National Aeronautics and Space Administration

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Enabling Thread Safety and Parallelism in the Program to Optimize Simulated Trajectories II

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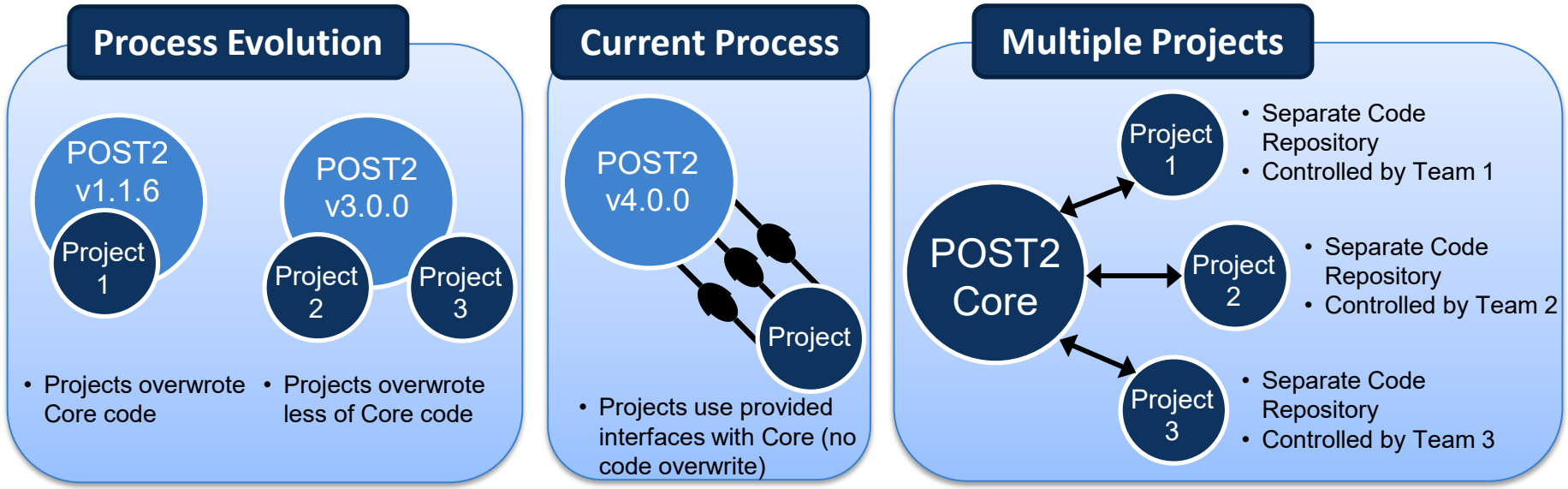
Background and Motivation

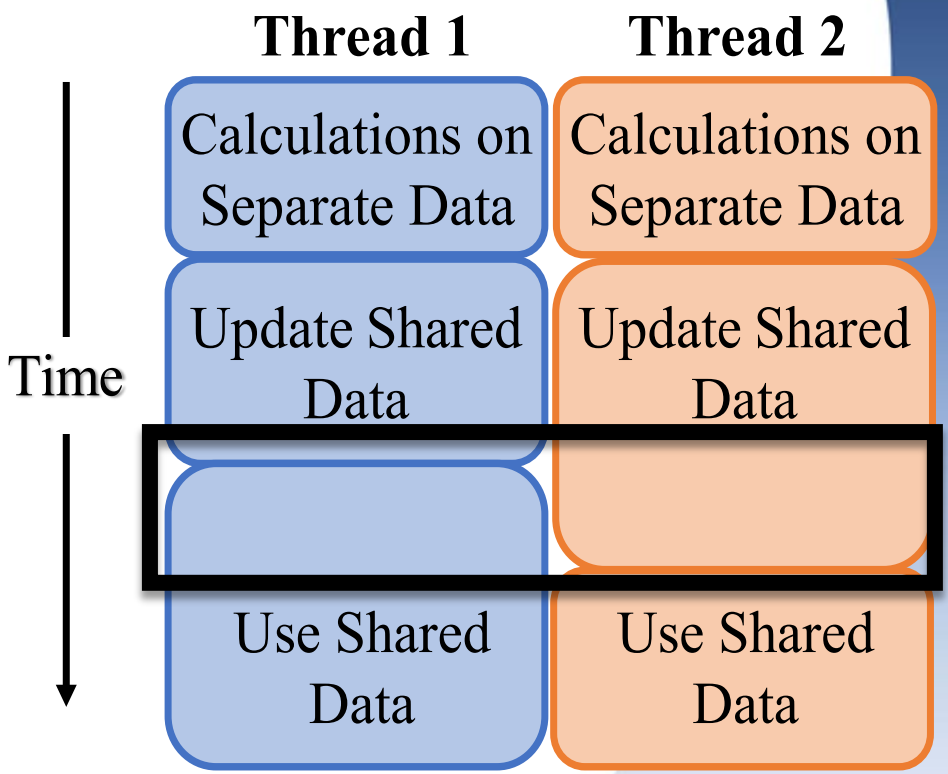
- The Program to Optimize Simulated Trajectories II (POST2) is a widely used, workhorse trajectory simulation tool that has been used to solve a variety of atmospheric ascent and entry problems, with one or more vehicles
- POST2 development began in the 1970s, and has undergone continuous development and updates at NASA Langley Research Center (LaRC) since the conversion from all Fortran to C with C++ in the late 2000s



