PMIx: A Tutorial

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Intel

Agenda

- Day 1: Server & Scheduler
  - Overview of PMIx
  - Detailed look at Launch
- Day 2: Client, Tools, & Events – Oh My!
  - Event notification
  - PMIx Client functions
  - PMIx Tool support

Terminology

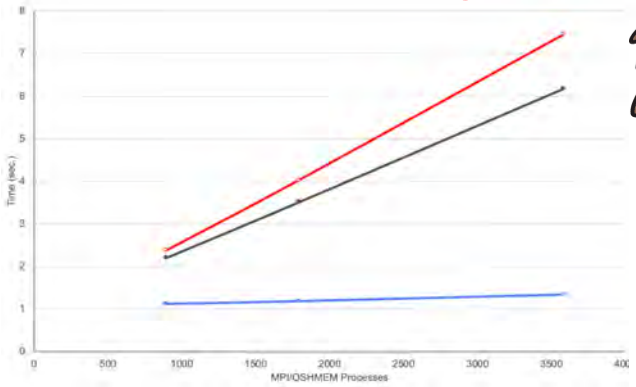
- Session
  - Allocation to a specific user
- Job
  - What was submitted to the scheduler for allocation and execution
  - Can span multiple sessions
- Task
  - Workflow to be executed within an application
  - Multiple jobs can coexist within a given session
  - In MPI terms, a “task” is synonymous with MPI_COMM_WORLD
- Application
  - One or more processes executing the same executable
  - Can be a script, typically a binary
  - A single task can be comprised of multiple apps

Day 1: Detail

- Overview
- PMIx Reference Implementation
- Server Initialization
  - Exercise
- Launch Sequence
  - Exercise

