Run-time from 300 years to 300 min: Lessons learned in large-scale modeling in FEniCS.

Abhinav Gupta, U Meenu Krishnan, Rajib Chowdhury, Anupam Chakrabarti

Department of Civil Engineering
Indian Institute of Technology Roorkee, India

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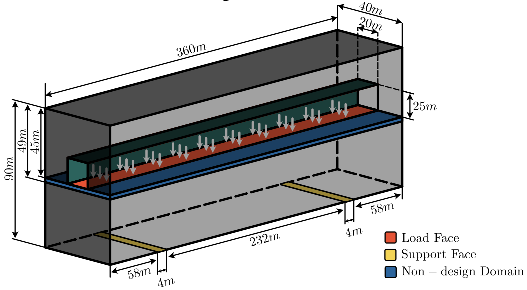
Motivation

Design Domain



Topologically optimised design

(I) Solve the topology optimization problem for a medium to large scale engineering structure.

(II) The problem could contain degrees of freedom ranging from a million to over a billion.

Lists - Itemize

- Point A
- Point B
  - part 1
  - part 2
- Point C
- Point D

Columns

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Single figure with caption

Figure: This is an caption!

Description Environment

API Application Programming Interface

LAN Local Area Network

ASCII American Standard Code for Information Interchange

Tables

Competitor Name	Swim	Cycle	Run	Total
John T	13:04	24:15	18:34	55:53
Norman P	8:00	22:45	23:02	53:47
Alex K	14:00	28:00	n/a	n/a
Sarah H	9:22	21:10	24:03	54:35

Table: Triathlon results

Blocks

Block Title

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Alert Block Title

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Definition

Then there's the definition environment which produces a standard ColorA color block but with the title already specified as 'definition'.

```
\begin{definition}
A prime number is a number that...
\end{definition}
```

Definition

A prime number is a number that...

Example

Next there's the example environment which produces a green block with the title 'Example'.

```
\begin{example}
Lorem ipsum dolor sit amet...
\end{example}
```

Example

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Theorem

There is also a group of blocks that are especially useful for presenting mathematics. For example the ‘theorem’ environment, the ‘corollary’ environment and the ‘proof’ environment.

```
\begin{theorem}[Pythagoras]
```
$a^2 + b^2 = c^2$
```
\end{theorem}
\begin{corollary}
```
$x + y = y + x$
```
\end{corollary}
\begin{proof}
```
$\omega + \phi = \epsilon$
```
\end{proof}
```

Theorem Blocks

Theorem (Pythagoras)

$a^2 + b^2 = c^2$

Corollary

$x + y = y + x$

Proof.

$\omega + \phi = \epsilon$ $\square$

Hyperlink

Before we can create any hyperlinks we need to tag the frames we want to link to using the ommand.

click here section 1 page ▸ columns page ▸▸ pictures page ◂ pictures page

A trivial Set Cover algorithm

Algorithm 1: $\texttt{MSC}(\mathcal{S},\mathcal{U})$

Input : A set cover instance $(\mathcal{S},\mathcal{U})$ and a variable $\mathcal{S}_{\mathrm{dom}}$.
Output : A minimum set cover of $(\mathcal{S},\mathcal{U})$.

if $\mathcal{S} = \emptyset$ **then**
    return $\emptyset$;
Let $S \in \mathcal{S}$ be a set of maximum cardinality;
$\mathcal{C}_1 = \{S\} \cup \texttt{MSC}(\{S' \backslash S \mid S' \in \mathcal{S} \backslash \{S\}\},\mathcal{U} \backslash S)$;
$\mathcal{C}_2 = \texttt{MSC}(\mathcal{S} \backslash \{S\},\mathcal{U})$;
$\mathcal{S}_{\mathrm{dom}} \leftarrow \emptyset$;
if $\mathcal{U} \subseteq \mathcal{C}_1$ **then**
    $\mathcal{S}_{\mathrm{dom}} \leftarrow \mathcal{C}_1$;
    if $\mathcal{U} \subseteq \mathcal{C}_2$ **then**
        if $|\mathcal{C}_2| < |\mathcal{C}_1|$ **then**
            $\mathcal{S}_{\mathrm{dom}} \leftarrow \mathcal{C}_2$;
return $\mathcal{S}_{\mathrm{dom}}$;

Conclusion

(I) General guidelines for handling medium to large-scale systems in FEniCS
   (i) Always profile the code and look for bottlenecks.
   (ii) Avoid use of loops in python. Look for efficient alternatives.
   (iii) Avoid re-evaluation of matrices that do not change.
   (iv) Evaluate and write only necessary simulation outputs.
   (v) In an iterative process evaluate output at every n^{th} step to further speed up the simulation.
   (vi) Properly select/configure the solver and preconditioner based on the problem.

(II) Stepping into the realm of large scale simulations require knowledge of good programming practices, parallelization, and a deep understanding of the working principles of the tools/libraries.

Thanks

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iitrabhi@gmail.com
computationalmechanics.in

References

- Hughes, T. J.R. and Cottrell, J. A. and Bazilevs, Y., Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement, *Computer Methods in Applied Mechanics and Engineering*, 194(39—41), 4135–4195, 2005.
- Kiendl,J. ,Bletzinger,K.-U., Linhard,J., Wüchner, R., Isogeometric shell analysis with Kirchhoff–Love elements, *Computer Methods in Applied Mechanics and Engineering*, 198(49-52), 3902–3914, 2009.
- Nguyen, V. P., Anitescu, C., Bordas, S. P. A.,and Rabczuk, T. , Isogeometric analysis: An overview and computer implementation aspects, *Mathematics and Computers in Simulation*, 117, 89–116, 2015.
- Zareh, M.,and Qian, X. , Kirchhoff–Love shell formulation based on triangular isogeometric analysis, *Computer Methods in Applied Mechanics and Engineering*, 347, 853–873, 2019.
- Bletzinger, K. U.,and Ramm, E., Form finding of shells by structural optimization, *Engineering with Computers*, 9(1), 27–35, 1993.
- Bandara, K., and Cirak, F. , Isogeometric shape optimisation of shell structures using multiresolution subdivision surfaces, *CAD Computer Aided Design*, 95, 62–71, 2018.
- Hirschler, T., Bouclier, R., Duval, A., Elguedj, T.,and Morlier, J., Isogeometric sizing and shape optimization of thin structures with a solid-shell approach, *Structural and Multidisciplinary Optimization*, 2018.