Increasing Fault Resiliency in a Message-Passing Environment

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Design
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- Checkpoint/Restart is common way to deal with faults
- What can we do to increase checkpoint interval?
- Explore redundant computation for MPI applications
  - Can it be done at user level?
  - What are requirements for RAS system and runtime?
  - What is the overhead
  - Cost versus benefit?
- Write *r*MPI library at MPI profiling layer to learn what the issues are

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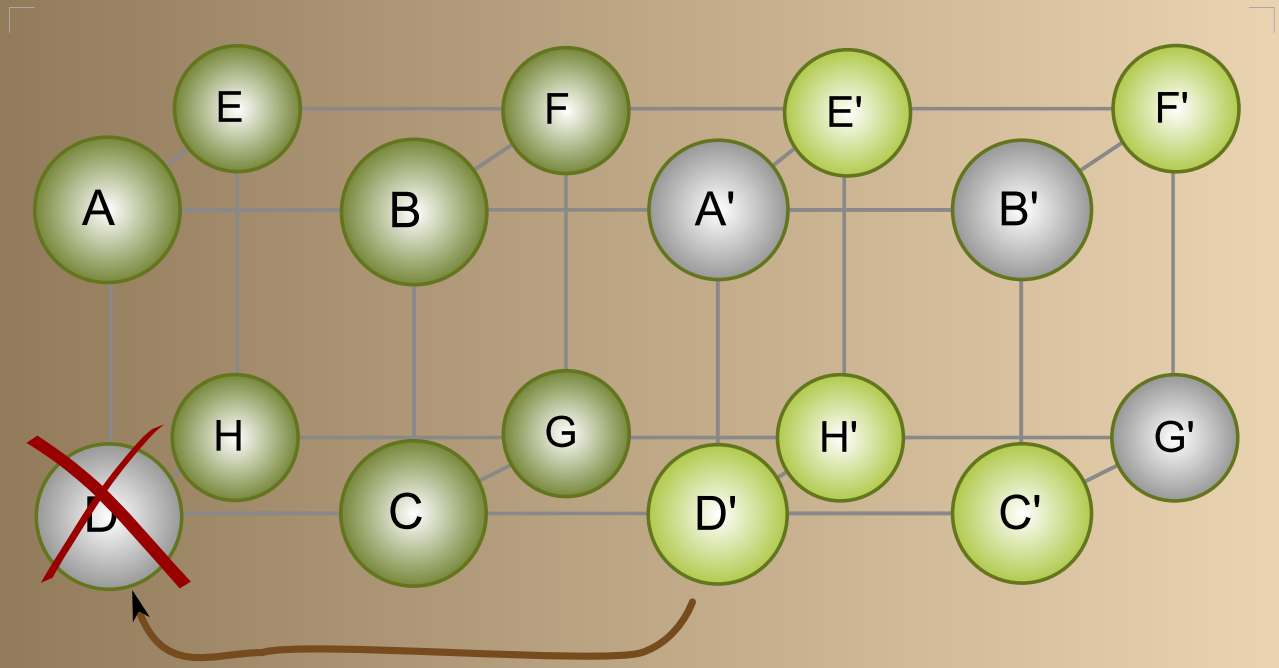

- Active and redundant node do same computation
- One node continues when the other fails
- `MPI_Comm_rank()` returns same value on both nodes
- Not each node needs to have a redundant partner

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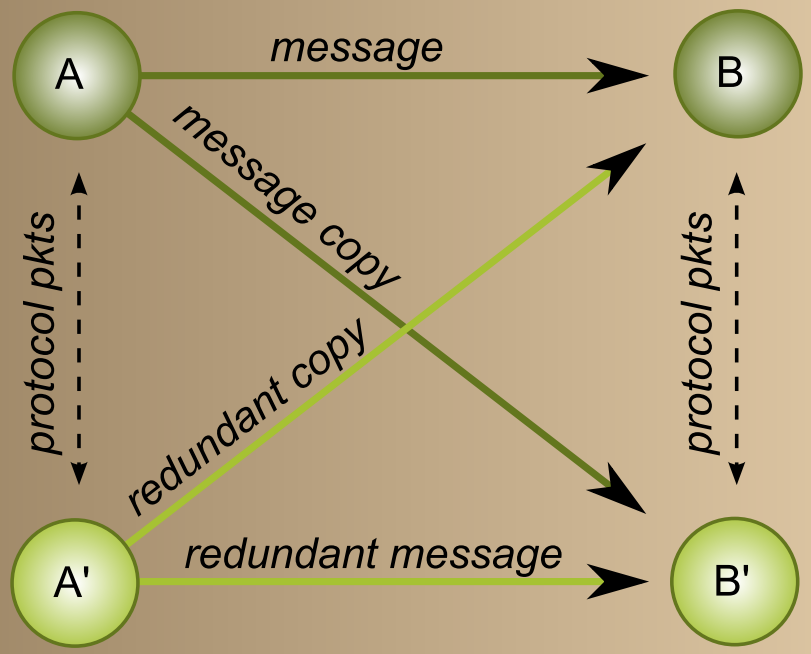

- Each message gets sent twice (4, if we count redundant nodes)
- Msg and redundant copy received into same buffer
- Redundant msg have unused tag bit set
- Protocol needed to coordinate receives and other MPI ops

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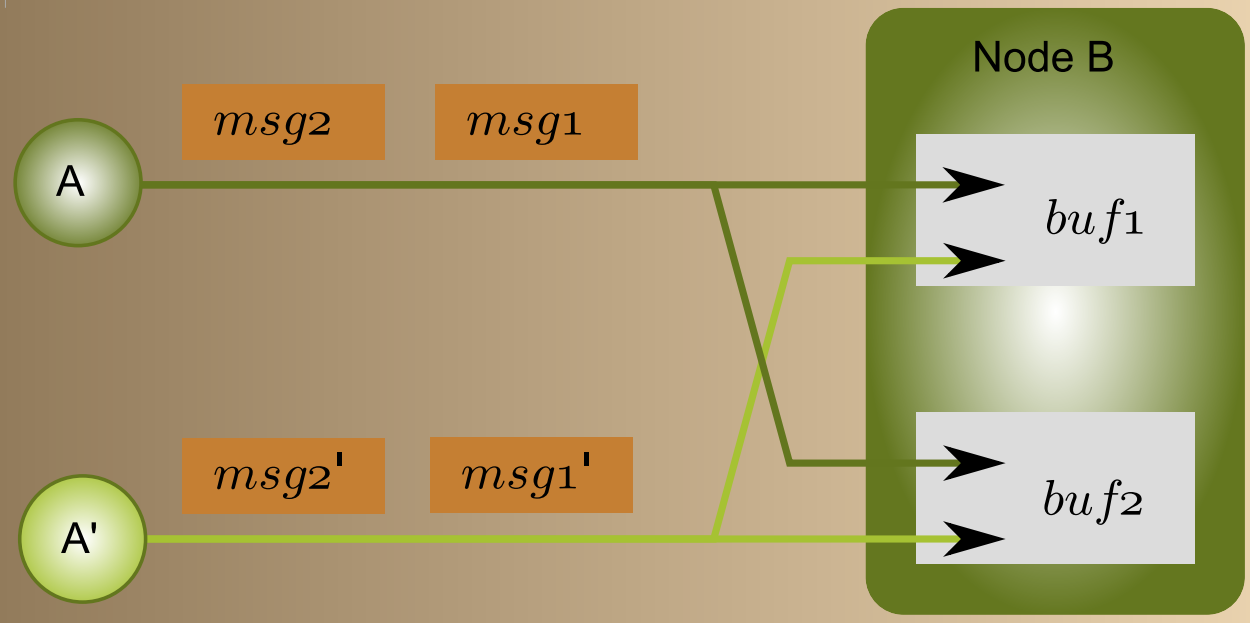

- Active and redundant node must receive msg in same order
- `MPI_ANY_SOURCE` and `MPI_ANY_TAG` are problematic
- Redundant node maintains queue of posted receives if `MPI_ANY_SOURCE`
- Coordinate with active node to post specific receive

Other Functions

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- Redundant node must return same info for probe, test, and time functions
- Active node does operation and sends result to redundant node
- Collectives use redundant point-to-point
- *r*MPI re-implements almost all of MPI
  - *r*MPI uses MPICH (mostly) as a transport layer

