Comparison of Numerical Performance of *Mathematica* 10 and Maple 18

Summary

While Maple claims support for a significant subset of the numerical computations performed by *Mathematica*, in most cases much faster methods have been implemented in *Mathematica*.

Over a test suite of 579 tasks, covering different operations on different types of numerical data, *Mathematica* was faster in 568 cases. The median difference measured found *Mathematica* to be more than 28 times faster than Maple.

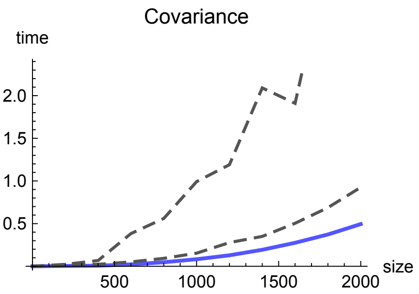
Category	Tests	Median *Mathematica* speed
Real data operations (Default data type)	19	13 times faster
Real data operations (Manual type override)	19	2.3 times faster
Complex number data operations	15	6 times faster
Complex number data operations (Manual type override)	15	4 times faster
Integer data operations	13	20 times faster
Integer data operations (Manual type override)	12	22 times faster
Sparse real data operations	7	33 000 times faster
Extended precision data operations (50 digits)	15	12 times faster
Extended precision data operations (1000 digits)	15	7 times faster
Random number generation	9	11 times faster
Elementary & special functions	90	2770 times faster
Elementary & special functions (Manual type override)	66	15 times faster
Complex elementary & special functions	90	35 times faster
Complex elementary & special functions (Manual type override)	90	47 times faster
Elementary & special functions (50 digits)	90	25 times faster
High precision function evaluation	9	32 times faster
Exact functions	4	9 times faster
GPU operations	1	3 times faster
Total	579	28 times faster

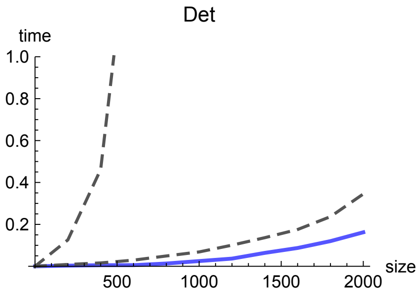
Tests were performed using Windows 7 64-bit with 3.07 GHz quad-core Intel i7 processors (W3580) with 20 GB of RAM. CUDA tests used a Tesla C2050/C2070 GPU with 448 cores and 2.5 GB of RAM.

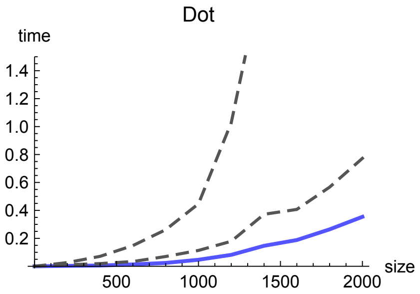
Machine-Precision Real Linear Algebra

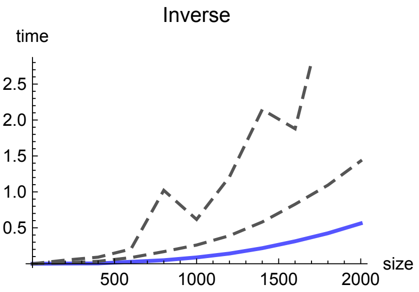
To achieve the very best performance in Maple, you must often use manual type control. This requires declaring the items in a dataset to all be of the same number type, as it is initialized. The penalty of this approach is that such Maple code will fail if any value is used that does not comply with the type declaration. Since it is not always easy to predict whether operations will potentially yield complex numbers, large numbers, or symbolic results, the default data type for all Maple operations is "anything," and most user code uses this type. Both manual and default Maple data type timings are shown in these comparisons.

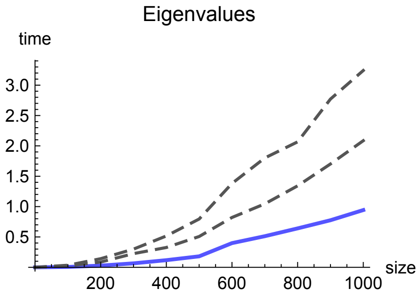
Mathematica operations are 2.7 times faster than Maple's inflexible (float[8]) data type and 13 times faster than its default type.

