Mathematics

ODE Function Summary

Initial Value ODE Problem Solvers

These are the MATLAB initial value problem solvers. The table lists the kind of problem you can solve with each solver, and the method each solver uses.

Solver	Solves These Kinds of Problems	Method
`ode45`	Nonstiff differential equations	Runge-Kutta
`ode23`	Nonstiff differential equations	Runge-Kutta
`ode113`	Nonstiff differential equations	Adams
`ode15s`	Stiff differential equations and DAEs	NDFs (BDFs)
`ode23s`	Stiff differential equations	Rosenbrock
`ode23t`	Moderately stiff differential equations and DAEs	Trapezoidal rule
`ode23tb`	Stiff differential equations	TR-BDF2

ODE Solution Evaluation

If you call an ODE solver with one output argument, it returns a structure that you can use to evaluate the solution at any point on the interval of integration.

Function	Description
`deval`	Evaluate the numerical solution using output of ODE solvers.

ODE Option Handling

An options structure contains named integration properties whose values are passed to the solver, and which affect problem solution. Use these functions to create, alter, or access an options structure.

Function	Description
`odeset`	Create or alter options structure for input to ODE solvers.
`odeget`	Extract properties from options structure created with `odeset`.

ODE Solver Output Functions

If an output function is specified, the solver calls the specified function after every successful integration step. You can use `odeset` to specify one of these sample functions as the OutputFcn property, or you can modify them to create your own functions.

Function	Description
`odeplot`	Time-series plot

odephas2	Two-dimensional phase plane plot
odephas3	Three-dimensional phase plane plot
odeprint	Print to command window

ODE Initial Value Problem Examples

These examples illustrate the kinds of problems you can solve in MATLAB. From the MATLAB Help browser, click the example name to see the code in an editor. Type the example name at the command line to run it.

> **Note** The Differential Equations Examples browser enables you to view the code for the ODE examples and DAE examples. You can also run the examples from the browser. Click on these links to invoke the browser, or type `odeexamples('ode')` or `odeexamples('dae')` at the command line.

Example	Description
amp1dae	Stiff DAE - electrical circuit
ballode	Simple event location - bouncing ball
batonode	ODE with time- and state-dependent mass matrix - motion of a baton
brussode	Stiff large problem - diffusion in a chemical reaction (the Brusselator)
burgersode	ODE with strongly state-dependent mass matrix - Burger's equation solved using a moving mesh technique
fem1ode	Stiff problem with a time-dependent mass matrix - finite element method
fem2ode	Stiff problem with a constant mass matrix - finite element method
hb1dae	Stiff DAE from a conservation law
hb1ode	Stiff problem solved on a very long interval - Robertson chemical reaction
orbitode	Advanced event location - restricted three body problem
rigidode	Nonstiff problem - Euler equations of a rigid body without external forces
vdpode	Parameterizable van der Pol equation (stiff for large μ)

Initial Value Problems for ODEs and DAEs Introduction to Initial Value ODE Problems

MATLAB Function Reference

ode45, ode23, ode113, ode15s, ode23s, ode23t, ode23tb

Solve initial value problems for ordinary differential equations (ODEs)

Syntax

```
[T,Y] = solver(odefun,tspan,y0)
[T,Y] = solver(odefun,tspan,y0,options)
[T,Y] = solver(odefun,tspan,y0,options,p1,p2...)
[T,Y,TE,YE,IE] = solver(odefun,tspan,y0,options)
sol = solver(odefun,[t0 tf],y0...)
```

where `solver` is one of `ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, or `ode23tb`.

Arguments

`odefun`	A function that evaluates the right-hand side of the differential equations. All solvers solve systems of equations in the form $y' = f(t, y)$ or problems that involve a mass matrix, $M(t, y)y' = f(t, y)$. The `ode23s` solver can solve only equations with constant mass matrices. `ode15s` and `ode23t` can solve problems with a mass matrix that is singular, i.e., differential-algebraic equations (DAEs).
`tspan`	A vector specifying the interval of integration, `[t0,tf]`. To obtain solutions at specific times (all increasing or all decreasing), use `tspan = [t0,t1,...,tf]`.
`y0`	A vector of initial conditions.
`options`	Optional integration argument created using the `odeset` function. See `odeset` for details.
`p1,p2...`	Optional parameters to be passed to `odefun`.

