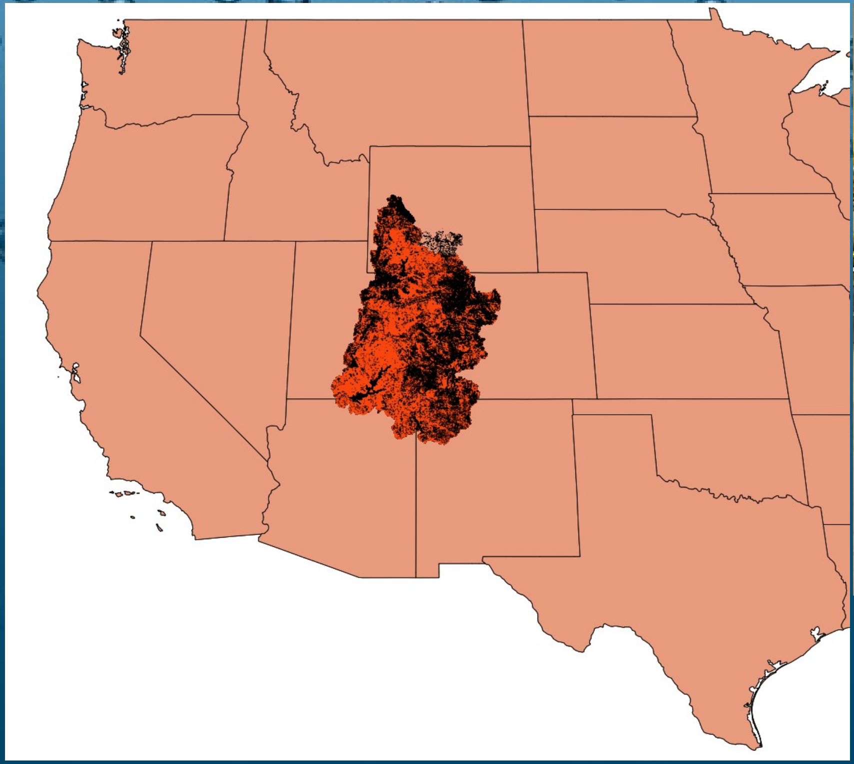
ADHydro

A Large-Scale Multi-Physics Hydrology Simulation Implemented with Charm++

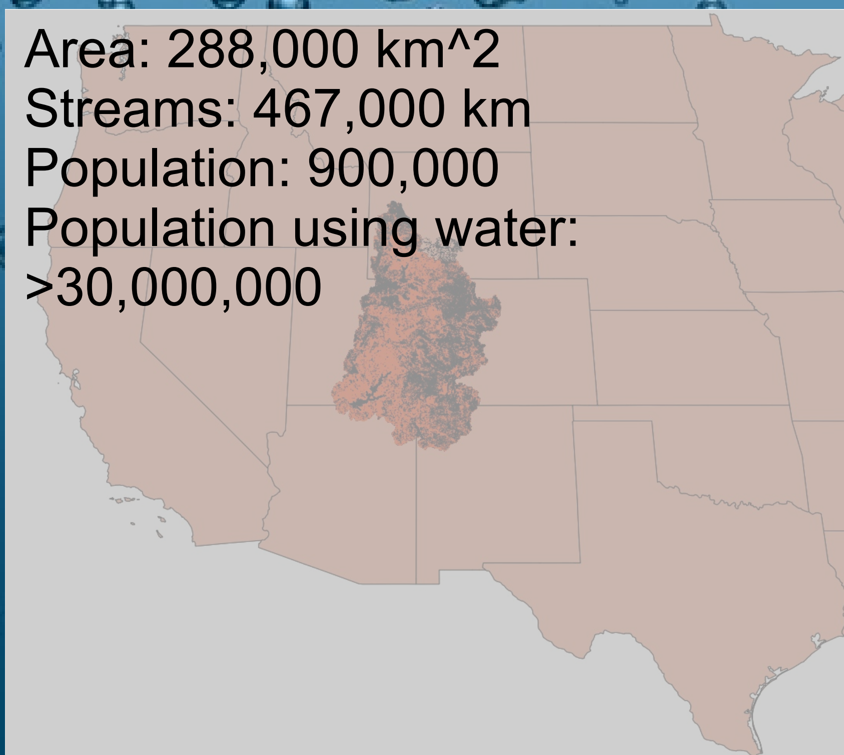
CI~WATER

A Utah-Wyoming Cyberinfrastructure
Water Modeling Collaboration

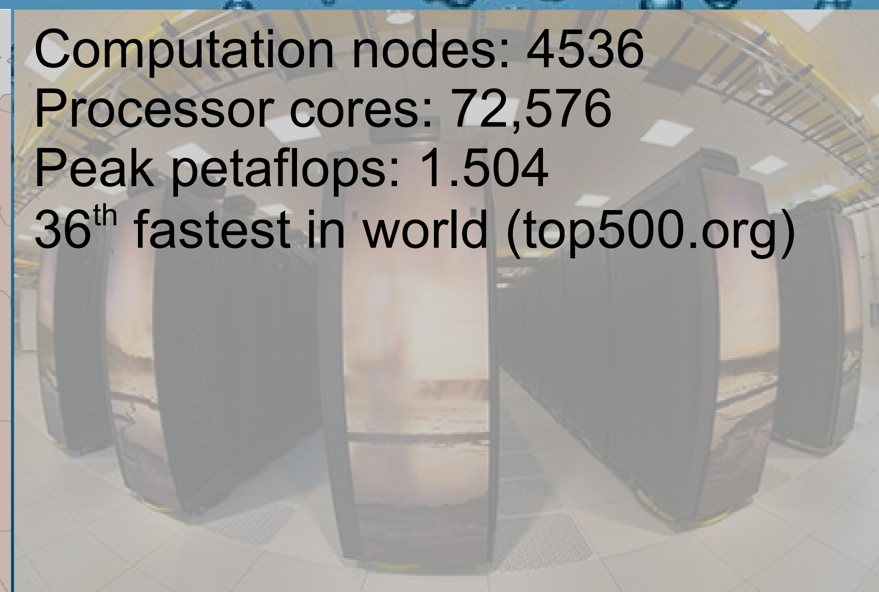
Goal:Upper Colorado Watershed on Yellowstone Supercomputer



Goal: Upper Colorado Watershed on Yellowstone Supercomputer



Area: 288,000 km^2
Streams: 467,000 km
Population: 900,000
Population using water: >30,000,000



Computation nodes: 4536
Processor cores: 72,576
Peak petaflops: 1.504
36th fastest in world (top500.org)

Research Questions

How will climate and land-use changes affect the availability of water for the Upper Colorado watershed states (CO, WY, UT, NM, AZ) over the coming decades?

How can water management be optimized, and how much benefit can be realized from such optimization?

– E.g. Changing from flood irrigation to center-pivot irrigation

Additional Research Goal

- Explore high spatial and temporal resolution from a capability-driven perspective.

Capability-Driven Resolution

- High resolution
  - Mesh elements as small as 1/2 acre or 100 meters of stream reach
- Variable resolution
  - Unstructured mesh
  - Offline mesh coarsening to explore effects of resolution
- Adaptive resolution
  - Implemented for temporal
  - Not yet implemented for spatial

Multi-Physics

- We are not a "conceptual" model
  - Select abstract coefficients to fit historical data
- We are a "physical" model
  - All inputs are in theory measurable in the lab

