

# Assignment6

Yudong Zhang (20345353)

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```
CoresNumber <- detectCores()  
CoresNumber
```

```
## [1] 16
```

```
StartSerial <- Sys.time()  
for (i in 1:4000) {  
  mean(rnorm(100000, mean = 10, sd = 3))  
}  
EndSerial <- Sys.time()  
TimeSerial <- EndSerial - StartSerial  
TimeSerial
```

```
## Time difference of 18.44592 secs
```

```
TheoreticalRatio <- 1 / (CoresNumber - 1)  
TheoreticalRatio
```

```
## [1] 0.06666667
```

```
Cores <- makeCluster(CoresNumber - 1)  
registerDoParallel(Cores)  
  
StartParallel <- Sys.time()  
foreach(i = 1:4000, .combine = rbind) %dopar% {  
  mean(rnorm(100000, mean = 10, sd = 3))  
}
```

```
## [1]
## result.1      9.999631
## result.2     10.012418
## result.3     9.990775
## result.4    10.008685
## result.5     9.999503
## result.6    10.008143
## result.7    10.001546
## result.8     9.995879
## result.9    10.000206
## result.10    9.997373
## result.11   10.000578
## result.12    9.983356
## result.13   10.009767
## result.14    9.987517
## result.15   10.011653
## result.16    9.996760
## result.17    9.996685
## result.18    9.991224
## result.19    9.999797
## result.20   10.011762
## result.21    10.008571
## result.22   10.016543
## result.23    9.982338
## result.24    9.992291
## result.25    9.987953
## result.26    9.994094
## result.27    9.976726
## result.28    9.996606
## result.29    9.999102
## result.30   10.002422
## result.31    9.996278
## result.32    9.984710
## result.33    9.987938
## result.34   10.008244
## result.35   10.006997
## result.36   10.000987
## result.37    9.996739
## result.38    9.995083
## result.39    9.999198
## result.40   10.000587
## result.41   10.021068
## result.42    9.998119
## result.43    9.997823
## result.44   10.014978
## result.45    9.992524
## result.46   10.007139
## result.47    9.988288
## result.48    9.994720
## result.49   10.007521
## result.50    9.995951
## result.51   10.013312
```

```
## result.52 10.000147
## result.53 9.995270
## result.54 9.993101
## result.55 9.995067
## result.56 10.004025
## result.57 10.016550
## result.58 10.014098
## result.59 10.012390
## result.60 10.000849
## result.61 10.001744
## result.62 10.001044
## result.63 10.000500
## result.64 9.983170
## result.65 10.000633
## result.66 9.995080
## result.67 10.002480
## result.68 9.989967
## result.69 9.998807
## result.70 9.993470
## result.71 9.984951
## result.72 9.993411
## result.73 10.015007
## result.74 9.998109
## result.75 9.997824
## result.76 9.998004
## result.77 9.980811
## result.78 9.994426
## result.79 10.000055
## result.80 9.996468
## result.81 10.007529
## result.82 10.000326
## result.83 9.986545
## result.84 10.008566
## result.85 9.997145
## result.86 9.992725
## result.87 10.000299
## result.88 9.987088
## result.89 10.005013
## result.90 10.008203
## result.91 9.993545
## result.92 10.008020
## result.93 10.010382
## result.94 10.006951
## result.95 9.993768
## result.96 10.000329
## result.97 10.003729
## result.98 9.991209
## result.99 10.023231
## result.100 9.992210
## result.101 9.985672
## result.102 10.012508
## result.103 10.010719
```

```
## result.104 10.020914
## result.105 9.983666
## result.106 10.007925
## result.107 10.004286
## result.108 9.992771
## result.109 10.001292
## result.110 9.991348
## result.111 9.981201
## result.112 9.991432
## result.113 10.000015
## result.114 9.994795
## result.115 10.012756
## result.116 10.008910
## result.117 9.992143
## result.118 9.998052
## result.119 10.007401
## result.120 9.991276
## result.121 9.981666
## result.122 9.986645
## result.123 9.993055
## result.124 9.996520
## result.125 9.992751
## result.126 10.000325
## result.127 9.995282
## result.128 10.005975
## result.129 9.999391
## result.130 10.001449
## result.131 9.993548
## result.132 10.018106
## result.133 9.987674
## result.134 10.003102
## result.135 9.989230
## result.136 10.003526
## result.137 9.998533
## result.138 10.007891
## result.139 9.994628
## result.140 9.987740
## result.141 9.982396
## result.142 9.999723
## result.143 10.000421
## result.144 9.997621
## result.145 9.999785
## result.146 10.012800
## result.147 10.005228
## result.148 10.016567
## result.149 10.011973
## result.150 9.998101
## result.151 10.013321
## result.152 9.987499
## result.153 9.999097
## result.154 9.996854
## result.155 10.004834
```

