MTV Student Virtual Research Symposium

Hammer: a flexible research framework for radiation transport solvers

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Motivation and Mission Relevance

Computational radiation transport tools

- model complex radiation transport scenarios to support numerous applications including the design and analysis of radiation detectors, nuclear reactors, shielding and criticality safety, and numerous others
- Typically grouped into two classes: deterministic and Monte Carlo
    - Deterministic transport is fast, but requires discretization in space, direction, and energy
    - Monte Carlo does not require discretization and is very accurate, but is usually slower

Our goal: Develop an open source framework to design novel radiation transport techniques encompassing both deterministic and Monte Carlo transport to provide a flexible tool for researchers to rapidly prototype novel ideas

Hammer is developed, maintained, and managed by students!

Why does Hammer exist?

Production codes

- Fast and well validated, and ideal for production analyses
- Steep learning curve to test new ideas that require modifying the source
- Long history of these products leads to managing around legacy coding practices

Hammer

- Captures complexity of real-world nonproliferation problems
- Easy to add new features
- Modern software engineering best practices
- Educational platform for modern SQA

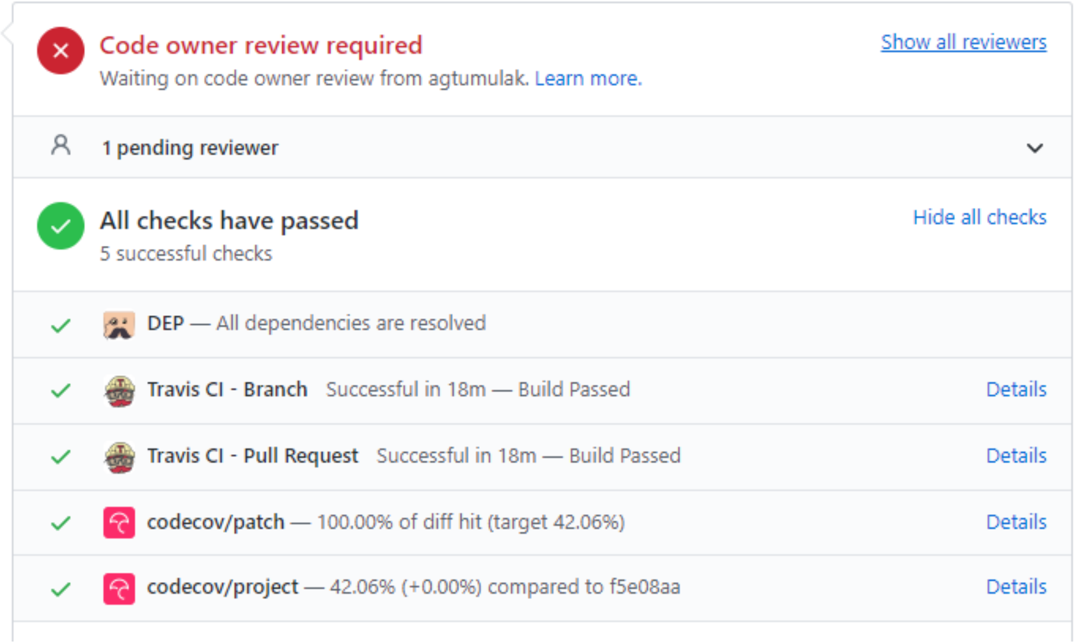
Research/test codes

- Very simple problems
- Disposable; only used to test one new algorithm/idea without broader context
- Not fully featured

What technologies does Hammer use?

