MCEM: Multi-Level Cooperative Exception Model for HPC Workflows

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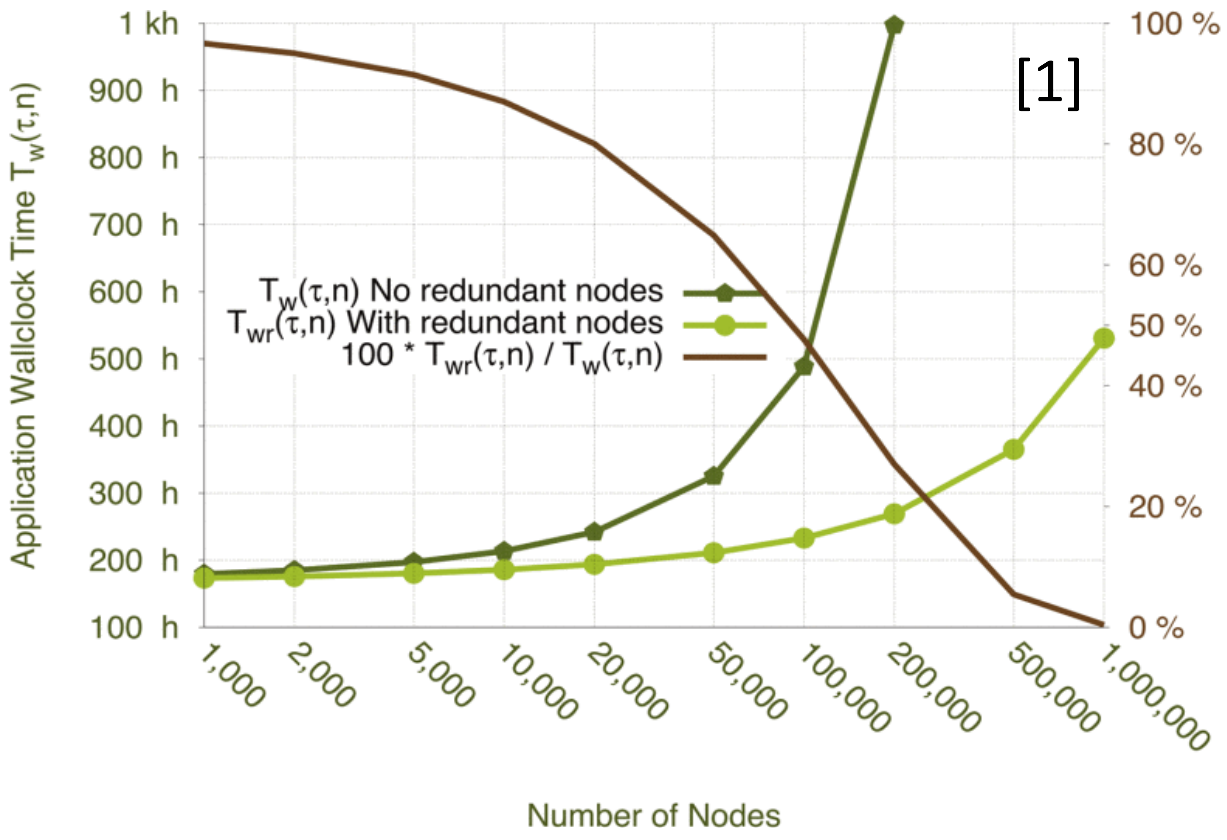
Fault-Tolerance in HPC



- The MTBF of our systems is shrinking
- The cost of checkpoint/restart is becoming prohibitively expensive
- The problem will only get worse with the inclusion of GPUs and node-local SSDs