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- Can't do `MPI_ANY_TAG` and `MPI_ANY_SOURCE` simultaneously
- Most mayor functions of MPI-2 implemented
- Are considering transactions to limit data volume
- Plan to open source it
- Few RAS features needed:
  - Notification of node availability
  - No Byzantine behavior (error correction protocol on network)
  - Messages to/from dead nodes must be consumed (no dead- or life-lock)

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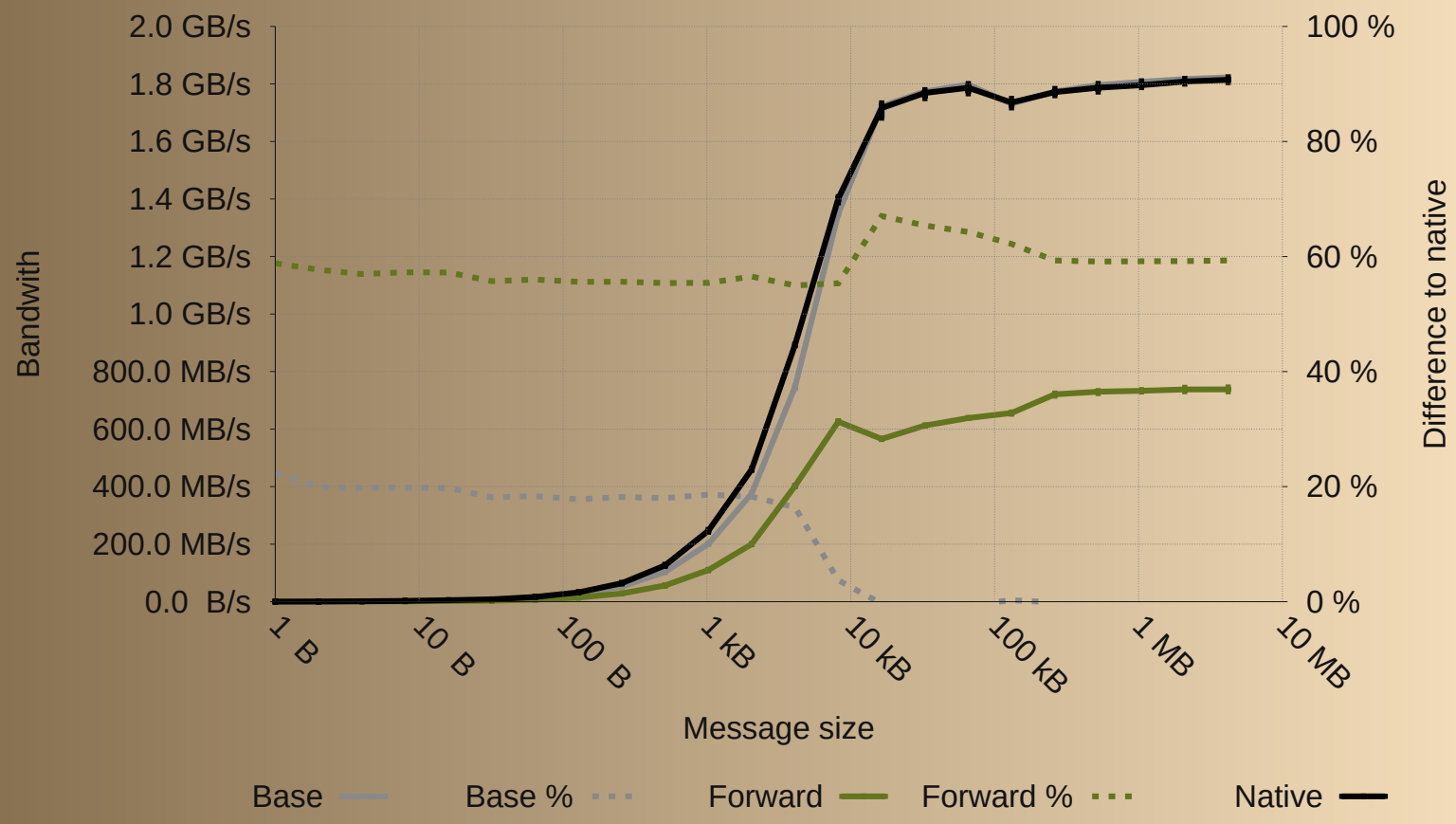

Native	Benchmark w/o *r*MPI
Base	*r*MPI, no redundancy
Forward	ABCD|A'B'C'D'

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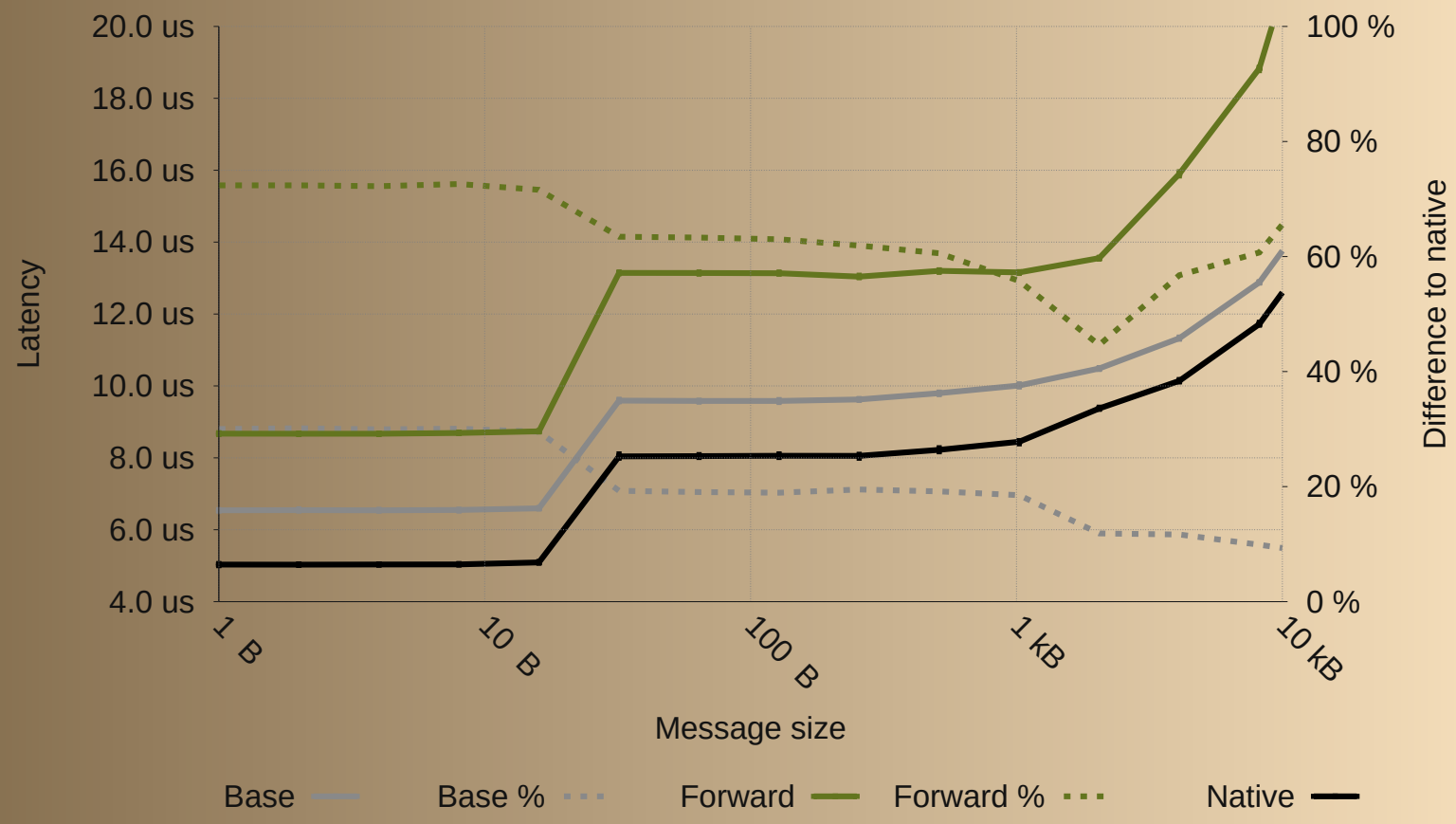

