Lecture 2

Textbooks

Main textbook:
The Art of Hybrid Systems
robotics.eecs.berkeley.edu/~sastry/ee291e/book.pdf

Good complementary lecture notes (chp. 1 - 4)
robotics.eecs.berkeley.edu/~sastry/ee291e/lygeros.pdf

Other textbooks:

A. van der Schaft and H. Schumacher. An Introduction to Hybrid Dynamical Systems. Lecture Notes in Control and Information Sciences 251, Springer-Verlag, 2000.

D. Liberzon. Switching in Systems and Control. Systems & Control: Foundations and Applications series. Birkhauser, Boston, 2003.

Evaluate the following advice...

Stefan Sagmeister

Be careful whose advice you take.

Be passionate about your education. Work on finding your passions.

View work as a hobby. Enjoy it (it’s your hobby after all).

Don’t strive for success. Avoid mediocracy.

Worrying solves nothing†. Act or forget.

Don't waste time on jealousy. Everybody who is honest is interesting†

Money does not make me happy. Neither does makeup.

Trying to look good limits my life†. Appreciate and enjoy your body.

Everybody thinks they are right†.

Traveling opens new perspectives. Travel alone (once in a while).

Learn a foreign language. Learn think mathematically.

† Stefan Sagmeister

Be careful whose advice you take.

Be passionate about your education. Work on finding your passions.

View work as a hobby. Enjoy it (it’s your hobby after all).

Don’t strive for success. Avoid mediocracy.

Worrying solves nothing†. Act or forget.

Don't waste time on jealousy. Everybody who is honest is interesting†

Money does not make me happy. Neither does makeup.

Trying to look good limits my life†. Appreciate and enjoy your body.

Everybody thinks they are right†.

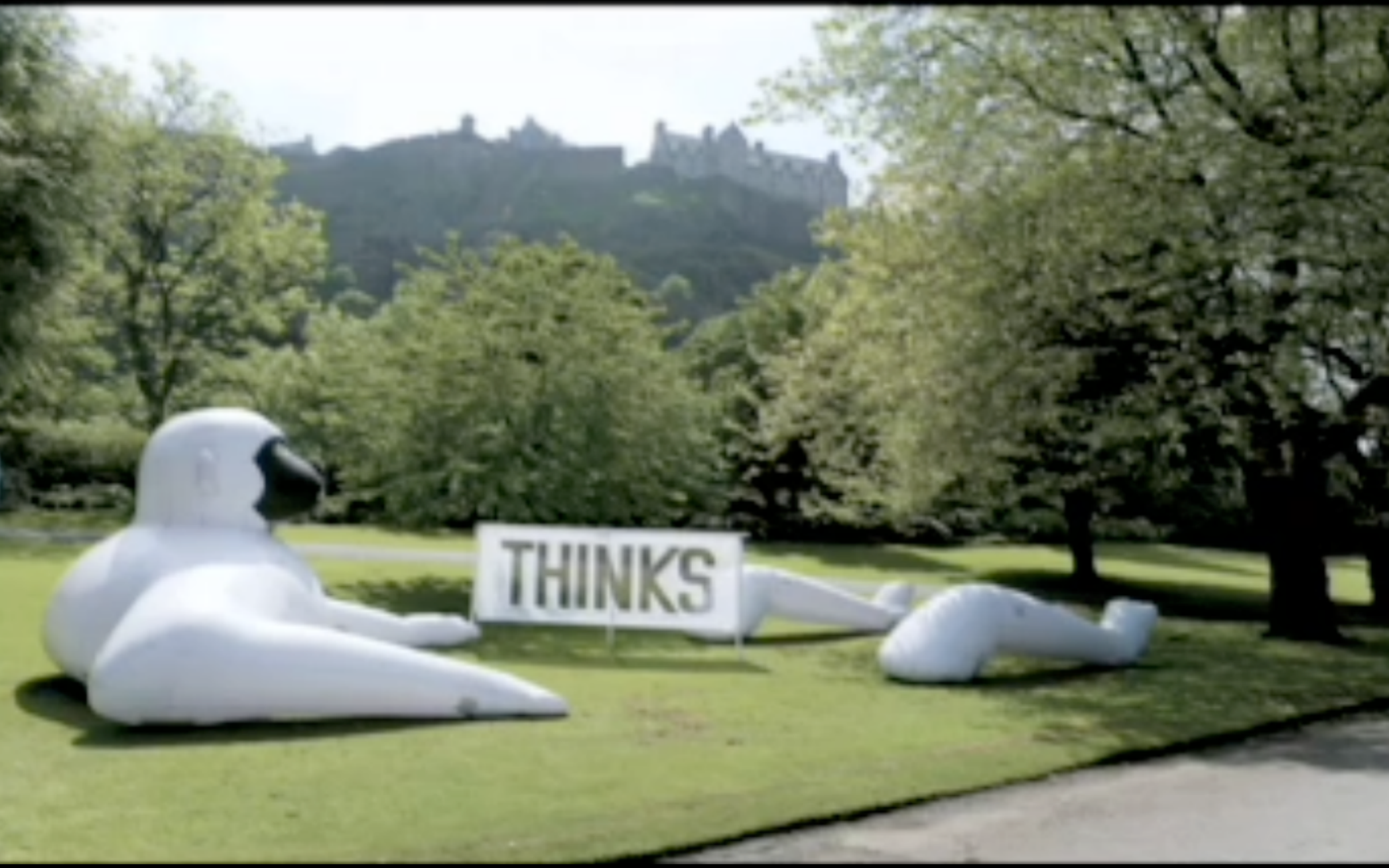
Traveling opens new perspectives. Travel alone (once in a while).

Learn a foreign language. Learn think mathematically.

