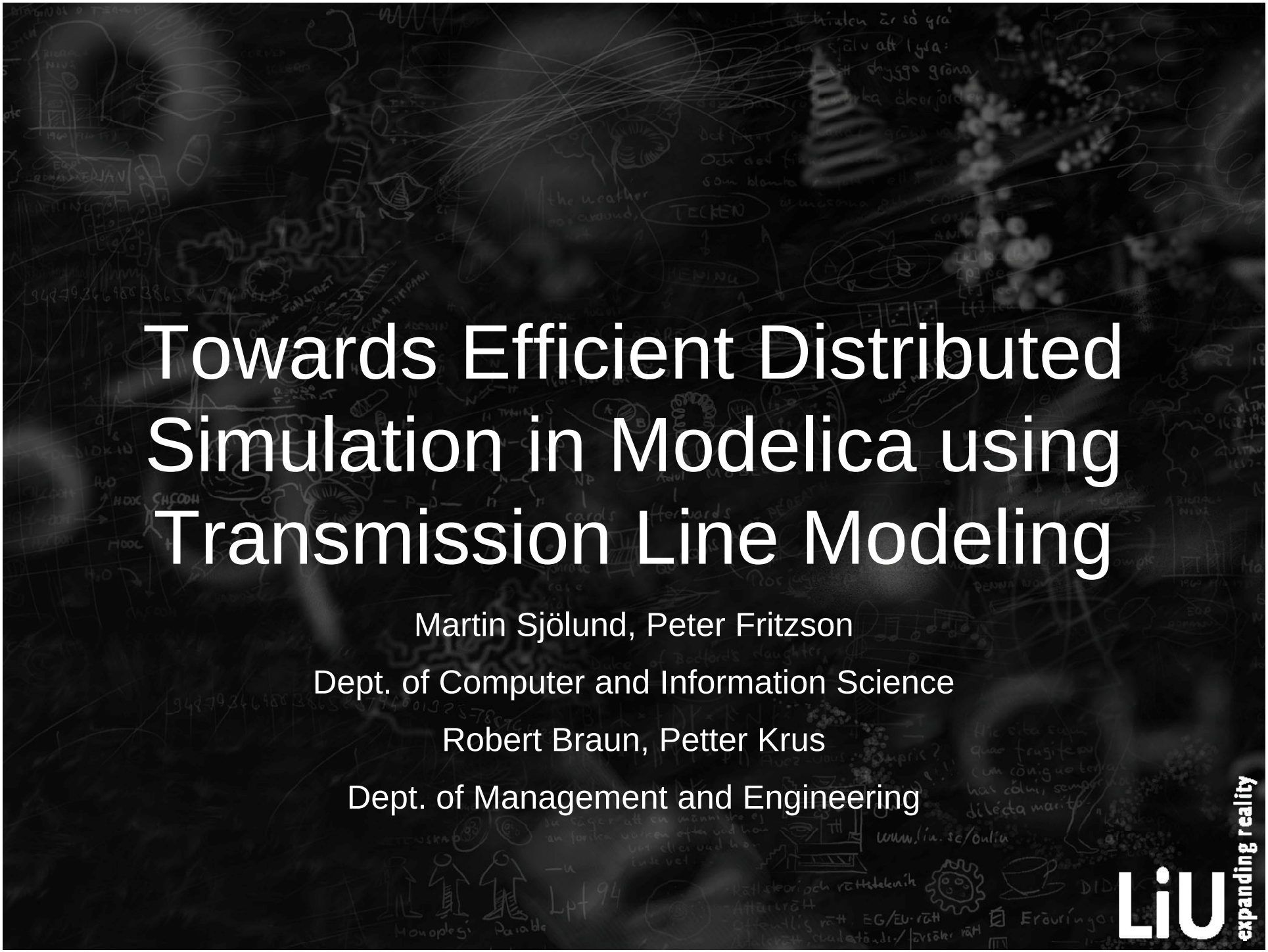

Towards Efficient Distributed Simulation in Modelica using Transmission Line Modeling

