

Ani3D-extension of parallel platform INMOST and hydrodynamic applications

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- Motivation
- Ani3D software package
- INMOST software platform
- Ani3D–INMOST integration
- Model hydrodynamic problems

- There are advanced serial FEM codes (e.g. Ani3D)
- Increasing the size of the problems to be solved
- Time and memory limitations for a serial computer
- Parallel mesh generation, discretization, linear system solution are required
- The direct code parallelization is too difficult
- There are software packages to operate with the distributed mesh data

Advanced Numerical Instruments 3D

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Description

Ani3D provides portable libraries for each step in the numerical solution of systems of PDEs with variable tensorial coefficients: (1) unstructured adaptive mesh generation, (2) metric-based mesh adaptation, (3) finite element discretization and interpolation, (4) algebraic solvers.

- Generation of tetrahedral meshes
- Mesh adaptation
- FEM discretization on tetrahedral meshes
- Solution of linear and nonlinear systems
- *Serial* code in Fortran and C

Open source code:

<http://sourceforge.net/projects/ani3d>

Ani-MBA library

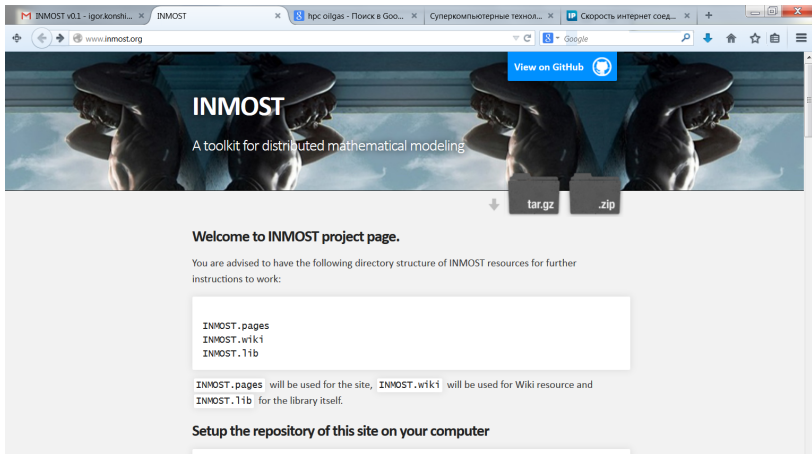
- generation of quasi-uniform meshes in a user-defined metric
- uniform refinement of tetrahedral meshes

Ani-FEM library

- local finite element discretization on tetrahedron
- assembling the local discretizations into a global linear system

the rest of libraries...

- Ani-C2F, Ani-INB, Ani-LMR, Ani-PRJ, Ani-RCB
- Ani-ILU, Ani-LU



INMOST v0.1 - igor.korshilov... x INMOST x hpc oilgas - Поиск в Goo... x Суперкомпьютерные технол... x Скорость интернет соед... x

www.inmost.org

View on GitHub

INMOST

A toolkit for distributed mathematical modeling

tar.gz .zip

Welcome to INMOST project page.

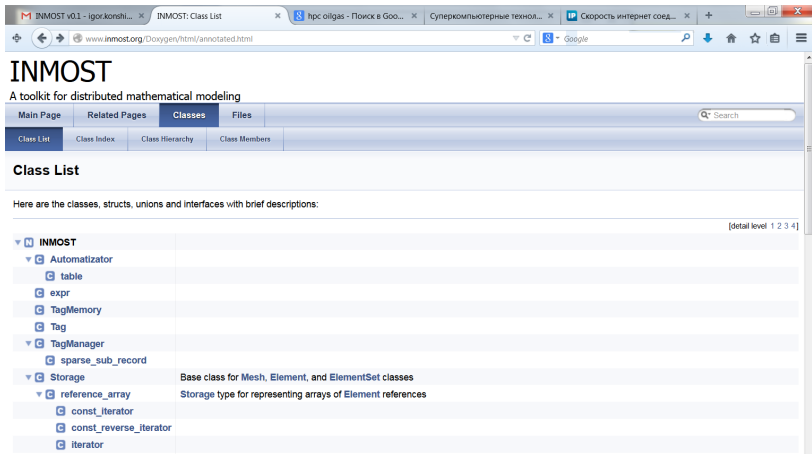
You are advised to have the following directory structure of INMOST resources for further instructions to work:

```
INMOST.pages
INMOST.wiki
INMOST.lib
```

INMOST.pages will be used for the site, INMOST.wiki will be used for Wiki resource and INMOST.lib for the library itself.

