

Efficient single-step BLUP computations with MiX99 software

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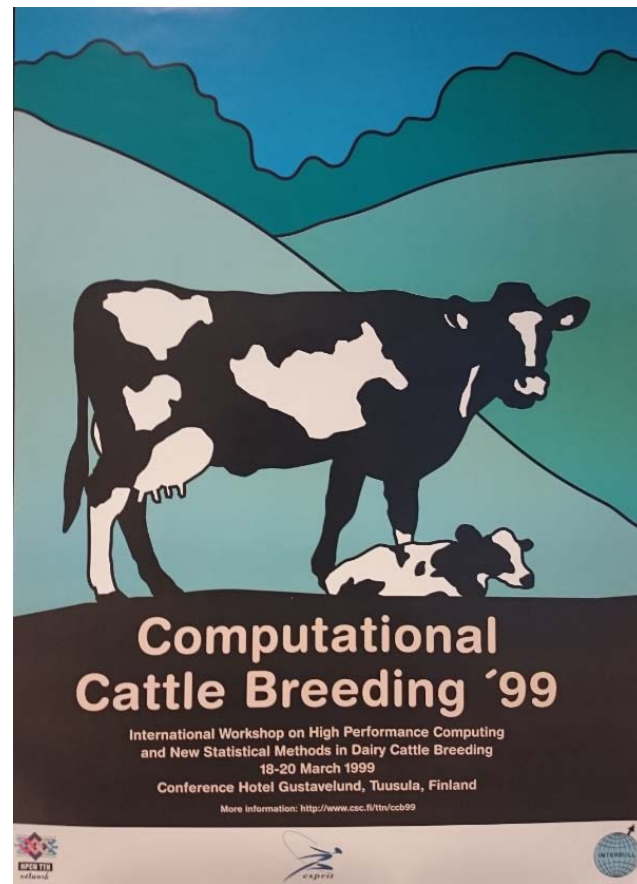
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www.luke.fi/mix99

MiX99: luke.fi/mix99

- First official version in 1999
 - Breeding value estimation of large data/model
 - PCG, parallel computing using MPI
- ApaX99: Reliability approximation
- Supporting programs
 - RelaX2
 - pedigree pruning, extracting, ordering, formatting and more...
 - Hginv: genomic relationship matrix inverse
 - etc.

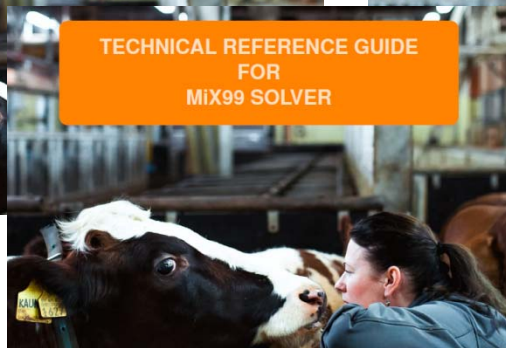
Approach and first results:



MiX99 breeding value estimation software

- Sire and animal models, repeatability model
- Multiple traits with any pattern of missing traits and different models
- Random regression models
- Reduced rank models
- Multiple residual variances
 - Heterogeneous variances by multiplicative models
- Threshold models (one categorical + several linear traits)
- Models with social effects
 - Covariance structure between an animal and its contemporary group members
- QTL effect model with external covariance matrix
- SNP-BLUP/GBLUP
- Single-step models: ssGBLUP, ssGTBLUP, APY
- Deregressed EBV, YD, DYD, ...

Flexibility in models by combining model options



RelaX2

program for pedigree analysis
User's guide for version 1.65

Ismo Strandén

November 21, 2014

HGINV program
Dec 2017, version 0.85

Genomic relationship matrix builder

MiX99 program flow

Preprocessing for MiX99
data formatting
pedigree formatting
Model with variance components

Preprocessor: mix99i

Solver: mix99s
mix99p for parallel

Approximate model reliabilities:
apax99 & apax99p

Efficient ssGBLUP computations by MiX99

Single-step BLUP (ssGBLUP) allows simultaneously combining genomic information with traditional pedigree information.

