Facilitating coupled model development for both climate and weather via CIME

(Common Infrastructure for Modeling the Earth)

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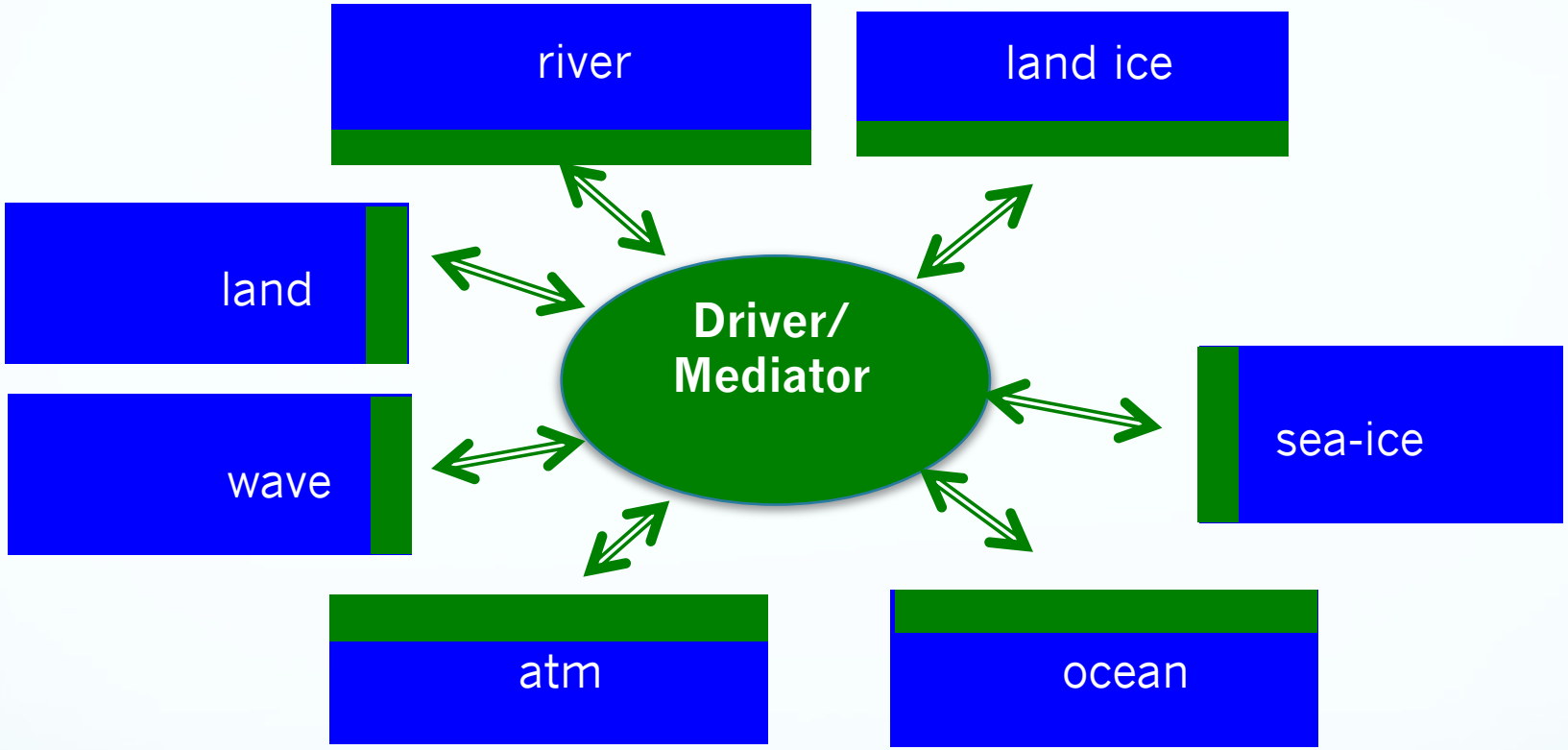
Outline

1. What is a coupled earth system model?
2. What is CIME and what is it comprised of?
3. How does CIME address the challenges of coupled earth system modeling?
   - Flexible coupling infrastructure
   - User-friendly case-control system
   - User-friendly regression testing, unit testing, porting and verification utilities
4. What are next steps for CIME to address NWP needs?
5. How are different parts of CIME collaboratively developed and prioritized?

What is a coupled model?