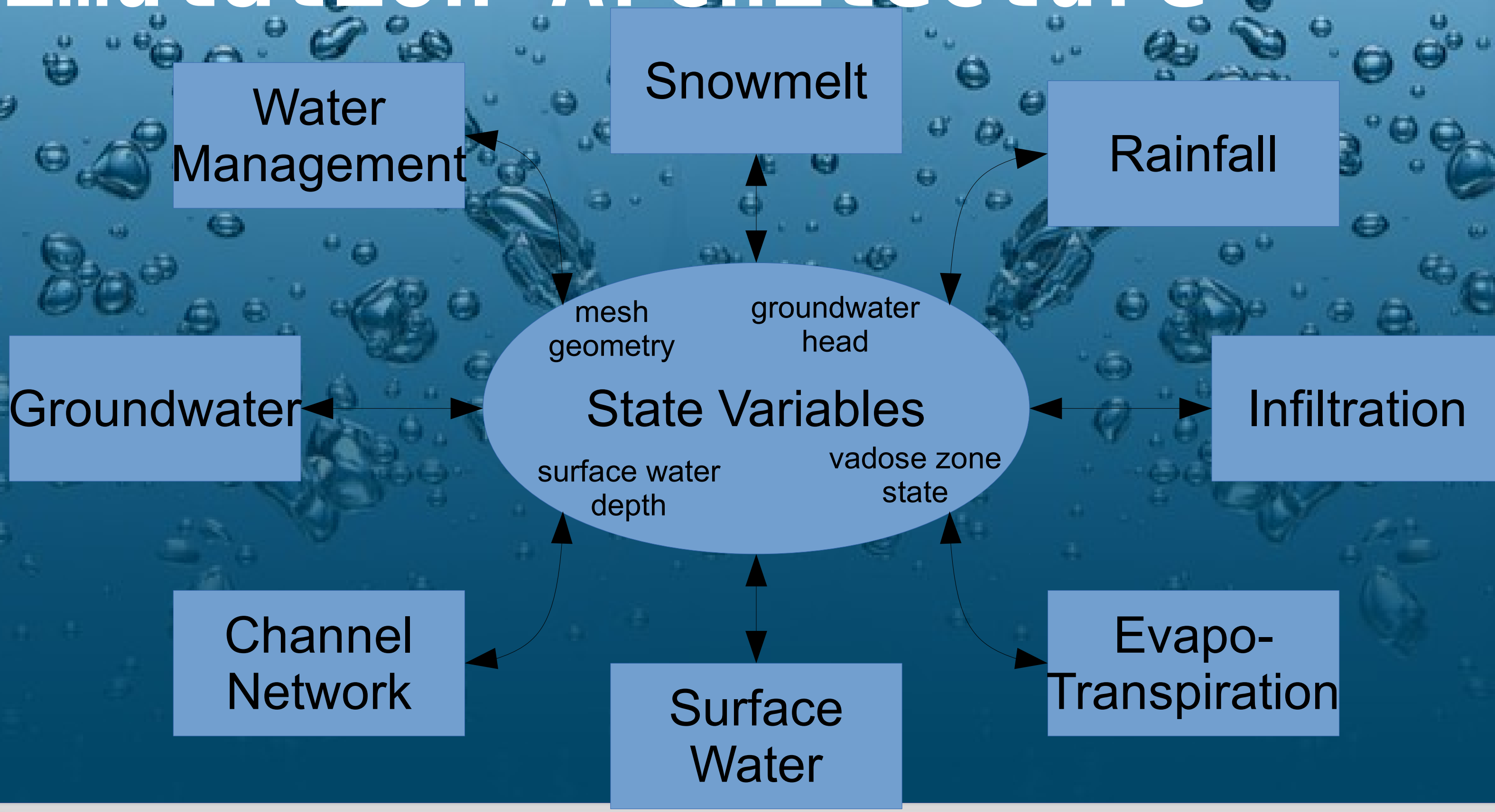
Multi-Physics

- We model multiple largely independent physical processes
- API for Independent swappable physics modules
  - Some are legacy codes
- "Arbitrary" water management
  - Irrigation and reservoir releases based on human decisions, not physics

Multi-Physics

- Explicit first-order simulation
- Guaranteed to conserve mass
- Guaranteed to converge