Model: $y = Xb + Wa + e$ where $e \sim (\mathbf{0}, \mathbf{R} \sigma_e^2)$ and $a \sim (\mathbf{0}, \mathbf{H} \sigma_a^2)$

Mixed model equations:

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}W \\ W'R^{-1}X & W'R^{-1}W + \lambda H^{-1} \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{a} \end{bmatrix} = \begin{bmatrix} X'R^{-1}y \\ W'R^{-1}y \end{bmatrix} \quad \lambda = \frac{\sigma_e^2}{\sigma_a^2}$$

where the inverse of the relationship matrix is

$$\mathbf{H}^{-1} = \mathbf{A}^{-1} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix}$$

where

- \mathbf{A}^{-1} is based on the pedigree relationships (sparse & easy to compute)
- $(\mathbf{A}_{22})^{-1}$ is based on the pedigree relationships for the genotyped animals
- \mathbf{G}^{-1} is based on genomic information \mathbf{Z} (dense)

Computations efficiently using sparse matrices, e.g., Taskinen et al. WCGALP 2018

Increase in genotyped animals increases the dense matrix part

MiX99: hybrid parallel computing

Mixed model equations:

$$\begin{bmatrix} \mathbf{X}'\mathbf{R}^{-1}\mathbf{X} & \mathbf{X}'\mathbf{R}^{-1}\mathbf{W} \\ \mathbf{W}'\mathbf{R}^{-1}\mathbf{X} & \mathbf{W}'\mathbf{R}^{-1}\mathbf{W} + \lambda\mathbf{H}^{-1} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{a}} \end{bmatrix} = \begin{bmatrix} \mathbf{X}'\mathbf{R}^{-1}\mathbf{y} \\ \mathbf{W}'\mathbf{R}^{-1}\mathbf{y} \end{bmatrix} \quad \lambda = \frac{\sigma_e^2}{\sigma_a^2}$$

where the inverse of the relationship matrix is

$$\mathbf{H}^{-1} = \mathbf{A}^{-1} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} \\ \mathbf{A}^{21} & \mathbf{A}^{22} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{G}^{-1} - \mathbf{A}_{22}^{-1} \end{bmatrix}$$

Full or APY version of \mathbf{G}^{-1} can be given or decomposition of \mathbf{L} in $\mathbf{G}^{-1} = \mathbf{L}\mathbf{L}'$

Sparse parts: distributed memory approach using MPI

Recent improvement in MiX99 (mix99p) is 'X'-option: faster but uses some more memory

Hybrid: MPI (distributed memory) and Cholmod library (shared memory parallel)

MPI is used when genomic matrix is not in memory, Intel® Math Kernel Library
ssGTBLUP with matrix in memory uses shared memory computing using MKL

Reducing computations by ssGTBLUP

Assume: $\mathbf{G} = \mathbf{G}_0 + \mathbf{C}$

where $\mathbf{G}_0 = \mathbf{Z}\mathbf{Z}'$ and $\mathbf{G}_\varepsilon = \mathbf{G}_0 + \varepsilon\mathbf{I} \rightarrow \mathbf{G}_\varepsilon^{-1} = \frac{1}{\varepsilon}\mathbf{I} - \mathbf{T}'_\varepsilon\mathbf{T}_\varepsilon$

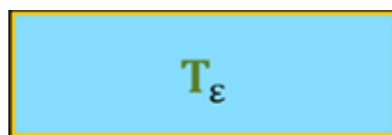
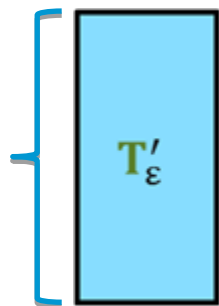
where $\mathbf{T}_\varepsilon = \frac{1}{\varepsilon}\mathbf{L}_\varepsilon^{-1}\mathbf{Z}'$ and $\mathbf{L}_\varepsilon\mathbf{L}'_\varepsilon = \frac{1}{\varepsilon}\mathbf{Z}'\mathbf{Z} + \mathbf{I}$