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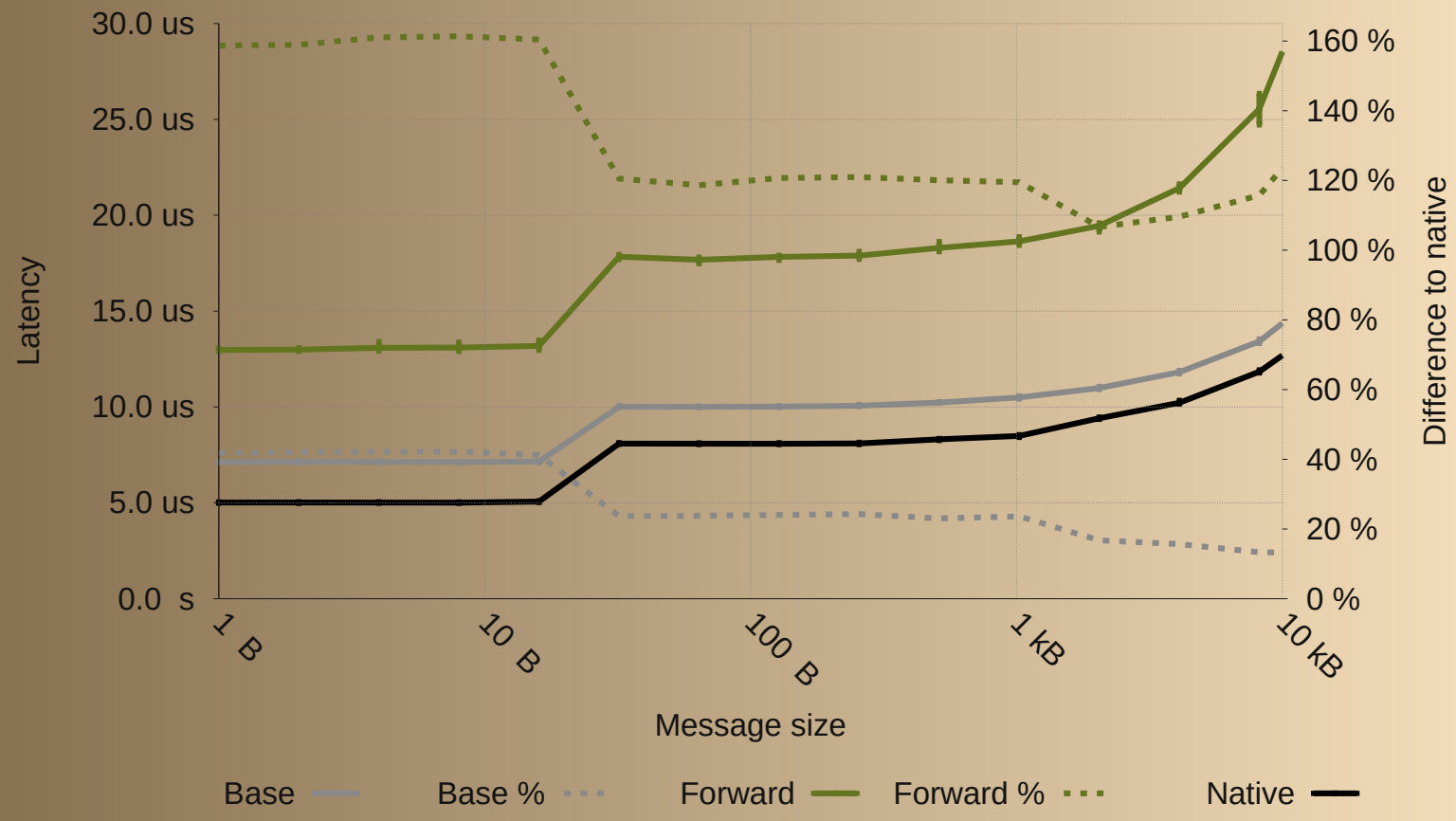

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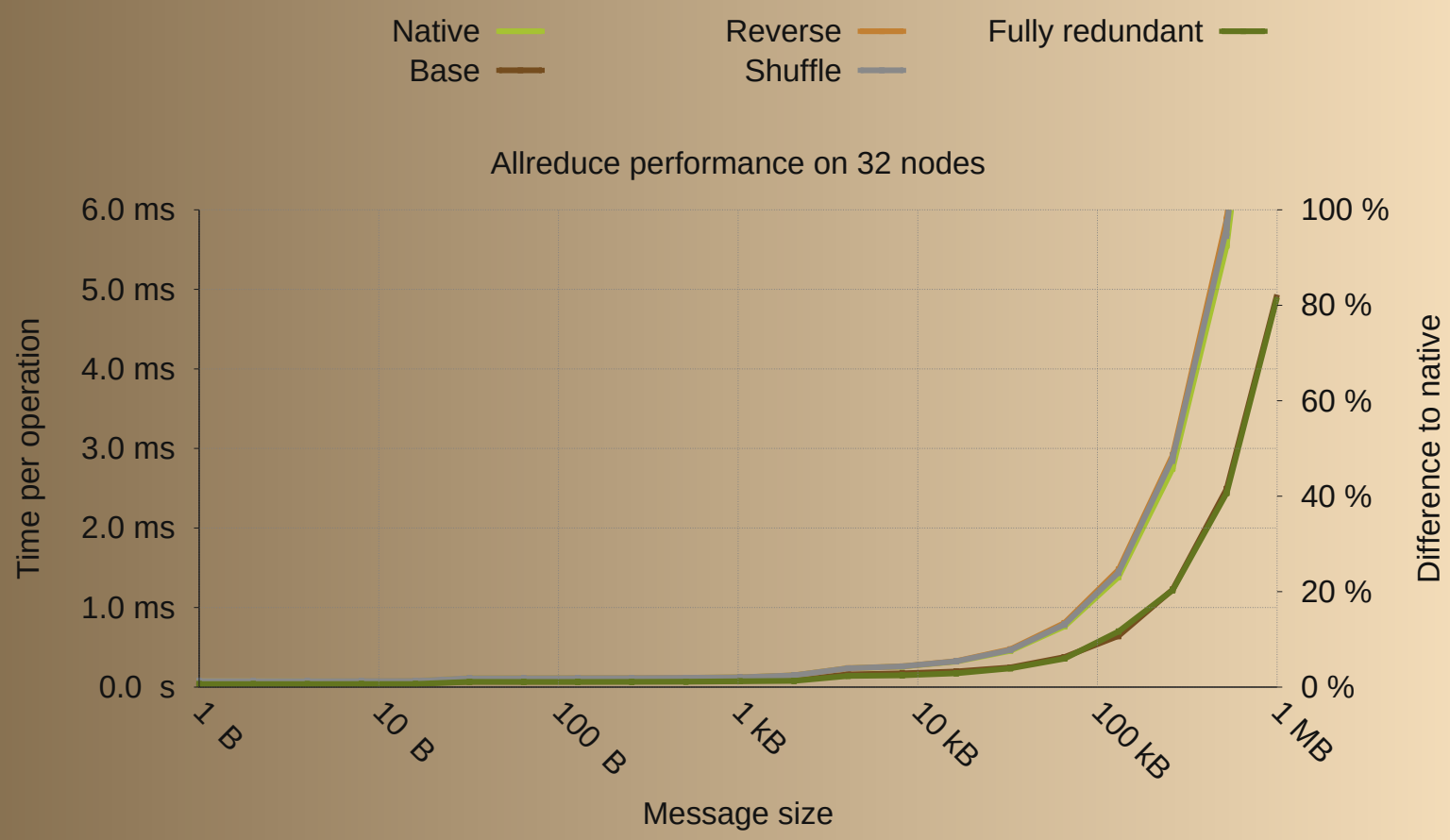