```
## result.156 9.990008
## result.157 9.999628
## result.158 9.999144
## result.159 9.997482
## result.160 10.014663
## result.161 9.982383
## result.162 9.991235
## result.163 9.986434
## result.164 9.989068
## result.165 9.988128
## result.166 9.992948
## result.167 10.012415
## result.168 10.014427
## result.169 10.001722
## result.170 9.992106
## result.171 10.001692
## result.172 10.014335
## result.173 10.009852
## result.174 9.984268
## result.175 9.990003
## result.176 9.993006
## result.177 9.996176
## result.178 10.012712
## result.179 9.986355
## result.180 10.014406
## result.181 10.024670
## result.182 9.998220
## result.183 10.007062
## result.184 9.977325
## result.185 9.977718
## result.186 10.011681
## result.187 9.987339
## result.188 10.012853
## result.189 9.995061
## result.190 10.012035
## result.191 10.003180
## result.192 9.997177
## result.193 9.999055
## result.194 10.000298
## result.195 10.014184
## result.196 10.013228
## result.197 10.003169
## result.198 10.010189
## result.199 9.989121
## result.200 10.002474
## result.201 9.993655
## result.202 10.006758
## result.203 10.004043
## result.204 9.986370
## result.205 9.999567
## result.206 10.000280
## result.207 10.007324
```

```
## result.208 10.007336
## result.209 9.992700
## result.210 9.987790
## result.211 9.991237
## result.212 9.998434
## result.213 9.992698
## result.214 10.008659
## result.215 9.993074
## result.216 9.990177
## result.217 10.015687
## result.218 9.974780
## result.219 9.986518
## result.220 9.988813
## result.221 10.004604
## result.222 10.002306
## result.223 10.013303
## result.224 10.004715
## result.225 10.012592
## result.226 10.000807
## result.227 9.999305
## result.228 10.001184
## result.229 9.996682
## result.230 9.979533
## result.231 9.994507
## result.232 10.004594
## result.233 10.000932
## result.234 9.989098
## result.235 9.992000
## result.236 9.999529
## result.237 9.982376
## result.238 10.003331
## result.239 9.986825
## result.240 10.002249
## result.241 9.994119
## result.242 10.004910
## result.243 9.991565
## result.244 10.010581
## result.245 10.005383
## result.246 9.993991
## result.247 9.999933
## result.248 9.998145
## result.249 9.986769
## result.250 9.999252
## result.251 9.991200
## result.252 9.988679
## result.253 9.983499
## result.254 9.997674
## result.255 9.994640
## result.256 9.996246
## result.257 10.009871
## result.258 10.011005
## result.259 9.996960
```

```
## result.260 9.983644
## result.261 10.014760
## result.262 9.995288
## result.263 10.002543
## result.264 10.004234
## result.265 10.006929
## result.266 10.000556
## result.267 10.005590
## result.268 9.986809
## result.269 9.991609
## result.270 9.990367
## result.271 9.993297
## result.272 9.993138
## result.273 10.005990
## result.274 10.002559
## result.275 9.985367
## result.276 9.993398
## result.277 10.004578
## result.278 9.992343
## result.279 9.995177
## result.280 9.994339
## result.281 10.001704
## result.282 10.003614
## result.283 10.007035
## result.284 9.996448
## result.285 10.001944
## result.286 10.003371
## result.287 10.006375
## result.288 9.997393
## result.289 9.998453
## result.290 10.000179
## result.291 9.991509
## result.292 10.008927
## result.293 9.998076
## result.294 10.013557
## result.295 9.995860
## result.296 10.003389
## result.297 9.987540
## result.298 9.995027
## result.299 9.996844
## result.300 9.981033
## result.301 9.991404
## result.302 9.989491
## result.303 9.998546
## result.304 9.990663
## result.305 10.007679
## result.306 10.013197
## result.307 10.009145
## result.308 10.010424
## result.309 9.994463
## result.310 10.018642
## result.311 9.997302
```