Woodbury matrix identity

\mathbf{T}_ε has size $n \times m$

→ Number of computations is $2nm$ instead of n^2

n = number of genotyped



m = number of markers/rank

Size of \mathbf{T}_ε matrix is the same as the original marker matrix.

ssGTBLUP gives the same solutions as ssGBLUP with $\mathbf{G}_\varepsilon^{-1}$ (e.g., Koivula et al. WCGALP 2018)

Example: ICBF carcass evaluations

- 9 trait multiple breed carcass evaluation
 - 9.5 million data records
- 13.35 million in pedigree
- 460,152 genotyped using 50,240 markers

- Two evaluations:
 - Animal model BLUP → fully sparse computations using MPI
 - ssGTBLUP approach → genomic dominates 1-processor computations (88%)
 - T matrix 98% highest eigenvalues kept: T matrix rank reduced to 33,501
 - T matrix read to memory: shared memory computing (BLAS/MKL/OpenMP)

MiX99 instructions for the preprocessor



DATAFILE ../../../../ICBF_1step_JAN_2016/data/data_mix99lin_beef_geno.txt

INTEGER block anim perm dam damp byr sex twin dampar scorer wtpar cullpar hyA hyB hyBp hyc hycp hyd hydP hys hysC hysD hysE hysF hysG hysH hysI hysJ hysK hysL hysM hysN hysO hysP hysQ hysR hysS hysT hysU hysV hysW hysX hysY hysZ hysAA hysAB hysAC hysAD hysAE hysAF hysAG hysAH hysAI hysAJ hysAK hysAL hysAM hysAN hysAO hysAP hysAQ hysAR hysAS hysAT hysAU hysAV hysAW hysAX hysAY hysAZ hysBA hysBB hysBC hysBD hysBE hysBF hysBG hysBH hysBI hysBJ hysBK hysBL hysBM hysBN hysBO hysBP hysBQ hysBR hysBS hysBT hysBU hysBV hysBW hysBX hysBY hysBZ hysCA hysCB hysCC hysCD hysCE hysCF hysCG hysCH hysCI hysCJ hysCK hysCL hysCM hysCN hysCO hysCP hysCQ hysCR hysCS hysCT hysCU hysCV hysCW hysCX hysCY hysCZ hysDA hysDB hysDC hysDD hysDE hysDF hysDG hysDH hysDI hysDJ hysDK hysDL hysDM hysDN hysDO hysDP hysDQ hysDR hysDS hysDT hysDU hysDV hysDW hysDX hysDY hysDZ hysEA hysEB hysEC hysED hysEE hysEF hysEG hysEH hysEI hysEJ hysEK hysEL hysEM hysEN hysEO hysEP hysEQ hysER hysES hysET hysEU hysEV hysEW hysEX hysEY hysEZ hysFA hysFB hysFC hysFD hysFE hysFF hysFG hysFH hysFI hysFJ hysFK hysFL hysFM hysFN hysFO hysFP hysFQ hysFR hysFS hysFT hysFU hysFV hysFW hysFX hysFY hysFZ hysGA hysGB hysGC hysGD hysGE hysGF hysGG hysGH hysGI hysGJ hysGK hysGL hysGM hysGN hysGO hysGP hysGQ hysGR hysGS hysGT hysGU hysGV hysGW hysGX hysGY hysGZ hysHA hysHB hysHC hysHD hysHE hysHF hysHG hysHH