WHAT'S NEW

Maple™ 2021

What's New in **Maple 2021**

From small but incredibly useful interface improvements to whole new areas of mathematics, Maple™ 2021 offers a range of enhancements across the entire product.

Always More Math

Maple is all about math, so every new release expands and deepens the Maple math engine so you can solve more problems.

Solving More ODEs and PDEs

Maple is the world leader in finding exact solutions to ordinary and partial differential equations, and Maple 2021 offers new techniques that let you solve more problems than ever.

Need for Speed

Performance enhancements include a significantly faster map command, which is used extensively throughout the Maple library and in user code.

Signals and Images

More tools mean you can analyze signals and images in new ways, using commands or the context menus.

Looks Just Right

Sometimes small changes can make a big difference, like when plot domains are automatically selected to put the most interesting features of a graph front and center.

Streamlining the Workflow

Working in Document Mode is now just a little smoother, with new ways to insert blank lines, combine math and text, and advance to the next computation.

LaTeX Made Easy

With its greatly improved LaTeX support, you can take advantage of Maple's authoring environment and then easily convert your work to LaTeX without the need for further adjustments.

Understanding the Universe

Maple's state-of-the-art environment for algebraic computations in physics is stronger than ever, with more tools for tackling problems in quantum mechanics, general relativity, and more.

Study Buddies

All three *Clickable Calculus*™ Study Guides are now included with Maple, to help you learn and teach Calculus, Precalculus, and Multivariate Calculus.

Learning about Differential Equations

The new Student ODEs package provides lots of tools for learning about differential equations, including helpful visualizations and step-by-step solvers.

Creating Content for Maple Learn™

New content creation tools make it easy to create sophisticated Maple Learn™ applications, and the tools can be used for Maple content, too.
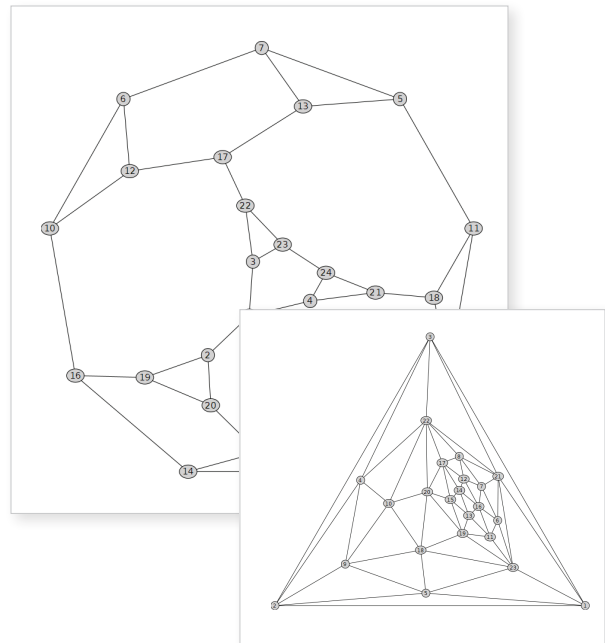
Advanced Mathematics

Maple 2021 includes a very large number of improvements that strengthen the math engine, expanding Maple's abilities to handle new areas of mathematics and solve harder problems, faster. In addition to the mathematical improvements described in more detail elsewhere, Maple 2021 enhances support for many areas of mathematics, and improves fundamental routines that are used regularly both by customers and by other Maple commands.

- Integration has been enhanced with improved algorithms for indefinite integration, and the ability to easily specify which integration method should be used and to compare the results from different methods.

- The *limit* command has been improved for the multivariate case of quotients of analytic functions, finding solutions to more problems than before.

- A new Multivariate Power Series package provides functionality for doing lazy computations with multivariate power series at high speed and high precision. The terms are computed only when necessary, and further terms can be computed at relatively little cost.

- Simplifications of expressions involving the Lambert W function have been improved.

- You can now numerically solve differential equations that are collected together in vectors, easily.

- A new and faster algorithm for checking for redundant constraints is available when projecting a polyhedral set to a lower coordinate dimension using the Polyhedral Sets package.

- The *asympt* command can now compute asymptotic expansions of the logarithmic integral.

- After a finite Galois field has been constructed using the GF package, there is now an easy syntax to create new field elements.

