UNIT 5

Simulink

1. Introduction

SIMULINK is a special toolbox for MATLAB that simulates the dynamic systems behaviour. SIMULINK can simulate linear systems and nonlinear systems, continuous time models and discrete time models, combinations of all of them, and hybrid systems. SIMULINK is a graphical environment where each model is built using click-and-drag mouse operations. SIMULINK models are saved in `*.mdl` files (versions up to v7) and `*.slx` files (version v8).

In the newest versions, SIMULINK has extended its possibilities and block libraries (*blocksets*). In particular, the STATEFLOW package allows the simulation of state machines.

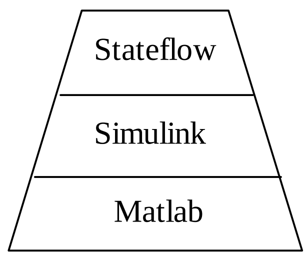


Fig. 1. Matlab, Simulink, and Stateflow hierarchy

Other interesting blocksets are, for instance, the communication ones (*Communications Blockset*, *CDMA Reference Blockset*) which include blocks to simulate devices such as PLLs or stations for emitting/receiving mobile signals; blocksets that allow the data exchange between SIMULINK and DSPs (Motorola, Texas Instruments) and between SIMULINK and different data acquisition cards (*Real-Time Workshop*); utility blocks (*Dials & Gauges Blockset*, *Virtual Reality*); and other advanced applications (*Power Systems*, *Neural Network*, *Fuzzy Logic*,...).

Type `>>ver` in the MATLAB command window to see which Simulink version is installed and which blocksets are available.

2. Simulink

2.1 Starting Simulink

To open the SIMULINK library browser, type `>>simulink` in the MATLAB command window, or click on the SIMULINK icon on the MATLAB toolbar (in v8).

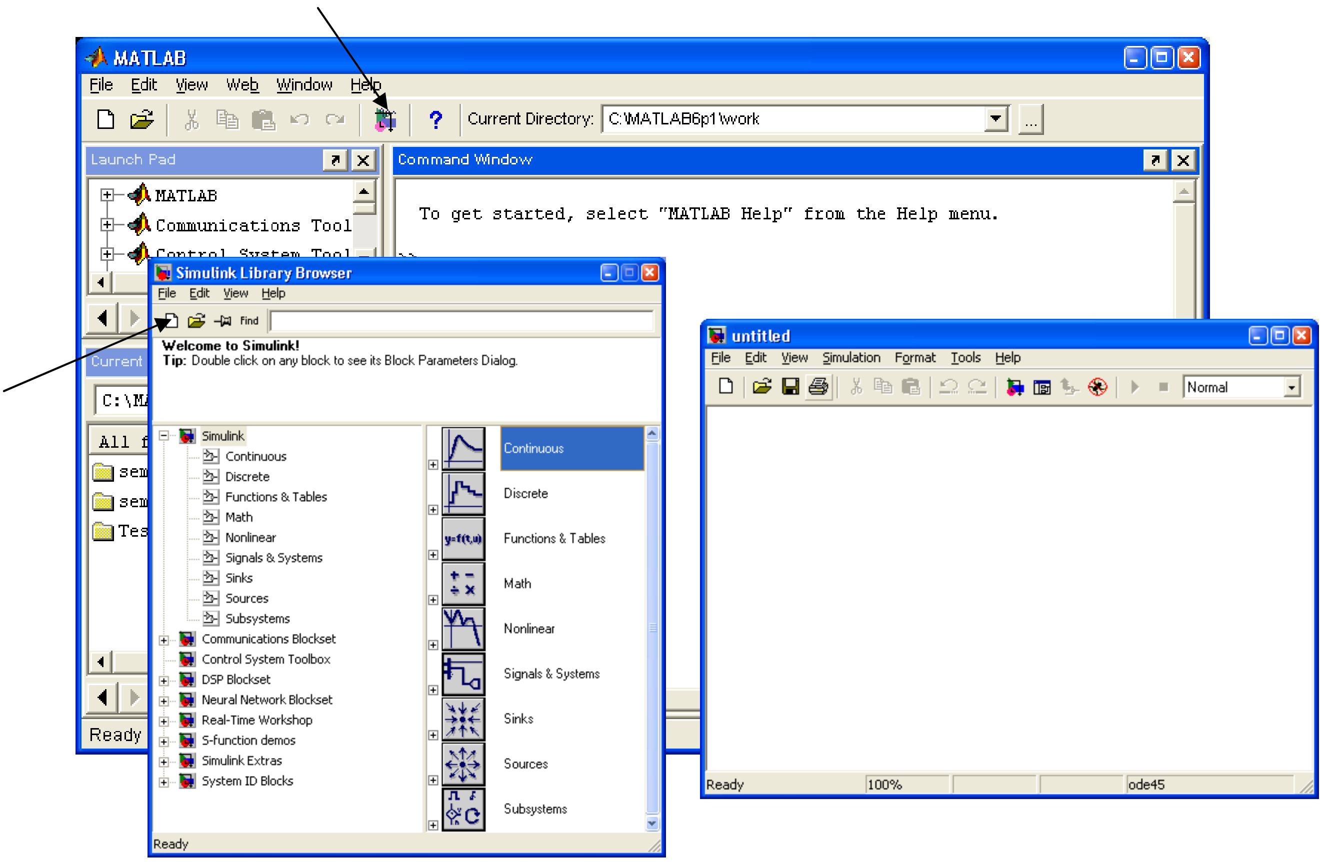


Fig. 2. Starting SIMULINK (in v6.1)

<u>Note</u>: if MATLAB has already been started, to edit an existing SIMULINK model, `model1.mdl`, you can enter `>>model1` in the MATLAB command window. If not,

you can double-click on the file name `model1.mdl` or `model1.slx` (this will start MATLAB and then open a window `model1` containing the model).

To create a new model select `File` → `New` → `Model` or click on the icon in the Simulink library (in v8).

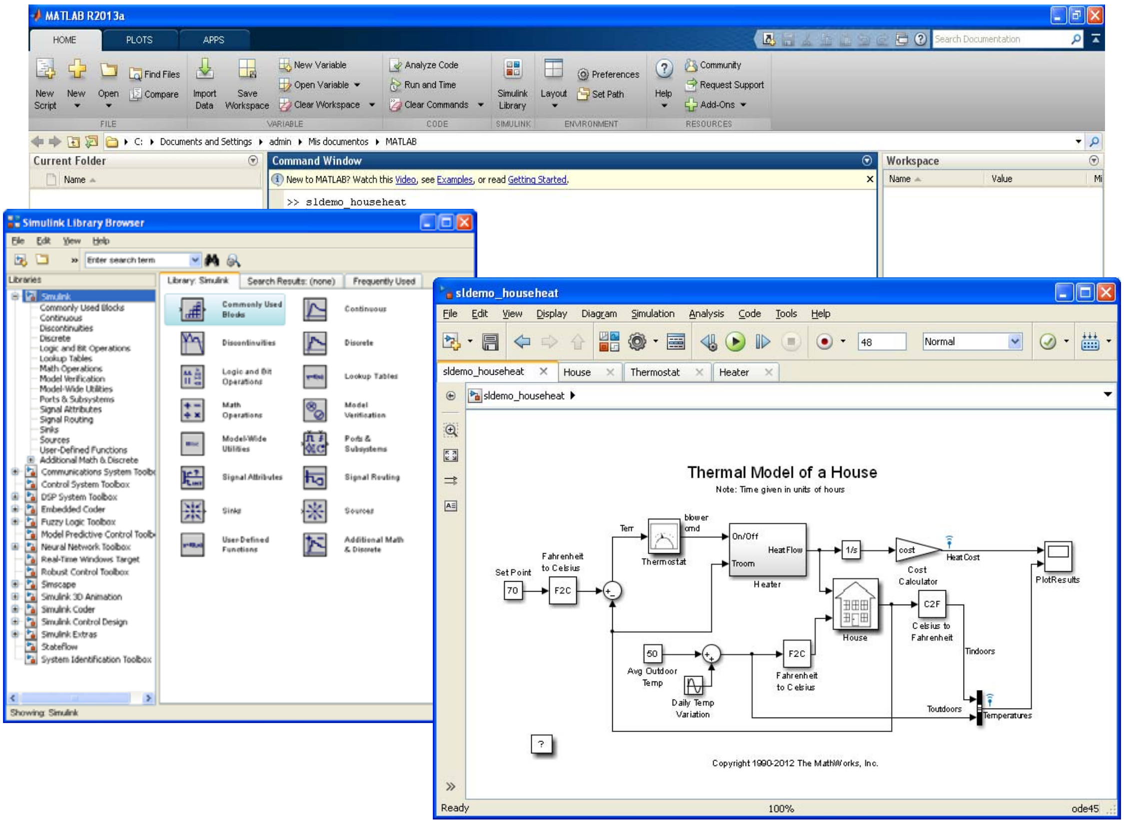


Fig. 3. Starting SIMULINK (in v8)

2.2 Model building

Model window: Each model (or submodel) is built in a different window. To create a new model, choose **New** from the **File** menu or click on the corresponding icon (see Fig. 2). This opens a new model window, `untitled`. Then you can drag the blocks from the SIMULINK library browser to the model window. It is advisable to take a look to the options in the menu bar and in the toolbar of the model window.

Block intercoonection: To interconnect blocks you can drag the mouse between the input and output ports of such blocks. An alternative is to select a block and, while pressing the `<ctrl>` key, select the other block. You can put labels everywhere (simply click on the desired location), change the block names and use different colours (`Format` → `Foreground Color`). You can also rotate the blocks (`Format` → `Flip block`, `Rotate block`), etc.

