 513                        | 1                                 | 1                                 | 36000          | 13583          | 27022          | 20309               | 20269                | 10                   |
| 10      | 485                        | 579                        | 2                                 | 2                                 | 35874          | 13717          | 27153          | 20398               | 20472                | 10                   |
| Average | 477.2                      | 519.3                      | 1.6                               | 1.6                               | 35877.3        | 13625.4        | 27185.2        | 20361.1             | 20444.1              | 10                   |

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d=1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 13844                      | 580                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 2       | 11994                      | 454                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 3       | 12808                      | 539                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 4       | 11899                      | 512                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 5       | 14142                      | 435                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 6       | 13876                      | 498                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 7       | 13427                      | 523                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 8       | 12050                      | 496                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 9       | 12946                      | 516                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| 10      | 12703                      | 522                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |
| Average | 12968.9                    | 507.85                     | 0                                 | 0                                 | 69964          | 0              | 69970          | 69970               | 0                    | 15                   |

- n=70000  
d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 12898                      | 515                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 2       | 12858                      | 424                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 3       | 13264                      | 574                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 4       | 13518                      | 470                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 5       | 12924                      | 500                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 6       | 12468                      | 540                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 7       | 12106                      | 518                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 8       | 12109                      | 582                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 9       | 11937                      | 518                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| 10      | 12584                      | 516                        | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |
| Average | 12666.6                    | 515.7                      | 0                                 | 0                                 | 69964          | 0              | 69970          | 0                   | 69970                | 15                   |

- n= 100000  
d=0

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 841ms                      | 719ms                      | 1                                 | 1                                 | 51247          | 19478          | 38819          | 29011               | 29286                | 10                   |
| 2       | 869                        | 816                        | 3                                 | 3                                 | 51233          | 19471          | 38870          | 29108               | 29233                | 10                   |
| 3       | 789                        | 836                        | 4                                 | 4                                 | 51361          | 19433          | 38898          | 29177               | 29154                | 11                   |
| 4       | 846                        | 805                        | 2                                 | 2                                 | 51381          | 19295          | 38680          | 29066               | 28909                | 11                   |
| 5       | 868                        | 707                        | 0                                 | 0                                 | 51418          | 19354          | 38785          | 29119               | 29020                | 10                   |
| 6       | 810                        | 830                        | 4                                 | 4                                 | 51438          | 19498          | 38961          | 29260               | 29199                | 10                   |
| 7       | 773                        | 698                        | 1                                 | 1                                 | 51351          | 19517          | 38938          | 29167               | 29288                | 10                   |
| 8       | 922                        | 708                        | 1                                 | 1                                 | 51347          | 19424          | 38870          | 29194               | 29100                | 11                   |
| 9       | 780                        | 808                        | 4                                 | 4                                 | 51202          | 19423          | 38952          | 29175               | 29200                | 10                   |
| 10      | 868                        | 707                        | 0                                 | 0                                 | 51418          | 19354          | 38785          | 29119               | 29020                | 10                   |
| Average | 836.11                     | 768.33                     | 2                                 | 2                                 | 51339.6        | 19424.7        | 38855.8        | 29139.6             | 29140.9              | 10.3                 |

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|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 29040                      | 668                        | 0                                 | 0                                 | 99964          | 0              | 99964          | 99969               | 0                    | 16                   |
| 2       | 25672                      | 773                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 3       | 25537                      | 779                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 4       | 26458                      | 809                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 5       | 27953                      | 790                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 6       | 25793                      | 702                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 7       | 26898                      | 803                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 8       | 25069                      | 717                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 9       | 29343                      | 798                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| 10      | 27177                      | 809                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |
| Average | 26894                      | 764.8                      | 0                                 | 0                                 | 99964          | 0              | 99969          | 99969               | 0                    | 16                   |

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|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | 26295                      | 589                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 2       | 26885                      | 651                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 3       | 26950                      | 665                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 4       | 27263                      | 720                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 5       | 27816                      | 699                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 6       | 23700                      | 816                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 7       | 26104                      | 710                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 8       | 28631                      | 812                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 9       | 27132                      | 808                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| 10      | 27059                      | 803                        | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |
| Average | 26783.5                    | 727.3                      | 0                                 | 0                                 | 99964          | 0              | 99969          | 0                   | 99969                | 16                   |