- The *intsolve* command has been updated to recognize some integral equations that contain integral transforms, and the method of collocation is now available to provide approximate solutions for certain types of integral equations.

- The Linear Recurrence Equations Tools package has been enhanced with the addition of several commands related to recurrence factorization and recognition, including *GuessRecurrence*, *GCRD*, *LCLM*, *RightDivision*, *OperatorToRecurrence*, *RecurrenceToOperator*, *MinimalRecurrence*, and others.

- Two new commands in the Generic subpackage of the Linear Algebra package can be used for addition and scalar multiplication of matrices and vectors over a specified domain of computation.

ODEs and PDEs

Maple is the world leader in finding exact solutions to ordinary and partial differential equations. Maple 2021 extends that lead even further with new algorithms and techniques for solving more ODEs and PDEs. In addition, Maple 2021 includes tools to help students just starting out with their first ODE course.

- There are significant improvements in *dsolve* for finding exact solutions of second order linear ODEs using hypergeometric functions. The algorithms implemented are at the frontier of the understanding of this problem, and handle classes of extended equations with apparent singularities as well as the most common linear equations with four and five singularities.

- For ODEs and PDEs, the Lie Algebras of Vector Fields package has a new command for analyzing the possible linearization of polynomially nonlinear equations and determining the corresponding mapping when it exists, allowing for the computation of more approximate and exact solutions.

- The new Student ODEs package covers the material in a standard first course in ODEs, and provides step-by-step tools for solving ODEs as well as interactive visualization.

Graph Theory

The Graph Theory package, which supports creating graphs, drawing graphs, manipulating graphs, and testing graphs for properties, has been expanded in Maple 2021.

- The new *Newick* and *PrueferCode* commands offer alternate ways to encode a tree as a string or list of integers.

- *IdentifyGraph* tests a graph for isomorphism against many of the named special graphs known to the Graph Theory package.

- *IsSubgraphIsomorphic* tests whether a given graph is isomorphic to a subgraph of another given graph.

- The *BipartiteMatching* command has been extended to support weighted graphs.

- The performance of many commands has been substantially improved.

- Maple 2021 provides support for 16 additional Special Graphs, including Banana Tree, Butterfly, Crown, Gosset, Markström, Watkins Snark, and others, bringing the total to 113.

Approximate Polynomial Algebra

Maple 2021 includes a new Approximate subpackage of Polynomial Tools, with commands for performing factoring, GCD, and division of multivariate polynomials that have floating-point coefficients or implied error in the coefficients. These commands are useful for cases where no exact answer is possible, and a solution is instead found for a nearby problem that does have a solution. Typically, this assumes that some amount of error or noise was introduced into the coefficients of the input polynomials that destroyed algebraic structure, and which these commands attempt to recover. This subpackage also provides commands for computing the matrices used for these operations.

Visualization

Maple is now even smarter about choosing the domain for the plot if you don't specify one. Maple analyzes the expressions and then automatically selects a domain that gives a more complete view of important graph features. For example, for low degree polynomials, the domain is always centered on the axis of symmetry of the plot, and it includes the zeroes and extrema of these polynomials. These improvements are available through the plot and plot3d commands as well as the context menus.

Other improvements in visualization include support for units in point and polygon plots, and improved appearance of arrow heads such as are used in vector plots.
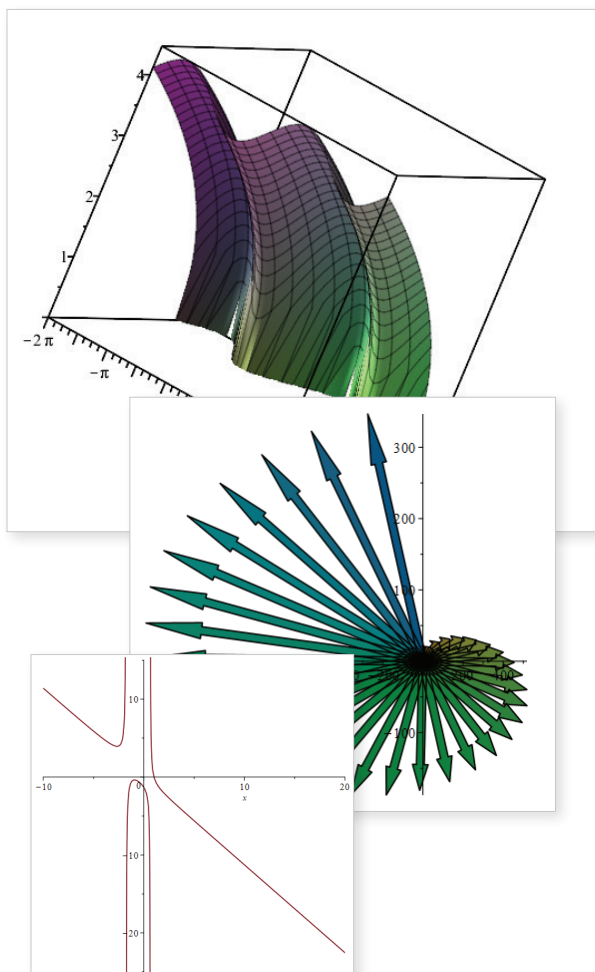
Interface