hysHI hysHJ hysHK hysHL hysHM hysHN hysHO hysHP hysHQ hysHR hysHS hysHT hysHU hysHV hysHW hysHX hysHY hysHZ hysIA hysIB hysIC hysID hysIE hysIF hysIG hysIH hysII hysIJ hysIK hysIL hysIM hysIN hysIO hysIP hysIQ hysIR hysIS hysIT hysIU hysIV hysIW hysIX hysIY hysIZ hysJA hysJB hysJC hysJD hysJE hysJF hysJG hysJH hysJI hysJJ hysJK hysJL hysJM hysJN hysJO hysJP hysJQ hysJR hysJS hysJT hysJU hysJV hysJW hysJX hysJY hysJZ hysKA hysKB hysKC hysKD hysKE hysKF hysKG hysKH hysKI hysKJ hysKK hysKL hysKM hysKN hysKO hysKP hysKQ hysKR hysKS hysKT hysKU hysKV hysKW hysKX hysKY hysKZ hysLA hysLB hysLC hysLD hysLE hysLF hysLG hysLH hysLI hysLJ hysLK hysLL hysLM hysLN hysLO hysLP hysLQ hysLR hysLS hysLT hysLU hysLV hysLW hysLX hysLY hysLZ hysMA hysMB hysMC hysMD hysME hysMF hysMG hysMH hysMI hysMJ hysMK hysML hysMN hysMO hysMP hysMQ hysMR hysMS hysMT hysMU hysMV hysMW hysMX hysMY hysMZ hysNA hysNB hysNC hysND hysNE hysNF hysNG hysNH hysNI hysNJ hysNK hysNL hysNM hysNO hysNP hysNQ hysNR hysNS hysNT hysNU hysNV hysNW hysNX hysNY hysNZ hysOA hysOB hysOC hysOD hysOE hysOF hysOG hysOH hysOI hysOJ hysOK hysOL hysOM hysON hysOP hysOQ hysOR hysOS hysOT hysOU hysOV hysOW hysOX hysOY hysOZ hysPA hysPB hysPC hysPD hysPE hysPF hysPG hysPH hysPI hysPJ hysPK hysPL hysPM hysPN hysPO hysPP hysPQ hysPR hysPS hysPT hysPU hysPV hysPW hysPX hysPY hysPZ hysQA hysQB hysQC hysQD hysQE hysQF hysQG hysQH hysQI hysQJ hysQK hysQL hysQM hysQN hysQO hysQP hysQQ hysQR hysQS hysQT hysQU hysQV hysQW hysQX hysQY hysQZ hysRA hysRB hysRC hysRD hysRE hysRF hysRG hysRH hysRI hysRJ hysRK hysRL hysRM hysRN hysRO hysRP hysRQ hysRR hysRS hysRT hysRU hysRV hysRW hysRX hysRY hysRZ hysSA hysSB hysSC hysSD hysSE hysSF hysSG hysSH hysSI hysSJ hysSK hysSL hysSM hysSN hysSO hysSP hysSQ hysSR hysSS hysST hysSU hysSV hysSW hysSX hysSY hysSZ hysTA hysTB hysTC hysTD hysTE hysTF hysTG hysTH hysTI hysTJ hysTK hysTL hysTM hysTN hysTO hysTP hysTQ hysTR hysTS hysTT hysTU hysTV hysTW hysTX hysTY hysTZ hysUA hysUB hysUC hysUD hysUE hysUF hysUG hysUH hysUI hysUJ hysUK hysUL hysUM hysUN hysUO hysUP hysUQ hysUR hysUS hysUT hysUU hysUV hysUW hysUX hysUY hysUZ hysVA hysVB hysVC hysVD hysVE hysVF hysVG hysVH hysVI hysVJ hysVK hysVL hysVM hysVN hysVO hysVP hysVQ hysVR hysVS hysVT hysVU hysVV hysVW hysVX hysVY hysVZ hysWA hysWB hysWC hysWD hysWE hysWF