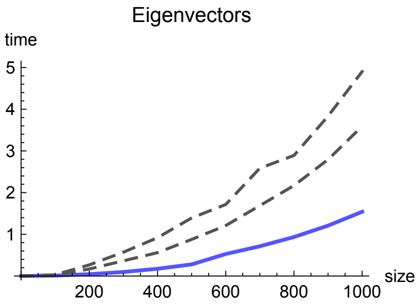


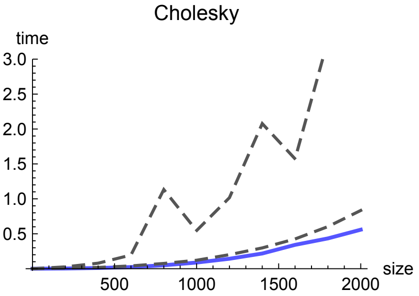


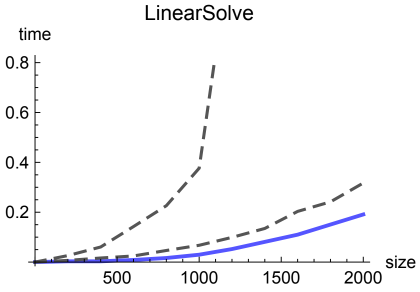


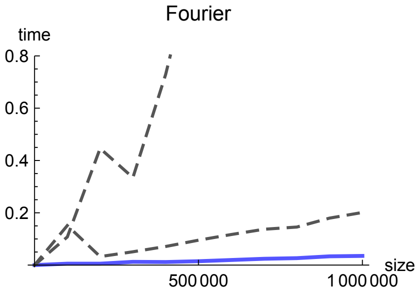


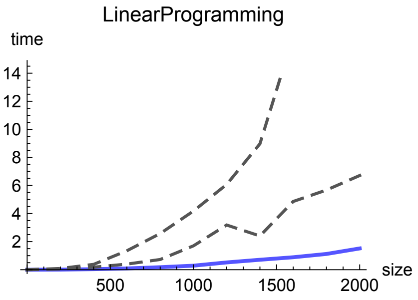


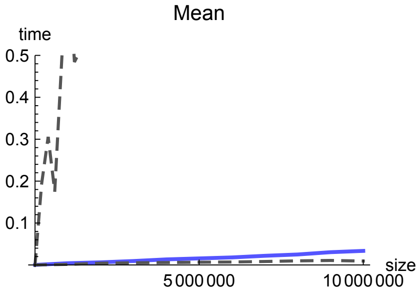


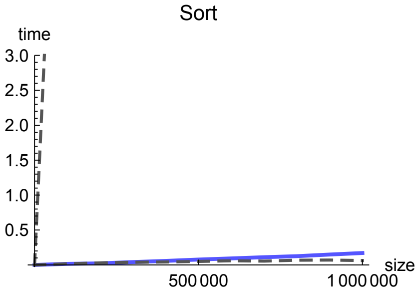


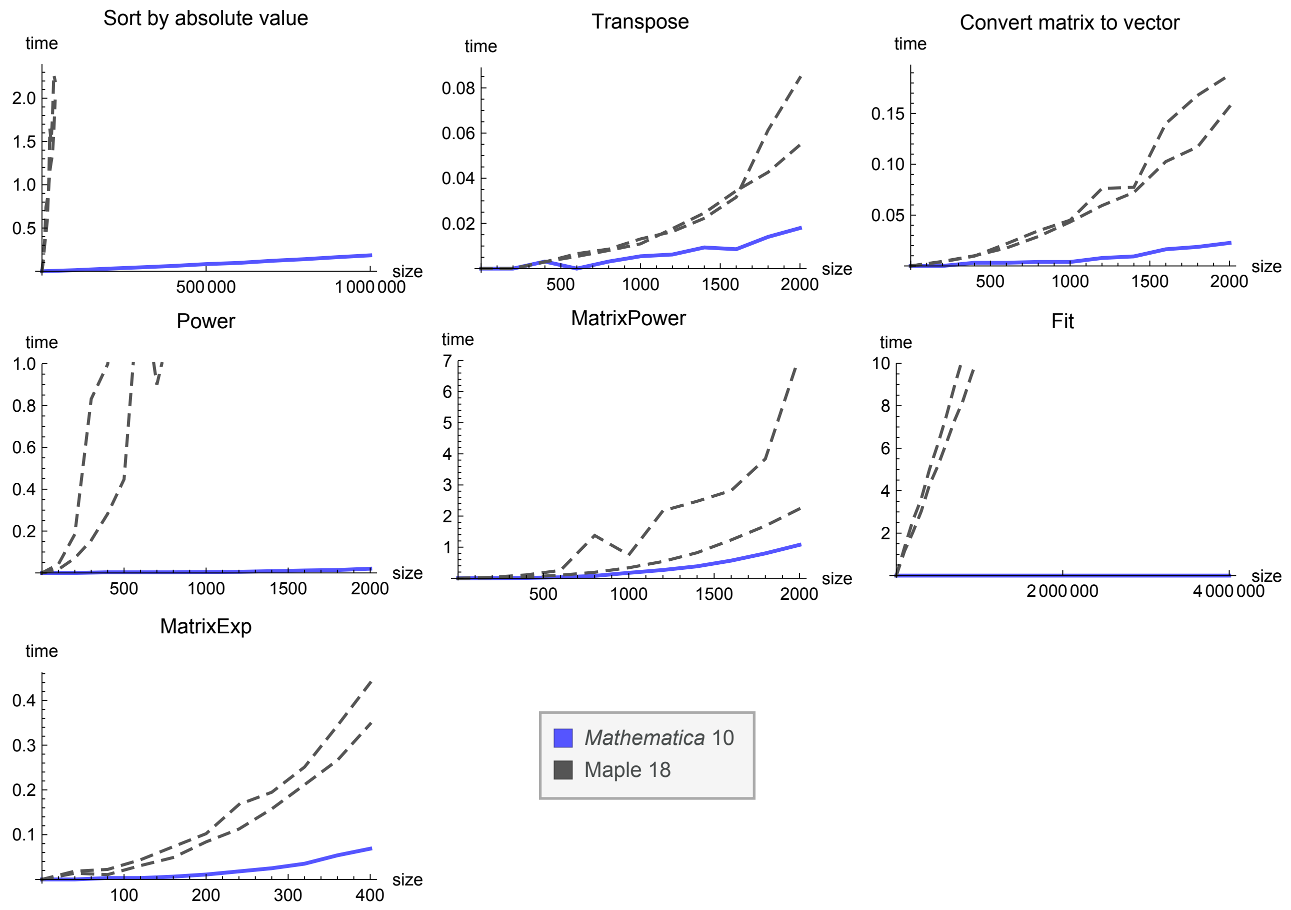










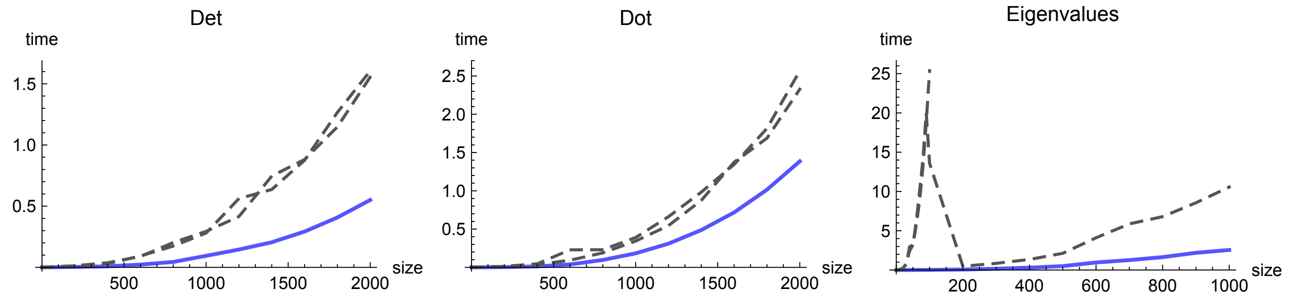


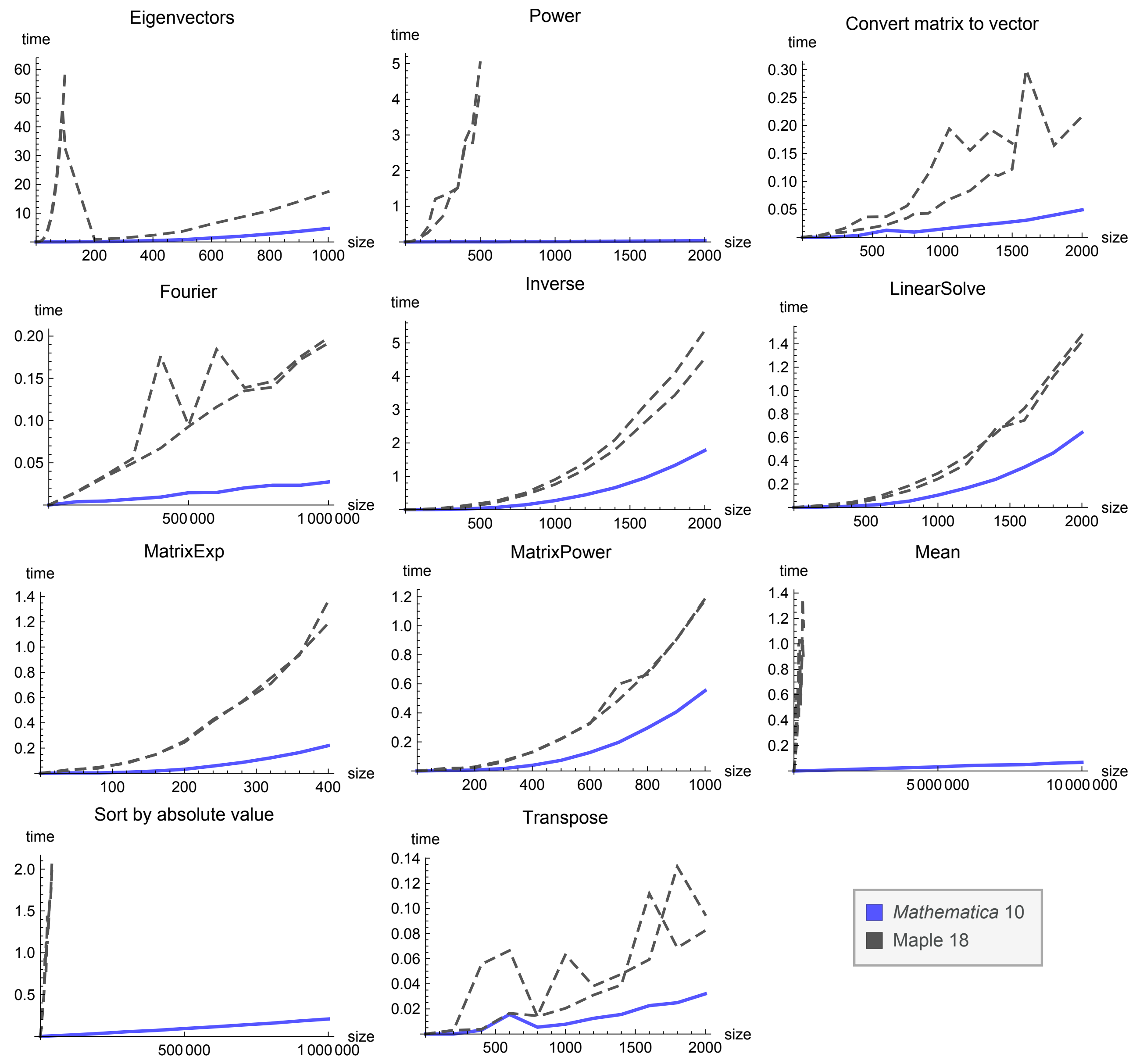
Implementation notes

All tests were performed using the documented commands in each system.
MapleSoft feedback has claimed that there are faster methods for converting a matrix to a vector than the documented command “convert(data,Vector)”, but they have not provided code or an explanation why the documented command does not use such methods.

Machine-Precision Complex Linear Algebra

For complex numbers, there is less advantage to manually setting the data type in Maple. *Mathematica* is more than 4-6 times faster.





Implementation notes

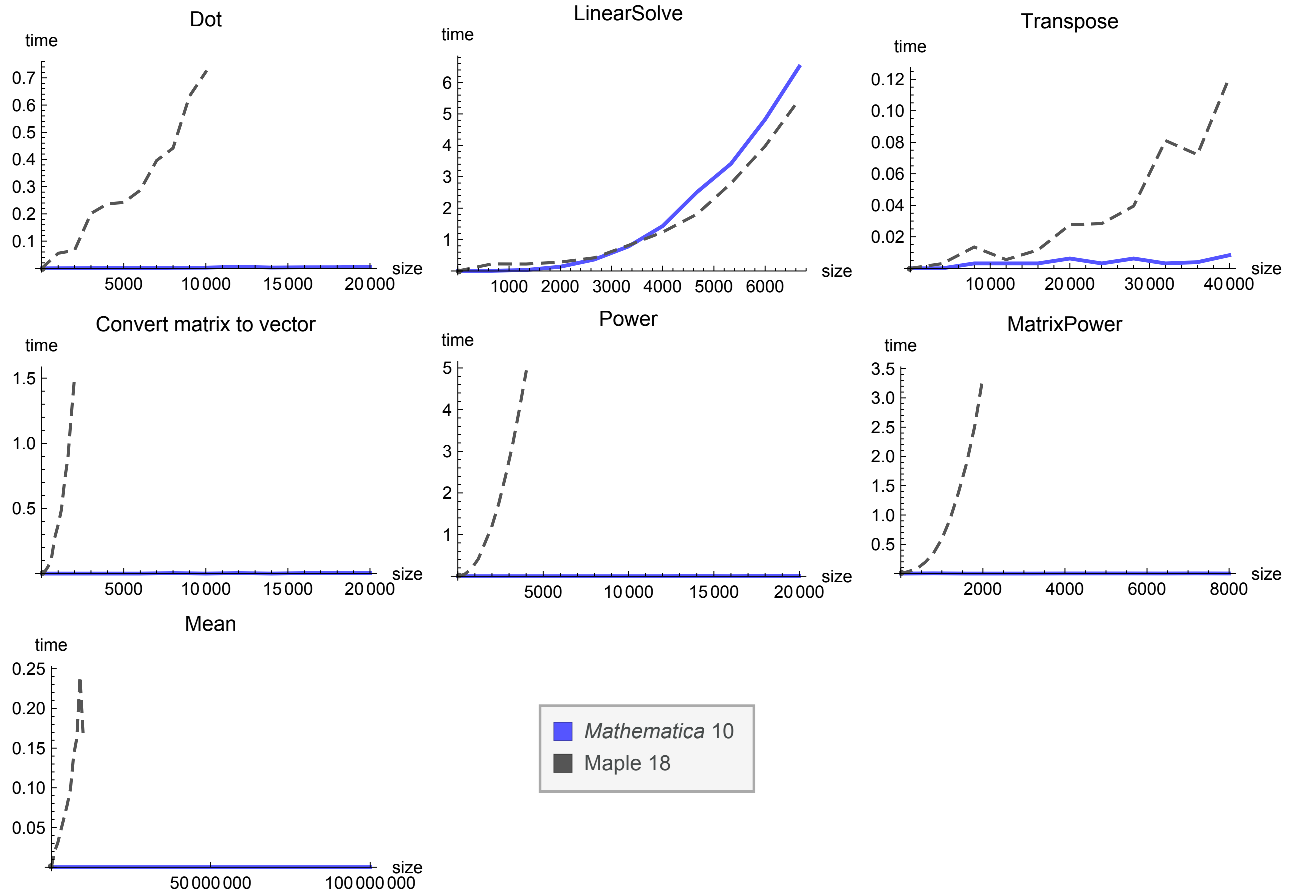
Functions in Maple's "Statistics" packages only work on real numbers. For this reason the Mean operation has been implemented using Maple's "add" command.

Maple 18's Eigenvalues and Eigenvectors commands persistently crashed for complex numbers and default data type, so these two tests were performed using Maple's deprecated eigenvalues and eigenvectors commands, the more modern command being used for the Complex[8] data type.

All other tests were performed using the documented command in each system.

Sparse Data

Maple and *Mathematica* both provide sparse data storage; however, Maple only appears to have implemented sparse methods for LinearSolve and Transpose. The difference in performance in other tests was so great that Maple was unable to perform many problems to a large enough scale for reliable comparison. In most of these plots, the *Mathematica* timings are too small to be visible on the scale required to plot the Maple timings.



Implementation notes

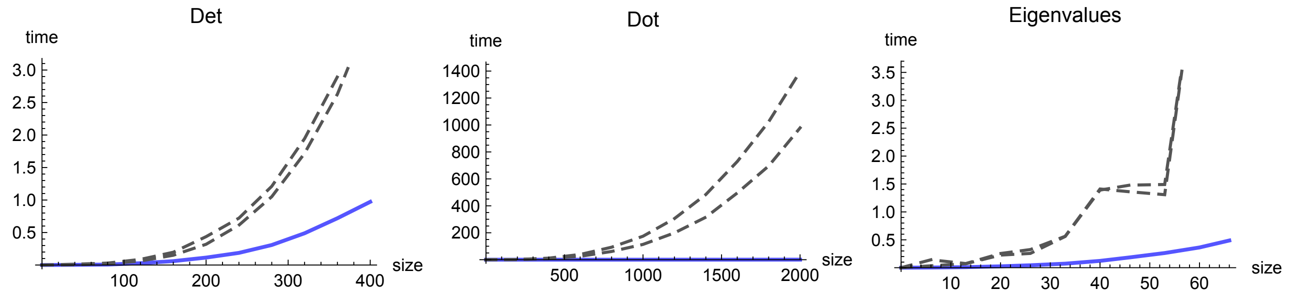
Tests for which neither system has sparse methods have been omitted, since these would be a repeat of the dense tests above.

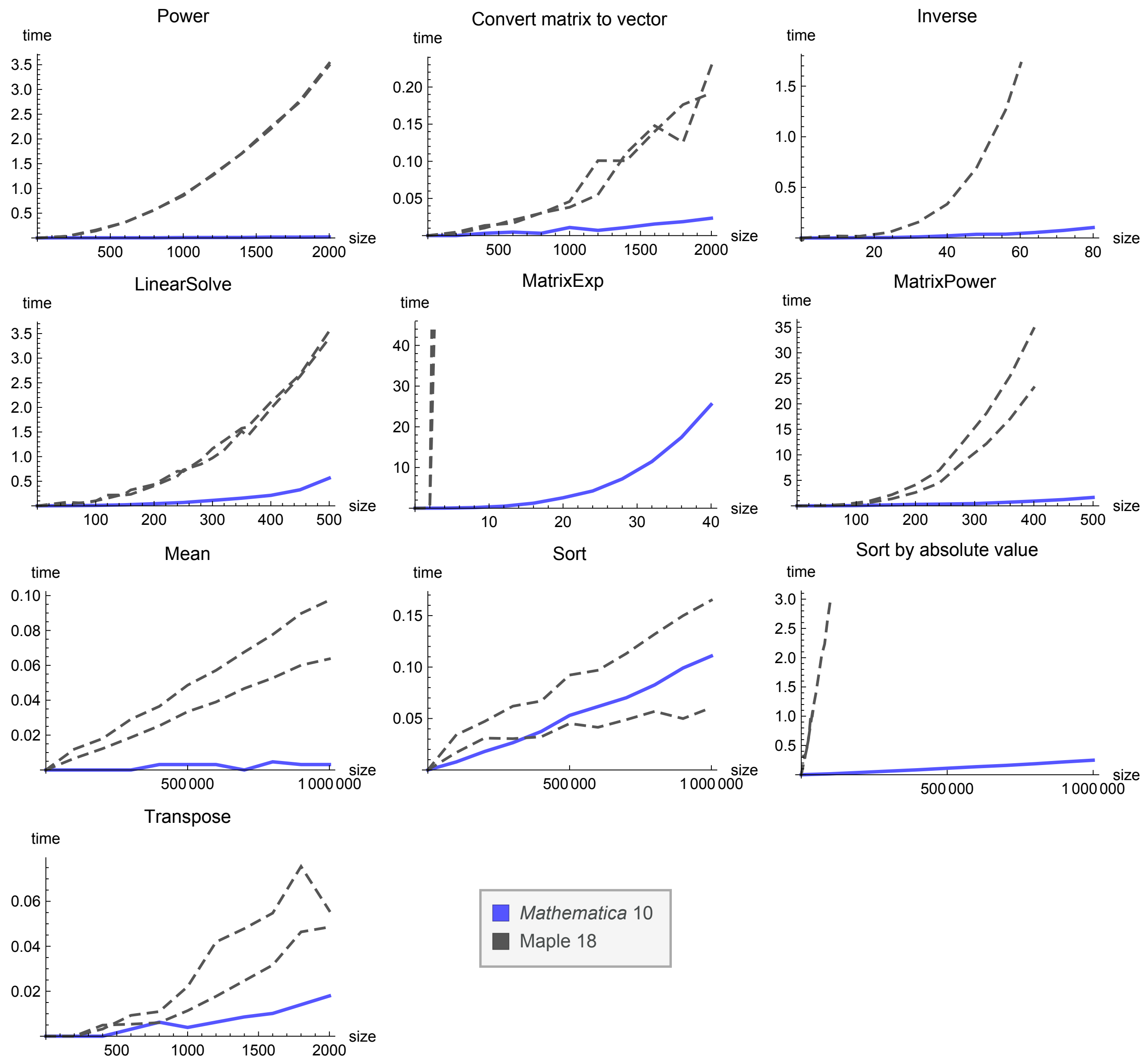
Integer Linear Algebra

Both *Mathematica* and Maple can perform exact integer arithmetic; however, again the Maple implementation does not seem to include many optimized integer algorithms. One of the biggest differences is seen with perhaps the most important matrix operation—multiplication (Dot)—where *Mathematica* was more than 2400 times faster.