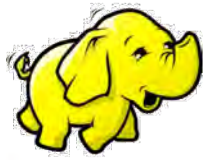
Origin: Changing Landscape

Launch time limiting scale



Programming model & runtime proliferation

Legion

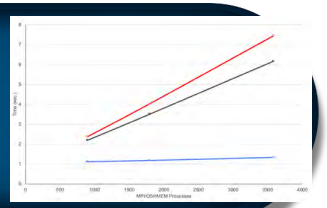


Hybrid applications

Model-specific tools

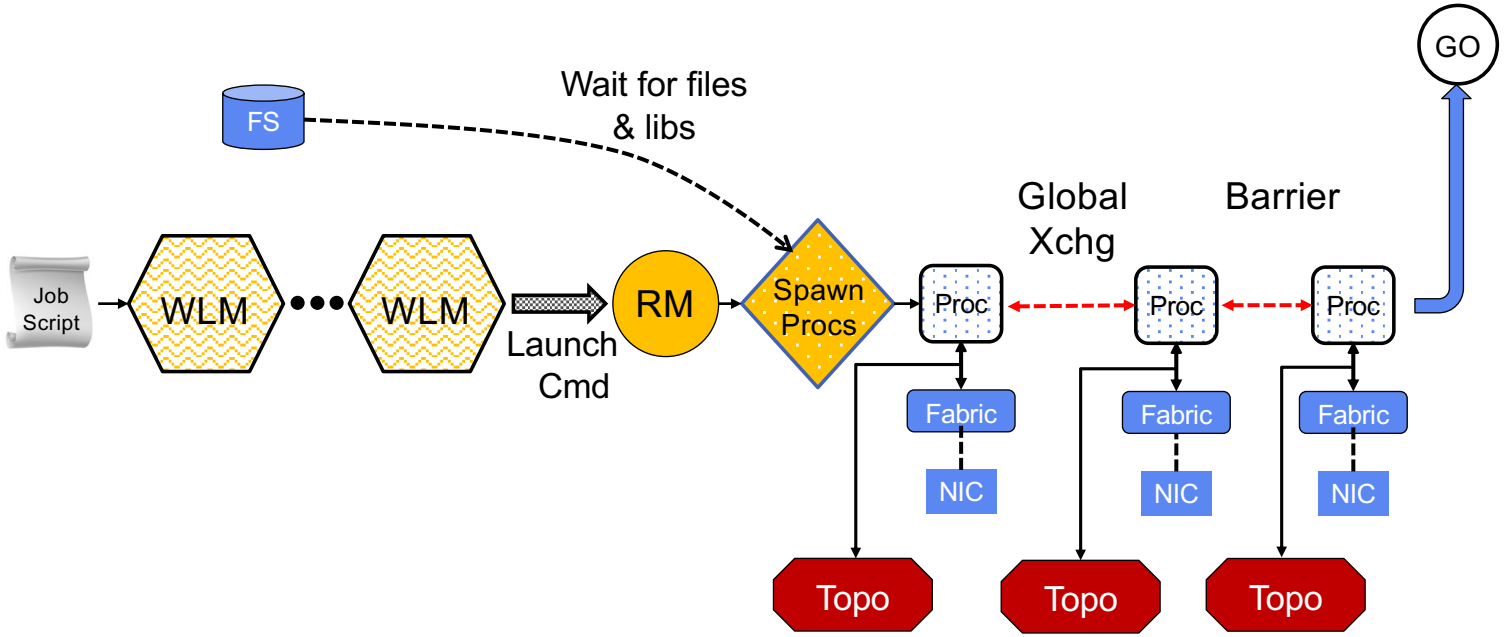
Container technologies

Start Someplace!

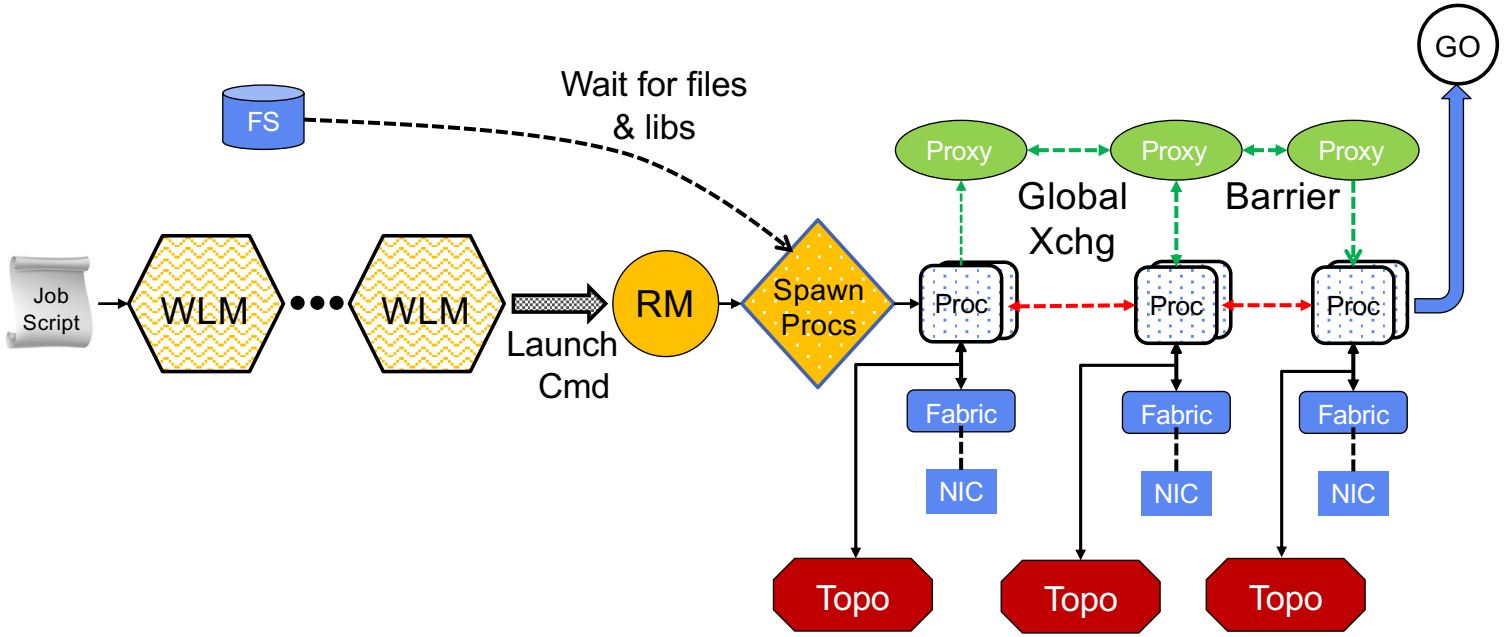


- Resolve launch scaling
  - Pre-load information known to RM/scheduler
  - Pre-assign communication endpoints
  - Eliminate data exchange during init
  - Orchestrate launch procedure