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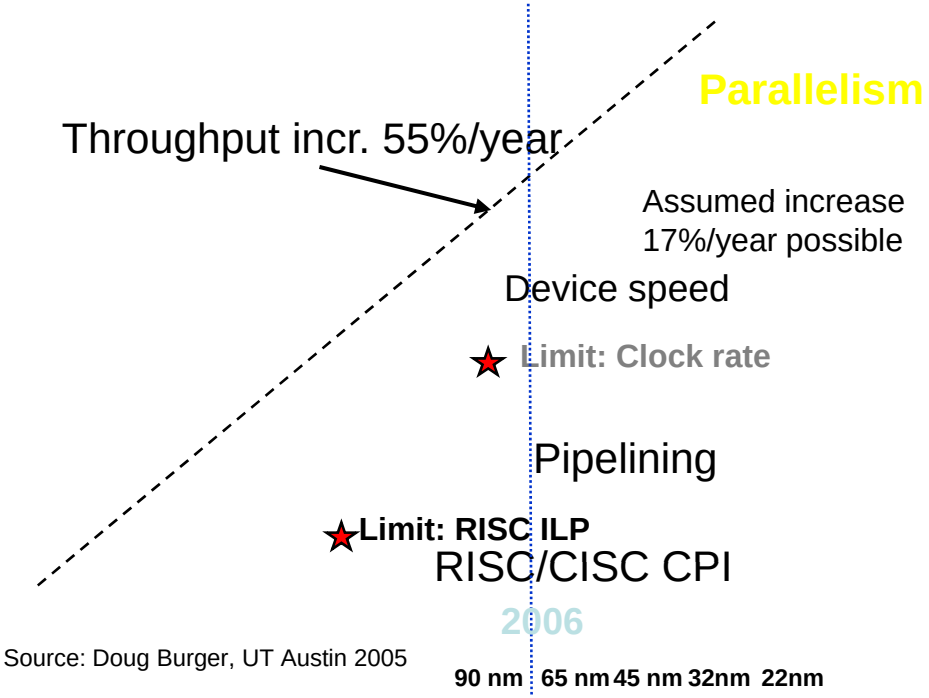
LiU expanding reality

Simulations are slow

- Centralized solvers are hard to parallelize
- Large systems do not scale well
- Stability depends on a global step size

Modern computation units

- Multi-Core is the standard even for home users
- Penalizes single-threaded applications
- Stuck with CPU performance from 2004

