# Testing Complex Software

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Developing a Testing and Continuous Integration Strategy for your Team tutorial @ Exascale Computing Project Annual Meeting

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## License and Citation


- **The requested citation the overall tutorial is: Gregory R. Watson and David M. Rogers, Developing a Testing and Continuous Integration Strategy for your Team tutorial, in Exascale Computing Project Annual Meeting, online, 2022. DOI: 10.6084/m9.figshare.19608927**
- Individual modules may be cited as *Speaker, Module Title*, in Better Scientific Software tutorial…

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# How to build your test suite?

- Two “levels”
  - Automated / scheduled testing
    - May be long running
    - Provide comprehensive coverage
  - Continuous integration
    - Quick diagnosis of error
- A mix of different granularities works well
  - Unit tests for isolating component or sub-component level faults
  - Integration tests with simple to complex configuration and system level
  - Restart tests

- Rules of thumb
  - Simple
  - Enable quick pin-pointing

Useful resources https://ideas-productivity.org/resources/howtos/

# Why not always use the most stringent testing?

- Effort spent in devising running and maintaining test suite is a tax on team resources
- When the tax is too high…
  - Team cannot meet code-use objectives
- When is the tax is too low…
  - Necessary oversight not provided
  - Defects in code sneak through

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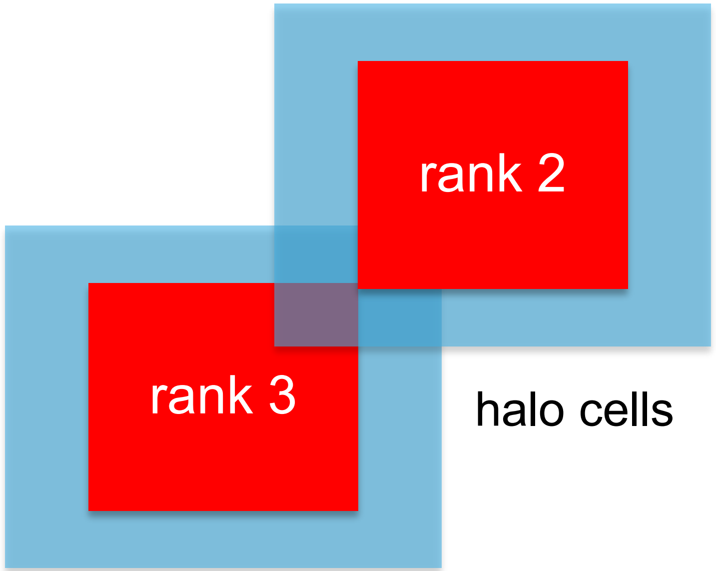

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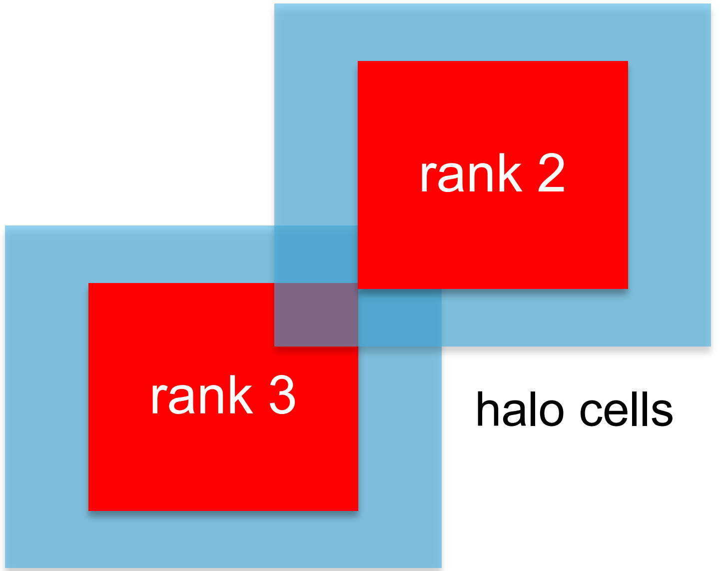
- Evaluate project needs:
  - Objectives: expected use of the code
  - Lifecycle stage: new or production or refactoring
  - Team: size and degree of heterogeneity
  - Lifetime: one off or ongoing production
  - Complexity: modules and their interactions