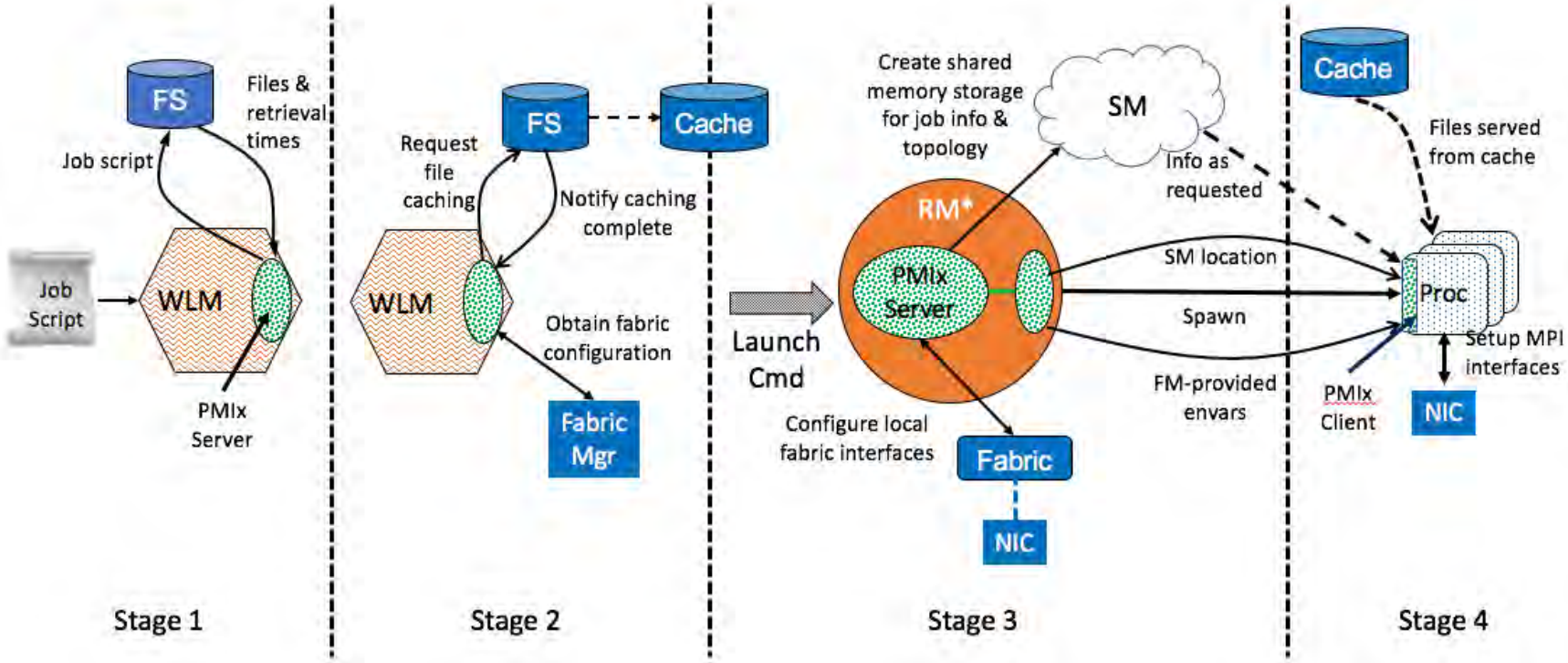
Traditional Launch Sequence



Newer Launch Sequence



PMIx Launch Sequence



*RM daemon, mpirun-daemon, etc.

Three Distinct Entities

- PMIx Standard
  - Defined set of APIs, attribute strings
  - Nothing about implementation
- PMIx Reference Library
  - A full-featured implementation of the Standard
  - Intended to ease adoption
- PMIx Reference RTE
  - Full-featured “shim” to a non-PMIx RM
  - Provides development environment

v3.1 released!

Where Is It Used?

