Modelica
Diskrétní a hybridní systémy

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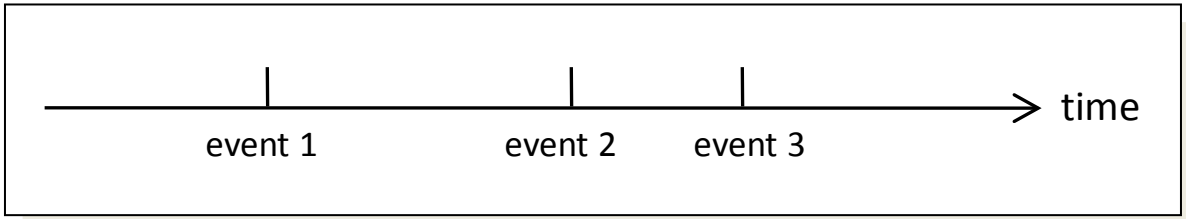
Použity části z přednášek Petera Fritzsona Discrete Events and Hybrid Systems

Do teď jsme probírali spojité modely

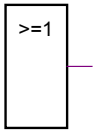
- Co je to spojitý model? Co je to spojitý systém?
- V přírodě (makrosvět) většinou spojitý
- Potřebujeme zjednušovat

Diskrétní systémy

- Změna stavu pouze v „clock“
- V mezičase setrvalé

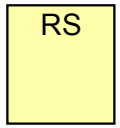


Digitální systémy



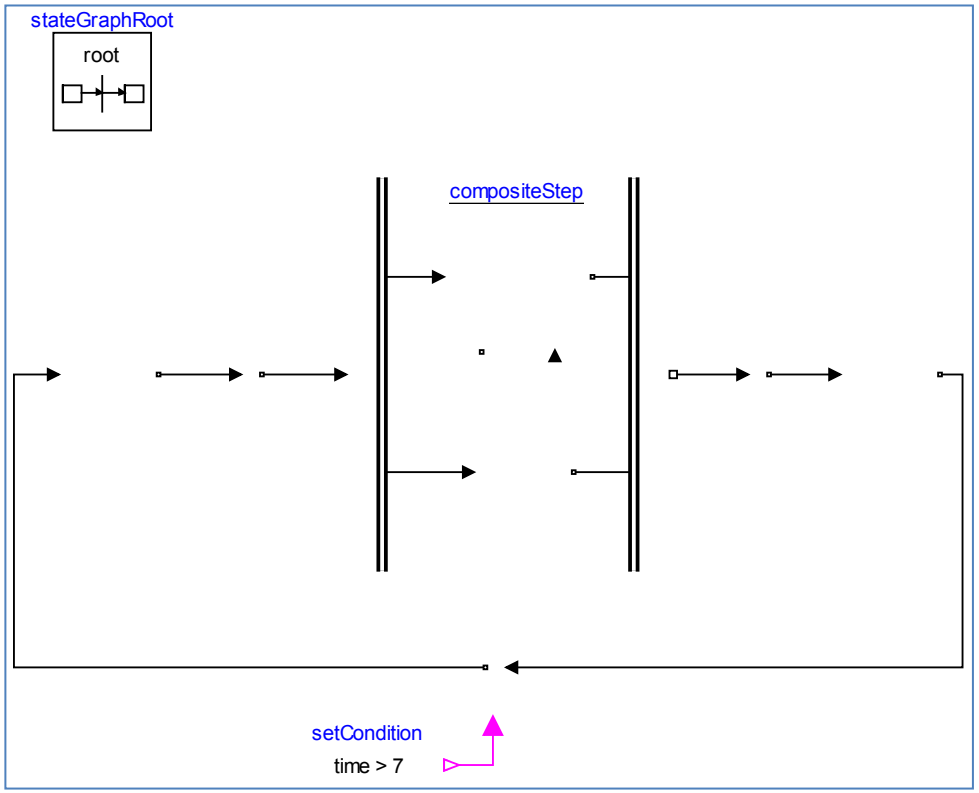
- Modelica.Electric.Digital
  - Hradla, RS, D
  - Logic, nikoli Boolean!
  - Logic hodnota;

Logic value	**Meaning**
'U'	Uninitialized
'X'	Forcing Unknown
'0'	Forcing 0
'1'	Forcing 1
'Z'	High Impedance
'W'	Weak Unknown
'L'	Weak 0
'H'	Weak 1
'-'	Don't care



Modelica.StateGraph

- Pro simulace stavových automatů



Základní diskrétní typy

- Boolean
- Integer
- Discrete Real

Spojité

- Real

Základ – if-equation

- If-equation
  - `if x > 5 then`
    - `k = true;`
    - `x = whatever;`
  - `elseif`
    - …
  - `else`
    - `k = false;`
    - `x = whatever2;`
  - `end;`
- Pozor:
  - Stejný počet rovnic ve VŠECH větvích
  - Vždy musí být **else** (pokud se jednoznačně nevylučuje)

If-expressions

- If-expresssion

```
Boolean returning;
equation
  returning = if velocity < 0.0 then true else false;
```

- nebo

```
Boolean returning;
equation
  returning = velocity < 0.0;
```

- Cílový překlad
- Dá se zapsat také jako if-equation:

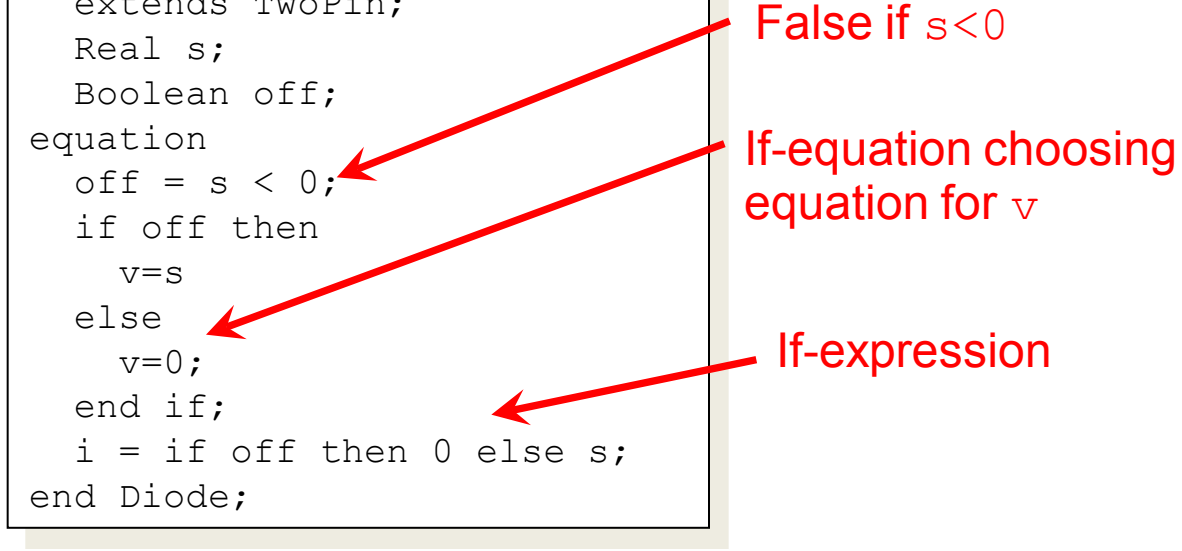
```
Boolean returning;
equation
  if velocity < 0.0 then
    returning = true;
  else
    returning = false;
  end if;
```

Event creation – if

if-equations, if-statements, and if-expressions

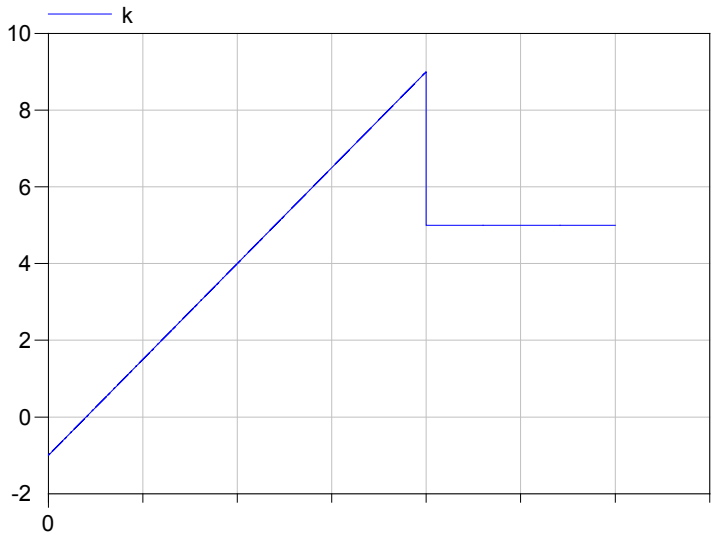
```
if <condition> then
  <equations>
elseif <condition> then
  <equations>
else
  <equations>
end if;
```

```
model Diode "Ideal diode"
  extends TwoPin;
  Real s;
  Boolean off;
equation
  off = s < 0;
  if off then
    v=s
  else
    v=0;
  end if;
  i = if off then 0 else s;
end Diode;
```



IF

- Jakýkoli if-equation musí být rozepsatelný do if-expression
  - Nemožno míchat s der
- Musí být pokryty všechny možnosti
- Postupuje se shora!




```
Real k;
Real m;
equation
  der(m) = 1;
  if time <= 20 then
    k = 0.5*m - 1;
  elseif time < 1 then
// ignorováno
    k = 0;
  else
    k = 5;
  end if;
```

Time

- Časová pozice
  - time
    - s_boolean = time > 30;
    - Je_pozde = if time > 14.15 then true else false;
    - cas = time;
    - when time > 20. then
      - casZlomu = time;
    - end when;

Co to jsou EVENTS

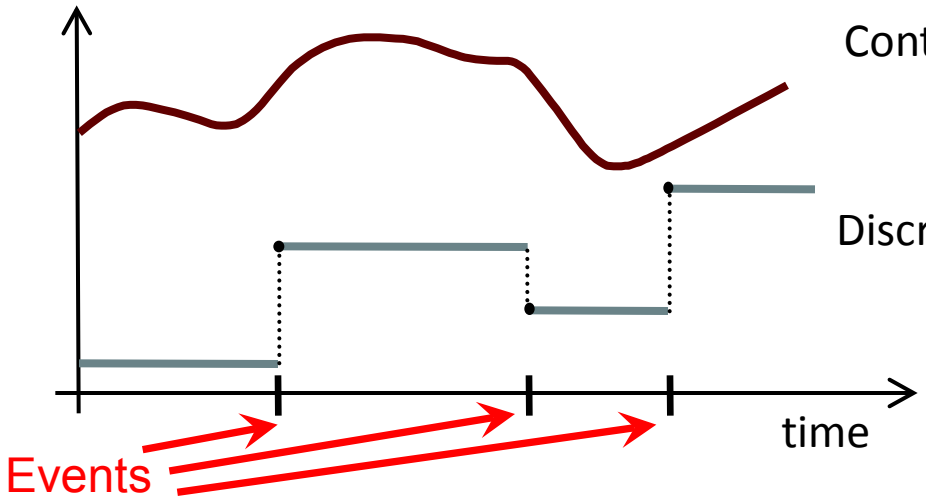
- Události nespojitosti
- Zastaví se výpočet integrace, nalezne se přesný čas události
  - (Přesný ale není naprosto přesný)
  - Chyba: nelze hledat přesnou rovnost
    - Místo toho např. m > 3 and m < 3 + 1e-6

```
Real m;
equation
  if m == 3 then
    …
  end if;
```

- Od času události platí rovnice v druhé větvi *if*

Hybrid Modeling

Hybrid modeling = continuous-time + discrete-time modeling




```
Real x;
Voltage v;
Current i;
```

```
discrete Real x;
Integer i;
Boolean b;
```

- A *point* in time that is instantaneous, i.e., has zero duration
- An *event condition* so that the event can take place
- A set of *variables* that are associated with the event
- Some *behavior* associated with the event,
  e.g. *conditional equations* that become active or are deactivated at the event

