TECHNISCHE UNIVERSITÄT DRESDEN

Institute of Scientific Computing

USING TIME-PARALLEL METHODS FOR THE SIMULATION OF A MACHINE TOOL

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   - About the project
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Sonderforschungsbereich
Transregio 96

- optimal design and operation of machine tools
- exploration and implementation of effective correction and compensation solutions
- enable high accuracy machining and energy-efficient manufacturing at the same time

02 Machine tool

Heat conduction

$$\partial_t T - \lambda \Delta T = 0$$

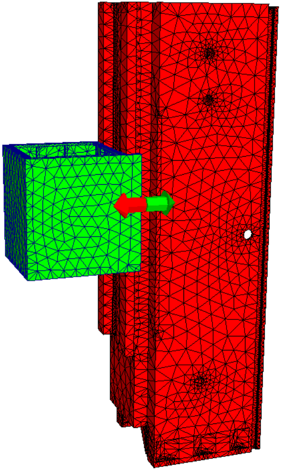
$$\lambda \partial_n T = S(\frac{2\pi t}{\epsilon}, x)(\beta - \alpha T)$$

S periodic with period ϵ

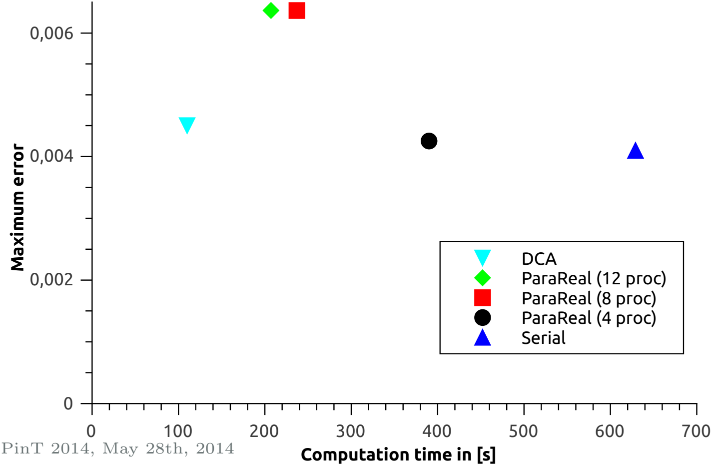
Semi-discretized problem

$$\dot{Y} = L(t)Y + f(t), \quad Y(0) = Y_0$$

$L(t)$, $f(t)$ periodic with period ϵ



02 Results: ParaReal and Defect Corrected Averaging (DCA)



02 DCA

Averaging:

$$\dot{\bar{\mathrm{Y}}} = \bar{\mathrm{L}}\mathrm{Y} + \bar{\mathrm{f}}, \quad \bar{\mathrm{Y}}(0) = \mathrm{Y}_0$$
$$\bar{\mathrm{L}} = \frac{1}{\epsilon}\int_0^\epsilon \mathrm{L}(\mathrm{t})\mathrm{dt}$$
$$\bar{\mathrm{f}} = \frac{1}{\epsilon}\int_0^\epsilon \mathrm{f}(\mathrm{t})\mathrm{dt}$$

Defect corrected averaging:

$$\dot{\mathrm{Y}}_\mathrm{c} = \mathrm{L}_\mathrm{c}\mathrm{Y}_\mathrm{c} + \mathrm{f}_\mathrm{c}, \quad \mathrm{Y}_\mathrm{c}(0) = \mathrm{Y}_0$$

L_c, f_c see next slides

02 Parameters for DCA

For L_c consider

$$\dot{Y}_h = L(t)Y_h, \quad Y_h(0) = Y_0$$

and

$$\dot{Y}_{c,h} = L_c Y_{x,h}, \quad Y_{c,h}(0) = Y_0$$

Determine L_c such, that

$$\forall Y_0 : Y_h(\epsilon) = Y_{c,h}(\epsilon)$$

Application of Lie-Group theory and truncation yields

$$L_c = \frac{1}{\epsilon}\int_0^\epsilon L(t)dt$$

02 Parameters for Defect Corrected Averaging (DCA), cont.

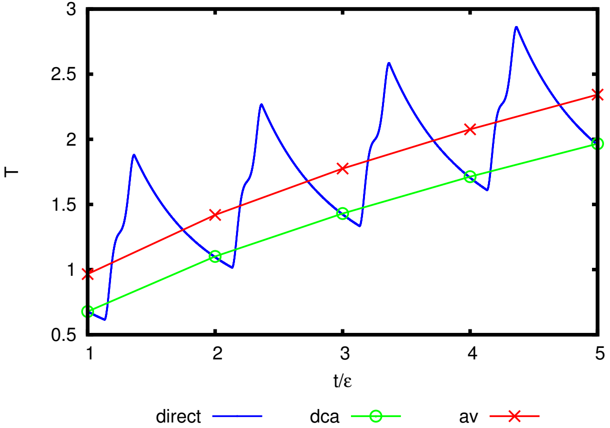
Determine f_c such, that for

$$Y(0) = Y_c(0) = 0 : \quad Y(\epsilon) = Y_c(\epsilon)$$

Leads to linear problem, which is solved using preconditioned GMRES

- choice of preconditioner depends on grid spacing and period ϵ
- most expensive part is the computation of $Y(\epsilon)$