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|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | 872                        | 843                        | 2                                 | 2                                 | 61574          | 23313          | 49491          | 34855               | 34949                | 11           |
| 2       | 856                        | 1020                       | 1                                 | 1                                 | 61588          | 23286          | 46389          | 34876               | 34799                | 11           |
| 3       | 816                        | 866                        | 2                                 | 2                                 | 61532          | 23275          | 46389          | 34743               | 34904                | 11           |
| 4       | 934                        | 1038                       | 6                                 | 6                                 | 61551          | 23191          | 46635          | 34968               | 34858                | 11           |
| 5       | 719                        | 804                        | 6                                 | 6                                 | 61496          | 23330          | 46649          | 35064               | 34915                | 11           |
| 6       | 736                        | 849                        | 2                                 | 2                                 | 61599          | 23396          | 46695          | 35116               | 34975                | 11           |
| 7       | 745                        | 848                        | 6                                 | 6                                 | 61578          | 23444          | 46594          | 34966               | 35072                | 10           |
| 8       | 799                        | 970                        | 4                                 | 4                                 | 61878          | 23437          | 46684          | 34995               | 35126                | 11           |
| 9       | 847                        | 920                        | 4                                 | 4                                 | 61583          | 23329          | 46718          | 34931               | 35116                | 11           |
| 10      | 820                        | 900                        | 3                                 | 3                                 | 61466          | 23196          | 46442          | 34842               | 34796                | 11           |
| Average | 814.4                      | 905.8                      | 3.6                               | 3.6                               | 61584.5        | 23319.7        | 46868.6        | 34935.6             | 34951                | 10.9         |

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|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | 37898                      | 1010                       | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 2       | 35821                      | 828                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 3       | 39099                      | 972                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 4       | 39212                      | 986                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 5       | 40932                      | 922                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 6       | 34991                      | 845                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 7       | 37829                      | 884                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 8       | 36170                      | 837                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 9       | 35058                      | 838                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| 10      | 35487                      | 905                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |
| Average | 37249.7                    | 902.7                      | 0                                 | 0                                 | 119963         | 0              | 119969         | 119969              | 0                    | 16           |

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d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | 34109                      | 829                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 2       | 37330                      | 846                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 3       | 34775                      | 803                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 4       | 35302                      | 809                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 5       | 33975                      | 981                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 6       | 36325                      | 932                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 7       | 35771                      | 947                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 8       | 34087                      | 883                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 9       | 34908                      | 916                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| 10      | 37970                      | 911                        | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |
| Average | 35455.2                    | 885.7                      | 0                                 | 0                                 | 119963         | 0              | 119969         | 0                   | 119969               | 16           |

- n= 200000
- d =0

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | 3060                       | 1795                       | 16                                | 16                                | 102649         | 38877          | 77758          | 58225               | 58410                | 11           |
| 2       | 2901                       | 1422                       | 8                                 | 8                                 | 102534         | 38769          | 77589          | 58274               | 5808                 | 11           |
| 3       | 2655                       | 1500                       | 6                                 | 6                                 | 102831         | 38845          | 77731          | 58366               | 58721                | 11           |
| 4       | 2869                       | 1680                       | 11                                | 11                                | 102668         | 38926          | 77496          | 58212               | 58210                | 11           |
| 5       | 2813                       | 1625                       | 16                                | 16                                | 102734         | 38711          | 77520          | 58192               | 58039                | 11           |
| 6       | 2952                       | 1665                       | 7                                 | 7                                 | 102530         | 38618          | 77602          | 58140               | 58080                | 11           |
| 7       | 2767                       | 1548                       | 5                                 | 5                                 | 102741         | 38997          | 77856          | 58435               | 58418                | 11           |
| 8       | 3421                       | 1772                       | 8                                 | 8                                 | 102928         | 38760          | 77565          | 58146               | 58179                | 11           |
| 9       | 2665                       | 1420                       | 14                                | 14                                | 102760         | 38758          | 77720          | 58141               | 58337                | 11           |
| 10      | 2780                       | 1623                       | 5                                 | 5                                 | 102667         | 38822          | 77606          | 58157               | 58271                | 11           |
| Average | 2888.3                     | 1605                       | 9.6                               | 9.6                               | 102704.2       | 38808.2        | 77644.3        | 58228.8             | 53047.3              | 11           |