Setup the repository of this site on your computer

The screenshot shows a web browser displaying the GitHub repository page for `INMOST-DEV/INMOST`. The browser's address bar shows the URL `https://github.com/INMOST-DEV/INMOST/wiki`. The GitHub logo is visible in the top left, and the repository name `INMOST-DEV / INMOST` is displayed below it. The page features a search bar, navigation links for `Explore`, `Features`, `Enterprise`, and `Blog`, and buttons for `Sign up` and `Sign in`. The repository statistics show `2` Watchers, `0` Stars, and `0` Forks. The main content area is titled `Home` and includes a message from Kirill Terekhov. A large heading reads `Welcome to the INMOST wiki!`. Below this, there are sections for `Compiling INMOST:`, `Reporting issues and preparing tests:`, and `Explore included examples:`, each with a link to a specific page. On the right side, there is a `Pages` sidebar with a search bar and a list of pages including `0100 Compilation`, `0200 Compilation Windows`, `0201 Obtain MSVC`, `0202 Obtain MSMPI`, `0203 Compilation INMOST Windows`, `0204 Compilation ParMETIS Windows`, `0205 Compilation Zoltan Windows`, and `0206 Compilation PFTSr`.



The screenshot shows a web browser displaying the INMOST Doxygen website. The browser's address bar shows the URL `www.inmost.org/Doxygen/html/annotated.html`. The page title is "INMOST" and the subtitle is "A toolkit for distributed mathematical modeling". The navigation menu includes "Main Page", "Related Pages", "Classes", and "Files". The "Classes" section is active, and the "Class List" sub-section is selected. The main content area displays a list of classes and interfaces under the "INMOST" namespace. The classes listed are: Automatzator (with sub-classes table, expr, TagMemory, Tag), TagManager (with sub-class sparse_sub_record), Storage (described as a base class for Mesh, Element, and ElementSet classes), reference_array (described as a storage type for representing arrays of Element references), const_iterator, const_reverse_iterator, and iterator.

INMOST
A toolkit for distributed mathematical modeling

Main Page Related Pages **Classes** Files

Class List Class Index Class Hierarchy Class Members

Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

[detail level 1 2 3 4]

- INMOST
 - Automatzator
 - table
 - expr
 - TagMemory
 - Tag
 - TagManager
 - sparse_sub_record
 - Storage **Base class for Mesh, Element, and ElementSet classes**
 - reference_array **Storage type for representing arrays of Element references**
 - const_iterator
 - const_reverse_iterator
 - iterator

- **I**ntegrated
- **N**umerical
- **M**odelling and
- **O**bject-oriented
- **S**upercomputing
- **T**echnologies

INMOST is the software platform for developing parallel numerical models on general meshes.

INMOST is a tool for supercomputer simulations characterized by a maximum generality of supported computational meshes, distributed data structure flexibility, cost-effectiveness, cross platform portability.

- Mesh data are distributed
- Conformal meshes with Tetrahedra, Hexahedra, Prisms, Pyramids, Polyhedra etc.
- Mesh elements hierarchy: Vertex, Edge, Face, Cell
- Mesh element can contain some data (tags)
- Specification of “ghost” elements (“hallo”)
- Exchange tag data for ghost elements
- Save/Load mesh data in a parallel format file (.pmf, .pvtk, ...)

- Assemble the distributed matrix and right-hand side of the linear system
- Parallel solution of the distributed linear system
- A set of internal linear solvers
- A set of external solvers: PETSc, Trilinos, SuperLU, ...