Example 1. Simple model building

Next figure shows how to build a simple model in order to simulate the step response of a continuous time second order system $H(s) = \dfrac{1}{s^2 + 0.5s + 1}$.

The excitation block `Step` has been dragged from the `Sources` library, the block `Scope` can be found in the `Sinks` library and the continuous time system `Transfer Fcn` can be found in the `Continuous` library.

To change the default parameters and put ours, it is necessary to double-click the block `Transfer Fcn` in the model window, and type the example numerator and denominator.

To run the model simulation, click on ▶ or select `Simulation` → `Start`. To change the simulation parameters (stop time, sampling, etc.) select `Simulation` → `Configuration Parameters…` (or `Simulation` → `Simulation Parameters…` depending on the particular version).

To see the simulation result, click on the `Scope` block to open it. Then click on the binoculars icon to auto scale the axes.

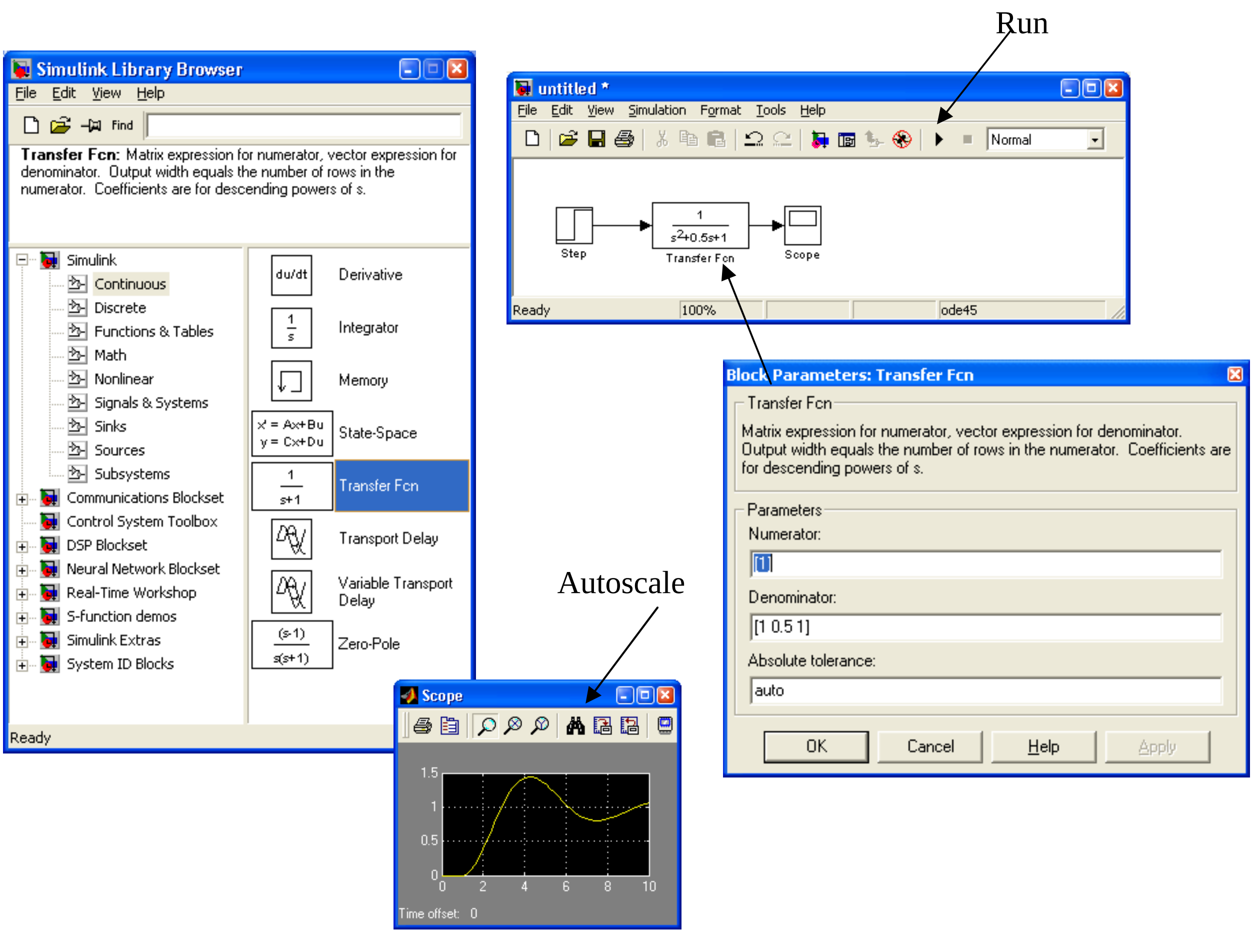


Fig. 4. Creating and running a new model

Next figure shows the same example in v8. Here the auto-scale icon is  and the run icon is . Note also that the v8 version includes a model browser in the model window.

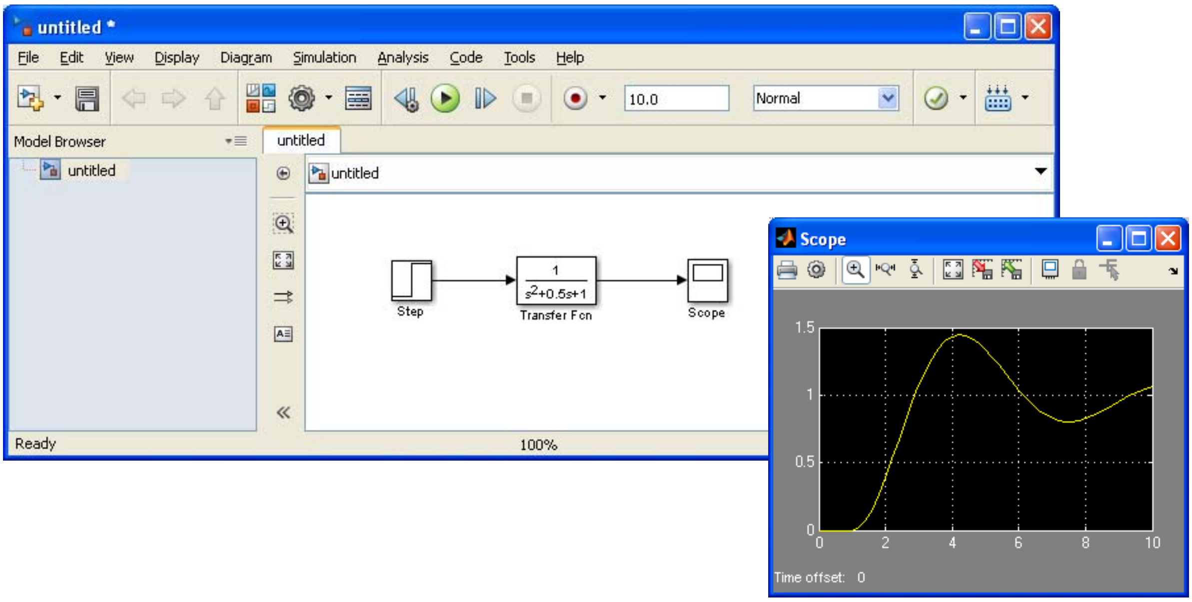


Fig. 5. Creating and running a new model (v8)

2.3 Simulation parameters and Scope block

Simulation parameters: In version 6.x, simulation parameters can be modified from the menu bar: `Simulation` → `Simulation parameters...`.

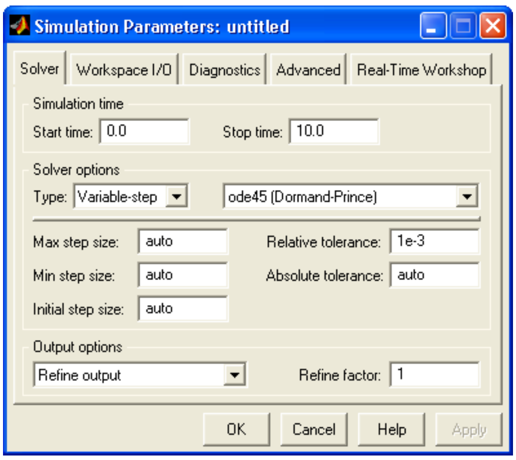


Fig. 6. Simulation parameters (v6)

In version 7.x, simulation parameters can be modified from the menu bar choosing the options: `Simulation` → `Configuration parameters...`.