# Additional Notes: Good Testing Practices

- Verify Code coverage
- Must have consistent policy on dealing with failed tests
  - Issue tracking
    - How quickly does it need to be fixed?
    - Who is responsible for fixing it?
- Someone should be watching the test suite
- When refactoring or adding new features, run a regression suite before check in
  - Add new regression tests or modify existing ones for the new features
- Code review before releasing test suite is useful
  - Another person may spot issues you didn't
  - Incredibly cost-effective

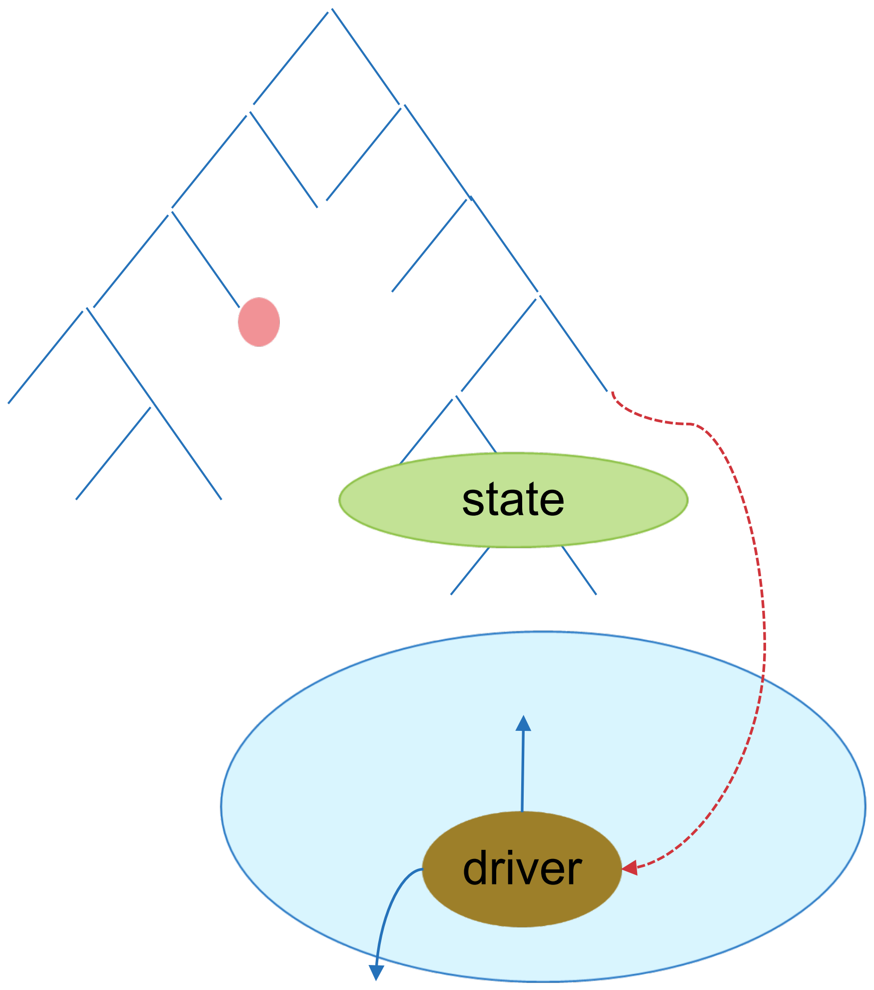
# Example 1: Test Development For a New Code

- Development of tests and diagnostics goes hand-in-hand with code development
  - Compare against simpler analytical or semi-analytical solutions
  - Build granularity into testing
  - Use scaffolding ideas to build confidence
  - Always inject errors to verify that the test is working
  - Non-trivial to devise good tests, but extremely important