In addition to the changes described elsewhere, Maple 2021 includes a variety of other enhancements to the interface that support your work in Maple. In particular, Maple 2021 includes several improvements to streamline the workflow when using Document Mode.

- In Document Mode, pressing Enter while in math input now moves the cursor to the next math input after evaluating the expression, so you can quickly update parameters and see the downstream effects using just the Enter key.

- When entering mathematical expressions as part of your text, it is now easier to ensure those expressions are entered as non-executable math when working in Document Mode.

- You can now insert a new blank line above your current line in Document mode simply by moving the cursor to the start of the line and pressing Enter.

- In a code edit region, pressing Enter now executes the code contained in the region, and Shift+Enter inserts a new line.

- When a number is displayed in scientific notation, it is now displayed with a visible multiplication symbol, ×, before the 10^n portion.

- A new option allows you to keep auto-saved files even after you restore a back-up.

- Warning messages about the use of *e* and *d* can be suppressed if desired.

- Maple now has a notification system that will be used to send you messages relevant to your use of Maple, such as the availability of a new release.

- The help search box has been improved to allow copying and pasting of terms into the search box.

Study Guides

The *Clickable Calculus* Study Guides for Precalculus, Calculus, and Multivariate Calculus are now available directly in Maple. Maple study guides are interactive Maple e-books that cover fundamental concepts through visualization, practice problems, and theory. Students can learn from hundreds of worked problems, and then apply these same tools and techniques to check their homework and get extra practice.
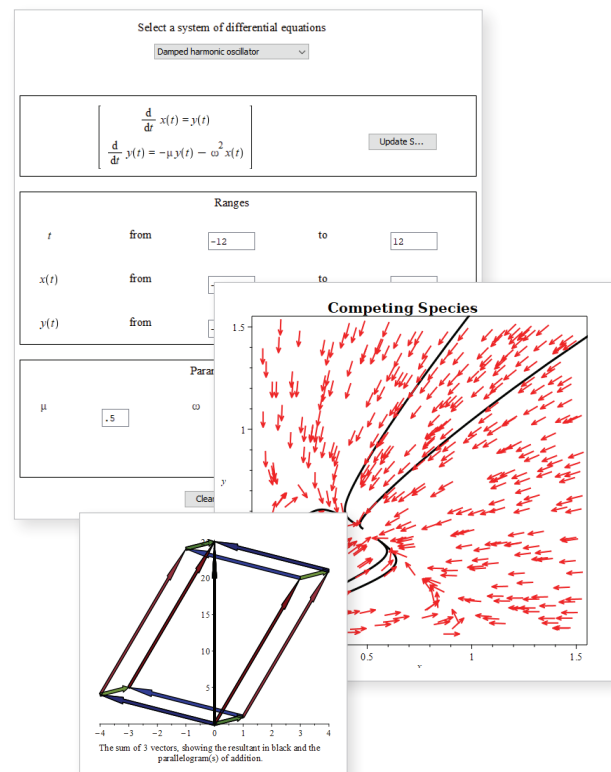
Chapter 5: Applications of Integration

Section 5.3: Volume by Slicing

▼ **Example 5.3.3**

By the method of slicing, obtain the volume of the solid whose base in the xy-plane is the region bounded by the x-axis, and the curves $y = \sin(x)$ and $x = \pi/2$, and whose cross sections parallel to the yz-plane are equilateral triangles.

