Apache Commons Math
A Java library of mathematical tools

Thomas Neidhart
tn@apache.org

Gilles Sadowski
erans@apache.org

FOSDEM 2013

February 02, 2013
Overview of the talk

- What is it?
- What does it provide?
- Some simple examples
- Who is using it?
- What to do after the presentation?
What is it?

- 100% pure, self-contained Java library
- mathematical methods & algorithms
- covers a wide range of topics
- aims for clean, documented and object-oriented code
- well tested and maintained
- following the Apache way
- Apache 2.0 license
Commons Math in Numbers

As of January 1, 2013

- 57 packages
  - 829 classes
  - 77,761 lines of code
- 50,512 lines of comments
  - 99.4% documented API
- 4,537 unit tests
  - 87.6% of code covered
- 98 open issues
  - 831 resolved issues
- 0 dependencies
What topics does it cover?

- Automatic Differentiation
- Numerical Integration
- Interpolation
- Root finders
- Arbitrary precision arithmetic
- Probability distributions
- Linear Algebra
- Fitting (non-linear least-squares, curve fitting)
- Ordinary differential equations (ODE)
- Linear/Non-linear optimization
- Random number generators
- Computational Geometry
- Special functions (Beta, Gamma)
- Kalman filter
- Fast Fourier transform
- Genetic algorithms
- Statistics (correlation, regression, descriptive, inference)
FastMath

- pure Java replacement for java.lang.Math
- better performance for most of the functions
- better accuracy than Math and StrictMath
- currently not always faster :-(

FOSDEM 2013
Apache Commons Math
February 02, 2013
# FastMath benchmark I

Number of calls: $10^9$

Java 1.7.0_03 (1.7.0_03-b21) OpenJDK 64-Bit Server VM (22.0-b10)