- Motivation is to enable thread safety to leverage high performance computing (HPC), such as multi-threaded central processing units (CPUs) or graphics processing units (GPUs), to improve POST2 performance, capability, and adaptability

Thread Safety

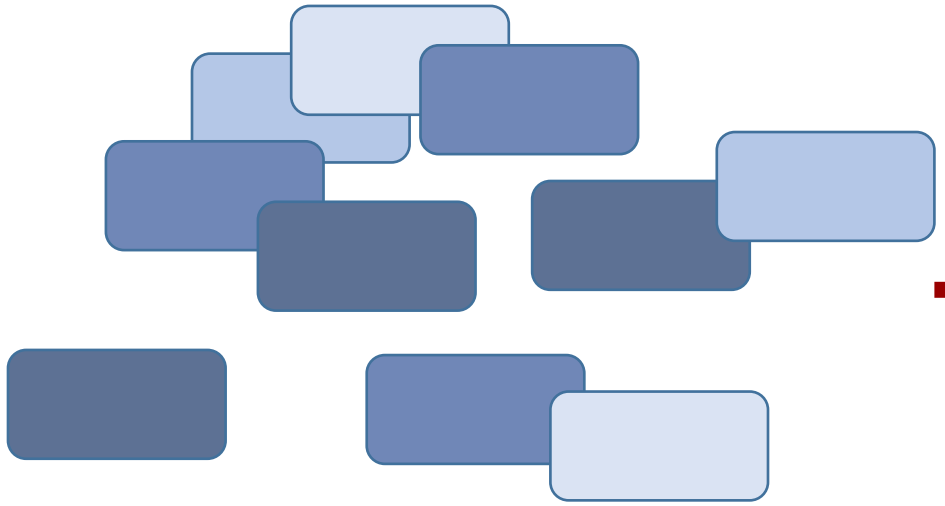
- **Software is thread-safe if the parallel execution has no effect on the results**
- **A major issue preventing thread safety is data races, when shared data is begin read from and written too simultaneously**
- **Memory access must be analyzed, as well as execution to ensure thread-safe code**



Memory Structure

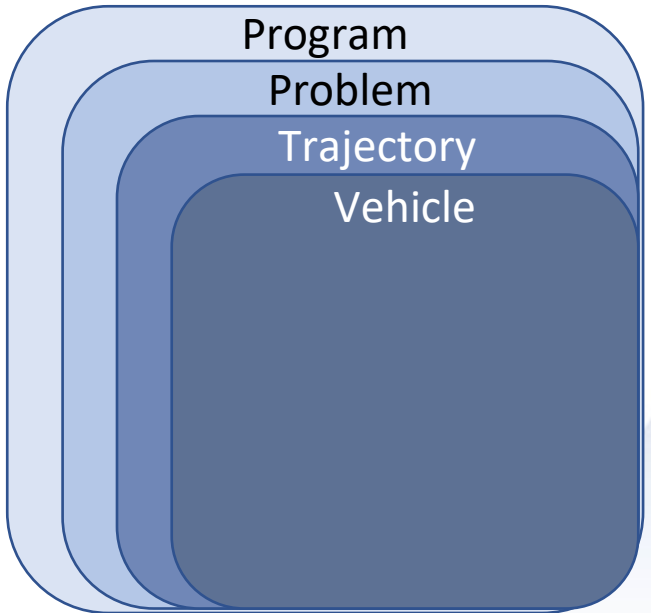
Before Thread-Safe Changes

- Many global memory structures, remnants of Fortran common blocks
- No grouping within global structures
- Branches of code written specifically for first, global vehicle