02 Comparison Averaging and DCA



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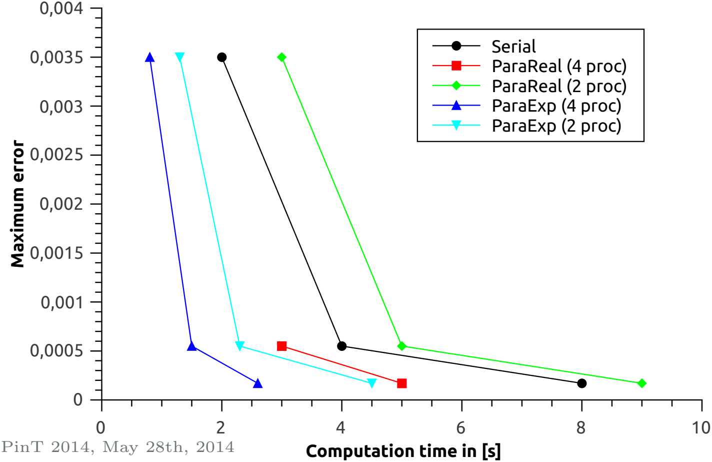
02 Results: ParaReal and ParaEXP for initial calculations necessary in DCA



HPCOM

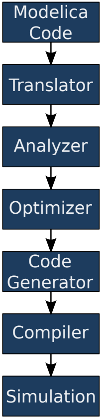
High Performance Computing Open Modelica

- application-oriented development of innovative algorithms and an HPC-software for multiscale machine simulations
- use mathematic as well as syntactic context information, taken from sub models, for the development of a total system

03 Open Modelica

- open source modelling and simulation environment
- models are written in the Modelica language

```
model BouncingBall
  constant Real g = 9.81;
  parameter Real c = 0.9;
  parameter Real radius = 0.1;
  Real height(start = 1);
  Real v(start = 0);
equation
  der(height) = v;
  der(v) = -g;
  when height <= radius then
    reinit(v, -c*pre(v));
  end when;
end BouncingBall;
```



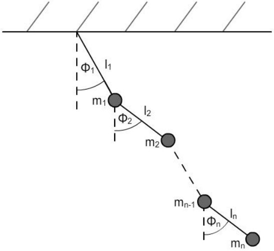
03 N-Pendulum

Mathematical formulation in absolute angels

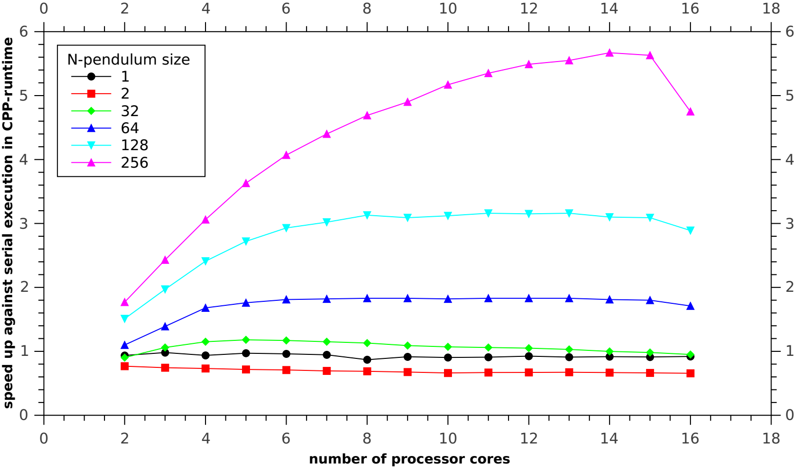
$$\begin{pmatrix} \dot{\phi} \\ \ddot{\phi} \end{pmatrix} = \begin{pmatrix} \mathrm{I} & 0 \\ 0 & \mathrm{M}^{-1}(\phi, \dot{\phi}) \end{pmatrix} \mathrm{f}(\phi, \dot{\phi})$$

Other possible formulations:

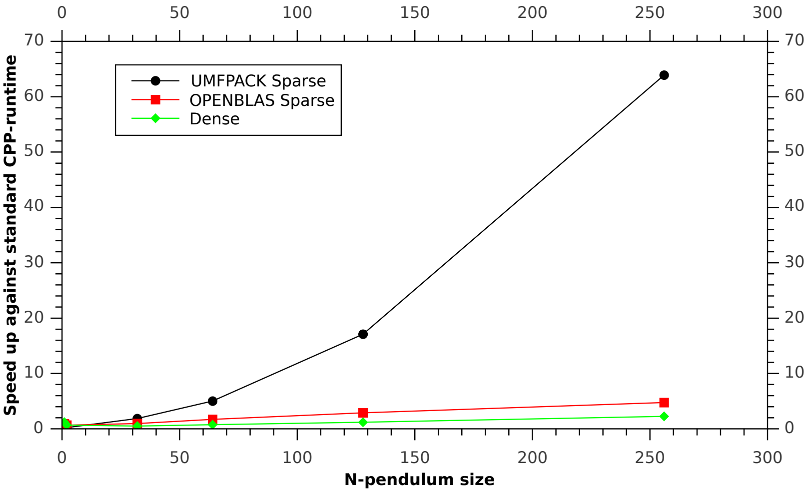
- in relative angles
- in Cartesian coordinates



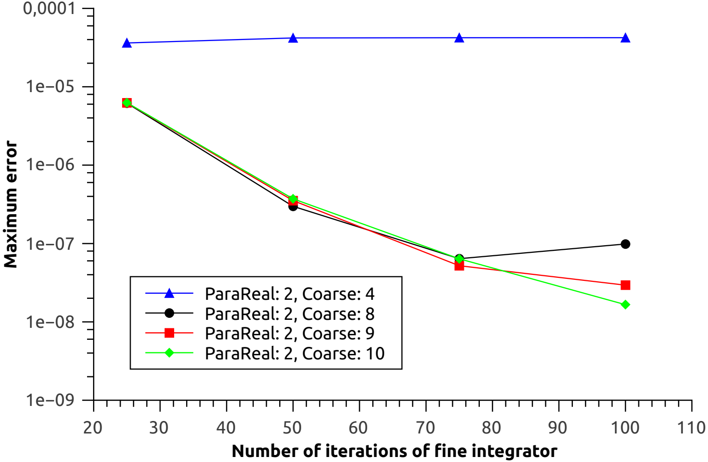
03 Results: OpenBLAS



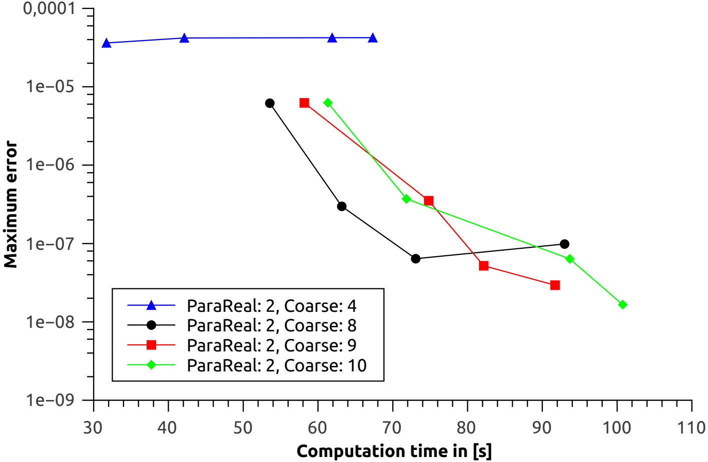
03 Results: Efficient linear algebra



03 Results: ParaReal

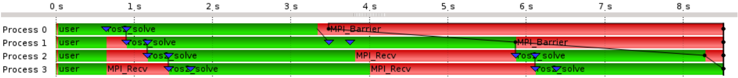


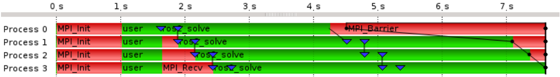
03 Results: ParaReal 2



04 Implementation issues

ParaReal





ParaEXP

- Expokit issues

Conclusions

- parallel in time methods are useful in both projects
- typical speed ups between 1.5–3
- parallel methods need careful implementation

Future work

- solving more complex problems, potential for higher speed ups
- implement efficient heuristics for the choice of optimal ParaReal parameters, when used with arbitrary problems in Open Modelica

Ideas from the conference

- DCA can act as a coarse integrator[1]
- it is probably a good idea to try PFASST

[1] a similar approach was already investigated by Wingate & Haut, see `http://arxiv.org/pdf/1303.6615.pdf`