DEFINED: Deterministic Execution for Interactive Control-Plane Debugging

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Control-Plane Software

- Participates in routing protocols to draw a network map

- Responsible for 95-99% of the observed bugs in today's networks
  (Altekar et al. Focus Replay Debugging Effort on the Control Plane. HotDep '10.)

Automatic Control-Plane Debugging

- Builds models of control-plane software to check for bugs and defects
- Detects anomalies but does not correct them
- Eventually, requires developers to understand and fix the bugs

Today's Solution: Interactive Debugging with Logging

- Records nondeterministic events to enable deterministic replay
- Two varieties:
  - Comprehensive logging
    - Records everything
    - Able to reproduce everything
    - Doesn't scale to today's production networks
  - Partial logging
    - Records partial information
    - Scales to large-scale networks
    - Unable to precisely reproduce execution

DEFINED Goals

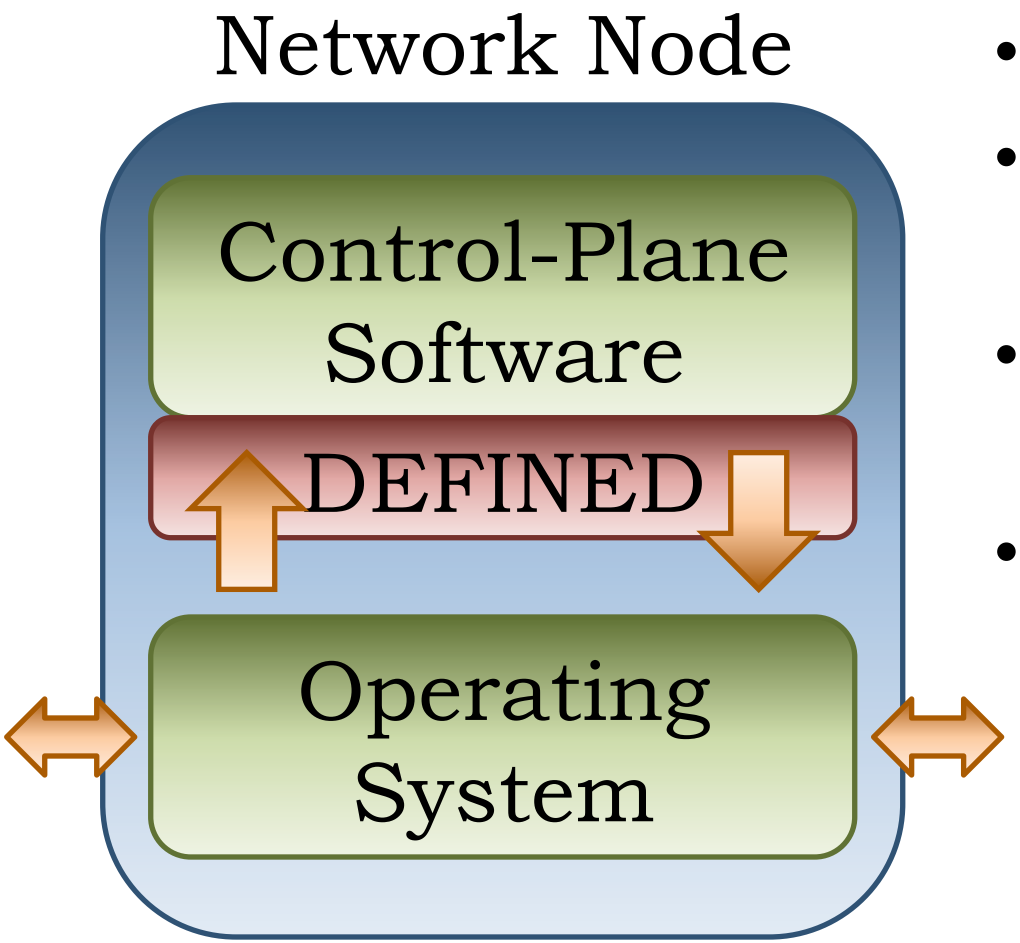
- Reproducibility
  - Precisely preserve execution without comprehensive logging
- Efficiency
  - Maintain fast convergence time in production networks
- Usability
  - Enable interactive control for debugging
- Scalability
  - Support enterprise and campus networks

Interactive Debugging with Deterministic Execution

- Nondeterministic events in control-plane software
  - External events
    - E.g., routers or links go down
  - Internal events
    - E.g., routers exchange messages

  (Bergan et al. Deterministic Process Groups in dOS. OSDI '10.)
- Logs only external events
- Eliminates nondeterminism from internal events

