# Steady State Combustion Problem

## 25 Conjugate Gradient Algorithms
## Comparison between conjugate gradient algorithms and their accelerated variants

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## 1. Conjugate Gradient Algorithms

```
   *-----------------------------------------------------
   | Fastest Conjugate Gradient Algorithm Project
   |                                      April 1, 2009
   | stoptest =     1
   | maxiter  = 10000
   | Conjugate Gradient with Powell restart.
   *-----------------------------------------------------

     1    CG-HS Algorithm. Function:Steady State Combustion
          Hestenes and Stiefel.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    849   233   1333   483      4087 -.5611447677677E+01  .4045770825003E-04
-------------------------------------------------------------------------------
TOTAL     849   233   1333   483     40.87 (seconds)    proc=  27.44%


     2    CG-FR Algorithm. Function:Steady State Combustion
          Fletcher and Reeves.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    844   246   1341   496      4055 -.5611448019870E+01  .3251403770844E-04
-------------------------------------------------------------------------------
TOTAL     844   246   1341   496     40.55 (seconds)    proc=  29.15%


     3    CG-PRP Algorithm. Function:Steady State Combustion
          Polak-Ribiere and Polyak.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    762   233   1195   432      3629 -.5611446008023E+01  .4755587896134E-04
-------------------------------------------------------------------------------
TOTAL     762   233   1195   432     36.29 (seconds)    proc=  30.58%


     4    CG-PRP+ Algorithm. Function:Steady State Combustion
          Polak-Ribiere and Polyak plus.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    762   233   1195   432      3632 -.5611446008023E+01  .4755587896134E-04
-------------------------------------------------------------------------------
TOTAL     762   233   1195   432     36.32 (seconds)    proc=  30.58%
```

```
     5    CG-CD Algorithm. Function:Steady State Combustion
          Conjugate Descent - Fletcher. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    907   265   1425   517      4310 -.5611446206004E+01  .4559532508387E-04
-------------------------------------------------------------------------------
TOTAL     907   265   1425   517     43.10 (seconds)    proc=  29.22%


     6    CG-LS Algorithm. Function:Steady State Combustion
          Liu and Storey.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    739   213   1179   439      3581 -.5611448020846E+01  .5247856419287E-04
-------------------------------------------------------------------------------
TOTAL     739   213   1179   439     35.81 (seconds)    proc=  28.82%


     7    CG-DY Algorithm. Function:Steady State Combustion
          Dai and Yuan.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    665   193   1044   378      3168 -.5611447550617E+01  .5119876644314E-04
-------------------------------------------------------------------------------
TOTAL     665   193   1044   378     31.68 (seconds)    proc=  29.02%


     8    CG-DL Algorithm. Function:Steady State Combustion
          Dai and Liao (t=1).  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    818   228   1276   457      3880 -.5611446768997E+01  .3986184090487E-04
-------------------------------------------------------------------------------
TOTAL     818   228   1276   457     38.80 (seconds)    proc=  27.87%


     9    CG-DL+ Algorithm. Function:Steady State Combustion
          Dai and Liao plus (t=1).  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    723   200   1131   407      3440 -.5611445672096E+01  .6112052849424E-04
-------------------------------------------------------------------------------
TOTAL     723   200   1131   407     34.40 (seconds)    proc=  27.66%


    10    CG-SDC Algorithm. Function:Steady State Combustion
          Andrei - Sufficient Descent Condition.  stoptest= 1
    aCGSD: beta = gtg/yts - ytg*stg/(yts*yts)
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000  10001  9930  10049    48     31392 -.5591968942810E+01  .1455646890798E+00
-------------------------------------------------------------------------------
TOTAL   10001  9930  10049    48    313.92 (seconds)    proc=  99.29%


    11    CG-hDY Algorithm. Function:Steady State Combustion
          hDY:Hybrid Dai and Yuan. max(c*DY,min(HS,DY)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000   1201   362   1940   738      5901 -.5611446760697E+01  .4591009459032E-04
-------------------------------------------------------------------------------
TOTAL    1201   362   1940   738     59.01 (seconds)    proc=  30.14%


    12    CG-hDYz Algorithm. Function:Steady State Combustion
          hDYz: Hybrid Dai and Yuan zero. max(0,min(HS,DY)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
```

```
 40000   1201   362   1940   738      5902 -.5611446760697E+01  .4591009459032E-04
-------------------------------------------------------------------------------------
TOTAL    1201   362   1940   738     59.02 (seconds)    proc=  30.14%


    13    CG-GN Algorithm. Function:Steady State Combustion