Fault-Tolerance is becoming increasingly important

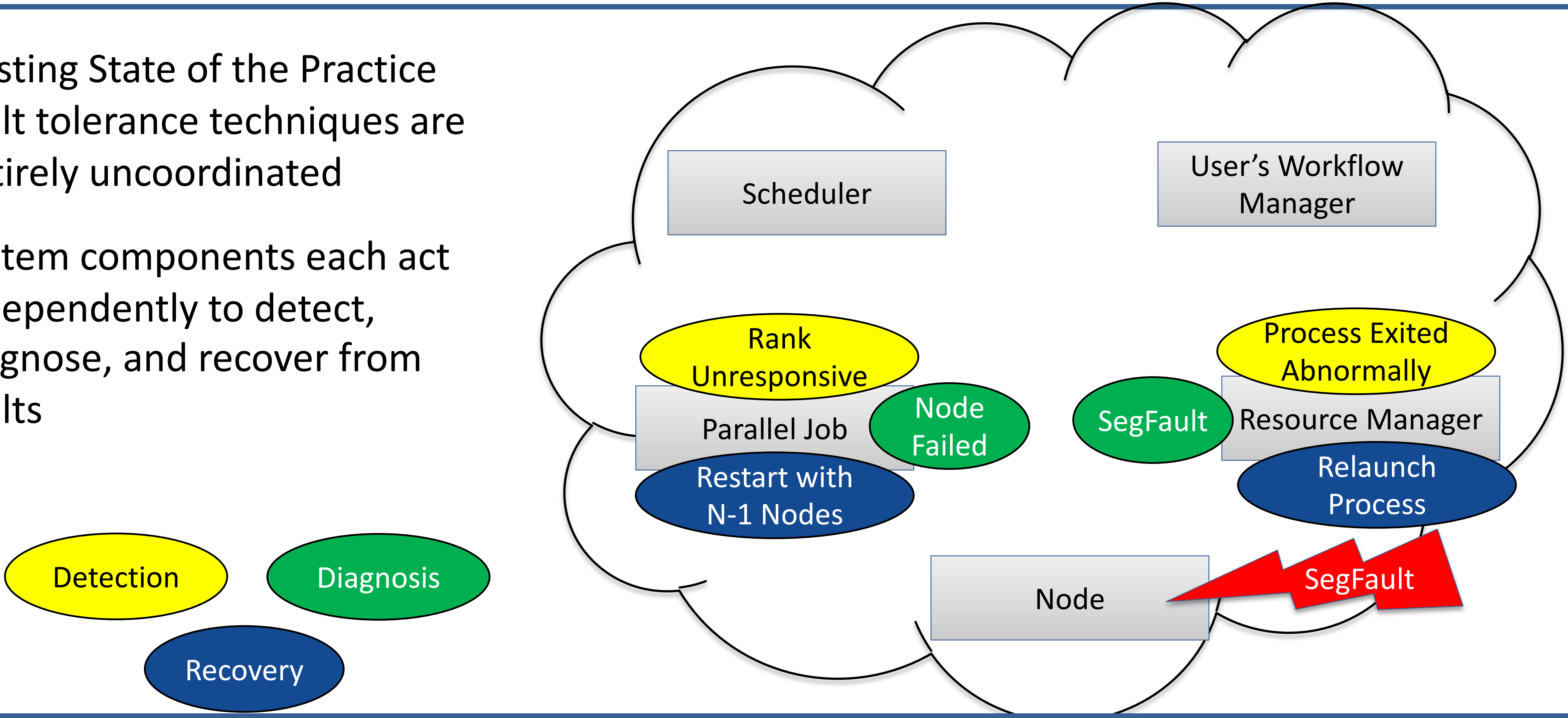
[1] R. Riesen, K. Ferreira and J. Stearley, "See applications run and throughput jump: The case for redundant computing in HPC," *2010 International Conference on Dependable Systems and Networks Workshops (DSN-W)*, Chicago, IL, 2010, pp. 29-34

Fault-Tolerance Primitives

- Detection
  - the observation of a fault, error, or degradation
- Isolation/Diagnosis
  - the identification of the root cause of the detected fault
- Recovery
  - the remediation of the fault by affected components

Fault Tolerance: State of the Practice

- Existing State of the Practice fault tolerance techniques are entirely uncoordinated
- System components each act independently to detect, diagnose, and recover from faults