Maple users can choose between a general data type or integer[8] but there appears to be no benefit in using the more limiting data type.

The median difference measures *Mathematica* to be over 20 times faster.





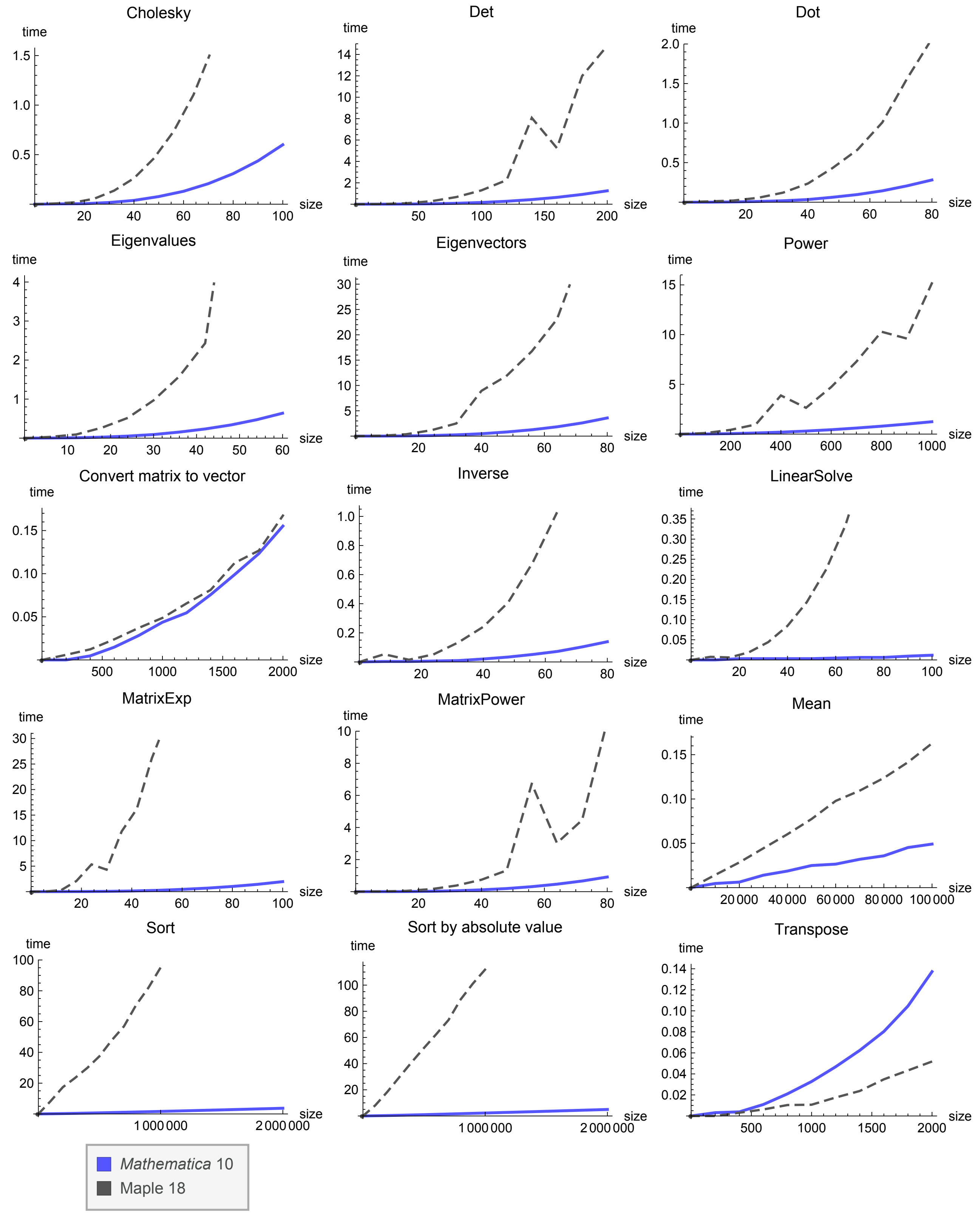
Implementation notes

Functions in Maple's "Statistics" packages are limited to machine-precision numbers only. For this reason the "Fit" test has been omitted and "Mean" has been implemented using the "add" command.

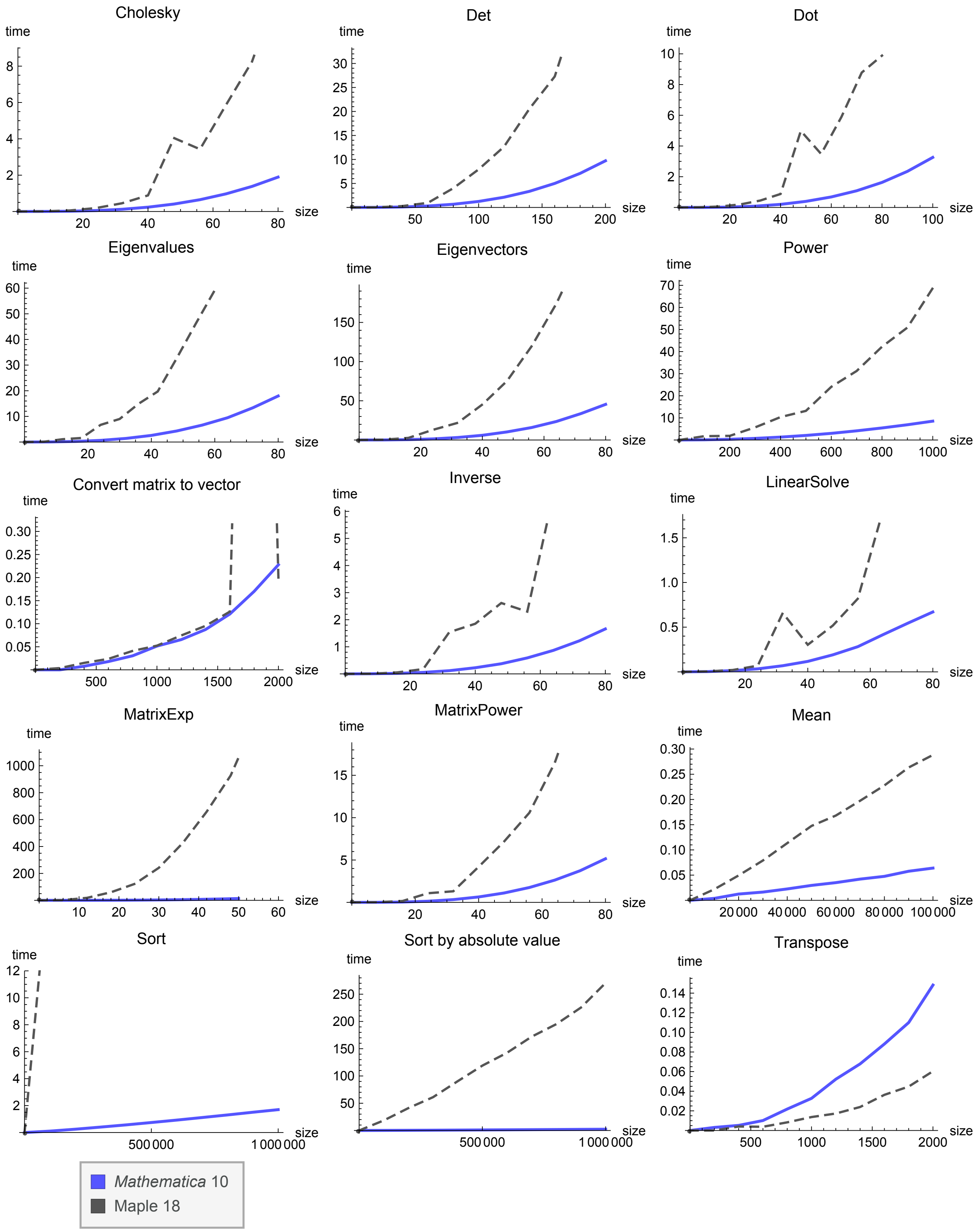
Maple cannot evaluate the Inverse task using the integer[8] type, so only default data type results are shown for this test.

Extended-Precision Data

Both *Mathematica* and Maple handle arbitrary-precision arithmetic. Only *Mathematica* tracks the number of reliable digits in the results of such calculations, and yet despite doing this additional validation work, *Mathematica* was 12 times faster for 50-decimal-place matrix computations.



Similar performance differences are seen when calculating at 1000-digit precision.

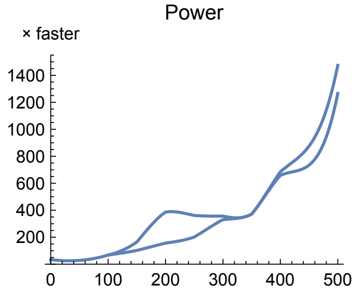


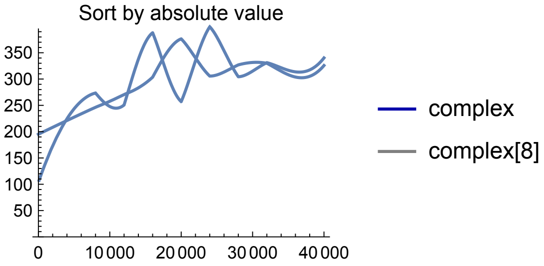
Implementation notes

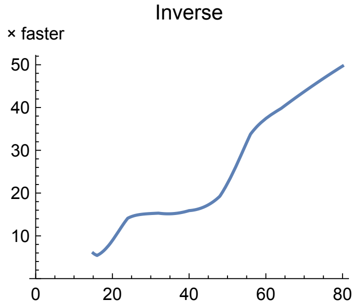
Some Maple functions are limited to machine-precision numbers. For this reason, tests for “Fit” and “Fourier” have been omitted and “Mean” has been implemented using “add”.

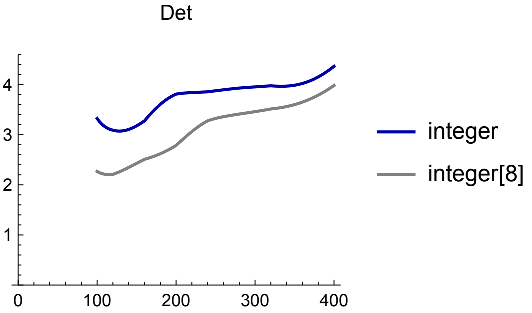
Scalability of Data Operations

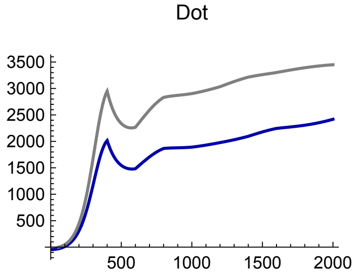
The ratio of Maple’s performance to *Mathematica*’s is mostly fairly independent of problem size; however, a few of the operations tested in the preceding sections have been implemented in Maple with poorly scaling algorithms. The larger the problem size, the more *Mathematica* will outperform Maple for these operations.

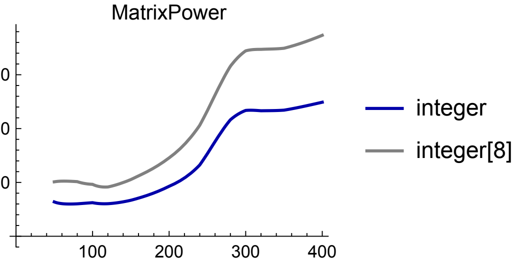








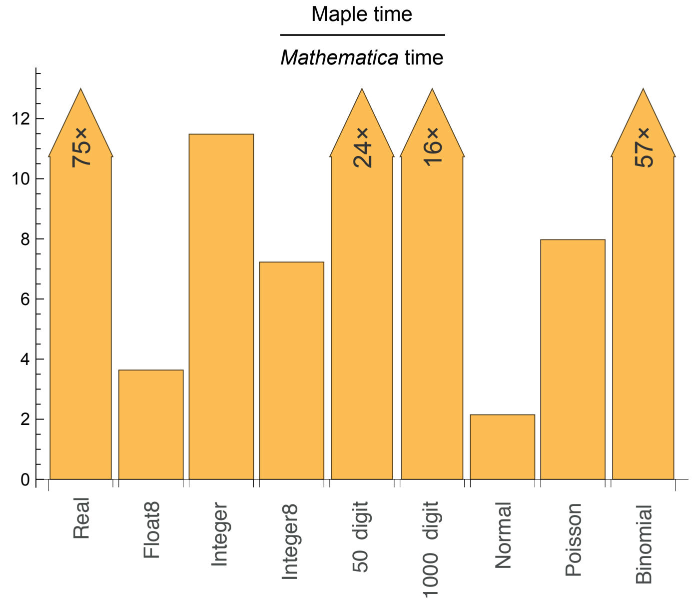




Random Numbers

Median performance for random number generation shows *Mathematica* to be 11 times faster than Maple.