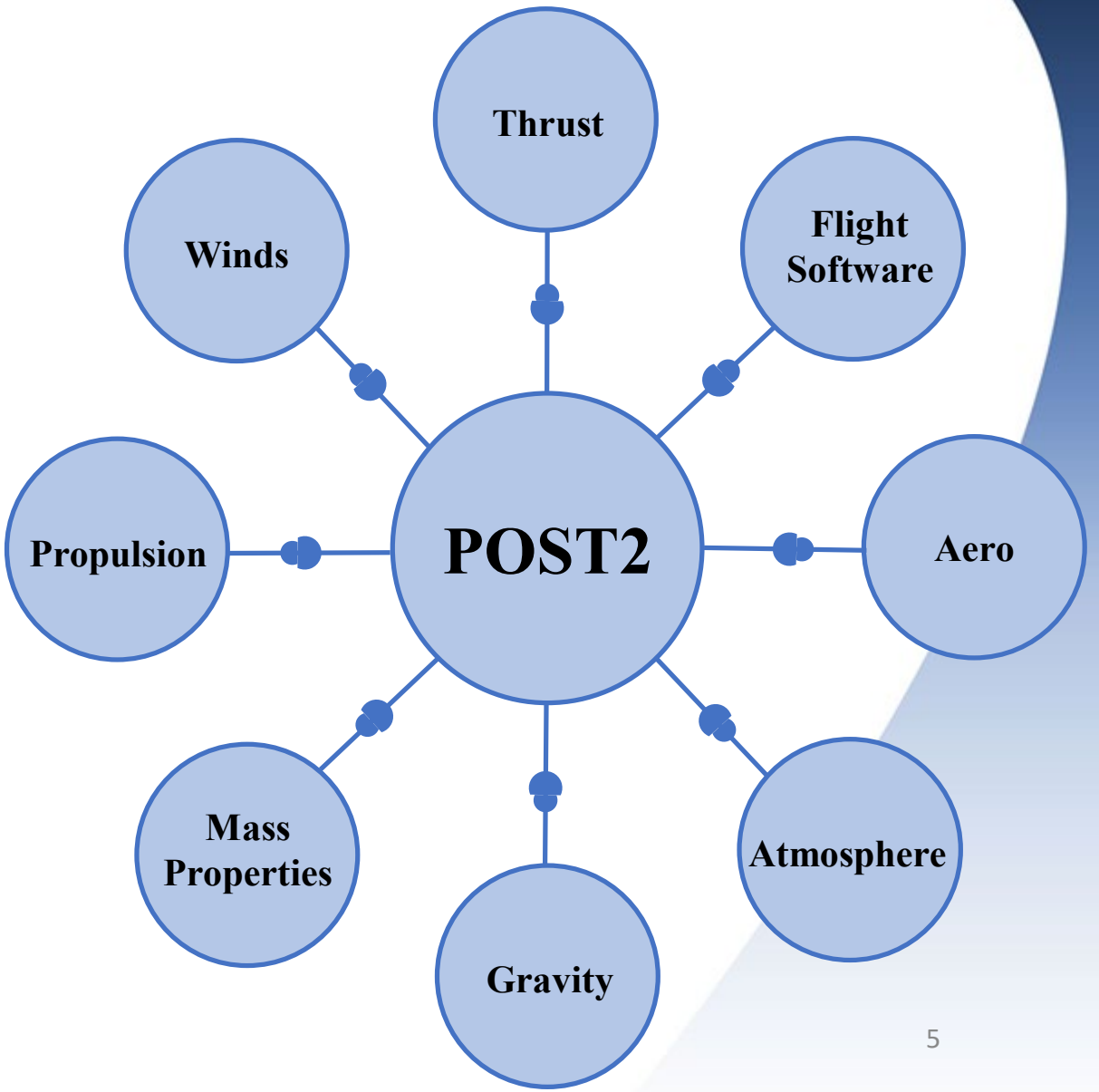
After Thread-Safe Changes

- Global memory space restructured into four-level hierarchy based on instruction execution
- Vehicle specific logic removed