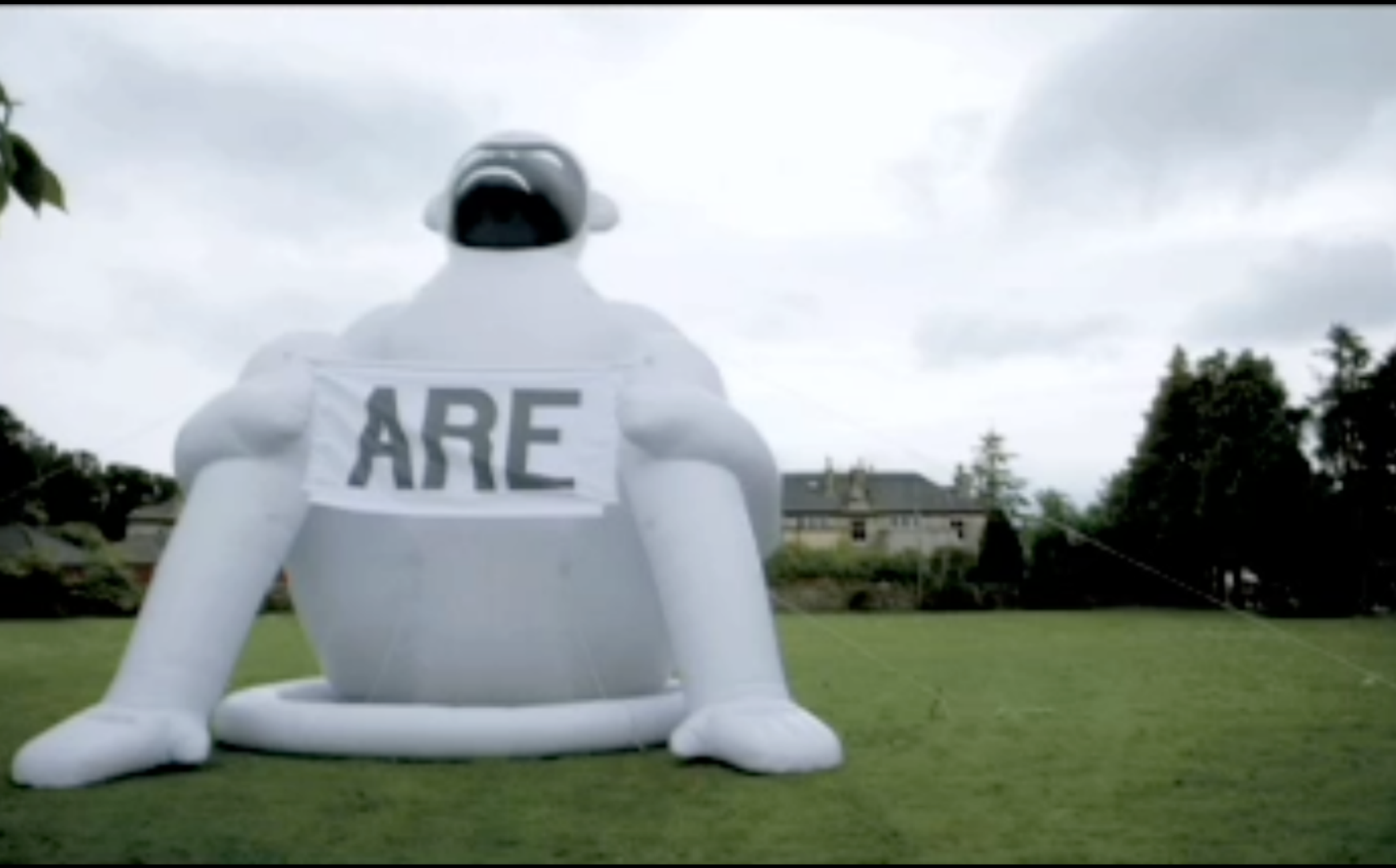
† Stefan Sagmeister

Inflatable monkey in Scotland (Stefan Sagmeister)


ALWAYS

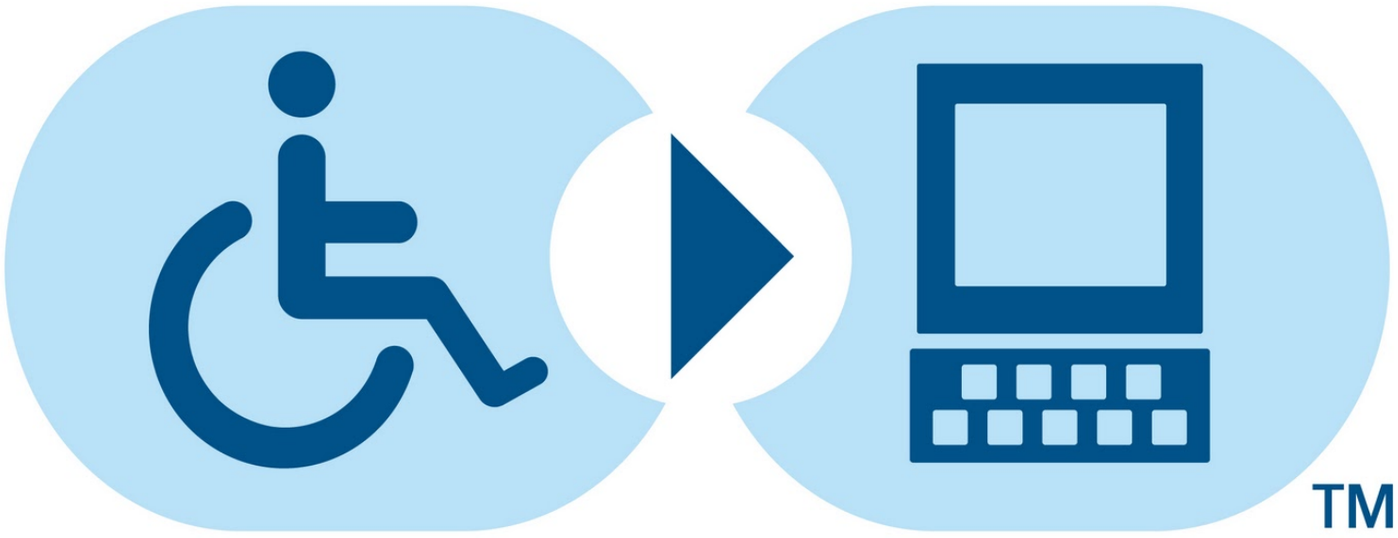

THINKS


THEY


ARE


RIGHT

...from an engineering/science perspective…



Collect data +
Develop models

If we have data, let's look at data.

If all we have are opinions, let's go with mine.

– Jim Barksdale, former Netscape CEO

In God we trust; all others must bring data

– W. Edwards Deming, statistician, professor, author, and consultant

Be careful whose advice you take.

Be passionate about your education. Work on finding your passions.

View work as a hobby. Enjoy it (it’s your hobby after all).

Don’t strive for success. Avoid mediocracy.

Worrying solves nothing†. Act or forget.

Don't waste time on jealousy. Everybody who is honest is interesting†

Money does not make me happy. Neither does makeup.

Trying to look good limits my life†. Appreciate and enjoy your body.

Everybody thinks they are right†. Use technology and learn from data + models.

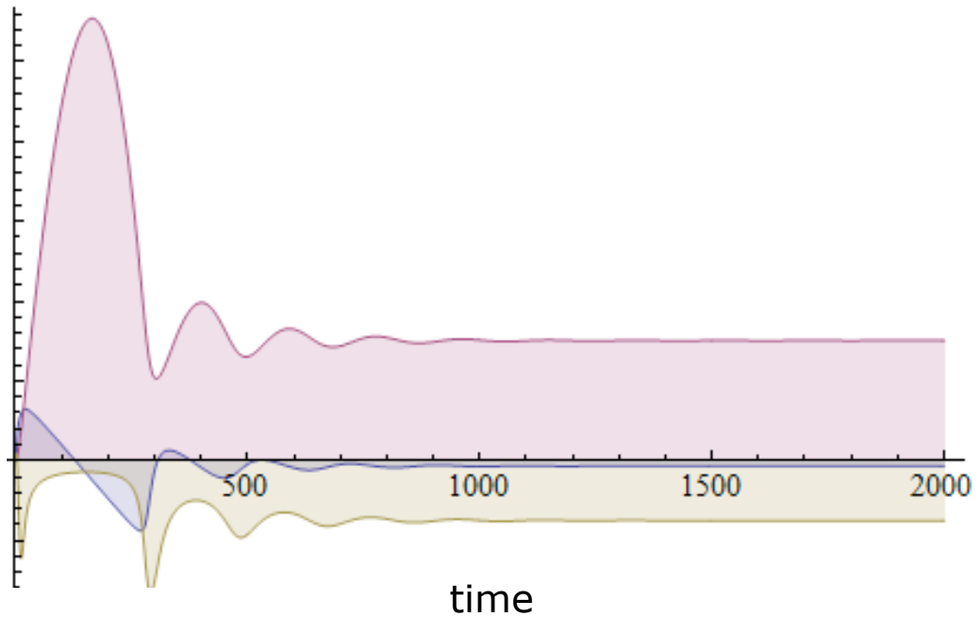
Traveling opens new perspectives. Travel alone (once in a while).