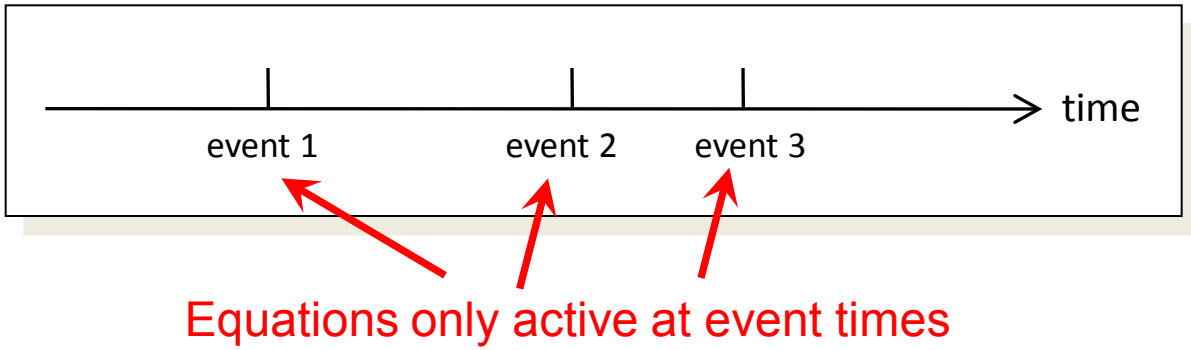
When

- *If* rozděluje, KTERÉ rovnice použít
- Rovnice *when* se provedou POUZE při události
  - When se chová trochu jako algorithm
  - Máme stop-stav

Event creation – when

when-equations

```
when <conditions> then
  <equations>
end when;
```



Time event

```
when time >= 10.0 then
   ...
end when;
```

Only dependent on time, can be scheduled in advance

State event

```
when sin(x) > 0.5 then
   ...
end when;
```

Related to a state. Check for zero-crossing

Event Priority

Erroneous multiple definitions, single assignment rule violated

```
model WhenConflictX   // Erroneous model: two equations define x
  discrete Real x;
  equation
  when time>=2 then   // When A: Increase x by 1.5 at  time=2
    x = pre(x)+1.5;
  end when;
  when time>=1 then   // When B: Increase x by 1 at   time=1
    x = pre(x)+1;
  end when;
end WhenConflictX;
```

Using event priority to avoid erroneous multiple definitions

```
model WhenPriorityX
  discrete Real x;
equation
  when time>=2 then        // Higher priority
    x = pre(x)+1.5;
  elsewhen time>=1 then    // Lower priority
    x = pre(x)+1;
  end when;
end WhenPriorityX;
```

Pozor na Dymolu!

Vnoření if a when

- Ify můžeme vnořovat (vždy lze vygenerovat if-expression)
- Wheny vnořovat nelze!
- Ify do whenů však lze

Reinit

- Reinit nám dovolí měnit hodnoty spojité proměnné
- Lze použít pouze na proměnné, které se někde vyskytují v der(__)
  - Jinak můžeme použít diskrétní proměnnou
- Pouze ve WHEN

```
reinit(veličina, hodnota);

reinit(rychlost, 0.0);
```

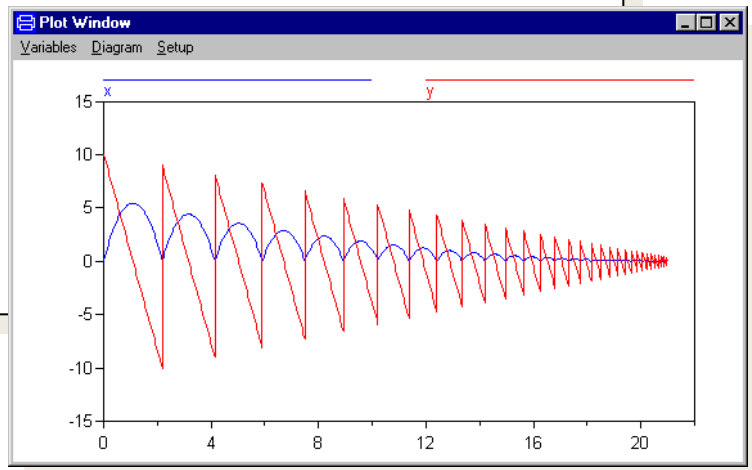
- Bouncing ball

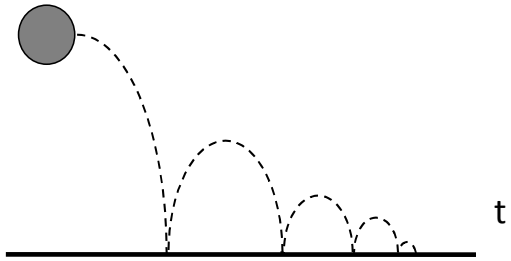
Discontinuous Changes to Variables at Events via When-Equations/Statements

The value of a *discrete-time* variable can be changed by placing the variable on the left-hand side in an equation within a `when`-equation, or on the left-hand side of an assignment statement in a `when`-statement

The value of a *continuous-time* state variable can be instantaneously changed by a `reinit`-equation within a `when`-equation

```
model BouncingBall "the bouncing ball model"
  parameter Real g=9.18;   //gravitational acc.
  parameter Real c=0.90;   //elasticity constant
  Real x(start=0),y(start=10);
equation
  der(x) = y;
  der(y)=-g;
  when x<0 then
    reinit(y, -c*y);
  end when;
end BouncingBall;
```





Čím odpálíme eventy?