Matrices with 2000x2000 element were generated for each number type using a uniform distribution [-10,10]. Normal, Poisson, and Binomial distributions were used to create a vector of 10^7 samples.



Implementation notes

Documented Maple commands were used in all cases.
Maple's default type for reals and its special "Float8" data generation were both compared to the default data type in *Mathematica*.
Maple's default type for integers and its special "Integer8" data generation were both compared to the default data type in *Mathematica*.
Maple's Poisson and Binomial distributions (and other discrete distributions) generate real numbers, while *Mathematica* correctly generates integers.

Function Evaluation

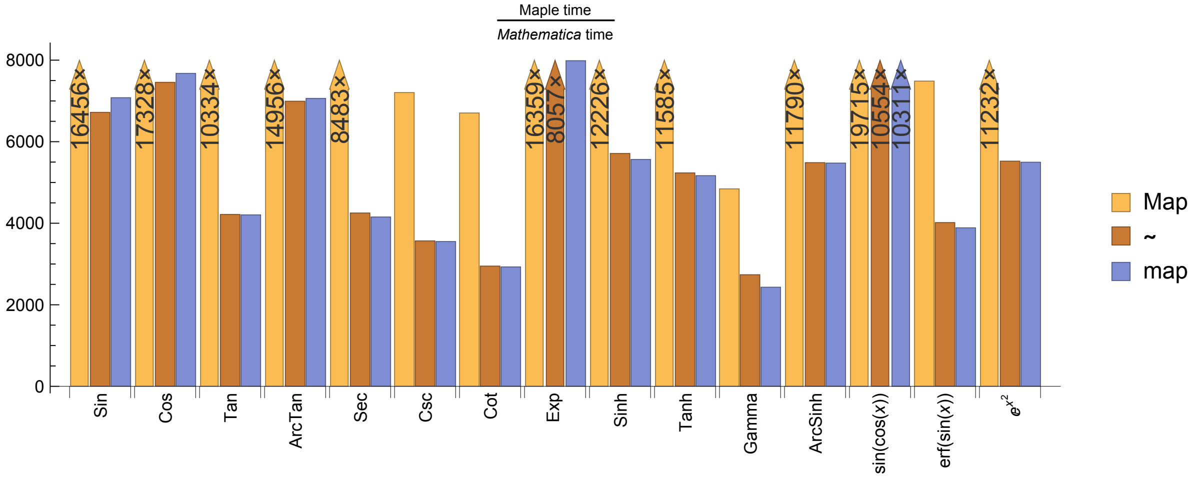
Getting Maple to apply other functions to data with optimal performance is a complicated task with a choice of tools for mapping the functions over the data and a choice of data types. Different circumstances require different choices and are often a trade-off between performance and flexibility or code robustness. In the following tests, each combination of the Maple commands "map", "Map", and "~" together with appropriate default and manual data specifications have been compared to *Mathematica*'s default data structure and "Map" command.

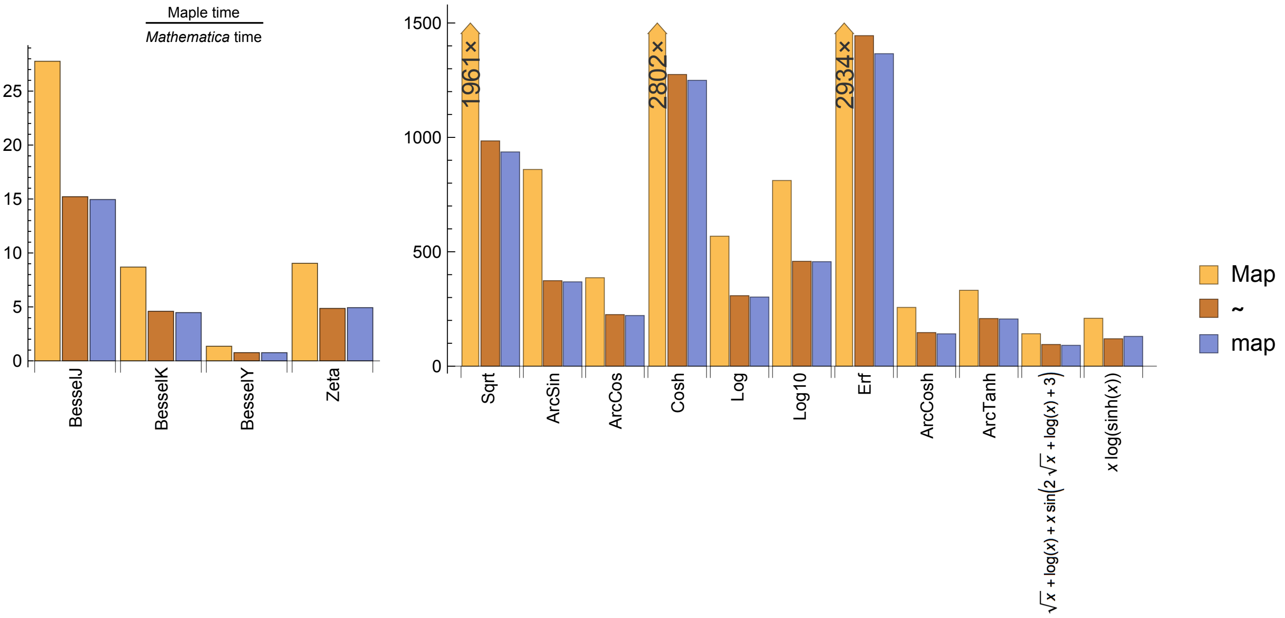
Maple's "map" command is functionally equivalent to *Mathematica*'s "Map", while Maple's "Map" is destructive (it replaces the original data, so extra work would be needed if one wanted to preserve or reuse the input data).

Reals

Using the default data type to represent data (as most users would), Maple is generally extremely slow compared to *Mathematica*, with the exception of Bessel functions, which are only modestly slower than *Mathematica*.

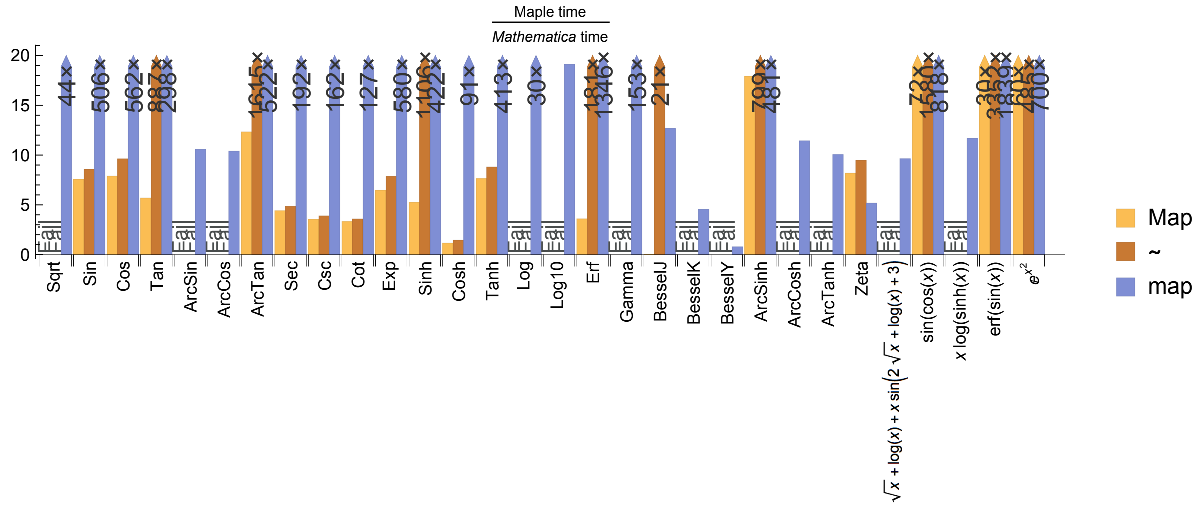
Times to evaluate functions over 10^7 real numbers are compared below.





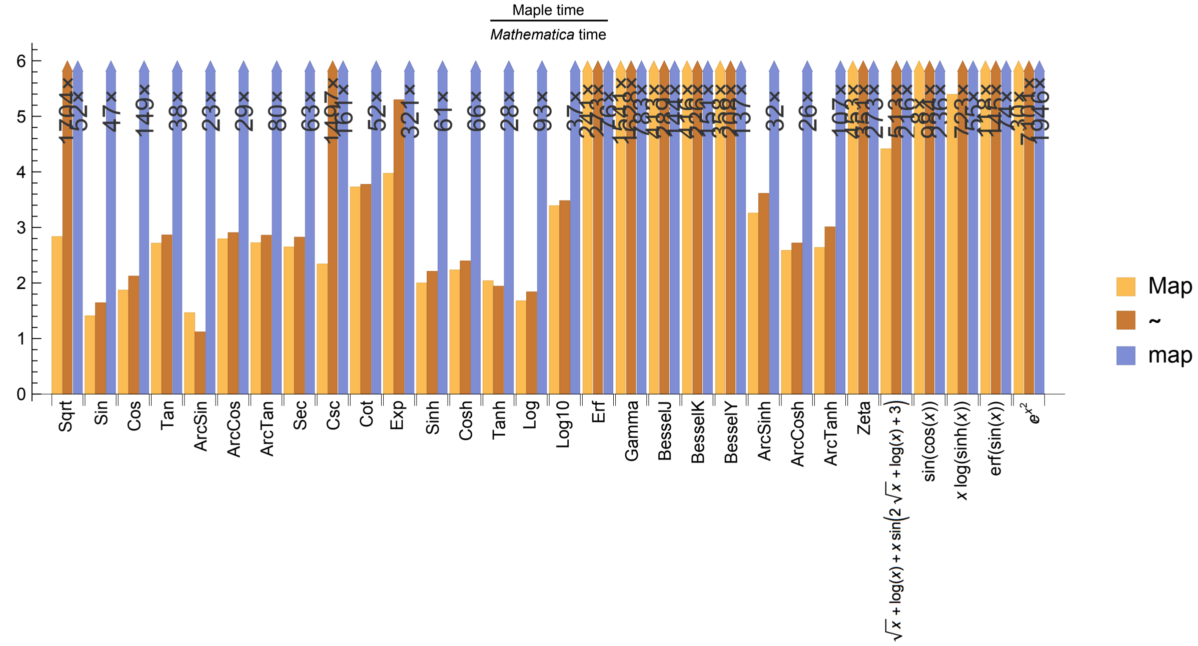
Better performance can be achieved in Maple by manually specifying (or converting) data to the “float[8]” data type. However, this comes at considerable cost to flexibility: firstly you must ensure that all the input data consists of machine reals. Code will fail if you attempt to store a value which is complex, symbolic, string, or NaN value. But more importantly, code will also fail completely if any single computation, using “Map” or “~”, *returns* a value which is not real. This means that you can only use this approach when you can completely predict the domain of both the input and output data.

Using the input data set in the interval [-10,10], Maple’s “Map” and “~” commands fail, for obvious reasons, for 9 of the tests, and “map”, while more robust, is typically more than 140 times slower than *Mathematica*. It is also important to note that while “Map” and “~” operations are generally much faster than “map” for applying single functions, this advantage largely disappears for applying composite functions to the data.

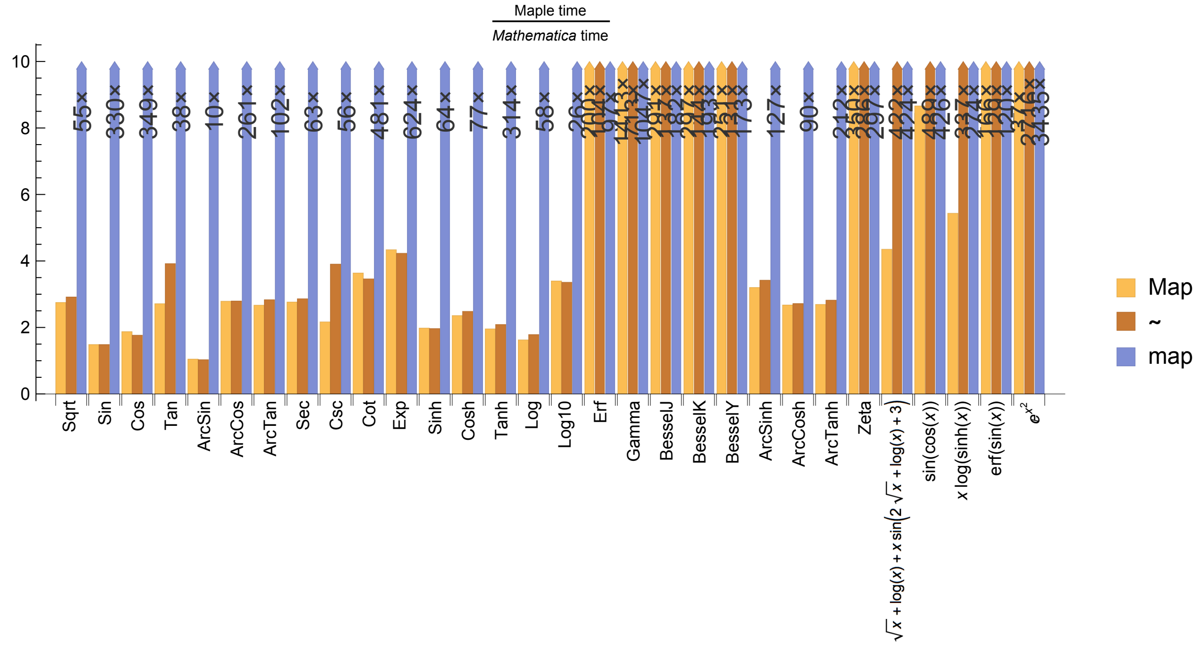


Complexes

For operations on complex numbers, Maple is often only modestly slower than *Mathematica* when using “Map” or “~” to apply single built-in functions. For composite functions and some special functions, the difference is much greater. When using “map” (the direct equivalent of *Mathematica*’s “Map” command), the difference is much greater.