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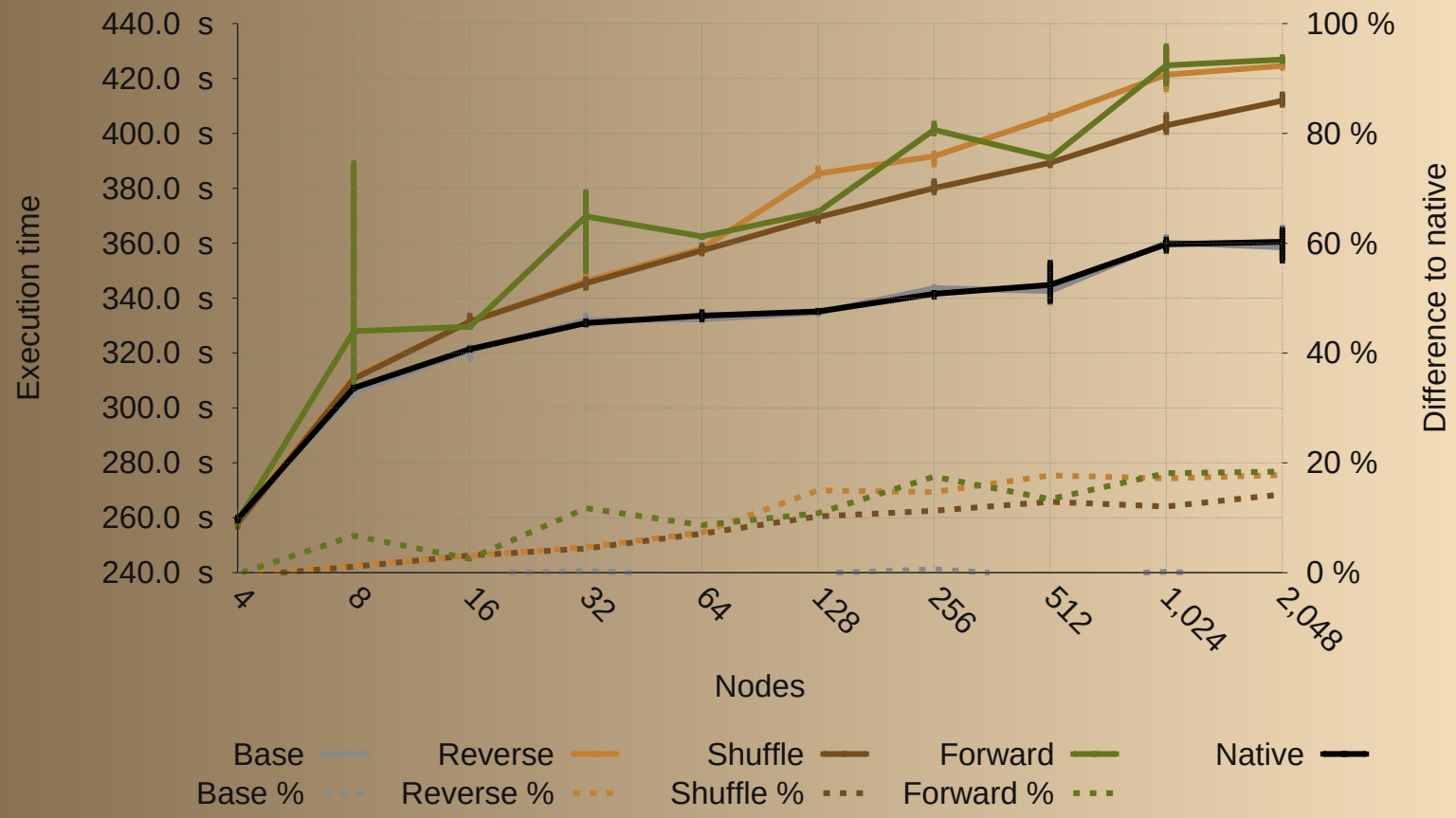

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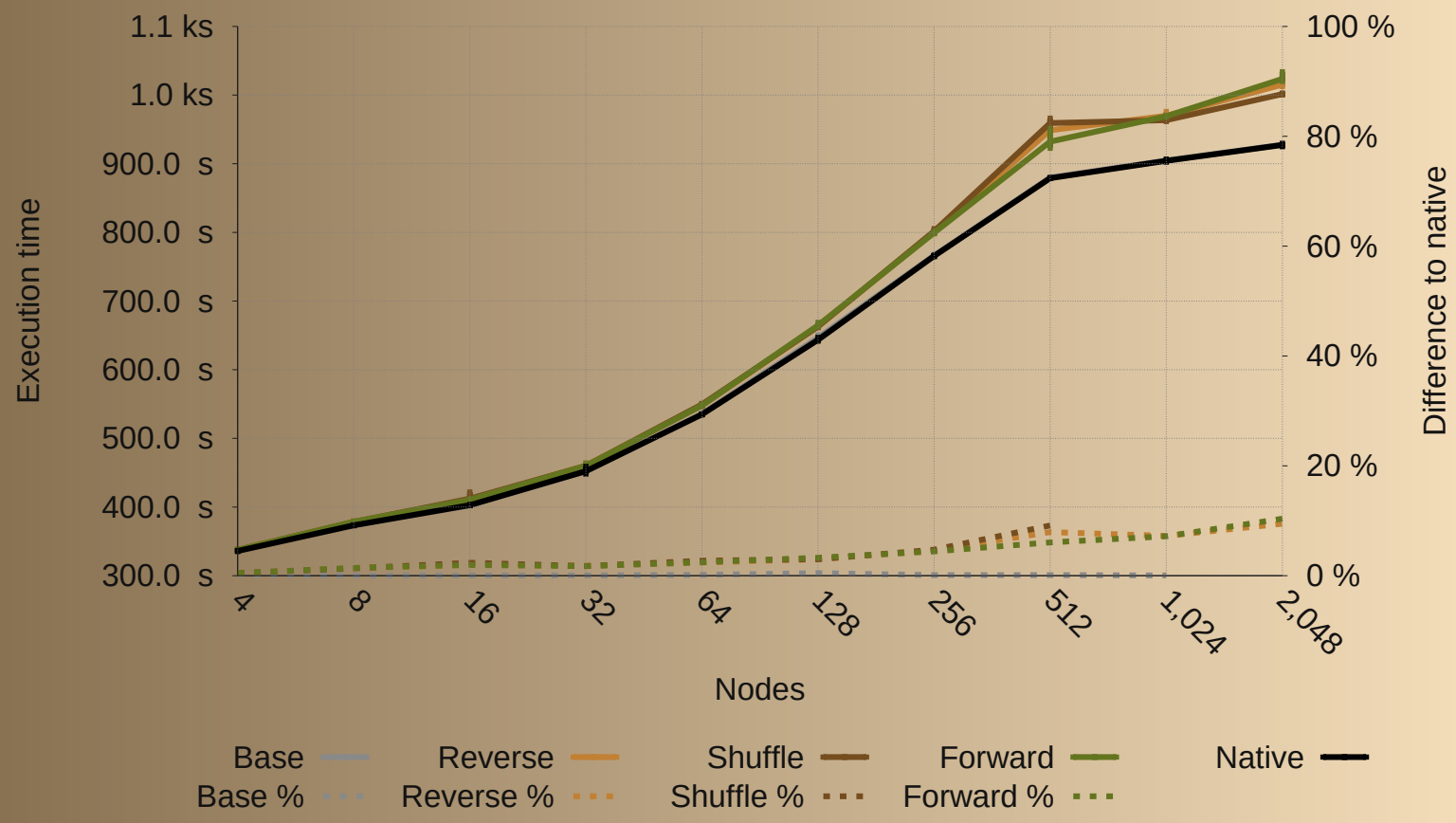

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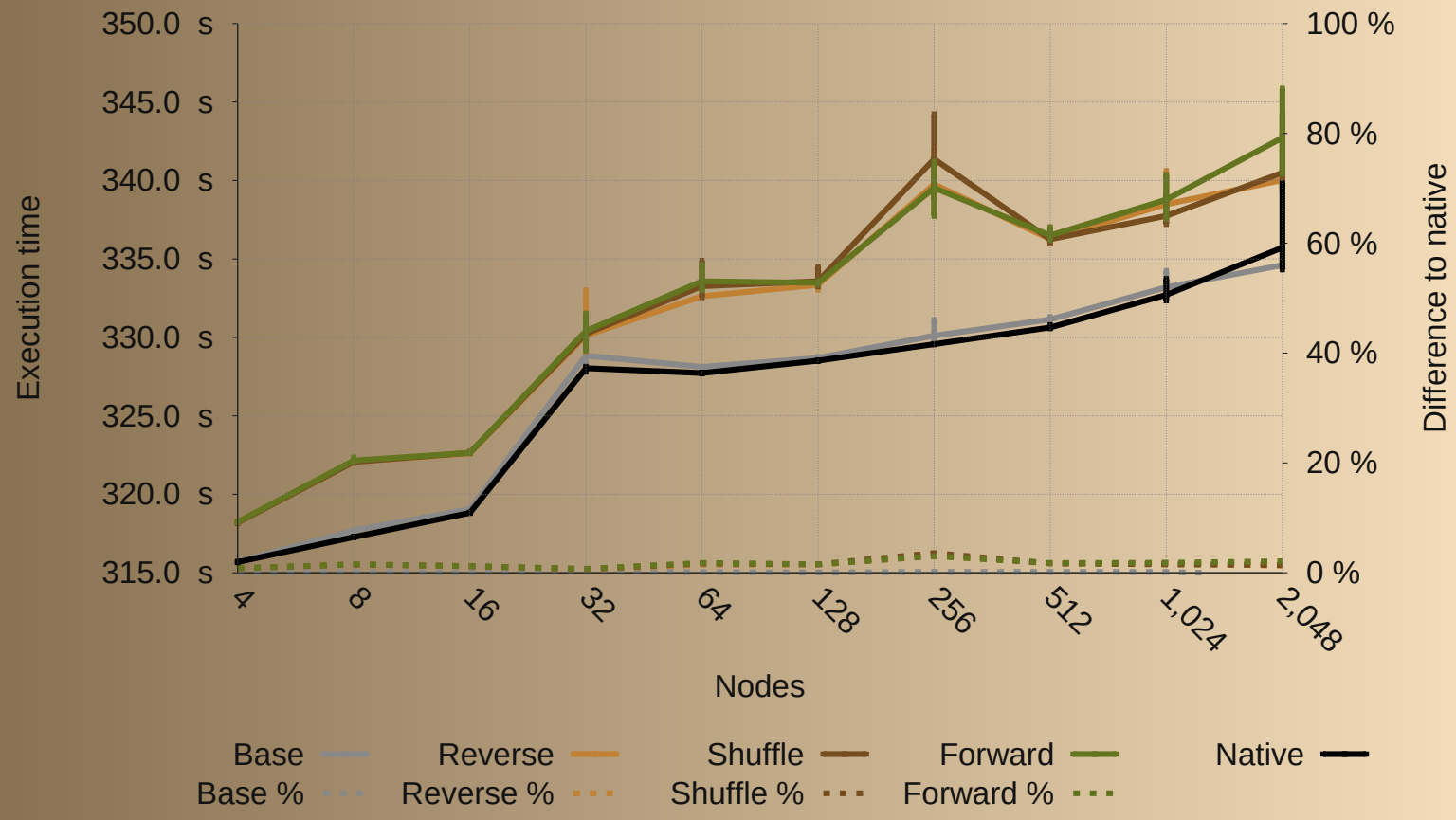