Description

`[T,Y] = solver(odefun,tspan,y0)` with `tspan = [t0 tf]` integrates the system of differential equations $y' = f(t, y)$ from time `t0` to `tf` with initial conditions `y0`. Function `f = odefun(t,y)`, for a scalar `t` and a column vector `y`, must return a column vector `f` corresponding to $f(t, y)$. Each row in the solution array `Y` corresponds to a time returned in column vector `T`. To obtain solutions at the specific times `t0`, `t1,...,tf` (all increasing or all decreasing), use `tspan = [t0,t1,...,tf]`.

`[T,Y] = solver(odefun,tspan,y0,options)` solves as above with default integration parameters replaced by property values specified in `options`, an argument created with the `odeset` function. Commonly used properties include a scalar relative error tolerance `RelTol` (`1e-3` by default) and a vector of absolute error tolerances `AbsTol` (all components are `1e-6` by default). See `odeset` for details.

`[T,Y] = solver(odefun,tspan,y0,options,p1,p2...)` solves as above, passing the additional parameters `p1,p2...` to the function `odefun`, whenever it is called. Use `options = []` as a place holder if no options are set.

`[T,Y,TE,YE,IE] = solver(odefun,tspan,y0,options)` solves as above while also finding where functions of (t,y), called event functions, are zero. For each event function, you specify whether the integration is to terminate at a zero and whether the direction of the zero crossing matters. This is done by setting the `Events` property to, say, `@EVENTS`, and creating a function [`value`,`isterminal`,`direction`] = `EVENTS`(`t`,`y`). For the `i`th event function:

- `value(i)` is the value of the function.
- `isterminal(i)` = `1` if the integration is to terminate at a zero of this event function and `0` otherwise.
- `direction(i) = 0` if all zeros are to be computed (the default), `+1` if only the zeros where the event function increases, and `-1` if only the zeros where the event function decreases.

Corresponding entries in `TE`, `YE`, and `IE` return, respectively, the time at which an event occurs, the solution at the time of the event, and the index `i` of the event function that vanishes.

`sol = *solver*(odefun,[t0 tf],y0...)` returns a structure that you can use with `deval` to evaluate the solution at any point on the interval `[t0,tf]`. You must pass `odefun` as a function handle. The structure `sol` always includes these fields:

`sol.x`	Steps chosen by the solver.
`sol.y`	Each column `sol.y(:,i)` contains the solution at `sol.x(i)`.
`sol.solver`	Solver name.

If you specify the `Events` option and events are detected, `sol` also includes these fields:

`sol.xe`	Points at which events, if any, occurred. `sol.xe(end)` contains the exact point of a terminal event, if any.
`sol.ye`	Solutions that correspond to events in `sol.xe`.
`sol.ie`	Indices into the vector returned by the function specified in the `Event` option. The values indicate which event has been detected.

If you specify an output function as the value of the `OutputFcn` property, the solver calls it with the computed solution after each time step. Four output functions are provided: `odeplot`, `odephas2`, `odephas3`, `odeprint`. When you call the solver with no output arguments, it calls the default `odeplot` to plot the solution as it is computed. `odephas2` and `odephas3` produce two- and three-dimnesional phase plane plots, respectively. `odeprint` displays the solution components on the screen. By default, the ODE solver passes all components of the solution to the output function. You can pass only specific components by providing a vector of indices as the value of the `OutputSel` property. For example, if you call the solver with no output arguments and set the value of `OutputSel` to `[1,3]`, the solver plots solution components 1 and 3 as they are computed.