hysWG hysWH hysWI hysWJ hysWK hysWL hysWM hysWN hysWO hysWP hysWQ hysWR hysWS hysWT hysWU hysWV hysWW hysWX hysWY hysWZ hysXA hysXB hysXC hysXD hysXE hysXF hysXG hysXH hysXI hysXJ hysXK hysXL hysXM hysXN hysXO hysXP hysXQ hysXR hysXS hysXT hysXU hysXV hysXW hysXX hysXY hysXZ hysYA hysYB hysYC hysYD hysYE hysYF hysYG hysYH hysYI hysYJ hysYK hysYL hysYM hysYN hysYO hysYP hysYQ hysYR hysYS hysYT hysYU hysYV hysYW hysYX hysYY hysYZ hysZA hysZB hysZC hysZD hysZE hysZF hysZG hysZH hysZI hysZJ hysZK hysZL hysZM hysZN hysZO hysZP hysZQ hysZR hysZS hysZT hysZU hysZV hysZW hysZX hysZY hysZZ hysAA hysAB hysAC hysAD hysAE hysAF hysAG hysAH hysAI hysAJ hysAK hysAL hysAM hysAN hysAO hysAP hysAQ hysAR hysAS hysAT hysAU hysAV hysAW hysAX hysAY hysAZ hysBA hysBB hysBC hysBD hysBE hysBF hysBG hysBH hysBI hysBJ hysBK hysBL hysBM hysBN hysBO hysBP hysBQ hysBR hysBS hysBT hysBU hysBV hysBW hysBX hysBY hysBZ hysCA hysCB hysCC hysCD hysCE hysCF hysCG hysCH hysCI hysCJ hysCK hysCL hysCM hysCN hysCO hysCP hysCQ hysCR hysCS hysCT hysCU hysCV hysCW hysCX hysCY hysCZ hysDA hysDB hysDC hysDD hysDE hysDF hysDG hysDH hysDI hysDJ hysDK hysDL hysDM hysDN hysDO hysDP hysDQ hysDR hysDS hysDT hysDU hysDV hysDW hysDX hysDY hysDZ hysEA hysEB hysEC hysED hysEE hysEF hysEG hysEH hysEI hysEJ hysEK hysEL hysEM hysEN hysEO hysEP hysEQ hysER hysES hysET hysEU hysEV hysEW hysEX hysEY hysEZ hysFA hysFB hysFC hysFD hysFE hysFF hysFG hysFH hysFI hysFJ hysFK hysFL hysFM hysFN hysFO hysFP hysFQ hysFR hysFS hysFT hysFU hysFV hysFW hysFX hysFY hysFZ hysGA hysGB hysGC hysGD hysGE hysGF hysGG hysGH hysGI hysGJ hysGK hysGL hysGM hysGN hysGO hysGP hysGQ hysGR hysGS hysGT hysGU hysGV hysGW hysGX hysGY hysGZ hysHA hysHB hysHC hysHD hysHE hysHF hysHG hysHH hysHI hysHJ hysHK hysHL hysHM hysHN hysHO hysHP hysHQ hysHR hysHS hysHT hysHU hysHV hysHW hysHX hysHY hysHZ hysIA hysIB hysIC hysID hysIE hysIF hysIG hysIH hysII hysIJ hysIK hysIL hysIM hysIN hysIO hysIP hysIQ hysIR hysIS hysIT hysIU hysIV hysIW hysIX hysIY hysIZ hysJA hysJB hysJC hysJD hysJE hysJF hysJG hysJH hysJI hysJJ hysJK hysJL hysJM hysJN hysJO hysJP hysJQ hysJR hysJS hysJT hysJU hysJV hysJW hysJX hysJY hysJZ hysKA hysKB hysKC hysKD hysKE hysKF hysKG hysKH hysKI hysKJ hysKK hysKL hysKM hysKN hysKO hysKP hysKQ hysKR hysKS hysKT hysKU hysKV hysKW hysKX hysKY hysKZ hysLA