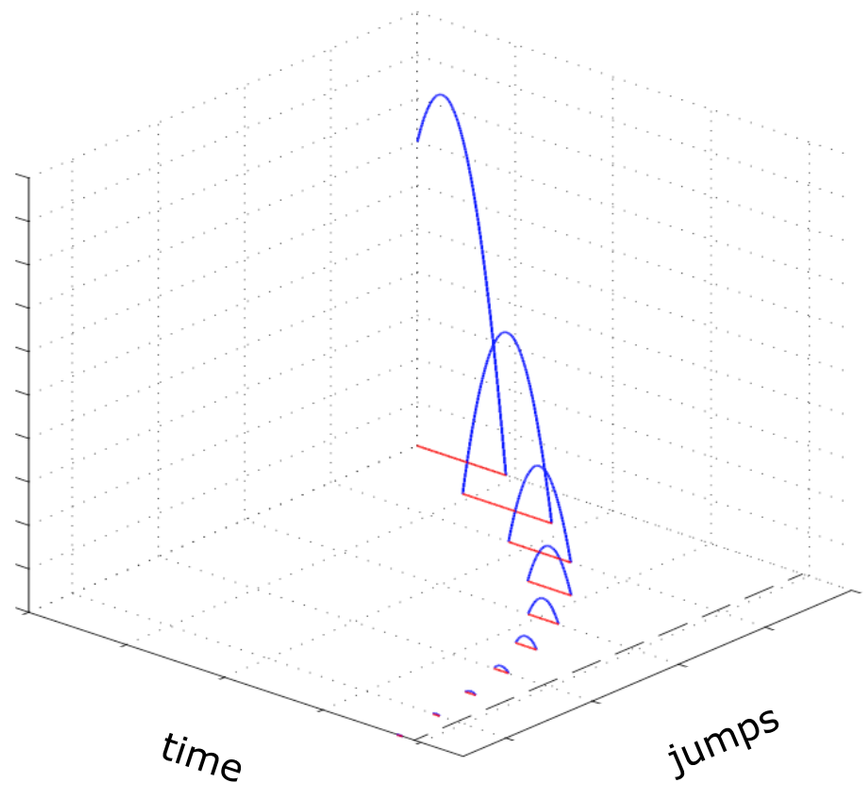
Learn a foreign language. Learn think mathematically.

† Stefan Sagmeister

Review

- State of the art modeling technique (characterize data on more sophisticated phenomena)
- Real love is hybrid! Stable? No! Why? Continuous + discrete dynamics.
- Other examples of hybrid systems
- Reality is less smooth than a set of differential eqs
- Notation, classification of dynamical systems