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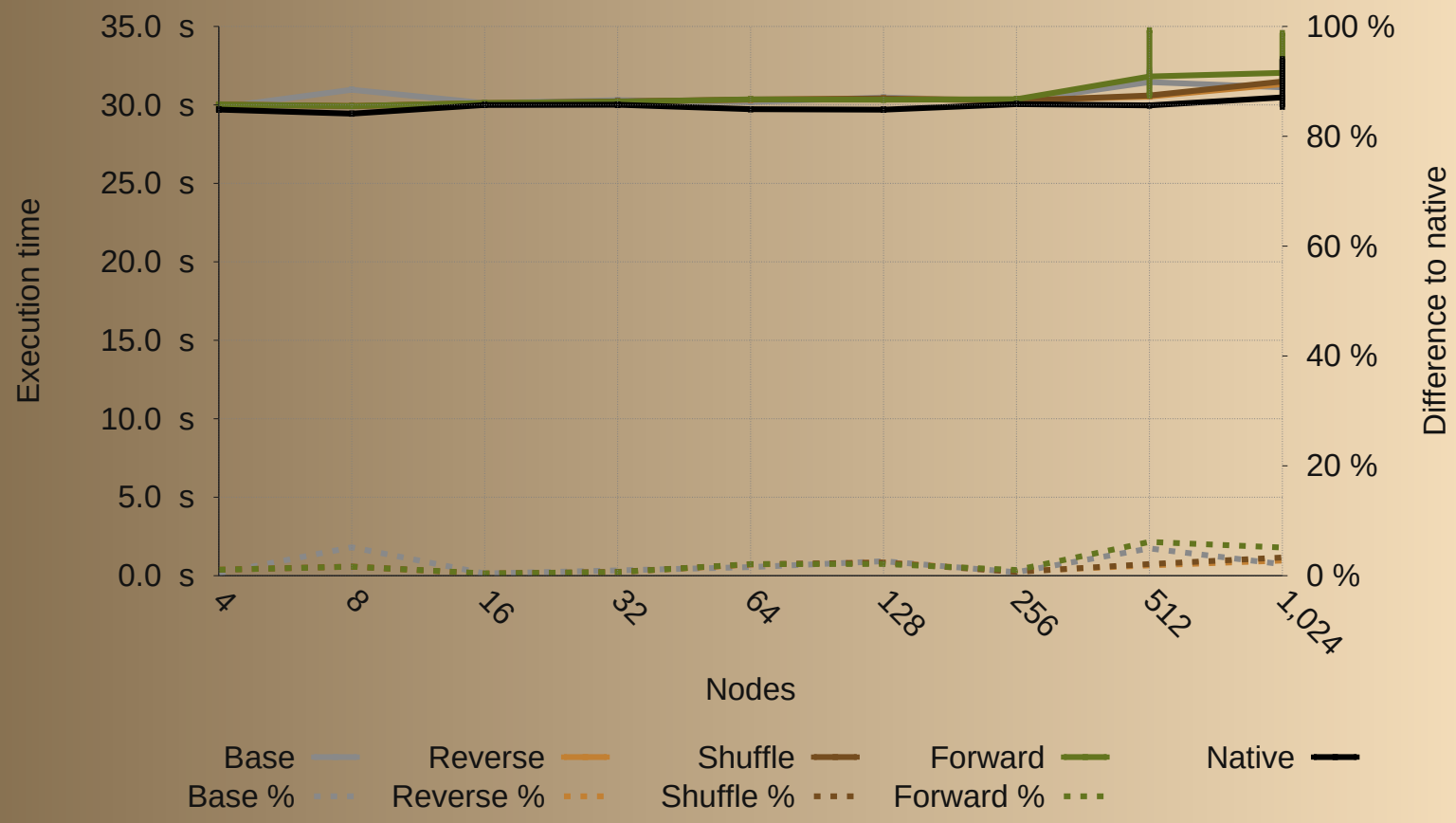

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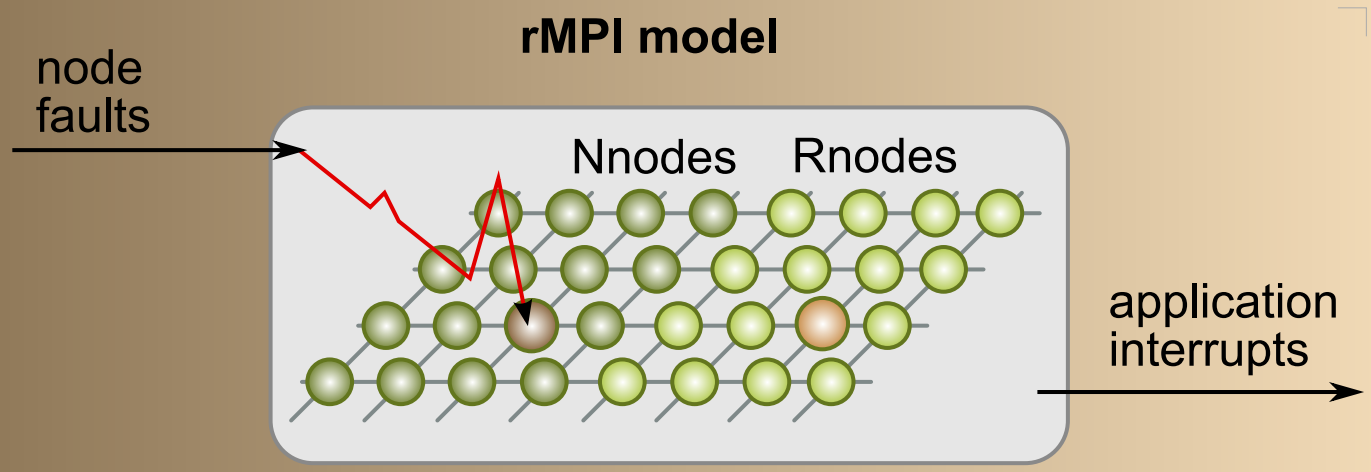

- Acts as a filter
  - Input is a series of faults
  - Output is application interrupts that cause a restart