DEFINED Overview



- A library
- Records external events
- Intercepts internal message events
- Provides deterministic timer APIs

DEFINED Algorithms

- DEFINED-RB for production networks
  - Designed for efficiency
  - Implements speculative execution with RollBacks
- DEFINED-LS for debugging networks
  - Designed for interactive control
  - Steps through network execution with a LockStep algorithm

Outline

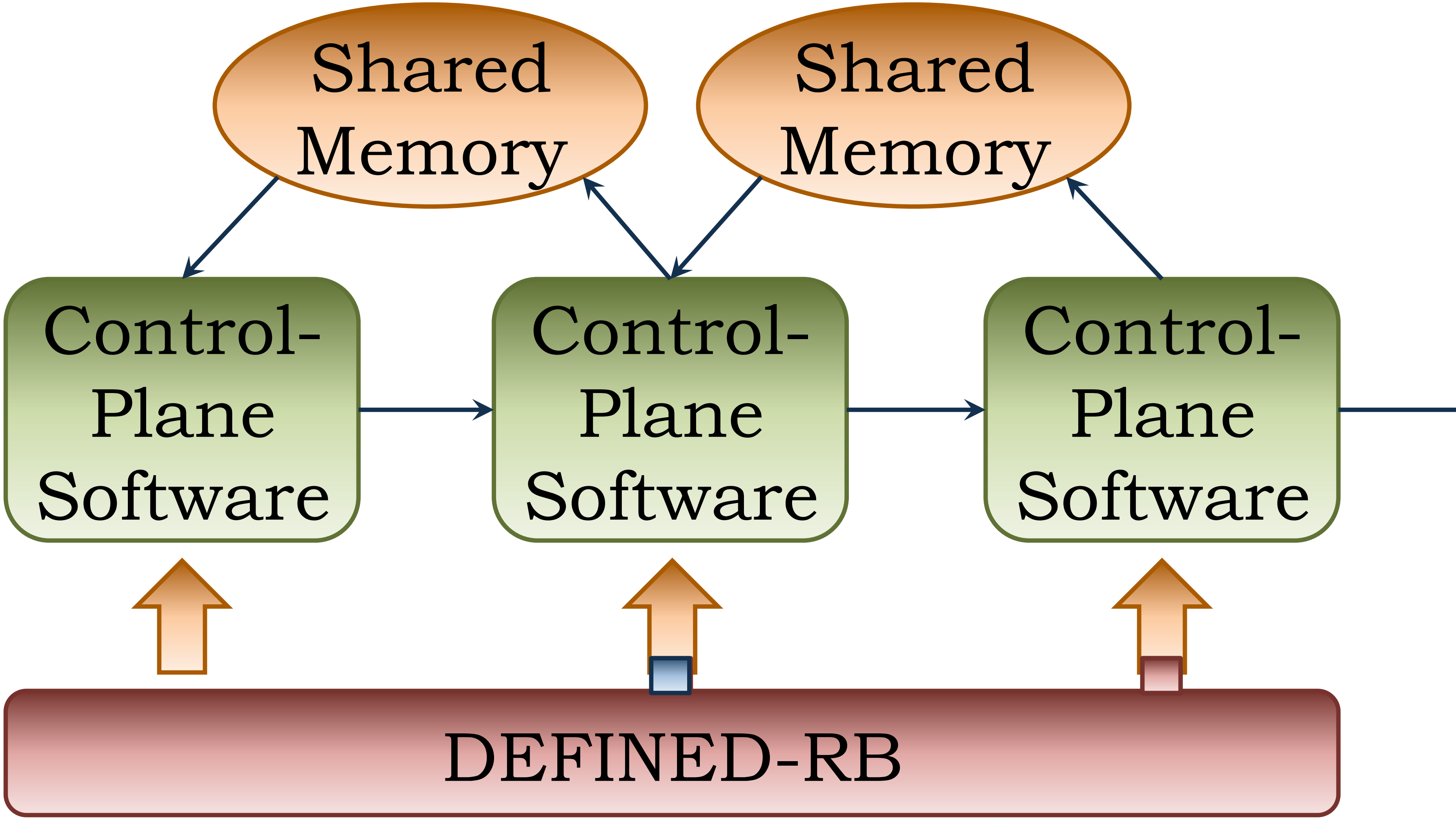
- DEFINED-RB in Production Networks
- DEFINED-LS in Debugging Networks
- Evaluation
- Conclusion

Interfacing with Production Networks

- Each network node independently determines an ordering function to order internal events

- If events execute in the "wrong" order, DEFINED-RB rolls back the state of the network node and replays events in the "correct" order

