Examples of genetic evaluation and estimation of variance components

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Public programs

In the course of research I have written many computer programs. Some of them are made them available to other researchers to:

1. promote ideas published in papers I (co)authored,
2. help discover bugs, that seem inevitable in any software.

These programs may still contain bugs. The programs may feel complicated to use due to 2 reasons: a) my resources to make them more user-friendly are limited, and 2) the users of these programs are assumed to be knowledgeable in mixed model theory.

The programs include:

1. JAA — Computes solutions to a class of mixed models. Iterates on data and has modest computing requirements. Supports cross-classified random and fixed effects, including the animal effect.

2. JAA20 — As above, with support for covariables and approximation of prediction error variances.

3. JSPFS — Estimates variance components in single trait mixed models using the EM algorithm and sparse matrix inversion. Supports cross-classified random and fixed effects, including covariables.

4. MTDFS — As above, for multiple traits. Uses canonical transformation and is restricted to a single random effect.

5. MTCAFS — Other name MTC. As above, but with extensions to several random effects.

6. RENUM — Renumbers effects consecutively. The original effects must be numeric, except for animals, which may be alphanumeric. For animals, the program removes a large part of redundant animals, verifies that progeny is born after parents, and assigns unknown parent groups.

These programs and more detailed documentation are available electronically by anonymous FTP from misz.animal.uiuc.edu (numerically 128.174.78.6).

Disclaimer

All programs have been developed for our own research. They are believed to be reasonably free of serious errors, but few attempts have been made to make them resistant to errors in parameter and input files. Please use them at your own risk.

Notation

In program listings, text in **bold** is typed by the user, changed parameter file entries are underlined, and added comments are in *italics*.

Example

Model:

observation = herd-year-month + permanent _environment + animal + residual

Data sets:

File typedata:

1. animal id
2. herd id
3. date of evaluation
4. trait 1
5. trait 2
6. trait 3

File pedigree:

1. animal id
2. sire id
3. dam id
4. year of birth

All examples were computed on a Sun 2 workstation.

Print first 10 records of the observation file

```
$ head typedata
8009408698  123813  8306  262  329  322
8009430793  123813  8507  407  405  400
8009469056  123813  8409  388  409  445
8009652481  123813  8409  336  312  361
8009652494  123813  8306  294  380  428
8009666718  123813  8306  294  415  376
8009915566  123813  8306  400  500  500
8009915569  123813  8306  384  312  283
8009915569  123813  8409  294  285  380
8009915572  123813  8306  300  343  396
```

Print first 10 records of the pedigree file

```
$ head pedigree
8009408698 8006584016 41491007 76
8009430793 8008843098 41683485 76
8009469056 8008602536 41683485 76
8009652481 8008724013 41562352 77
8009652494 8008980733 41583197 77
8009666718 8009027083 41590582 78
8009915566 8009256204 41702837 78
8009915569 8009305088 41688995 78
8009915572 8008980738 41590582 78
8009915573 8009110700 41727076 78
```

Renumber to consecutive numbers

```
$ renum
 RENUM - renumbering tool
 has capacity to renumber up to approximately    9374 animals
 and     8333 other levels
input data file?
typedata
output data file?
type.ren
printout data name?
out.ren
give positions of columns to be renumbered into single factor, 0
ends
2 3
0
give minimum number of observations per level for each
    factor, 0 if all observations retained
1
give positions of columns to pass unchanged
```

```
4 5 6
give position of animal in data file, 0 if none
1
name of the pedigree file
pedigree
name of the output pedigree file?
ped.ren
positions of animal, sire, dam and year of birth
in the pedigree file, year of birth = 0 if missing
1 2 3 4
give years to separate unknown parent groups, or 0
81 84 87
give minimum, average, and maximum generation interval
1 4 20
data files read to 120 column only

 Example parameter file for program JAA was stored in file
renum.jaa
 Summaries and messages were stored in file renum.msg
```

(Processing took 30 seconds and 300k memory)

Print first 10 lines of the renumbered observation file (herd-year-month, animal, traits 1-3)

```
$ head type.ren
1 1 262 329 322
3 2 407 405 400
2 3 388 409 445
2 4 336 312 361
1 5 294 380 428
1 6 294 415 376
1 7 400 500 500
1 8 384 312 283
2 8 294 285 380
1 9 300 343 396
```