Function Pointers

- **Used to interface custom model code for a particular project or mission by hooking into POST2 sockets**
- **Eliminates the need to change Core POST2 code**
- **User code must match specific function signature (return type and argument type)**
  - Before Thread-Safe Changes: 2 function pointer types, leveraging global memory access
  - After Thread-Safe Changes: 1 function pointer type, can only access memory through passed in arguments



User Input

- **User input is one of the features that allows POST2 to be generalized**
- **Defines initial conditions, physics model types, integration method, user models via function pointers, etc.**
- **POST2 tables are one of the more powerful and useful aspects**
  - $y = (a * b)x + (c * d)$
  - Evaluated at the simulation rate
  - Can be multi-dimensional

x: value of lookup table (**POST2 variable**)
a: numerical component of table multiplier
b: mnemonic component of table multiplier (**POST2 variable**)
c: numerical component of table bias
d: mnemonic component of table bias (**POST2 variable**)

- **Generalized equations**
  - Range from very simple to very complex, including conditionals, nesting, and most standard math functions (sin, pow, etc.)
  - Nearly any combination of **POST2 variables**
  - Evaluated at the simulation rate

User Input

- **POST2 tables are one of the more powerful and useful aspects**
  - $y = (a * b)x + (c * d)$
  - Evaluated at the simulation rate

x: value of lookup table (**POST2 variable**)

b: mnemonic component of table multiplier (**POST2 variable**)

d: mnemonic component of table bias (**POST2 variable**)

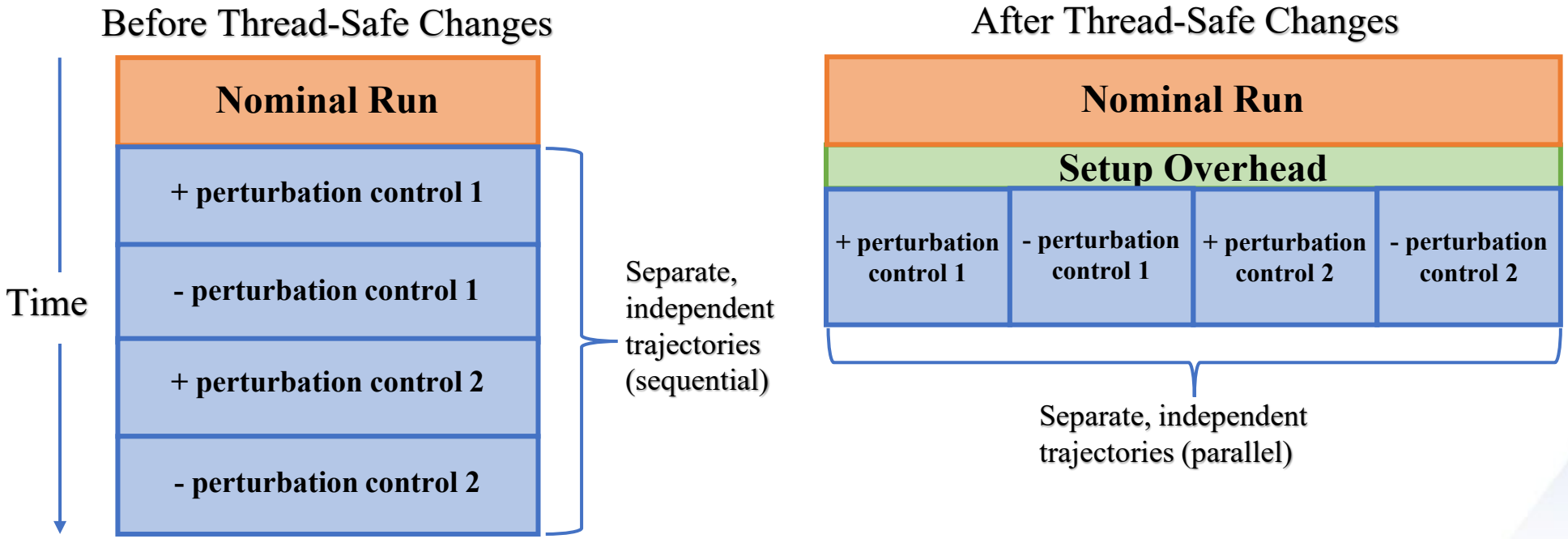
- **Flexibility to utilize any POST2 variable poses challenge**
- **Need to log information on variables so that value at any point in simulation can be found**
  - Nearly any combination of **POST2 variables**
  - Evaluated at the simulation rate
  - Before Thread-Safe changes: Store absolute address to be dereferenced later, relative only to existing Trajectories or Vehicles
  - After Thread-Safe changes: Store relative address offset from template Trajectory/Vehicle, relative to any future Trajectories or Vehicles