Rolling Back Software States

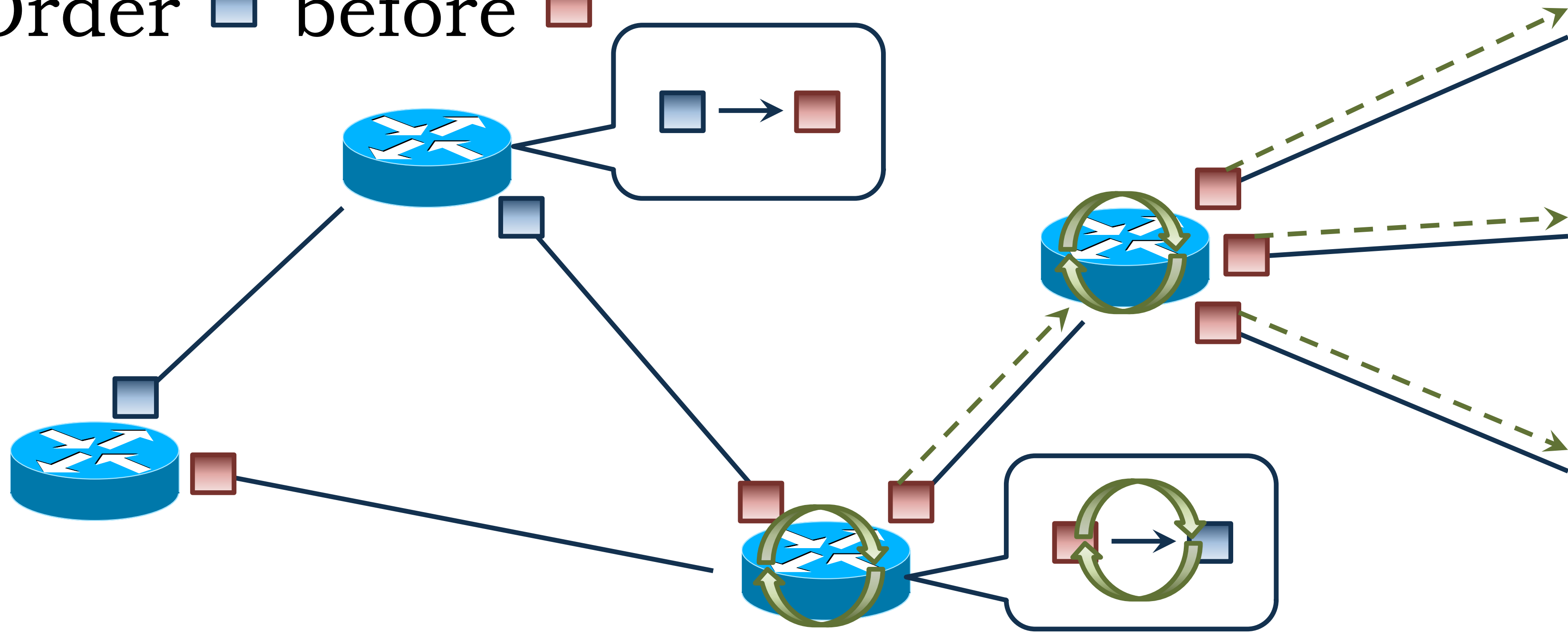


Ordering Internal Events with Logical Timestamps

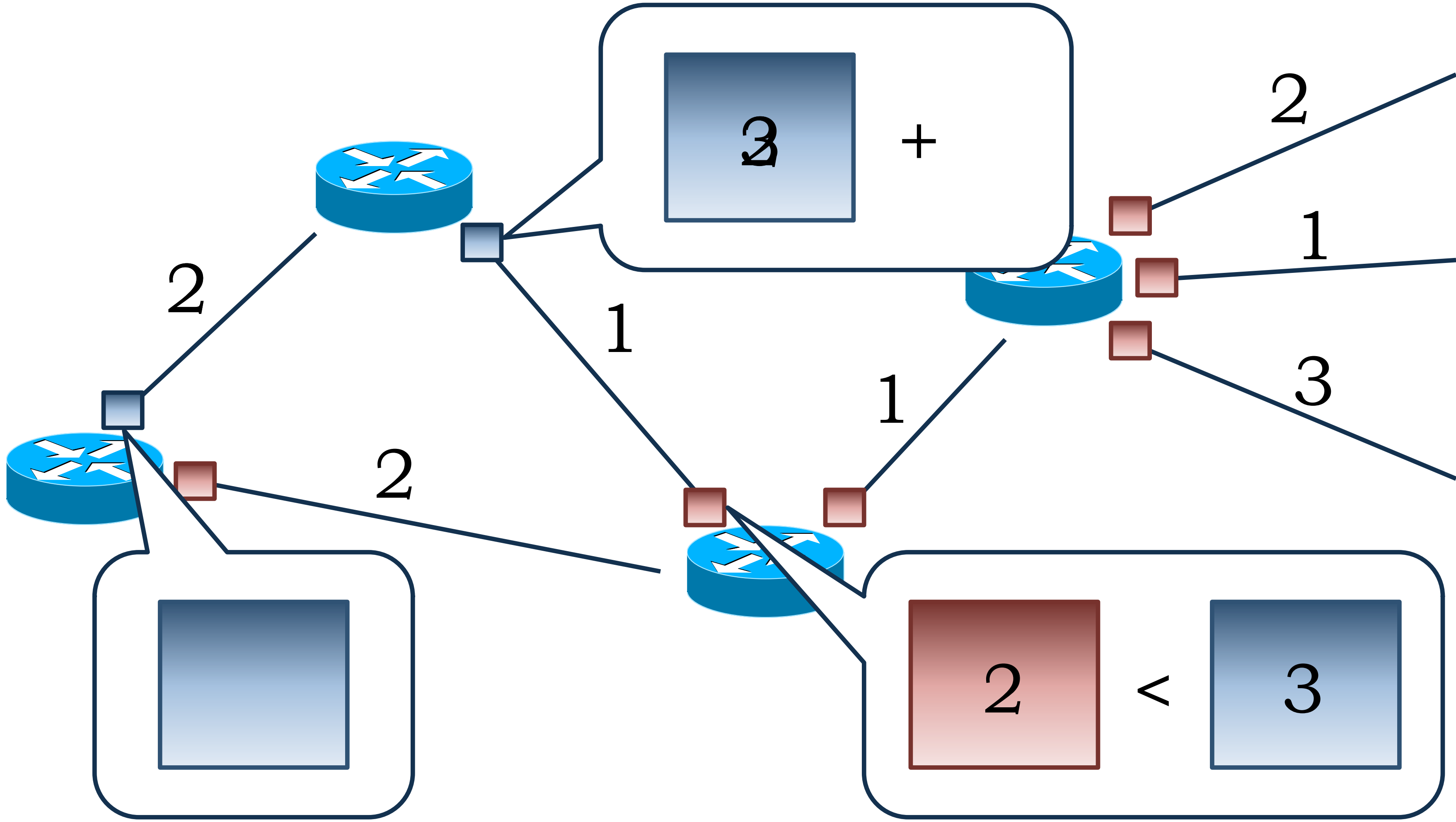
- One network node periodically broadcast logical timestamps
- Each node records external events in logical time
- Each node tags and orders internal messages with logical timestamps and fires timers in logical time