Simulation Architecture



Reasons for Using Charm++

- Partitioning
- Load Balancing
- Checkpointing
- Easy to overlap computation and communication
- Doesn't require learning advanced features of C++
  - Domain experts are not computer scientists

Recent Implementation Work

- Regions
  - Chare objects that contain multiple mesh elements
  - Reduces chare-switching overhead
  - Aggregates messages
- Heterogeneous timestepping
  - Neighbors agree on flow rate and expiration time and can then independently step forward to expiration time with different timesteps

Heterogeneous timestepping

Step 1: Calculate nominal flow rate

Each element makes an agreement with each of its neighbors about the “nominal” flow rate between them and an expiration time for this nominal flow rate

Heterogeneous timestepping

Step 1: Calculate nominal flow rate

This nominal flow rate will not be recomputed until the expiration time

- Although less water than that may flow if the sender runs out of water
- The expiration time must account for both the Courant number of the flow and factors like looking ahead in the forcing file to detect upcoming shocks

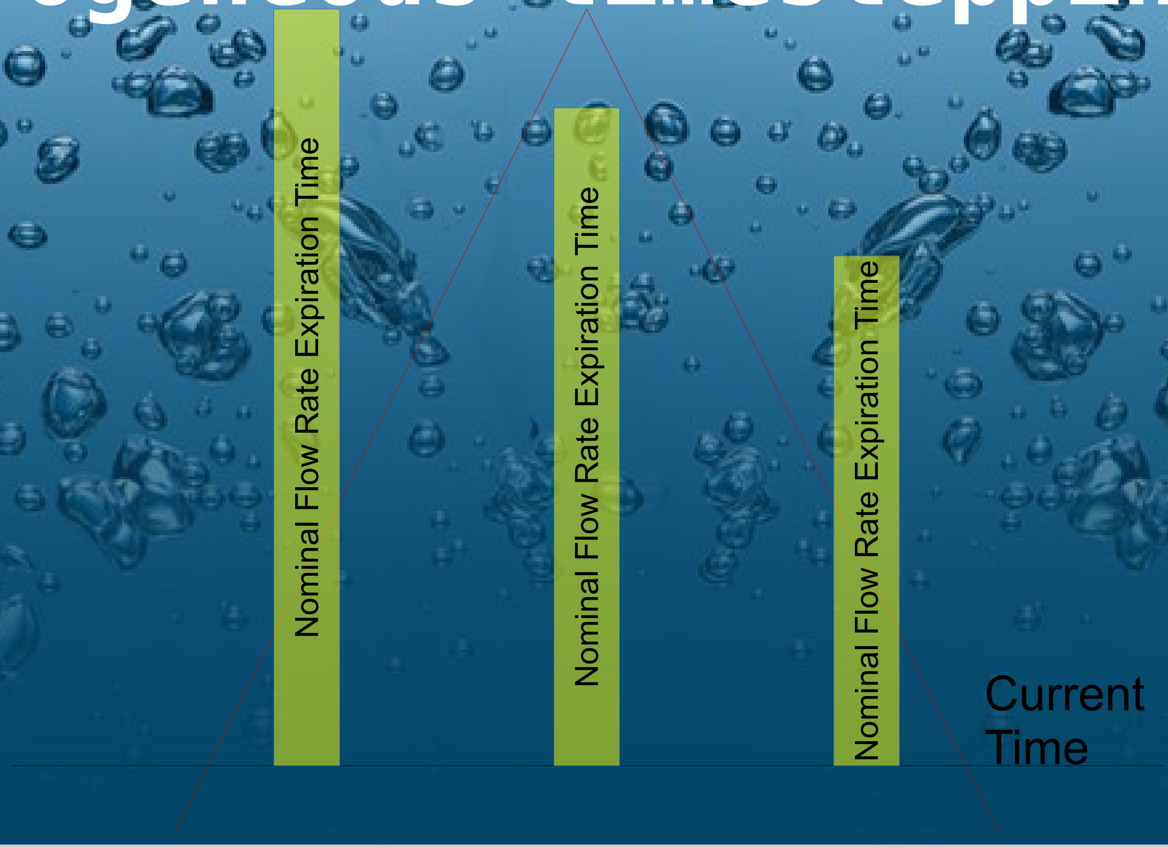
Heterogeneous timestepping

Step 1: Calculate nominal flow rate

Both neighbors agree to sync up at the expiration time to recalculate a new nominal flow rate and expiration time