Print first 10 lines of the renumbered pedigree file (animal, sire, dam, 1-number_of_known_parents, year of birth, known or estimated year of birth (0 if not provided), number of known, not necessarily contributing parents, number of records (before elimination due to other effects), number of progeny (incl. noncontributing animals, original id)

```
$ head ped.ren
 1 2698 2148 2 75 2 1 3 8009408698
 2 2698 2149 2 76 2 1 0 8009430793
 3 2698 2149 2 75 2 1 7 8009469056
 4 2150 2151 1 76 2 1 8 8009652481
```

```
 5 2698 2152 2 76 2 1 5 8009652494
 6 2698 2153 2 76 2 1 4 8009666718
 7 2698 2698 3 78 2 1 2 8009915566
 8 2698 2698 3 78 2 2 2 8009915569
 9 2698 2153 2 78 2 1 0 8009915572
 10 2154 2155 1 76 2 2 2 8009915573
```

Renumbering details for effects other than animal

```
$ cat out.ren
 records        4539

 factor    renumbered level      #      original levels
 ------------------------------------------------------------
 1 :  2  3
                    1          65      123813        8306
                    2          87      123813        8409
                    3          85      123813        8507
                    4          86      123813        8602
                    5          86      123813        8609
                    6          80      123813        8704
                    7         133      123813        8711
.......................................................
                   46         126      411978        9108
                   47         141      411978        9203
                   48         119      413608        8301
                   49          80      413608        8404
                   50          33      413608        8504
                   51           3      413608        8703
```

Renumbering details for all other effects

```
$ cat renum.msg
 input data file: typedata
 output data file: type.ren
 input pedigree file: pedigree
 output pedigree file: ped.ren
 data records:                              4539
 original levels:                             51
 levels after cutting:                        51

 Renumbered factors
 factor            levels
     1                  51
```

```
 Animal factor summary

 pedigree records:                          3000
 animals found:                             3344
 animals eliminated:                         647
 repeated pedigrees:                         853

 Consecutive number assignment

 animals with records                          1  -    2147
 parents with pedigree record               2148  -    2147
 parents without pedigree record            2148  -    2697
 unknown parent groups                      2698  -    2701



 Unknown parent group allocation

     group no. consecutive no              #        years
             1           2698             949        0-  81
             2           2699             184       82-  84
             3           2700              85       85-  87
             4           2701              37       88-
```

Unknown parent groups should contain many animals (> 100-200) to be estimated with sufficient accuracy. The last 2 or 3 groups should have been merged and perhaps the first one split!

```
 Example parameter file for program JAA was stored in file
renum.jaa
```

Renum wrote a template of a parameter file used by later programs. The template usually needs editing!

$ **cat renum.jaa**

type.ren	*data file*
ped.rend	*observation file*
jaaout	*messages file*
2 3 0.70 10	*2 effects, trait in column 3, relaxation factor .7, 10 round to begin with*
1 51 0.00	*Effect in column 1 with 51 levels; variance ratio = 0 (fixed effect)*
2 2701 -2.00	*Effect column 2 with 2701 effects, random (2.00), animal (minus)*

Single trait estimation of variance components

The parameter file is updated to reflect extra permanent environmental effect (with 2147 levels, see renum.msg). Also, variance ratios are adjusted. Changed items below are underlined.

```
$ cat renum.jaa
type.ren
ped.ren
jaaout
   3   3  0.70  10
   1      51    0.00
   2    2147    3.00
   2    2701   -2.50
```

```
$ jspfs
name of a file with parameters, con - if console:
renum.jaa
 read   2697 pedigree records       4 unknown parent groups
filled  22408 out of  150000  elements in hash table 1
filled  15269 out of  120000  elements in hash table 2
    3.92000s
smpa used   39798 out of   270000 words
ra used   15151 out of   120000 words
before odrv    4.67000
ordering time =    32.3400
symbolic factorization time=    32.5300
 used  12.72% memory
numerical factorization time=    33.2000
 used  16.33% memory
sparse inversion time=    34.9500
 used  35.15% memory
trace     35.0300
 vround 1 se= 2191.0365 s( 2)= 1035.4501 alfa= 2.1160 ex= 0.0000
 vround 1 se= 2191.0365 s( 3)= 1337.6576 alfa= 1.6380 ex= 0.0000
trace  38.0900
 vround 2 se= 1986.7850 s( 2)= 1172.4338 alfa= 1.6946 ex= 1.3106
```