Lack of coordination results in undetected faults and inefficiency

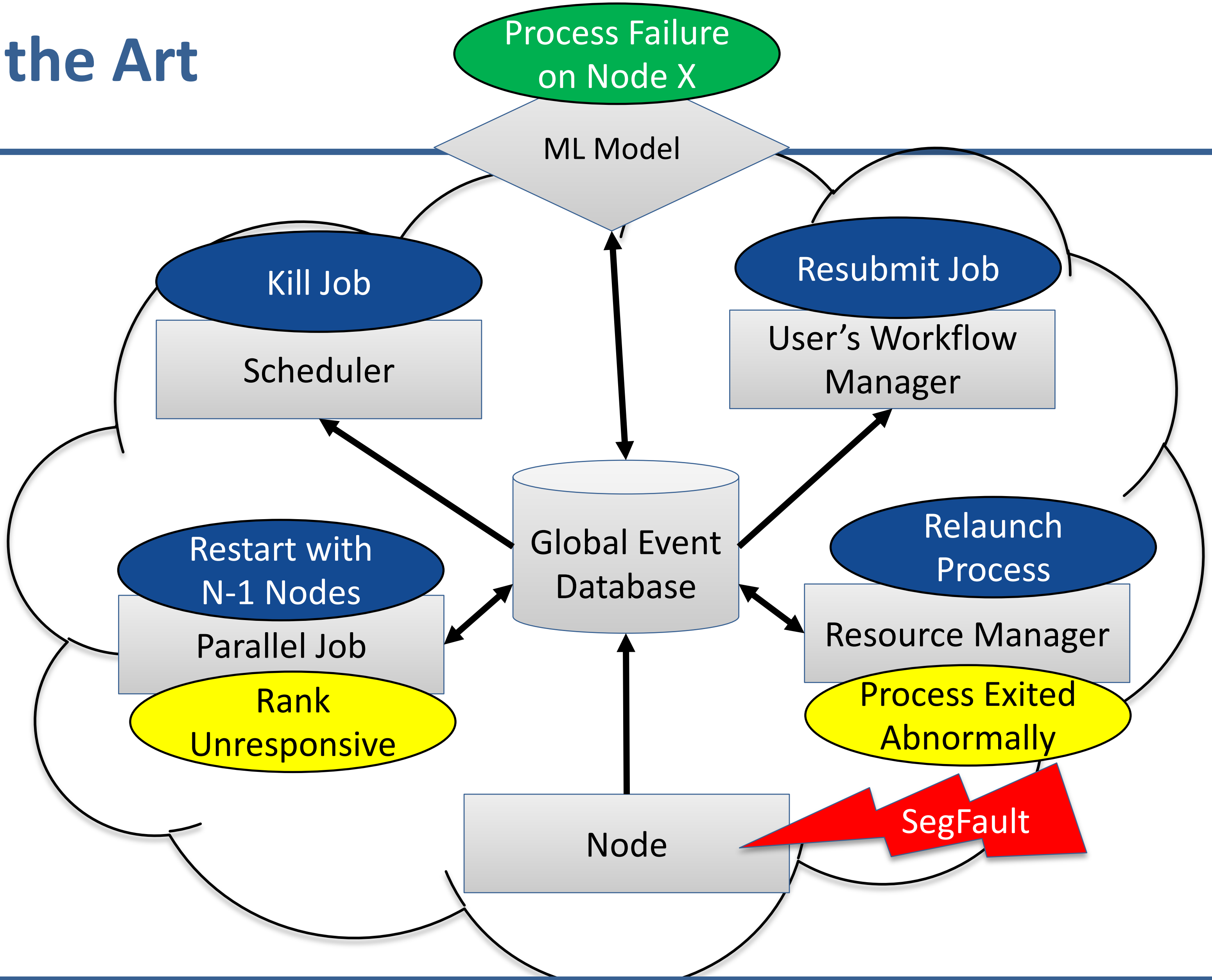
Fault Tolerance: State of the Art

- Components coordinate to detect and diagnose faults
- System components each perform their own uncoordinated recovery actions
- These actions are usually redundant and sometimes contradictory

Detection

Diagnosis

Recovery



Process Failure on Node X

ML Model

Kill Job

Scheduler

Resubmit Job

User’s Workflow Manager

Global Event Database

Restart with N-1 Nodes

Parallel Job

Rank Unresponsive

Relaunch Process

Resource Manager

Process Exited Abnormally

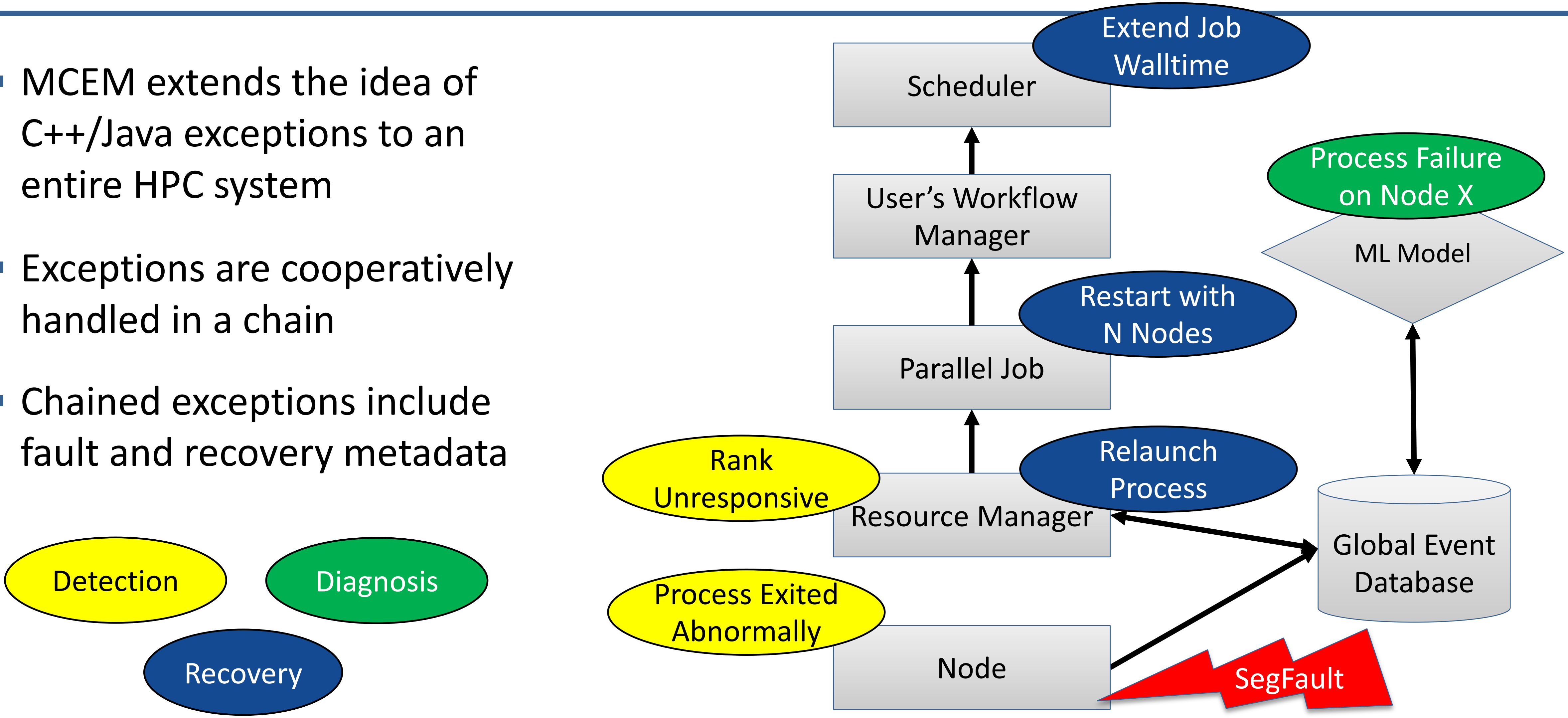
Node

SegFault

Lack of coordinated recovery results in suboptimal and redundant work

MCEM: Multi-Level Cooperative Exception Model

- MCEM extends the idea of C++/Java exceptions to an entire HPC system
- Exceptions are cooperatively handled in a chain
- Chained exceptions include fault and recovery metadata