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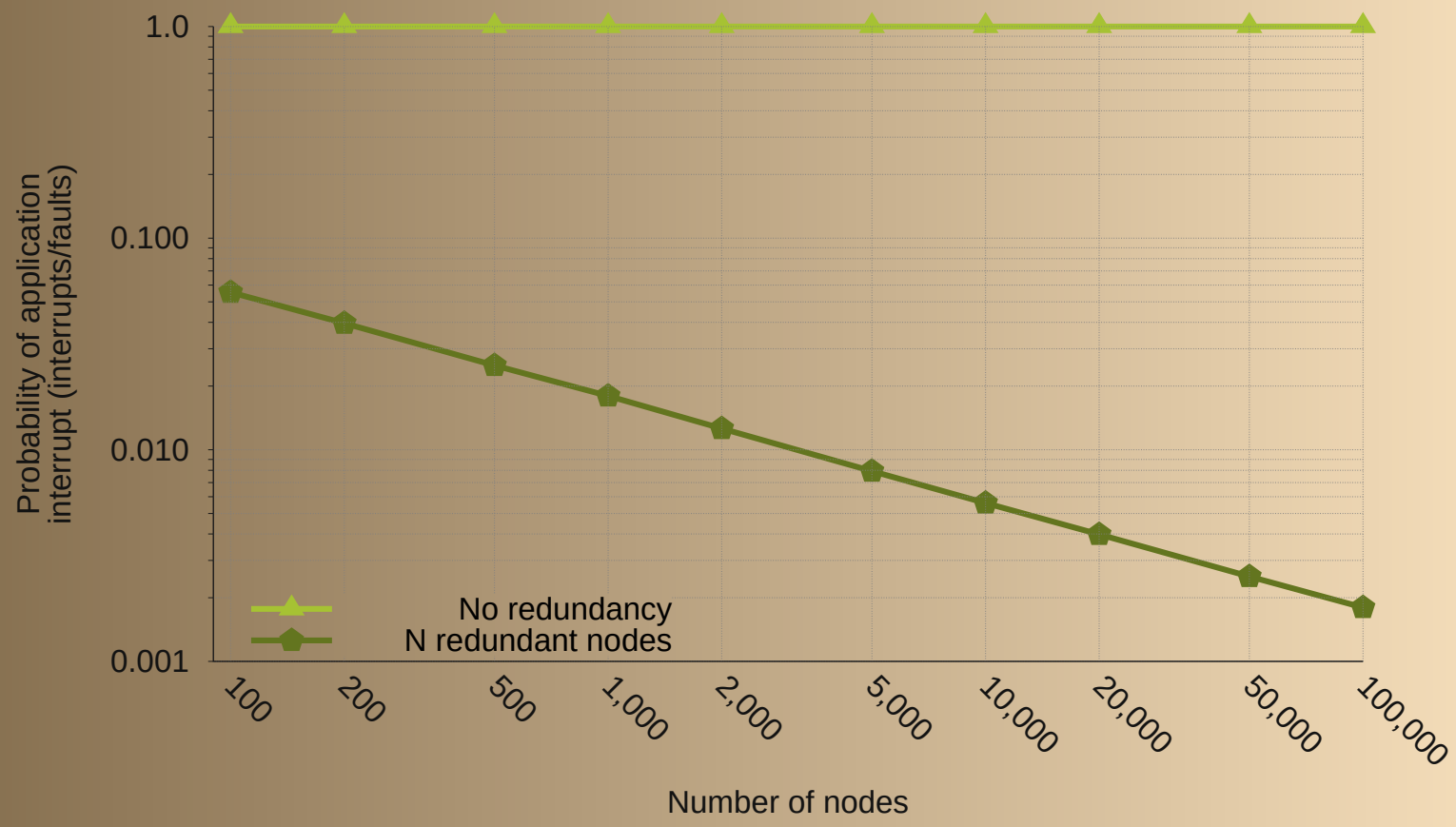

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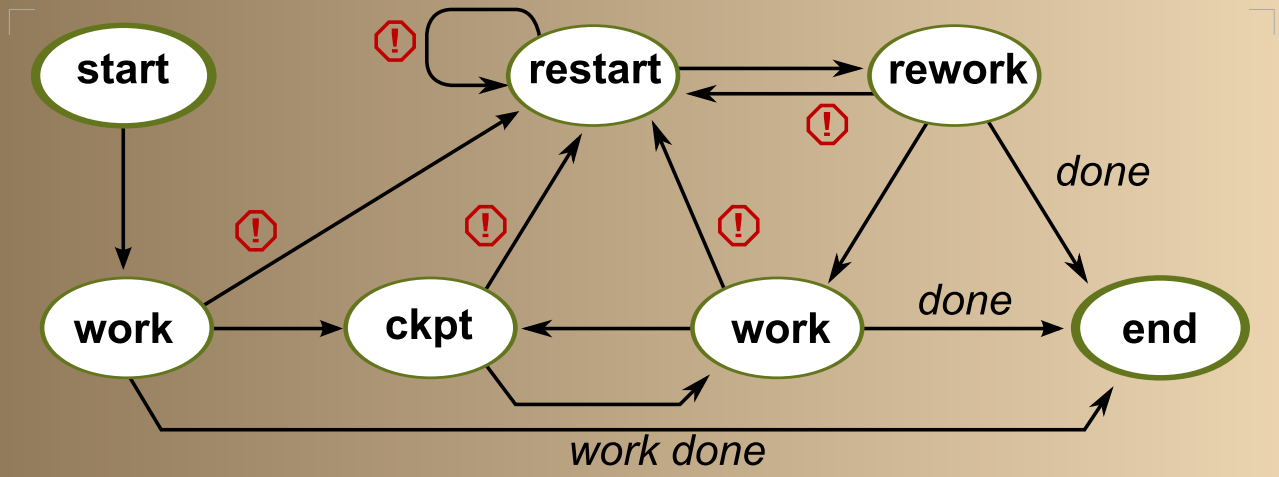

- Application needs to finish a set amount of work
- Do checkpoints and restart when necessary

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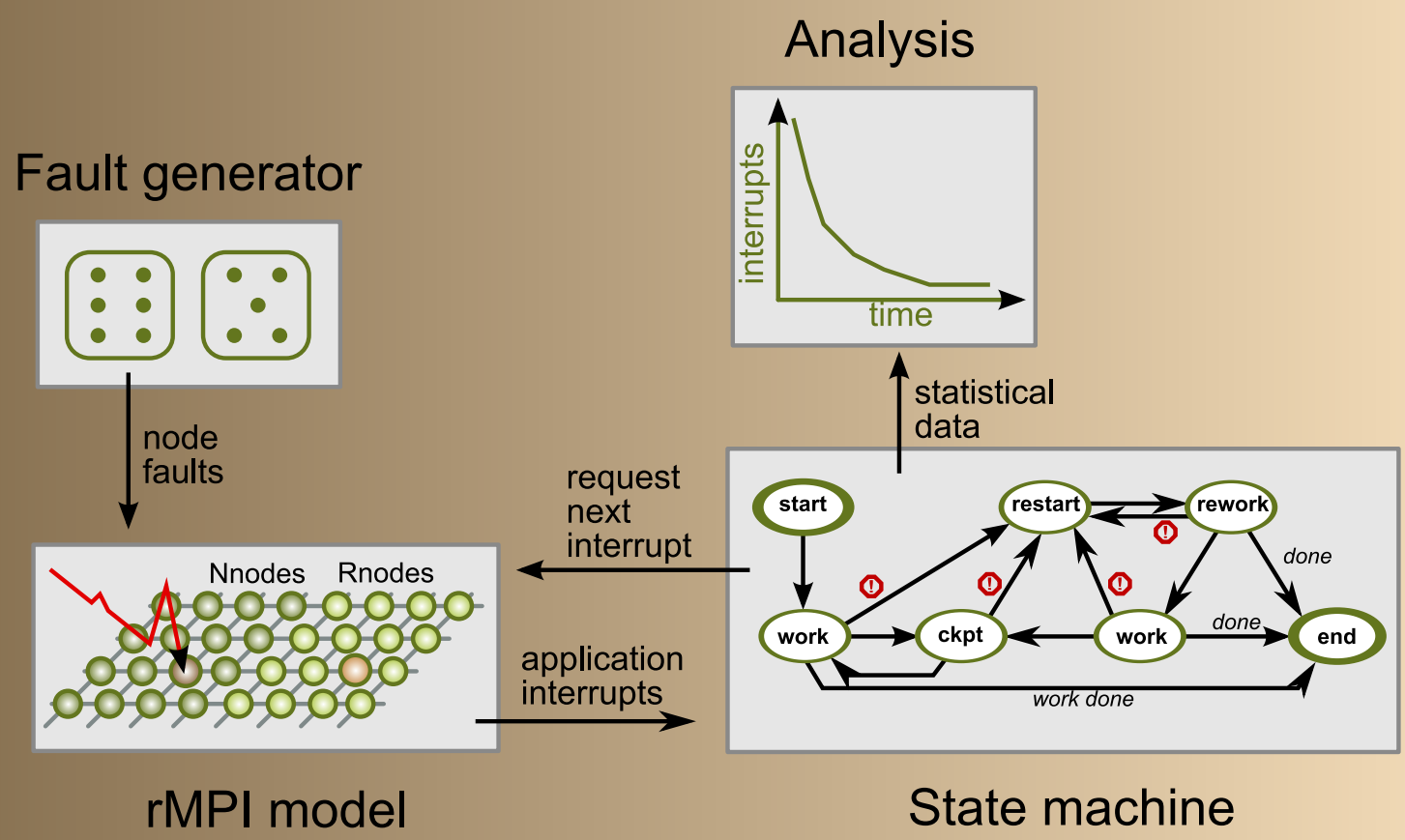