For the stiff solvers `ode15s`, `ode23s`, `ode23t`, and `ode23tb`, the Jacobian matrix $\partial f/\partial y$ is critical to reliability and efficiency. Use odeset to set `Jacobian` to `@FJAC` if `FJAC(T,Y)` returns the Jacobian $\partial f/\partial y$ or to the matrix $\partial f/\partial y$ if the Jacobian is constant. If the `Jacobian` property is not set (the default), $\partial f/\partial y$ is approximated by finite differences. Set the `Vectorized` property '`on`' if the ODE function is coded so that `odefun(T,[Y1,Y2 ...])` returns [`odefun(T,Y1)`, `odefun(T,Y2) ...`]. If $\partial f/\partial y$ is a sparse matrix, set the `JPattern` property to the sparsity pattern of $\partial f/\partial y$, i.e., a sparse matrix `S` with `S(i,j)` = 1 if the `i`th component of $f(t, y)$ depends on the `j`th component of y, and 0 otherwise.

The solvers of the ODE suite can solve problems of the form $M(t, y)y' = f(t, y)$, with time- and state-dependent mass matrix M. (The `ode23s` solver can solve only equations with constant mass matrices.) If a problem has a mass matrix, create a function `M = MASS(t,y)` that returns the value of the mass matrix, and use odeset to set the `Mass` property to `@MASS`. If the mass matrix is constant, the matrix should be used as the value of the `Mass` property. Problems with state-dependent mass matrices are more difficult:

- If the mass matrix does not depend on the state variable y and the function `MASS` is to be called with one input argument, `t`, set the `MStateDependence` property to '`none`'.
- If the mass matrix depends weakly on y, set `MStateDependence` to '`weak`' (the default) and otherwise, to '`strong`'. In either case, the function `MASS` is called with the two arguments (`t`,`y`).

If there are many differential equations, it is important to exploit sparsity:

- Return a sparse $M(t, y)$.
- Supply the sparsity pattern of $\partial f / \partial y$ using the `JPattern` property or a sparse $\partial f / \partial y$ using the `Jacobian` property.
- For strongly state-dependent $M(t, y)$, set `MvPattern` to a sparse matrix `S` with `S(i,j) = 1` if for any `k`, the (`i,k`) component of $M(t, y)$ depends on component `j` of y, and `0` otherwise.

If the mass matrix M is singular, then $M(t, y)y' = f(t, y)$ is a differential algebraic equation. DAEs have solutions only when y_0 is consistent, that is, if there is a vector yp_0 such that

$M(t_0, y_0)yp_0 = f(t_0, y_0)$. The `ode15s` and `ode23t` solvers can solve DAEs of index 1 provided that `y0` is sufficiently close to being consistent. If there is a mass matrix, you can use odeset to set the `MassSingular` property to `'yes'`, `'no'`, or `'maybe'`. The default value of `'maybe'` causes the solver to test whether the problem is a DAE. You can provide `yp0` as the value of the `InitialSlope` property. The default is the zero vector. If a problem is a DAE, and `y0` and `yp0` are not consistent, the solver treats them as guesses, attempts to compute consistent values that are close to the guesses, and continues to solve the problem. When solving DAEs, it is very advantageous to formulate the problem so that M is a diagonal matrix (a semi-explicit DAE).

Solver	**Problem Type**	**Order of Accuracy**	**When to Use**
`ode45`	Nonstiff	Medium	Most of the time. This should be the first solver you try.
`ode23`	Nonstiff	Low	If using crude error tolerances or solving moderately stiff problems.
`ode113`	Nonstiff	Low to high	If using stringent error tolerances or solving a computationally intensive ODE file.
`ode15s`	Stiff	Low to medium	If `ode45` is slow because the problem is stiff.
`ode23s`	Stiff	Low	If using crude error tolerances to solve stiff systems and the mass matrix is constant.
`ode23t`	Moderately Stiff	Low	If the problem is only moderately stiff and you need a solution without numerical damping.
`ode23tb`	Stiff	Low	If using crude error tolerances to solve stiff systems.

The algorithms used in the ODE solvers vary according to order of accuracy [6] and the type of systems (stiff or nonstiff) they are designed to solve. See Algorithms for more details.