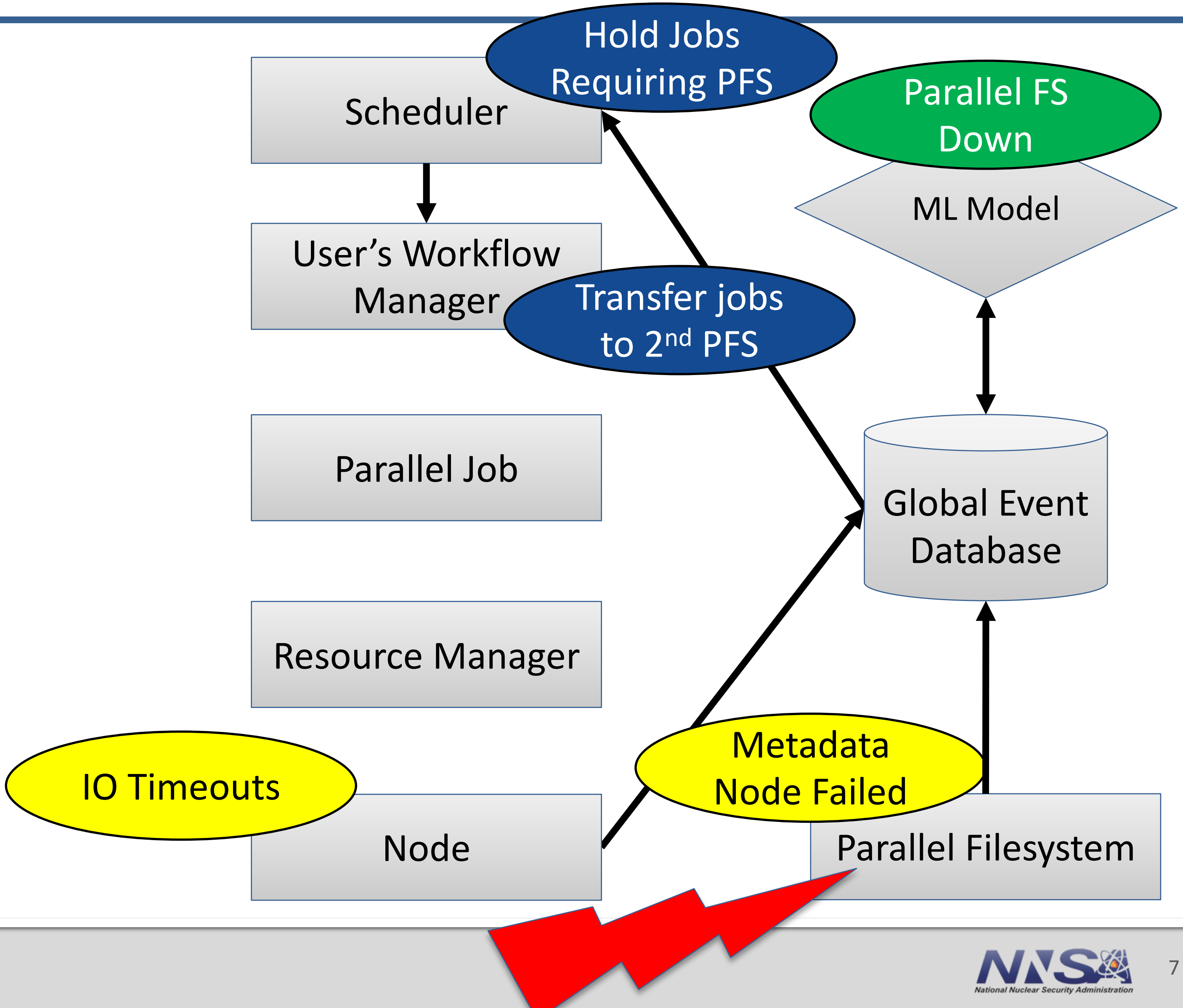
MCEM: Global Exceptions

- Propagating up works well for exceptions originating from a single, isolated resource (i.e., *local exception*)
- Reverse propagation direction for exceptions originating from a shared resource (i.e., *global exception*)