Mesh

- read and partition
- refine on each processor *preserving conformity*
- merge

Init

- enumerate respective elements
- create tags for DOFs numbers
- synchronize tags

Assemble

- generate local matrix for each tetrahedron
- assemble them into a global matrix

Formulation

$$\begin{aligned} -\Delta \mathbf{u} + \nabla p &= 0 & \text{in } \Omega \\ \nabla \cdot \mathbf{u} &= 0 & \text{in } \Omega \\ \mathbf{u} &= \mathbf{u}_0 & \text{on } \partial\Omega_1 \\ \mathbf{u} &= 0 & \text{on } \partial\Omega_2 \\ \frac{\partial \mathbf{u}}{\partial \mathbf{n}} - p &= 0 & \text{on } \partial\Omega_3 \end{aligned}$$

$$\mathbf{u}_0 = (64 \cdot (y - 0.5) \cdot (1 - y) \cdot z \cdot (1 - z), 0, 0)$$

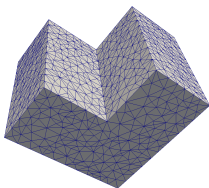


Figure: The coarsest mesh S0

Table: The problems parameters

| Problem name | S0 | S1 | S2 |
|----------------------|----------|----------|-----------|
| Number of nodes | 5187 | 36824 | 279903 |
| Number of edges | 31637 | 243079 | 1908542 |
| Number of tetrahedra | 25113 | 200904 | 1607232 |
| Matrix size | 115659 | 876533 | 6845238 |
| Number of nonzeros | 10751851 | 84374191 | 668849086 |

Results for S0 and S1 problem

Table: The solution of S0 problem on $p = 1, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{prec} | T_{iter} | N_{iter} | Dens | PM | T_{sol} | S |
|-----|------------------|------------------|-------------------|-------------------|-------------------|------|----|------------------|------|
| 1 | 0.06 | 8.77 | 3.30 | 4.26 | 102 | 0.81 | 0 | 7.56 | 1.00 |
| 2 | 0.04 | 5.72 | 2.27 | 3.27 | 132 | 0.96 | 0 | 5.54 | 1.36 |
| 4 | 0.03 | 3.95 | 1.57 | 2.34 | 152 | 1.18 | 0 | 3.91 | 1.93 |
| 8 | 0.02 | 2.25 | 1.19 | 1.81 | 172 | 1.53 | 5 | 3.00 | 2.52 |
| 16 | 0.02 | 1.63 | 1.20 | 1.40 | 182 | 2.01 | 3 | 2.83 | 2.67 |
| 32 | 0.02 | 1.49 | 1.50 | 1.33 | 182 | 2.80 | 10 | 2.83 | 2.67 |

Table: The solution of S1 problem on $p = 1, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{prec} | T_{iter} | N_{iter} | Dens | PM | T_{sol} | S |
|-----|------------------|------------------|-------------------|-------------------|-------------------|------|----|------------------|------|
| 1 | 0.38 | 69.07 | 31.41 | 97.20 | 242 | 0.85 | 0 | 128.61 | 1.00 |
| 2 | 0.28 | 40.97 | 20.30 | 76.88 | 322 | 0.93 | 0 | 97.18 | 1.32 |
| 4 | 0.21 | 25.31 | 12.76 | 47.88 | 332 | 1.03 | 0 | 60.64 | 2.12 |
| 8 | 0.14 | 13.76 | 7.83 | 28.68 | 332 | 1.15 | 1 | 36.51 | 3.52 |
| 16 | 0.10 | 8.37 | 4.77 | 18.46 | 362 | 1.37 | 3 | 23.23 | 5.53 |
| 32 | 0.06 | 5.09 | 4.12 | 12.70 | 402 | 1.65 | 8 | 16.82 | 7.64 |

Table: The solution of S2 problem on $p = 4, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{prec} | T_{iter} | N_{iter} | Dens | PM | T_{sol} | S |
|-----|------------------|------------------|-------------------|-------------------|-------------------|------|----|------------------|------|
| 4 | 1.48 | 181.05 | 142.29 | 1484.02 | 722 | 0.97 | 0 | 1626.31 | 1.00 |
| 8 | 0.90 | 94.03 | 76.01 | 847.62 | 802 | 1.03 | 0 | 923.63 | 1.76 |
| 16 | 0.58 | 52.03 | 72.70 | 481.50 | 802 | 1.10 | 2 | 554.20 | 2.93 |
| 32 | 0.37 | 29.23 | 26.88 | 288.73 | 802 | 1.21 | 2 | 315.61 | 5.15 |