- Both neighbors must end a timestep end at exactly the expiration time

Heterogeneous timestepping



Heterogeneous timestepping

Step 2: Select timestep

Each element selects its timestep end time

- This can be no later than its earliest nominal flow rate expiration time, although it can be earlier
- It does not have to be the same as any other element's timestep end time except when recalculating a nominal flow rate with a neighbor

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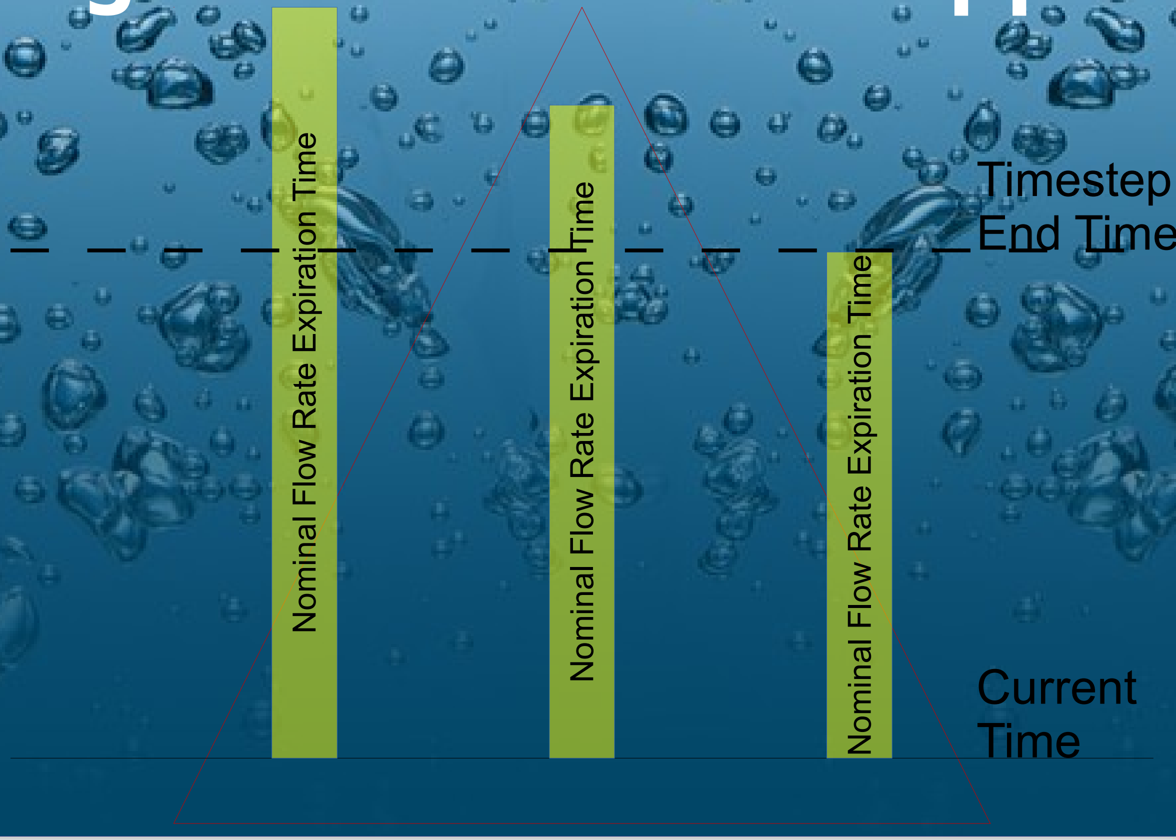
Heterogeneous timestepping