We use:

- object-oriented c++17
- cross-platform CMake build system
  - Windows, MacOS, Linux, CAEN Linux server
- git version control; currently hosted on Github
- unit testing & continuous integration
  - Travis CI, CodeCov, Catch2
- supports threading (MPI support in future)
- Doxygen documentation
- Paraview output support
- human-readable xml interface



Human-readable interface

- human-readable xml interface, parsed with pugixml

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</materials>

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  <estimator name="total_flux_tl" type="flux" method="track length" apply="my_rectangular_mesh" particle="neutron" output_format="vtk">
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  </estimator>
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<surfaces>
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<output path="../output/" />

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    <surface name="test_sphere_1" sense="-1"/>
    <variance_reduction type="forced collisions" roulette="1"/>
  </cell>
  <cell name="test_cell_2" material="test_mat">
    <surface name="test_sphere_1" sense="+1"/>
    <surface name="test_sphere_2" sense="-1"/>
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  </cell>
</cells>

<meshes>
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      <y min="0" max="0.05" bins="100" />
      <z min="0" max="0.1" bins="100"/>
    </cartesian_mesh>
</meshes>
```

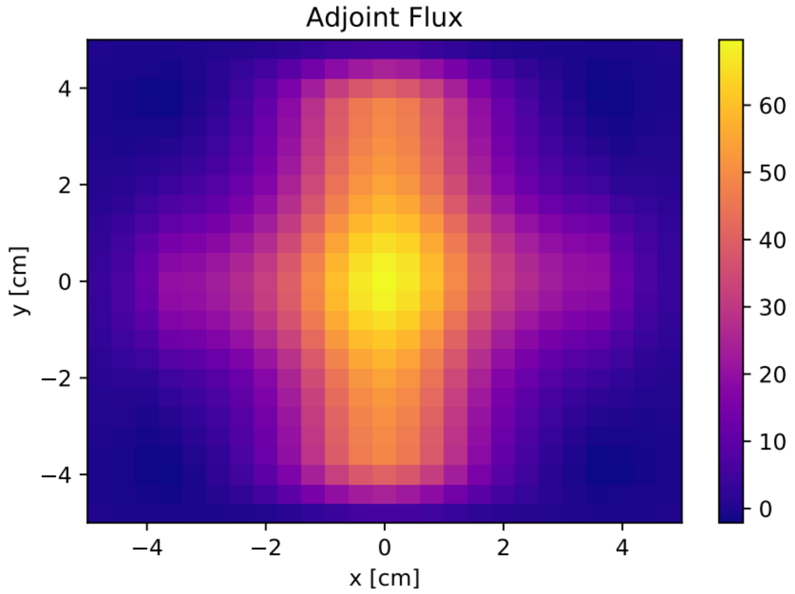
What can Hammer do?

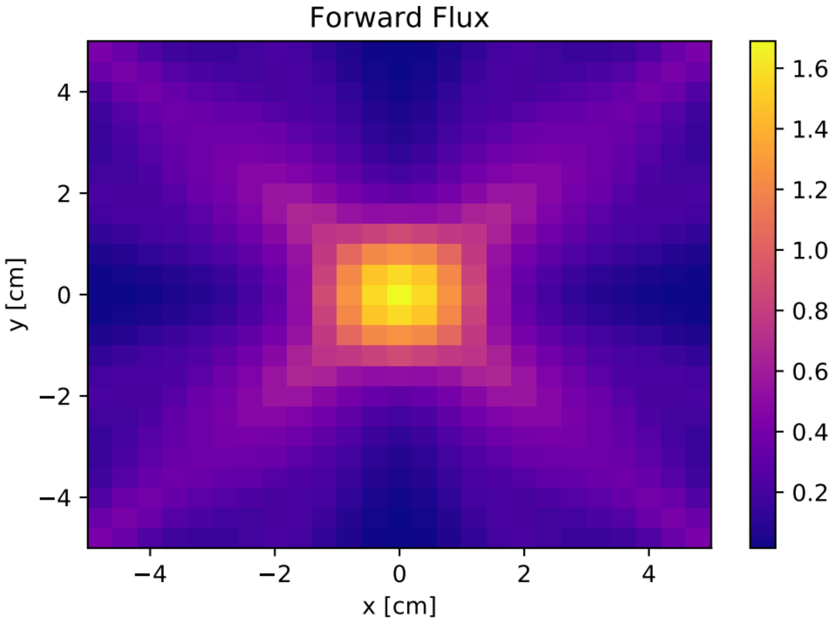
Fixed-source calculations:

- 3D Monte Carlo; multigroup and continuous energy
- 2D SN; forward and adjoint
- neutrons and photons

Mesh based calculations:

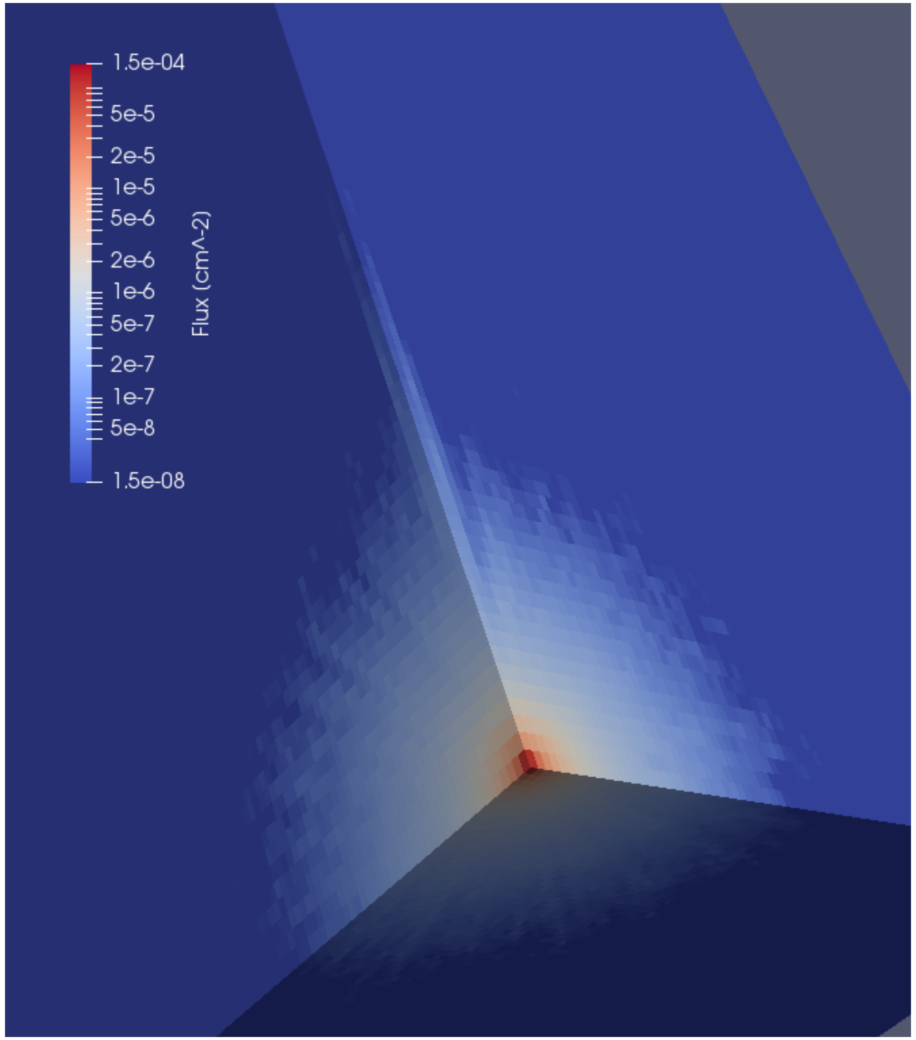
- structured rectangular, cylindrical and spherical
- unstructured tetrahedral
- 1D/2D/3D with rotations
- used for estimators, variance reduction, SN





What else can Hammer do?

- **Full-featured Monte Carlo variance reduction:**
  - importance splitting, rouletting
  - weight windows