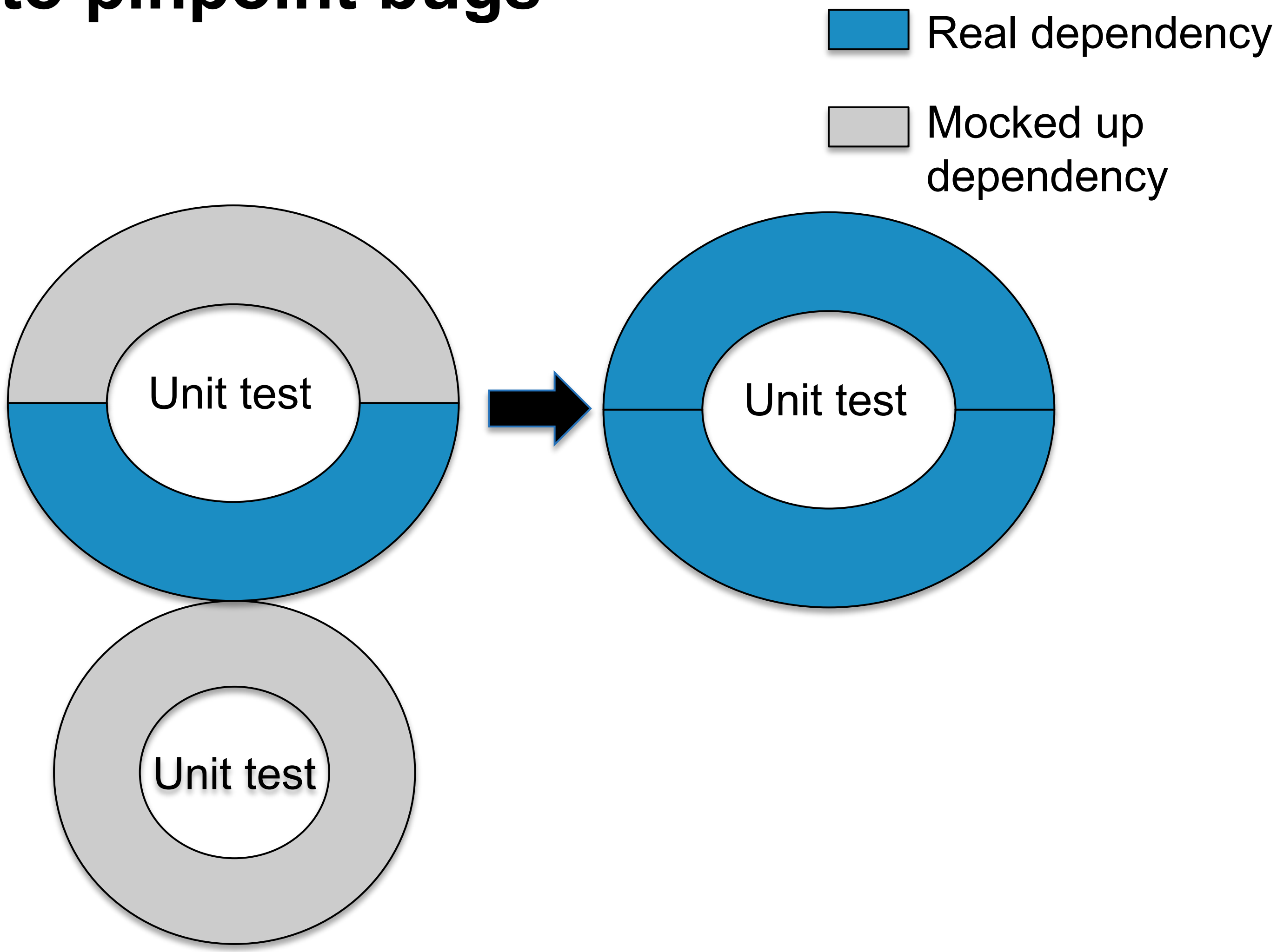
# Example 2: Test Development For a Legacy Code