Detection

Diagnosis

Recovery



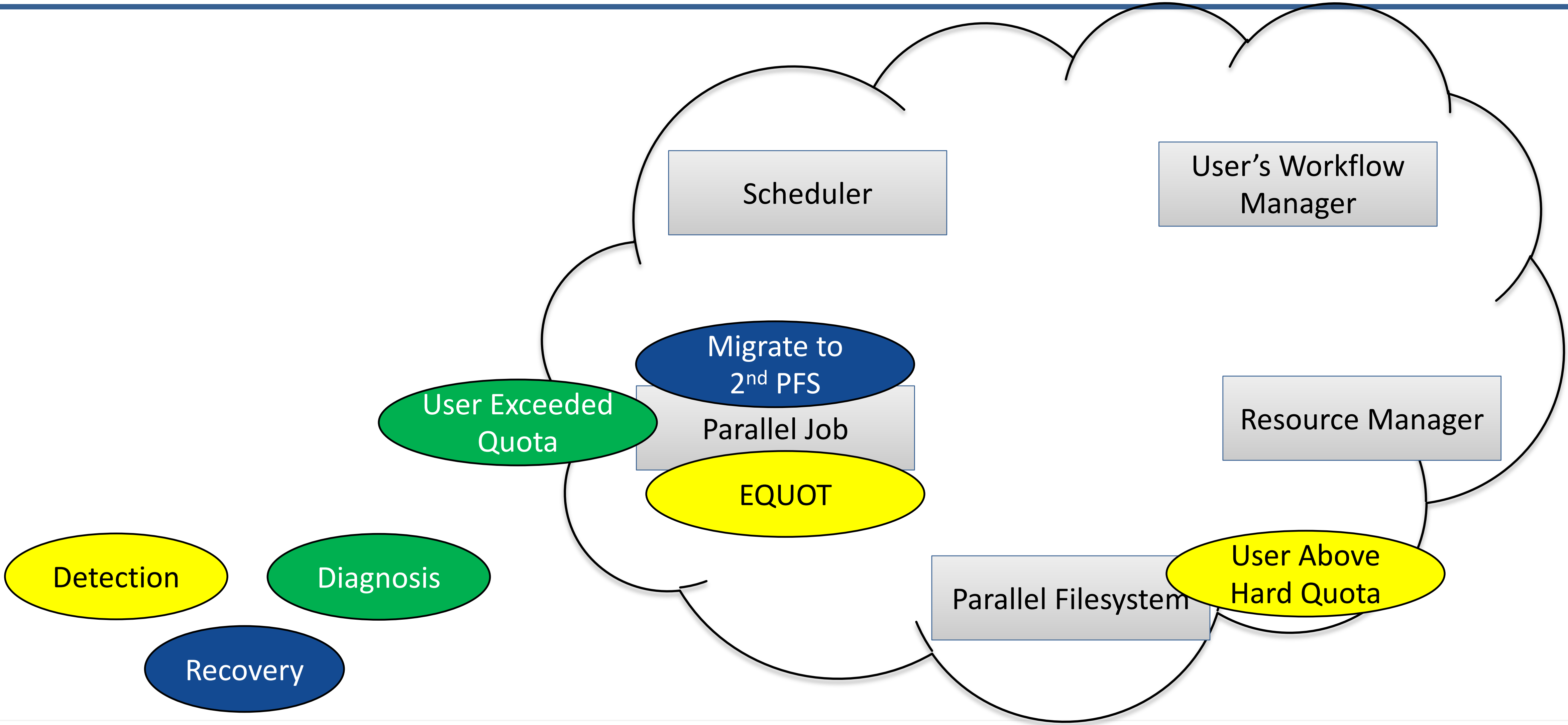
MCEM: Fault Model

- Hard faults
  - Segmentation Faults, Node Failures, Network Link Failure, PFS Down, User Exceeded Disk Quota
- Soft faults
  - Network or PFS performance degraded, User Approaching Disk Quota
- Fault length
  - Effects must last long enough to be reliably detected, isolated, and recovered from – O(minutes)