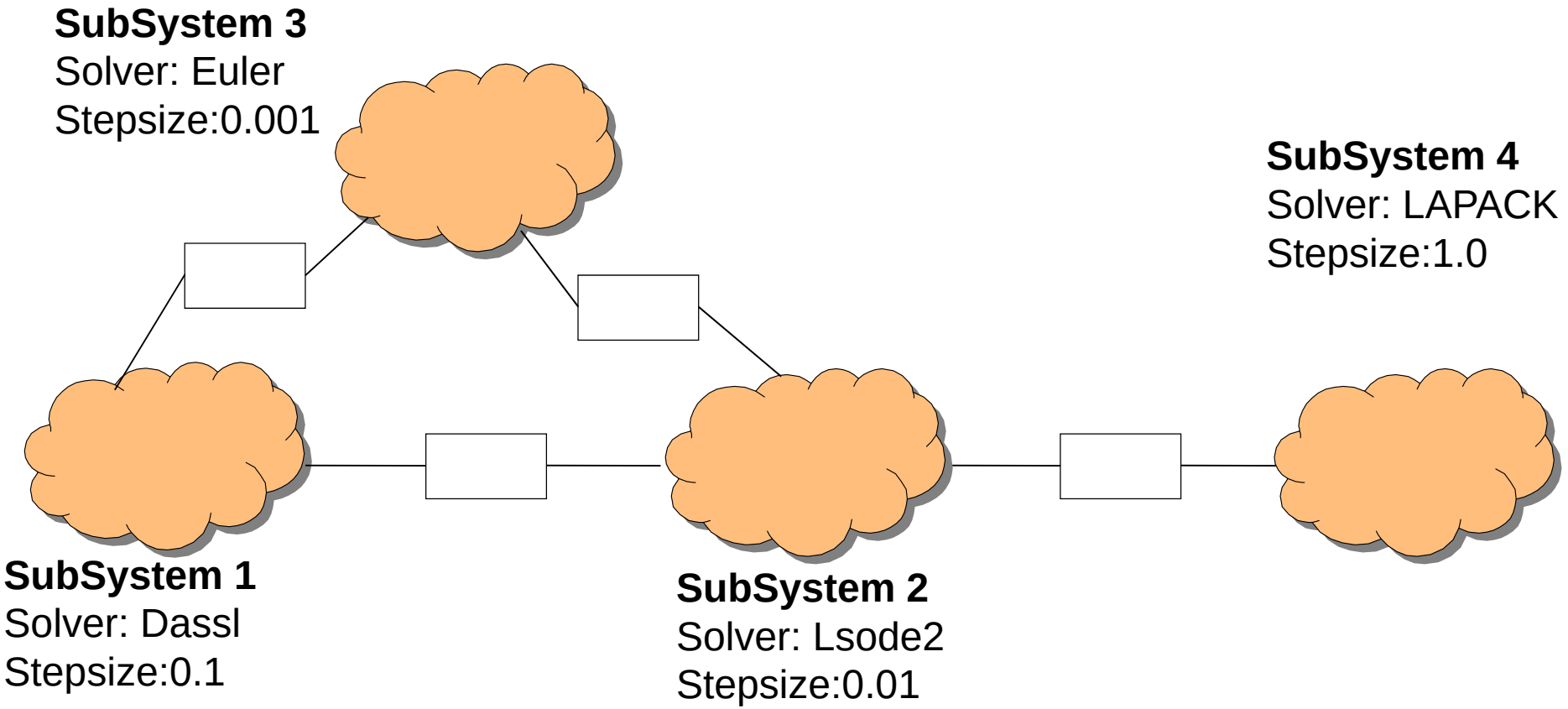


Source: Doug Burger, UT Austin 2005

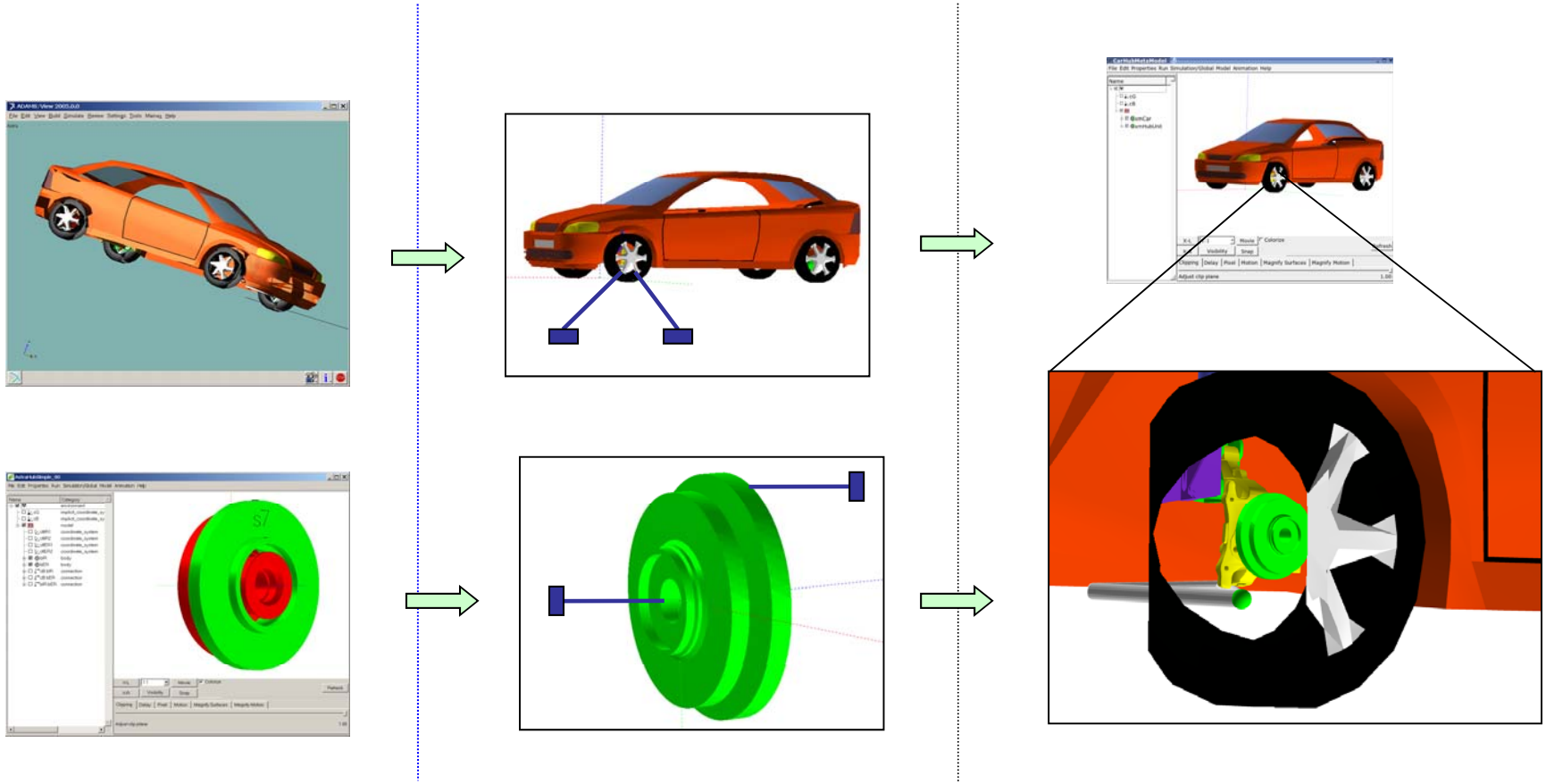
Problems and Solutions

- Problem 1: Speeding up group of simulations
  - Parallel parameter sweep with one simulation per core
- Problem 2: Speeding up single simulation for short real-time deadlines
  - Simplifying the model
  - Parallelizing single simulation

Distributed model



Partitioning the model



Changing the model

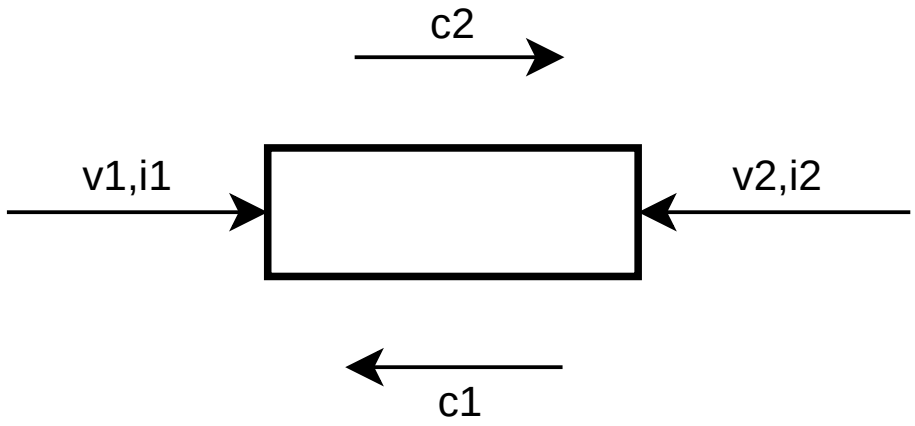
- Changing the connections?
- Find a better model
- Retain physically accuracy

Transmission Line Modeling

- TLM – Transmission Line Modeling – numerically stable co-simulation
- Physically motivated delays are inserted into TLM element models
- Originally used in hydraulics with propagation delays along pipes