se=residual variance, s(x) is variance of x effect, alfa=variance ratio, ex=variance ratio if Aitken extrapolation were performed

```
 vround 2 se= 1986.7850 s( 3)= 1594.8933 alfa= 1.2457 ex= -0.9182
trace  41.1600
..............................................................
 vround 10 se= 1800.9201 s( 2)= 1243.6914 alfa= 1.4480 ex= 0.6792
 vround 10 se= 1800.9201 s( 3)= 2072.7703 alfa= 0.8688 ex=-0.8271
how many iterations more?, extrapolate (1)?
10 0
```

perform Aitken extrapolation only when ex values are close for a couple of rounds. Not a case until round 20!

```
trace  65.6800
 vround 11 se= 1800.9614 s( 2)= 1232.0966 alfa= 1.4617 ex= 2.1498
 vround 11 se= 1800.9614 s( 3)= 2088.3660 alfa= 0.8624 ex=-0.8125
trace  68.7700
...............................................................
 vround 17 se= 1801.8294 s( 2)= 1176.1833 alfa= 1.5319 ex= 1.7200
 vround 17 se= 1801.8294 s( 3)= 2161.4039 alfa= 0.8336 ex=
-0.7846
trace  87.2600
 vround 18 se= 1801.9637 s( 2)= 1168.8541 alfa= 1.5416 ex= 1.7178
 vround 18 se= 1801.9637 s( 3)= 2170.9618 alfa= 0.8300 ex=-0.7838
trace  90.3300
 vround 19 se= 1802.0905 s( 2)= 1161.9962 alfa= 1.5509 ex= 1.7161
 vround 19 se= 1802.0905 s( 3)= 2179.9141 alfa= 0.8267 ex=-0.7831
trace  93.3900
 vround 20 se= 1802.2102 s( 2)= 1155.5775 alfa= 1.5596 ex= 1.7148
 vround 20 se= 1802.2102 s( 3)= 2188.3014 alfa= 0.8236 ex=-0.7826
how many iterations more?, extrapolate (1)?
3 1
trace  96.4500
 vround 21 se= 1805.5841 s( 2)= 1055.8521 alfa= 1.7101 ex= 0.0000
 vround 21 se= 1805.5841 s( 3)= 2313.9041 alfa= 0.7803 ex= 0.0000
trace   99.5100
 vround 22 se= 1804.7963 s( 2)= 1056.7066 alfa= 1.7079 ex= 1.7062
 vround 22 se= 1804.7963 s( 3)= 2315.9436 alfa= 0.7793 ex=-0.7785
trace  102.5600
 vround 23 se= 1804.4412 s( 2)= 1057.0954 alfa= 1.7070 ex= 1.7062
 vround 23 se= 1804.4412 s( 3)= 2316.8611 alfa= 0.7788 ex=-0.7785
how many iterations more?, extrapolate (1)?
3 1
trace  105.850
 vround 24 se= 1804.1497 s( 2)= 1057.4235 alfa= 1.7062 ex= 0.0000
 vround 24 se= 1804.1497 s( 3)= 2317.6034 alfa= 0.7785 ex= 0.0000
trace  109.040
 vround 25 se= 1804.1497 s( 2)= 1057.4277 alfa= 1.7062 ex= 1.7060
 vround 25 se= 1804.1497 s( 3)= 2317.5977 alfa= 0.7785 ex=-0.7785
trace  112.170
 vround 26 se= 1804.1496 s( 2)= 1057.4316 alfa= 1.7062 ex= 1.7060
 vround 26 se= 1804.1496 s( 3)= 2317.5924 alfa= 0.7785 ex=
-0.7785
how many iterations more?, extrapolate (1)?
3 1
trace  115.440
 vround 27 se= 1804.1471 s( 2)= 1057.4974 alfa= 1.7061 ex= 0.0000
 vround 27 se= 1804.1471 s( 3)= 2317.5099 alfa= 0.7785 ex= 0.0000
trace  118.560
 vround 28 se= 1804.1477 s( 2)= 1057.4967 alfa= 1.7061 ex= 1.7061
 vround 28 se= 1804.1477 s( 3)= 2317.5082 alfa= 0.7785 ex=-0.7785
```

```
trace  121.730
 vround 29 se= 1804.1480 s( 2)= 1057.4963 alfa= 1.7061 ex= 1.7061
 vround 29 se= 1804.1480 s( 3)= 2317.5075 alfa= 0.7785 ex=-0.7785
how many iterations more?, extrapolate (1)?
0 0
solutions were stored in file solrenum.jaa
```