Multithreaded Execution

- **The work to be completed in parallel needs to outweigh the amount of time it takes to divide the work amongst multiple threads**
- **Qualitative analysis showed that Trajectories (level) running concurrently was the most impactful**
  - At the Vehicle level, not enough work to justify splitting it up
- **For some optimization and guidance schemes multiple trajectories need to be simulated**
- **Open Multi-Processing (OpenMP) was the Application Programming Interface (API) chosen for parallelizing threads**
  - Leveraging the `parallel for` construct
  - For this work, only utilizing CPUs

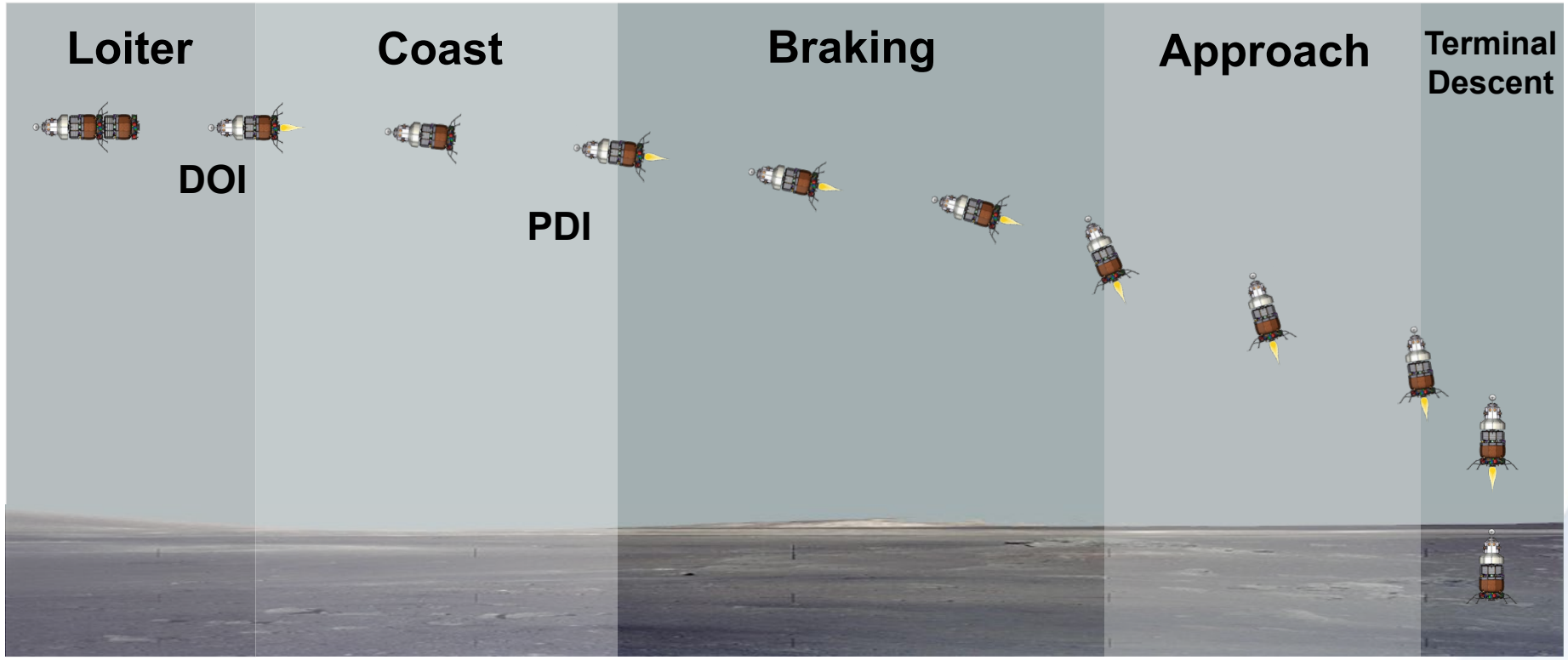
Parallel Optimization Framework

- **Default optimization scheme in POST2 is the projected gradient method**
- **Multiple derivatives are needed to build a sensitivity or Jacobian matrix**
  - Controls for the optimization problem determine derivatives needed
- **Derivatives approximated via finite differencing**
  - Depending on type, e.g. central 2nd order, the number of trajectories needed changes