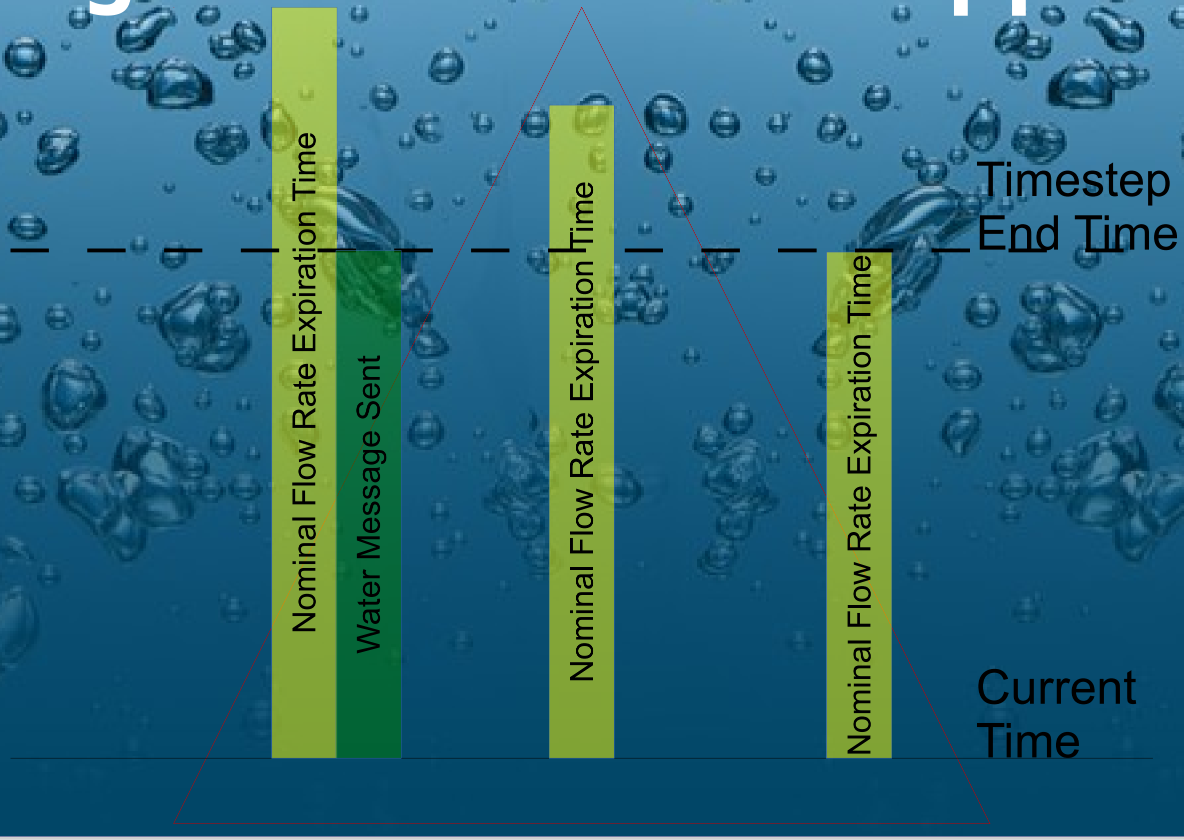
Heterogeneous timestepping

Step 3: Send outflow water

Each element calculates its actual outflows for its current timestep including flow limiting if it runs out of water

Each element sends messages containing this water to its neighbors

Heterogeneous timestepping



Heterogeneous timestepping

Step 4: Wait for inflow water

Each element waits until it has received water messages for all of its inflows to at least its current timestep end time

- Neighbors might have shorter timesteps so the element may have to wait for multiple water messages from a single neighbor