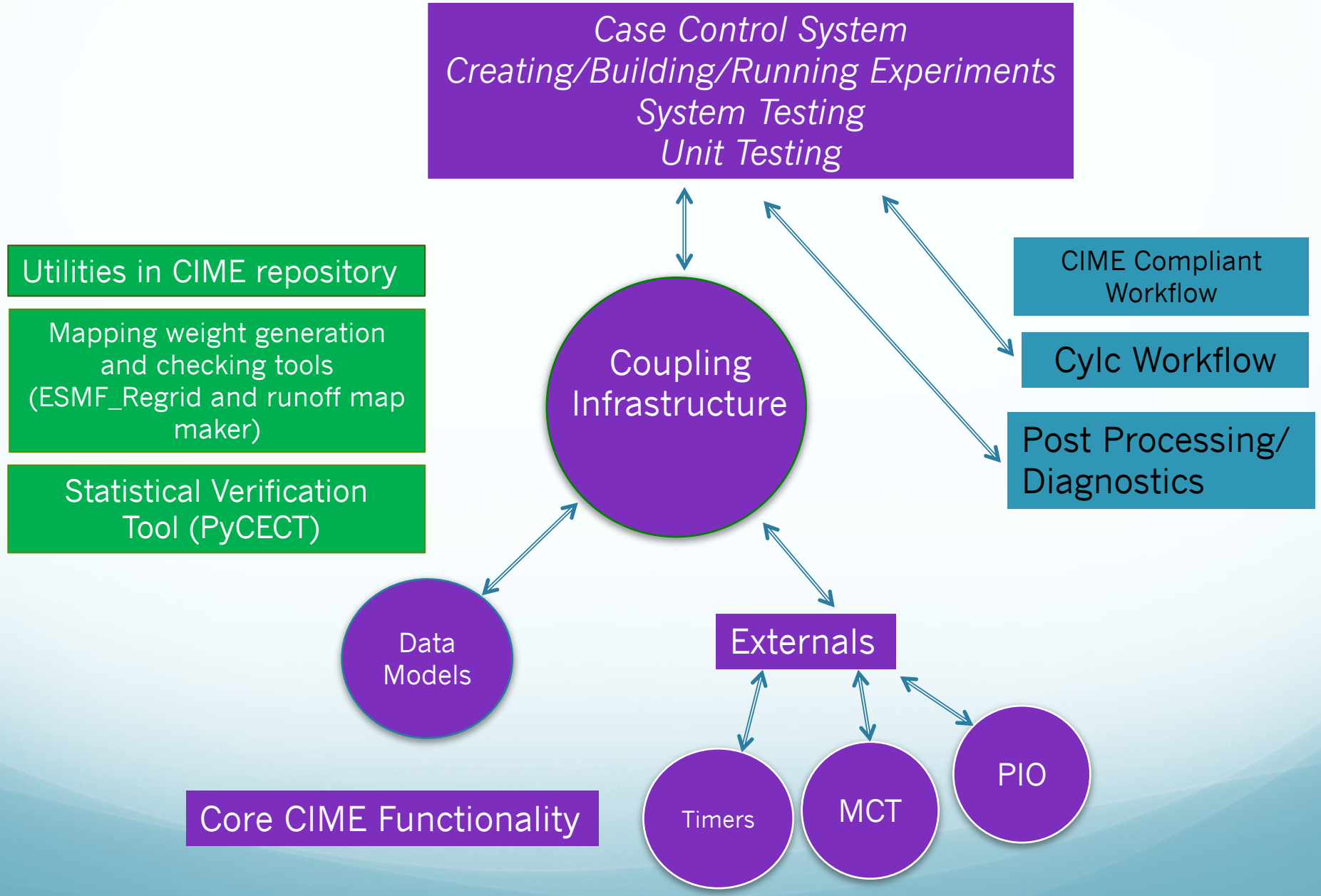
- A set of fully independent component models representing different parts of the earth system each at different time scales, potentially different resolutions and different processor layouts
- In order to provide dynamic feedbacks, the component models periodically exchange state and flux information via a coupling framework
- Managing a coupled model requires managing complexity of configuring, building and running a variety of component models, resolutions and processor layouts
- CIME was developed to address these challenges!

Why do we need a coupling infrastructure?