  - exponential transform
  - forced collisions
  - forced flight (DXTRAN)
- **Monte Carlo estimators:**
  - track length/collision flux in volume
  - flux/current on surface
  - Flux at a point
  - bin over energy, group, collision order, time, angle, spatial mesh, …
  - flux tally modifier for reaction rate



What will Hammer be able to do?

Ongoing feature projects:

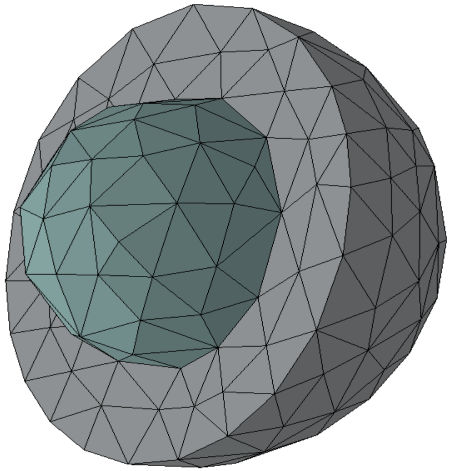
- fully featured CSG: lattices, regions, complements, …
- transport in stochastic media
- Hybrid MC/deterministic methods, including FW-CADIS
- in-house physics event generator for fission, radioactive decay, …

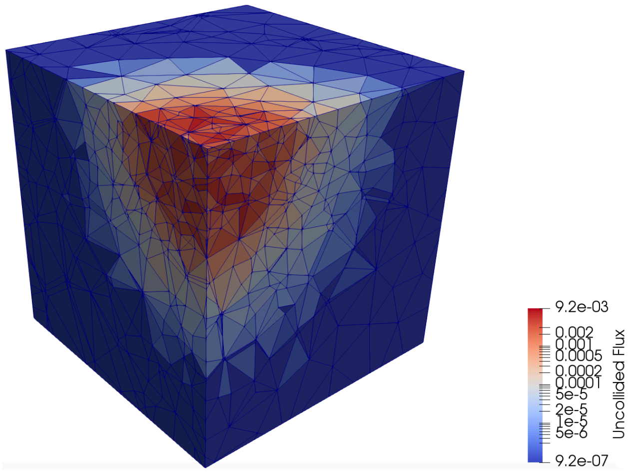
Up next:

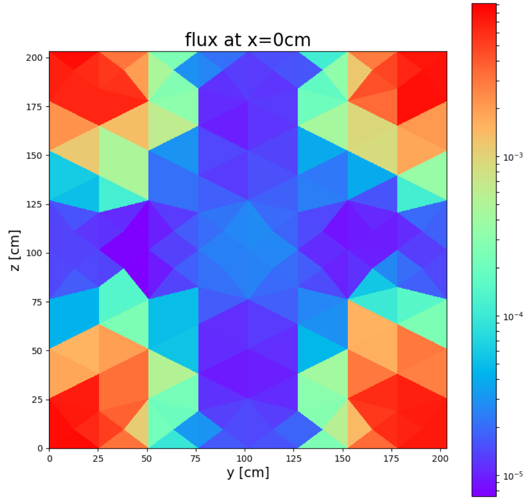
- k/α-eigenvalue
- differential operator sampling for sensitivity analysis
- charged particle transport
- neutrino transport
- depletion
- MPI
- MCNPX-PoliMi style particle tracking for custom analysis of detector problems

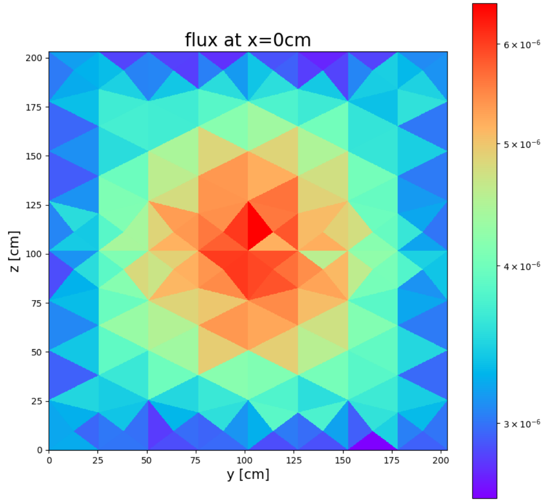
Hybrid Methods: Direct Coupling

- Collaboration with deterministic solver, NC State code, THOR
  - Highly parallel S_N transport solver on an unstructured tetrahedral mesh
  - suffers from numerical artifacts called "**ray effects**"
- Hammer provides n^{th}-order collided source to the THOR
- Coupling mitigates ray effects

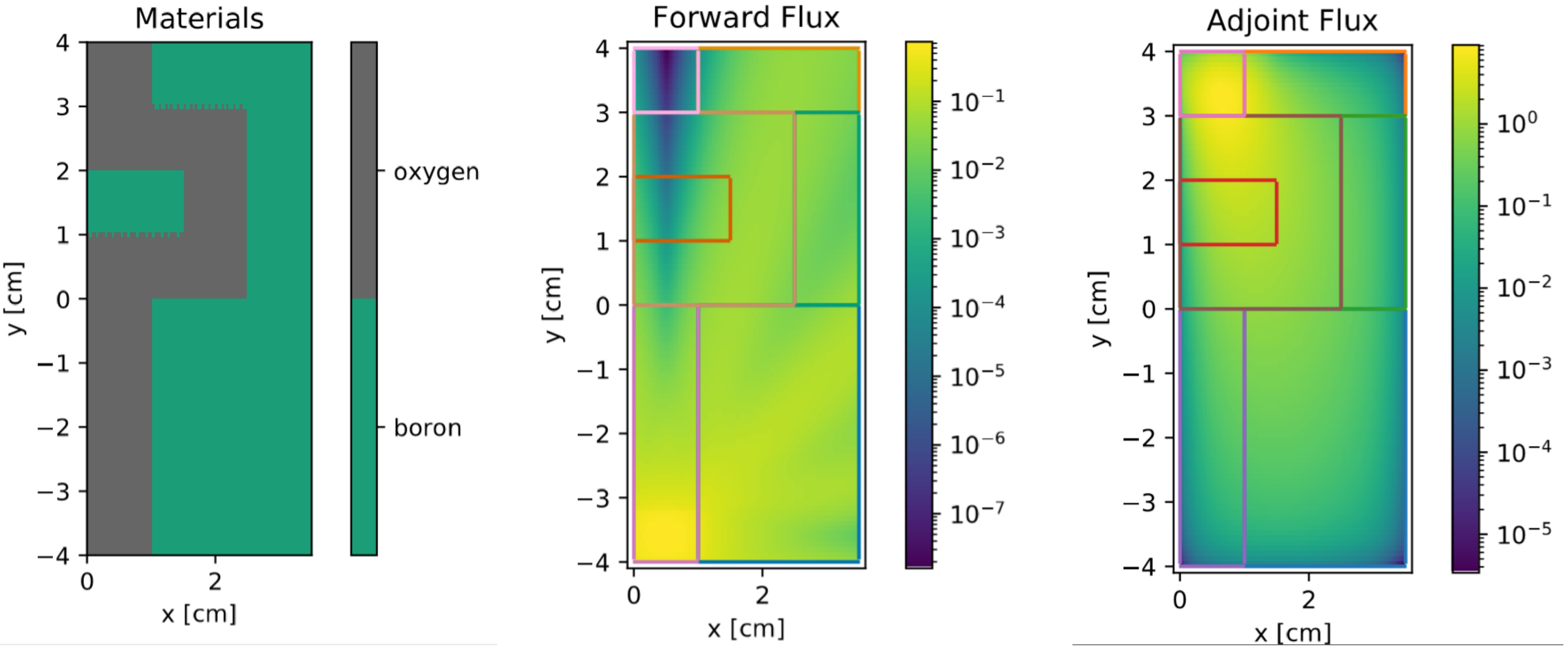