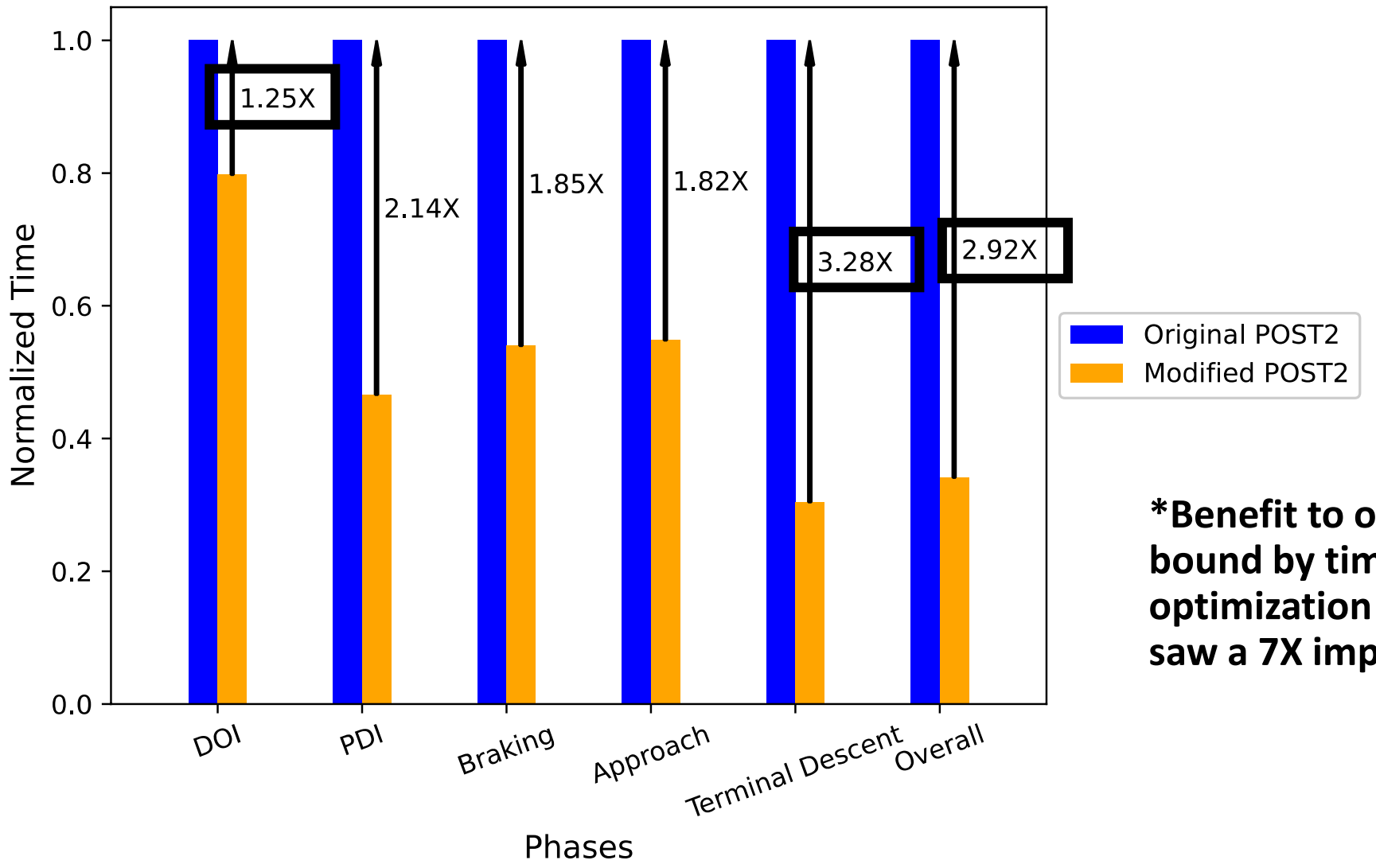
Human-Scale Lunar Lander

- NASA government reference human-scale Lunar lander was set to utilize parallel optimization [AAS 20-592]
- 3 degree of freedom (DOF) simulation broken into multiple phases that each have optimization