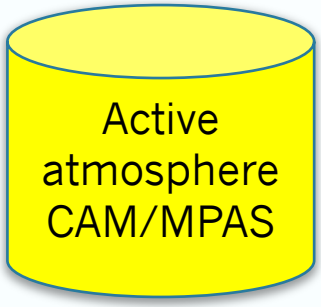
- Components do not exchange data with each other – but only via communication with a mediator
- Each component can run on its own grid, decomposition, data structures and processor layout
- Driver runs on all Pes and controls the temporal evolution of the system
- Mediator does remapping and merging from source -> destination components

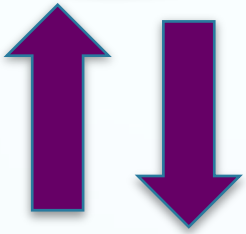
CIME is comprised of 3 categories – case control system, utilities, workflow

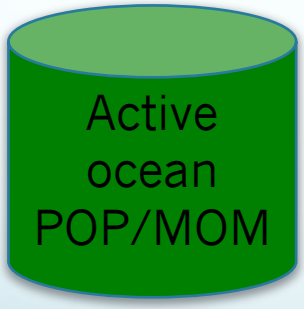


CIME Coupling Infrastructure

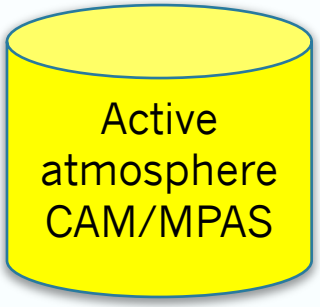
Controlling Component Feedbacks

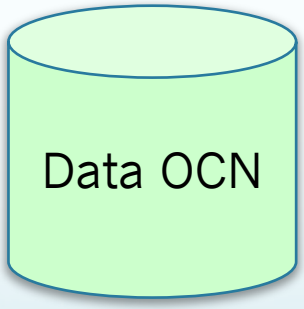






CAM and POP/MOM affect each other during simulation



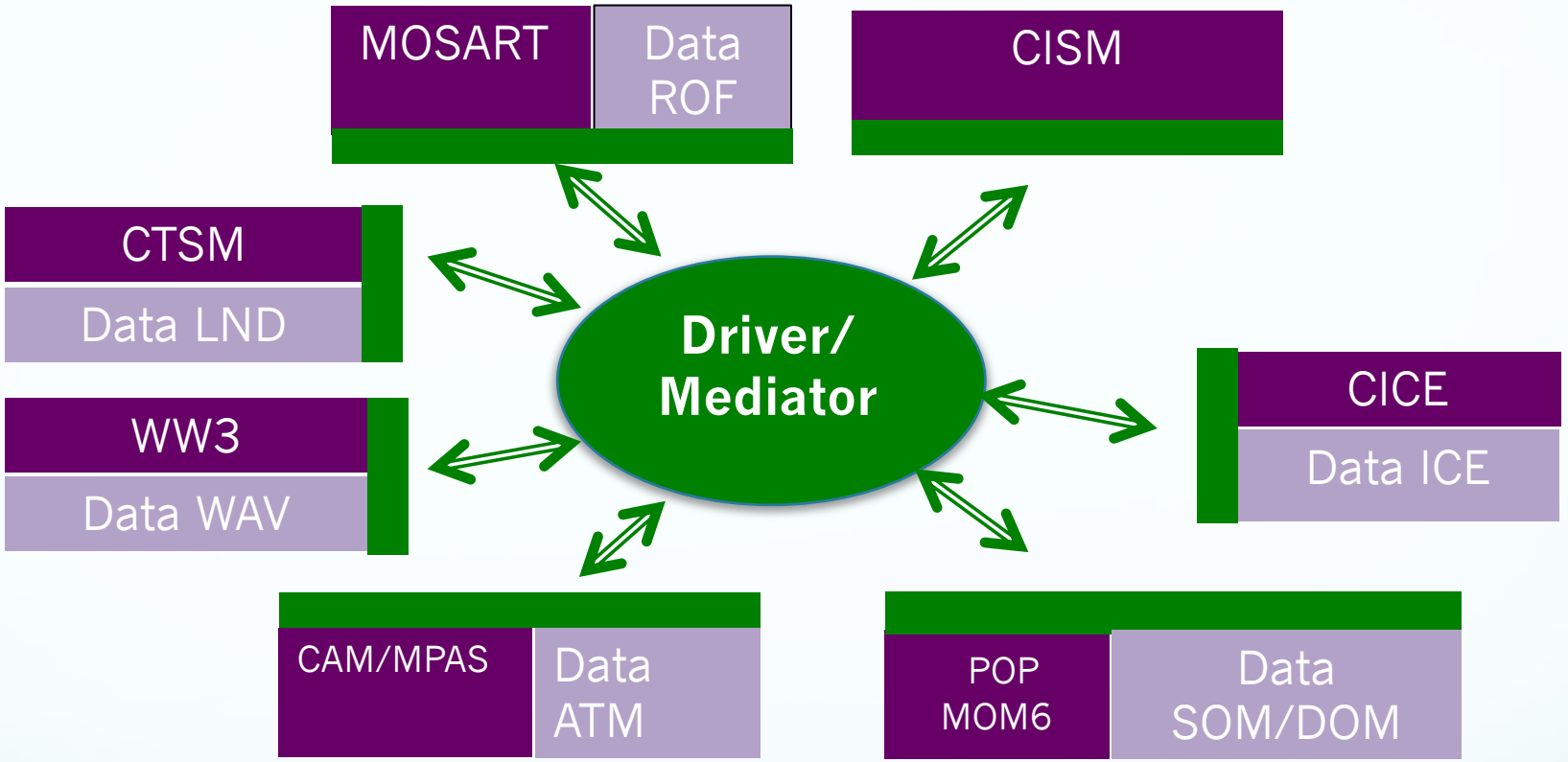


Only Data OCN affects CAM – prescribed SST

Coupling framework enables feedbacks to be easily turned off and on for any component

KEY to adding to new science to a component

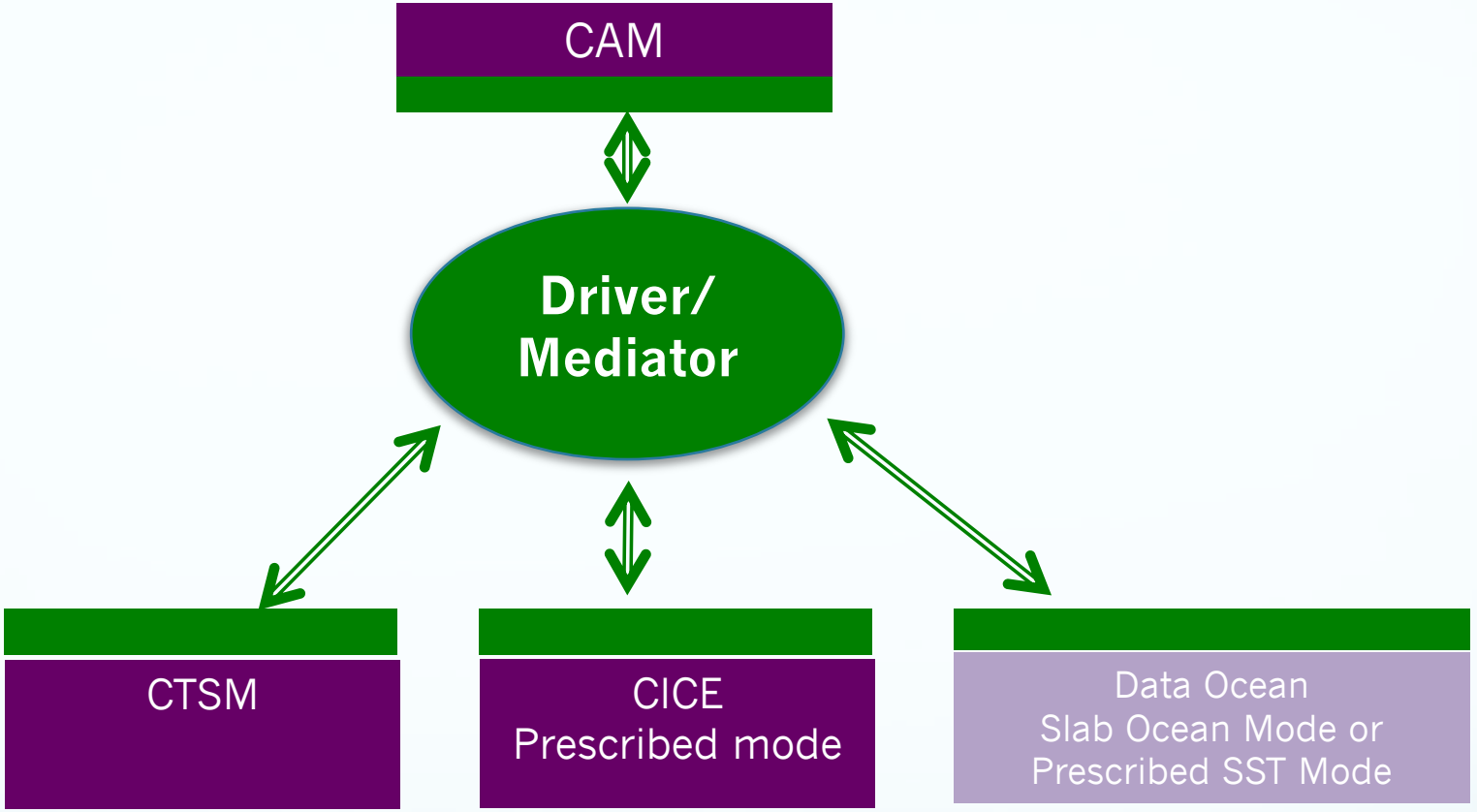
Inter-component Activation and Deactivation of Feedbacks