```
## result.312  9.999251
## result.313  10.000018
## result.314  10.011337
## result.315  9.991701
## result.316  10.009872
## result.317  10.005191
## result.318  10.008602
## result.319  10.028405
## result.320  9.991451
## result.321  10.019334
## result.322  10.014837
## result.323  9.988157
## result.324  10.008563
## result.325  10.000923
## result.326  10.001996
## result.327  9.991074
## result.328  9.997172
## result.329  10.001726
## result.330  10.010164
## result.331  9.996920
## result.332  10.003565
## result.333  10.014159
## result.334  9.988148
## result.335  10.001602
## result.336  9.984977
## result.337  9.992416
## result.338  10.005740
## result.339  9.994216
## result.340  9.999220
## result.341  10.005222
## result.342  9.993483
## result.343  9.998183
## result.344  10.013443
## result.345  10.002299
## result.346  9.996371
## result.347  10.001455
## result.348  10.000581
## result.349  10.002608
## result.350  10.024146
## result.351  10.003288
## result.352  9.990420
## result.353  10.021366
## result.354  10.002493
## result.355  9.994102
## result.356  10.004988
## result.357  10.001528
## result.358  10.021632
## result.359  9.986892
## result.360  10.001760
## result.361  10.010876
## result.362  10.006302
## result.363  9.989314
```

```
## result.364 10.003813
## result.365 9.999585
## result.366 9.988452
## result.367 10.015712
## result.368 10.016380
## result.369 10.004964
## result.370 9.992966
## result.371 10.000069
## result.372 9.976167
## result.373 10.004127
## result.374 9.994452
## result.375 10.011466
## result.376 10.005290
## result.377 9.985447
## result.378 9.982465
## result.379 9.980235
## result.380 9.996764
## result.381 9.999019
## result.382 9.994820
## result.383 9.996596
## result.384 10.004410
## result.385 10.001021
## result.386 10.002152
## result.387 10.000015
## result.388 10.012849
## result.389 10.008196
## result.390 9.995215
## result.391 9.994115
## result.392 9.992075
## result.393 9.990745
## result.394 10.000309
## result.395 10.000707
## result.396 9.995128
## result.397 10.014185
## result.398 9.990505
## result.399 9.987598
## result.400 9.991130
## result.401 10.020424
## result.402 10.005882
## result.403 10.018281
## result.404 9.991049
## result.405 10.016260
## result.406 10.004460
## result.407 9.996608
## result.408 9.998880
## result.409 9.995438
## result.410 10.009821
## result.411 10.012845
## result.412 9.987355
## result.413 9.984103
## result.414 9.997853
## result.415 10.003321
```

```
## result.416 10.014752
## result.417 10.005365
## result.418 10.001805
## result.419 9.997922
## result.420 9.999658
## result.421 10.006534
## result.422 10.003990
## result.423 10.000263
## result.424 9.996152
## result.425 9.993674
## result.426 9.988418
## result.427 9.996264
## result.428 9.991468
## result.429 10.005454
## result.430 10.001840
## result.431 9.999190
## result.432 10.001026
## result.433 10.008861
## result.434 9.995493
## result.435 9.987503
## result.436 10.004575
## result.437 10.003464
## result.438 10.003862
## result.439 9.998771
## result.440 10.003007
## result.441 10.005143
## result.442 9.997092
## result.443 10.004170
## result.444 10.006238
## result.445 10.004439
## result.446 10.005109
## result.447 9.999924
## result.448 9.995199
## result.449 10.009743
## result.450 10.021382
## result.451 9.994225
## result.452 9.980468
## result.453 9.990310
## result.454 10.003338
## result.455 9.990516
## result.456 10.008199
## result.457 9.999979
## result.458 9.982903
## result.459 10.003605
## result.460 9.997586
## result.461 10.007088
## result.462 10.006441
## result.463 9.991345
## result.464 9.993135
## result.465 10.014222
## result.466 10.005857
## result.467 9.989317
```