- n= 200000
- d=1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | Core dumped                | 1830                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 2       | Core dumped                | 1528                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 3       | Core dumped                | 1511                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 4       | Core dumped                | 1553                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 5       | Core dumped                | 1325                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 6       | Core dumped                | 1358                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 7       | Core dumped                | 1502                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 8       | Core dumped                | 1304                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 9       | Core dumped                | 1633                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| 10      | Core dumped                | 1400                       | Core dumped                       | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |
| Average |                            | 1494.4                     |                                   | 0                                 | 199962         | 0              | 199967         | 199967              | 0                    | 17           |

- n= 200000  
d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | Core Dumped                | 1477                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 2       | Core Dumped                | 1648                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 3       | Core Dumped                | 1379                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 4       | Core Dumped                | 1449                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 5       | Core Dumped                | 1430                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 6       | Core Dumped                | 1423                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 7       | Core Dumped                | 1555                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 8       | Core Dumped                | 1543                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 9       | Core Dumped                | 1591                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| 10      | Core Dumped                | 1646                       | Core Dumped                       | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |
| Average |                            | 1514.1                     |                                   | 0                                 | 199962         | 0              | 199967         | 0                   | 199967               | 17           |



- n= 250000  
d=0

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|
| 1       | core dumped                | 5008                       | 17                                | 17                                | 128118         | 48435          | 97131          | 72868               | 72698                |
| 2       |                            | 4860                       | 16                                | 16                                | 128500         | 48286          | 96910          | 72800               | 72396                |
| 3       |                            | 5553                       | 11                                | 11                                | 128533         | 48510          | 97060          | 72914               | 73058                |
| 4       |                            | 7231                       | 18                                | 18                                | 128274         | 48677          | 97090          | 73103               | 72664                |
| 5       |                            | 5117                       | 9                                 | 9                                 | 128271         | 48837          | 97135          | 72915               | 73058                |
| 6       |                            | 5196                       | 10                                | 10                                | 128330         | 48781          | 97263          | 73048               | 72996                |
| 7       |                            | 5210                       | 9                                 | 9                                 | 128185         | 48480          | 97131          | 72812               | 72799                |
| 8       |                            | 5597                       | 15                                | 15                                | 128410         | 47893          | 96506          | 72327               | 72072                |
| 9       |                            | 5602                       | 16                                | 16                                | 128254         | 48431          | 96999          | 72750               | 72680                |
| 10      |                            | 7769                       | 15                                | 15                                | 128274         | 48677          | 97090          | 73103               | 72664                |
| Average |                            | 5714.3                     | 13.6                              | 13.6                              | 128314.9       | 48500.7        | 97031.5        | 72864               | 72708.5              |

- n= 250000  
d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black height counter |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|----------------------|
| 1       | core dumped                | 4965                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 2       |                            | 4827                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 3       |                            | 5516                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 4       |                            | 4990                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 5       |                            | 5031                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 6       |                            | 5179                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 7       |                            | 4839                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 8       |                            | 4594                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 9       |                            | 7409                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| 10      |                            | 6034                       | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |
| Average |                            | 5338.4                     | 0                                 | 0                                 | 249961         | 0              | 249967         | 0                   | 249967               | 17                   |

- n= 250000  
d=1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | core dumped                | 5095                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 2       |                            | 5330                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 3       |                            | 5001                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 4       |                            | 5147                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 5       |                            | 4876                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 6       |                            | 4855                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 7       |                            | 4922                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 8       |                            | 5762                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 9       |                            | 7067                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| 10      |                            | 4543                       | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |
| Average |                            | 5259.8                     | 0                                 | 0                                 | 249967         | 0              | 249961         | 249961              | 249967               | 17           |