- Generalized to other engineering domains

$$c_1(t) = V_2(t - T_{tlm}) + Z_F I_2(t - T_{tlm})$$
$$c_2(t) = V_1(t - T_{tlm}) + Z_F I_1(t - T_{tlm})$$
$$P_1(t) = Z_F I_1(t) + c_1(t)$$
$$P_2(t) = Z_F I_2(t) + c_2(t)$$

c1, c2 are the TLM-parameters
Ttlm is the information propagation time
Zf is the implicit impedance



HOPSAN

- TLM-specific simulation software
- Efficient simulations
- Easy to connect components
- Hard to create new components
  - Written in C++ or Fortran
- Hard to read old code
  - Explicit discretization

Does TLM work in Modelica?

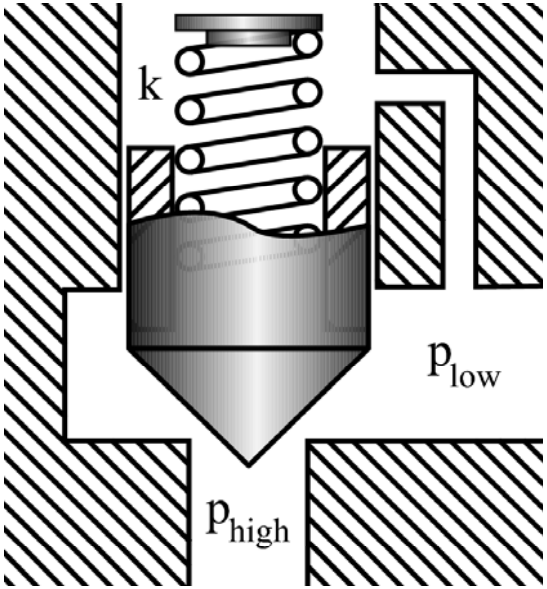
- The discretization is done by the compiler and/or solver
- There are multiple solvers to choose from
- Equation-based models are easy to read and maintain

Decoupling subsystems using delay()?