          Gilbert and Nocedal.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    719   196   1138   418      3454 -.5611447852883E+01  .5153588237288E-04
-------------------------------------------------------------------------------------
TOTAL     719   196   1138   418     34.54 (seconds)    proc=  27.26%


    14    CG-HuS Algorithm. Function:Steady State Combustion
          PRP-FR: Hu and Storey. max(0,min(PRP,FR)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    719   196   1138   418      3454 -.5611447852883E+01  .5153588237288E-04
-------------------------------------------------------------------------------------
TOTAL     719   196   1138   418     34.54 (seconds)    proc=  27.26%


    15    CG-TAS Algorithm. Function:Steady State Combustion
          Touat-Ahmed and Storey. (PRP <= FR). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    719   196   1138   418      3454 -.5611447852883E+01  .5153588237288E-04
-------------------------------------------------------------------------------------
TOTAL     719   196   1138   418     34.54 (seconds)    proc=  27.26%


    16    LS-CD Algorithm. Function:Steady State Combustion
          Hybrid Liu&Storey-Conjugate Descent. max(0,min(LS,CD)) stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    842   246   1329   486      4037 -.5611447026190E+01  .4830904293196E-04
-------------------------------------------------------------------------------------
TOTAL     842   246   1329   486     40.37 (seconds)    proc=  29.22%


    17    CG-BM Algorithm. Function:Steady State Combustion
          Birgin and Martinez (scaled Perry). Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    897   234   1420   521      4325 -.5611447555130E+01  .4601632302671E-04
-------------------------------------------------------------------------------------
TOTAL     897   234   1420   521     43.25 (seconds)    proc=  26.09%


    18    CG-BM+ Algorithm. Function:Steady State Combustion
          Birgin and Martinez plus (scaled Perry). Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    742   211   1158   415      3526 -.5611447914484E+01  .3723300010501E-04
-------------------------------------------------------------------------------------
TOTAL     742   211   1158   415     35.26 (seconds)    proc=  28.44%


    19    CG-sPRP Algorithm. Function:Steady State Combustion
          Scaled Polak-Ribiere and Polyak. Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    884   264   1418   533      4312 -.5611443748537E+01  .6208219027392E-04
-------------------------------------------------------------------------------------
TOTAL     884   264   1418   533     43.12 (seconds)    proc=  29.86%


    20    CG-sFR Algorithm. Function:Steady State Combustion
          Scaled Fletcher and Revees. Theta spectral. stoptest= 1
```

```
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    793   241   1240   446      3771 -.5611444204920E+01  .6201174773869E-04
--------------------------------------------------------------------------------
TOTAL     793   241   1240   446     37.71 (seconds)    proc=  30.39%


    21    New CG Algorithm. Function:Steady State Combustion
          Andrei New Sufficient Descent from PRP. stoptest= 1
    PRP-SDC: beta = (ytg-yty*stg/gtgprev)/yts
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    536   174    862   324      2620 -.5611447742926E+01  .4136255732868E-04
--------------------------------------------------------------------------------
TOTAL     536   174    862   324     26.20 (seconds)    proc=  32.46%


    22    New CG Algorithm. Function:Steady State Combustion
          Andrei New Sufficient Descent from DY. stoptest= 1
          ACGSD: beta=ytg/yts-ytg*stg/(yts**2)

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    824   236   1287   462      3915 -.5611445669752E+01  .5187750574688E-04
--------------------------------------------------------------------------------
TOTAL     824   236   1287   462     39.15 (seconds)    proc=  28.64%


    23    New CG Algorithm. Function:Steady State Combustion
          Andrei Sufficient Descent from DY (max). stoptest= 1
          ACGSDz: beta=max(0,ytg/yts)*(1-stg/yts)

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    821   230   1282   460      3901 -.5611446967055E+01  .5345250038166E-04
--------------------------------------------------------------------------------
TOTAL     821   230   1282   460     39.01 (seconds)    proc=  28.01%


    24    New CG Algorithm. Function:Steady State Combustion
          PRP - DY with Newton direction. (NDOMB) stoptest= 1
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    634   177    984   349      3094 -.5611447846832E+01  .4452343318014E-04
--------------------------------------------------------------------------------
TOTAL     634   177    984   349     30.94 (seconds)    proc=  27.92%


    25    New CG Algorithm. Function:Steady State Combustion
          PRP - DY with Conjugacy Condition. (CCOMB) stoptest= 1
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    729   196   1140   410      3468 -.5611448096275E+01  .4273039073845E-04
--------------------------------------------------------------------------------
TOTAL     729   196   1140   410     34.68 (seconds)    proc=  26.89%
```