- n= 300000
- d=0

|   | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1 | Core Dumped                | 4786                       | Core Dumped                       | 24                                | 154241         | 58328          | 116723         | 87576               | 87475                | 11           |
| 2 | Core Dumped                | 2691                       | Core Dumped                       | 26                                | 153969         | 58330          | 116585         | 87459               | 87456                | 11           |
| 3 | Core Dumped                | 2731                       | Core Dumped                       | 20                                | 154151         | 58202          | 116884         | 87515               | 87571                | 11           |
| 4 | Core Dumped                | 2714                       | Core Dumped                       | 23                                | 153934         | 58196          | 116570         | 87420               | 87346                | 11           |
| 5 | Core Dumped                | 2630                       | Core Dumped                       | 19                                | 153773         | 58222          | 116524         | 87248               | 87498                | 11           |
| 6 | Core Dumped                | 2576                       | Core Dumped                       | 20                                | 154193         | 58268          | 116501         | 87385               | 87384                | 11           |
| 7 | Core Dumped                | 2652                       | Core Dumped                       | 22                                | 154190         | 58220          | 116758         | 87496               | 87482                | 11           |

|         |             |      |             |      |          |         |          |         |         |    |
|---------|-------------|------|-------------|------|----------|---------|----------|---------|---------|----|
| 8       | Core Dumped | 2824 | Core Dumped | 17   | 153956   | 58212   | 116162   | 87212   | 87253   | 11 |
| 9       | Core Dumped | 2777 | Core Dumped | 27   | 154270   | 58112   | 116525   | 87328   | 87309   | 11 |
| 10      | Core Dumped | 2729 | Core Dumped | 15   | 153937   | 58246   | 116787   | 87453   | 87760   | 11 |
| Average |             | 2911 |             | 21.3 | 154061.4 | 58233.6 | 116601.9 | 87409.2 | 87453.4 | 11 |

- n= 300000  
d=1

|   | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1 | Core Dumped                | 2548                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 2 | Core Dumped                | 2958                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 3 | Core Dumped                | 2389                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 4 | Core Dumped                | 2515                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 5 | Core Dumped                | 2291                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 6 | Core Dumped                | 2421                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 7 | Core Dumped                | 2210                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 8 | Core Dumped                | 2332                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |
| 9 | Core Dumped                | 2300                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 299966              | 0                    | 17           |

|         |             |      |             |   |        |   |        |        |   |    |
|---------|-------------|------|-------------|---|--------|---|--------|--------|---|----|
| 10      | Core Dumped | 2276 | Core Dumped | 0 | 299958 | 0 | 299966 | 299966 | 0 | 17 |
| Average |             | 2424 |             | 0 | 299958 | 0 | 299966 | 299966 | 0 | 17 |

- n= 300000  
d=-1

|         | Running time for BST(real) | Running time for RBT(real) | Number of duplicates Counter(BST) | Number of duplicates Counter(RBT) | Case 1 counter | Case 2 counter | Case 3 counter | Left rotate counter | Right rotate counter | Black Height |
|---------|----------------------------|----------------------------|-----------------------------------|-----------------------------------|----------------|----------------|----------------|---------------------|----------------------|--------------|
| 1       | Core Dumped                | 2448                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 2       | Core Dumped                | 2321                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 3       | Core Dumped                | 2080                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 4       | Core Dumped                | 2369                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 5       | Core Dumped                | 2115                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 6       | Core Dumped                | 2419                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 7       | Core Dumped                | 2355                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 8       | Core Dumped                | 2419                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 9       | Core Dumped                | 2441                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| 10      | Core Dumped                | 2523                       | Core Dumped                       | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |
| Average |                            | 2349                       |                                   | 0                                 | 299958         | 0              | 299966         | 0                   | 299966               | 17           |

NOTE: All the readings above are real timings in milliseconds.

**Counter behavior:**

We observed the following behavior for counters in different inputs.

$D=1$  and  $D=-1$  (for inverse sorted and sorted input): case 2 counter is 0 .

$D=1$  (sorted input): right rotate counter is 0.

$D=-1$  (inverse sorted input): left rotate counter is 0.

**Height of the respective trees:**

The height of the tree increases the running time for BST also increases.

The running time of BST is  $O(h)$  for operations where  $h$  is the height of the tree.

The running time of RBT is  $O(\log n)$  for operations.

In case of sorted input, the nodes are added to the right of root node for Binary Search Tree so the height of the tree goes on increasing and so does the running time.

In case of inverse sorted input, the nodes are added to the left of root node for Binary Search Tree so the height of the tree goes on increasing and so does the running time.

We observed that for large inputs in case of sorted and inverse sorted, the running time of Binary Search Tree is greater than the running time of Red Black Tree.