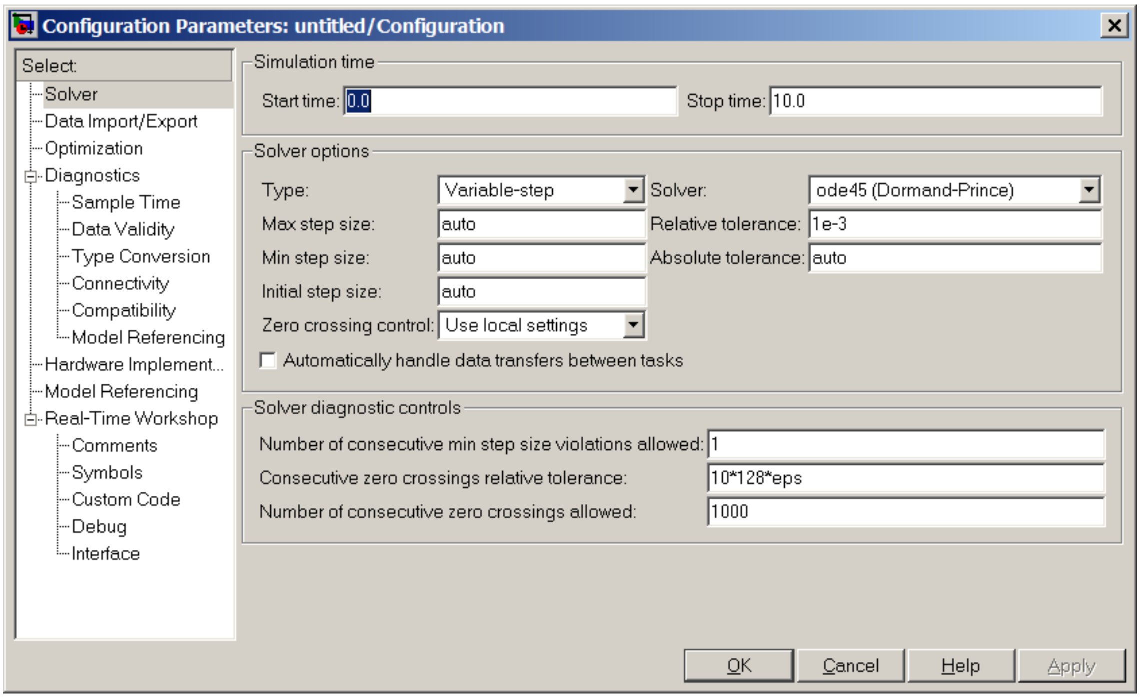


Fig. 7. Simulation parameters (v7)

In version 8.x, simulation parameters can be modified from the menu bar choosing the options: `Simulation` → `Model configuration parameters....` or clicking on the  icon.

Run: To run the simulation click on  or select `Simulation` → `Start` in the model window (see Example 1).

Function sim: It is also posible to run a Simulink model from the command window or from an M file with `sim`. In our example:

```
>>sim('untitled')

Warning: Using a default value of 0.2 for maximum step size. The
simulation step size will be equal to or less than this value.
You can disable this diagnostic by setting 'Automatic solver
parameter selection' diagnostic to 'none' in the Diagnostics page
of the configuration parameters dialog.
```

Interaction with the MATLAB workspace: SIMULINK models can access `*.m` files, `*.mat` files, and variables in MATLAB *workspace* by means blocks such as *From File*, *From Workspace* (*Sources* library), *To File*, *To WorkSpace* (*Sinks* library) and *MATLAB Fcn* (*Functions & Tables* library).

It is also possible refer to workspace variables inside a Simulink model. For example:

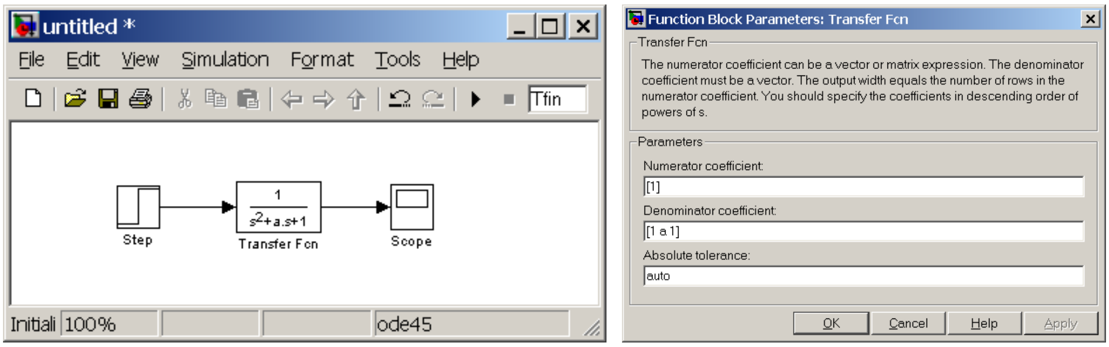


Fig. 8. Simulink model with *workspace* variables (`a` and `Tfin`)

To run the model, these variables must have a value.

```
>>a=0.5;Tfin=10;
>>sim('untitled')
```

Model Explorer: Click on  to open the model explorer ( in v8). In particular, the `Base Workspace` contains the variables available for the Simulink models.

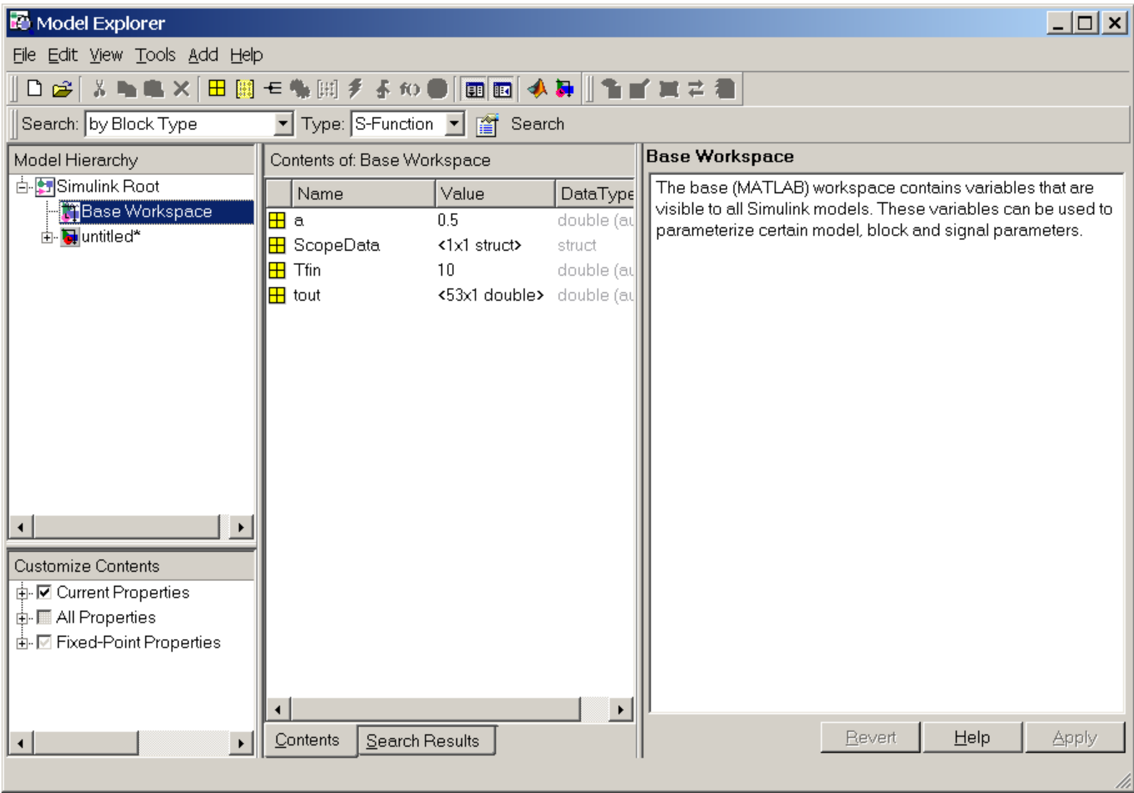
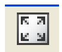


Fig. 9. Model Explorer

Scope block: To visualize a simulation result, click on the `Scope` block to open the plot window. Optionally, auto-scale the result with  (or  in v8) or zoom x-axis and y-axis using the corresponding icons  in v8) in the scope window toolbar (see Fig. 10).

To include a title, click with the right button on the plot to open the context menu and select `Axes properties…`:

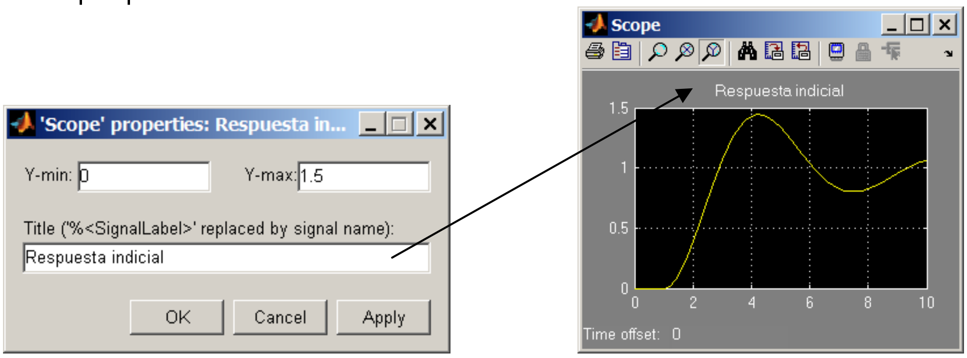
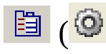


Fig. 10. Scope title

To modify the `Scope` parameters click on  in v8). By default, only the last 5000 samples are displayed on the `Scope`. If we want to see more than 5000 samples we must de-select the option `Limit data points to last:` in `Data history` (see Fig. 11).

The result of a Simulink simulation can be stored in the Matlab *workspace* by means of the *Scope* window (see Fig. 11).

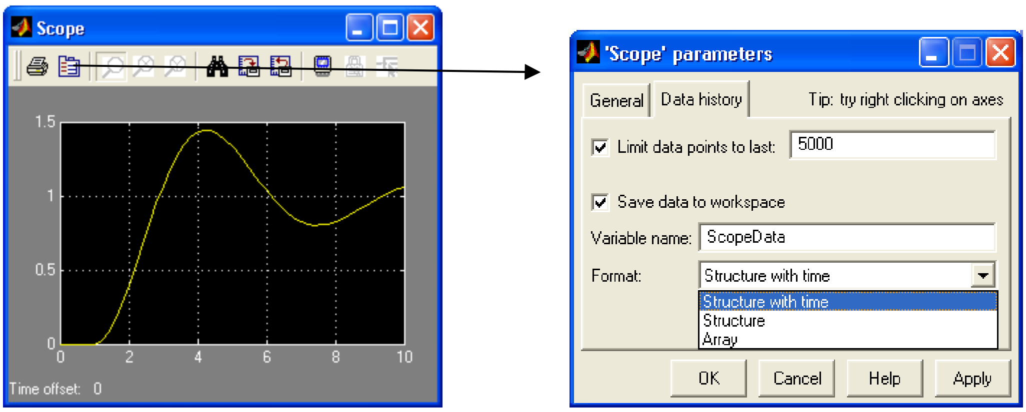


Fig. 11. Saving results to workspace

The option `Save data to workspace` allows to pass to the *workspace* the values represented in the `Scope`. Three formats are available: `Structure with time`, `Structure` and `Array`.