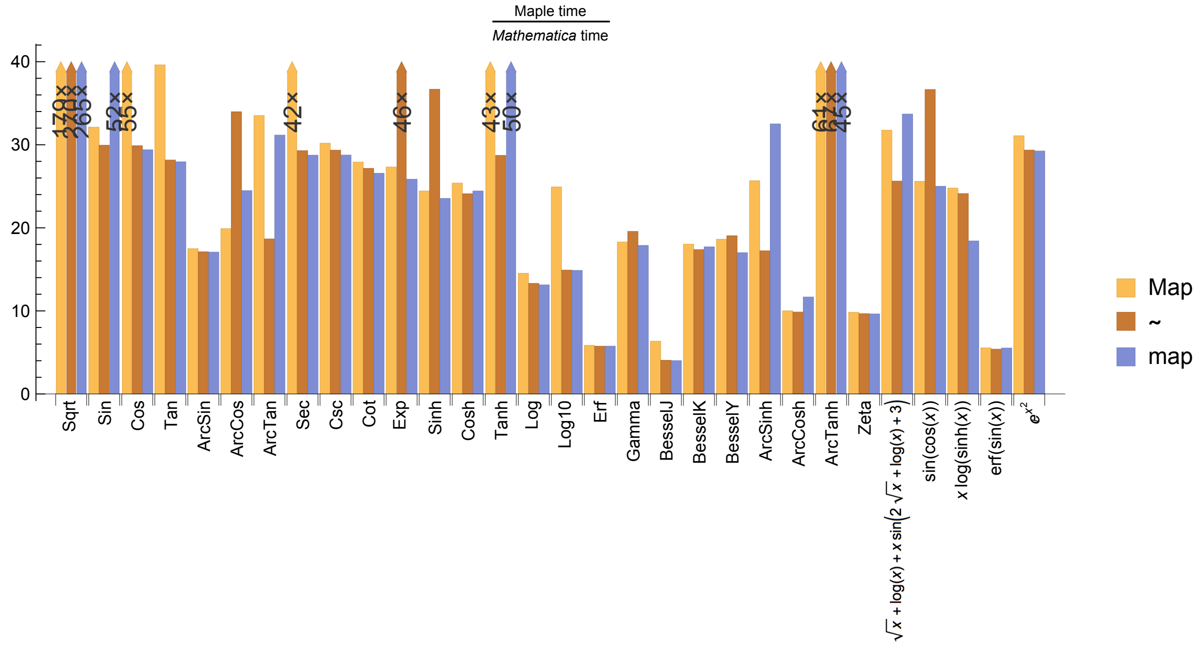


There is a small benefit to using the Complex[8] data type for Maple’s “Map” and “~” commands at the cost of slowing down operations using “map”.



Extended precision

When working in 50-decimal-place extended arithmetic, it makes little difference how you apply functions in Maple. The median performance is 25 times slower than *Mathematica.*



Getting the best performance out of Maple requires significant system knowledge and carefully chosen manual intervention.

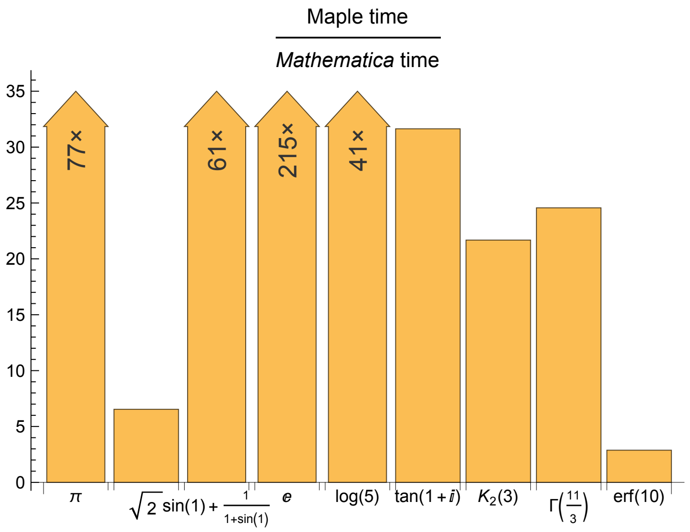
In contrast, all *Mathematica* computations were performed using the same function and the same automatic data type, and still outperformed Maple in every test except BesselY using real float data (but not using Maple's "Map" command or its "~" command with float[8] data type).

Implementation notes

All tests performed on a vector of 10^7 uniform random numbers in the interval [10,10] or [-10,10]+I*[-10,10] for complex data.

High-Precision Evaluation

When evaluating exact numeric expressions to very high precision, *Mathematica* provides automatic precision tracking to ensure that it achieves the target number of correct digits (as opposed to just using input with the target number of digits). The examples in this test were too simple for this to matter, but despite this extra verification work, *Mathematica* evaluated the following expressions to high precision with a median performance 9 times faster than Maple.



Implementation notes

“BesselK”, “Gamma” and “Erf” calculations were evaluated to 5000 digits.
Other expressions were evaluated to 1 000 000 digits.

Exact Numeric Functions

While calculating exact numeric results (in terms of rationals, radicals, and constants such as π) is arguably symbolic computation, Maple’s performance does not appear to improve.

Function	Largest test value	*Mathematica* speed
BernoulliB	6000	2.9 times faster
Fibonacci	500 000	7 times faster
HarmonicNumber	10 000	Maple cannot compute for n > 50
Zeta	100 000	12 times faster
Binomial	10^{14}	140 times faster

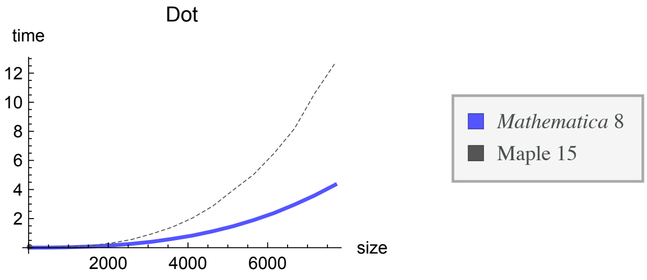
Implementation notes

Maple does not automatically evaluate “Zeta(n)” for n>50, so “expand(Zeta(n))” is used.

GPU Performance

Maple's CUDA support is extremely limited, with only a single function, "Dot", implemented, and only for double-precision CUDA hardware. It has no OpenCL or single-precision support. *Mathematica* can run arbitrary CUDA or OpenCL code, and has many built-in CUDA accelerated functions.

Testing the one function that Maple does support shows that the *Mathematica* implementation is 3 times faster.



Implementation notes

CUDA tests were performed using Maple 15 and *Mathematica* 8.

General Testing Methodology

Tests were performed using Windows 7 64-bit with 3.07 GHz quad-core Intel i7 processors with 24 GB of RAM. CUDA tests used a Tesla C2050/C2070 GPU with 448 cores and 2.5 GB of RAM. Tests were performed using Maple 18.00 and *Mathematica* 10.0.1 default installations, except CUDA tests which used Maple 15 and *Mathematica* 8.

Some tests have been scaled back to smaller problems in the Maple version to enable Maple to perform them in the available time and memory. Where standard Maple functions cannot perform the requested computations, tests have been excluded or, where trivial, alternative Maple implementations have been created. See source code for details. Median values are calculated only from tests that Maple is able to perform.

For most functions, the test suite finds the average time for 5 evaluations for each size of problem, but high-precision evaluations were performed only once, since both systems cache the results for later reuse.

Maple is unable to perform the entire test suite in 20GB of RAM, so where tests crashed or failed to complete within 24 hours, Maple was restarted and the test repeated. Such failures have not been included in the results. *Mathematica* tests were performed in a single run.

Relative performance ratios use the largest problem size for each test performed, except where the Maple test has had to be scaled back. In these cases, the available data has been fitted to the curve $a\,x^2 + b\,x$, and this model used to estimate a time for the largest problem size timed in *Mathematica*.

Source code for the tests is included so that results can be replicated independently. The entire test, including random data generated, takes approximately 110 minutes in *Mathematica* and several days in Maple.

Revision Notes

Significant changes since version 2 of this benchmark:
- Increased size of test suite from 508 tests to 579 tests
- Increased scale of some tests
- Used new random number generators in Maple 18
- Used deprecated “eigenvalues” and “eigenvectors” commands to work around new crashes in Maple 18
- Increased memory on test machine

Significant changes since version 1 of this benchmark:
- Increased size of test suite from 164 tests to 508 tests
- Tested Maple “Map” and “In place” (~) command as well as “map”
- Changed data range from [0,1] to [-10,10]
- Reduced the repetitions from 10 to 5 and steps from 20 to 10
- Fixed faulty LinearProgramming tests to give the same tasks to both systems and ensure feasibility.
- Improved localization within Maple test code
- Removed programming tests which did not relate to numeric computation
- Used more modern test computer with more memory

Appendix: Test Code

Mathematica

Test code

```
$HistoryLength = 0;
SetDirectory[C:\Users\jonm\Desktop\BenchmarkData];
steps = 10;
repeats = 5;
maxVector = 10^6;
maxMatrix = 2000;
maxSparseMatrix = 20 000;
makeData[type_, i_] := Switch[type,
  RealVector, RandomReal[{-10, 10}, i],
  RealMatrix, RandomReal[1, {i, i}],
  ExtendedMatrix, RandomReal[1, {i, i}, WorkingPrecision → 50],
  ExtendedMatrix1000, RandomReal[1, {i, i}, WorkingPrecision → 1000],
  ExtendedVector, RandomReal[1, {i}, WorkingPrecision → 50],
  ExtendedVector1000, RandomReal[1, {i}, WorkingPrecision → 1000],
  IntegerMatrix, RandomInteger[100, {i, i}],
  IntegerVector, RandomInteger[100, i],
  SparseMatrix,
  SparseArray[Table[{RandomInteger[{1, i}], RandomInteger[{1, i}]} → Random[],
    {i^2 / 10 000}], {i, i}],
  SparseVector, SparseArray[Table[RandomInteger[{1, i}] → Random[],
    {Floor[i / 10 000 ]}], {i}],
  MediumSparseMatrix, SparseArray[Table[{RandomInteger[{1, i}],
      RandomInteger[{1, i}]} → Random[], {i^2 / 200 }], {i, i}],
  ComplexMatrix, RandomComplex[{0, 1 + I}, {i, i}],
  ComplexVector, RandomComplex[{0, 1 + I}, {i}],
  _, Print[type]
 ]
```

```
timedReport[path_, fn_, hi_, type_] := Block[{data}, Export[
    Mathematica <> ToString[$VersionNumber] <> path <> .txt, Table[{Floor[t],
      Mean[Table[
        data = makeData[type, Floor[t]];
        AbsoluteTiming[fn[data]][[1]], {repeats}]]}
     , {t, hi/steps, hi, hi/steps}], Table]];

highPrecisionReport[path_, fns_, n_] :=
 Export[Mathematica <> ToString[$VersionNumber] <> path <> .txt,
  Map[AbsoluteTiming[N[#, n]][[1]] &, fns]]

NumericTest[path_, fns_List, n_, type_] :=
  Block[{data}, Export[Mathematica <> ToString[$VersionNumber] <> path <> .txt,
    Table[data = makeData[type, n];
     AbsoluteTiming[i[data]][[1]], {i, fns}]]];

evaluateTest[path_, expr_Hold] :=
 Export[Mathematica <> ToString[$VersionNumber] <> path <> .txt,
  Apply[List, First /@ Map[AbsoluteTiming, expr]]]
```

Function evaluations

```
fnList = {Sqrt, Sin, Cos, Tan, ArcSin, ArcCos, ArcTan,
   Sec, Csc, Cot, Exp, Sinh, Cosh, Tanh, Log, Log10, Erf, Gamma,
   BesselJ[0, #] &, BesselK[1, #] &, BesselY[3, #] &, ArcSinh, ArcCosh,
   ArcTanh, Zeta, # Sin[Log[#] + 2 * Sqrt[#] + 3] + Sqrt[#] + Log[#] &,
   Sin[Cos[#]] &, # Log[Sinh[#]] &, Erf[Sin[#]] &, Exp[#^2] &};

NumericTest[ElementaryFunctions, fnList, 10 maxVector , RealVector];
NumericTest[ElementaryFunctionsComplex, fnList, maxVector , ComplexVector];
NumericTest[ElementaryFunctionsExtended,
  fnList, maxVector / 10, ExtendedVector];
NumericTest[ElementaryFunctionsSparse, fnList, 100 000 maxVector , SparseVector];
```