Cascading Rollbacks Within a Logical Time Unit

Order ■ before ■



Optimized Ordering Function with Latency Information



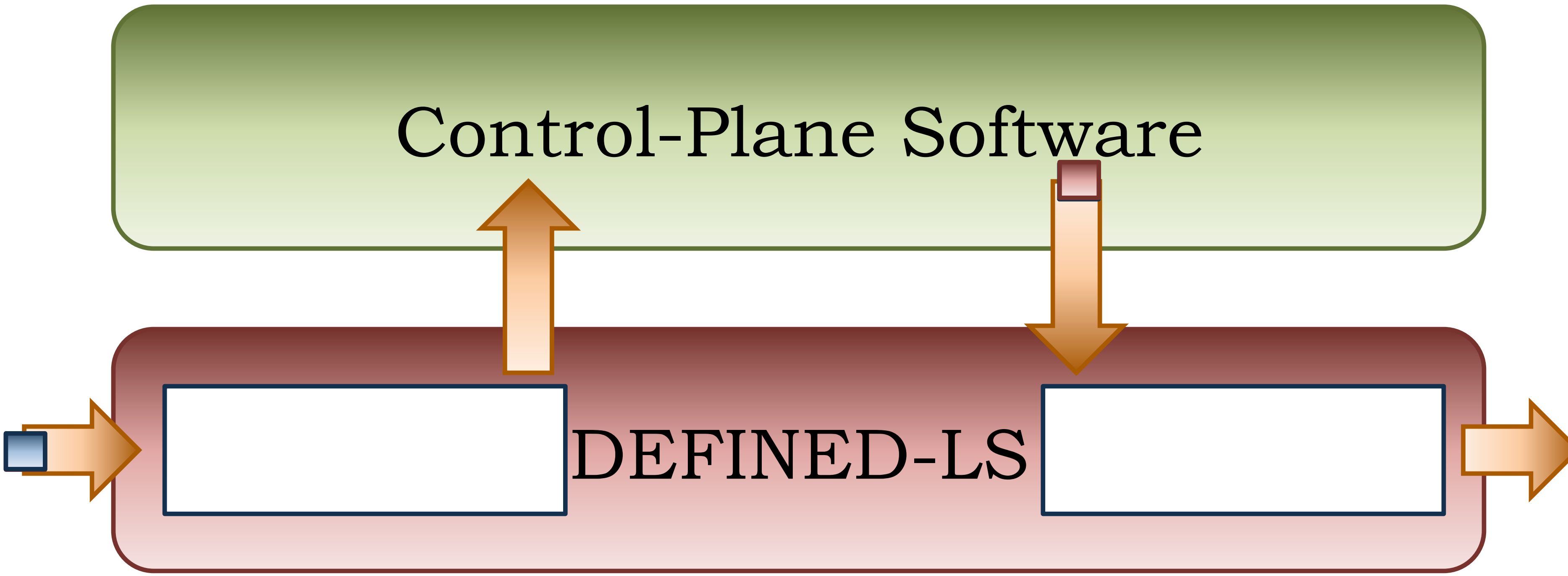
Stepping through Debugging Networks

- DEFINED-LS divides network execution into logical steps
- Each step has two phases
  - Transmission phase
    - Each network node sends messages to neighboring nodes
  - Processing phase
    - Each network node processes its internal events

A Step in DEFINED-LS

Processing Phase

Transition Phase



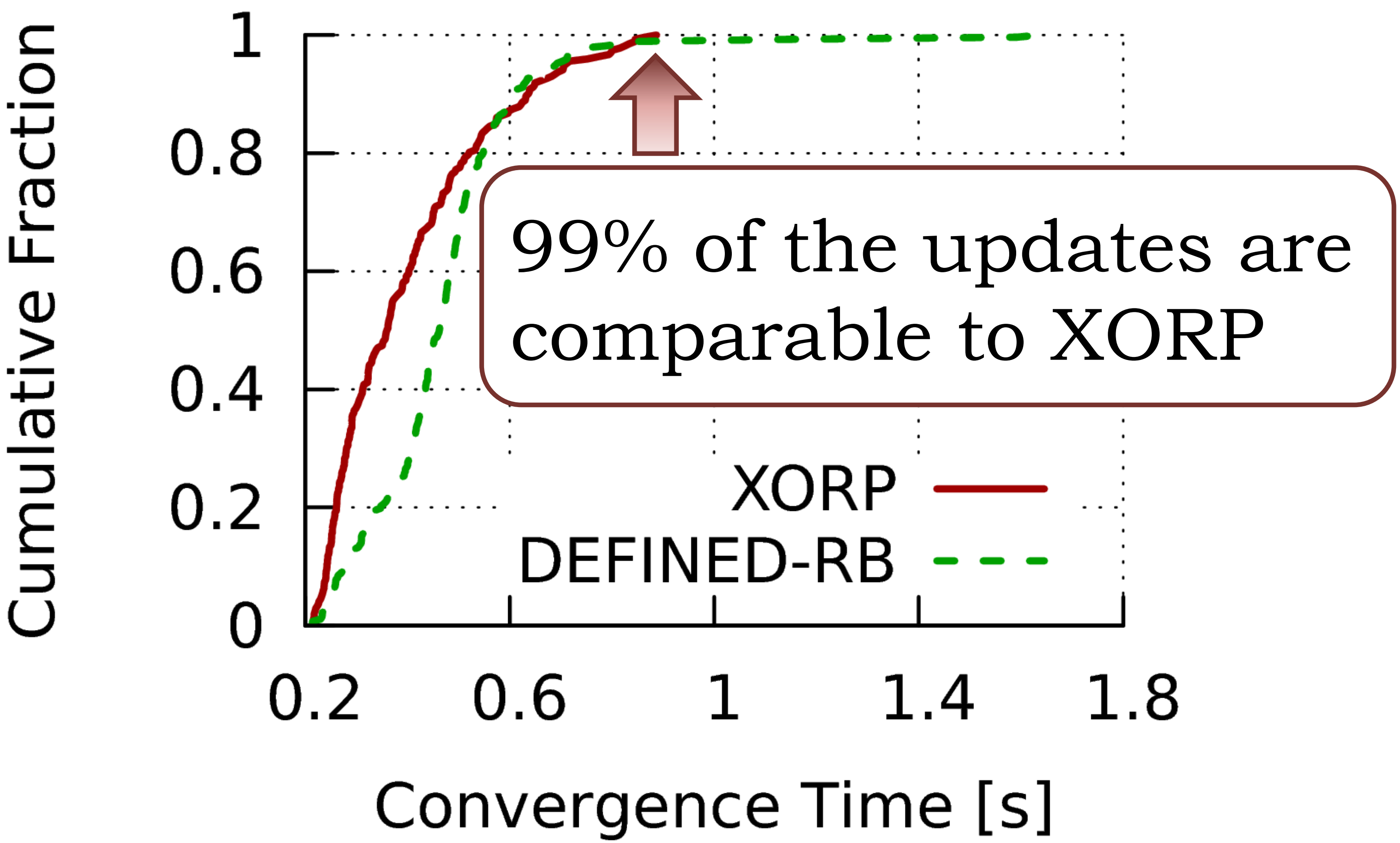
Centralized Coordinator for Interactive Stepping