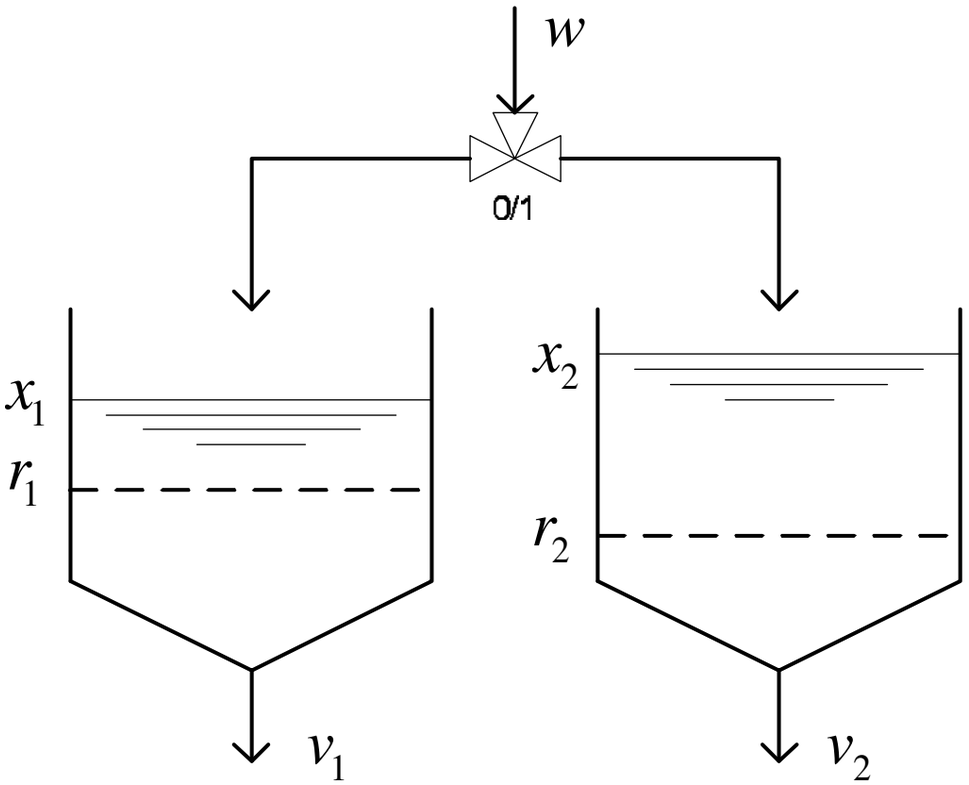


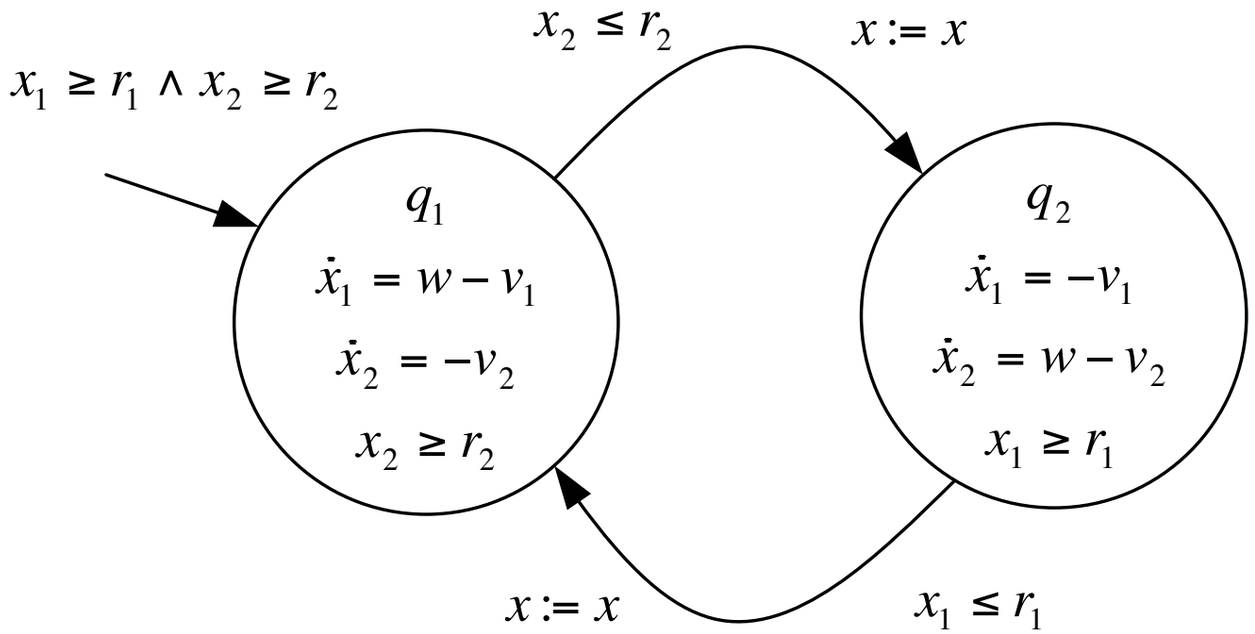


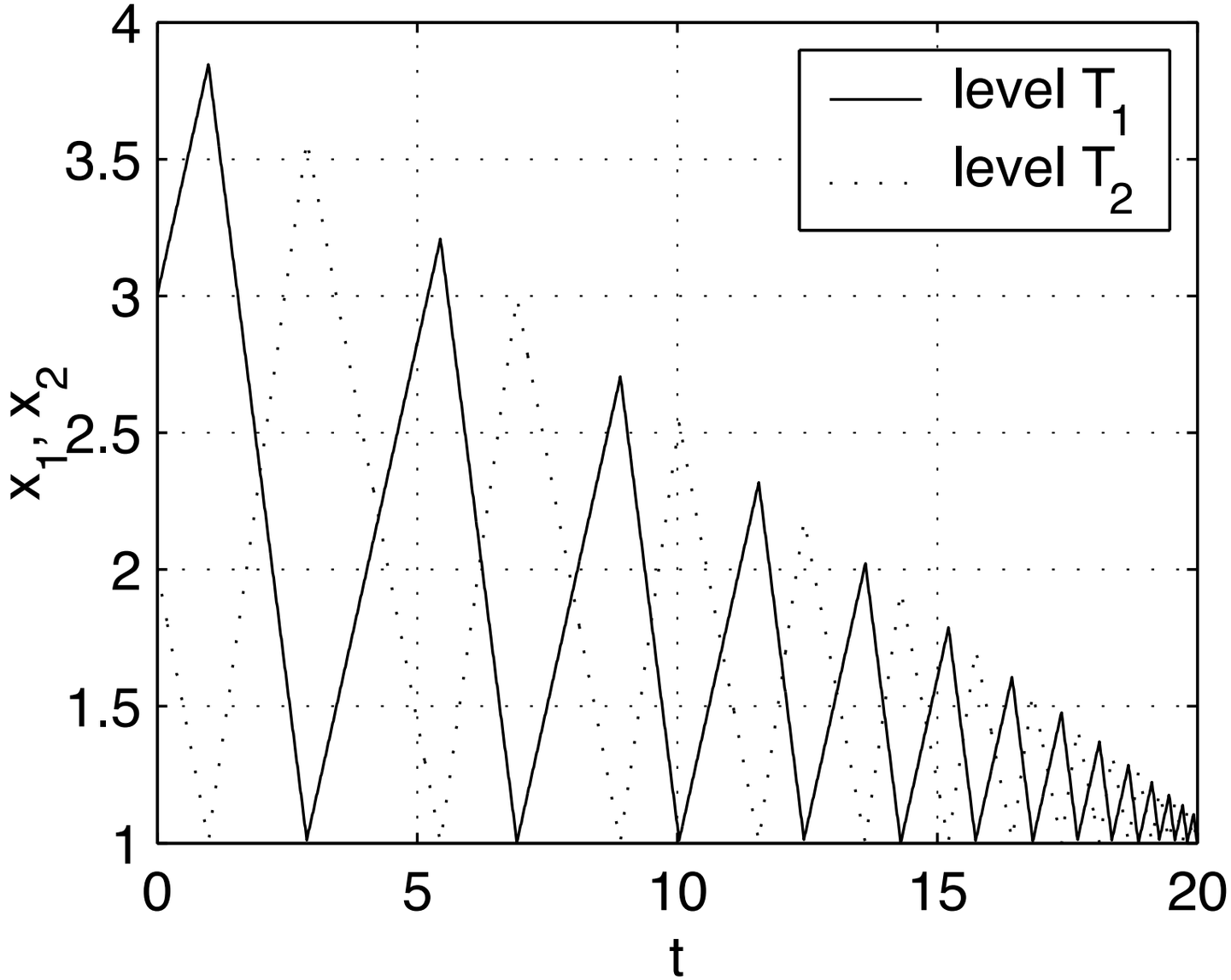
Today

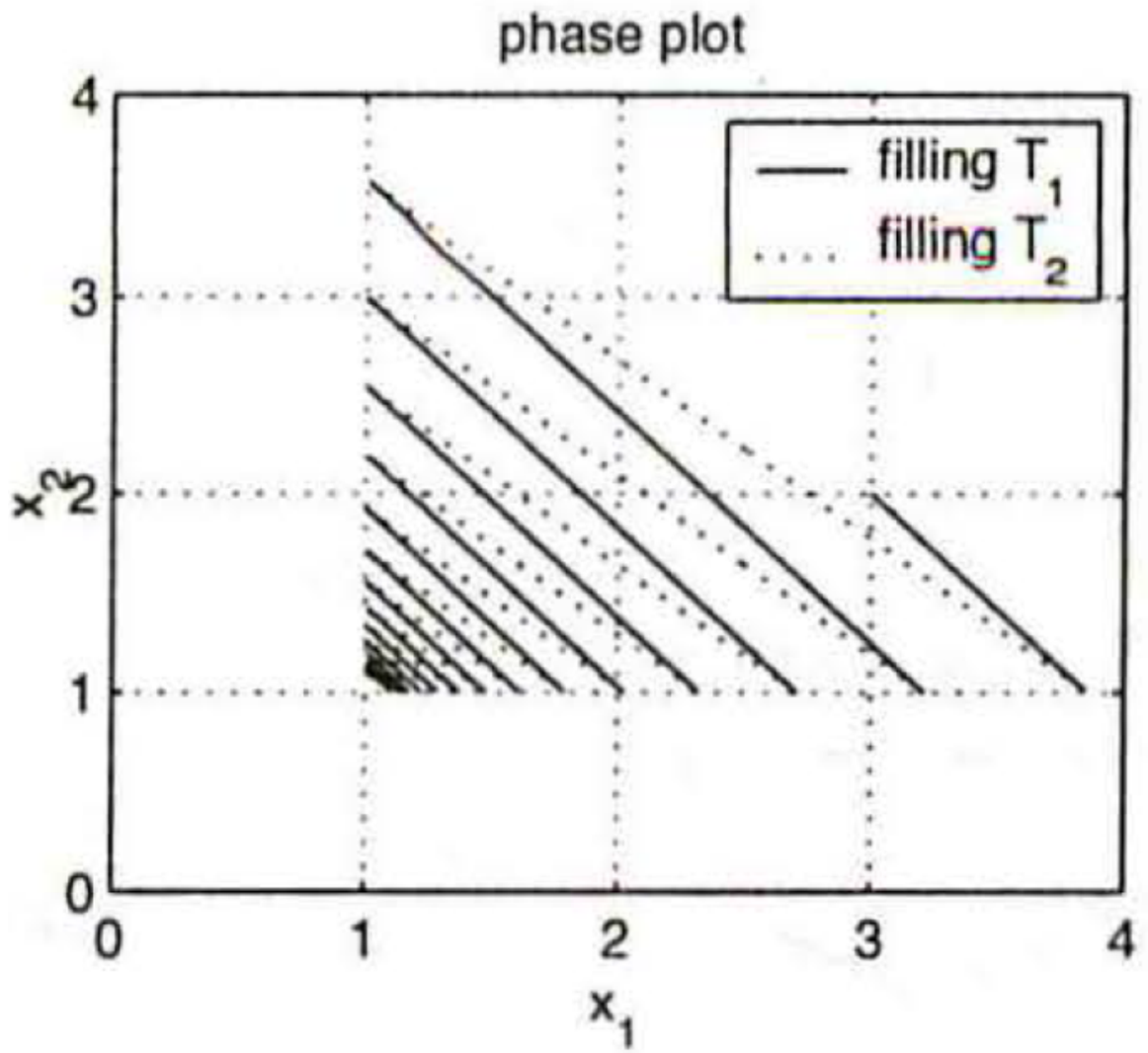
- Hybrid automata (deterministic case)
  - Definitions
  - Time sets + Executions
- Classification of solutions
- Next class: existence of solutions

Tank example






level T_1
level T_2
x_1, x_2
t
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20


phase plot
filling T_1
filling T_2
x_2
x_1
0
1
2
3
4

Simulating Hybrid Systems

- MATLAB’s Simulink
    - suitable for a small number of discrete modes
    - difficult to recover hybrid model
- Stateflow
    - good for large numbers of discrete modes and complex transitions
    - poor integration between continuous and discrete
- SHIFT
    - very good semantics (easily understandable), poor numerical algorithms
- Modelica
    - very good numerical algorithms
    - very convenient for large models with interconnected components
    - difficult to recover hybrid model

- MATLAB’s Simulink
    - suitable for a small number of discrete modes
    - difficult to recover hybrid model
- Stateflow
    - good for large numbers of discrete modes and complex transitions
    - poor integration between continuous and discrete
- SHIFT
    - very good semantics (easily understandable), poor numerical algorithms
- Modelica
    - very good numerical algorithms
    - very convenient for large models with interconnected components
    - difficult to recover hybrid model