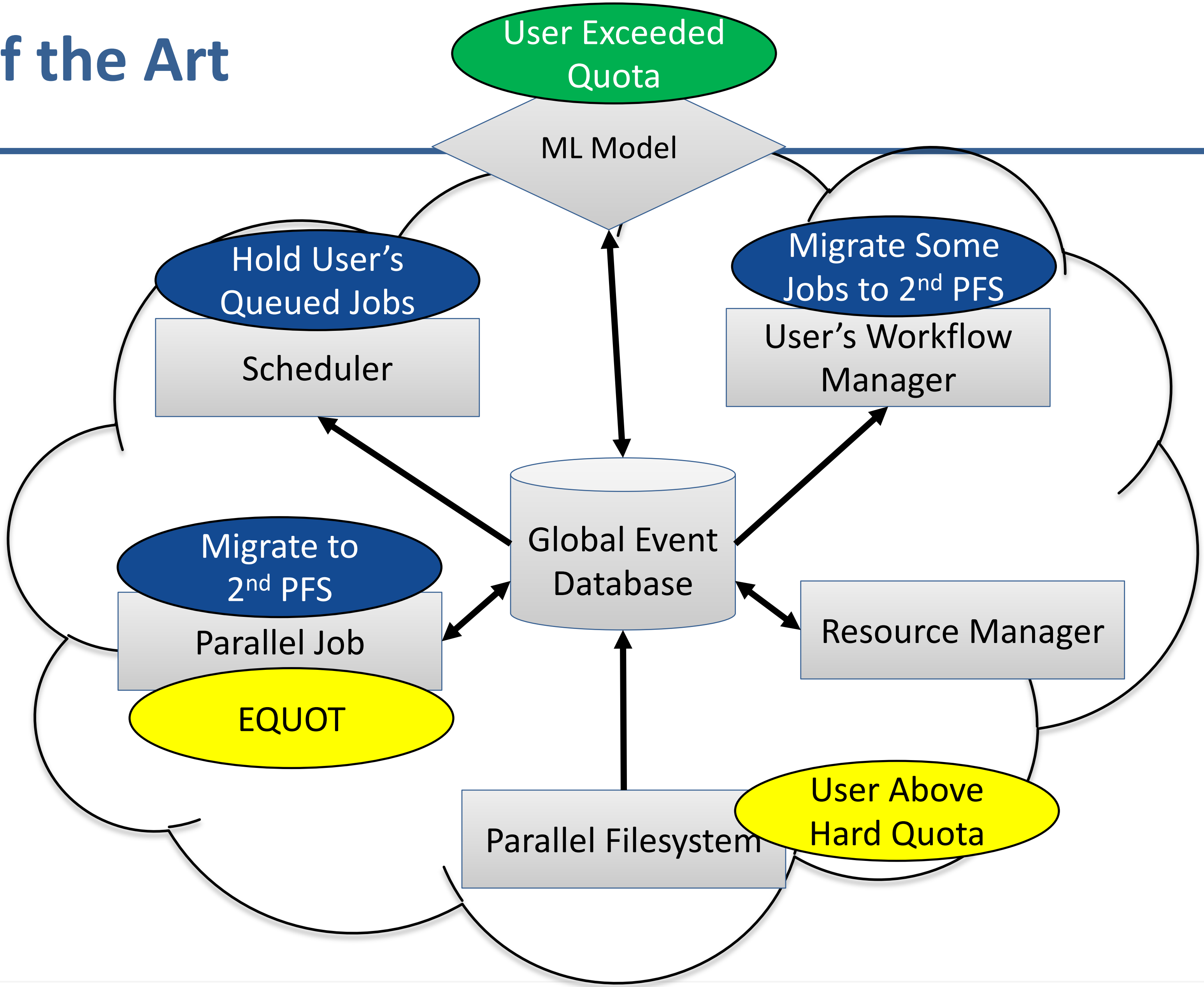
MCEM Exception Recovery Examples

Failure Type	Resource Manager	Parallel Job	Workflow Manager	Scheduler
Parallel Launcher Failure	--	--	Retry job (transient) Log system error (permanent)	--
Application Failure (i.e., mesh tangling)	--	--	Launch mesh relaxation job	--
Process Failure	Relaunch Process	Restart w/ N ranks	--	Grant job addt'l time
Node Failure	Mark node down	Restart w/ N-1 ranks OR req addt'l node	--	Grant job addt'l node
User Approaching or Exceeding Disk Quota	--	--	Migrate some/all workflow jobs to secondary filesystem	Hold queued jobs requiring PFS access