Options

Different solvers accept different parameters in the options list. For more information, see `odeset` and Improving ODE Solver Performance in the "Mathematics" section of the MATLAB documentation.

Parameters	**ode45**	**ode23**	**ode113**	**ode15s**	**ode23s**	**ode23t**	**ode23tb**
`RelTol`, `AbsTol`, `NormControl`	√	√	√	√	√	√	√
`OutputFcn`, `OutputSel`, `Refine`, `Stats`	√	√	√	√	√	√	√
`Events`	√	√	√	√	√	√	√
`MaxStep`, `InitialStep`	√	√	√	√	√	√	√
`Jacobian`, `JPattern`, `Vectorized`	--	--	--	√	√	√	√

`Mass`
`MStateDependence`
`MvPattern`
`MassSingular`
	√
	√
	--
	--
		√
		√
		--
		--
			√
			√
			--
			--
				√
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						√
						√
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							√
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							--

`InitialSlope`	--	--	--	√	--	√	--
`MaxOrder`, `BDF`	--	--	--	√	--	--	--

Examples

Example 1. An example of a nonstiff system is the system of equations describing the motion of a rigid body without external forces.

$$\begin{aligned} y'_1 &= y_2\, y_3 & y_1(0) &= 0 \\ y'_2 &= -y_1\, y_3 & y_2(0) &= 1 \\ y'_3 &= -0.51\, y_1\, y_2 & y_3(0) &= 1 \end{aligned}$$

To simulate this system, create a function `rigid` containing the equations

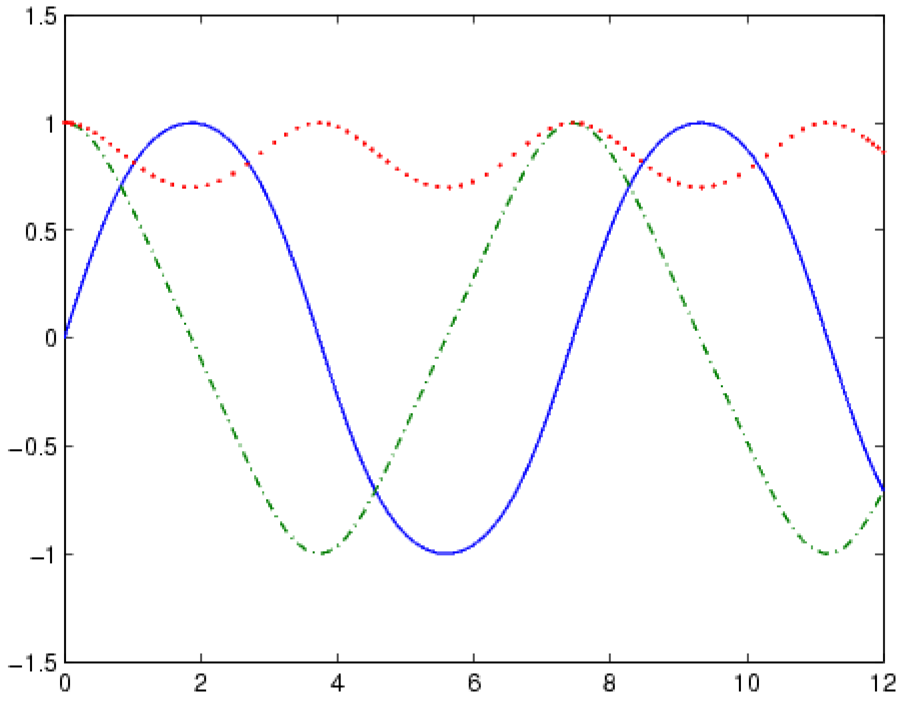
```
function dy = rigid(t,y)
dy = zeros(3,1);    % a column vector
dy(1) = y(2) * y(3);
dy(2) = -y(1) * y(3);
dy(3) = -0.51 * y(1) * y(2);
```