▼ **Solution**

▼ *Mathematical Solution*

Figure 5.3.3(a) contains an image of the solid. Figure 5.3.3(b) animates the slices.

Student Packages

- The new Student ODEs package helps students work with, plot, and solve individual ordinary differential equations and systems of ordinary differential equations. It provides:

    - Step-by-step solutions for solving an ODE or system of ODEs, including first and second order ODEs and IVPs, Cauchy-Euler equations, series solutions, and more

- Commands that allow students to perform individual solving steps without jumping to the final answer

- Control over the choice of solving methods when desired

- Commands that are useful for reducing the order of ODEs

- A visualization tool that produces an interactive plot of a first order differential equation system of two equations, along with controls to explore and manipulate the plot, or to adjust the input ODE or system and its parameters

- The Student Basics package includes new commands that produce step-by-step solutions for solving equations, factoring polynomials, and performing long division.

- With the new Degrees package, you can now perform trigonometric computations in degrees instead of radians more easily.

- The Student Linear Algebra package has been expanded to include a singular values command.

Select a system of differential equations

Damped harmonic oscillator

$$\frac{d}{dt} x(t) = y(t)$$
$$\frac{d}{dt} y(t) = -\mu\, y(t) - \omega^2 x(t)$$

Update S...

Ranges

t	from	-12	to	12
$x(t)$	from		to	
$y(t)$	from			

Para

μ .5 ω

Clear

Competing Species

The sum of 3 vectors, showing the resultant in black and the parallelogram(s) of addition.

Solution Steps

Maple 2021 includes numerous new algorithms for showing step-by-step solutions for a variety of problems in mathematics

- The Student Basics package now includes commands that show complete, step-by-step solutions for solving an equation or system of equations, factoring a polynomial, and long division.

- The *ShowSolution* command in the Student Calculus1 package has been improved to show more detailed steps when solving integration, differentiation, and limit problems.

- The *ODESteps* command in the new Student ODE package provides detailed steps when solving ordinary differential equations and systems of ODEs.

- The tutors for matrix inverse, eigenvalues, eigenvectors, and Gauss Jordon elimination, in the Student Linear Algebra package, now offer the option of returning a step-by-step solution directly to the worksheet.

- Solution step commands can also be used to create a Maple Learn document containing the step-by-step solution.

Maple Learn Content Tools

Maple Learn is a new online environment that is designed specifically for teaching and learning mathematics and solving math problems from high school to second year university. Maple 2021 includes many tools for authoring content that is created in Maple and used by students in Maple Learn. Many of these tools can also be used to create Maple content for use inside Maple.
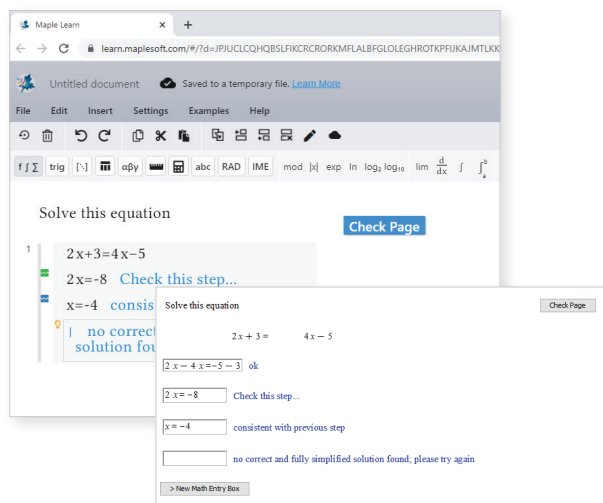

- Maple 2021 provides new tools for creating documents and interactive applications programmatically in the new Canvas subpackage of Document Tools. The new concept of a canvas has two main uses.

  - The canvas allows you to create Maple Learn content in Maple and then share it through Maple Learn. This allows instructors to take advantage of Maple's more advanced document and analysis tools to create sophisticated content that students can then use in Maple Learn.

  - The canvas provides a framework for Maple users to easily build applications where the number of required input fields is not known in advance. The user can create as many input fields as they need while they use the application, and Maple looks after the details of creating and extracting the information from those fields for you.