Format structure with time: If we choose format *Structure with Time*, in the workspace we will see two new variables:

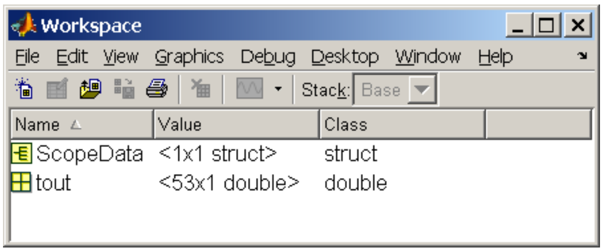


Fig. 12. Format *Struct with time* in Matlab's *workspace*

The variable `ScopeData` is a struct array with the following fields:

```
>> ScopeData
ScopeData =
         time: [53x1 double]
      signals: [1x1 struct]
    blockName: 'untitled/Scope'
```

`'time'`, `'signals'` and `'blockName'` are the three fields that form the structure `ScopeData`. Note that the field `'signals'` is a structure, as well. To get more information about these data types, enter `>>help struct` and `>>help cell`.

Functions fieldnames, isfield, getfield: To see which fields are in `ScopeData` we can use `fieldnames` (this command stores the result in a *cell array*)

```
>> names=fieldnames(ScopeData)
names =
    'time'
    'signals'
    'blockName'
```

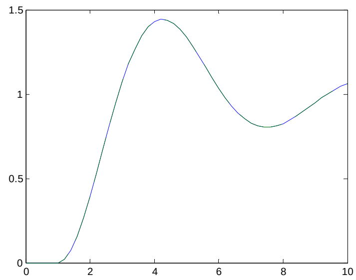
To see if a specified field belongs to a struct: `isfield(ScopeData, 'time')`.

To access to the fields we can use the dot or the command `getfield`:

```
>> ScopeData.signals
ans =
        values: [53x1 double]
    dimensions: 1
         label: ''
         title: ''
     plotStyle: 0

>> ScopeData.signals.dimensions
ans =
     1

>> y=getfield(ScopeData,'signals')
y =
        values: [53x1 double]
    dimensions: 1
         label: ''
         title: ''
     plotStyle: 0
```

Note that the following commands yield to the same result:

```
y1=getfield(ScopeData,'signals','values');
y2=ScopeData.signals.values;
plot(tout,y1,tout,y2,'--')
```



Array format: If we have chosen the format *Array*, we can directly access the variables:

```
>> size(ScopeData)
ans =
    53     2
>> size(tout)
ans =
    53     1
```

The following two commands have the same result:

```
>> plot(tout,ScopeData(:,2))
>> plot(ScopeData(:,1),ScopeData(:,2))
```

An alternative way to explore the variables is using the workspace window and the variables editor:

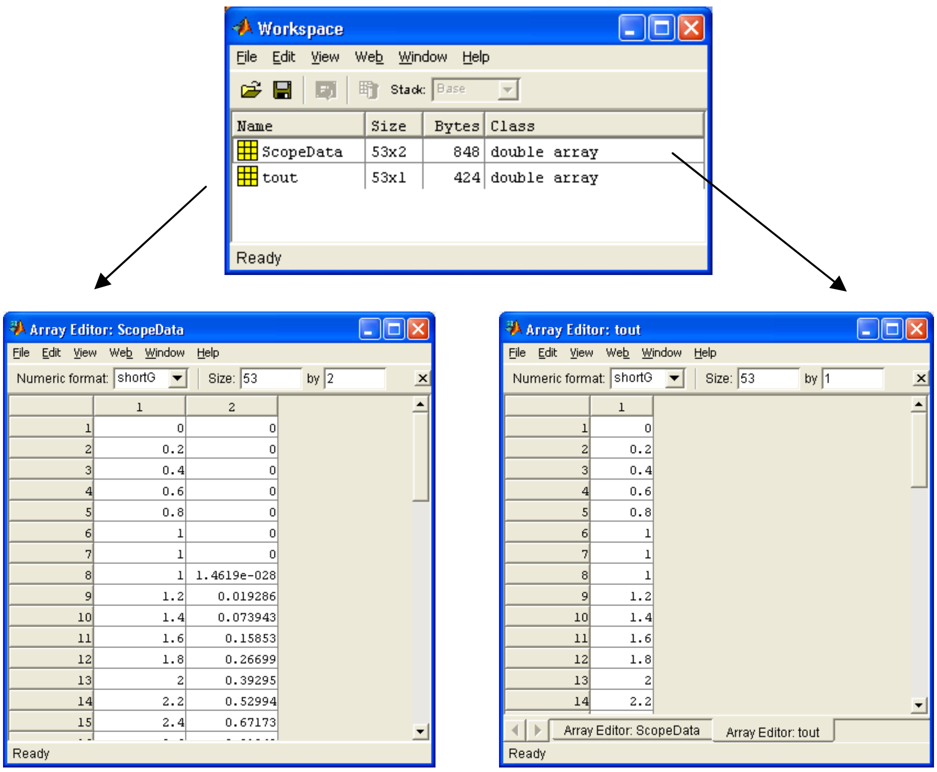


Fig. 13. Accessing the simulation results

Structure format: In the previous example, if we had chosen the format *Structure*, the variables in the Matlab *Workspace* will be again `ScopeData` and `tout`, but now the field time in `ScopeData` will be empty.

```
>> ScopeData
ScopeData =
          time: []
       signals: [1x1 struct]
     blockName: 'untitled/Scope'
```

2.4 Subsystems and masks

Creating subsystems: It is possible to group several blocks to obtain a subsystem. To do this, select with the mouse the corresponding blocks and then select `Edit` → `Create Subsystem`. (Note: the `Gain` block can be dragged from the `Math Operations` library or `Math` library, depending on the particular version.)

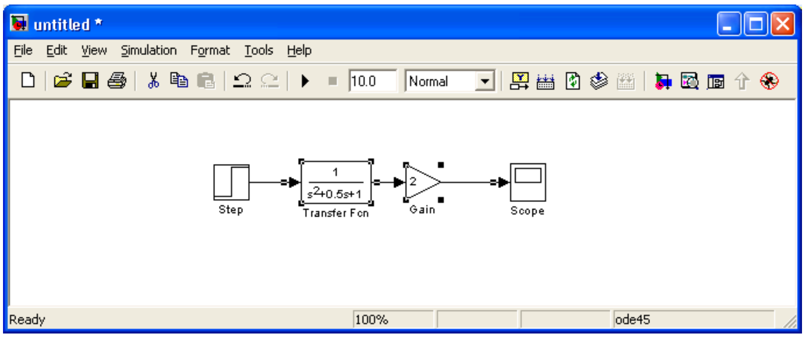


Fig. 14. Selecting blocks…

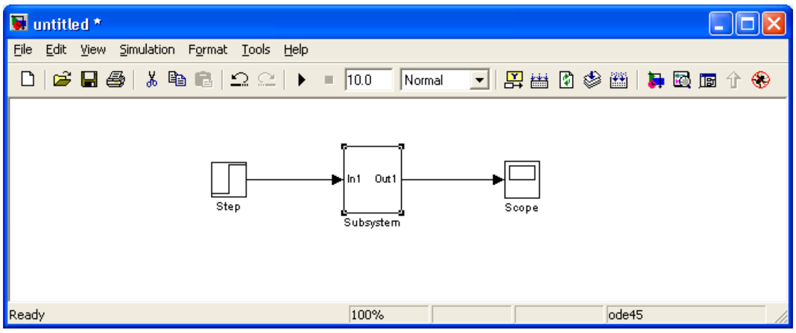


Fig. 15. …to create a subsystem.

Notice that, when creating a new subsystem, all input/output ports are created, numbered and labeled. To edit the subsystem, click on it. A new window containing the subsystem will be opened:

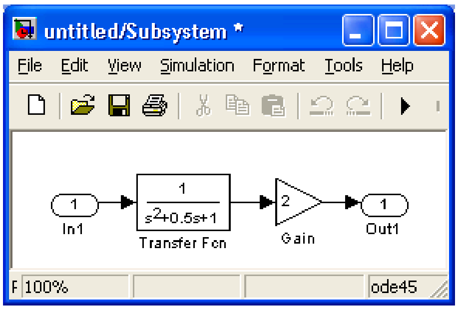


Fig. 16. Subsystem window

In the v8 version, the model browser shows all the subsystems. See Fig. 17.