- Coordinates phase transitions among network nodes
- Allows developers to issue a “step” command
- Steps may be chosen at various levels of granularity (per-event or per-logical-time-unit)

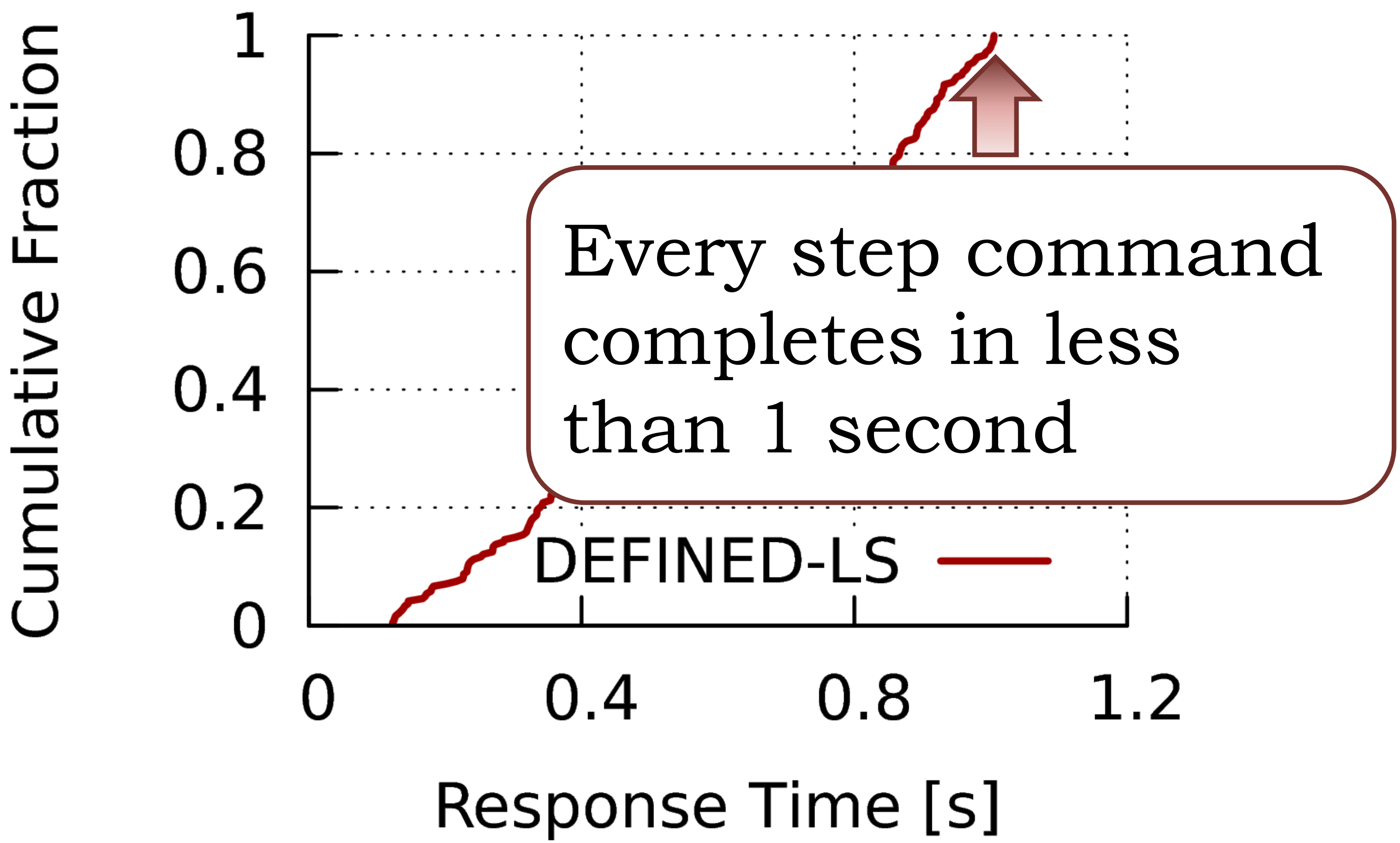
Evaluation Methodology

- Software: XORP OSPF 1.6
- Environment: Emulab
- Topology: Rocketfuel and BRITE
  (we present results from the Rocketfuel Sprintlink topology)
- Traces: 2 weeks of Tier-1 ISP area 0 OSPF traces
  (324 network nodes and 651 events)