In this example we change the error tolerances using the `odeset` command and solve on a time interval `[0 12]` with an initial condition vector `[0 1 1]` at time `0`.

```
options = odeset('RelTol',1e-4,'AbsTol',[1e-4 1e-4 1e-5]);
[T,Y] = ode45(@rigid,[0 12],[0 1 1],options);
```

Plotting the columns of the returned array `Y` versus `T` shows the solution

```
plot(T,Y(:,1),'-',T,Y(:,2),'-.',T,Y(:,3),'.')
```



Example 2. An example of a stiff system is provided by the van der Pol equations in relaxation oscillation. The limit cycle has portions where the solution components change slowly and the problem is quite stiff, alternating with regions of very sharp change where it is not stiff.

$$\begin{array}{ll} y'_1 = y_2 & y_1(0) = 0 \\ y'_2 = 1000(1-y_1^2)y_2 - y_1 & y_2(0) = 1 \end{array}$$

To simulate this system, create a function `vdp1000` containing the equations

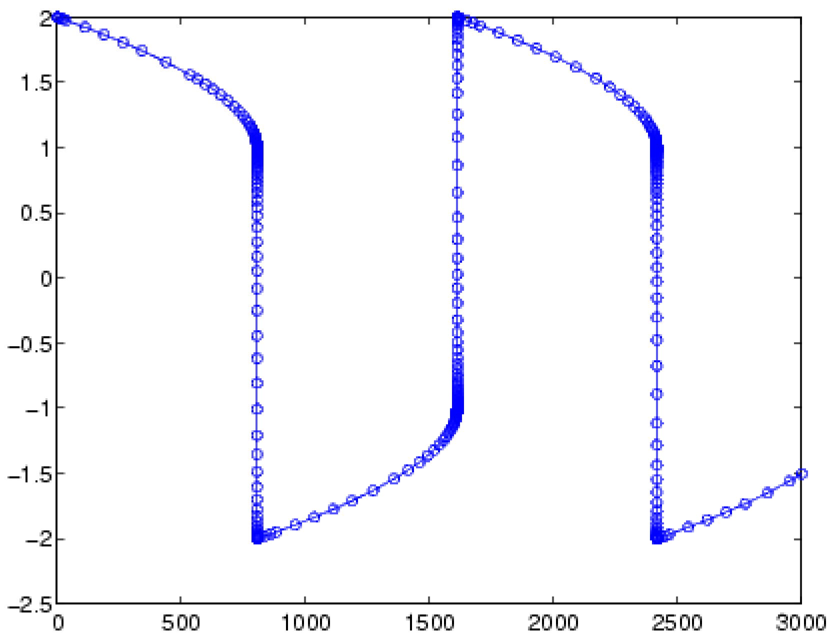
```
function dy = vdp1000(t,y)
dy = zeros(2,1);    % a column vector
dy(1) = y(2);
dy(2) = 1000*(1 - y(1)^2)*y(2) - y(1);
```

For this problem, we will use the default relative and absolute tolerances (`1e-3` and `1e-6`, respectively) and solve on a time interval of `[0 3000]` with initial condition vector `[2 0]` at time `0`.

```
[T,Y] = ode15s(@vdp1000,[0 3000],[2 0]);
```

Plotting the first column of the returned matrix `Y` versus `T` shows the solution

```
plot(T,Y(:,1),'-o')
```



Algorithms

`ode45` is based on an explicit Runge-Kutta (4,5) formula, the Dormand-Prince pair. It is a *one-step* solver - in computing `y(t`$_n$`)`, it needs only the solution at the immediately preceding time point, `y(t`$_{n-1}$`)`. In general, `ode45` is the best function to apply as a "first try" for most problems. [3]

`ode23` is an implementation of an explicit Runge-Kutta (2,3) pair of Bogacki and Shampine. It may be more efficient than `ode45` at crude tolerances and in the presence of moderate stiffness. Like `ode45`, `ode23` is a one-step solver. [2]

`ode113` is a variable order Adams-Bashforth-Moulton PECE solver. It may be more efficient than `ode45` at stringent tolerances and when the ODE file function is particularly expensive to evaluate. `ode113` is a *multistep* solver - it normally needs the solutions at several preceding time points to compute the current solution. [7]

The above algorithms are intended to solve nonstiff systems. If they appear to be unduly slow, try using one of the stiff solvers below.