(total time 2 minutes; memory 3 Mbytes)

Estimates:
heritability = 2317/(2317+1057+1804)=.44,
repeatability = (2317+1057)/(2317+1057+1804)=.65

Multivariate analysis

For multivariate analysis change parameter file (changes underlined)to reflect three traits

```
$ cat renum1.jaa
type.ren
ped.ren
jaaout
   3   3  3
   1      51    0.00
   2    2147    3.00
   2    2701   -2.50
```

```
$ mtc
name of a file with parameters, con - if console:
renum1.jaa
 read   2697 pedigree records       4 unknown parent groups
filled  22408 out of  90000  elements in hash table 1
filled  15269 out of  63000  elements in hash table 2
    4.01000s
smpa used   39798 out of   90000 words
ra used   15151 out of   31500 words
before odrv    4.59000
ordering time =    9.66000
symbolic factorization time=    9.85000
 used  22.23% memory
 relative off-diagonals in G after diagonalization:  0.33E-10
0.33E-10
variance ratios after transformation in round   1
   3.000     3.000     3.000     2.500     2.500     2.500
tcanon  9.88000
trhs  11.5500
numerical factorization time=  12.8300
 used  28.89% memory
sparse inversion time=  14.6300
 used  62.10% memory
computed variance ratios:
   2.282     2.529     2.287     1.767     2.019     1.768
 convR=  1.0      convG=  1.0      1.0
finish? (rounds-more?)
10
 relative off-diagonals in G after diagonalization:  0.12E-01
0.74E-02
variance ratios after transformation in round   2
   1.468     2.595     6.665     1.147     2.098     5.634
computed variance ratios:
   1.620     2.676     7.387     1.229     2.124     6.084
 convR= 0.20      convG= 0.23E-01   0.30E-01
```

```
 relative off-diagonals in G after diagonalization:  0.11E-01
0.69E-02
.............................................................
variance ratios after transformation in round   9
   3.316     1.265     12.42     2.312    0.7875     9.209
computed variance ratios:
   3.349     1.280     12.59     2.294    0.7799     9.143
 convR= 0.44E-05    convG= 0.12E-03   0.99E-04
 relative off-diagonals in G after diagonalization:  0.94E-02
0.40E-02
...............................................................

variance ratios after transformation in round   11
   3.372     1.292     13.01     2.272    0.7725     9.289
computed variance ratios:
   3.404     1.306     13.12     2.258    0.7670     9.193
 convR= 0.14E-05    convG= 0.10E-03   0.59E-04
finish? (rounds-more?)
10
 relative off-diagonals in G after diagonalization:  0.92E-02
0.37E-02
variance ratios after transformation in round   12
   3.402     1.305     13.23     2.257    0.7664     9.277
computed variance ratios:
   3.432     1.319     13.31     2.244    0.7616     9.177
 convR= 0.92E-06    convG= 0.94E-04   0.49E-04
 relative off-diagonals in G after diagonalization:  0.91E-02
0.36E-02
................................................................

variance ratios after transformation in round   29
   3.731     1.449     14.69     2.126    0.7150     8.611
computed variance ratios:
   3.741     1.454     14.74     2.122    0.7137     8.587
 convR= 0.11E-07    convG= 0.10E-04   0.42E-05
 relative off-diagonals in G after diagonalization:  0.89E-02
0.25E-02
variance ratios after transformation in round   30
   3.741     1.454     14.74     2.122    0.7136     8.590
computed variance ratios:
   3.750     1.459     14.79     2.119    0.7123     8.568
 convR= 0.86E-08    convG= 0.92E-05   0.37E-05
 relative off-diagonals in G after diagonalization:  0.89E-02
0.25E-02
..............................................................
variance ratios after transformation in round   40
   3.815     1.488     15.16     2.097    0.7035     8.448
computed variance ratios:
   3.820     1.491     15.20     2.095    0.7028     8.438
 convR= 0.13E-08    convG= 0.25E-05   0.97E-06
 relative off-diagonals in G after diagonalization:  0.89E-02
```

```
0.23E-02
variance ratios after transformation in round   41
   3.820     1.491     15.20     2.095    0.7028     8.438
computed variance ratios:
   3.825     1.493     15.23     2.093    0.7022     8.429
 convR= 0.11E-08    convG= 0.22E-05   0.85E-06
```

