

# Iterative Refinement in Three Precisions

*Tuesday, 5 November 2019 13:45 (45 minutes)*

Support for floating point arithmetic in multiple precisions is becoming increasingly common in emerging architectures.

For example, half precision is now available on the NVIDIA V100 GPUs, on which it runs twice as fast as single precision with a proportional savings in energy consumption. Further, the NVIDIA V100's half-precision tensor cores can provide up to a 16x speedup over double precision.

We present a general algorithm for solving an  $n$ -by- $n$  nonsingular linear system  $Ax = b$  based on iterative refinement in three precisions. The working precision is combined with possibly different precisions for solving for the correction term and for computing the residuals. Our rounding error analysis of the algorithm provides sufficient conditions for convergence and bounds for the attainable normwise forward error and normwise and componentwise backward errors, generalizing and unifying many existing rounding error analyses for iterative refinement.

We show further that by solving the correction equations by GMRES preconditioned by the LU factors the restriction on the condition number can be weakened to allow for the solution of systems which are extremely ill-conditioned with respect to the working precision. Compared with a standard  $Ax = b$  solver that uses LU factorization in single precision, these results suggest that on architectures for which half precision is efficiently implemented it will be possible to solve certain linear systems  $Ax = b$  in less time and with greater accuracy.

We present recent performance results on the latest GPU architectures which show that this approach can result in practical speedups and also discuss recent work in extending this approach to iterative refinement for least squares problems.

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