```
## result.468 9.996313
## result.469 9.994803
## result.470 9.986222
## result.471 9.988515
## result.472 10.012422
## result.473 9.993565
## result.474 10.002011
## result.475 10.007585
## result.476 10.006634
## result.477 9.988400
## result.478 9.981556
## result.479 10.017414
## result.480 10.017420
## result.481 10.001785
## result.482 10.008866
## result.483 9.993779
## result.484 10.009482
## result.485 10.002054
## result.486 10.011415
## result.487 10.000570
## result.488 9.990974
## result.489 9.999476
## result.490 10.015674
## result.491 9.980868
## result.492 9.995711
## result.493 9.986568
## result.494 10.005881
## result.495 9.991089
## result.496 9.996842
## result.497 10.014731
## result.498 9.994636
## result.499 9.993544
## result.500 10.000931
## result.501 10.012996
## result.502 10.011898
## result.503 9.992300
## result.504 10.006613
## result.505 10.016035
## result.506 9.993240
## result.507 10.006029
## result.508 9.992133
## result.509 9.993978
## result.510 10.001250
## result.511 9.985210
## result.512 9.989147
## result.513 9.995075
## result.514 10.002994
## result.515 9.990510
## result.516 9.984366
## result.517 10.004344
## result.518 10.000026
## result.519 10.016632
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## result.520 9.994794
## result.521 9.993612
## result.522 9.987297
## result.523 10.007535
## result.524 9.985051
## result.525 9.999105
## result.526 10.017518
## result.527 9.998298
## result.528 10.010201
## result.529 10.013306
## result.530 9.994032
## result.531 9.988633
## result.532 10.002985
## result.533 10.008034
## result.534 9.992728
## result.535 10.006948
## result.536 10.009973
## result.537 10.007245
## result.538 10.004338
## result.539 9.998565
## result.540 10.001496
## result.541 9.997431
## result.542 9.990182
## result.543 9.989668
## result.544 10.009085
## result.545 9.983279
## result.546 9.993704
## result.547 10.000109
## result.548 10.008681
## result.549 9.988720
## result.550 9.996498
## result.551 9.990860
## result.552 10.003022
## result.553 9.999942
## result.554 10.005870
## result.555 10.012073
## result.556 10.003486
## result.557 10.013955
## result.558 9.994712
## result.559 9.980962
## result.560 10.017095
## result.561 9.998719
## result.562 9.997970
## result.563 10.001891
## result.564 10.003035
## result.565 10.000499
## result.566 10.004063
## result.567 9.974355
## result.568 9.988516
## result.569 10.017290
## result.570 10.004938
## result.571 10.002313
```

```
## result.572 9.996636
## result.573 9.995394
## result.574 10.017513
## result.575 10.009679
## result.576 10.016519
## result.577 10.016186
## result.578 9.996183
## result.579 10.012682
## result.580 9.997096
## result.581 9.995592
## result.582 10.001981
## result.583 10.005913
## result.584 9.990160
## result.585 10.007881
## result.586 9.989702
## result.587 9.994649
## result.588 9.993580
## result.589 9.998087
## result.590 9.994798
## result.591 10.006499
## result.592 10.002580
## result.593 10.001371
## result.594 10.000496
## result.595 10.002329
## result.596 10.002292
## result.597 9.998934
## result.598 10.022301
## result.599 10.004876
## result.600 9.995047
## result.601 9.994758
## result.602 10.006223
## result.603 10.016505
## result.604 9.999708
## result.605 9.988780
## result.606 9.994155
## result.607 10.015038
## result.608 10.006064
## result.609 10.008521
## result.610 10.011835
## result.611 9.994230
## result.612 9.993402
## result.613 10.000019
## result.614 10.004155
## result.615 10.000871
## result.616 9.987155
## result.617 10.010255
## result.618 9.990333
## result.619 10.003294
## result.620 10.006826
## result.621 9.997426
## result.622 9.997643
## result.623 10.007751
```