For good accuracy, convergence criterions convG and convR should be below 1e-6, while diagonalization level should be below 1e-2.

```
finish? (rounds-more?)
0

      Heritability, repeatability and variances
trait   h^2    r^2   residual      effect
                                    1           2
  1   0.441   0.650   1806.       1082.       2276.
  2   0.349   0.523   2118.       769.4       1551.
  3   0.408   0.604   1738.       862.4       1794.
heritabilities on diagonal, genetic correlations above,phenotypic
below
  0.44  0.76  0.78
  0.61  0.35  0.95
  0.65  0.83  0.41
```

(Total 7.5 minutes and 4 Mbytes of memory)

The above estimates are probably inflated due to small (and very selected) sample

For estimation of breeding values, add 1 at the end to request approximation of EFR ("effective number of records"). Reliability = EFR/(EFR + animal_variance_ratio) In this case, the ratio is 2.50.

```
$ cat renum2.jaa
type.ren
ped.ren
jaaout
   3   3  0.70  10
   1      51    0.00
   2    2147    3.00
   2    2701   -2.50
1
```

Estimation of breeding values and accuracies by jaa20

Because the system of equations in not full rank, the solutions are not unique although estimable function are. Especially, solutions will change when the order of parameters changes.

```
$ jaa20
name of a file with parameters, con - if console:
renum2.jaa
iteration no.  convergence criterion   last solution
  1    1.00000  0.
  2    1.25089E-02   -1.55775
  3    1.44692E-02   -3.65280
  4    9.06921E-03   -4.83105
  5    5.25465E-03   -5.77580
  6    4.71741E-03   -6.97025
  7    2.80692E-03   -7.76238
  8    1.67017E-03   -8.03068
  9    1.64074E-03   -8.34621
 how many more iterations, 0-none?
40
  10    9.91685E-04   -8.98133
  11    6.16794E-04   -9.65120
  12    5.67883E-04   -9.96897
  13    3.42211E-04   -9.97552
  14    2.28457E-04   -9.96636
  15    1.97561E-04   -9.94866
  16    1.10729E-04   -9.81554
  17    8.23527E-05   -9.70354
  18    6.61531E-05   -9.71196
  19    3.71847E-05   -9.73641
  20    2.83531E-05   -9.74832
  21    2.21738E-05   -9.80435
  22    1.29083E-05   -9.85967
  23    1.02231E-05   -9.85623
  24    7.51070E-06   -9.82487
  25    4.48016E-06   -9.79651
  26    3.68470E-06   -9.76372
  27    2.34305E-06   -9.72505
  28    1.56222E-06   -9.68882
  29    1.25211E-06   -9.66224
  30    8.33604E-07   -9.64682
  31    5.39722E-07   -9.63211
  32    4.44054E-07   -9.61407
  33    2.75445E-07   -9.60433
  34    1.92064E-07   -9.60471
  35    1.50408E-07   -9.60446
  36    9.17401E-08   -9.60436
  37    6.82633E-08   -9.61213
  38    5.04465E-08   -9.62436
```

```
  39    3.12934E-08   -9.63411
  40    2.41969E-08   -9.64148
  41    1.73349E-08   -9.64787
  42    1.02343E-08   -9.65246
  43    8.42514E-09   -9.65552
  44    5.89217E-09   -9.65765
  45    3.56182E-09   -9.65833
  46    2.95657E-09   -9.65796
  47    1.94332E-09   -9.65796
  48    1.24605E-09   -9.65821
  49    1.02896E-09   -9.65759
```