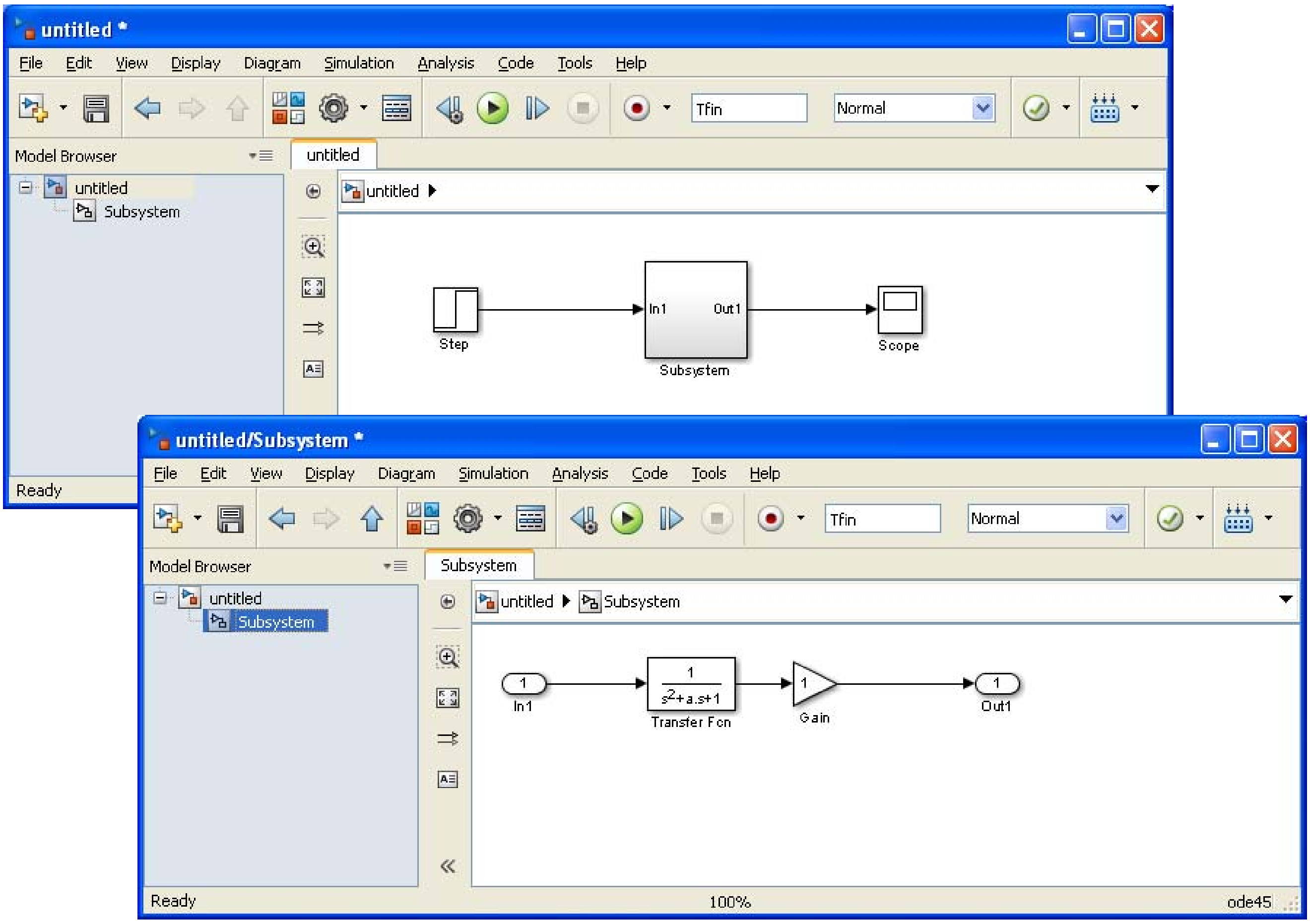


Fig. 17. Model browser in v8

Masks: It is possible to customize subsystem blocks by means of the mask editor (`Edit` → `Mask Subsystem`, or from the context menu over the subsystem: `Mask` → `Create mask`). You can change the subsystem icon, insert help comments, and introduce additional parameters (this is useful in the case of S functions that will be presented next). For instance, in version 7.x, if you put as `Drawing commands` the following command: `image(imread('b747.jpg'))`, the result is:

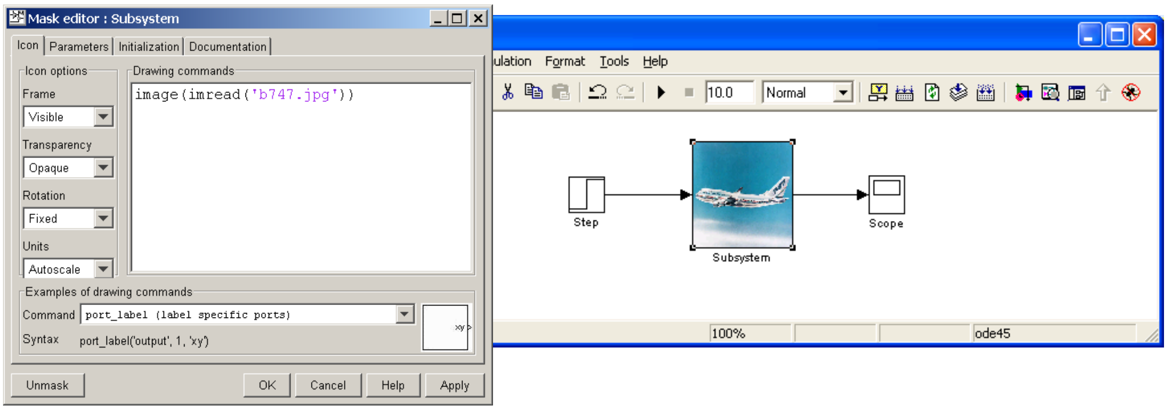


Fig. 18. Masking subsystems

To modify an already created mask, select `Edit` → `Edit Mask...`.

2.5 S Functions

S functions are SIMULINK blocks that can be programmed by the user (in MATLAB language or in C language). They are used to simulate complex dynamic systems (with time-varying parameters and/or with nonlinear components, different sampling rates, etc.). They are also used to communicate with external devices in *hardware-in-the-loop* applications. In this latter case, the S function contains the C program that allows the real time interaction between the acquisition card and the model input/output ports. In the case the code is written in the C language, it is necessary to compile and link the S functions using the `mex` utility of MATLAB.

S functions for the simulation of dynamic systems: There exist several template files (continuous time systems `csfunc.m`, discrete time systems `dsfunc.m`) that can be copied to the work folder to be modified with the particular user system and parameters.

```
>> which csfunc.m
C:\Program files\MATLAB704\toolbox\simulink\blocks\csfunc.m
```

S functions consist in a series of basic subroutines which SIMULINK executes in a sequential way:

- Initialization (`mdlInitializeSizes`), flag=0
- Derivative computation in continuous time systems (`mdlDerivatives`), flag=1
- Difference computation in discrete time systems (`mdlUpdate`), flag=2
- System output computation (`mdlOutputs`), flag=3, and
- Ending tasks (`mdlTerminate`), flag=9.

Note that this structure simulates (sample-to-sample) the system state equations. Firstly, the state equation (`mdlDerivatives`) $\dot{\mathbf{x}} = \mathbf{Ax} + \mathbf{Bu}$ is executed, and then the output equation (`mdlOutputs`) $\mathbf{y} = \mathbf{Cx} + \mathbf{Du}$ is executed. In the case of discrete time systems, the first equation to be executed is the differences equation (`mdlUpdate`) $\mathbf{x}[n+1]=\mathbf{A}\mathbf{x}[n]+\mathbf{B}\mathbf{u}[n]$.

Csfunc function: The template file `csfunc.m` contain the following statements. Note that it corresponds to a system with 2 states, 2 inputs, and 2 outputs.

```
>> type csfunc

function [sys,x0,str,ts] = csfunc(t,x,u,flag)
%CSFUNC An example M-file S-function for defining a continuous system.
%   Example M-file S-function implementing continuous equations:
%      x' = Ax + Bu
%      y  = Cx + Du
%
%   See sfuntmpl.m for a general S-function template.
%
%   See also SFUNTMPL.

%   Copyright 1990-2002 The MathWorks, Inc.
%   $Revision: 1.9 $

A=[-0.09   -0.01
    1          0];
B=[ 1   -7
    0   -2];
C=[ 0    2
    1   -5];
D=[-3    0
    1    0];

switch flag,
  %%%%%%%%%%%%%%%%%%
  % Initialization %
  %%%%%%%%%%%%%%%%%%
  case 0,
    [sys,x0,str,ts]=mdlInitializeSizes(A,B,C,D);
  %%%%%%%%%%%%%%%
  % Derivatives %
  %%%%%%%%%%%%%%%
  case 1,
    sys=mdlDerivatives(t,x,u,A,B,C,D);
  %%%%%%%%%%%
  % Outputs %
  %%%%%%%%%%%
  case 3,
    sys=mdlOutputs(t,x,u,A,B,C,D);
  %%%%%%%%%%%%%%%%%%%
  % Unhandled flags %
  %%%%%%%%%%%%%%%%%%%
  case { 2, 4, 9 },
    sys = [];
  %%%%%%%%%%%%%%%%%%%%
  % Unexpected flags %
  %%%%%%%%%%%%%%%%%%%%
  otherwise
    error(['Unhandled flag = ',num2str(flag)]);
end
% end csfunc
%
%=============================================================================
% mdlInitializeSizes
% Return the sizes, initial conditions, and sample times for the S-function.
%=============================================================================
%
function [sys,x0,str,ts]=mdlInitializeSizes(A,B,C,D)
sizes = simsizes;
sizes.NumContStates  = 2;
sizes.NumDiscStates  = 0;
sizes.NumOutputs     = 2;
sizes.NumInputs      = 2;
sizes.DirFeedthrough = 1;
sizes.NumSampleTimes = 1;
```

```
sys = simsizes(sizes);
x0  = zeros(2,1);
str = [];
ts  = [0 0];
% end mdlInitializeSizes
%
%=============================================================================
% mdlDerivatives
% Return the derivatives for the continuous states.
%=============================================================================
%
function sys=mdlDerivatives(t,x,u,A,B,C,D)
sys = A*x + B*u;
% end mdlDerivatives
%
%=============================================================================
% mdlOutputs
% Return the block outputs.
%=============================================================================
%
function sys=mdlOutputs(t,x,u,A,B,C,D)
sys = C*x + D*u;
% end mdlOutputs
```

To simulate an S function, drag the corresponding block to the model window. The `S-Function` block can be found in `Simulik` → `User-Defined Functions`. Double-click on the block to edit it and write "csfunc" in the "S-function name" space.