<table>
<thead>
<tr>
<th>Function</th>
<th>Class</th>
<th>Time/call (ms)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>log</td>
<td>StrictMath</td>
<td>5.22349648e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.04540923e-05</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>2.42863614e-05</td>
<td>47</td>
</tr>
<tr>
<td>log10</td>
<td>StrictMath</td>
<td>7.06720929e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.05568765e-05</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>7.56041686e-05</td>
<td>107</td>
</tr>
<tr>
<td>log1p</td>
<td>StrictMath</td>
<td>3.72191413e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>3.78759816e-05</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>7.50277567e-05</td>
<td>201</td>
</tr>
<tr>
<td>pow</td>
<td>StrictMath</td>
<td>1.73481768e-04</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>1.64277768e-04</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>1.05758357e-04</td>
<td>60</td>
</tr>
<tr>
<td>exp</td>
<td>StrictMath</td>
<td>3.47634732e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.28322028e-05</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>1.72182428e-05</td>
<td>50</td>
</tr>
<tr>
<td>sin</td>
<td>StrictMath</td>
<td>2.86189157e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.72834491e-05</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>2.13875014e-05</td>
<td>75</td>
</tr>
<tr>
<td>asin</td>
<td>StrictMath</td>
<td>3.61743365e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>3.63858979e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>6.65170752e-05</td>
<td>184</td>
</tr>
<tr>
<td>cos</td>
<td>StrictMath</td>
<td>3.23569717e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>3.09660350e-05</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>2.37797205e-05</td>
<td>73</td>
</tr>
<tr>
<td>acos</td>
<td>StrictMath</td>
<td>3.74091467e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>3.72805271e-05</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>8.99709198e-05</td>
<td>240</td>
</tr>
<tr>
<td>tan</td>
<td>StrictMath</td>
<td>4.36050840e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>3.94326807e-05</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>3.96236785e-05</td>
<td>91</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>Class</th>
<th>Time/call (ms)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>atan</td>
<td>StrictMath</td>
<td>2.38076340e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.38346576e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>2.78287849e-05</td>
<td>117</td>
</tr>
<tr>
<td>atan2</td>
<td>StrictMath</td>
<td>6.14545612e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>6.25871086e-05</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>6.24287698e-05</td>
<td>102</td>
</tr>
<tr>
<td>hypot</td>
<td>StrictMath</td>
<td>2.51933255e-04</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>2.51892886e-04</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>1.78561127e-05</td>
<td>71</td>
</tr>
<tr>
<td>cbrt</td>
<td>StrictMath</td>
<td>7.08035203e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>7.09881088e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>4.12985279e-05</td>
<td>58</td>
</tr>
<tr>
<td>sqrt</td>
<td>StrictMath</td>
<td>6.69162232e-06</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>6.63196797e-06</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>6.62463956e-06</td>
<td>99</td>
</tr>
<tr>
<td>cosh</td>
<td>StrictMath</td>
<td>7.51256426e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>7.52944414e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>3.91062794e-05</td>
<td>52</td>
</tr>
<tr>
<td>sinh</td>
<td>StrictMath</td>
<td>7.52920027e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>7.58819054e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>5.80563672e-05</td>
<td>77</td>
</tr>
<tr>
<td>tanh</td>
<td>StrictMath</td>
<td>6.94914940e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>7.01421819e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>6.10102135e-05</td>
<td>88</td>
</tr>
<tr>
<td>expm1</td>
<td>StrictMath</td>
<td>4.19029705e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>4.18109329e-05</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>3.19643464e-05</td>
<td>76</td>
</tr>
<tr>
<td>abs</td>
<td>StrictMath</td>
<td>5.08597800e-06</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Math</td>
<td>5.14014393e-06</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>FastMath</td>
<td>5.37928625e-06</td>
<td>105</td>
</tr>
</tbody>
</table>
Example - Gauss Integration

```java
import o.a.c.m.analysis.UnivariateFunction;
import o.a.c.m.analysis.function.Cos;
import o.a.c.m.analysis.integration.gauss.GaussIntegratorFactory;
import o.a.c.m.analysis.integration.gauss.GaussIntegrator;

// ...

GaussIntegratorFactory factory = new GaussIntegratorFactory();
UnivariateFunction cos = new Cos();
// create an Gauss integrator for the interval [0, PI/2]
GaussIntegrator integrator = factory.legendre(7, 0, 0.5 * Math.PI);
double s = integrator.integrate(cos);
```
import o.a.c.m.analysis.UnivariateFunction;
import o.a.c.m.analysis.solvers.BrentSolver;
import o.a.c.m.analysis.solvers.UnivariateSolver;

// ...

UnivariateFunction f = new UnivariateFunction() {
    public double value(double x) {
        return FastMath.sin(x);
    }
};

UnivariateSolver solver = new BrentSolver();
// we know that the root is somewhere between 3 and 4 ;-

double result = solver.solve(100, f, 3, 4);
import o.a.c.m.linear.RealMatrix;
import o.a.c.m.linear.MatrixUtils;
import o.a.c.m.linear.EigenDecomposition;

// ...

RealMatrix matrix =
    MatrixUtils.createRealMatrix(new double[][] {
        { 5, 10, 15 },
        { 10, 20, 30 },
        { 15, 30, 45 }
    });

EigenDecomposition ed = new EigenDecomposition(matrix);
double[] eigValues = ed.getRealEigenvalues();
Example - Linear optimization: Simplex method