Hybrid Methods: FW-CADIS



MTV and National Lab Impact

We have summer 2020 internships/ongoing collaborations with:

- LANL (x2)
  - advanced forced flight variance reduction, hybrid methods, unstructured mesh, critical experiment design
- ORNL (x2)
  - expand variance reduction and sensitivity analysis capabilities of Shift
- LLNL (x2)
  - transport in stochastic media
- SNL (x1)
  - transport in stochastic media

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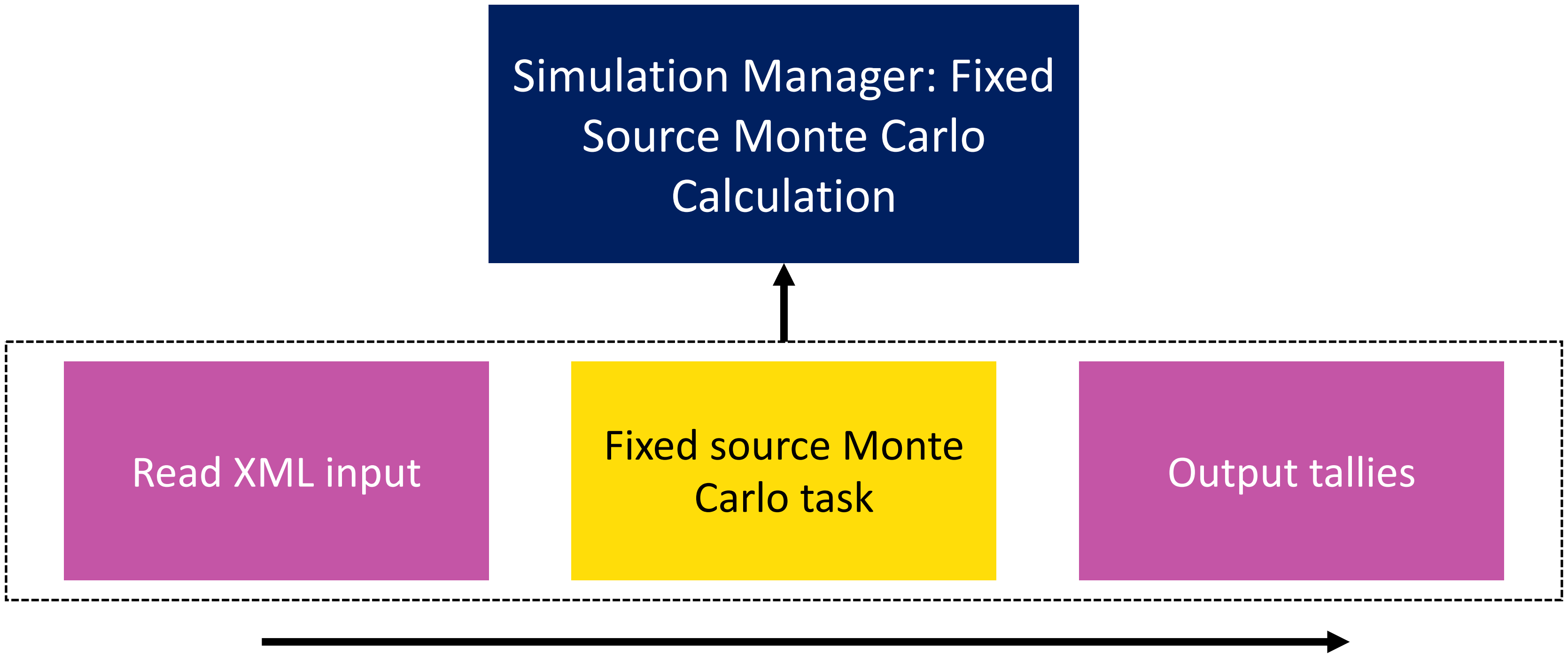
Conclusions and Impact

Hammer will:

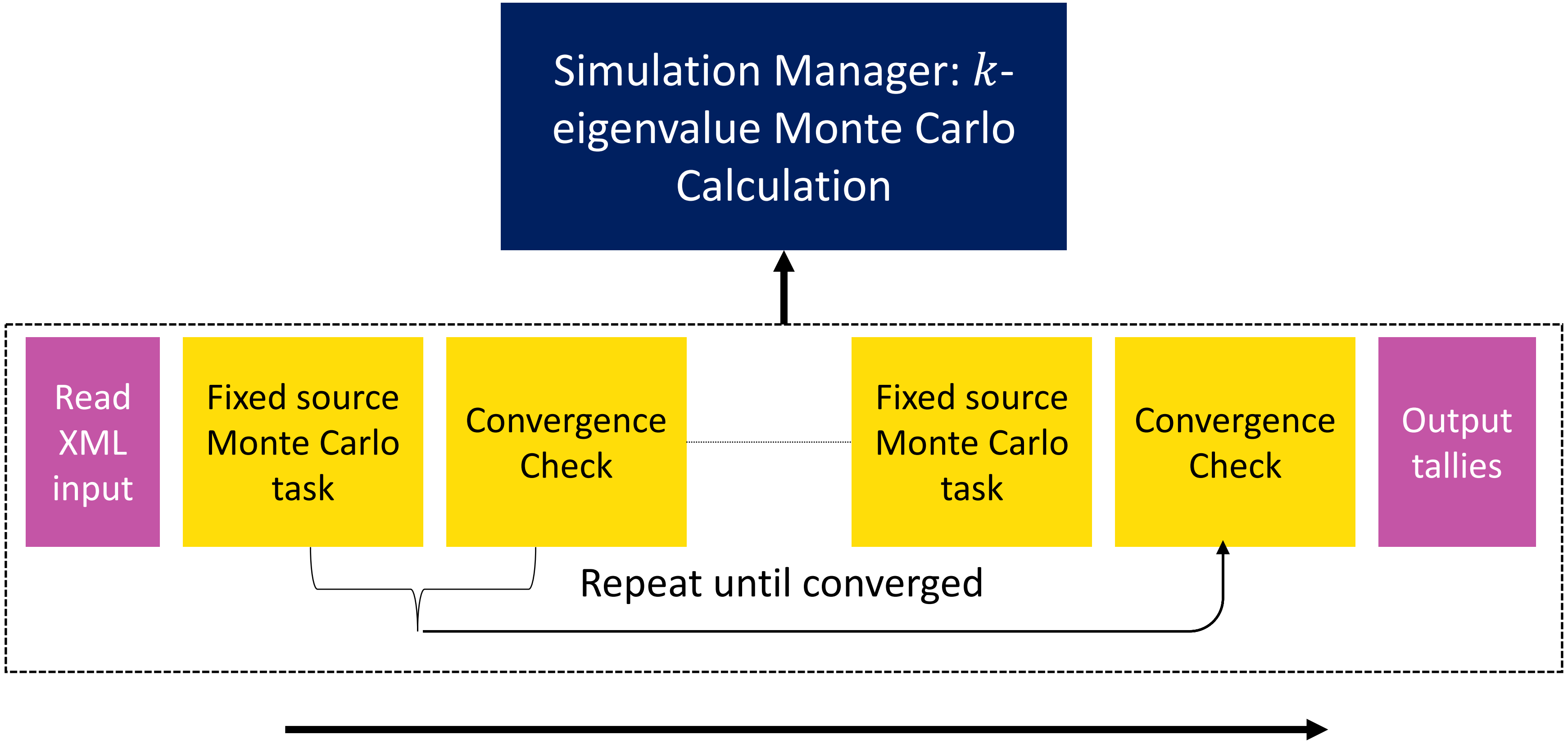
- support the development of next-generation monitoring technologies by providing the tools to design and model them