`ode15s` is a variable order solver based on the numerical differentiation formulas (NDFs). Optionally, it uses the backward differentiation formulas (BDFs, also known as Gear's method) that are usually less efficient. Like `ode113`, `ode15s` is a multistep solver. Try `ode15s` when `ode45` fails, or is very inefficient, and you suspect that the problem is stiff, or when solving a differential-algebraic problem. [9], [10]

`ode23s` is based on a modified Rosenbrock formula of order 2. Because it is a one-step solver, it may be more efficient than `ode15s` at crude tolerances. It can solve some kinds of stiff problems for which `ode15s` is not effective. [9]

`ode23t` is an implementation of the trapezoidal rule using a "free" interpolant. Use this solver if the problem is only moderately stiff and you need a solution without numerical damping. `ode23t` can solve DAEs. [10]

`ode23tb` is an implementation of TR-BDF2, an implicit Runge-Kutta formula with a first stage that is a trapezoidal rule step and a second stage that is a backward differentiation formula of order two. By construction, the same iteration matrix is used in evaluating both stages. Like `ode23s`, this solver may be more efficient than `ode15s` at crude tolerances. [8], [1]

See Also

`deval`, `odeset`, `odeget`, `@` (function handle)

References

[1] Bank, R. E., W. C. Coughran, Jr., W. Fichtner, E. Grosse, D. Rose, and R. Smith, "Transient Simulation of Silicon Devices and Circuits," *IEEE Trans. CAD*, 4 (1985), pp 436-451.

[2] Bogacki, P. and L. F. Shampine, "A 3(2) pair of Runge-Kutta formulas," *Appl. Math. Letters*, Vol. 2, 1989, pp 1-9.

[3] Dormand, J. R. and P. J. Prince, "A family of embedded Runge-Kutta formulae," *J. Comp. Appl. Math.*, Vol. 6, 1980, pp 19-26.

[4] Forsythe, G. , M. Malcolm, and C. Moler, *Computer Methods for Mathematical Computations*, Prentice-Hall, New Jersey, 1977.

[5] Kahaner, D. , C. Moler, and S. Nash, *Numerical Methods and Software*, Prentice-Hall, New Jersey, 1989.

[6] Shampine, L. F. , *Numerical Solution of Ordinary Differential Equations*, Chapman & Hall, New York, 1994.

[7] Shampine, L. F. and M. K. Gordon, *Computer Solution of Ordinary Differential Equations: the Initial Value Problem*, W. H. Freeman, San Francisco, 1975.

[8] Shampine, L. F. and M. E. Hosea, "Analysis and Implementation of TR-BDF2," *Applied Numerical Mathematics 20*, 1996.

[9] Shampine, L. F. and M. W. Reichelt, "The MATLAB ODE Suite," *SIAM Journal on Scientific Computing*, Vol. 18, 1997, pp 1-22.

[10] Shampine, L. F., M. W. Reichelt, and J.A. Kierzenka, "Solving Index-1 DAEs in MATLAB and Simulink," *SIAM Review*, Vol. 41, 1999, pp 538-552.

nzmax odefile

MATLAB Function Reference

odeget

Extract properties from options structure created with `odeset`

Syntax

```
o = odeget(options,'name')
o = odeget(options,'name',default)
```

Description

`o = odeget(options,'name')` extracts the value of the property specified by string `'name'` from integrator options structure `options`, returning an empty matrix if the property value is not specified in `options`. It is only necessary to type the leading characters that uniquely identify the property name. Case is ignored for property names. The empty matrix `[]` is a valid `options` argument.

`o = odeget(options,'name',default)` returns `o = default` if the named property is not specified in `options`.