Quota Exceeded: State of the Practice



Quota Exceeded: State of the Art

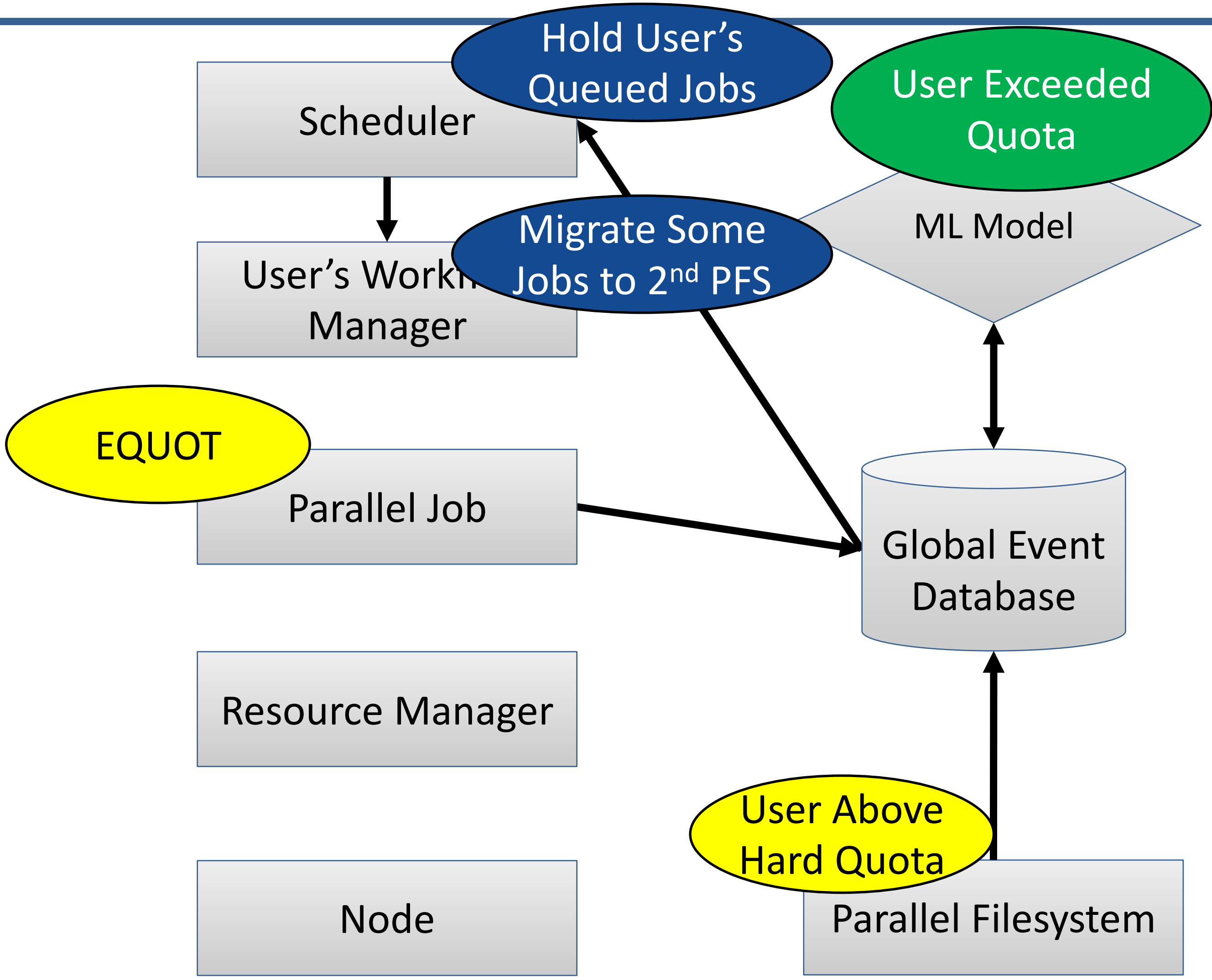


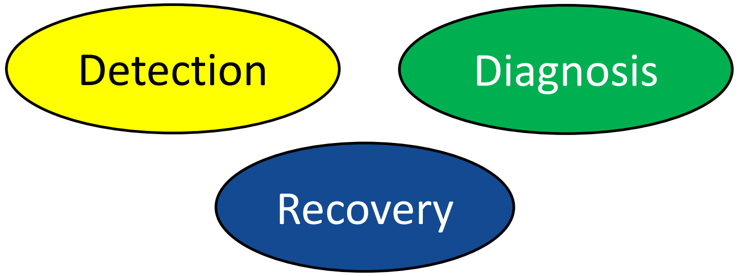
Detection

Diagnosis

Recovery

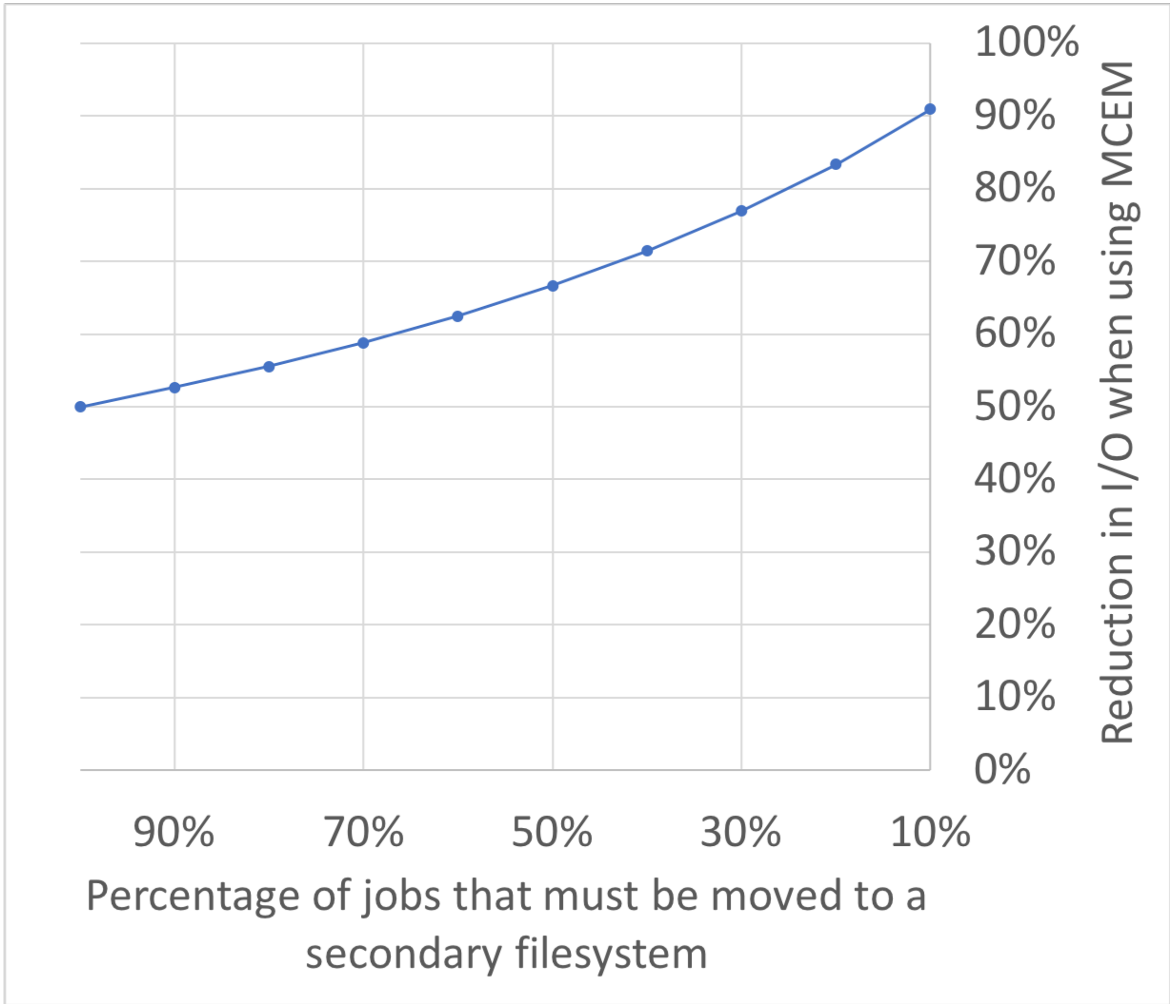
Quota Exceeded: MCEM





Evaluation

- In SOA, parallel applications all transition to 2nd filesystem, and the WFM re-transitions some/all of the jobs
- MCEM allows the WFM to only move the minimal subset of jobs exactly once



MCEM can reduce IO by up to 90%

Implementation: Resource Manager

- Why to implement within the system RM
  - Communication already implemented and fault-tolerant (hopefully)
  - Can be a plugin/module, result in less code to write and audit

- Why not to implement within the system RM
  - If the RM daemon dies, so does MCEM
  - RM failures then become potentially undetectable and certainly unrecoverable

Implementation: Runtime Interface

- Flux
  - flux job raise –severity=1 –type=“segmentation fault” $ID ’{“rank”: “262”, “pid”: 1182, “node”: ”quartz454”}’
  - flux job eventlog $ID
  - flux_event_subscribe (h, "job-exception")

- PMIx
  - PMIx_Notify_event
  - PMIx_Register_event_handler
    - Supports registering a handler for multiple events, simultaneously
    - “Multi-code” handlers always execute after “single-code” handlers
    - Supports specifying relative handler precedence within a “category”