hysLB hysLC hysLD hysLE hysLF hysLG hysLH hysLI hysLJ hysLK hysLL hysLM hysLN hysLO hysLP hysLQ hysLR hysLS hysLT hysLU hysLV hysLW hysLX hysLY hysLZ hysMA hysMB hysMC hysMD hysME hysMF hysMG hysMH hysMI hysMJ hysMK hysML hysMN hysMO hysMP hysMQ hysMR hysMS hysMT hysMU hysMV hysMW hysMX hysMY hysMZ hysNA hysNB hysNC hysND hysNE hysNF hysNG hysNH hysNI hysNJ hysNK hysNL hysNM hysNO hysNP hysNQ hysNR hysNS hysNT hysNU hysNV hysNW hysNX hysNY hysNZ hysOA hysOB hysOC hysOD hysOE hysOF hysOG hysOH hysOI hysOJ hysOK hysOL hysOM hysON hysOP hysOQ hysOR hysOS hysOT hysOU hysOV hysOW hysOX hysOY hysOZ hysPA hysPB hysPC hysPD hysPE hysPF hysPG hysPH hysPI hysPJ hysPK hysPL hysPM hysPN hysPO hysPP hysPQ hysPR hysPS hysPT hysPU hysPV hysPW hysPX hysPY hysPZ hysQA hysQB hysQC hysQD hysQE hysQF hysQG hysQH hysQI hysQJ hysQK hysQL hysQM hysQN hysQO hysQP hysQQ hysQR hysQS hysQT hysQU hysQV hysQW hysQX hysQY hysQZ hysRA hysRB hysRC hysRD hysRE hysRF hysRG hysRH hysRI hysRJ hysRK hysRL hysRM hysRN hysRO hysRP hysRQ hysRR hysRS hysRT hysRU hysRV hysRW hysRX hysRY hysRZ hysSA hysSB hysSC hysSD hysSE hysSF hysSG hysSH hysSI hysSJ hysSK hysSL hysSM hysSN hysSO hysSP hysSQ hysSR hysSS hysST hysSU hysSV hysSW hysSX hysSY hysSZ hysTA hysTB hysTC hysTD hysTE hysTF hysTG hysTH hysTI hysTJ hysTK hysTL hysTM hysTN hysTO hysTP hysTQ hysTR hysTS hysTT hysTU hysTV hysTW hysTX hysTY hysTZ hysUA hysUB hysUC hysUD hysUE hysUF hysUG hysUH hysUI hysUJ hysUK hysUL hysUM hysUN hysUO hysUP hysUQ hysUR hysUS hysUT hysUU hysUV hysUW hysUX hysUY hysUZ hysVA hysVB hysVC hysVD hysVE hysVF hysVG hysVH hysVI hysVJ hysVK hysVL hysVM hysVN hysVO hysVP hysVQ hysVR hysVS hysVT hysVU hysVV hysVW hysVX hysVY hysVZ hysWA hysWB hysWC hysWD hysWE hysWF hysWG hysWH hysWI hysWJ hysWK hysWL hysWM hysWN hysWO hysWP hysWQ hysWR hysWS hysWT hysWU hysWV hysWW hysWX hysWY hysWZ hysXA hysXB hysXC hysXD hysXE hysXF hysXG hysXH hysXI hysXJ hysXK hysXL hysXM hysXN hysXO hysXP hysXQ hysXR hysXS hysXT hysXU hysXV hysXW hysXX hysXY hysXZ hysYA hysYB hysYC hysYD hysYE hysYF hysYG hysYH hysYI hysYJ hysYK hysYL hysYM hysYN hysYO hysYP hysYQ hysYR hysYS hysYT hysYU hysYV hysYW hysYX hysYZ hysZA hysZB hysZC hysZD hysZE hysZF hysZG hysZH hysZI hysZJ hysZK hysZL hysZM hysZN hysZO hysZP hysZQ hysZR hysZS hysZT hysZU hysZV hysZW hysZX hysZY hysZZ