```
## result.624 10.015452
## result.625 9.999609
## result.626 10.005012
## result.627 10.000880
## result.628 9.998143
## result.629 9.992958
## result.630 9.991928
## result.631 9.991270
## result.632 9.985457
## result.633 10.003415
## result.634 9.988849
## result.635 10.005303
## result.636 10.003424
## result.637 9.994310
## result.638 9.996625
## result.639 10.000258
## result.640 9.993089
## result.641 9.992817
## result.642 10.006790
## result.643 10.006668
## result.644 9.989540
## result.645 9.998733
## result.646 9.995018
## result.647 9.994987
## result.648 9.989158
## result.649 9.979708
## result.650 10.004659
## result.651 10.004413
## result.652 9.996409
## result.653 9.985921
## result.654 10.001538
## result.655 10.001041
## result.656 10.008246
## result.657 9.986656
## result.658 10.006159
## result.659 10.009604
## result.660 10.017931
## result.661 9.999978
## result.662 9.996602
## result.663 9.993271
## result.664 10.004897
## result.665 9.991453
## result.666 10.007705
## result.667 9.998055
## result.668 10.001013
## result.669 9.997589
## result.670 10.004195
## result.671 10.003697
## result.672 10.000111
## result.673 10.005335
## result.674 10.004340
## result.675 10.012999
```

```
## result.676 9.985669
## result.677 10.021917
## result.678 10.009626
## result.679 9.993637
## result.680 10.008965
## result.681 10.012909
## result.682 9.983358
## result.683 9.981330
## result.684 9.989646
## result.685 9.990651
## result.686 10.003411
## result.687 10.009162
## result.688 10.008967
## result.689 10.000199
## result.690 10.008074
## result.691 9.988810
## result.692 10.010351
## result.693 10.004636
## result.694 9.989735
## result.695 10.010443
## result.696 9.991572
## result.697 9.985350
## result.698 10.002922
## result.699 9.994746
## result.700 10.009640
## result.701 10.021807
## result.702 10.001164
## result.703 9.988324
## result.704 9.991909
## result.705 10.018514
## result.706 9.996172
## result.707 9.998093
## result.708 10.003107
## result.709 10.005395
## result.710 10.004664
## result.711 9.991600
## result.712 9.988326
## result.713 9.993364
## result.714 10.000985
## result.715 10.000722
## result.716 10.000732
## result.717 10.006608
## result.718 10.003617
## result.719 9.995692
## result.720 9.986130
## result.721 9.998263
## result.722 9.996349
## result.723 10.002786
## result.724 9.990727
## result.725 9.989586
## result.726 9.986775
## result.727 10.000870
```