- Combine *r*MPI model with state machine
- Finish a set amount of work
- Do checkpoints and restart when necessary

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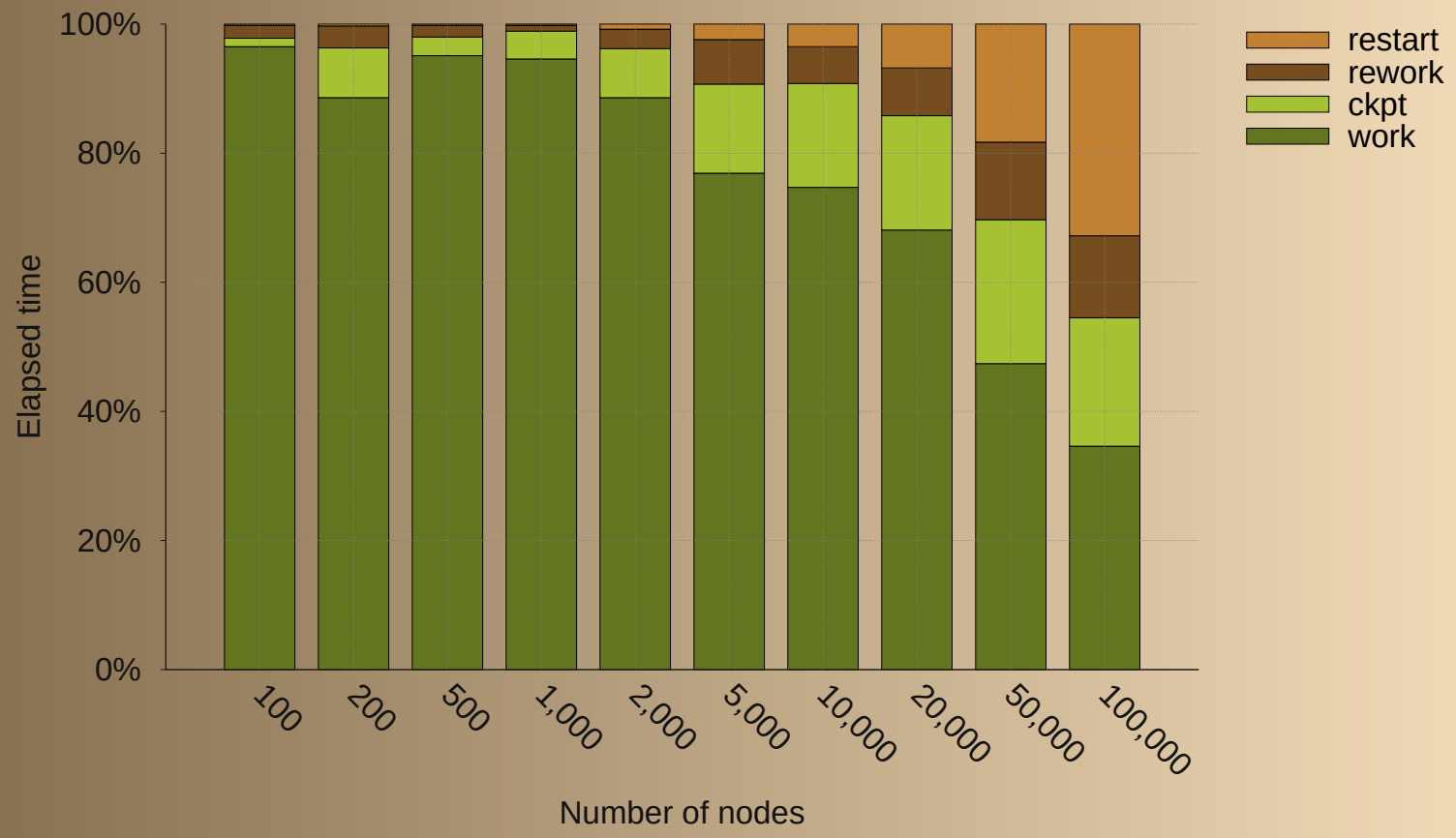

Normalized time spent in work, checkpoint, restart, and rework.
168h work, 5 min checkpoint, 10 min restart, 5-year node MTBF

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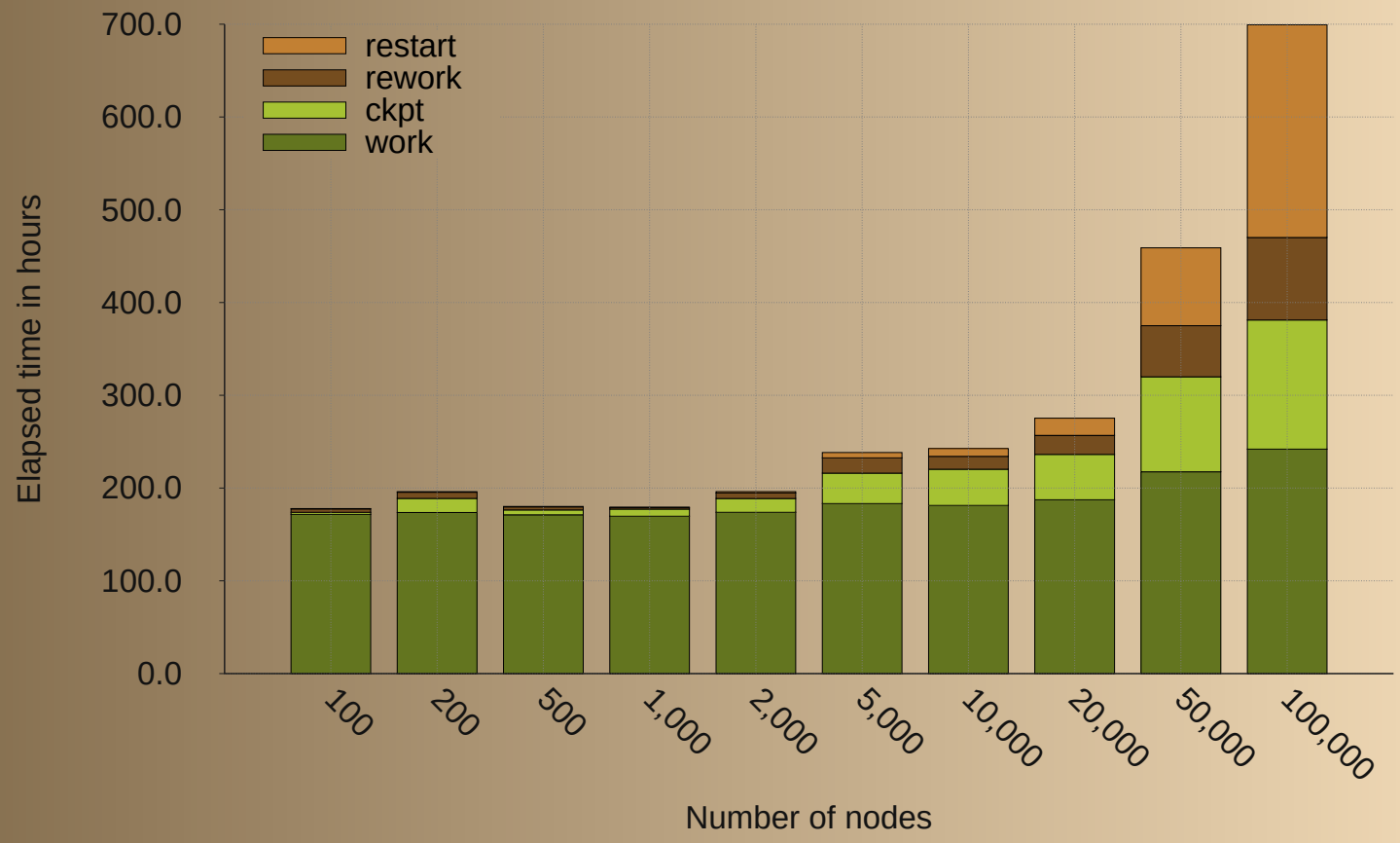