Real matrix operations

```
timedReport[FourierReal, Fourier, maxVector, RealVector];
timedReport[SortReal, Sort, maxVector, RealVector];
timedReport[SortCustomReal, SortBy[#, Abs] &, maxVector, RealVector];
timedReport[MeanReal, Mean, 10 maxVector, RealVector];
timedReport[DotReal, #.# &, maxMatrix , RealMatrix];
timedReport[InverseReal, Inverse, maxMatrix, RealMatrix];
Quiet@
  timedReport[LinearSolveReal, LinearSolve[#, #[[1]]] &, maxMatrix, RealMatrix];
timedReport[CholeskyReal, CholeskyDecomposition[Transpose[#].#] &,
  maxMatrix, RealMatrix];
timedReport[MatrixPowerReal, MatrixPower[#, 5] &, maxMatrix, RealMatrix];
timedReport[DetReal, Det, maxMatrix, RealMatrix];
timedReport[TransposeReal, Transpose, maxMatrix, RealMatrix];
timedReport[FlattenReal, Flatten, maxMatrix, RealMatrix];
timedReport[EigenvaluesReal, Eigenvalues, maxMatrix / 2, RealMatrix];
timedReport[EigenvectorsReal, Eigenvectors, maxMatrix / 2, RealMatrix];
timedReport[LinearProgrammingReal,
  LinearProgramming[Abs[#[[1]]], Abs[#], Abs[#[[2]]], Method → CLP] &,
  maxMatrix, RealMatrix];
timedReport[ElementPowerReal, #^5 &, maxMatrix, RealMatrix];
timedReport[MovingAverageReal, MovingAverage[#, 10] &, maxVector, RealVector];
timedReport[FitReal, (Function[{data}, Fit[data, x, x]][Transpose[{#, #}]]) &;,
  4 * maxVector, RealVector];
timedReport[MatrixExpReal, MatrixExp, maxMatrix / 5, RealMatrix];
timedReport[CovarianceReal, Covariance, maxMatrix, RealMatrix];
```

Complex matrix operations

```
timedReport[FourierComplex, Fourier, maxVector, ComplexVector];
timedReport[SortCustomComplex, SortBy[#, Abs] &, maxVector, ComplexVector];
timedReport[MeanComplex, Mean, 10 maxVector, ComplexVector];
timedReport[DotComplex, #.# &, maxMatrix , ComplexMatrix];
timedReport[InverseComplex, Inverse, maxMatrix, ComplexMatrix];
timedReport[LinearSolveComplex,
  LinearSolve[#, #[[1]]] &, maxMatrix, ComplexMatrix];
timedReport[CholeskyComplex, CholeskyDecomposition[ConjugateTranspose[#].#] &,
  maxMatrix, ComplexMatrix];
timedReport[MatrixPowerComplex, MatrixPower[#, 5] &,
  maxMatrix / 2, ComplexMatrix];
timedReport[DetComplex, Det, maxMatrix, ComplexMatrix];
timedReport[EigenvaluesComplex, Eigenvalues, maxMatrix / 2, ComplexMatrix];
timedReport[EigenvectorsComplex, Eigenvectors, maxMatrix / 2, ComplexMatrix];
timedReport[TransposeComplex, Transpose, maxMatrix, ComplexMatrix];
timedReport[FlattenComplex, Flatten, maxMatrix, ComplexMatrix];
timedReport[ElementPowerComplex, #^5 &, maxMatrix, ComplexMatrix];
timedReport[MatrixExpComplex, MatrixExp, maxMatrix / 5, ComplexMatrix];
```

Sparse matrix operations

```
timedReport[DotSparse, #.# &, maxSparseMatrix, SparseMatrix];
Quiet@timedReport[LinearSolveSparse,
   LinearSolve[#, #[[1]]] &, maxSparseMatrix / 3, MediumSparseMatrix];
timedReport[TransposeSparse, Transpose, 2 * maxSparseMatrix, SparseMatrix];
timedReport[FlattenSparse, Flatten, maxSparseMatrix, SparseMatrix];
timedReport[ElementPowerSparse, #^5 &, maxSparseMatrix, SparseMatrix];
timedReport[MeanSparse, Mean, maxVector * 100, SparseVector];
timedReport[MatrixPowerSparse,
  MatrixPower[#, 5] &, 2 * maxSparseMatrix / 5, SparseMatrix];
timedReport[MovingAverageSparse, MovingAverage[#, 10] &,
  10 maxVector, SparseVector];
```

Integer matrix operations

```
timedReport[DotInteger, #.# &, maxMatrix , IntegerMatrix];
timedReport[InverseInteger, Inverse, maxMatrix / 25, IntegerMatrix];
timedReport[LinearSolveInteger,
  LinearSolve[#, #[[1]]] &, maxMatrix / 4, IntegerMatrix];
timedReport[MatrixPowerInteger, MatrixPower[#, 5] &,
  maxMatrix / 4, IntegerMatrix];
timedReport[DetInteger, Det, maxMatrix / 5 , IntegerMatrix];
timedReport[TransposeInteger, Transpose, maxMatrix, IntegerMatrix];
timedReport[FlattenInteger, Flatten, maxMatrix, IntegerMatrix];
timedReport[MeanInteger, Mean, maxVector, IntegerVector];
timedReport[SortInteger, Sort, maxVector, IntegerVector];
timedReport[SortCustomInteger, SortBy[#, Abs] &, maxVector, IntegerVector];
timedReport[EigenvaluesInteger, Eigenvalues, maxMatrix / 30, IntegerMatrix];
timedReport[ElementPowerInteger, #^5 &, maxMatrix, IntegerMatrix];
timedReport[MatrixExpInteger, MatrixExp, 40, IntegerMatrix];
```

50-digit precision operations

```
timedReport[DotExtended, #.# &, maxMatrix / 25 , ExtendedMatrix];
timedReport[InverseExtended, Inverse, maxMatrix / 25, ExtendedMatrix];
timedReport[CholeskyExtended,
  CholeskyDecomposition[Transpose[#].#] &, maxMatrix / 20, ExtendedMatrix];
timedReport[EigenvaluesExtended, Eigenvalues, 60, ExtendedMatrix];
timedReport[EigenvectorsExtended, Eigenvectors, 80, ExtendedMatrix];
timedReport[ElementPowerExtended, #^5 &, maxMatrix / 2, ExtendedMatrix];
timedReport[LinearSolveExtended,
  LinearSolve[#, #[[1]]] &, maxMatrix / 20, ExtendedMatrix];
timedReport[DetExtended, Det, maxMatrix / 10, ExtendedMatrix];
timedReport[TransposeExtended, Transpose, maxMatrix, ExtendedMatrix];
timedReport[FlattenExtended, Flatten, maxMatrix, ExtendedMatrix];
(*timedReport[FourierExtended,Fourier,maxVector/100,ExtendedVector];*)
(*Maple converts to floats*)
timedReport[MeanExtended, Mean, maxVector / 10, ExtendedVector];
timedReport[SortExtended, Sort, 2 * maxVector, ExtendedVector];
timedReport[SortCustomExtended,
  SortBy[#, Abs] &, 2 * maxVector, ExtendedVector];
timedReport[EigenvectorsExtended, Eigenvectors, maxMatrix / 25, ExtendedMatrix];
timedReport[MatrixPowerExtended,
  MatrixPower[#, 5] &, maxMatrix / 25, ExtendedMatrix];
timedReport[MatrixExpExtended, MatrixExp, 100, ExtendedMatrix];
```

1000-digit precision operations

```
timedReport[DotExtended1000, #.# &, maxMatrix / 20 , ExtendedMatrix1000];
timedReport[InverseExtended1000, Inverse, maxMatrix / 25, ExtendedMatrix1000];
timedReport[CholeskyExtended1000,
  CholeskyDecomposition[Transpose[#].#] &, maxMatrix / 25, ExtendedMatrix1000];
timedReport[EigenvaluesExtended1000, Eigenvalues, 80, ExtendedMatrix1000];
timedReport[EigenvectorsExtended1000, Eigenvectors, 80, ExtendedMatrix1000];
timedReport[ElementPowerExtended1000, #^5 &, maxMatrix / 2, ExtendedMatrix1000];
timedReport[LinearSolveExtended1000,
  LinearSolve[#, #[[1]]] &, maxMatrix / 25, ExtendedMatrix1000];
timedReport[DetExtended1000, Det, maxMatrix / 10, ExtendedMatrix1000];
timedReport[TransposeExtended1000, Transpose, maxMatrix, ExtendedMatrix1000];
timedReport[FlattenExtended1000, Flatten, maxMatrix, ExtendedMatrix1000];
(*timedReport[FourierExtended1000,
  Fourier,maxVector/100,ExtendedVector1000];*)
(*Maple converts to floats*)
timedReport[MeanExtended1000, Mean, maxVector / 10, ExtendedVector1000];
timedReport[SortExtended1000, Sort, maxVector, ExtendedVector1000];
timedReport[SortCustomExtended1000,
  SortBy[#, Abs] &, maxVector, ExtendedVector1000];
timedReport[MatrixPowerExtended1000, MatrixPower[#, 5] &,
  maxMatrix / 25, ExtendedMatrix1000];
timedReport[MatrixExpExtended1000, MatrixExp, 50, ExtendedMatrix1000];
```

Exact functions

```
evaluateTest[ExactFunctions, Hold[
   Table[BernoulliB[i], {i, 6000}],
   Table[Fibonacci[i], {i, 0, 500 000, 1000}],
   (*Table[HarmonicNumber[i],{i,10000}], Maple fails*)
   Table[Zeta[i], {i, 0, 100 000, 10 000}],
   Table[Binomial[i^2, i], {i, 1, 10 000}]
  ]];
```

Random numbers

```
evaluateTest[RandomNumbers, Hold[
   makeData[RealMatrix, 2000],
   makeData[RealMatrix, 2000],
   makeData[IntegerMatrix, 2000],
   makeData[IntegerMatrix, 2000],
   makeData[ExtendedMatrix, 2000],
   makeData[ExtendedMatrix1000, 2000],
   RandomVariate[NormalDistribution[0, 1], 10^7],
   RandomVariate[PoissonDistribution[4], 10^7],
   RandomVariate[BinomialDistribution[10, 0.2], 10^7]
  ]];
```

High precision

```
highPrecisionReport[ManyDigits,

                              1
  {Pi, Sqrt[2], Sin[1] + ──────────, Exp[1], Log[5], Tan[1 + I]}, 1 000 000];
                         1 + Sin[1]
highPrecisionReport[FewerDigits, {BesselK[2, 3], Gamma[11 / 3], Erf[10]}, 5000];
```