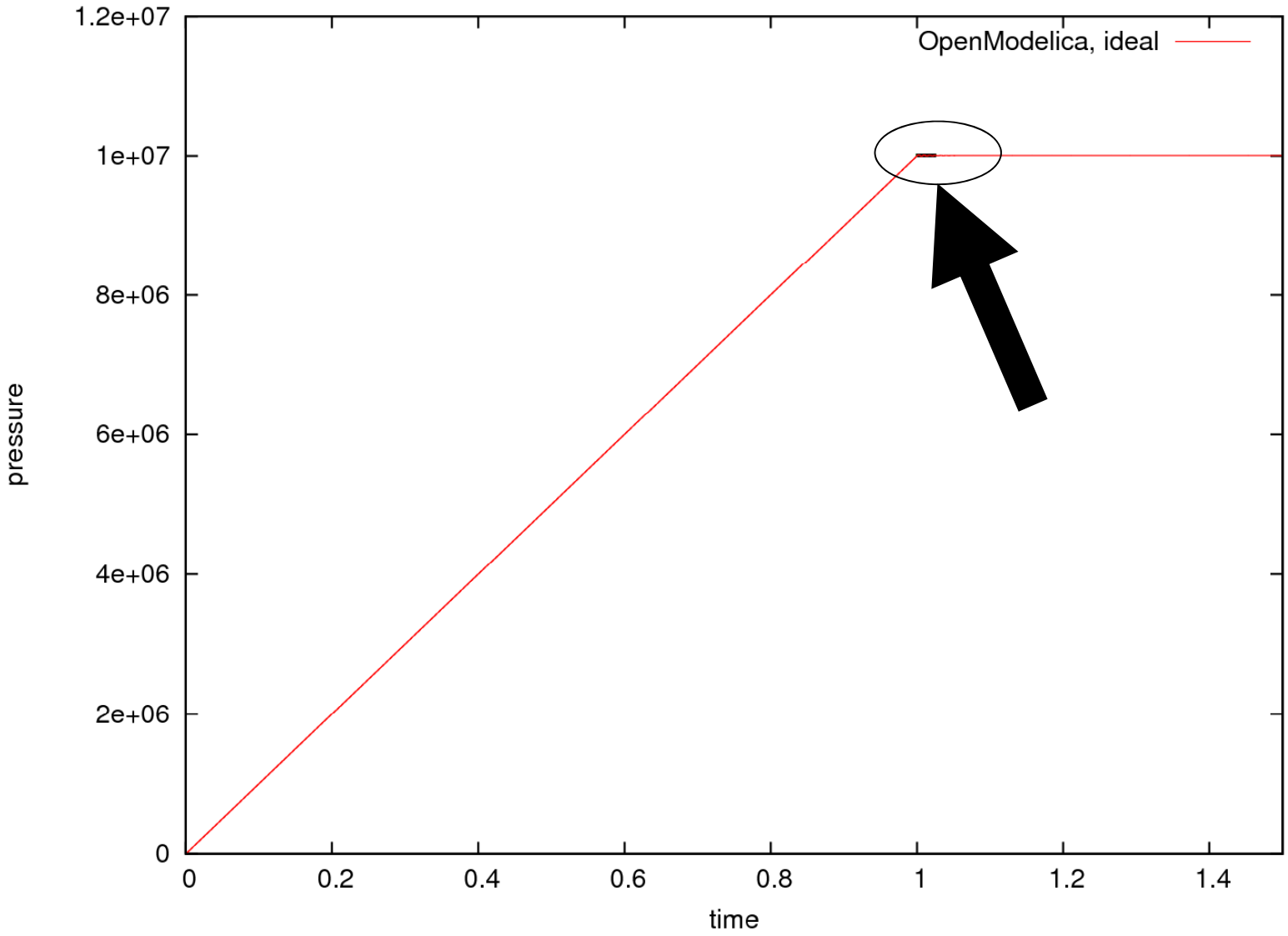
- Breaks dependencies between components
- Interpolation and performance problems
- Initialization cannot be decoupled
  - During initialization, the delay is the actual expression without delay in Modelica