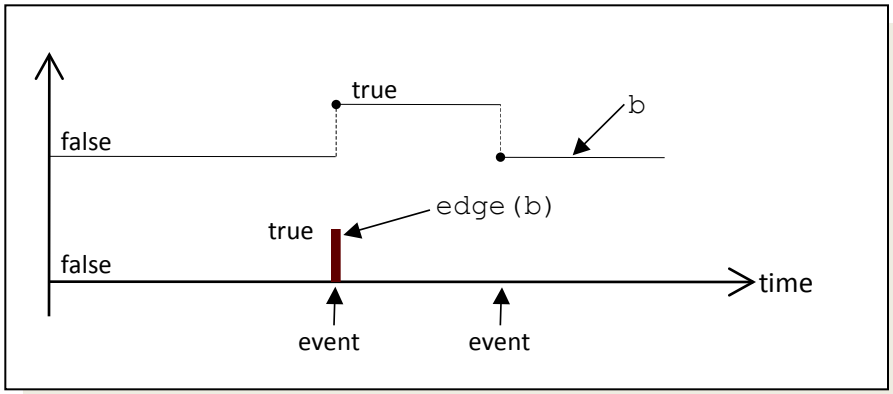
if (a > 3 and b < 1) or (C_boolean and D_integer == 4) then

- if/when time > 3.14159265358
- if/when sample(start, interval)
- if/when edge(x)
- if/when change(x)

- a_bool = edge(x);
- c_boo = change(a_boo);

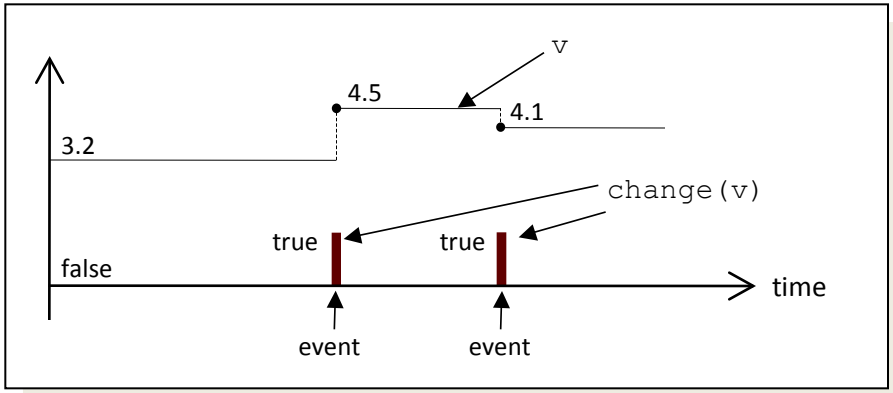
Detecting Changes of Boolean Variables Using `edge()` and `change()`

Detecting changes of boolean variables using `edge()`



The expression `edge(b)` is true at events when b switches from false to true

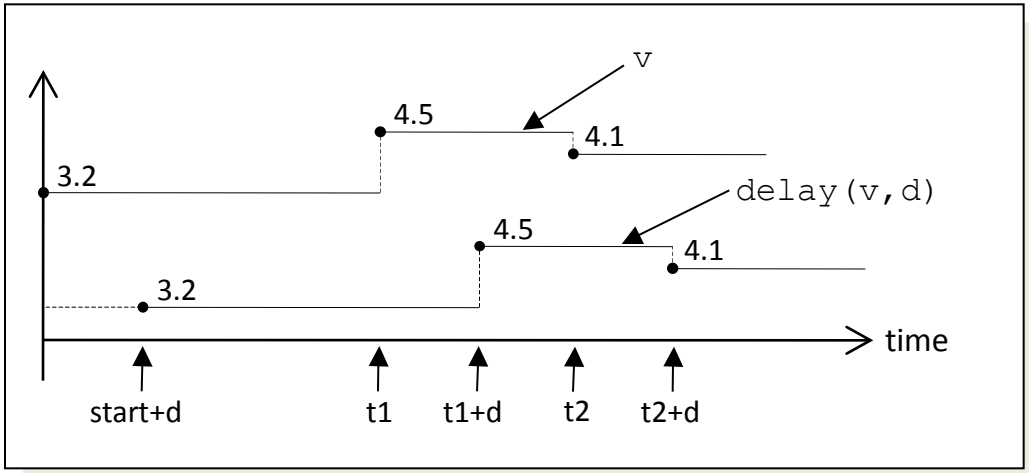
Detecting changes of discrete-time variables using `change()`



The expression `change(v)` is true at instants when v changes value

Creating Time-Delayed Expressions

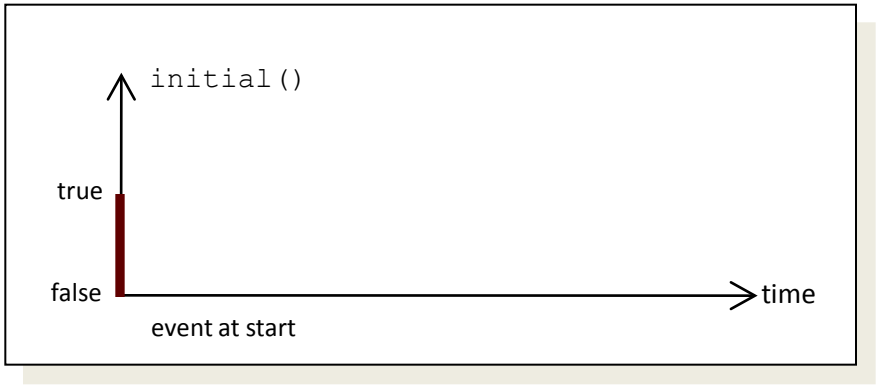
Creating time-delayed expressions using `delay()`



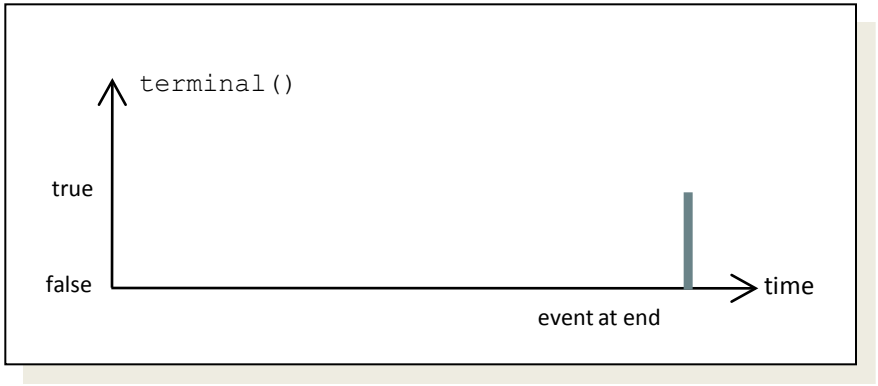
In the expression `delay(v,d)` *v* is delayed by a delay time *d*