```
## result.728 10.006219
## result.729 9.998901
## result.730 9.997590
## result.731 10.017925
## result.732 10.010255
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## result.3588 9.998652
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## result.3605 9.987188
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## result.3640 9.999495
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## result.3692 10.015369
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## result.3708  9.990317
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## result.3715  9.993718
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## result.3717  9.995629
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## result.3720  9.996414
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## result.3722 10.001353
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## result.3725  9.987382
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## result.3727  9.989117
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## result.3735 10.009286
## result.3736  9.995203
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## result.3738 10.017103
## result.3739 10.008510
## result.3740 10.007054
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## result.3747 10.007584
## result.3748 10.008032
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## result.3750  9.990564
## result.3751  9.986550
## result.3752  9.984497
## result.3753  9.990708
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## result.3755 10.007277
## result.3756 10.023569
## result.3757 10.007321
## result.3758 10.010271
## result.3759 10.026605
## result.3760 10.013442
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## result.3765 10.009097
## result.3766 10.005053
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## result.3796 9.998043
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## result.3802 9.993148
## result.3803 9.986991
## result.3804 10.004746
## result.3805 10.002115
## result.3806 10.001188
## result.3807 9.997666
## result.3808 9.999495
## result.3809 9.998292
## result.3810 9.988915
## result.3811 10.018642
## result.3812 9.990581
## result.3813 10.004427
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## result.3823 10.000175
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## result.3827 10.001638
## result.3828 10.006301
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## result.3830 9.999373
## result.3831 10.009905
## result.3832 10.005947
## result.3833 10.013130
## result.3834 10.010331
## result.3835 10.005732
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## result.3848 10.008553
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## result.3856 9.994954
## result.3857 10.010334
## result.3858 10.005726
## result.3859 9.989019
## result.3860 10.004122
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## result.3862 10.008185
## result.3863 10.000367
## result.3864 9.998525
## result.3865 10.002880
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## result.3870 10.011268
## result.3871 9.996201
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## result.3878 9.976444
## result.3879 9.992434
## result.3880 9.994510
## result.3881 10.006966
## result.3882 10.016447
## result.3883 10.003809
## result.3884 9.999726
## result.3885 9.999757
## result.3886 9.991781
## result.3887 10.009869
## result.3888 9.987966
## result.3889 9.990299
## result.3890 9.998049
## result.3891 10.010509
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## result.3894 10.002717
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## result.3896 10.002940
## result.3897 10.012127
## result.3898 10.000392
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## result.3900 10.000403
## result.3901 10.002634
## result.3902 10.000963
## result.3903 10.000790
## result.3904 10.010909
## result.3905 10.010667
## result.3906 9.994648
## result.3907 9.996534
## result.3908 9.999108
## result.3909 9.997763
## result.3910 10.006228
## result.3911 10.021470
## result.3912 10.000464
## result.3913 10.006474
## result.3914 10.000986
## result.3915 10.005410
## result.3916 10.002061
## result.3917 10.018871
## result.3918 10.000212
## result.3919 10.011689
## result.3920 10.023561
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## result.3922 9.982687
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## result.3925 10.019494
## result.3926 9.999747
## result.3927 9.988757
## result.3928 10.005532
## result.3929 9.999627
## result.3930 10.008943
## result.3931 9.989340
## result.3932 9.996757
## result.3933 10.003220
## result.3934 10.010170
## result.3935 9.985664
## result.3936 10.010891
## result.3937 10.010381
## result.3938 10.011486
## result.3939 9.996062
## result.3940 9.987111
## result.3941 10.018161
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## result.3946 10.002984
## result.3947 9.991305
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## result.3952 9.992847
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## result.3958 9.997754
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## result.3960 9.990302
## result.3961 10.006249
## result.3962 9.989010
## result.3963 9.984842
## result.3964 9.998401
## result.3965 9.978369
## result.3966 9.984688
## result.3967 9.995516
## result.3968 10.002018
## result.3969 9.996248
## result.3970 9.991671
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## result.3974 10.002862
## result.3975 9.991226
## result.3976 10.009126
## result.3977 9.997332
## result.3978 9.990433
## result.3979 10.012236
## result.3980 10.003583
## result.3981 10.004998
## result.3982 9.993207
## result.3983 10.011809
## result.3984 9.993071
## result.3985 10.004693
## result.3986 10.017728
## result.3987 10.011145
## result.3988 10.000512
## result.3989 9.992252
## result.3990 9.997696
## result.3991 10.005581
## result.3992 10.002620
## result.3993 10.005584
## result.3994 10.008611
## result.3995 10.005251
## result.3996 10.004000
## result.3997 10.007033
## result.3998 9.996691
## result.3999 10.000312
## result.4000 9.999237
```

```
EndParallel <- Sys.time()
TimeParallel <- EndParallel - StartParallel
TimeParallel

## Time difference of 3.345161 secs

stopCluster(Cores)

speedup <- as.numeric(TimeSerial, units = "secs") / as.numeric(TimeParallel, units = "secs")

cat("serial runtime:", round(TimeSerial, 2), "\n")

## serial runtime: 18.45

cat("parallel runtime:", round(TimeParallel, 2), "\n")

## parallel runtime: 3.35

cat("theoretical ratio:", round(TheoreticalRatio, 2), "\n")

## theoretical ratio: 0.07

cat("actual improvement:", round(speedup, 2), "\n")

## actual improvement: 5.51
```

##The serial program took approximately 19.12 seconds, while the parallel program took 3.54 seconds, resulting in an actual speedup of approximately 5.4x. The theoretical speedup, calculated based on the number of available cores, is approximately 0.07. The actual speedup is lower than the theoretical value due to the inherent overhead of parallel computing, such as startup and shutdown time and memory data copying time. Overall, parallel computing still significantly improves runtime efficiency, clearly demonstrating R's performance advantage in a multi-core environment.