# 2. Accelerated Conjugate Gradient Algorithms

```
*-------------------------------------------------
| Fastest Conjugate Gradient Algorithm Project
|                                      April 1, 2009
| stoptest =     1
| maxiter  = 10000
| Accelerated Conjugate Gradient with Powell restart.
*-------------------------------------------------

  1    CG-HS Algorithm. Function:Steady State Combustion
       Hestenes and Stiefel.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1934 -.5611448493596E+01  .2374434219660E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.34 (seconds)    proc=    .00%


  2    CG-FR Algorithm. Function:Steady State Combustion
       Fletcher and Reeves.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1895 -.5611448491506E+01  .2419134355961E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.95 (seconds)    proc=    .00%


  3    CG-PRP Algorithm. Function:Steady State Combustion
       Polak-Ribiere and Polyak.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1899 -.5611448493605E+01  .2374295155084E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.99 (seconds)    proc=    .00%


  4    CG-PRP+ Algorithm. Function:Steady State Combustion
       Polak-Ribiere and Polyak plus.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1898 -.5611448493605E+01  .2374295155084E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.98 (seconds)    proc=    .00%


  5    CG-CD Algorithm. Function:Steady State Combustion
       Conjugate Descent - Fletcher. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1892 -.5611448491393E+01  .2419036641368E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.92 (seconds)    proc=    .00%


  6    CG-LS Algorithm. Function:Steady State Combustion
       Liu and Storey.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1899 -.5611448493598E+01  .2374415284776E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.99 (seconds)    proc=    .00%


  7    CG-DY Algorithm. Function:Steady State Combustion
       Dai and Yuan.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
```

```
 40000    299     0    632    33      1897 -.5611448491509E+01  .2419068569678E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.97 (seconds)    proc=    .00%


     8    CG-DL Algorithm. Function:Steady State Combustion
          Dai and Liao (t=1).  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    299     0    632    33      1899 -.5611448493595E+01  .2374436684539E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.99 (seconds)    proc=    .00%


     9    CG-DL+ Algorithm. Function:Steady State Combustion
          Dai and Liao plus (t=1).  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    299     0    632    33      1905 -.5611448493595E+01  .2374436684489E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.05 (seconds)    proc=    .00%


    10    CG-SDC Algorithm. Function:Steady State Combustion
          Andrei - Sufficient Descent Condition.  stoptest= 1
    aCGSD: beta = gtg/yts - ytg*stg/(yts*yts)
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    299     0    632    33      1903 -.5611448493594E+01  .2374453057875E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.03 (seconds)    proc=    .00%


    11    CG-hDY Algorithm. Function:Steady State Combustion
          hDY:Hybrid Dai and Yuan. max(c*DY,min(HS,DY)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000   1084   208   2758   589      8304 -.5611446772477E+01  .5884201868039E-04
-------------------------------------------------------------------------------------
TOTAL    1084   208   2758   589     83.04 (seconds)    proc=  19.19%


    12    CG-hDYz Algorithm. Function:Steady State Combustion
          hDYz: Hybrid Dai and Yuan zero. max(0,min(HS,DY)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000   1084   208   2758   589      8315 -.5611446772477E+01  .5884201868039E-04
-------------------------------------------------------------------------------------
TOTAL    1084   208   2758   589     83.15 (seconds)    proc=  19.19%


    13    CG-GN Algorithm. Function:Steady State Combustion
          Gilbert and Nocedal.  stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    299     0    632    33      1896 -.5611448493605E+01  .2374295155080E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.96 (seconds)    proc=    .00%


    14    CG-HuS Algorithm. Function:Steady State Combustion
          PRP-FR: Hu and Storey. max(0,min(PRP,FR)). stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------------
 40000    299     0    632    33      1899 -.5611448493605E+01  .2374295155080E-04
-------------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.99 (seconds)    proc=    .00%