- The new *SolvePractice* command in the Grading package creates an interactive application where you can enter the step-by-step solution to the given problem, and then click a button that will analyze your steps and provide feedback.

- The *PracticeSheet* command, which generates a grid of math practice problems intended for basic drills, now has an option to return a canvas that can be deployed to Maple Learn.

- Commands that generate step-by-step solutions, such as the *ShowSolution* command in the Student Calculus 1 package, can generate a canvas that is scripted in such a way that it will reveal solution steps in an animated fashion.

Physics

Maple provides a state-of-the-art environment for algebraic computations in physics, with emphasis on ensuring that the computational experience is as natural as possible. Along with general consolidation and improvements, Maple 2021 provides significant enhancements to further strengthen the functionality for physics in particle physics, quantum mechanics and general relativity. Some of the many improvements include:

- New options in the *FeynmanDiagrams* command handle the situations where you want to study scattering amplitudes without external legs normalization factors, use different gauge choices for the fields, or use a generic form of a propagator.

- A new *FeynmanIntegral* module evaluates the Feynman integrals that appear in the output of the *FeynmanDiagrams* command.

- The simplification of products of Dirac matrices was improved.

- Significant improvements were made to the manipulation and simplification of expressions involving non-commutative tensor operators.

- You can compute derivatives and functional derivatives of spinor fields, and with respect to spinor fields.

- Improved information is displayed when you set a spacetime metric.

$$\left(\Delta\left(A_\lambda(p_2), A_\tau(-p_2)\right) = \frac{-I\, g_{\lambda,\, \tau}}{p_2{}^2 + I\, \epsilon}\right)$$
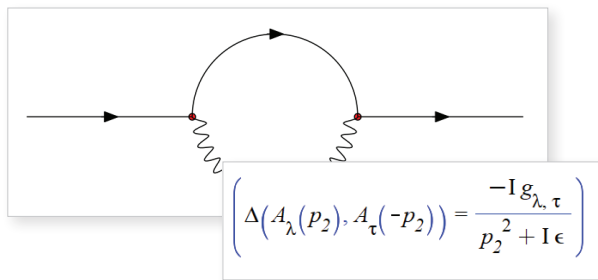
Thermophysical Data

Maple 2021 enhances the Thermophysical Data package with reference atmosphere models. These models describe how air pressure, temperature, density, and molecular weight typically change with altitude. Two models are available — the 1976 US Standard Atmosphere and the International Standard Atmosphere. Altitude can be specific as geopotential or geometric. Geopotential altitude adjusts for the variation in gravity with altitude.
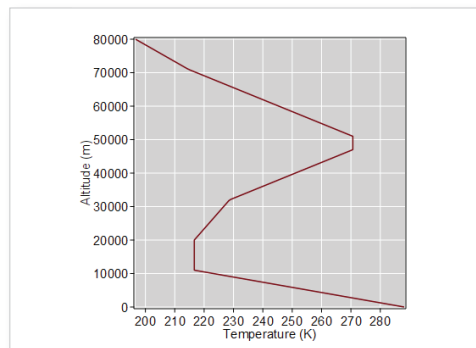

Signal and Image Processing

The Signal Processing and Image Tools packages have been expanded with new and updated commands and enhanced tools in the Context Panel.

- New commands find the power spectral density of a signal, and compute the band power, mean frequency, and spectral entropy, either for the entire signal, or a specific frequency band.

- The *PowerSpectrum* command now accepts signals (in addition to FFTs) and other new options.

- The *Welch* command estimates the power spectrum of a signal, while attenuating the effect of noise at the expense of frequency resolution.

- The *MUSIC* command performs the Multiple Signal Classifier (MUSIC) method on a signal, which estimates frequencies present in a noisy signal.

- The new *ShortTimeFourierTransform* command computes the short-time Fourier transform of a signal.

- The new commands *ShortTimeBandPower*, *ShortTimeMeanFrequency*, and *ShortTimeSpectralEntropy* compute the respective statistics for each short-time interval.

- The new *FilterFrequencyResponse* command determines the response of an FIR or IIR digital filter from taps.

- The *EquivalentNoiseBandwidth* command computes the equivalent-noise bandwidth of a window.

- The new *Hampel* command applies the Hampel filter to a 1-D signal to remove outliers from data.