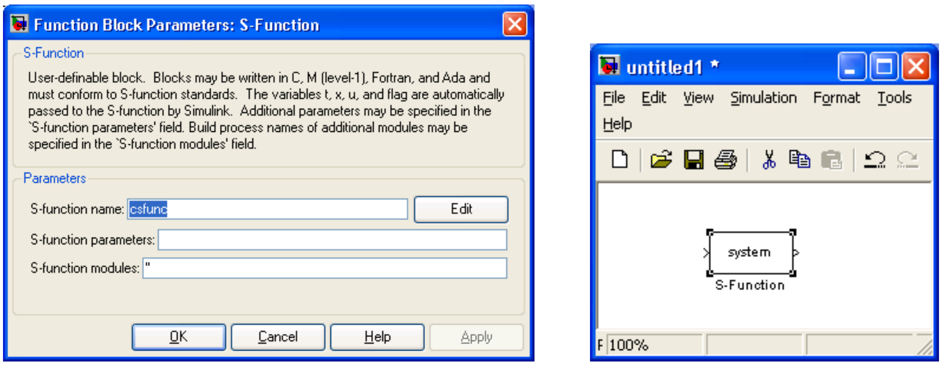


Fig. 19. Editing a S function

Complete the Simulink model with an excitation block (sine) and a Scope block. Run the simulation. Note that the simulation gives error because we are trying to excite a two input system with a one-dimensional input signal:

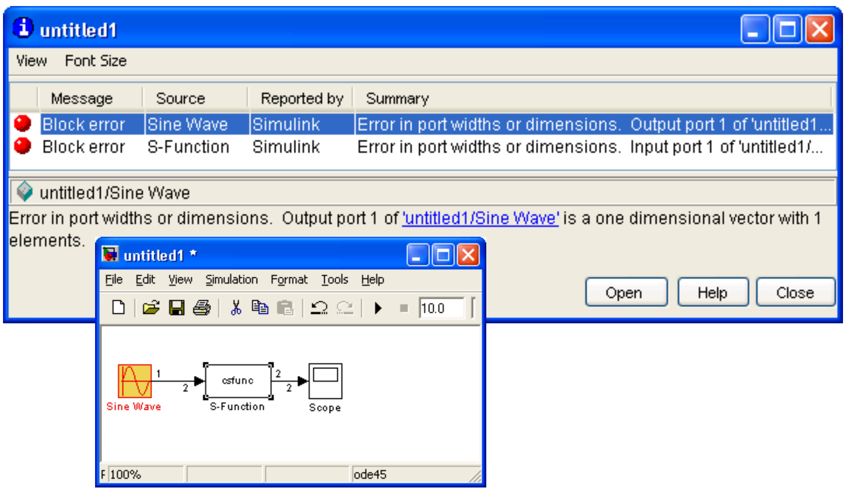


Fig. 20. Error due to the dimensions

To solve the problem drag a `Demux` block and run the simulation again. The result is now:

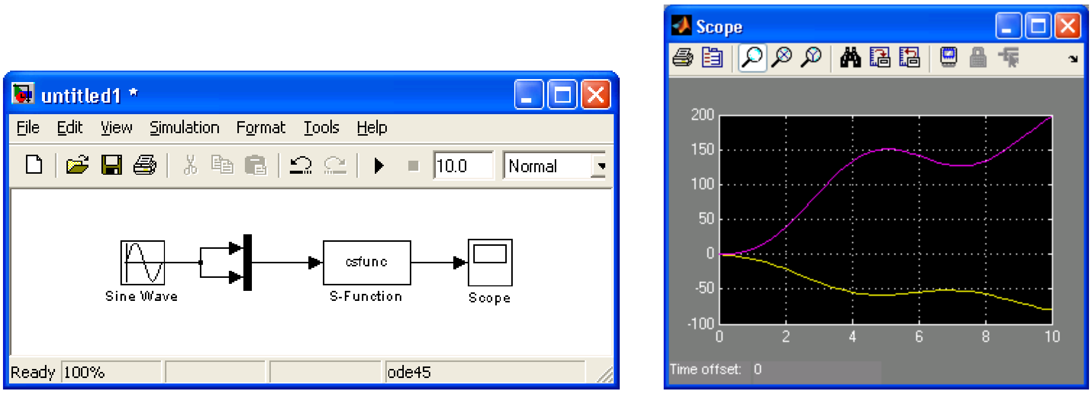


Fig. 21. Simulation of a 2 input 2 output system

Debugger: Simulink has its own *debugger*. Click on  to open it (go to Simulation→ Debug → Debug model in v8). If we had run the debugger before the simulation we had noticed the conflict in the ports dimension. See Fig. 22.

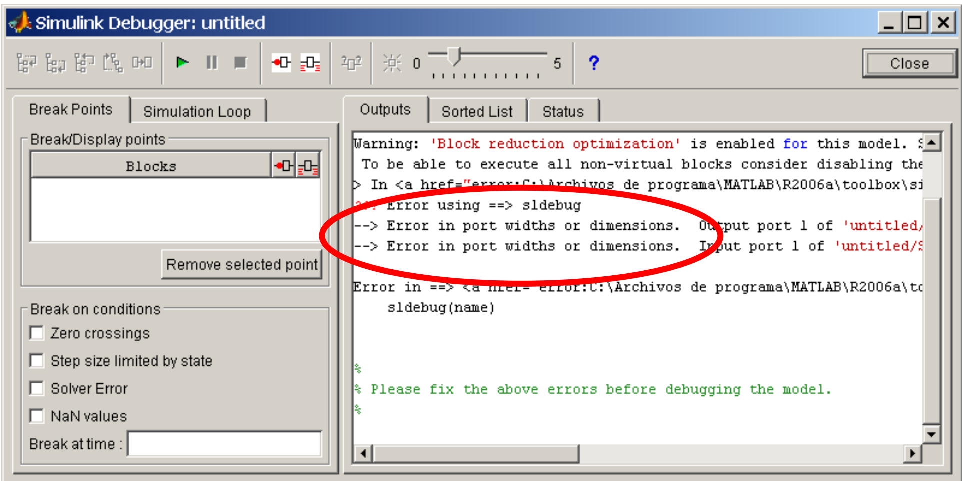


Fig. 22. *Debugger* in Simulink

3. Stateflow

Start: To start STATEFLOW it is necessary that SIMULINK is already opened. To create a new Stateflow model, drag the "Chart" block to a new model window and double-click on it.

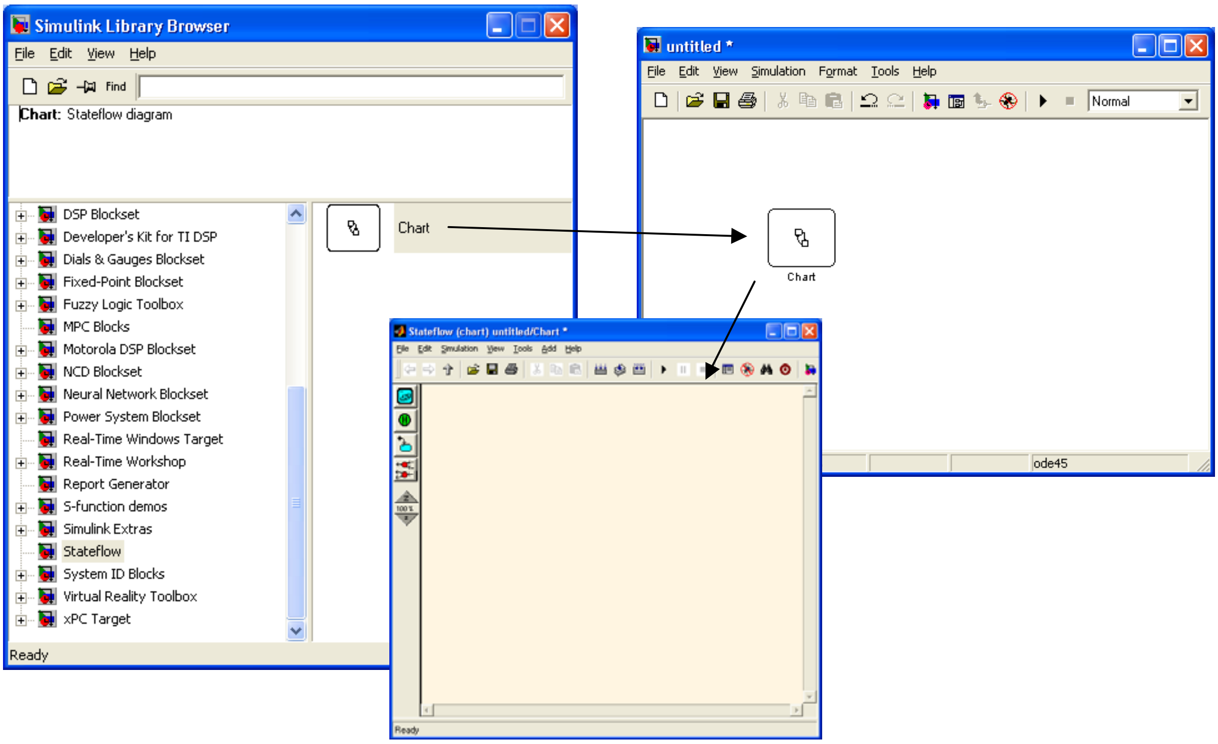
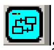
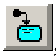
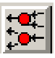


Fig. 23. Starting Stateflow

Palette: To create the state machine, drag the elements at the side of the Stateflow window. These constitutive elements are: States , Historic , Default transition , Connecting point  (or decision point). More recent versions include Truth table , Function  and Matlab Function .