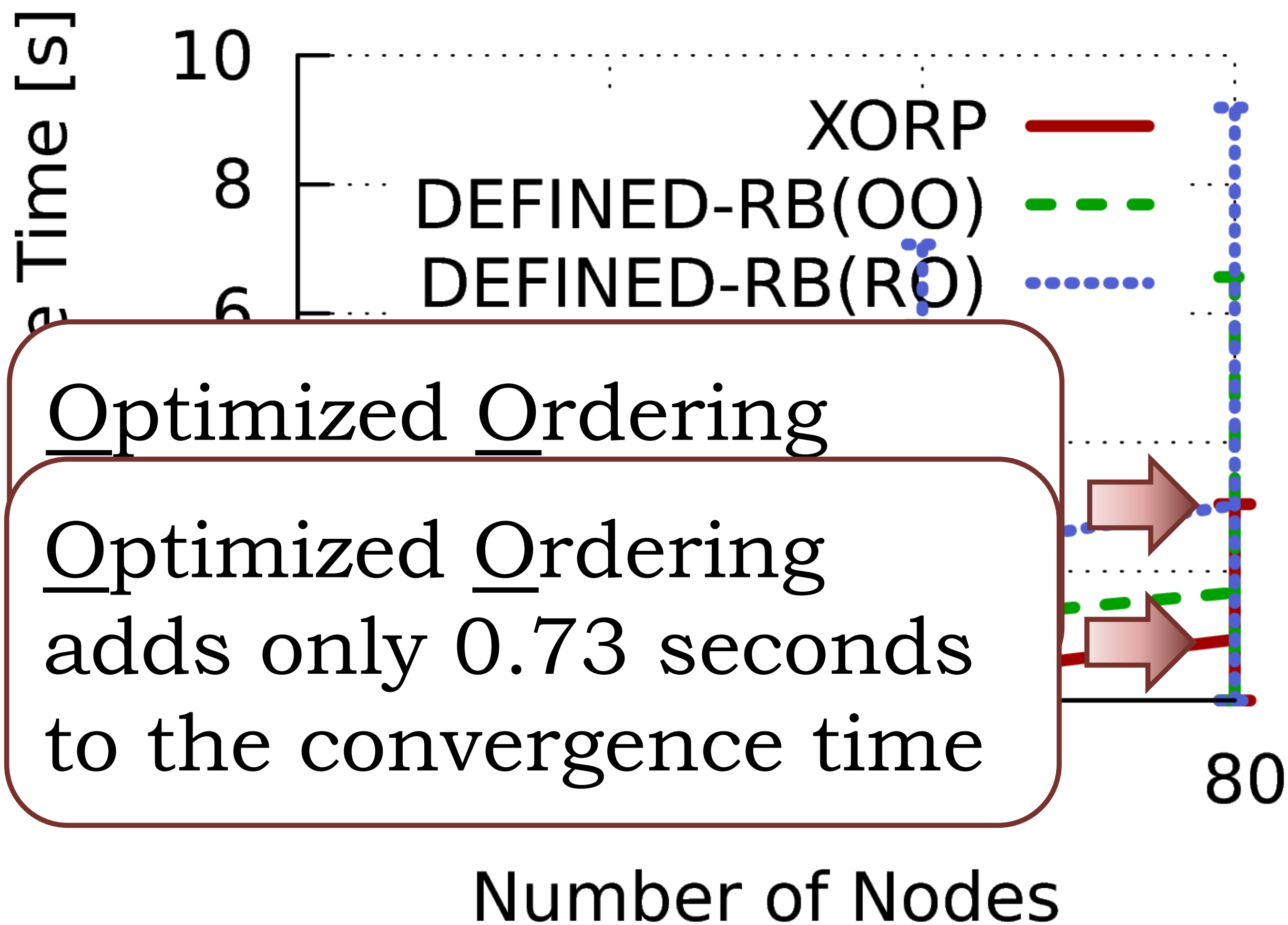
DEFINED-RB Performance



DEFINED-LS Performance



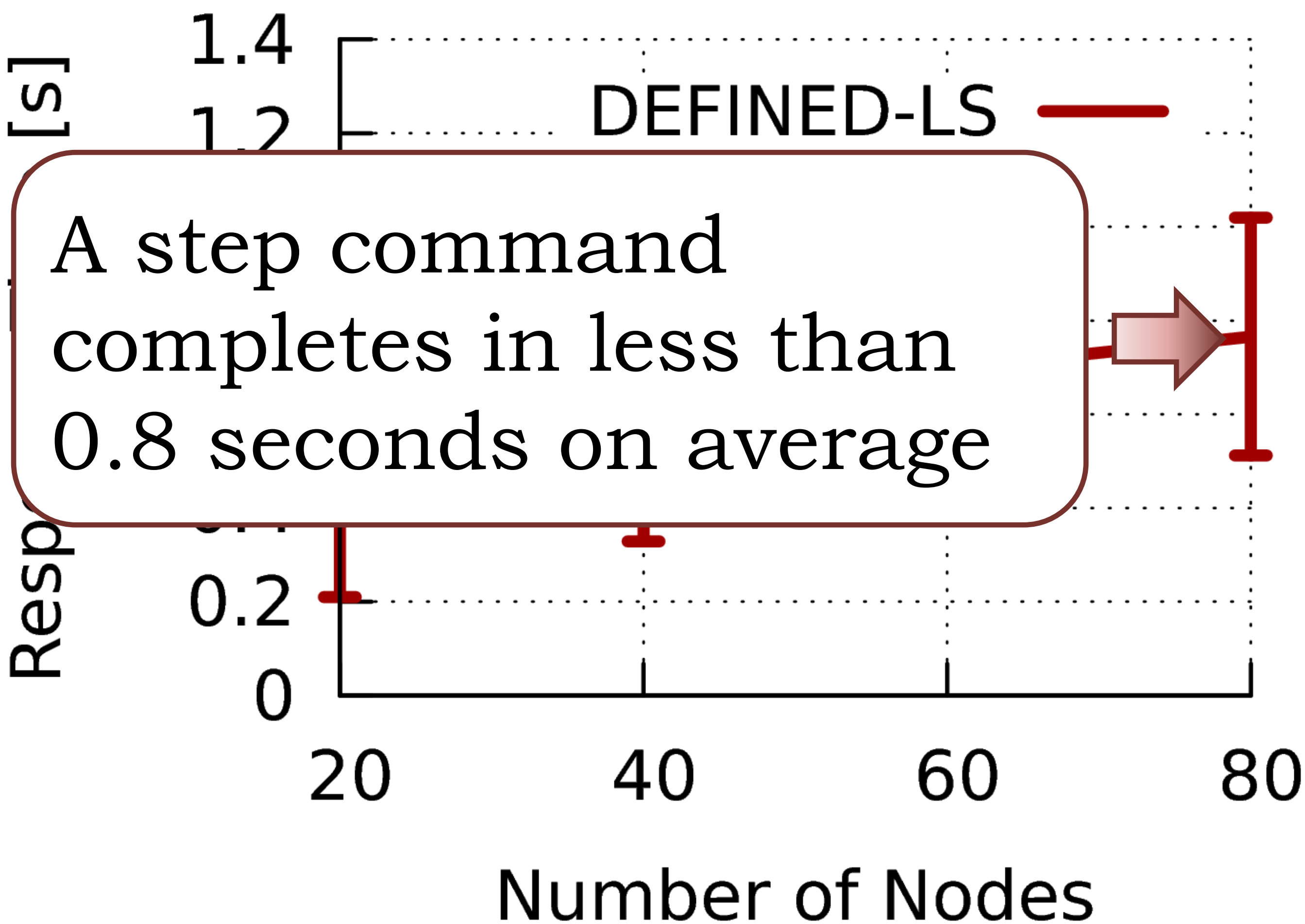
DEFINED-RB Scalability



Optimized Ordering

Optimized Ordering adds only 0.73 seconds to the convergence time

DEFINED-LS Scalability



A step command completes in less than 0.8 seconds on average

Conclusion

- A debugger for control-plane software
- Uses deterministic execution to avoid logging internal nondeterminism
- Implements speculative execution to maintain efficiency in production networks
- Leverages a lockstep algorithm to provide interactive control in debugging networks

THANK YOU