Coupling infrastructure permits interoperability of active and data components

Inter-component feedbacks are easily activated and deactivated using CIME case control system

“stand-alone” CAM Configuration



- All components are on same grid – but each can have its own decomposition that ensures optimal load balancing
- CTSM, CICE and DOCN can all run concurrently on disjoint PES, optimizing performance

CIME Case Control System

CIME Case Control System

- Complexity in CESM continues to grow rapidly
  - *currently support hundreds of out-of-the box experimental configurations and tests.* Creating a new experiment can be very complex – no single user can know the entire details of all components!

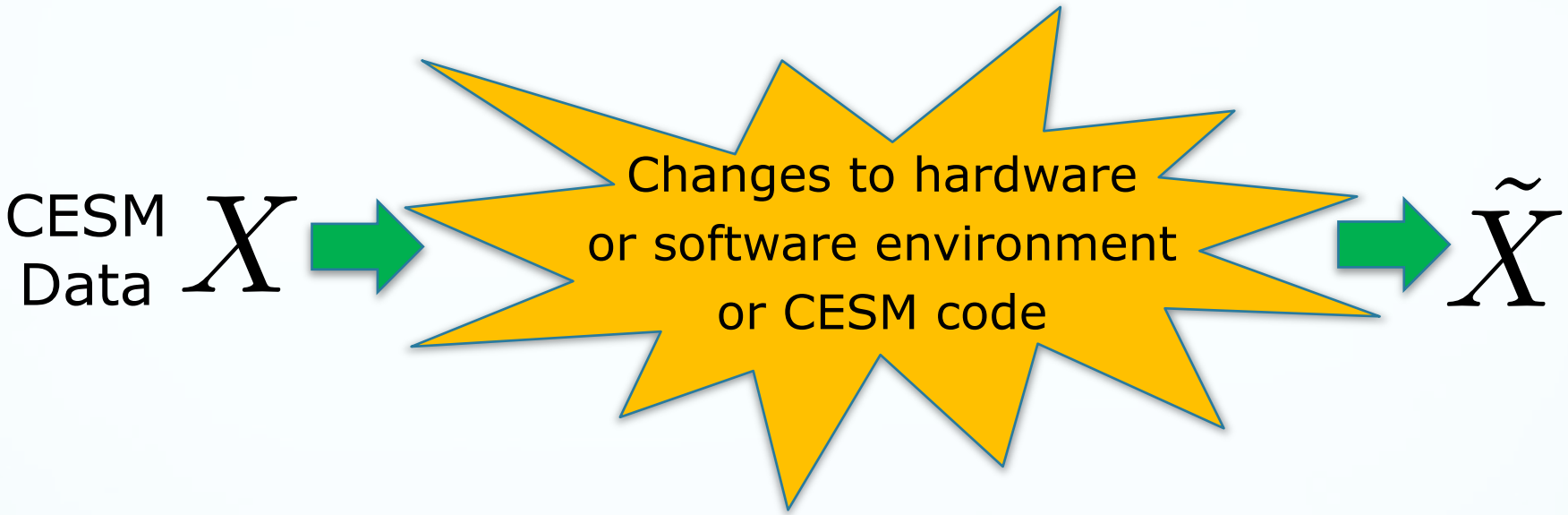
- CIME Case Control System is a python based object-oriented package
  - Lets users easily create customized experiments (using only 4 commands) with desired target feedbacks, component resolutions and component configurations.
  - *Keeps complexity hidden from users – not dependent on the users having expert knowledge of the entire system.*
  - Parallel diagnostic packages can be run from case directory
  - Provenance: experiment can be saved into run database so that it can be duplicated at a later time
  - Can easily be plugged into CYLC workflow