- The new *IntegrateData* command is used to estimate the area beneath a 1-D signal.

- The *FindPeakPoints* command has been updated to include a new calling sequence, an option for specifying a maximum height, and an option for skipping sorting when the independent data are known to be sorted.

- New commands *RealToComplex* and *ComplexToReal* combine containers with the real and imaginary parts into a single container with the complex values, and decompose a container with complex values into separate containers with the real and imaginary parts.

- The *RootMeanSquare* command now supports multidimensional arrays, vectors, matrices, and lists when computing the root mean square.

- The new *RootMeanSquareError* and *RelativeRootMeanSquareError* commands are useful for quantifying errors.

- The *Mean* command now supports multidimensional containers and weights.

- The *Phase* command now includes an option for unwrapping the phases, so that there are no large jumps.

- The *SampleImage* command in the Image Tools package returns the requested image from a repository of sample images.
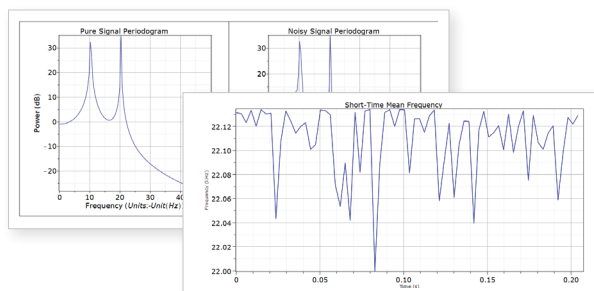
Quantum Chemistry Toolbox

The Maple Quantum Chemistry Toolbox from RDMChem, a separate add-on product to Maple, is a powerful environment for the computation and visualization of the electronic structure of molecules. In Maple 2021, this toolbox has significant new features and enhancements.
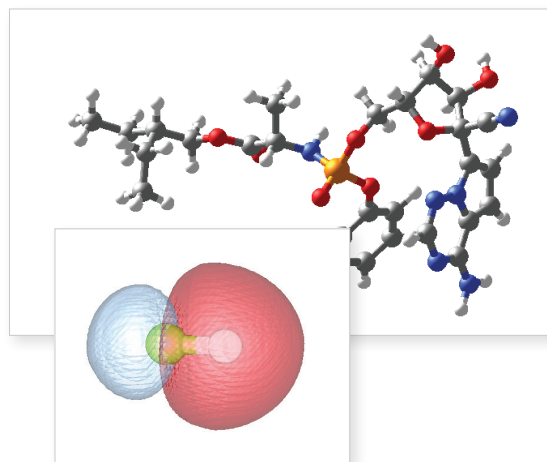
- A molecular dictionary provides a wealth of information about molecules.

- A new method for the ground and excited state of molecules further enhances the package's suite of electronic structure solvers.

- A new command for purifying density matrices has applications for the mitigation of errors in quantum computing,

- An optional parameter for the plotting of molecular orbitals allows for customized colors.

- Optional parameters for the generation of molecular integrals support arbitrary molecular orbitals and active spaces.

- The collection of built-in lessons for classroom learning in undergraduate-to-graduate chemistry and physics has been expanded, with a new lesson for Physical Chemistry and Undergraduate Quantum Mechanics on Vibrational Motion and the Harmonic Oscillator.

- The interactive Maplet interface for rapid exploration of a molecule and its properties has been improved.

- Numerous enhancements have been made to many methods and commands throughout the package.

Deep Learning

The Deep Learning package offers a variety of new specialty forms of neural networks, including convolutional neural networks that are often used for tasks such as image and video recognition, and recurrent neural networks that are often used for text processing or classification. The package also includes new tools that allow you to build your own sophisticated special purpose neural networks by composing layers of different types.

Performance

Performance improvements in Maple 2021 speed up computations of the individual commands themselves, as well as the other Maple library commands that depend on them.

- The *map* command, along with related commands such as element-wise operators and zip, have been sped up significantly for common operations. In particular, there is a facility that recognizes some operations that are frequently mapped, and uses a faster implementation for these operations in cases when applicable. Many examples run between 10 and 60 times faster than before, and use much less memory.

- The version of the GMP library used for large integer arithmetic by Maple has been upgraded to version 6.2.0, resulting in improved support for new hardware and performance improvements for various integer operations.