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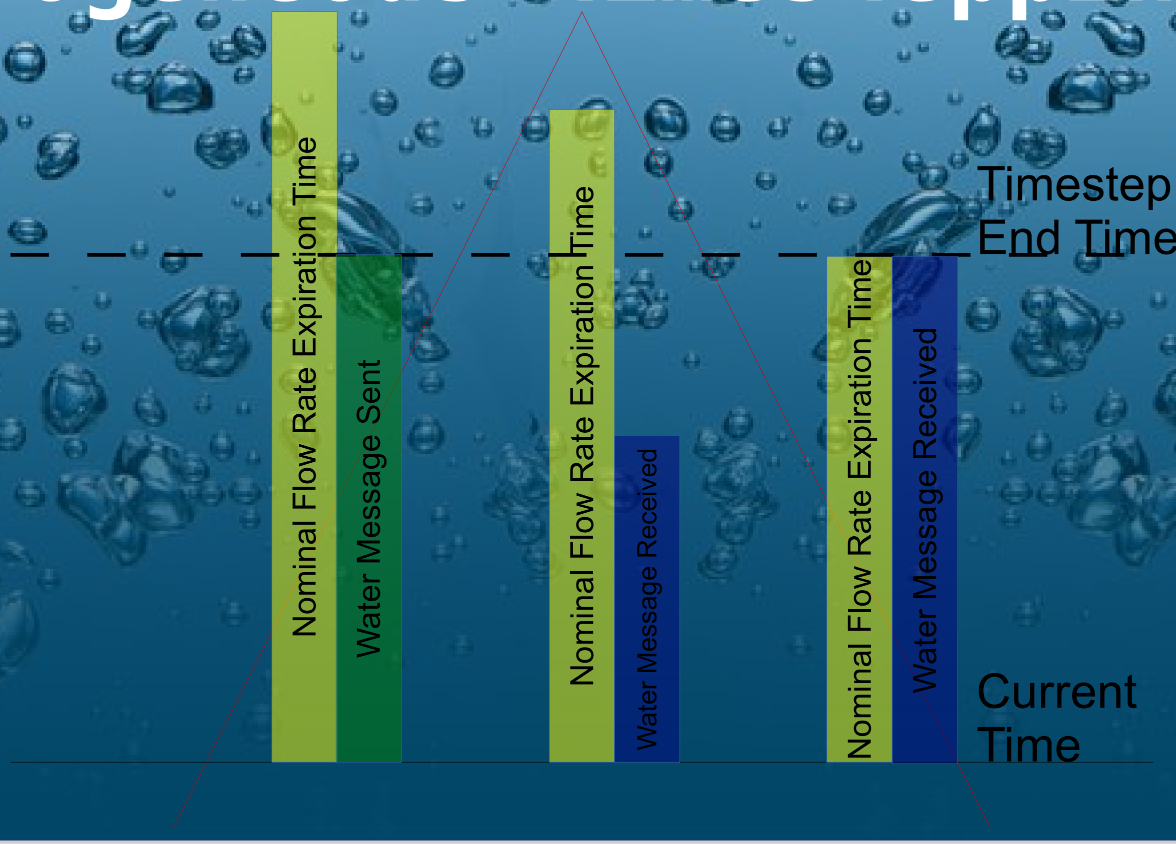
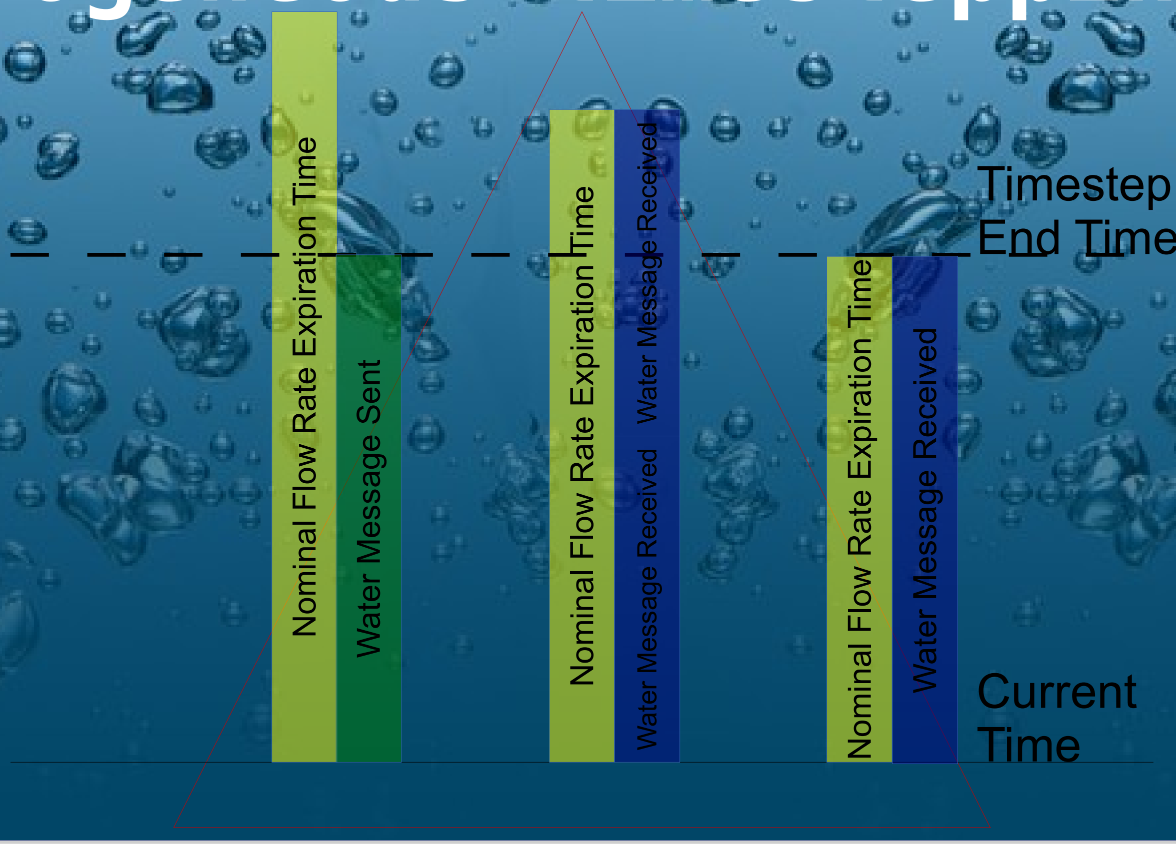