`initial` and `terminal` events

Initialization actions are triggered by `initial()`

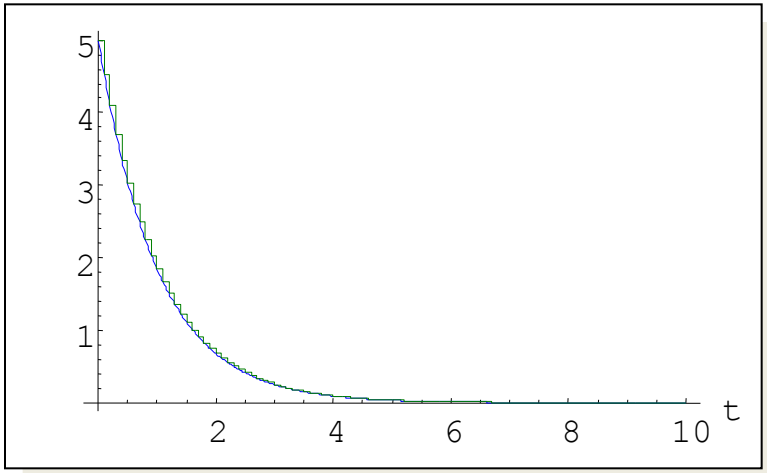


Actions at the end of a simulation are triggered by `terminal()`



A Sampler Model

```
model Sampler
  parameter Real sample_interval = 0.1;
  Real x(start=5);
  Real y;
equation
  der(x) = -x;
  when sample(0, sample_interval) then
    y = x;
  end when;
end Sampler;
```

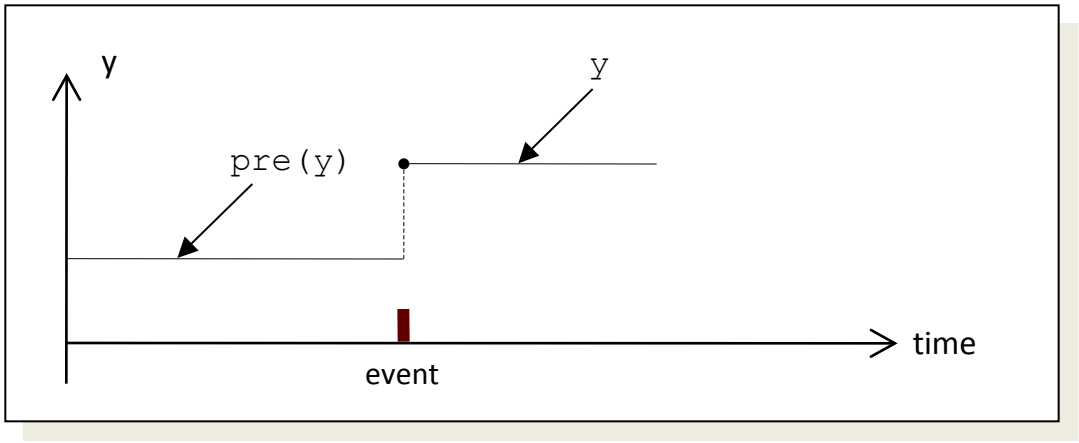


PRE

- Předešlá hodnota
- ~ jiná proměnná

Obtaining Predecessor Values of a Variable Using `pre()`

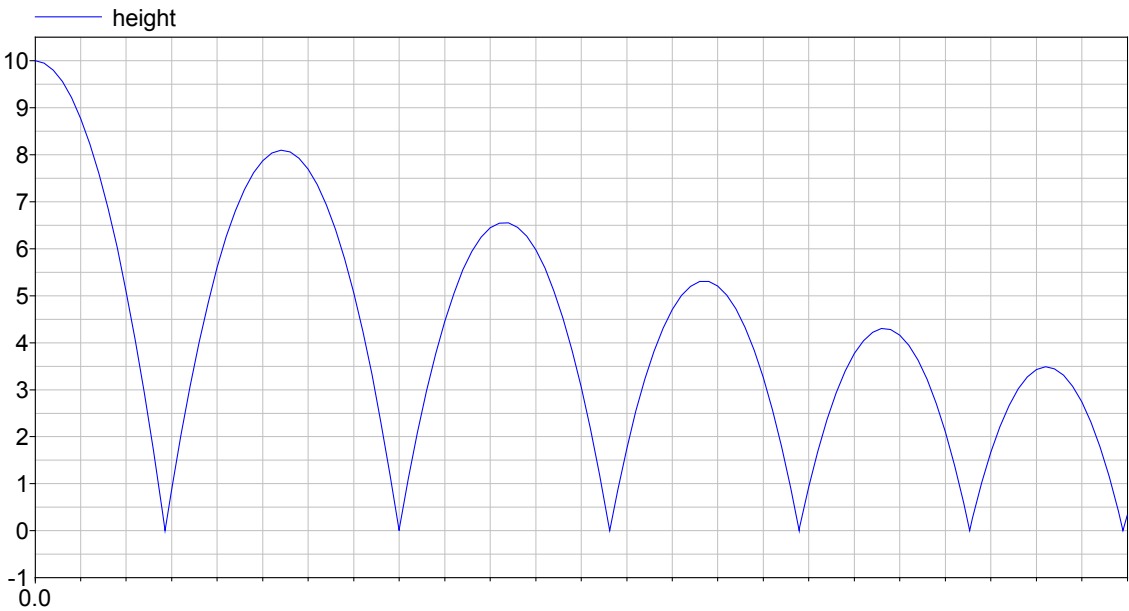
At an event, `pre(y)` gives the previous value of y immediately before the event, except for event iteration of multiple events at the same point in time when the value is from the previous iteration