There may not be existing tests

- Isolate a small area of the code
- Dump a useful state snapshot
- Build a test driver
  - Start with only the files in the area
  - Link in dependencies
    - Copy if any customizations needed
- Read in the state snapshot
- Restart from the saved state
- Verify correctness
  - Always inject errors to verify that the test is working



# Example 3: Structuring Tests to pinpoint bugs

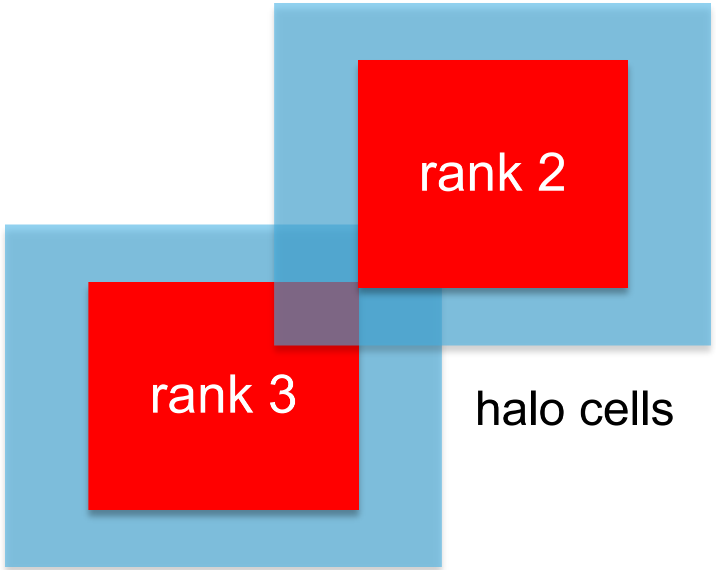


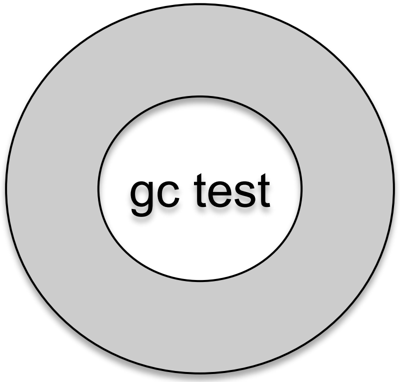

- Bottom-up picture
  - Components can be exercised against known simpler applications
  - Same applies to combination of components
- Build a scaffolding of verification tests to gain confidence

# Example 3: Structured Testing

## Unit test for Grid halo cell fill

- Verification of guard/ghost/halo cell fill
- Initialize field on interior cells (red)
- Apply guard cell fill
- Check for equivalence with known fill pattern



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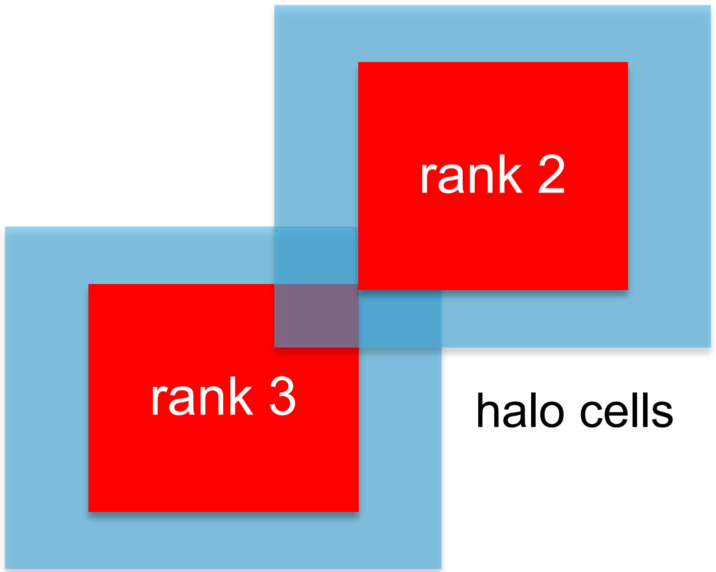
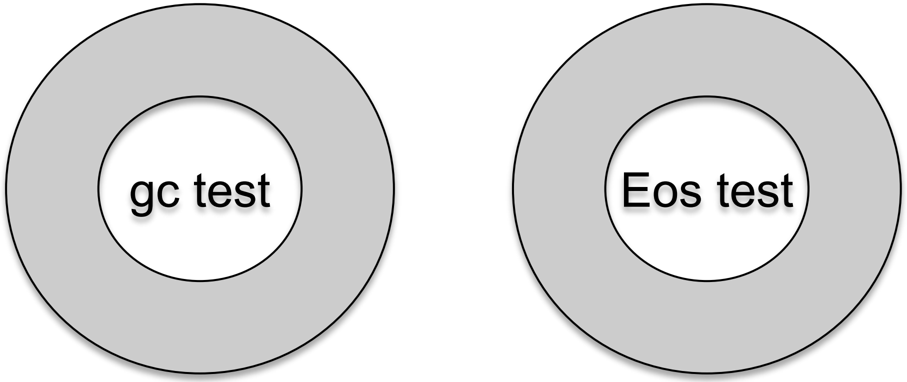