- make it easier to tailor the solver to a specific application/experiment
- provide hands on training for the next generation of computational physicists in in-demand software engineering and project management skills

Contact: Prof. Brian Kiedrowski (bckiedro@umich.edu)

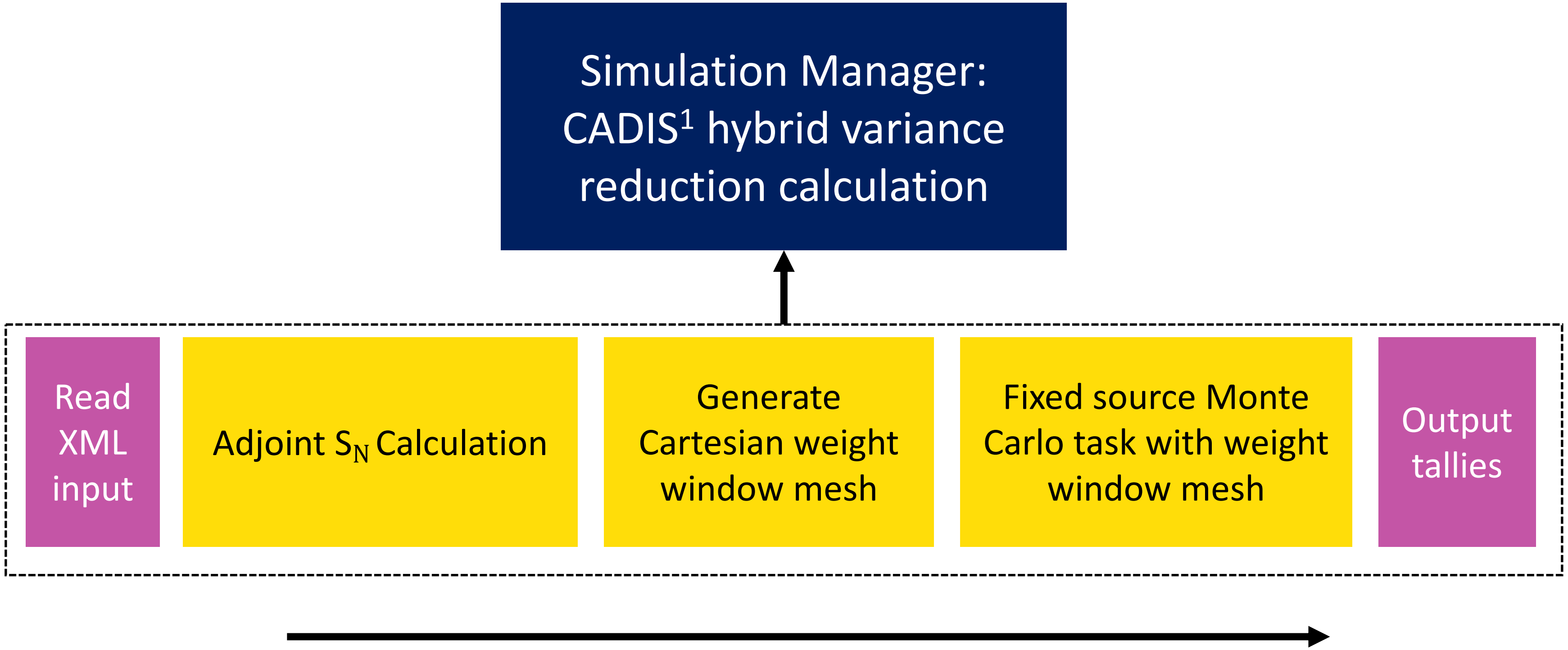
Hammer: a modular design



Hammer: a modular design



Hammer: a modular design



1. J. C. Wagner and A. Haghighat. "Automated Variance Reduction of Monte Carlo Shielding Calculations Using the Discrete Ordinates Adjoint Function," *Nuclear Science and Engineering*, 128, pp. 186–208 (1998).

Acknowledgements

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