Lunar Lander Results

Lower is Better



***Benefit to overall time bound by time spent within optimization region, which saw a 7X improvement**

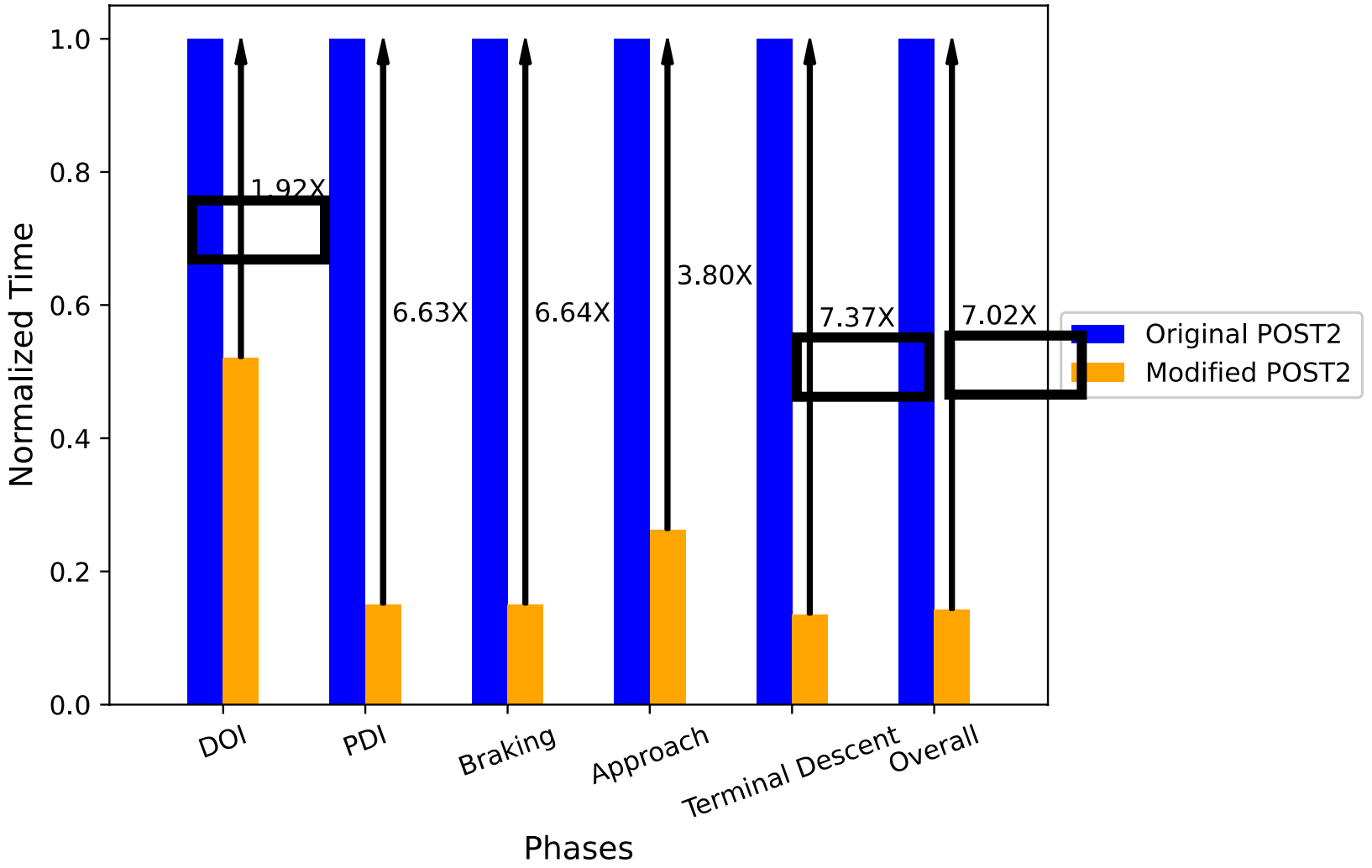
Summary and Future Work

- Heritage trajectory simulation tool, POST2, was modified to be thread-safe
- POST2 was then upgraded to enable parallel calculations to generate optimization solutions
- Lunar lander simulation utilizing parallel optimization shown to improve overall run time approximately 3X
- Additional efficiencies can be gained by utilizing more complex OpenMP constructs, as well as modifying when the parallel trajectories are launched within the execution
- Memory restructuring allowed for task creating API for POST2
- If interested in requesting access to POST2, https://www.nasa.gov/post2/request