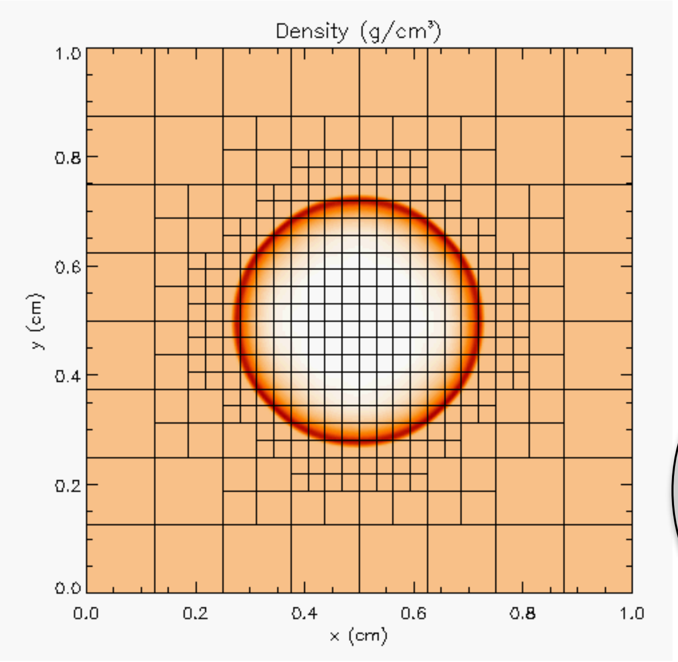



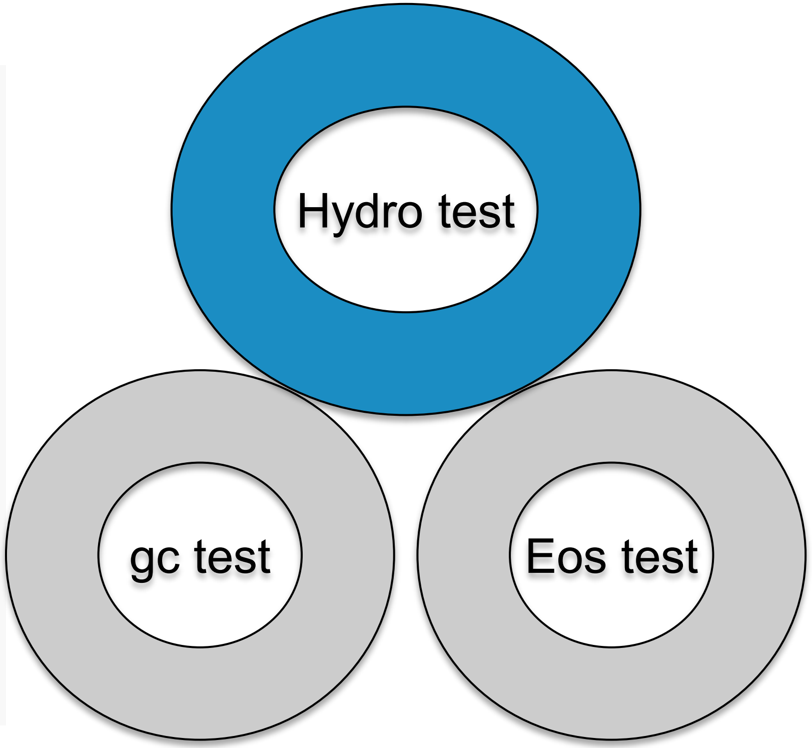

Next, build an EOS Test – is E(V,T) consistent with P(V,T)?

# Example 3: Structured Testing

## Unit test for Hydrodynamics

- Sedov blast wave
- High pressure at the center
- Shock moves out spherically
- Known analytical solution




Though it exercises mesh, hydro and eos, if mesh and eos are verified first, then this test verifies hydro

**More testing needed for Grid using AMR**
**Flux correction and regridding**

# Example 3: Structured Testing

**For AMR, correct behavior of flux conservation and regridding should also be verified.**

**Reason about correctness for testing Flux correction and regridding**

IF Guardcell fill and EOS unit tests passed

- Run Hydro without AMR
  - If failed fault is in Hydro
- Run Hydro with AMR, but no dynamic refinement
  - If failed fault is in flux correction