Convergence below 10e-06 is usually sufficient

```
 how many more iterations, 0-none?
0
 In approximate Prediction Error Variance for animals it will be
assumed that:
  first effect is fixed like HYS
  the last effect is animal
  effect before the last is permanent environment
 detected       4 unknown parent group(s)

           Calculation of approximate PEV

 iteration no. convergence PEV(1)  PEV(2) ....
        1  916.8806  1.2772  0.7434  1.6358  1.8127  1.3858
more pev rounds?
5
        2  970.5330  1.5832  0.7434  1.4593  1.8252  1.8200
        3  696.7351  1.6564  0.7710  1.6499  2.1809  1.8793
        4  502.9659  1.7419  0.7850  1.7563  2.3345  1.9525
        5  357.3745  1.8020  0.7937  1.8219  2.4501  2.0045
        6  251.5577  1.8440  0.7996  1.8653  2.5338  2.0400
more pev rounds?
5
        7  176.0641  1.8733  0.8037  1.8943  2.5935  2.0639
        8  122.8023  1.8938  0.8066  1.9140  2.6358  2.0801
        9   85.4800  1.9081  0.8086  1.9272  2.6659  2.0910
       10   59.4356  1.9180  0.8100  1.9362  2.6871  2.0984
       11   41.3065  1.9250  0.8110  1.9423  2.7021  2.1034
```

Convergence to 1-5% of original value is sufficient

```
more pev rounds?
0
solutions and reliabilities were stored in file sol
```

Print messages file

```
$cat jaaout
iteration no.  convergence criterion   last solution
  1    1.00000  0.
  2    1.25089E-02   -1.55775
................................
  46    2.95657E-09   -9.65796
  47    1.94332E-09   -9.65796
  48    1.24605E-09   -9.65821
  49    1.02896E-09   -9.65759

           Calculation of approximate PEV

 iteration no. convergence PEV(1)    PEV(2) ....
       1  916.8806  1.2772  0.7434  1.6358  1.8127  1.3858
............................................................
      11   41.3065  1.9250  0.8110  1.9423  2.7021  2.1034

  4539 records  4899 equations

solutions of factor  1  var. ratio  0.
   1:  305.1121   2:  286.2624   3:  296.2005   4:  346.5326
   5:  339.6574   6:  361.3795   7:  329.5870   8:  315.0382
   9:  319.4854  10:  344.6087  11:  302.6514  12:  326.6187
  13:  314.8734  14:  347.8259  15:  330.5576  16:  337.0867
  17:  316.3046  18:  323.2482  19:  360.1327  20:  363.7310
  21:  354.0697  22:  338.0883  23:  299.3730  24:  269.2602
  25:  254.5380  26:  287.6992  27:  338.6224  28:  316.0580
  29:  309.9366  30:  309.1578  31:  290.5121  32:  250.1046
  33:  335.9875  34:  328.8289  35:  311.0511  36:  337.2393
  37:  364.4048  38:  350.2770  39:  321.8100  40:  349.6934
  41:  357.6898  42:  336.3453  43:  358.6937  44:  346.8690
  45:  348.0636  46:  361.9219  47:  354.0283  48:  320.5478
  49:  319.8862  50:  298.8404  51:  320.1252

solutions of factor  2  var. ratio    3.00000

solutions of factor  2  var. ratio   -2.50000
```

Initial 10 solutions (heard-year-month_of_classification)

```
$ head sol
   305.1121 0.000
   286.2624 0.000
   296.2005 0.000
   346.5326 0.000
   339.6574 0.000
   361.3795 0.000
   329.5870 0.000
   315.0382 0.000
```

```
   319.4854 0.000
   344.6087 0.000
```

Last 10 solutions: 6 animal effects and 4 unknown parent groups. Accuracies (EFRs), for animals only, are in the second column.

$ **tail sol**

```
    -5.2573 0.096
   -13.9487 0.096
   -30.6629 0.130
   -30.6629 0.130
     0.4333 0.097
    13.1817 0.100
    -3.7906 0.000
    -6.6349 0.000
    -2.0957 0.000
    -9.6576 0.000
```

The last 4 solutions - unknown parent groups - do not increase, as expected. Most probably this is due to small number of animals in the last 3 groups, as mentioned earlier.