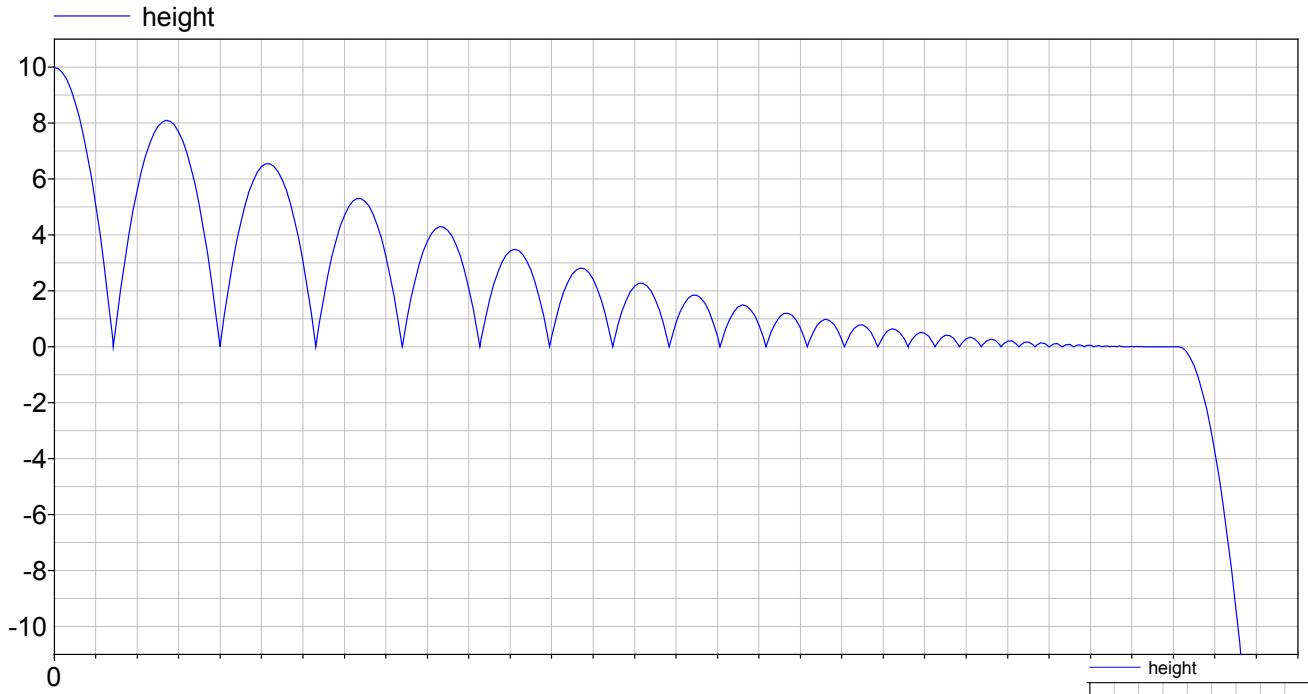
- The variable *y* has one of the basic types `Boolean`, `Integer`, `Real`, `String`, or `enumeration`, a subtype of those, or an array type of one of those basic types or subtypes
- The variable y is a discrete-time variable
- The `pre` operator can *not* be used within a function

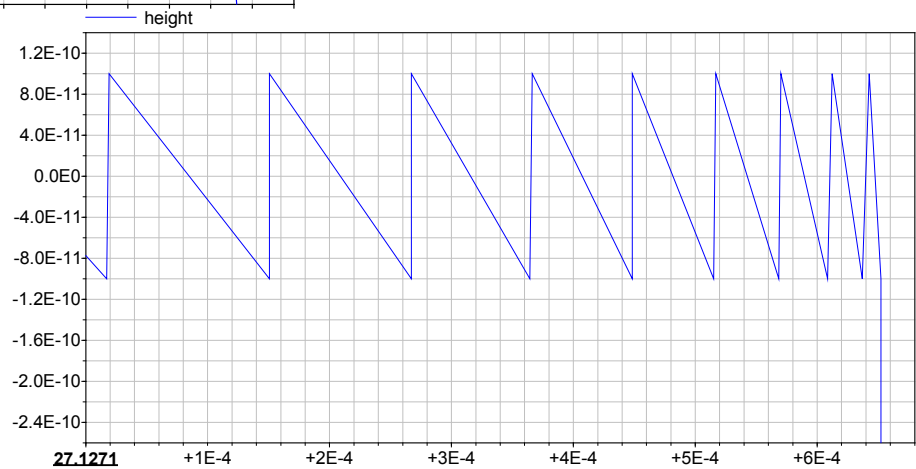
Zeno effect – bouncing ball - 1

```
model BouncingBall "the bouncing ball model - crash at T=27.5"
parameter Real g=9.81;   //gravitational acc.
parameter Real c=0.90;   //elasticity constant
Real height(start=10);
Real velocity(                start=0);
equation
  der(height) = velocity;
  der(velocity)=-g;
  when height<0 then
    reinit(velocity, -c*velocity);
  end when;
end BouncingBall;
```