- Run Hydro with AMR and dynamic refinement
  - If failed fault is in regridding

# Example 4: Coverage Matrix (Interoperabilities)

## First line of defense – code coverage tools

- Code coverage tools necessary but not sufficient
- Do not give any information about interoperability

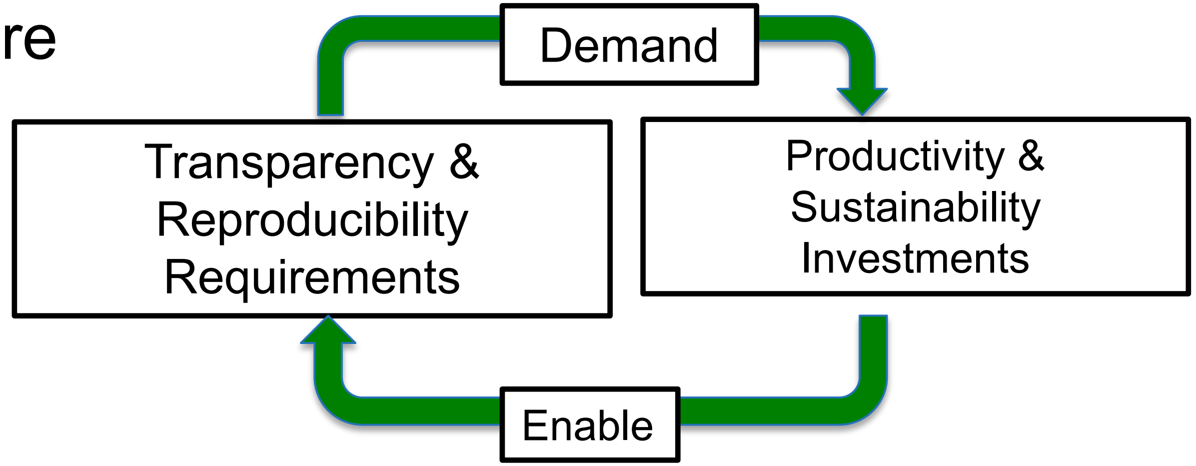
| | Hydro | EOS | Gravity | Burn | Particles |
|---|---|---|---|---|---|
| AMR | CL | CL | | CL | CL |
| UG | SV | SV | | | SV |
| Multigrid | WD | WD | WD | WD | |
| FFT | | | PT | | |

- Map your tests and examples – what do they do?
- Follow the order
  - All unit tests – including full module tests (e.g. CL)
  - Tests sensitive to perturbations (e.g. SV)
  - Most stringent tests for solvers (e.g. WD, PT)
  - Least complex test to cover remaining spots (**Aha!**)

# Incentives for Paying Attention to Reproducibility

Common statement: “I would love to do a better job on my software, but I need to..."