- The underlying algorithm for computing binomial coefficients has been greatly improved for integer inputs. For example, in the case where the second argument is large, some computations run a hundred times faster.

- The algorithm for computing multinomial coefficients in the Combinatorics package has been improved so that it is computed using the binomial command and thus is now much faster than the previous algorithm.

- Operations on numeric expressions in the Simple Units environment are much faster.

- A number of commands in the Graph Theory package perform faster in Maple 2021 compared to previous versions of Maple.

- The *Project* command in the Polyhedral Sets package now uses a faster algorithm that checks for redundant constraints.

Language and Programming

- You can now use multi-level break or next statements, where you specify which nested loop it is that you want to break out of early when the condition is met.

- The Document Tools package, which provides tools for creating documents and interactive applications programmatically, has been extended to include a new framework for Maple users to easily build applications where the number of required input fields is not known in advance.

- The Code Tools package includes new tools to help ensure you have good test coverage for the Maple code you write, and to report on test failures. It also has a new command that returns a list of all members of a module and its submodules.

- There is a new message passing style option for calling methods when using objects, and the built-in functions *entries*, *indices*, and *xormap* now support being overloaded by objects.
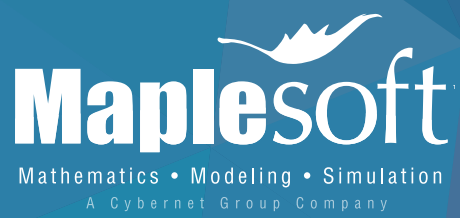
- New commands for logic involving sequences include *xormap*, *andseq*, *orseq*, and *xorseq*.

- The *zip* command now supports new options, evalhf and inplace, which can increase speed and decrease memory use in certain situations.

- The commands *map*, *seq*, *select*, *remove*, and *selectremove* now each have three new options, fold, reduce, and scan, for combining the resulting expressions using a specified function.

- The *select*, *remove*, and *selectremove* commands can now use selecting functions where the operands from the expression can be any argument to the selecting function.

- The *seq* command has a new option that allows you to create evenly spaced sequences with the desired number of elements.

- New commands in the Array Tools package include *IsMonotonic*, *GeneralInnerProduct*, *GeneralOuterProduct*, *ScanAlongDimenension*, and *ReduceAlongDimension*.

- *DEQueue* provides a means to construct a double-ended queue, which supports efficiently adding and removing entries from both the front and the back.

- The List Tools package includes new methods for splitting a list into sublists by slicing or dealing.

- The new Persistent Table package provides an easier way to work with an object that is backed by a file containing an SQLite table, where any information stored in the table persists when Maple is shut down or restarted.

- The DataFrame and DataSeries objects now support the entries and indices commands.

- In the Units package, the *Split* command splits the coefficient from its unit.

- There are additional calling sequences for using log functions with a specified base.

- The *subs* command has a member option to limit substitutions to the top-level entries of a container.

- The *trace* command has a new option to limit the information shown during execution of a traced procedure to only procedure entry and exit.

- An extension to *evalhf* gives you the option of returning a hardware float instead of converting the result to software floating-point before returning.

- You can now use the :: operator to assert a type on the control variable of a for loop.

- The exports command for retrieving exports from a module has new options for selecting the scope and specifying a type.

LaTeX Export

The LaTeX conversion tools have been completely rewritten in Maple 2021, providing broader, more robust support for converting Maple content to LaTeX. You can now author course lessons, entire scientific papers, or other documents directly in Maple, taking advantage of Maple's what-you-see-is-what-you-get editing capabilities, and then simply export the document to LaTeX without the need for further adjustments..

- Export is available for individual expressions or the entire document, though the *latex* command, context menu operations, copying the expression to the clipboard using Copy As>LaTeX, and the File>Export As menu.

- Input and output in the LaTeX documented are formatted using automatic line breaking.

- When the Maple document makes use of equation labels in the calculations and text, the exported document now also adds hyperlinks from those labels to the target equation.

- Many options are available so you can fine-tune the resulting LaTeX, including whether or not prompts should appear, how to display multiplication, which symbol to use for the imaginary unit, spacing after a square root symbol or function name, how to handle powers of trigonometric functions, and more.

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