Assessing Energy Efficiency of Fault Tolerance Protocols for HPC Systems

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Exascale

Energy

- Power management (20MW budget)
- Administrative considerations (1MW $\rightarrow$ \$1M/year)
- System codesign (architectural features)

Fault Tolerance

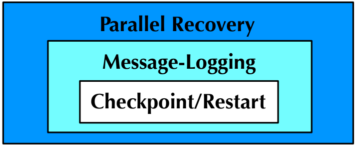
- Size of the machine (200,000 sockets $\rightarrow$ MTBF)
- Types of failures (memory, accelerator, network)
- Different strategies

Energy Efficiency of Fault Tolerance Protocols

Agenda

Fault Tolerance Protocols

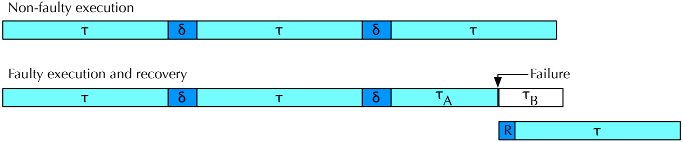
- **Checkpoint/Restart**
  - State is saved periodically
  - Coordinated global checkpoint
  - Checkpoint stored locally
  - Failure → global rollback
- **Message-Logging**
  - Messages are stored at sender
  - Non-determinism logged
  - Determinants in causal path
  - Failure → local rollback
- **Parallel Recovery**
  - Tasks are migratable
  - Failure → recovery in parallel



Caveat

- Many variants of checkpoint/restart
- Several message-logging protocols
- Hybrid schemes

Optimum Checkpoint Period



Daly's modified model:

$$\tau = \sqrt{2\delta(M+R)} - \delta$$

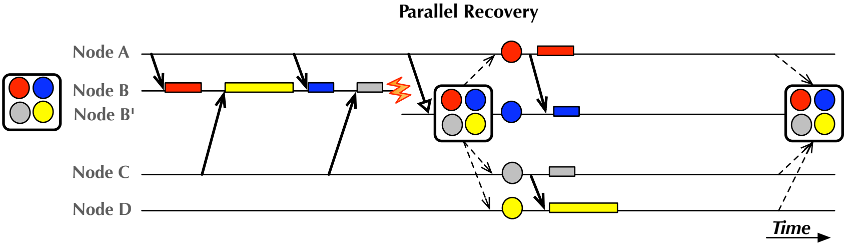
Questions

- Optimum τ for message-logging and parallel recovery?
- Optimum τ to minimize energy?
- Execution time vs energy consumption?

Charm++ Runtime System

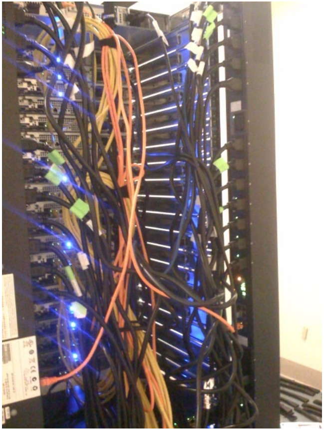
- Migratable Objects Model
- Asynchronous Method Invocation
- Adaptive MPI → each rank becomes an object
- Application-level checkpoint

- One process per *logical* node
- Failure injection: `kill -9 pid`
- Failure detection → automatic restart on replacement node
- Fault tolerance protocols at object-level



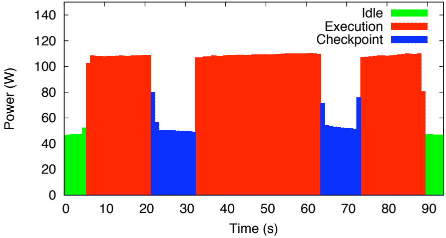
Energy Cluster

- **General Features**
  - 40 single-socket nodes
  - Each node has a four-core Intel Xeon and 4GB of main memory
  - Gigabit ethernet switch
- **Power Measuring**
  - Liebert power distribution unit (PDU)
  - Power measurement per-node
  - 1-second interval frequency

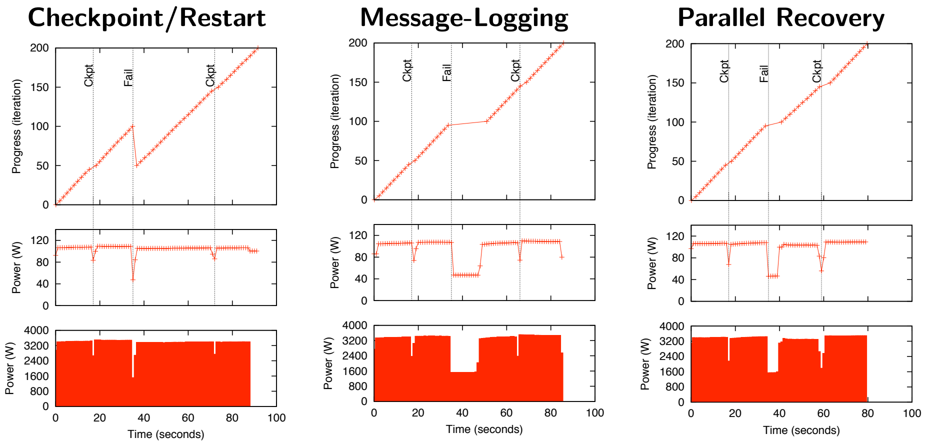


Checkpoint/Restart

- Test program
  - 7-point stencil
  - Nearest neighbor in 3D
  - Barrier after each step
  - Virtualization ratio = 32
  - 200 steps (checkpoints at 50 and 150)
- Local disk checkpoint