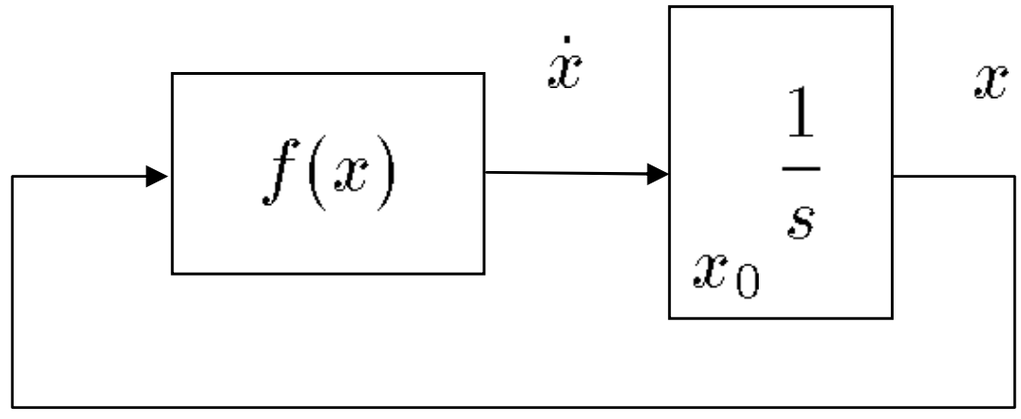
MATLAB's Simulink

Simulink

$$\dot{x} = f(x) \qquad x(0) = x_0$$

1. What you see: graphical user interface to build models of dynamical systems

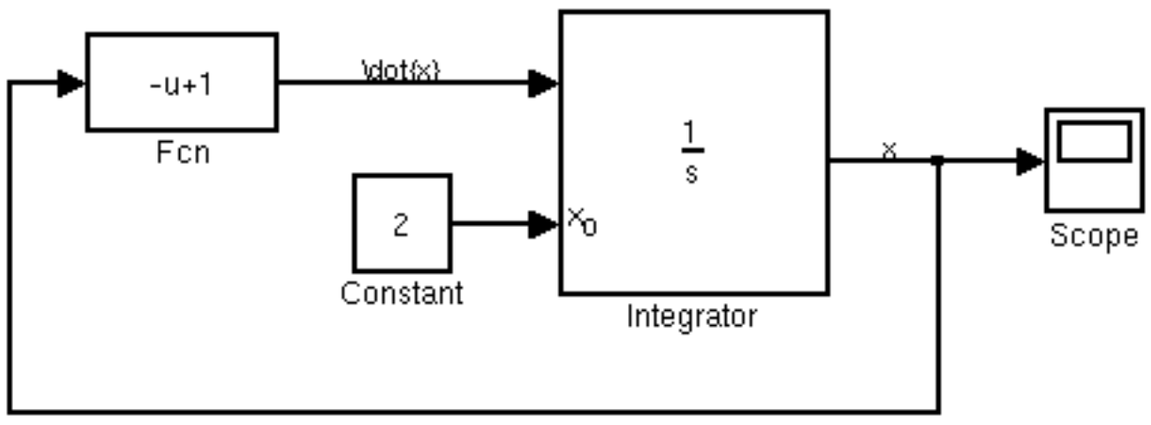
$$x(t) = x_0 + \int_0^t f(x(\tau))d\tau \quad \Leftrightarrow$$