Heterogeneous timestepping



Heterogeneous timestepping

Step 5: Advance time

Each element updates its water state and advances current time to the end of its timestep

Then the element returns to step 1 if any of its nominal flow rates have expired or step 2 if not

Backup Slides

Heterogeneous timestepping

- Guaranteed to conserve water
- A quantity of water is removed from one bucket, and the same quantity of water is added to another bucket
- Water cannot be received until the sender removes that water from its bucket
- No element ever sends more water than it has

Heterogeneous timestepping

Guaranteed Not To Deadlock

If an element is waiting to calculate a nominal flow rate with me its current time must be strictly greater than my current time and its timestep end time must be greater than or equal to my timestep end time

If an element is waiting for a water message from me its timestep end time must be strictly greater than my timestep end time

Heterogeneous timestepping

Guaranteed Not To Deadlock

If an element is waiting on me through a transitive chain that does not include waiting on a water message then its current time is strictly greater than my current time

If an element is waiting on me through a transitive chain that does include waiting on a water message then its timestep end time is strictly greater than my timestep end time

There can be no cycles in the waits-for graph

Collaborators

Utah State University

UW

BYU
Brigham Young University

The University of Utah

U.S. Army Engineer Research and Development Center
CERL CHL GSL EL ITL CRREL TEC

NCAR | National Center for
UCAR | Atmospheric Research