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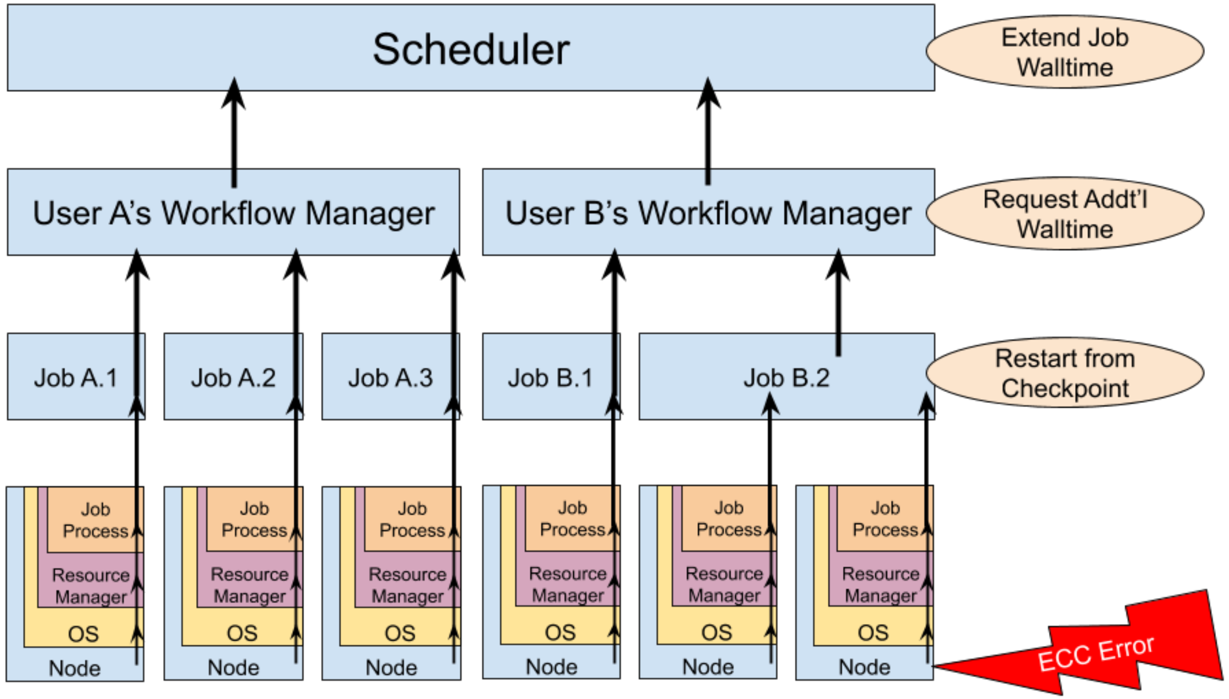
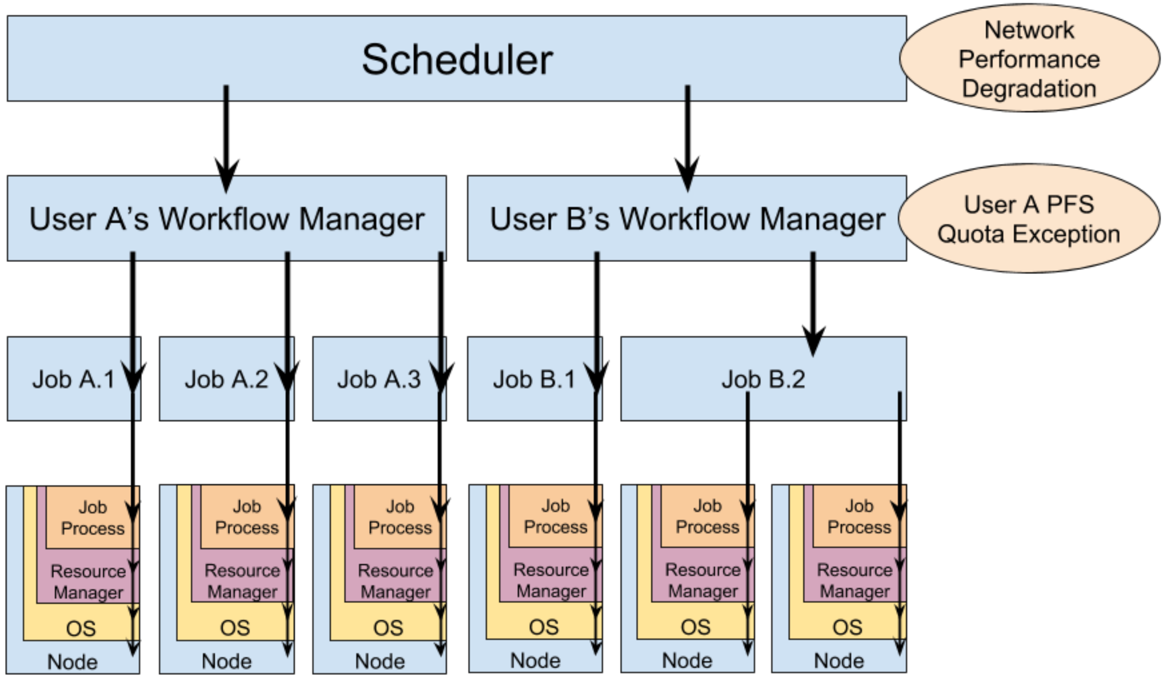
Backup Slides

MCEM’s Exception Propagation Order

Local Exceptions



Global Exceptions


Scheduler
Network Performance Degradation
User A’s Workflow Manager
User B’s Workflow Manager
User A PFS Quota Exception
Job A.1
Job A.2
Job A.3
Job B.1
Job B.2
Job Process
Resource Manager
OS
Node