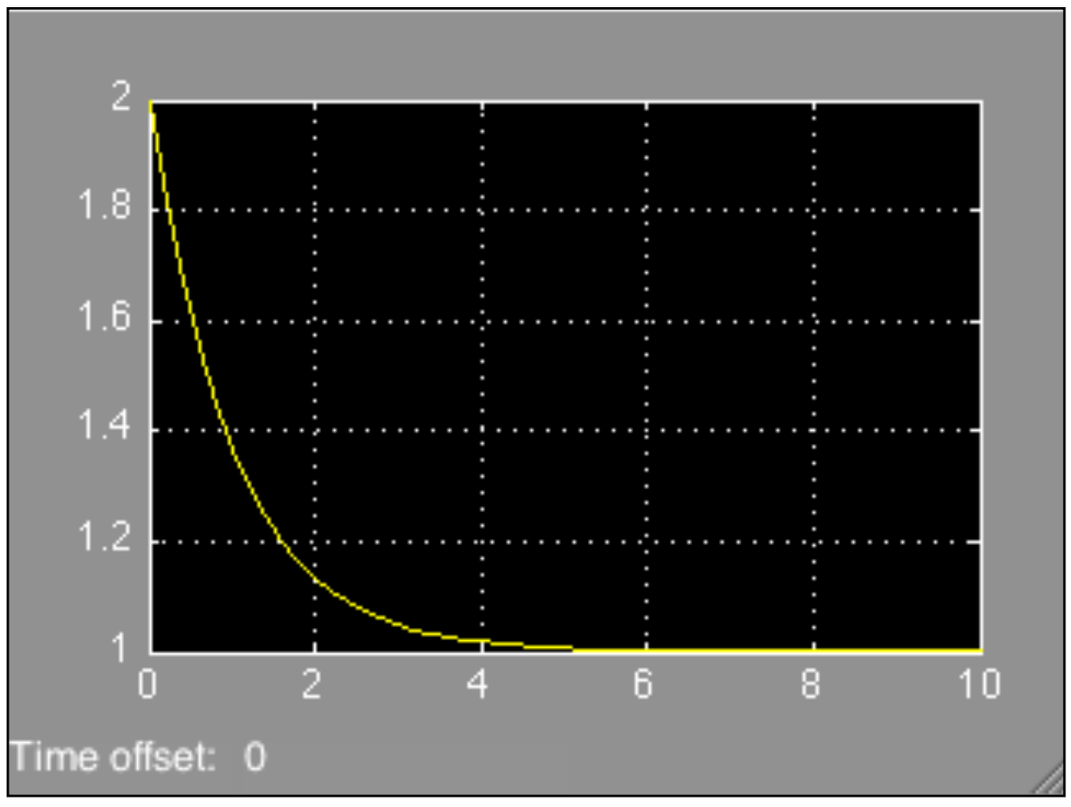


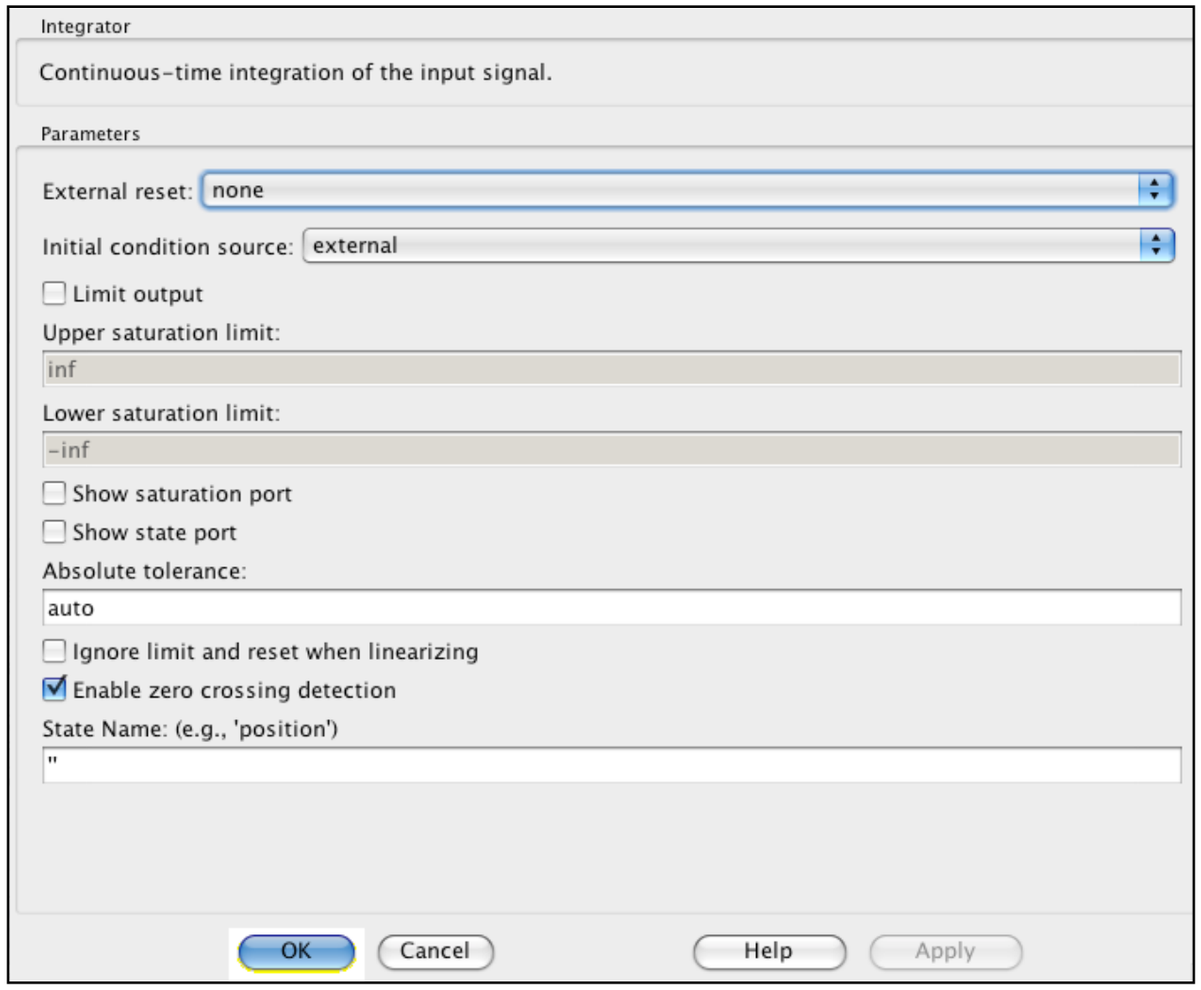
2. What's behind: numerical solver of ODEs with zero-crossing detection