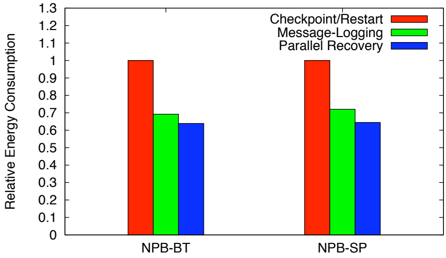


Total Energy Consumed



Energy Consumption in Recovery

- Test programs
  - NAS Parallel Benchmarks
  - Block Tridiagonal (BT) and Scalar Pentadiagonal (SP)
  - Virtualization ratio = 4



Summary

	Jacobi3D	NPB-BT	NPB-SP
Language	Charm++	MPI	MPI
Problem size	1024^3	class C	class C
Number of cores	128	100	100
Virtualization ratio	32	4	4
Recovery parallelism	8	4	4
Message-logging overhead	1.0%	3.6%	4.1%
Max power (C)	106	102	95
Max power (M)	106	102	96
Max power (P)	106	102	96

Message-logging does NOT increase power draw

Execution Time and Energy Model

Parameter	Description	Value
V	Optimal virtualization ratio	> 8
W	Time to solution with V	25 h
M	Mean-time-to-interrupt of the system	-
S	Total number of sockets in the system	-
δ	Checkpoint time	180 s
τ	Optimum checkpoint period	-
R	Restart time	30 s
T	Total execution time	-
E	Total energy consumption	-
μ	Message-logging slowdown	1.02
P	Available parallelism during recovery	8
ϕ	Message-logging recovery speedup	1.2
σ	Parallel recovery speedup	P
λ	Parallel recovery slowdown	$\frac{P+1}{P}$
H	Max power of each socket	100 W
L	Base power of each socket	40 W

Execution Time and Energy Formulas

$$T = T_{Solve} + T_{Checkpoint} + T_{Recover} + T_{Restart}$$

$$E = E_{Solve} + E_{Checkpoint} + E_{Recover} + E_{Restart}$$

Execution Time (Parallel Recovery)

$$T = W\mu + \left(\frac{W\mu}{\tau} - 1\right)\delta + \frac{T}{M}\left(\delta + \frac{\tau - \delta}{2\sigma} + \frac{\tau + \delta}{2}(\lambda - 1)\right) + \frac{T}{M}R$$

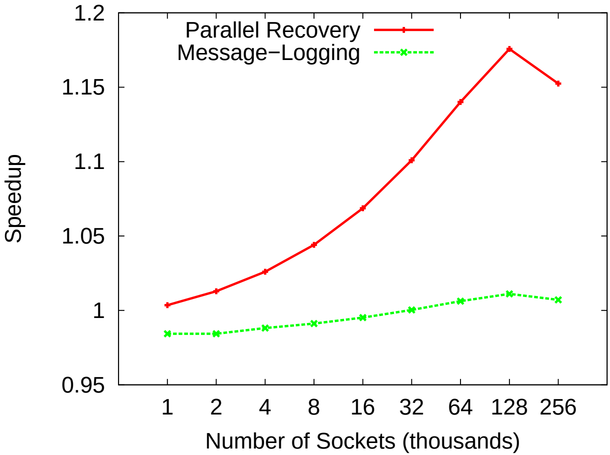
Energy (Parallel Recovery)

$$E = W\mu SH + \left(\frac{W\mu}{\tau} - 1\right)\delta SL +$$
$$\frac{T}{M}\left(\delta SL + \frac{\tau-\delta}{2\sigma}(PH + (S-P)L) + \frac{\tau+\delta}{2}(\lambda - 1)SH\right) + \frac{T}{M}RSL$$