MISSING -99

DATASORT BLOCK=block PEDIGREECODE=anim
WITHINBLOCK anim hysccowp hysccow hycarc hylin hypwpr hywpr hyscpr hyscq damp

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PEDIGREE anim am

INBRFILE ../../../../ICBF_1step_JAN_2016/ped_mix99_beef_geno.inbr
INBREEDING PEDIGREECODE=1 FINBR=3

RANDOM damp hyscpr hyscpr hywpr hypwpr hylin hycarc hycarc hysccow hysccowp
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PARALLEL 4 21953

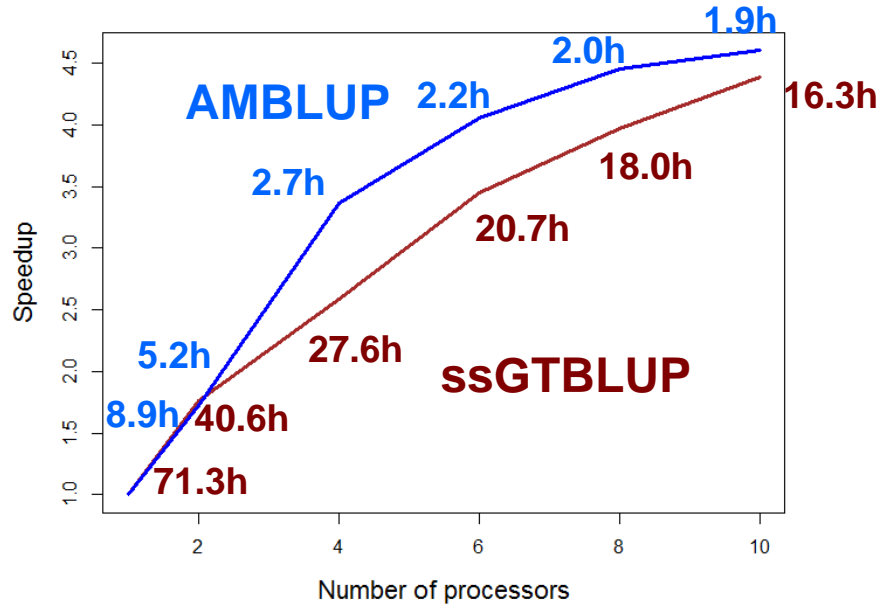
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cprice	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- - - - -
wprice	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- - - - -
pwpr	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- - - - -
musc	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- as0 as2 as3 - -
conf	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- - - - as1au a2s
cullconf	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	hrbxb hrbxd dhrbxb dhrbxd dfrac	- - - - -
dxd_musc	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	- - - - -	- - - - -
dxd_conf	=	AA AU BA BB CH FR HE HO JE LM PI MO PT SA SH SI	- - - - -	- - - - -

Speedups:

sparse matrix computations by MPI,
dense computations by parallel BLAS



Conclusions

- MiX99 is a flexible program that allows many models for breeding value estimation
- Data sets can be very large
 - parallel computing can be used to reduce computing time
- Sparse and dense matrix computations can be done with different approaches:
 - Distributed or shared memory computing, or both for different matrix parts
- Even with modest number of genotyped animals, computations were dominated by the dense matrix computations due to genomic data

Parallel computing using dense matrix operations reduced computing time

MiX99 is kernel in MiXBLUP software (www.mixblup.eu)



Irish Cattle Breeding Federation (ICBF) is acknowledged for the data and model used in this study.





MiX99 – Solving Large Mixed Model Equations

FRONTPAGE > CUSTOMER SOLUTIONS > EXPERTISE AREAS > LIVESTOCK AND FEED > MIX99 – SOLVING LARGE MIXED MODEL EQUATIONS

Expertise areas

Livestock and feed

Mix99 – Solving Large Mixed Model Equations

Smart plant production

Aquaculture and water economy

Forest bioeconomy

Food

Biomasses and energy

Circular economy

MiX99 is a software suite for breeding value estimation of large-scale genetic and genomic evaluations. MiX99 can be used with wide variety of prediction models and data sets. The software is used world-wide in national and international evaluations for cattle but also for pigs, horses, sheep, goats, fish, foxes, poultry and barley.

Some of the most important applications are genomic evaluations with massive number of genotyped animals and large random regression test-day models for national dairy cattle evaluations. MiX99 software is available for Linux and Windows environments, optionally utilizing parallel computing.

MiX99 software packages

To meet the different needs of world-wide research projects and industry users, MiX99 software suite is available in three different packages: MiX99, MiX99 Pro and

Further information

mix99@luke.fi

Presentations

[MiX99 Workshop 2014 \(program\)](#)

MiX99 introduction

[MiX99 overview](#)

[MiX99 tutorial](#)

[MiX99 documentation](#)

Solving large models with