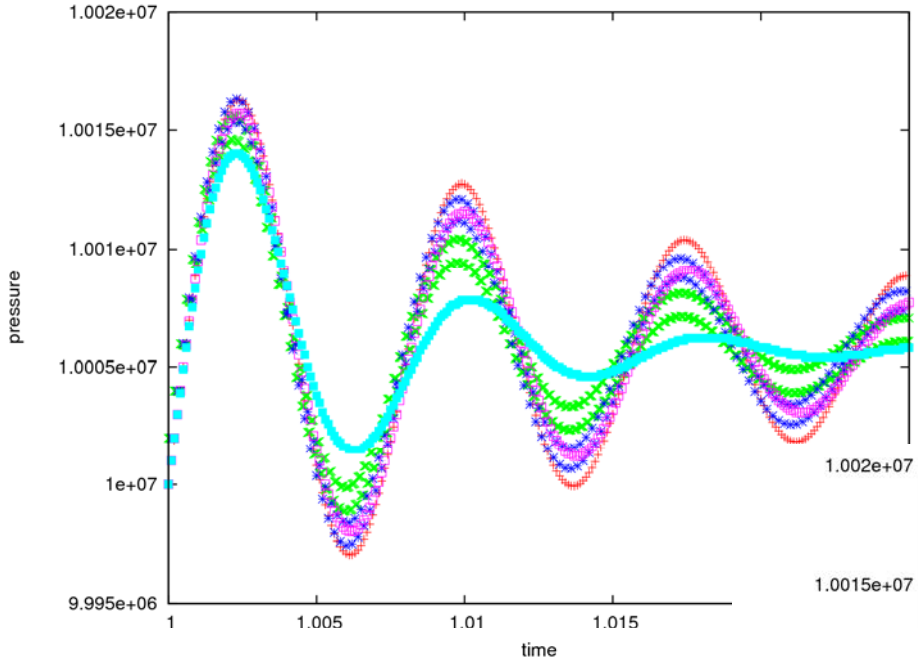
Prototype model

- Pressure relief valve
- 3x2 variations of the model
  - TLM delay-lines between subsystems using delay(), sample(), or der()
  - Spring modeled using der() or explicit euler using the delay() operator



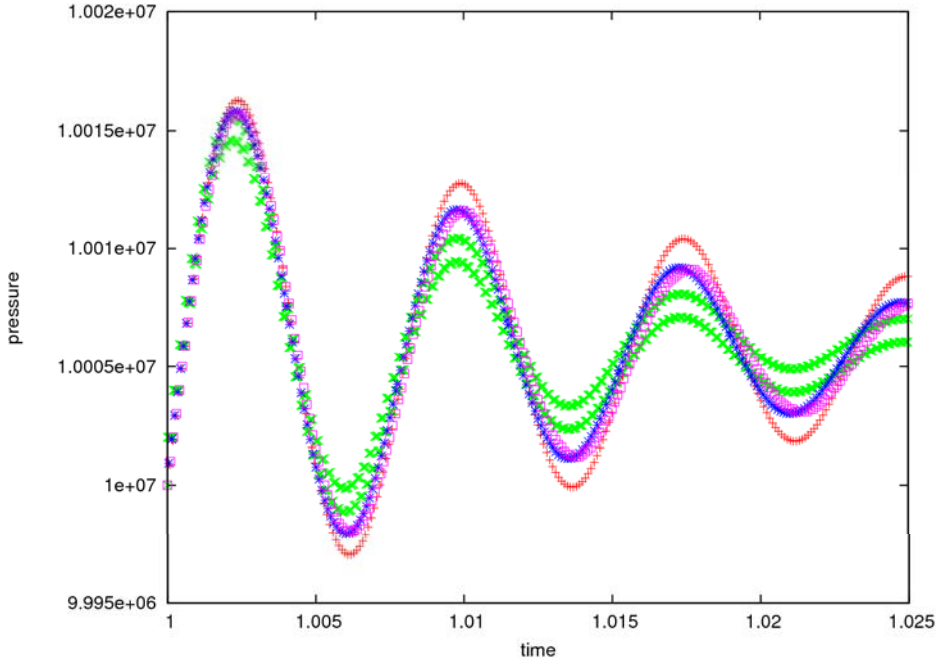

```
Real v = (x-delay(x,T))/T;
// v = der(x)

Real a = (v-delay(v,T))/T;
// a = der(v)
```


1.2e+07
1e+07
8e+06
6e+06
4e+06
2e+06
0
pressure
0
0.2
0.4
0.6
0.8
1
1.2
1.4
time
OpenModelica, ideal



Spring using delay()

der()
sample()
delay()
HOPSAN
HOPSAN, a=0



Spring using der()

Future

- Support manual partitioning of models in OpenModelica
- Integrate these methods in the new OpenModelica parallel backend
- Integrate HOPSAN and OpenModelica models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