Time-optimum τ

Energy-optimum τ

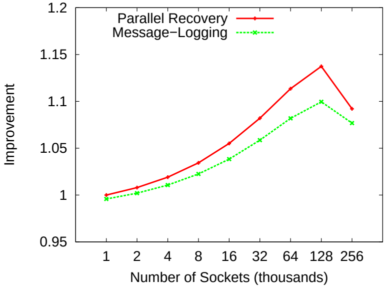
Improvement in Execution Time



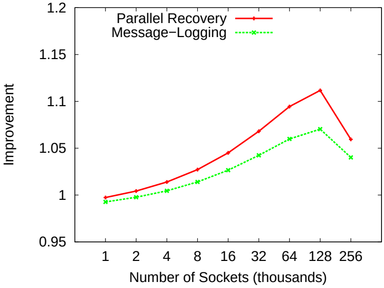
Up to 17% improvement

Improvement in Energy

Time-optimum τ



Energy-optimum τ



Up to 13% improvement

Discussion

- Trend in ratio of base to maximum power

Processor	Release Date	Max Power	Base Power	Base/Max Ratio
Intel Xeon (E5520)	Q1,09	125	60	0.48
Intel Nehalem (i7 860)	Q3,09	151	52	0.34
Intel Sandy Bridge (i7 2600)	Q1,11	101	21	0.21

- Migratability and over-decomposition in scientific applications

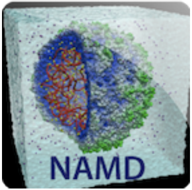
Conclusions

- *"Minimize execution time $\Longrightarrow$ minimize energy"* (not true)
  - Increase checkpoint frequency
  - Recovery is more energy-efficient with message logging
- Energy overhead of message-logging
  - It does not increase power draw
  - It increases energy consumption on the forward path
- Parallel recovery leverages message-logging
  - It provides the minimum execution time (users happy)
  - It offers the minimum energy consumed (administrators happy)
  - The model predicts 17% reduction in execution time, 13% reduction in energy consumed

Future Work

- Particle-simulation applications:

Molecular Dynamics



Quantum Chemistry

Cosmology

- Enhancements to analytical model:
  - Different failure distributions: Weibull, log-normal
  - No upper bound for checkpoint period
- Energy-aware fault tolerance protocols

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Obrigado!
Q&A

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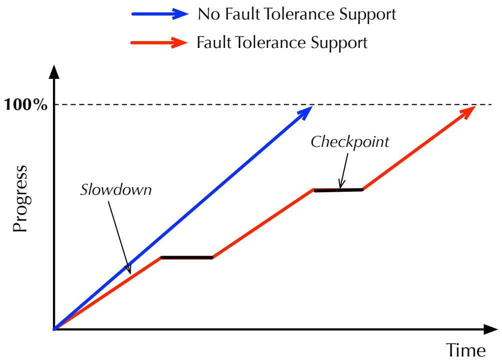
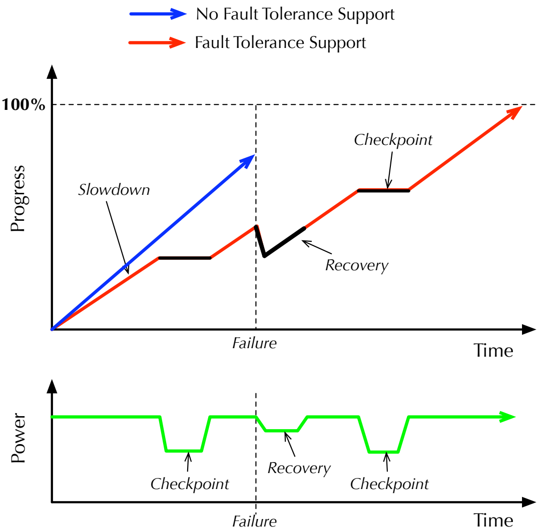
Progress Diagram

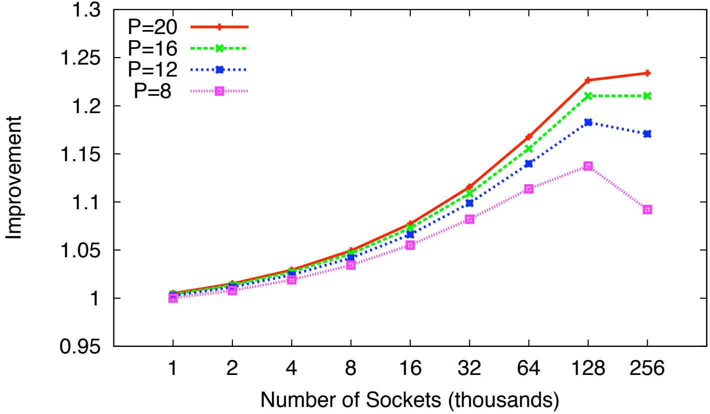


Performance Overhead

Progress Diagram for Energy Efficient Fault Tolerance



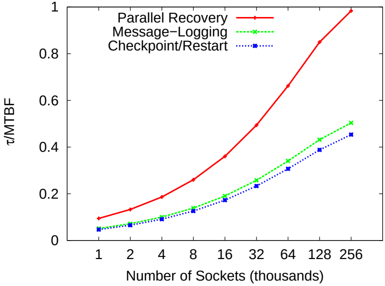
Effect of Higher Parallelism During Recovery



Optimum Checkpoint Period

- Optimum checkpoint period (τ) vs MTBF

Time-optimum τ



Energy-optimum τ