Maximize $2x_2 + 6x_1 + 7x_0$
with constraints

\[
\begin{align*}
x_2 + 2x_1 + x_0 & \leq 2 \\
-x_2 + x_1 + x_0 & \leq -1 \\
2x_2 - 3x_1 + x_0 & \leq -1
\end{align*}
\]

```java
import o.a.c.m.optim.linear.LinearObjectiveFunction;
import o.a.c.m.optim.linear.LinearConstraint;
import o.a.c.m.optim.linear.SimplexSolver;

/// ...

LinearObjectiveFunction f = new LinearObjectiveFunction(new double[] { 2, 6, 7 }, 0);
ArrayList<LinearConstraint> constraints = new ArrayList<LinearConstraint>();
constraints.add(new LinearConstraint(new double[] { 1, 2, 1 }, Relationship.LEQ, 2));
constraints.add(new LinearConstraint(new double[] { -1, 1, 1 }, Relationship.LEQ, -1));
constraints.add(new LinearConstraint(new double[] { 2, -3, 1 }, Relationship.LEQ, -1));

SimplexSolver solver = new SimplexSolver();
PointValuePair solution = solver.optimize(new MaxIter(100), f, new LinearConstraintSet(constraints),
                                          GoalType.MAXIMIZE, new NonNegativeConstraint(false));
```
Who is using Commons Math?
Responses from our community:

<table>
<thead>
<tr>
<th>Field</th>
<th>Topic</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td>Orekit - open-source space dynamics library</td>
<td><a href="http://www.orekit.org">http://www.orekit.org</a></td>
</tr>
<tr>
<td>Astronomy</td>
<td>Gaia Project: data processing of astrometric, photometric, and spectroscopic data from 1 billion stars</td>
<td><a href="http://www.rssd.esa.int/index.php?project=GAIA&amp;page=DPAC_Introduction">http://www.rssd.esa.int/index.php?project=GAIA&amp;page=DPAC_Introduction</a></td>
</tr>
<tr>
<td>Material Science</td>
<td>Simulate the mechanical behaviour of composite materials</td>
<td><a href="http://navier.enpc.fr/BRISARD-Sebastien">http://navier.enpc.fr/BRISARD-Sebastien</a></td>
</tr>
<tr>
<td>Biotech</td>
<td>Nuclear Magnetic Resonance (NMR) data analysis package for molecular structure refinement</td>
<td><a href="http://www.onemoonscientific.com">http://www.onemoonscientific.com</a></td>
</tr>
<tr>
<td>Medical Technology</td>
<td>Image processing of 3D human MRI and CT scans</td>
<td><a href="http://www.stjude.org">http://www.stjude.org</a></td>
</tr>
<tr>
<td>Finance</td>
<td>Risk management and analysis</td>
<td><a href="http://www.osloclearing.no/">http://www.osloclearing.no/</a></td>
</tr>
</tbody>
</table>

A maven dependency search:

- Apache Hama - parallel computing framework
- Myrrix - A real-time recommender system
- Apache Mahout - scalable machine learning
- Redberry - Symbolic Tensor Algebra System
- Facebook jcommon-stats - well you know it
- ...
How to use it yourself?

Maven:

```xml
<dependency>
  <groupId>org.apache.commons</groupId>
  <artifactId>commons-math3</artifactId>
  <version>3.1.1</version>
</dependency>
```

Download:

http://commons.apache.org/math/download_math.cgi
Links

- Project homepage: http://commons.apache.org/math/
- Issue tracker: https://issues.apache.org/jira/browse/MATH
- Mailinglists: dev@commons.apache.org & user@commons.apache.org
e-mail subject: [math]
- Wiki: http://wiki.apache.org/commons/MathWishList
How to contribute?

- Check out the user guide
  http://commons.apache.org/math/userguide/index.html
- Ask questions on the user mailinglist
- Participate in discussions on the dev mailinglist
- Create bug reports / feature requests / improvements in JIRA
- Send patches (code, documentation, examples)
- Provide feedback - most welcome!
Hot Topics

- refactoring Linear Algebra package
- refactoring Optimization package
- Exception handling - checked vs. unchecked
- Add more computational geometry algorithms
- Upgrade to more recent Java versions (fork/join framework)
- (real) FastMath vs. AccurateMath (integration of jodk)
- improve user guide / examples
- lots of new feature requests . . .
The End!

- Questions?