Total time spent in work, checkpoint, restart, and rework.
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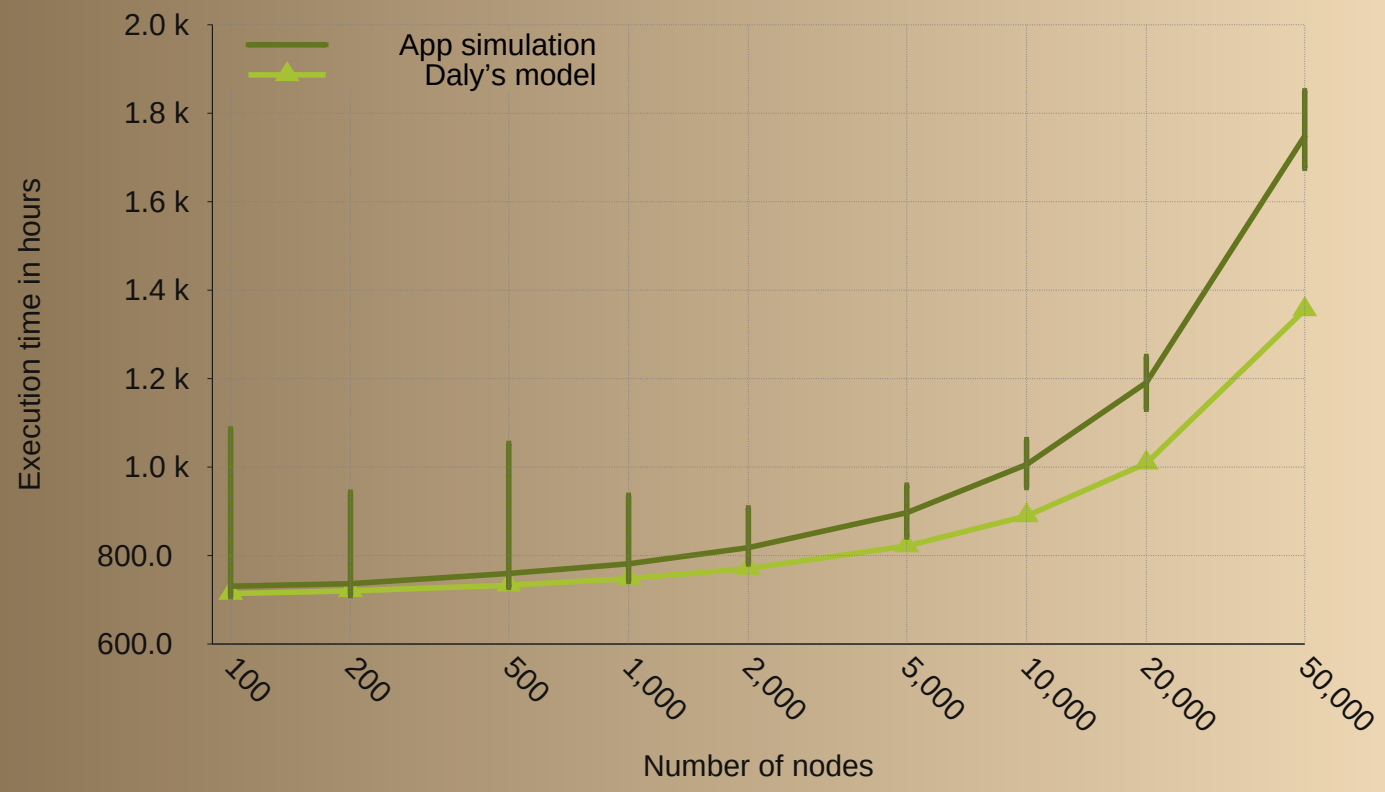
Daly's equation from *A higher order estimate of the optimum checkpoint interval for restart dumps*.

$$T_w(\tau) = \Theta e^{\frac{R}{\Theta}}(e^{\frac{\tau+\delta}{\Theta}} - 1)\frac{T_s}{\tau} \quad \text{for} \quad \delta << T_s$$



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Implications and Trade-Offs

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$$R = \frac{T_w + T_{o(\text{none})}}{T_w + T_{o(\text{full})} + T_{r\text{MPI}}} \quad (1)$$

- T_w: amount of work
- $T_{o(\text{none})}$: checkpoint, restart, rework overhead without redundant nodes
- $T_{o(\text{full})}$: overhead with redundant nodes
- If $R > 2$ then using redundant nodes makes sense

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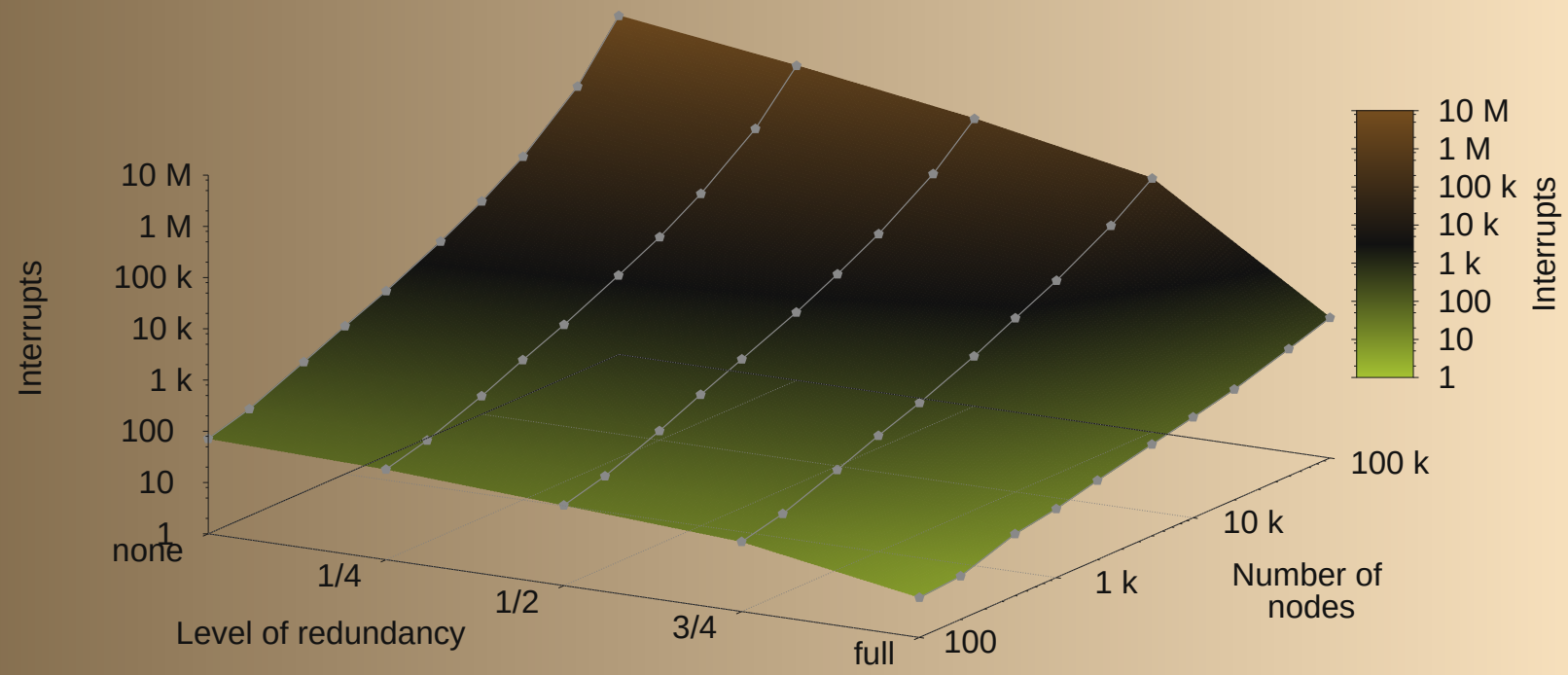

5,000h work, 5 min checkpoint, 10 min restart, 1-year node MTBF

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- Redundant MPI library can be done at user level
- Overhead for applications is not significant for most applications
- Application restart simulator allows modeling of
  - varying node counts
  - node MTBF
  - level of redundancy
  - failure distribution function (exponential, gamma, weibull)
  - amount of work, checkpoint and restart times
- Model helps determine when redundancy pays off