Formulation

$$\begin{aligned}\frac{\partial c}{\partial t} - \nabla(D\nabla c) + \mathbf{v} \cdot \nabla c &= 0 \quad \text{in } \Omega \\ c &= g \quad \text{on } \partial\Omega \\ D &= \begin{pmatrix} 0.001 & 0 & 0 \\ 0 & 0.001 & 0 \\ 0 & 0 & 0.001 \end{pmatrix} \\ \mathbf{v} &= (1, 0, 0)\end{aligned}$$

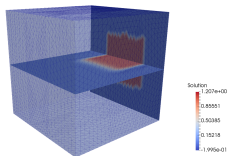


Figure: The concentration at time $t = 0.5$

Table: The problems parameters

| Problem name | L0 | L1 | L2 |
|----------------------|--------|---------|----------|
| Number of nodes | 20417 | 155905 | 1218561 |
| Number of tetrahedra | 111616 | 892928 | 7143424 |
| Matrix size | 20417 | 155905 | 1218561 |
| Number of nonzeros | 291393 | 2281217 | 18053121 |

Table: The solution of problem on mesh L0 on $p = 1, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{sol} | T_{Σ} | S |
|-----|------------------|------------------|------------------|--------------|------|
| 1 | 2.87 | 62.68 | 3.27 | 68.82 | 1.00 |
| 2 | 1.93 | 40.45 | 2.05 | 44.43 | 1.54 |
| 4 | 1.29 | 26.94 | 1.24 | 29.47 | 2.33 |
| 8 | 0.82 | 16.76 | 0.76 | 18.34 | 3.75 |
| 16 | 0.58 | 11.91 | 0.53 | 13.02 | 5.28 |
| 32 | 0.45 | 8.89 | 0.55 | 9.89 | 6.95 |

Table: The solution of problem on mesh L1 on $p = 1, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{sol} | T_{Σ} | S |
|-----|------------------|------------------|------------------|--------------|-------|
| 1 | 26.16 | 552.87 | 33.86 | 612.89 | 1.00 |
| 2 | 16.48 | 327.93 | 21.31 | 365.72 | 1.67 |
| 4 | 9.83 | 197.89 | 12.19 | 219.91 | 2.78 |
| 8 | 5.75 | 114.81 | 7.28 | 127.84 | 4.79 |
| 16 | 3.56 | 73.57 | 4.03 | 81.16 | 7.55 |
| 32 | 2.31 | 47.28 | 2.45 | 52.04 | 11.77 |

Table: The solution of problem on mesh L2 on $p = 1, \dots, 32$ processors

| p | T_{ini} | T_{ass} | T_{sol} | T_{Σ} | S |
|-----|------------------|------------------|------------------|--------------|-------|
| 1 | 436.82 | 5692.31 | 723.23 | 6852.36 | 1.00 |
| 2 | 169.17 | 2628.09 | 258.71 | 3055.97 | 2.24 |
| 4 | 94.33 | 1461.24 | 147.30 | 1702.87 | 4.02 |
| 8 | 53.62 | 874.21 | 91.24 | 1019.07 | 6.72 |
| 16 | 31.52 | 522.99 | 53.28 | 607.79 | 11.27 |
| 32 | 17.6 | 308.84 | 29.61 | 356.05 | 19.24 |

- The Ani3D-extension of the parallel platform INMOST is presented.
- The extension widens the functionality of INMOST by the FE and meshing libraries of the Ani3D software package.
- Numerical experiments demonstrated the efficiency of the presented approach for the parallel solution of two model hydrodynamic problems.
- The examples can be downloaded at

https://github.com/INMOST-DEV/INMOST/tree/master/Examples/Ani_Inmost