Maple

```
with(LinearAlgebra):
with(DiscreteTransforms):
with(combinat,    fibonacci):
```

```
with(Statistics):
with(RandomTools[MersenneTwister]):
with(GraphTheory):
with(RandomGraphs):
with(Optimization):
with(RandomTools):
with(stats):
with(combinat):
steps := 10:
repeats := 5:
maxVector := 10^6:
maxMatrix := 2000:
maxSparseMatrix := 20000:

makeData := proc (type, size) local dat, i:
        if type = “Vector” then dat := RandomVector[row](size, generator = -10.0 .. 10.0)
        elif type = “Matrix” then dat := Generate((‘Matrix’)(float(range = -10 .. 10, method = uniform), size, size))
        elif type = “VectorFloat8” then dat := RandomVector[row](size, generator = -10.0 .. 10.0, datatype = float[8])
        elif type = “MatrixFloat8” then dat := RandomMatrix(size, size, generator = -10.0 .. 10.0, datatype = float[8])
        elif type = “SparseMatrix” then dat := Matrix(size, size, storage = sparse):
                for i to floor((1/10000)*size^2) do dat[RandomTools[Generate](integer(range = 1 .. size)), Generate(integer(range = 1 .. size))] := 2*GenerateFloat()-1 end do
        elif type = “MediumSparseMatrix” then dat := Matrix(size, size, storage = sparse): for i to floor((1/200)*size^2)
                do dat[RandomTools[Generate](integer(range = 1 .. size)), Generate(integer(range = 1 .. size))] := 20*GenerateFloat()-10 end do
        elif type = “SparseVector” then dat := Vector(size, storage = sparse): for i to floor((1/10000)*size) do dat[RandomTools[Generate](integer(range = 1 .. size))] := 20*GenerateFloat()-10 end do
        elif type = “IntegerMatrix” then dat := Generate((‘Matrix’)(integer(range = -10 .. 10), size, size))
        elif type = “IntegerVector” then dat := Generate((‘Vector’)(integer(range = -10 .. 10), size))
        elif type = “IntegerMatrix8” then dat := Generate((‘Matrix’)(integer(range = -10 .. 10), size, size, datatype = integer[8]))
        elif type = “IntegerVector8” then dat := Generate((‘Vector’)(integer(range = -10 .. 10), size, datatype = integer[8]))
        elif type = “BigNumberMatrix” then dat := RandomMatrix(size, size, generator = proc (x) 20*GenerateFloat(digits = 50)-10 end proc)
        elif type = “BigNumberVector” then dat := RandomVector[row](size, generator = proc (x) 20*GenerateFloat(digits = 50)-10 end proc)
        elif type = “BigNumberMatrix1000” then dat := RandomMatrix(size, size, generator = proc (x) 20*GenerateFloat(digits = 1000)-10 end proc)
        elif type = “BigNumberVector1000” then dat := RandomVector[row](size, generator = proc (x) 20*GenerateFloat(digits = 1000)-10 end proc)
        elif type = “ComplexVector” then dat := makeData(“Vector”, size)+I*makeData(“Vector”, size)
        elif type = “ComplexMatrix” then dat := makeData(“Matrix”, size)+I*makeData(“Matrix”, size)
        elif type = “ComplexVector8” then dat := makeData(“VectorFloat8”, size)+I*makeData(“VectorFloat8”, size)
        elif type = “ComplexMatrix8” then dat := makeData(“MatrixFloat8”, size)+I*makeData(“MatrixFloat8”, size)
        else print(type) end if:dat end proc:

timedDataOperation := proc (expr, size, type) local totaltime, data, i:
totaltime := 0:
for i to repeats do data := makeData(type, size):
totaltime := totaltime+time[real](expr(data)) end do:
totaltime/repeats end proc:

timedReport := proc (filename, expr, hi, type) ExportMatrix(cat(“Maple”, filename, “.txt”), convert([seq([floor(s), timedDataOperation(‘expr’, floor(s), type)], s = hi/steps .. hi, hi/steps)], Matrix)) end proc:

numericfntest := proc (fn, n, type) local data:
        data := makeData(type, n):
        time[real](map(fn, data)) end proc:
```

```
numerictest := proc (file, fns, n, type) ExportMatrix(cat(“Maple”, file, “.txt”), Matrix([seq(numericfntest(i, n, type), i in fns)])) end proc:

numerictestinplace := proc (file, fns, n, type) ExportMatrix(cat(“Maple”, file, “.txt”), Matrix([seq(numericfntestinplace(i, n, type), i in fns)])) end proc:

numerictestelementwise := proc (file, fns, n, type) ExportMatrix(cat(“Maple”, file, “.txt”), Matrix([seq(elementwisefntest(i, n, type), i in fns)])) end proc:

numericfntestinplace := proc (fn, n, type) local data:
data := makeData(type, n):
time[real](Map(fn, data)) end proc:
elementwisefntest := proc (fn, n, type) local data:
data := makeData(type, n):
time[real](fn(data)) end proc:
highPrecisionTest := proc (file, fns, n) ExportMatrix(cat(“Maple”, file, “.txt”), Matrix([seq(time[real](evalf(i, n)), i in fns)])) end proc:
RandomInteger := proc (x, y) RandomTools[Generate](integer(range = 1 .. 100)) end proc:

fnList := [sqrt, sin, cos, tan, arcsin, arccos, arctan, sec, csc, cot, exp, sinh, cosh, tanh, log, log10, erf, GAMMA, proc (x) BesselJ(0, x) end proc, proc (x) BesselK(1, x) end proc, proc (x) BesselY(3, x) end proc, arcsinh, arccosh, arctanh, Zeta, proc (x) x*sin(log(x)+2*sqrt(x)+3)+sqrt(x)+log(x) end proc, proc (x) sin(cos(x)) end proc, proc (x) log(sinh(x)) end proc, proc (x) erf(sin(x)) end proc, proc (x) exp(x^2) end proc]:

elementwisefnList := [`~`[sqrt], `~`[sin], `~`[cos], `~`[tan], `~`[arcsin], `~`[arccos], `~`[arctan], `~`[sec], `~`[csc], `~`[cot], `~`[exp], `~`[sinh], `~`[cosh], `~`[tanh], `~`[log], `~`[log10], `~`[erf], `~`[GAMMA], `~`[proc (x) BesselJ(0, x) end proc], `~`[proc (x) BesselK(1, x) end proc], `~`[proc (x) BesselY(3, x) end proc], `~`[arcsinh], `~`[arccosh], `~`[arctanh], `~`[Zeta], `~`[proc (x) x*sin(log(x)+2*sqrt(x)+3)+sqrt(x)+log(x) end proc], `~`[proc (x) sin(cos(x)) end proc], `~`[proc (x) log(sinh(x)) end proc], `~`[proc (x) erf(sin(x)) end proc], `~`[proc (x) exp(x^2) end proc]]:

fnListSafe := [sin, cos, tan, arctan, sec, csc, cot, exp, sinh, cosh, tanh, erf, proc (x) BesselJ(0, x) end proc, arcsinh, Zeta, proc (x) sin(cos(x)) end proc, proc (x) erf(sin(x)) end proc, abs, floor, proc (x) exp(x^2) end proc]:

elementwisefnListSafe := [`~`[sin], `~`[cos], `~`[tan], `~`[arctan], `~`[sec], `~`[csc], `~`[cot], `~`[exp], `~`[sinh], `~`[cosh], `~`[tanh], `~`[erf], `~`[proc (x) BesselJ(0, x) end proc], `~`[arcsinh], `~`[Zeta], `~`[proc (x) sin(cos(x)) end proc], `~`[proc (x) erf(sin(x)) end proc], `~`[proc (x) exp(x^2) end proc]]:

timedReport(“DotSparse”, ‘proc (x) x.x end proc’, (1/2)*maxSparseMatrix, “SparseMatrix”):
timedReport(“LinearSolveSparse”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, (1/3)*maxSparseMatrix, “MediumSparseMatrix”):
timedReport(“LinearProgrammingSparse”, ‘proc (x) LPSolve(abs(Row(x, 1)), [-abs(x), -abs(Row(x, 2))], [0, infinity]) end proc’, (1/10)*maxSparseMatrix, “MediumSparseMatrix”):
timedReport(“TransposeSparse”, ‘Transpose’, 2*maxSparseMatrix, “SparseMatrix”):
timedReport(“FlattenSparse”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “SparseMatrix”):
timedReport(“MatrixPowerSparse”, ‘proc (x) x^5 end proc’, maxMatrix, “SparseMatrix”):
timedReport(“MeanSparse”, ‘Mean’, 10*maxVector, “SparseVector”):
timedReport(“ElementPowerSparse”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/5)*maxSparseMatrix, “SparseMatrix”):
timedReport(“FourierReal”, ‘FourierTransform’, maxVector, “Vector”):
timedReport(“SortReal”, ‘sort’, maxVector, “Vector”):
timedReport(“MeanReal”, ‘Mean’, 2*maxVector, “Vector”):
timedReport(“DotReal”, ‘proc (x) x.x end proc’, maxMatrix, “Matrix”):
timedReport(“InverseReal”, ‘MatrixInverse’, maxMatrix, “Matrix”):
timedReport(“LinearSolveReal”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, maxMatrix, “Matrix”):
timedReport(“CholeskyReal”, ‘proc (S) LUDecomposition*(Transpose(S).S, method = ‘Cholesky’) end proc’, maxMatrix, “Matrix”):
timedReport(“MatrixPowerReal”, ‘proc (x) x^5 end proc’, maxMatrix, “Matrix”):
timedReport(“DetReal”, ‘Determinant’, maxMatrix, “Matrix”):
timedReport(“TransposeReal”, ‘Transpose’, maxMatrix, “Matrix”):
timedReport(“FlattenReal”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “Matrix”):
```

```
timedReport(“EigenvaluesReal”, ‘Eigenvalues’, (1/2)*maxMatrix, “Matrix”):
timedReport(“EigenvectorsReal”, ‘Eigenvectors’, (1/2)*maxMatrix, “Matrix”):
timedReport(“LinearProgrammingReal”, ‘proc (x) LPSolve(abs(Row(x, 1)), [-abs(x), -abs(Row(x, 2))], [0, infinity]) end proc’, (1/4)*maxMatrix, “Matrix”):
timedReport(“ElementPowerReal”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/2)*maxMatrix, “Matrix”):
timedReport(“FitReal”, ‘proc (m) Fit(b*x+a, m, m, x) end proc’, maxVector, “Vector”):
timedReport(“MatrixExpReal”, ‘MatrixExponential’, (1/5)*maxMatrix, “Matrix”):
timedReport(“CovarianceReal”, ‘CovarianceMatrix’, maxMatrix, “Matrix”):
timedReport(“FourierFloat8”, ‘FourierTransform’, maxVector, “VectorFloat8”):
timedReport(“SortFloat8”, ‘sort’, maxVector, “VectorFloat8”):
timedReport(“MeanFloat8”, ‘Mean’, 10*maxVector, “VectorFloat8”):
timedReport(“DotFloat8”, ‘proc (x) x.x end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“InverseFloat8”, ‘MatrixInverse’, maxMatrix, “MatrixFloat8”):
timedReport(“LinearSolveFloat8”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“CholeskyFloat8”, ‘proc (S) LUDecomposition*(Transpose(S).S, method = ‘Cholesky’) end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“MatrixPowerFloat8”, ‘proc (x) x^5 end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“DetFloat8”, ‘Determinant’, maxMatrix, “MatrixFloat8”):
timedReport(“TransposeFloat8”, ‘Transpose’, maxMatrix, “MatrixFloat8”):
timedReport(“FlattenFloat8”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“EigenvaluesFloat8”,’Eigenvalues’(1/2)*maxMatrix,”MatrixFloat8”):
timedReport(“EigenvectorsFloat8”,’Eigenvectors’(1/2)*maxMatrix,”MatrixFloat8”):
timedReport(“LinearProgrammingFloat8”, ‘proc (x) LPSolve(abs(Row(x, 1)), [-abs(x), -abs(Row(x, 2))], [0, infinity]) end proc’, (1/4)*maxMatrix, “MatrixFloat8”):
timedReport(“ElementPowerFloat8”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/2)*maxMatrix, “MatrixFloat8”):
timedReport(“FitFloat8”, ‘proc (m) Fit(b*x+a, m, m, x) end proc’, maxVector, “VectorFloat8”):
timedReport(“MatrixExpFloat8”, ‘MatrixExponential’, (1/5)*maxMatrix, “MatrixFloat8”):
timedReport(“CovarianceFloat8”, ‘CovarianceMatrix’, maxMatrix, “MatrixFloat8”):
timedReport(“LinearProgrammingReal”, ‘proc (x) LPSolve(abs(Row(x, 1)), [-abs(x), -abs(Row(x, 2))], [0, infinity]) end proc’, maxMatrix, “Matrix”):
timedReport(“LinearProgrammingFloat8”, ‘proc (x) LPSolve(abs(Row(x, 1)), [-abs(x), -abs(Row(x, 2))], [0, infinity]) end proc’, maxMatrix, “MatrixFloat8”):
timedReport(“FourierComplex”, ‘FourierTransform’, maxVector, “ComplexVector”):
timedReport(“SortComplex”, ‘sort’, maxVector, “ComplexVector”):
timedReport(“MeanComplex”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, (1/3)*maxVector, “ComplexVector”):
timedReport(“DotComplex”, ‘proc (x) x.x end proc’, maxMatrix, “ComplexMatrix”):
timedReport(“InverseComplex”, ‘MatrixInverse’, maxMatrix, “ComplexMatrix”):
timedReport(“LinearSolveComplex”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, maxMatrix, “ComplexMatrix”):
timedReport(“CholeskyComplex”, ‘proc (S) LUDecomposition(map(conjugate, Transpose(S)).S, method = ‘Cholesky’) end proc’, maxMatrix, “ComplexMatrix”):
timedReport(“MatrixPowerComplex”, ‘proc (x) x^5 end proc’, (1/2)*maxMatrix, “ComplexMatrix”):
timedReport(“DetComplex”, ‘Determinant’, maxMatrix, “ComplexMatrix”):
#timedReport(“EigenvaluesComplex”,’Eigenvalues’(1/2)*maxMatrix,”ComplexMatrix”):#crashes
#timedReport(“EigenvectorsComplex”,’Eigenvectors’(1/2)*maxMatrix,”ComplexMatrix”):#crashes