Example

Having constructed an ODE options structure,

```
options = odeset('RelTol',1e-4,'AbsTol',[1e-3 2e-3 3e-3]);
```

you can view these property settings with `odeget`.

```
odeget(options,'RelTol')
ans =

       1.0000e-04

odeget(options,'AbsTol')
ans =

    0.0010    0.0020    0.0030
```

See Also

`odeset`

odefile odeset

MATLAB Function Reference

odeset

Create or alter options structure for input to ordinary differential equation (ODE) solvers

Syntax

```
options = odeset('name1',value1,'name2',value2,...)
options = odeset(oldopts,'name1',value1,...)
options = odeset(oldopts,newopts)
odeset
```

Description

The `odeset` function lets you adjust the integration parameters of the ODE solvers. The ODE solvers can integrate systems of differential equations of one of these forms

$$y' = f(t, y)$$

or

$$M(t, y)y' = f(t, y)$$

See below for information about the integration parameters.

`options = odeset('name1',value1,'name2',value2,...)` creates an integrator options structure in which the named properties have the specified values. Any unspecified properties have default values. It is sufficient to type only the leading characters that uniquely identify a property name. Case is ignored for property names.

`options = odeset(oldopts,'name1',value1,...)` alters an existing options structure `oldopts`.

`options = odeset(oldopts,newopts)` alters an existing options structure `oldopts` by combining it with a new options structure `newopts`. Any new options not equal to the empty matrix overwrite corresponding options in `oldopts`.

`odeset` with no input arguments displays all property names as well as their possible and default values.

ODE Properties

The available properties depend on the ODE solver used. There are several categories of properties:

- Error tolerance
- Solver output
- Jacobian matrix
- Event location
- Mass matrix and differential-algebraic equations (DAEs)
- Step size
- `ode15s`

Note This reference page describes the ODE properties for MATLAB, Version 6. The Version 5 properties are supported only for backward compatibility. For information on the Version 5 properties, type at the MATLAB command line: `more on, type odeset, more off`.

Error Tolerance Properties

Property	Value	Description
`RelTol`	Positive scalar {`1e-3`}	A relative error tolerance that applies to all components of the solution vector. The estimated error in each integration step satisfies `e(i) <= max(RelTol*abs(y(i)),AbsTol(i))`
`AbsTol`	Positive scalar or vector {`1e-6`}	The absolute error tolerance. If scalar, the tolerance applies to all components of the solution vector. Otherwise the tolerances apply to corresponding components.
`NormControl`	`on` | {`off`}	Control error relative to norm of solution. Set this property `on` to request that the solvers control the error in each integration step with `norm(e) <= max (RelTol*norm(y),AbsTol)`. By default the solvers use a more stringent component-wise error control.

Solver Output Properties

Property	Value		Description
`OutputFcn`	Function	Installable output function. The ODE solvers provide sample functions that you can use or modify:	
		`odeplot`	Time series plotting (default)
		`odephas2`	Two-dimensional phase plane plotting
		`odephas3`	Three-dimensional phase plane plotting
		`odeprint`	Print solution as it is computed
		To create or modify an output function, see ODE Solver Output Properties in the "Differential Equations" section of the MATLAB documentation.	
`OutputSel`	Vector of indices	Specifies the components of the solution vector that the solver passes to the output function.	
`Refine`	Positive integer	Produces smoother output, increasing the number of output points by the specified factor. The default value is `1` in all solvers except `ode45`, where it is `4`. `Refine` doesn't apply if `length(tspan) > 2`.	
`Stats`	`on` | {`off`}	Specifies whether the solver should display statistics about the computational cost of the integration.	

Jacobian Matrix Properties (for ode15s, ode23s, ode23t, and ode23tb)

Property	Value	Description
`Jacobian`	Function | constant matrix	Jacobian function. Set this property to `@FJac` (if a function `FJac(t,y)` returns $\partial f/\partial y$) or to the constant value of $\partial f/\partial y$.
`JPattern`	Sparse matrix of {0,1}	Sparsity pattern. Set this property to a sparse matrix S with $S(i,j) = 1$ if component i of $f(t,y)$ depends on component j of y, and 0 otherwise.