    15    CG-TAS Algorithm. Function:Steady State Combustion
          Touat-Ahmed and Storey. (PRP <= FR). stoptest= 1
```

```
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1897 -.5611448493605E+01  .2374295155080E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.97 (seconds)    proc=    .00%


    16    LS-CD Algorithm. Function:Steady State Combustion
          Hybrid Liu&Storey-Conjugate Descent. max(0,min(LS,CD)) stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1895 -.5611448493598E+01  .2374415284770E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.95 (seconds)    proc=    .00%


    17    CG-BM Algorithm. Function:Steady State Combustion
          Birgin and Martinez (scaled Perry). Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1902 -.5611448493596E+01  .2374433862008E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.02 (seconds)    proc=    .00%


    18    CG-BM+ Algorithm. Function:Steady State Combustion
          Birgin and Martinez plus (scaled Perry). Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1906 -.5611448493596E+01  .2374433862016E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.06 (seconds)    proc=    .00%


    19    CG-sPRP Algorithm. Function:Steady State Combustion
          Scaled Polak-Ribiere and Polyak. Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    692   132   1746   361      5254 -.5611446311717E+01  .5681490915577E-04
--------------------------------------------------------------------------------
TOTAL     692   132   1746   361     52.54 (seconds)    proc=  19.08%


    20    CG-sFR Algorithm. Function:Steady State Combustion
          Scaled Fletcher and Revees. Theta spectral. stoptest= 1

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    802   168   2028   423      6098 -.5611446317873E+01  .4949308650686E-04
--------------------------------------------------------------------------------
TOTAL     802   168   2028   423     60.98 (seconds)    proc=  20.95%


    21    New CG Algorithm. Function:Steady State Combustion
          Andrei New Sufficient Descent from PRP. stoptest= 1
    PRP-SDC: beta = (ytg-yty*stg/gtgprev)/yts
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    770   166   2008   467      6043 -.5611439447761E+01  .8804454610579E-04
--------------------------------------------------------------------------------
TOTAL     770   166   2008   467     60.43 (seconds)    proc=  21.56%


    22    New CG Algorithm. Function:Steady State Combustion
          Andrei New Sufficient Descent from DY. stoptest= 1
          ACGSD: beta=ytg/yts-ytg*stg/(yts**2)

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
--------------------------------------------------------------------------------
 40000    299     0    632    33      1900 -.5611448493594E+01  .2374453057207E-04
--------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.00 (seconds)    proc=    .00%
```

```
    23    New CG Algorithm. Function:Steady State Combustion
          Andrei Sufficient Descent from DY (max). stoptest= 1
          ACGSDz: beta=max(0,ytg/yts)*(1-stg/yts)

     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    299     0    632    33      1903 -.5611448493594E+01  .2374453057203E-04
-------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.03 (seconds)    proc=    .00%


    24    New CG Algorithm. Function:Steady State Combustion
          PRP - DY with Newton direction. (NDOMB) stoptest= 1
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    299     0    632    33      1899 -.5611448493595E+01  .2374436684524E-04
-------------------------------------------------------------------------------
TOTAL     299     0    632    33     18.99 (seconds)    proc=    .00%


    25    New CG Algorithm. Function:Steady State Combustion
          PRP - DY with Conjugacy Condition. (CCOMB) stoptest= 1
     n   iter   irs  fgcnt lscnt   time(c)        fxnew              gnorm
-------------------------------------------------------------------------------
 40000    299     0    632    33      1901 -.5611448493596E+01  .2374434219656E-04
-------------------------------------------------------------------------------
TOTAL     299     0    632    33     19.01 (seconds)    proc=    .00%
```

**Remarks.**

This problem belongs to the MINPACK2 collection.

These results have been obtained with APPL5.FOR package which implements 25 conjugate gradient algorithms in classical and accelerated versions. To use the accelerated version of these algorithms the value of the logical parameter accel must be set to .true.

Observe the differences between cpu time corresponding to the conjugate gradient algorithms and their accelerated versions.

**References**


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