timedReport(“TransposeComplex”, ‘Transpose’, maxMatrix, “ComplexMatrix”):
timedReport(“FlattenComplex”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “ComplexMatrix”):
timedReport(“ElementPowerComplex”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/4)*maxMatrix, “ComplexMatrix”):
timedReport(“MatrixExpComplex”, ‘MatrixExponential’, (1/5)*maxMatrix, “ComplexMatrix”):
timedReport(“EigenvaluesComplex”, ‘linalg[eigenvalues]’, 1/2*((1/10)*maxMatrix), “ComplexMatrix”): #replacement for crashing test Eigenvalues
timedReport(“EigenvectorsComplex”, ‘linalg[eigenvectors]’, 1/2*((1/10)*maxMatrix), “ComplexMatrix”):#replacement for crashing test Eigenvectors
timedReport(“EigenvaluesComplex8”, ‘linalg[eigenvalues]’, 1/2*((1/10)*maxMatrix), “ComplexMatrix8”):#replacement for crashing test Eigenvalues
timedReport(“EigenvectorsComplex8”, ‘linalg[eigenvectors]’, 1/2*((1/10)*maxMatrix), “ComplexMatrix8”):#replacement for crashing test Eigenvectors
timedReport(“FourierComplex8”, ‘FourierTransform’, maxVector, “ComplexVector8”):
timedReport(“SortComplex8”, ‘sort’, maxVector, “ComplexVector”):
```

```
timedReport(“MeanComplex8”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, (1/3)*maxVector, “ComplexVector8”):
timedReport(“DotComplex8”, ‘proc (x) x.x end proc’, maxMatrix, “ComplexMatrix8”):
timedReport(“InverseComplex8”, ‘MatrixInverse’, maxMatrix, “ComplexMatrix8”):
timedReport(“LinearSolveComplex8”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, maxMatrix, “ComplexMatrix8”):
timedReport(“CholeskyComplex8”, ‘proc (S) LUDecomposition(map(conjugate, Transpose(S)).S, method = ‘Cholesky’)
end proc’, maxMatrix, “ComplexMatrix8”):
timedReport(“MatrixPowerComplex8”, ‘proc (x) x^5 end proc’, (1/2)*maxMatrix, “ComplexMatrix8”):
timedReport(“DetComplex8”, ‘Determinant’, maxMatrix, “ComplexMatrix8”):
timedReport(“TransposeComplex8”, ‘Transpose’, maxMatrix, “ComplexMatrix8”):
timedReport(“FlattenComplex8”, ‘proc (m) convert(m, Vector[row]) end proc’, 3*maxMatrix*(1/4), “ComplexMatrix8”):
timedReport(“ElementPowerComplex8”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/4)*maxMatrix,
“ComplexMatrix8”):
timedReport(“MatrixExpComplex8”, ‘MatrixExponential’, (1/5)*maxMatrix, “ComplexMatrix8”):
#timedReport(“EigenvaluesComplex8”,’Eigenvalues’(1/2)*maxMatrix,”ComplexMatrix8”):#crashes
#timedReport(“EigenvectorsComplex8”,’Eigenvectors’(1/2)*maxMatrix,”ComplexMatrix8”):#crashes
timedReport(“DotInteger”, ‘proc (x) x.x end proc’, maxMatrix, “IntegerMatrix”):
timedReport(“InverseInteger”, ‘MatrixInverse’, (1/25)*maxMatrix, “IntegerMatrix”):
timedReport(“LinearSolveInteger”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, (1/4)*maxMatrix, “IntegerMatrix”):
timedReport(“MatrixPowerInteger”, ‘proc (x) x^5 end proc’, (1/5)*maxMatrix, “IntegerMatrix”):
timedReport(“DetInteger”, ‘Determinant’, (1/5)*maxMatrix, “IntegerMatrix”):
timedReport(“TransposeInteger”, ‘Transpose’, maxMatrix, “IntegerMatrix”):
timedReport(“FlattenInteger”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “IntegerMatrix”):
timedReport(“MeanInteger”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, maxVector, “IntegerVector”):
timedReport(“SortInteger”, ‘sort’, maxVector, “IntegerVector”):
timedReport(“EigenvaluesInteger”, ‘Eigenvalues’, (1/30)*maxMatrix, “IntegerMatrix”):
timedReport(“ElementPowerInteger”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, maxMatrix, “IntegerMatrix”):
timedReport(“DotInteger8”, ‘proc (x) x.x end proc’, maxMatrix, “IntegerMatrix8”):
timedReport(“LinearSolveInteger8”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, (1/4)*maxMatrix, “IntegerMatrix8”):
timedReport(“MatrixPowerInteger8”, ‘proc (x) x^5 end proc’, (1/5)*maxMatrix, “IntegerMatrix8”):
timedReport(“DetInteger8”, ‘Determinant’, (1/5)*maxMatrix, “IntegerMatrix8”):
timedReport(“TransposeInteger8”, ‘Transpose’, maxMatrix, “IntegerMatrix8”):
timedReport(“FlattenInteger8”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “IntegerMatrix8”):
timedReport(“MeanInteger8”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, maxVector, “IntegerVector8”):
timedReport(“SortInteger8”, ‘sort’, maxVector, “IntegerVector8”):
timedReport(“EigenvaluesInteger8”, ‘Eigenvalues’, (1/30)*maxMatrix, “IntegerMatrix8”):
timedReport(“ElementPowerInteger8”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, maxMatrix, “IntegerMatrix8”):
steps := 3:
timedReport(“MatrixExpInteger8”, ‘MatrixExponential’, 3, “IntegerMatrix8”):
timedReport(“MatrixExpInteger”, ‘MatrixExponential’, 3, “IntegerMatrix”):
steps := 10:
timedReport(“SortCustomFloat8”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’,
(1/25)*maxVector, “VectorFloat8”):
timedReport(“SortCustomReal”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’,
(1/25)*maxVector, “Vector”):
timedReport(“SortCustomComplex”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’,
(1/25)*maxVector, “ComplexVector”):
timedReport(“SortCustomComplex8”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’,
(1/25)*maxVector, “ComplexVector8”):
timedReport(“SortCustomInteger”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’,
(1/25)*maxVector, “IntegerVector”):
timedReport(“SortCustomInteger8”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’, 100000,
“IntegerVector8”):

ExportMatrix(“MapleExactFunctions.txt”, Matrix([[
          time[real](seq(bernoulli(i), i = 1 .. 6000)),
          time[real](seq(fibonacci(i), i = 1 .. 500000, 1000)),
          time[real](seq(expand(Zeta(i)), i = 0 .. 100000, 10000)),
          time[real](seq(binomial(i^2, i), i = 1 .. 10000))]])):

ExportMatrix(“MapleRandomNumbers.txt”, Matrix([[
```

```
        time[real](makeData(“Matrix”, 2000)),
        time[real](makeData(“MatrixFloat8”, 2000)),
        time[real](makeData(“IntegerMatrix”, 2000)),
        time[real](makeData(“IntegerMatrix8”, 2000)),
        time[real](makeData(“BigNumberMatrix”, 2000)),
        time[real](makeData(“BigNumberMatrix1000”, 2000)),
        time[real](Sample(RandomVariable(Normal(0, 1)), 10^7)),
        time[real](Sample(RandomVariable(Poisson(4)), 10^7)),
        time[real](Sample(RandomVariable(BinomialDistribution(10, .2)), 10^7))]])):

numerictest(“ElementaryFunctionsFloat8”, fnList, 10*maxVector, “VectorFloat8”):
numerictest(“ElementaryFunctionsComplex”, fnList, maxVector, “ComplexVector”):
numerictest(“ElementaryFunctionsComplex8”, fnList, maxVector, “ComplexVector8”):
numerictestinplace(“ElementaryFunctionsInPlaceFloat8”, fnListSafe, 10*maxVector, “VectorFloat8”):
numerictestinplace(“ElementaryFunctionsInPlaceComplex”, fnList, maxVector, “ComplexVector”):
numerictestinplace(“ElementaryFunctionsInPlaceComplex8”, fnList, maxVector, “ComplexVector8”):
numerictestinplace(“ElementaryFunctionsInPlace”, fnList, 10*maxVector, “Vector”):
#numerictestinplace(“ElementaryFunctionsInPlaceFloat8”,fnList,10*maxVector,”VectorFloat8”): #fails due to domain
error
numerictestelementwise(“ElementaryFunctionsElementwiseFloat8”, elementwisefnListSafe, 10*maxVector,
“VectorFloat8”):
numerictestelementwise(“ElementaryFunctionsElementwiseComplex”, elementwisefnList, maxVector, “ComplexVector”):
numerictestelementwise(“ElementaryFunctionsElementwiseComplex8”, elementwisefnList, maxVector,
“ComplexVector8”):
numerictestelementwise(“ElementaryFunctionsElementwise”, elementwisefnList, 10*maxVector, “Vector”):
numerictestinplace(“ElementaryFunctionsInPlaceSparse”, fnList, 10000*maxVector, “SparseVector”):
numerictest(“ElementaryFunctions”, fnList, 10*maxVector, “Vector”):
highPrecisionTest(“ManyDigits”, [‘Pi’, ‘sqrt(2)’, ‘sin(1)+1/(1+sin(1))’, ‘exp(1)’, ‘log(5)’, ‘tan(1+I)’], 1000000):
highPrecisionTest(“FewerDigits”, [‘BesselK(2, 3)’, ‘GAMMA(11/3)’, ‘erf(10)’], 5000):
Digits := 50:
timedReport(“DotExtended”, ‘proc (x) x.x end proc’, (1/25)*maxMatrix, “BigNumberMatrix”):
timedReport(“InverseExtended”, ‘MatrixInverse’, (1/25)*maxMatrix, “BigNumberMatrix”):
timedReport(“EigenvaluesExtended”, ‘Eigenvalues’, 60, “BigNumberMatrix”):
timedReport(“LinearSolveExtended”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, (1/25)*maxMatrix,
“BigNumberMatrix”):
timedReport(“CholeskyExtended”, ‘proc (S) LUDecomposition*(Transpose(S).S, method = ‘Cholesky’) end proc’,
(1/25)*maxMatrix, “BigNumberMatrix”):
timedReport(“MatrixPowerExtended”, ‘proc (x) x^5 end proc’, (1/25)*maxMatrix, “BigNumberMatrix”):
timedReport(“DetExtended”, ‘Determinant’, (1/10)*maxMatrix, “BigNumberMatrix”):
timedReport(“TransposeExtended”, ‘Transpose’, maxMatrix, “BigNumberMatrix”):
timedReport(“FlattenExtended”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “BigNumberMatrix”):
#timedReport(“FourierExtended”, ‘Fourier’, (1/100)*maxVector, “BigNumberVector”): # Maple converts input to floats
timedReport(“SortExtended”, ‘sort’, maxVector, “BigNumberVector”):
timedReport(“MeanExtended”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, (1/10)*maxVector, “BigNumberVector”):
timedReport(“EigenvectorsExtended”, ‘Eigenvectors’, (1/25)*maxMatrix, “BigNumberMatrix”):
timedReport(“ElementPowerExtended”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/2)*maxMatrix,
“BigNumberMatrix”):
timedReport(“MatrixExpExtended”, ‘MatrixExponential’, 60, “BigNumberMatrix”):
timedReport(“SortCustomExtended”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’, maxVector,
“BigNumberVector”):
numerictest(“ElementaryFunctionsExtended”, fnList, (1/10)*maxVector, “BigNumberVector”):
numerictestelementwise(“ElementaryFunctionsElementwiseExtended”, elementwisefnList, (1/10)*maxVector,
“BigNumberVector”):
numerictestinplace(“ElementaryFunctionsInPlaceExtended”, fnList, (1/10)*maxVector, “BigNumberVector”):
Digits := 1000:
timedReport(“DotExtended1000”, ‘proc (x) x.x end proc’, (1/25)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“InverseExtended1000”, ‘MatrixInverse’, (1/25)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“EigenvaluesExtended1000”, ‘Eigenvalues’, 60, “BigNumberMatrix1000”):
timedReport(“LinearSolveExtended1000”, ‘proc (x) LinearSolve(x, Column(x, 1)) end proc’, (1/25)*maxMatrix,
“BigNumberMatrix1000”):
```

```
timedReport(“CholeskyExtended1000”, ‘proc (S) LUDecomposition*(Transpose(S).S, method = ‘Cholesky’) end proc’, (1/25)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“MatrixPowerExtended1000”, ‘proc (x) x^5 end proc’, (1/25)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“DetExtended1000”, ‘Determinant’, (1/10)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“TransposeExtended1000”, ‘Transpose’, maxMatrix, “BigNumberMatrix1000”):
timedReport(“FlattenExtended1000”, ‘proc (m) convert(m, Vector[row]) end proc’, maxMatrix, “BigNumberMatrix1000”):
#timedReport(“FourierExtended1000”, ‘Fourier’, (1/100)*maxVector, “BigNumberVector1000”): # Maple converts input to floats
timedReport(“SortExtended1000”, ‘sort’, maxVector, “BigNumberVector1000”):
timedReport(“MeanExtended1000”, ‘proc (x) add(i, i = x)/Dimension(x) end proc’, (1/10)*maxVector, “BigNumberVector1000”):
timedReport(“EigenvectorsExtended1000”, ‘Eigenvectors’, (1/25)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“ElementPowerExtended1000”, ‘proc (m) map(proc (x) x^5 end proc, m) end proc’, (1/2)*maxMatrix, “BigNumberMatrix1000”):
timedReport(“MatrixExpExtended1000”, ‘MatrixExponential’, 60, “BigNumberMatrix1000”):
timedReport(“SortCustomExtended1000”, ‘proc (data) sort(data, proc (x, y) abs(y) < abs(x) end proc) end proc’, maxVector, “BigNumberVector1000”):
```