Transitions are established by dragging the mouse between states and, to edit them, click on them and write on the "?" symbol.

Example 2. Lamp and timer.

We want to simulate the two states ("encendido" and "apagado") of a particular device. The device is in "encendido" state if the external variable "hora" is greater than 12. The state is "apagado" if "hora" is smaller or equal to 12. The default state is "apagado".

Firstly, drag two state blocks to the stateflow window and label them "apagado" and "encendido" respectively. Insert a default transition over "apagado" to indicate that it is the default state. Draw the transitions between the two states and write the corresponding Boolean conditions. (Remark: Boolean conditions are between [ ] while actions to execute during a transition are written between { }).

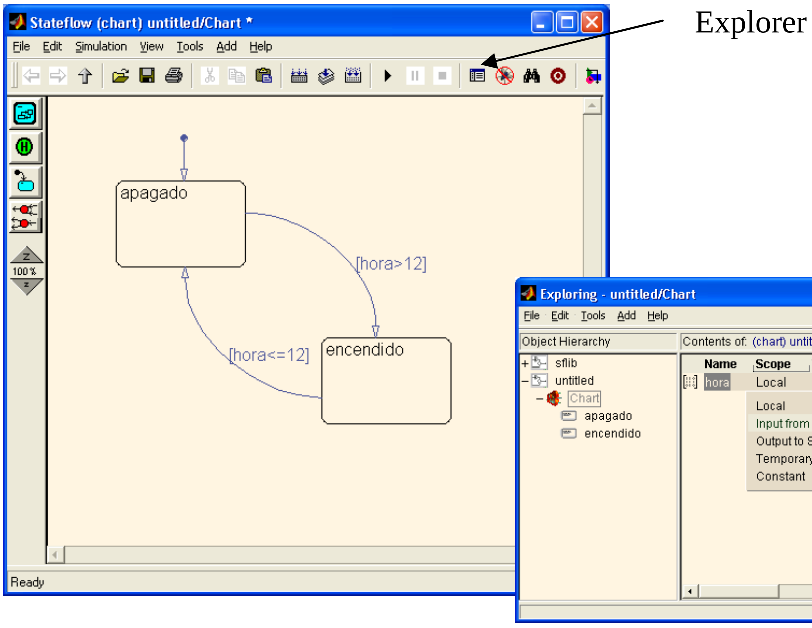


Fig. 24. Building a stateflow model (v6)

To indicate that variable "hora" is external to the stateflow chart, select the explorer (click on  in the toolbar or select `View` → `Model Explorer` in the menu bar). In the explorer, select `Add` → `Data` and set up the following parameters: `Name=hora`, `Scope=Input from Simulink` (or `Input`, depending on the particular version). Note that input "hora" appears now in the block chart of the Simulink model.

The model explorer presents many interesting options (see, for instance, the model advisor).

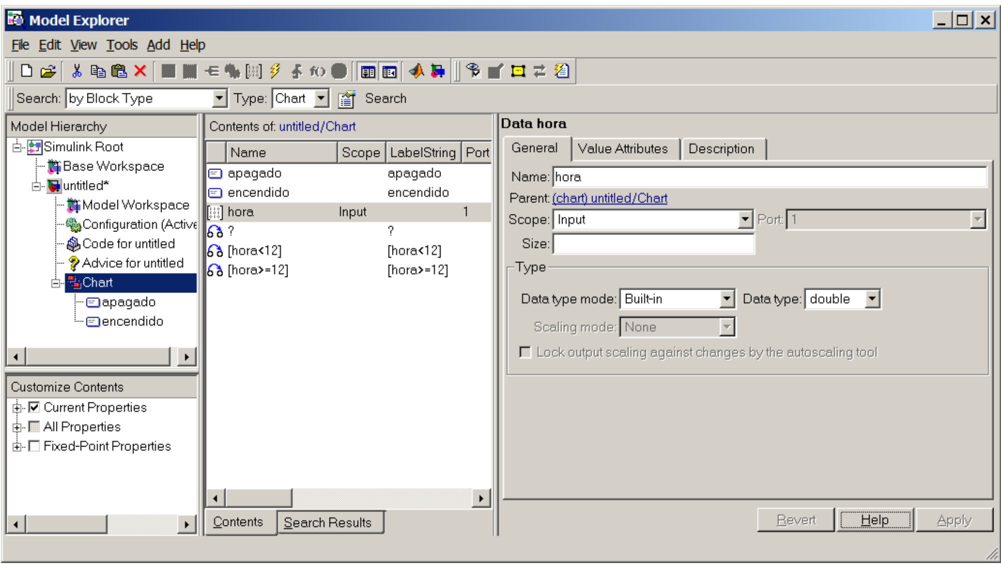


Fig. 25. Model explorer in v7

Now, generate a Simulink variable varying from 0 to 24 and excite the chart block with it. For instance, "hora" can be a sinus of amplitude 12, frequency 0.5Hz and offset 12. Final simulation time is 10s and sampling period is fixed and equal to 0.001.

To run the simulation, click on the corresponding button or select `Simulation` → `Start`. In the Matlab command window will appear some messages regarding the building of the state machine

During the simulation, you can see which one of the two states is activated at each time.

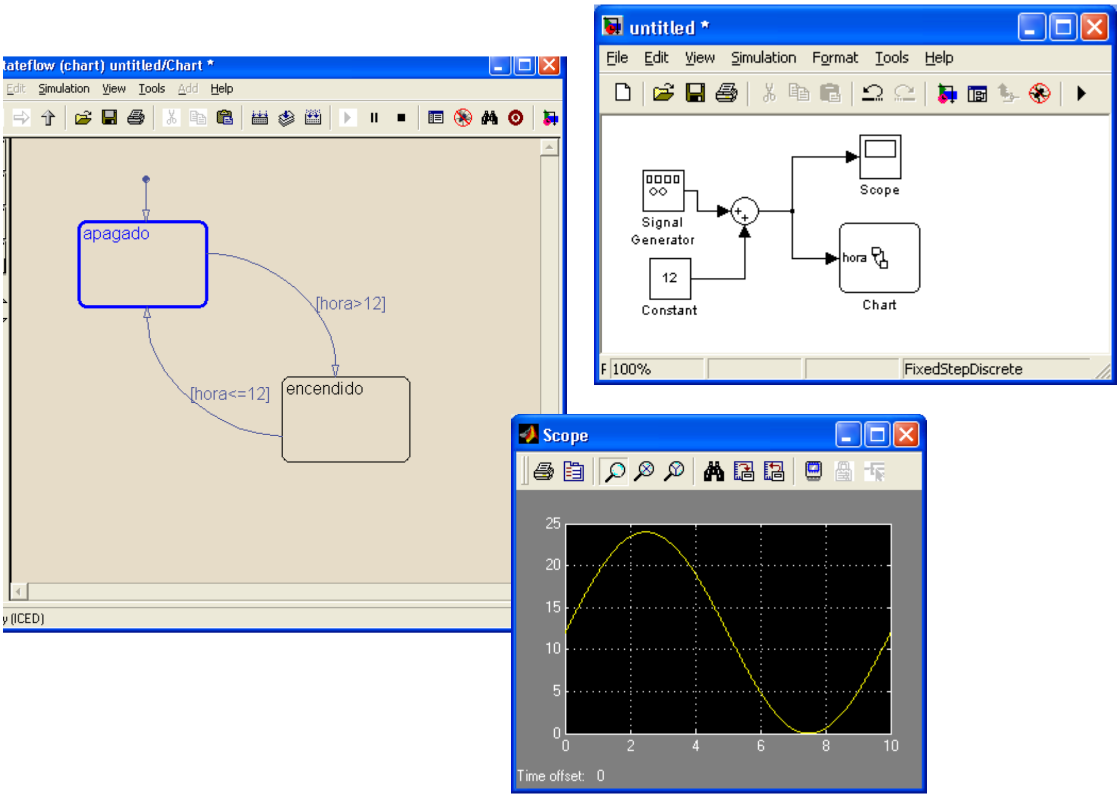


Fig. 26. Stateflow chart execution

Actions during the states: They can be executed when entering the state (entry: or en:), during the state (during: or du:), or when leaving the state (exit: or ex:).

To execute a Matlab function during the states you must use the command ml, for example, en: a=ml('sin(x)') or en: a=ml('sin(%f)',x), if x is a local variable of Stateflow.

4. Animation effects with Simulink

Next example illustrates how to get an animation effect by means S-functions and GUI tools.

Example 3. Bouncing ball.