Backup

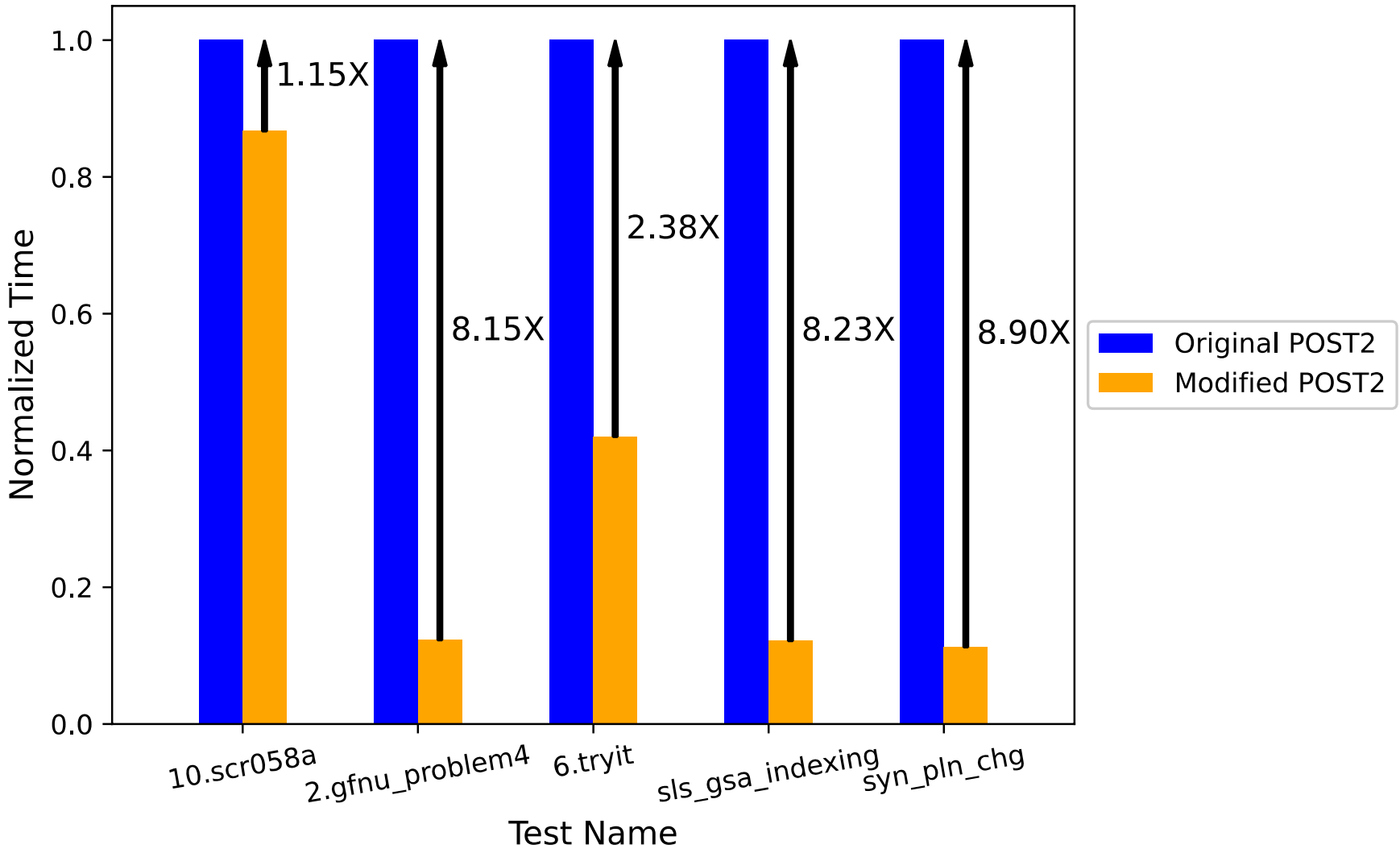
Lunar Lander Gradient Calculations

Lower is Better



Regression Tests Gradient Calculations

Lower is Better



Regression Tests Overall Time

Lower is Better