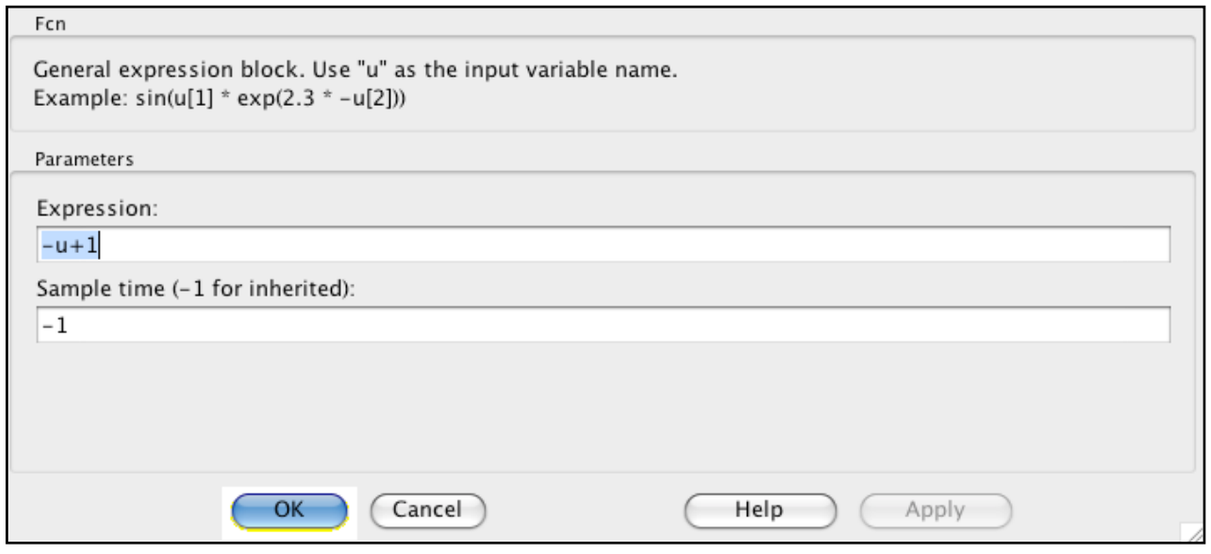
ODEs with initial conditions

$$\begin{aligned} \dot{x} &= -x + 1 \\ x(0) &= 2 \end{aligned}$$

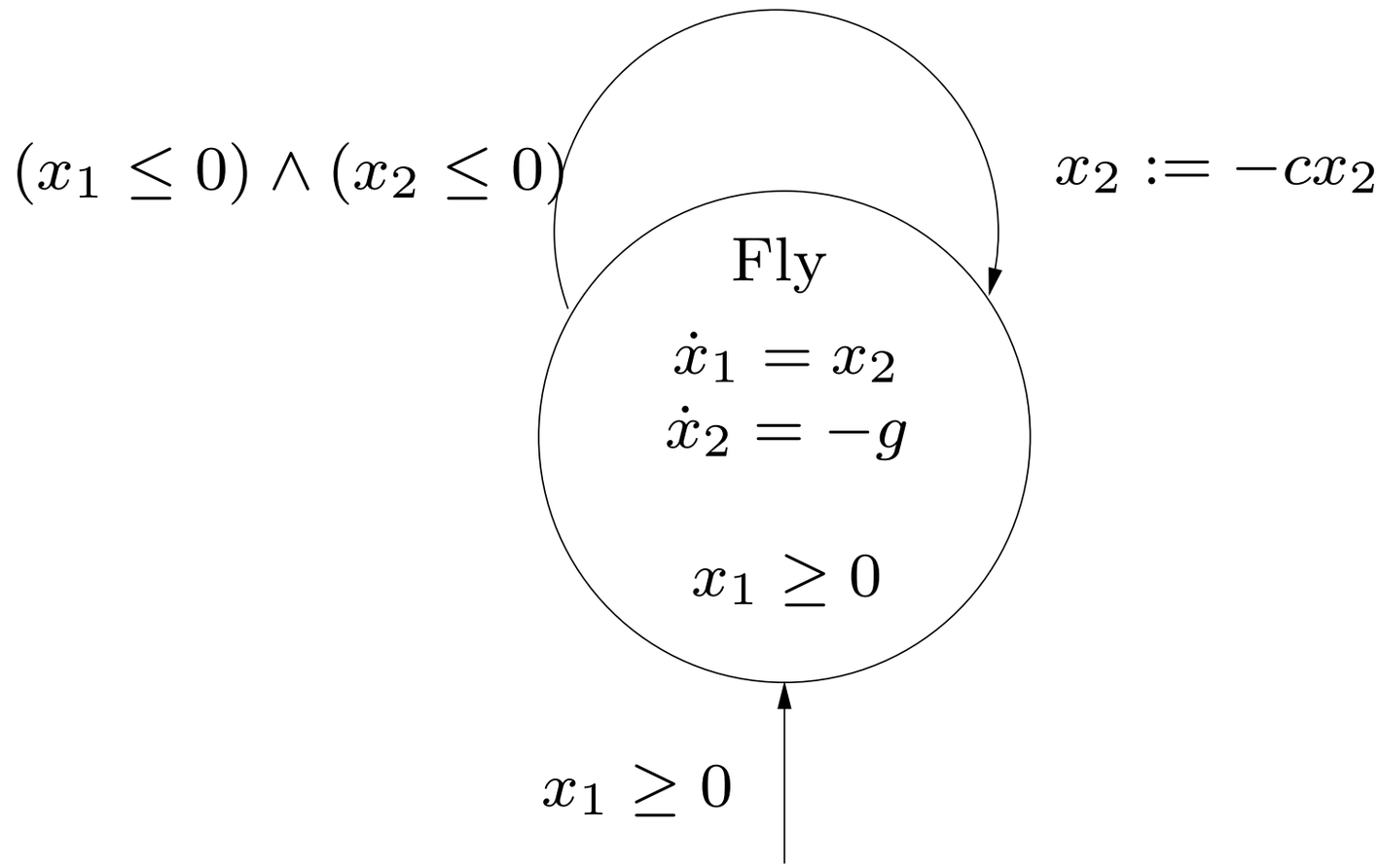




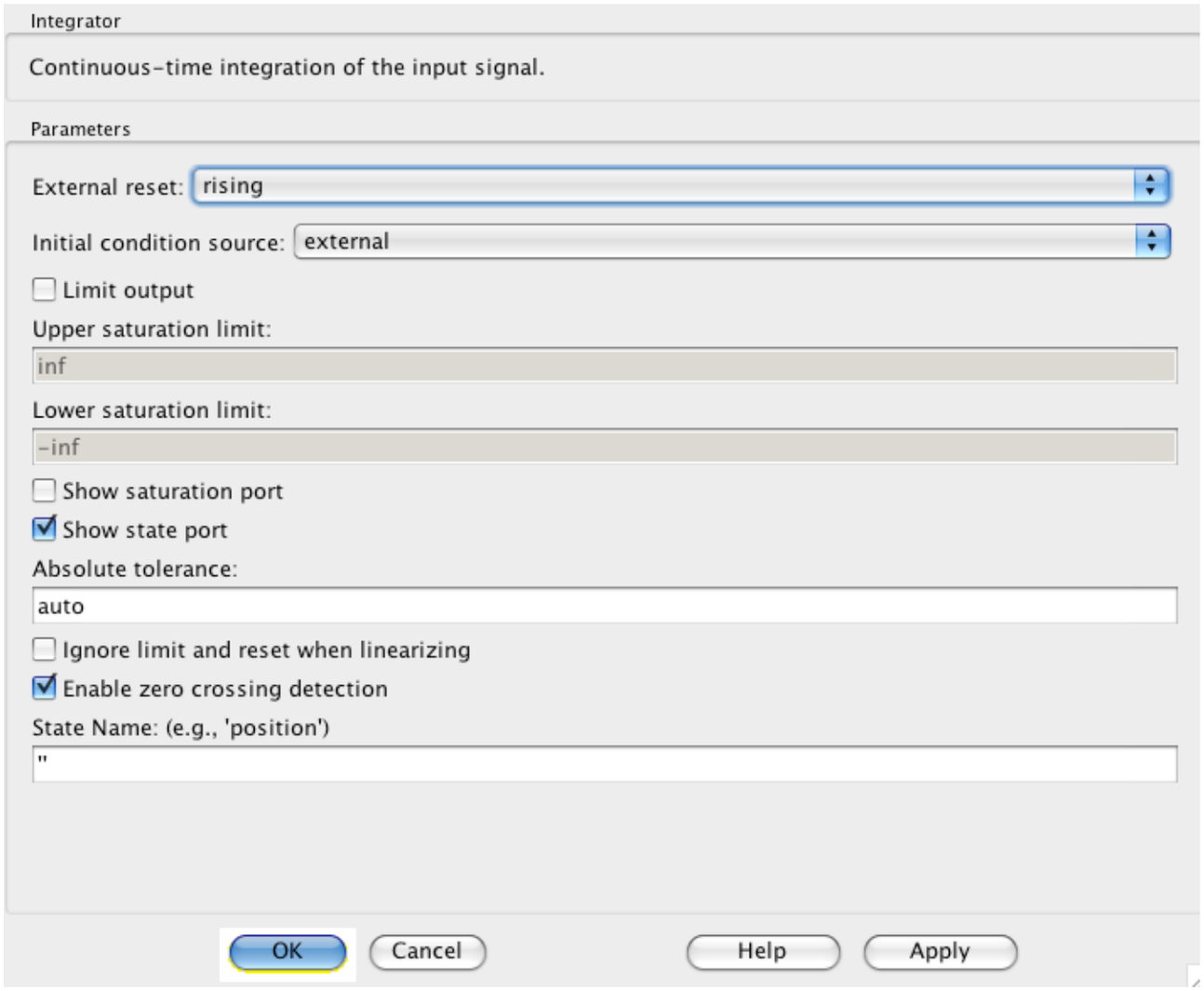


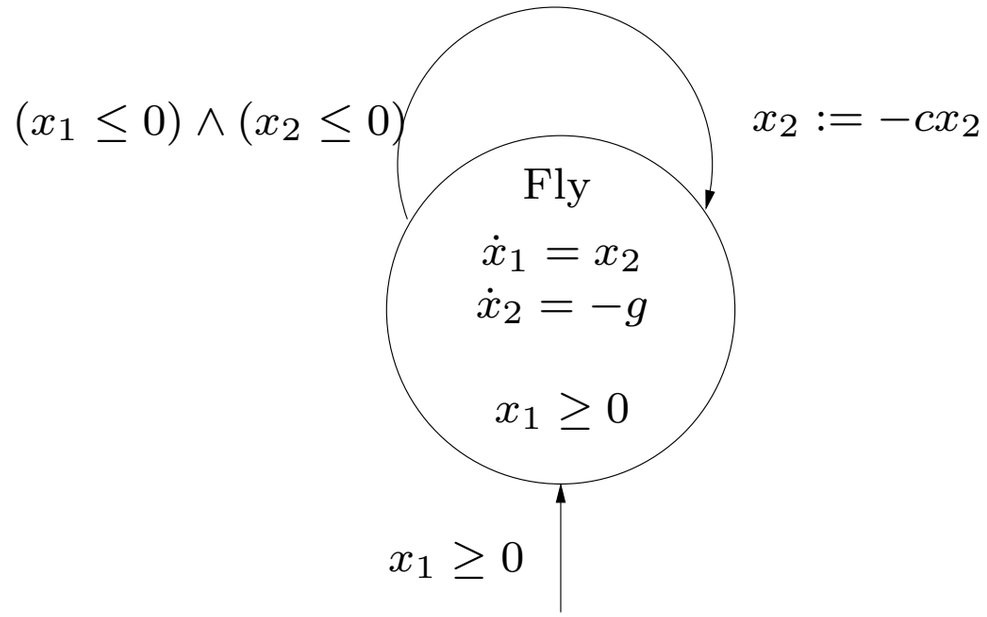


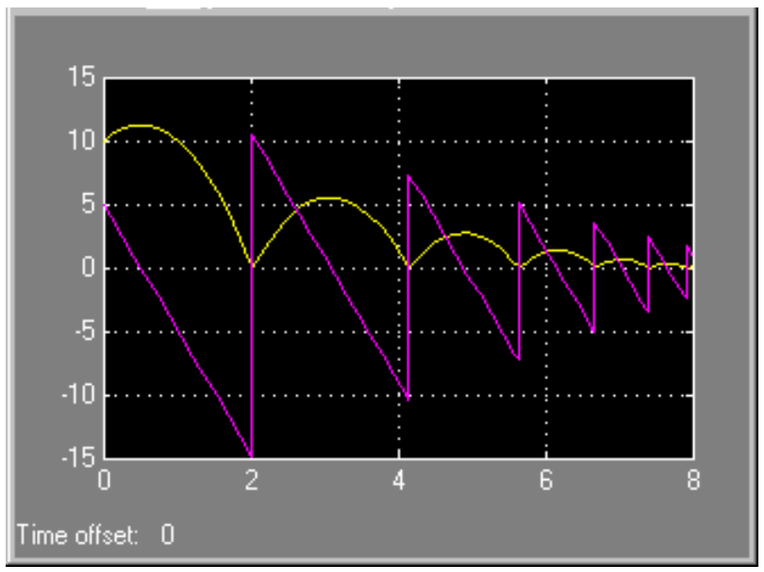
Bouncing ball

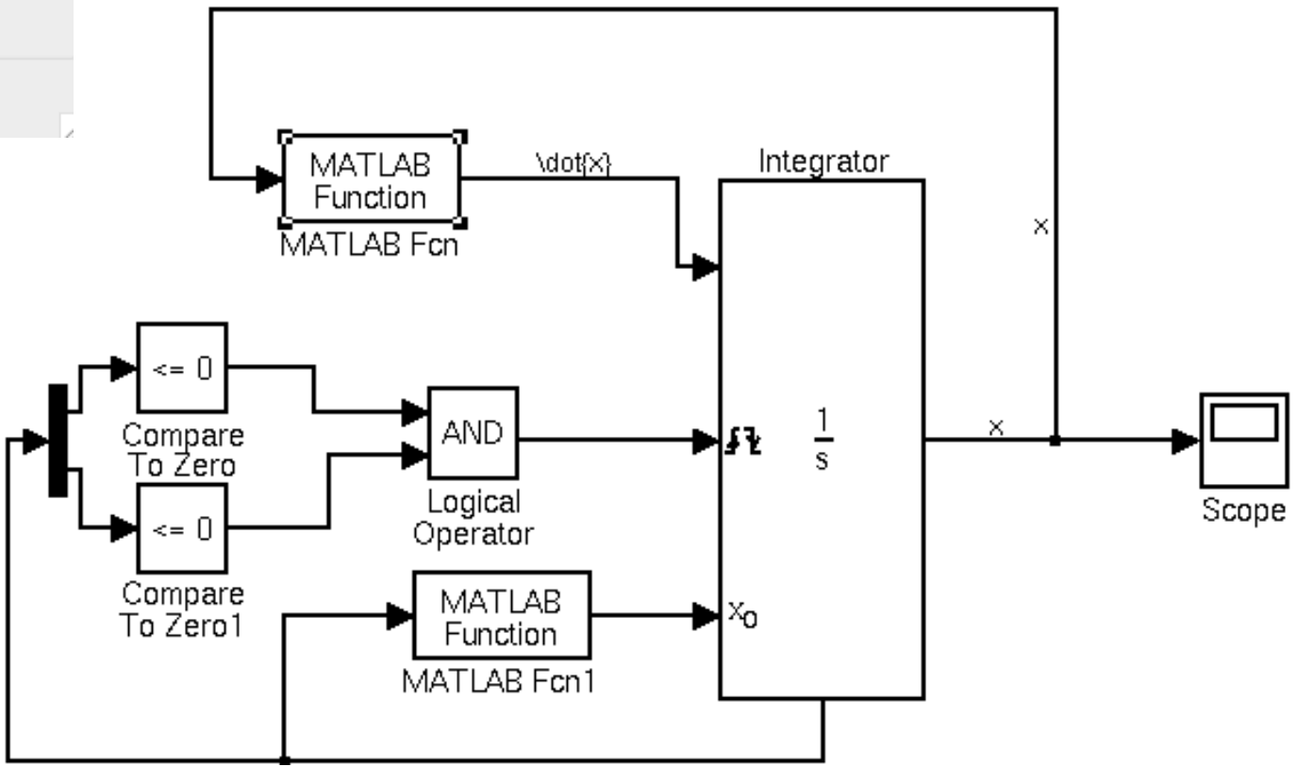


ODEs with resets



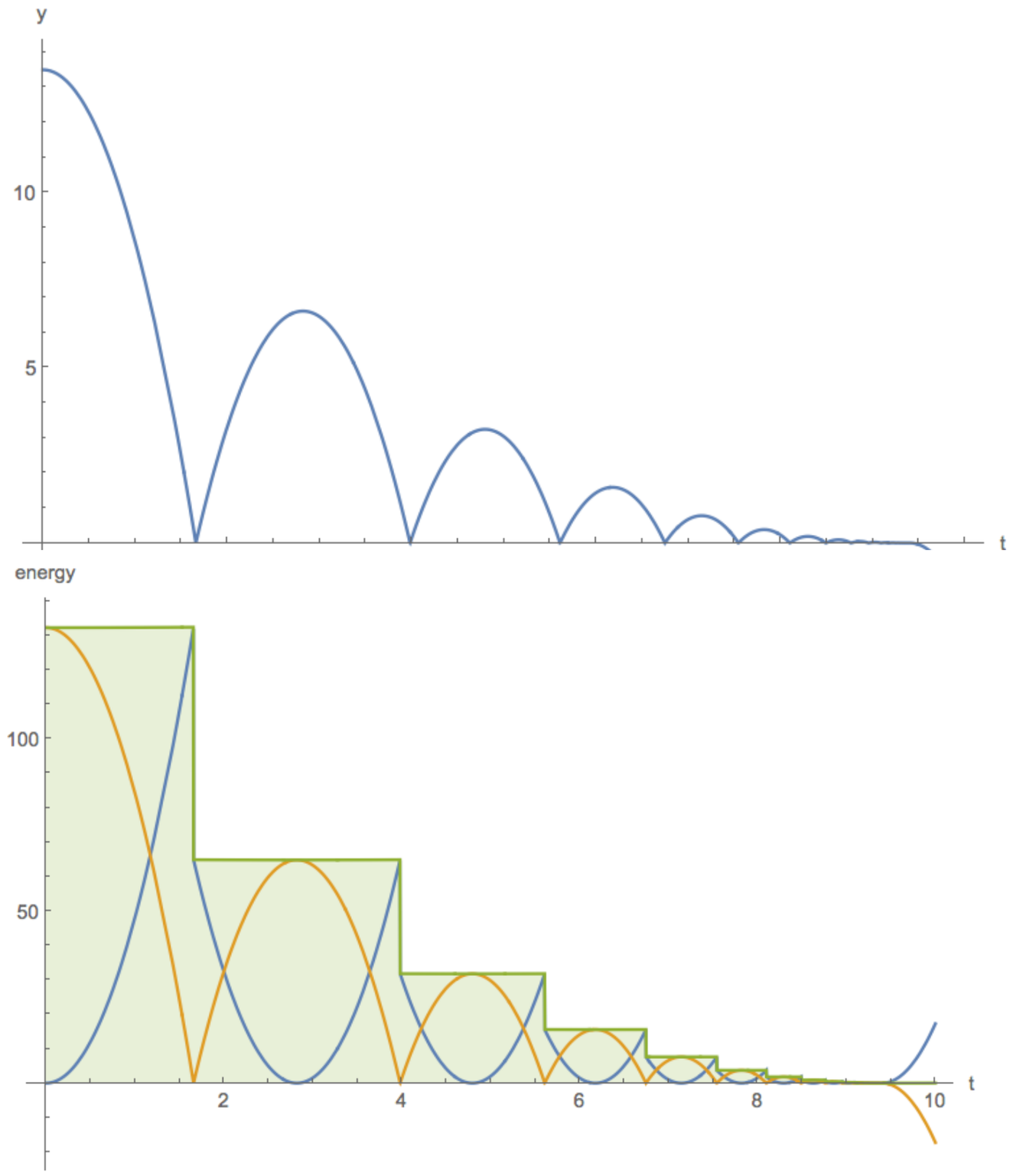






Mathematica

```
imagesize = 500;
ball =
  NDSolve[{y''[t] == -9.81, y[0] == 13.5,
    y'[0] == 0, WhenEvent[y[t] == 0,
     y'[t] → -0.7 y'[t]]}, y,
   {t, 0, 10}];
kin[v_] := .5 v^2;
pot[y_] := 9.8 y;
energy[y_, v_] := kin[v] + pot[y];
GraphicsGrid[
 {{Plot[y[t] /. ball, {t, 0, 10},
    AxesLabel → {"t", "y"},
    ImageSize → imagesize],
   Plot[Evaluate[
     {kin[y'[t]], pot[y[t]],
      energy[y[t], y'[t]]} /. ball],
    {t, 0, 10}, Filling → {3 → 0},
    AxesLabel → {"t", "energy"}]}}]
```



What can go wrong?

- Problems in the continuous evolution
  - existence
  - uniqueness
  - finite escape
- Problems in the hybrid execution:
  - chattering
  - zeno
- Non-continuous dependency on initial conditions

...next class!