`Vectorized`	`on` | `{off}`	Vectorized ODE function. Set this property `on` to inform the stiff solver that the ODE function `F` is coded so that `F(t,[y1 y2 ...])` returns the vector `[F(t,y1) F(t,y2) ...]`. That is, your ODE function can pass to the solver a whole array of column vectors at once. A stiff function calls your ODE function in a vectorized manner only if it is generating Jacobians numerically (the default behavior) and you have used `odeset` to set `Vectorized` to `on`.

Event Location Property

Property	**Value**	**Description**
`Events`	Function	Locate events. Set this property to `@Events`, where `Events` is the event function. See the ODE solvers for details.

Mass Matrix and DAE-Related Properties

Property	**Value**	**Description**
`Mass`	Constant matrix | function	For problems $My' = f(t,y)$ set this property to the value of the constant mass matrix m. For problems $M(t,y)y' = f(t,y)$, set this property to `@Mfun`, where `Mfun` is a function that evaluates the mass matrix $M(t,y)$.
`MStateDependence`	`none` | `{weak}` | `strong`	Dependence of the mass matrix on y. Set this property to `none` for problems $M(t)y' = f(t,y)$. Both `weak` and `strong` indicate $M(t,y)$, but `weak` results in implicit solvers using approximations when solving algebraic equations. For use with all solvers except `ode23s`.
`MvPattern`	Sparse matrix	$\partial(M(t,y)v)/\partial y$ sparsity pattern. Set this property to a sparse matrix S with $S(i,j) = 1$ if for any k, the (i,k) component of $M(t,y)$ depends on component j of y, and 0 otherwise. For use with the `ode15s`, `ode23t`, and `ode23tb` solvers when `MStateDependence` is strong.
`MassSingular`	`yes` | `no` | `{maybe}`	Indicates whether the mass matrix is singular. The default value of `'maybe'` causes the solver to test whether the problem is a DAE. For use with the `ode15s` and `ode23t` solvers.
`InitialSlope`	Vector	Consistent initial slope yp_0, where yp_0 satisfies $M(t_0,y_0)yp_0 = f(t_0,y_0)$. For use with the `ode15s` and `ode23t` solvers when solving DAEs.

Step Size Properties

Property	**Value**	**Description**
`MaxStep`	Positive	An upper bound on the magnitude of the step size that the solver uses. The

	scalar	default is one-tenth of the `tspan` interval.
`InitialStep`	Positive scalar	Suggested initial step size. The solver tries this first, but if too large an error results, the solver uses a smaller step size.

In addition there are two options that apply only to the `ode15s` solver.

ode15s Properties

Property	**Value**	**Description**
`MaxOrder`	1 | 2 | 3 | 4 | {5}	The maximum order formula used.
`BDF`	`on` | `{off}`	Set `on` to specify that `ode15s` should use the backward differentiation formulas (BDFs) instead of the default numerical differentiation formulas (NDFs).

See Also

`deval`, `odeget`, `ode45`, `ode23`, `ode23t`, `ode23tb`, `ode113`, `ode15s`, `ode23s`, `@` (function handle)

odeget ones

MATLAB Function Reference

deval

Evaluate the solution of a differential equation problem

Syntax

```
sxint = deval(sol,xint)
```

Description

`sxint = deval(sol,xint)` evaluates the solution of a differential equation problem at each element of the vector `xint`. For each `i`, `sxint(:,i)` is the solution corresponding to `xint(i)`.

The input argument `sol` is a structure returned by an initial value problem solver (`ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, `ode23tb`) or the boundary value problem solver (`bvp4c`). The ordered row vector `sol.x` contains the independent variable. For each `i`, the column `sol.y(:,i)` contains the solution at `sol.x(i)`. The structure `sol` also contains data needed for interpolating the solution in `(x(i),x(i+1))`. The form of this data depends on the solver that creates `sol`. The field `sol.solver` contains the name of that solver.

Elements of `xint` must be in the interval `[sol.x(1),sol.x(end)]`.

See Also

ODE solvers: `ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, `ode23tb`

BVP solver: `bvp4c`

detrend diag