Zeno effect – bouncing ball - 2





Zeno effect – bouncing ball - 3

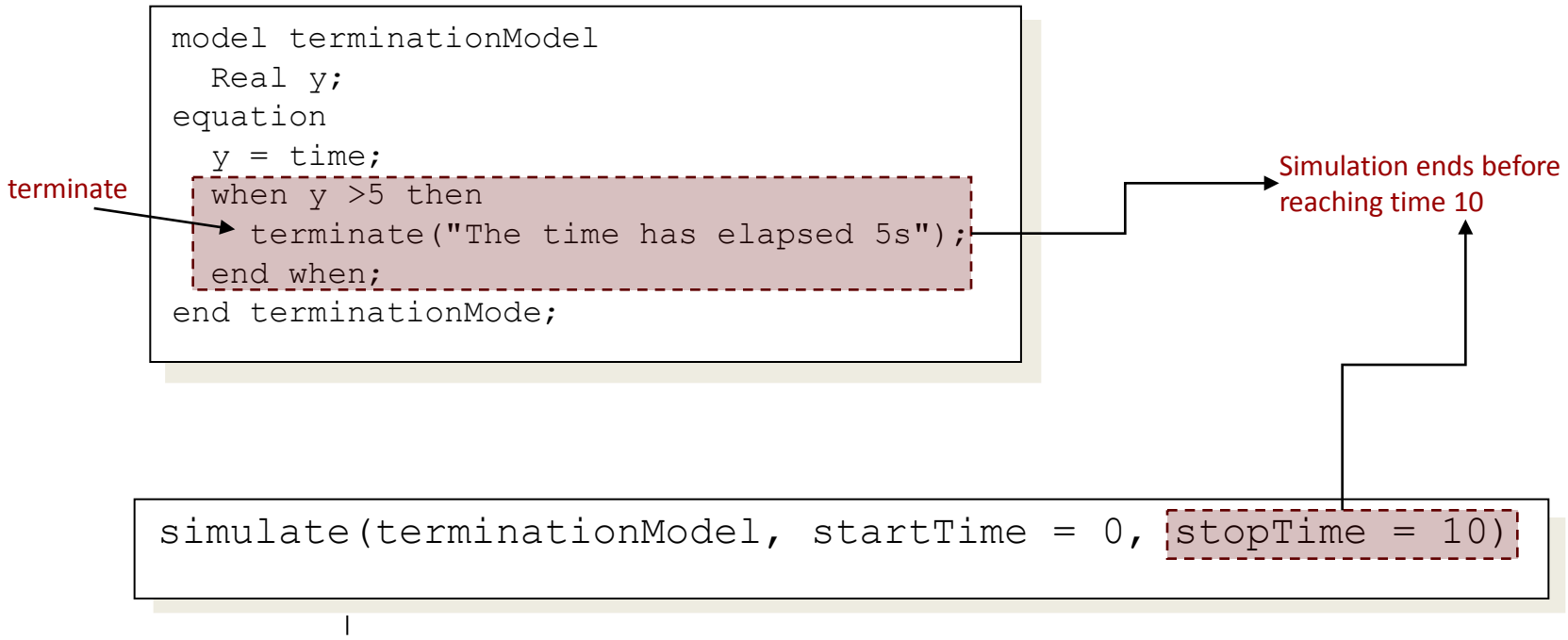
- Řešení
  - Dát si na to pozor
  - Terminate simulation

```
when height < 1e-6 then
  terminate("Propadli sme podlahou");
end when;
```

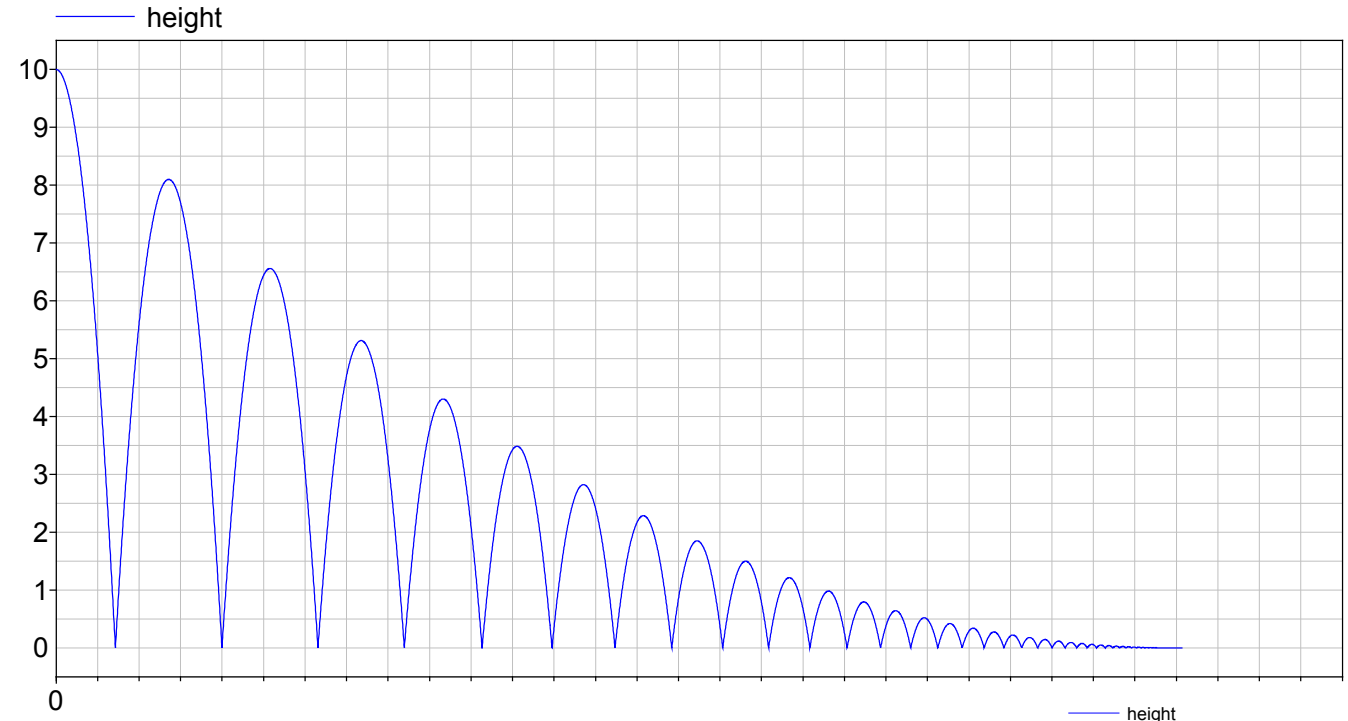
  - Rozlišit Letí / stojí

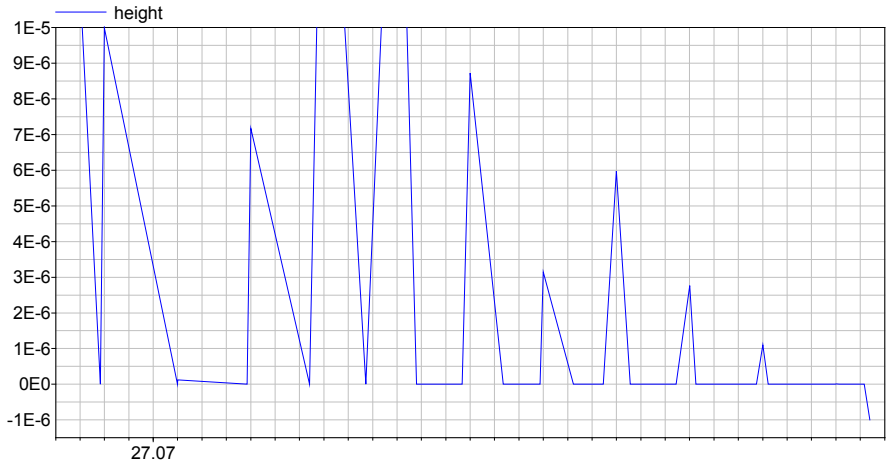
Terminating a Simulation

There `terminate()` function is useful when a wanted result is achieved and it is no longer useful to continue the simulation. The example below illustrates the use:



Zeno effect – bouncing ball - 4





Dioda

Dioda

- Jednoduše:
- Zavíráme a otvíráme jen proudem?
- Pozor na nulu!

```
if i < 0 then
  v = Roff*i;
else
  v = Ron*i;
end if;
```

```
If v < 0 then
  v = Roff*i;
else
  v = Ron*i;
end if;
```

Dioda 2

- Pomocí vložené proměnné

```
off = s < 0;
if off then
  v = s;
else
  v = 0;
end if;
i = if off then 0 else s;
```

- Anebo lépe

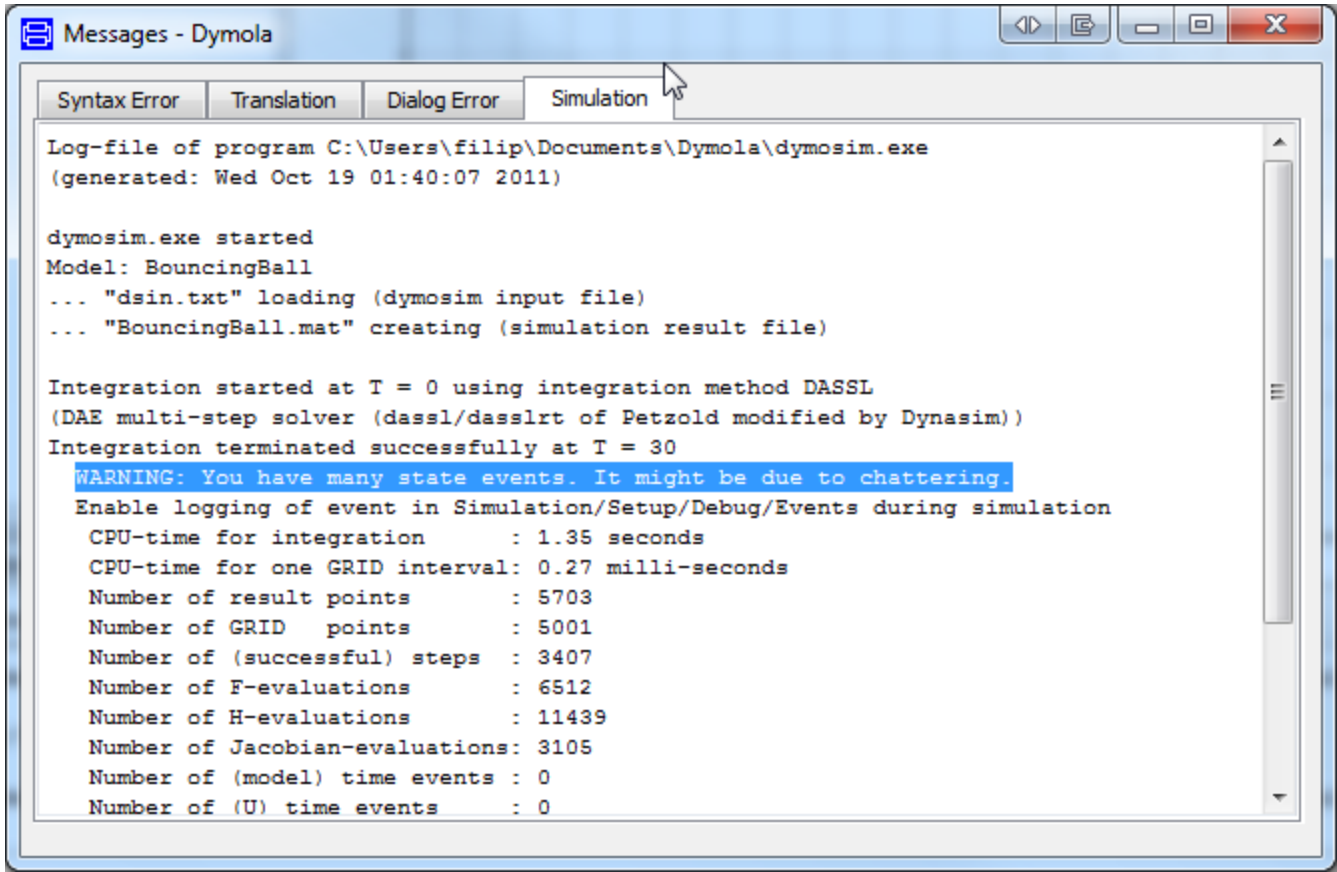
```
off = s < 0;
//off – s je napeti, not off – s je proud
v = s * (if off then 1 else Ron);
i = s * (if off then 1/Roff else 1);
```

Modelica.Electrical.Analog.Ideal.IdealDiode

```
  constant Modelica.SIunits.Voltage unitVoltage= 1  annotation(HideResult=true);
  constant Modelica.SIunits.Current unitCurrent= 1  annotation(HideResult=true);
equation
  off = s < 0;
  v = (s*unitCurrent)*(if off then 1 else Ron) + Vknee;
  i = (s*unitVoltage)*(if off then Goff else 1) + Goff*Vknee;
```

Možné problémy

- Chattering – někde nám to příliš kmitá
- Numerika, numerika, numerika..



Příklady!!

Shrnutí

- Co to je hybridní simulace
- Rozdíl mezi if a when
- Reinit
- Numerické problémy
- terminate()