CIME Regression and Unit Testing

- Case Control System is accompanied by an extensible and robust regression testing framework that is utilized by all CESM components
- All prognostic components leverage the testing framework – component specific tests are specified by component itself - not centralized
- Can run hundreds of tests with different resolutions, feedbacks, and science complexity, with one command

CIME Tool for Verification and Porting

CESM Ensemble Consistency Test (ECT)



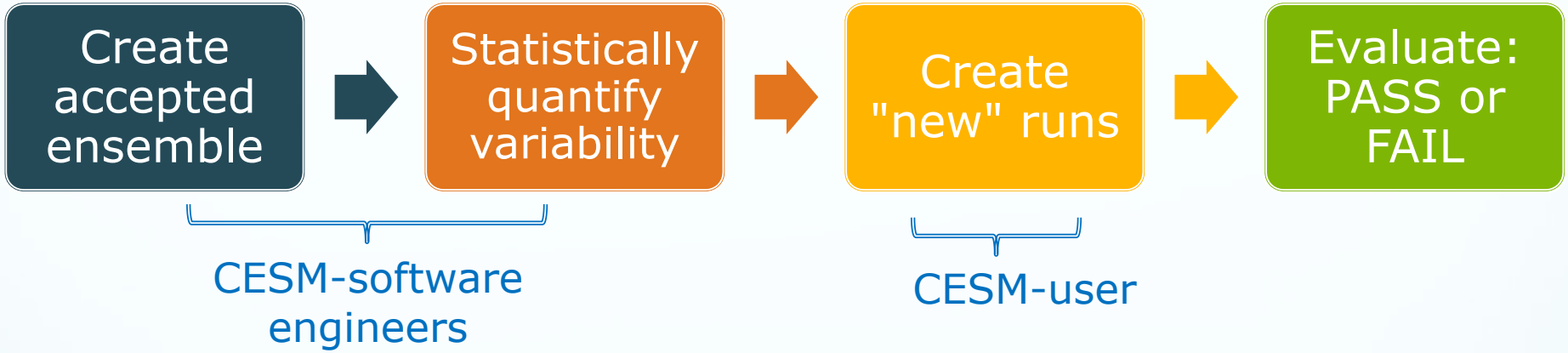
Big question: If $X \neq \tilde{X}$, is the new result correct?

Alternative question:

Is $\tilde{X}$ *statistically distinguishable* from X ?

CESM Ensemble Consistency Test (ECT)

Approach: Evaluate new data in the context of an "accepted" *ensemble* of CESM runs



Highlights:

- enables "letting go" of bit-for-bit reproducibility
- objective, user-friendly 9 time-step test
- rapid feedback for model developers

Next Steps in CIME Development for NWP Needs

New Features planned for CIME

- Addition of new capabilities in the case control system to accommodate forecast capability and not just climate capability
- Migration of coupling framework to ESMF/NUOPC
  - Will bring in run-time regridding and run-time sequencing of components
  - ESMF/NUOPC is becoming the de-facto coupling standard – this will lead to enhanced interoperability of the system
  - Working jointly with NOAA to create shared coupling framework - coupling infrastructure will be that used by EMC/UFS (ease R20)

CIME Governance and Development

How is CIME developed?

- Open joint collaboration on public GitHub repository between DOE/NCAR software developers without any formal governance
- CIME is developed and tested stand-alone
  - CIME stand-alone continuous integration (Travis CI)
  - CIME stand-alone regression tests and unit tests (required for pull requests)
  - Prognostic component regression tests use CIME testing framework as well

Why does this work (1)

- CIME infrastructure has been set up to permit this joint open collaboration
  - Modular object-oriented python (and Fortran) code reuse between efforts
  - Shared code whenever possible
  - Separation when necessary
    - machines, compilers have are implemented in separate locations in CIME – but use the same underlying code

Why does this work (2)

- GitHub is a transformative way to collaborate
- Issues are raised in GitHub and resolved collaboratively
- Pull requests (PRs) are reviewed by both groups and the implementations must satisfy both groups in order for the PR to be accepted
  - In practice, this GitHub process is easy and transparent
- Documentation has been created via sphinx/rst and has been jointly developed and updated

Questions?