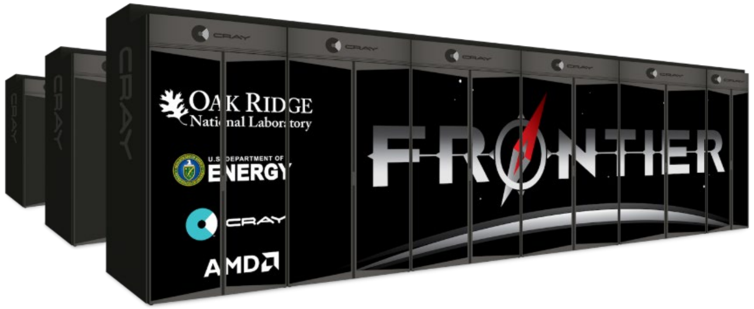
- Get this paper submitted
- Complete this project task
- Do something my employer values more




**Goal**: Change incentives to include valuing of better software, better science

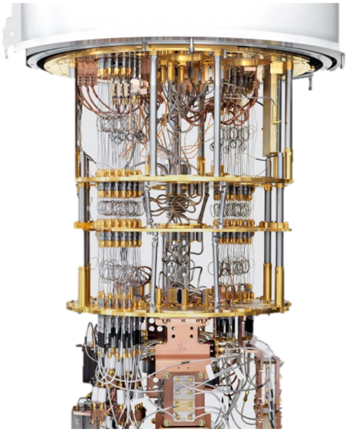
This is a long-term goal, requiring a culture change in (computational) science which in the early stages

# Additional Motivation – Testing Practices




- Supercomputer Cycles are Scarce Resources
  - Goal = capture QA details during science runs


- Many people need to have confidence in your results:
  - You
  - Your project lead or boss
  - Your sponsor
  - Your reviewers or referees
  - Your readers



- Testing helps build credibility *without* repeating runs.

# Strategies for Improving Reproducibility

- **Solid versioning practices are fundamental to reproducibility**
  - Source code, dependencies, copy through to outputs
- **Build in quality from the start**
  - Expectation for documentation and level of testing (write in-sync with code).
  - Increasing expectations as code becomes more "public"
  - Peer review / team productivity tracking meetings
- Watch Out for Numerical Artifacts
  - Integer overflows, floating point underflows, numerical algorithm stability
- Plan Ahead for Experimental Campaign Progression
  - How do scaling tests & intermediate outputs relate to code features?
  - What in-run correctness checks exist?
  - What if a patch needs to be applied during a campaign?

# Testing Strategies for Improving Reproducibility

- **Testing, testing, and more testing!**
- Add “regression tests”
  - If you fix a bug, add a test to make sure that bug doesn’t creep back in
- Add more tests
  - Be creative
  - Think about common cases, then corner cases
  - Think about misuse (unintentional or intentional)
  - Think about synthetic tests with synthetic data
  - Think about low-cost tests that can be “always on” (even if they’re not so stringent)
  - Can you detect silent data corruption?
- Physics / Math Based Strategies
  - Conserved quantities, symmetries, synthetic operators
- Design by Contract
  - Input / Output specifications, program invariants
- Test your third-party dependencies
  - Are your tools doing what you think they’re doing?
  - What if you’re using a new version?
  - How do you decide if it is okay to upgrade to a new version?
- Test your tests!
  - Make sure tests fail when they’re supposed to!
- Thoroughly verify the code
  - Does the code do what you intended it to do?
  - On all relevant platforms (compilers, hardware, etc.)
- Test regularly
  - To identify and document where changes to the underlying
    platform change code behavior/results

# Takeaways

- Context: understand testing needs and costs
- Devise tests to enable quick pinpointing of errors through reasoning about their behavior
- test at various granularities – bottom-up (UNIT/verification) through top-down (integration/validation)
- Tests at various complexities – CI vs. regression
- Maintain a holistic validation strategy: think globally, act locally

…….Questions ?