Firstly, create a Simulink model (pilota.mdl) with the following blocks:

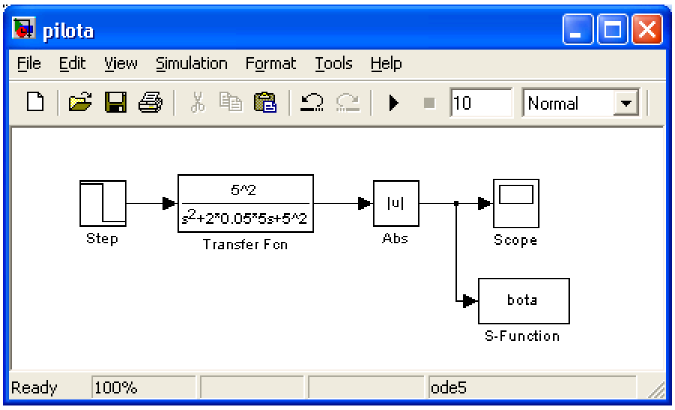


Fig. 27. Excitation generation

The Step block and the Transfer Function block contain the following parameters:

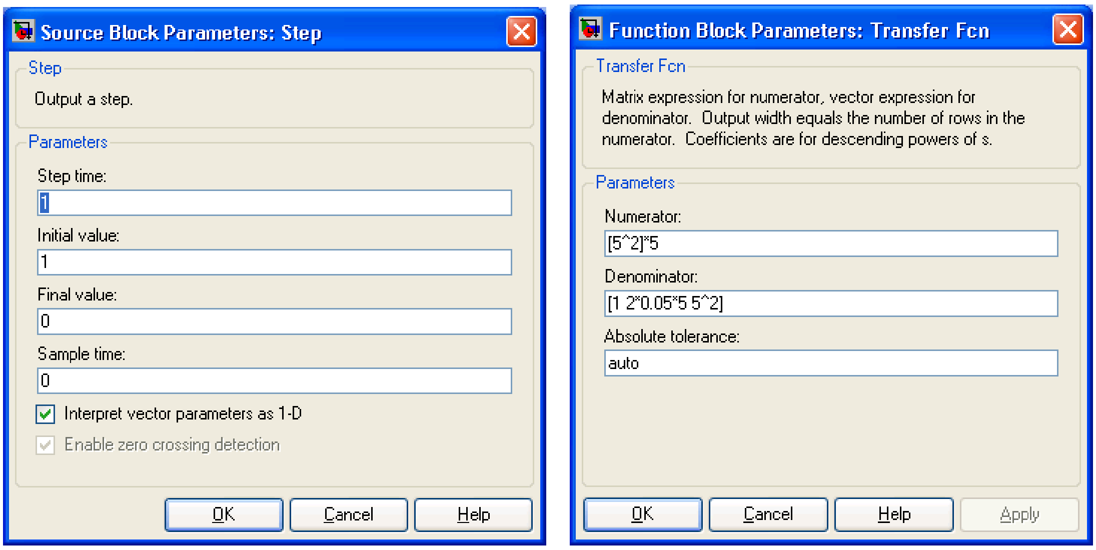


Fig. 28. Parameters of Step and Transfer Function

The animation effect is implemented by the following S-function block:

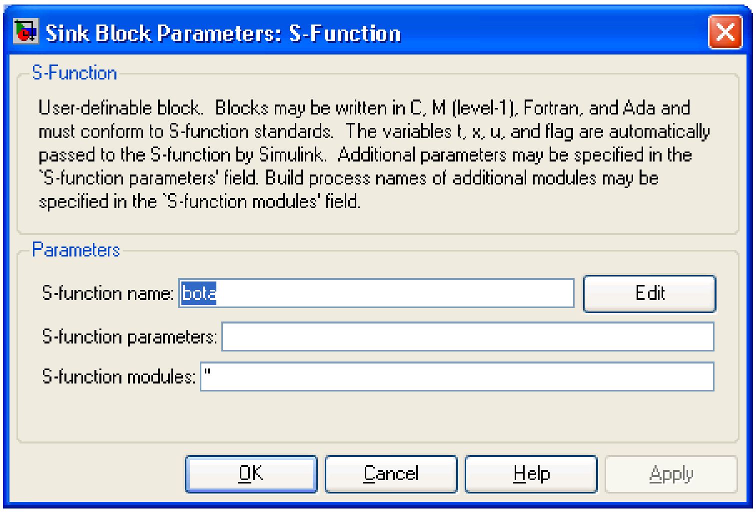
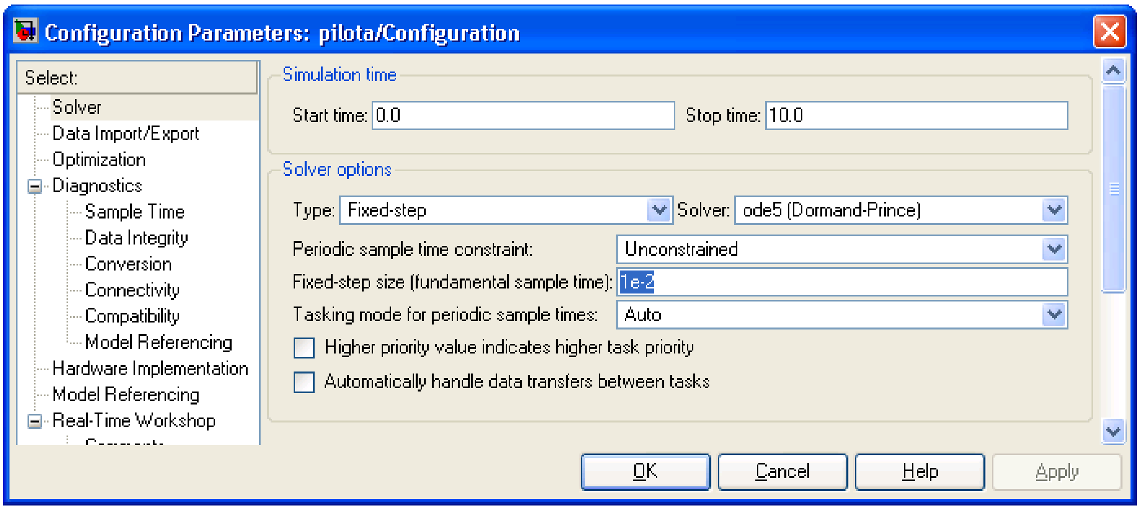


Fig. 29. S function parameters

where bota.m contains the following instructions:

```
function [sys,x0] = bota(t,x,u,flag)
%
%BOTA  Animació:  jo tinc una pilota que bota, bota, bota...
%

global figH bolaH

if not(isempty(flag)) & flag==0  %inicialització
    %
    figH=figure('Name','pilota que bota','numbertitle','off');
    %
    radi=1;phi=linspace(0,2*pi);
    bola=radi*exp(j*phi)+j;
    bolaH=patch(real(bola),imag(bola),'b');
    set(bolaH,'userdata',bola)
    axis([-5 5 0 10]),axis('square')
    %
    sys=[0 0 0 1 0 0];  %dimensions 0-ve 1-in 0-out
    x0=[];
    %
end

if not(isempty(flag)) & flag==2  %actualització bola
    %
    if any(get(0,'children')==figH)
        posic=u;
        bola=get(bolaH,'userdata');
        nova_bola=(bola+j*posic);
        set(bolaH,'xdata',real(nova_bola),'ydata',imag(nova_bola),'erase','normal');
    end
    %
    %sortida.  No torna res
    sys=[];
    x0=[];
    drawnow;
end

if not(isempty(flag)) & flag==9  %terminació
    close
end
```

Adjust the simulation parameters (Simulation → Configuration Parameters) to the following:



Open the Scope block and click on the Play button. The simulation results are:

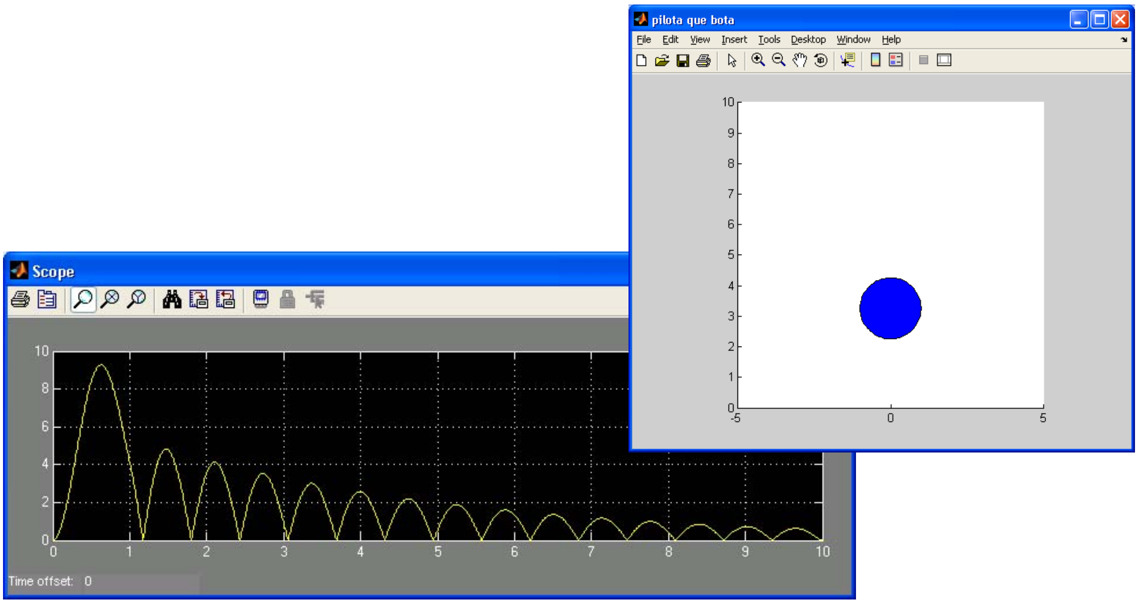


Fig. 30. Bouncing ball