- Libraries
  - OMPI, MPICH, Intel MPI, HPE-MPI, Spectrum MPI, Fujitsu MPI
  - OSHMEM, SOS, OpenSHMEM, …
- RMs
  - Slurm, Fujitsu, IBM's JSM, PBSPro (2019), Kubernetes(?)
  - Slurm enhancement (LANL/ECP)

- New use-cases
  - Spark, TensorFlow
  - Debuggers (TotalView, DDT)
  - MPI
    - Re-ordering for load balance (UTK/ECP)
    - Fault management (UTK)
    - On-the-fly session formation/teardown (MPIF)
  - Logging information
  - Containers
    - Singularity, Docker, Amazon

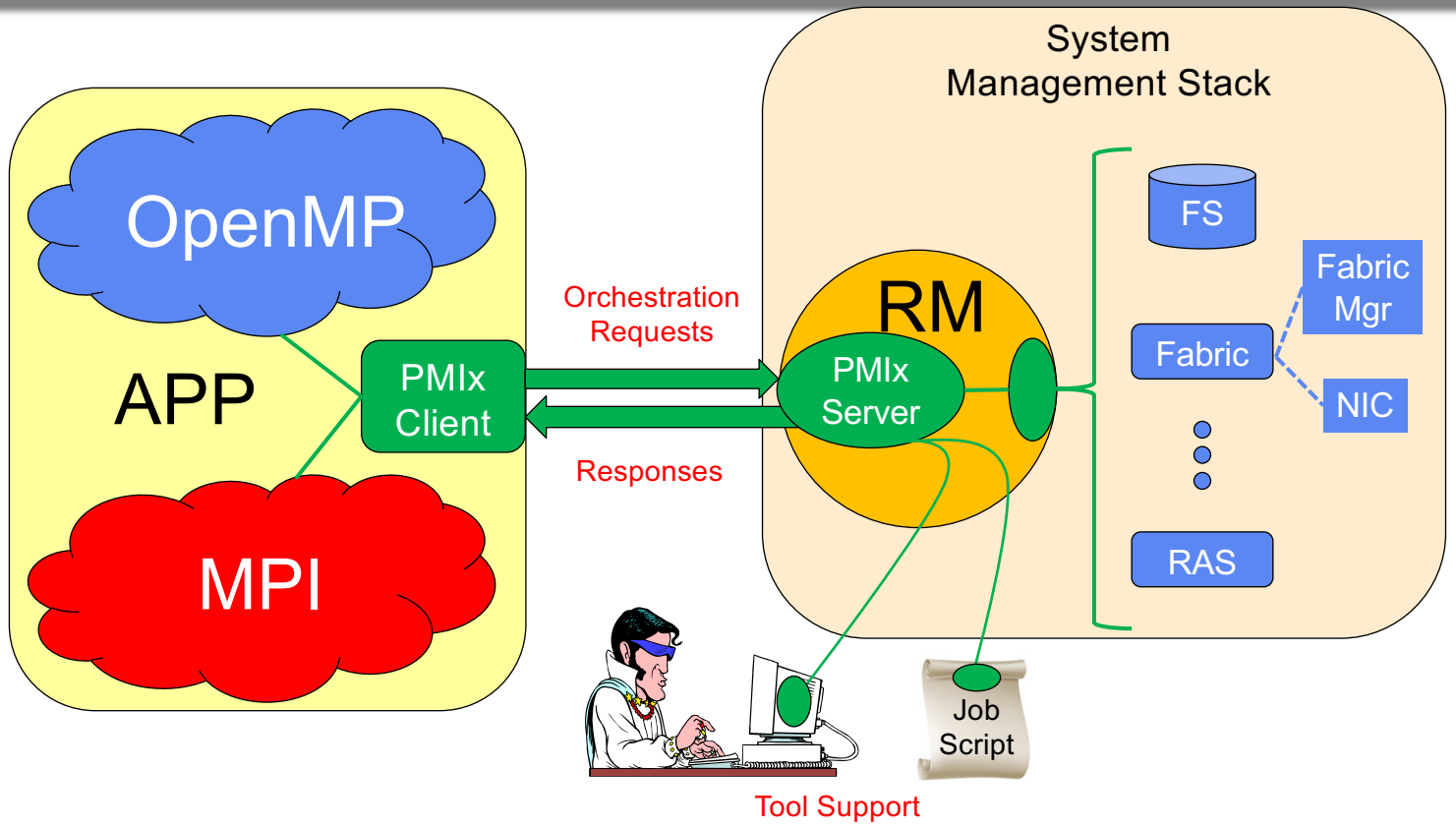
Build Upon It

- Async event notification
- Cross-model notification
  - Announce model type, characteristics
  - Coordinate resource utilization, programming blocks
- Generalized tool support
  - Co-launch daemons with job
  - Forward stdio channels
  - Query job, system info, network traffic, process counters, etc.
  - Standardized attachment, launch methods

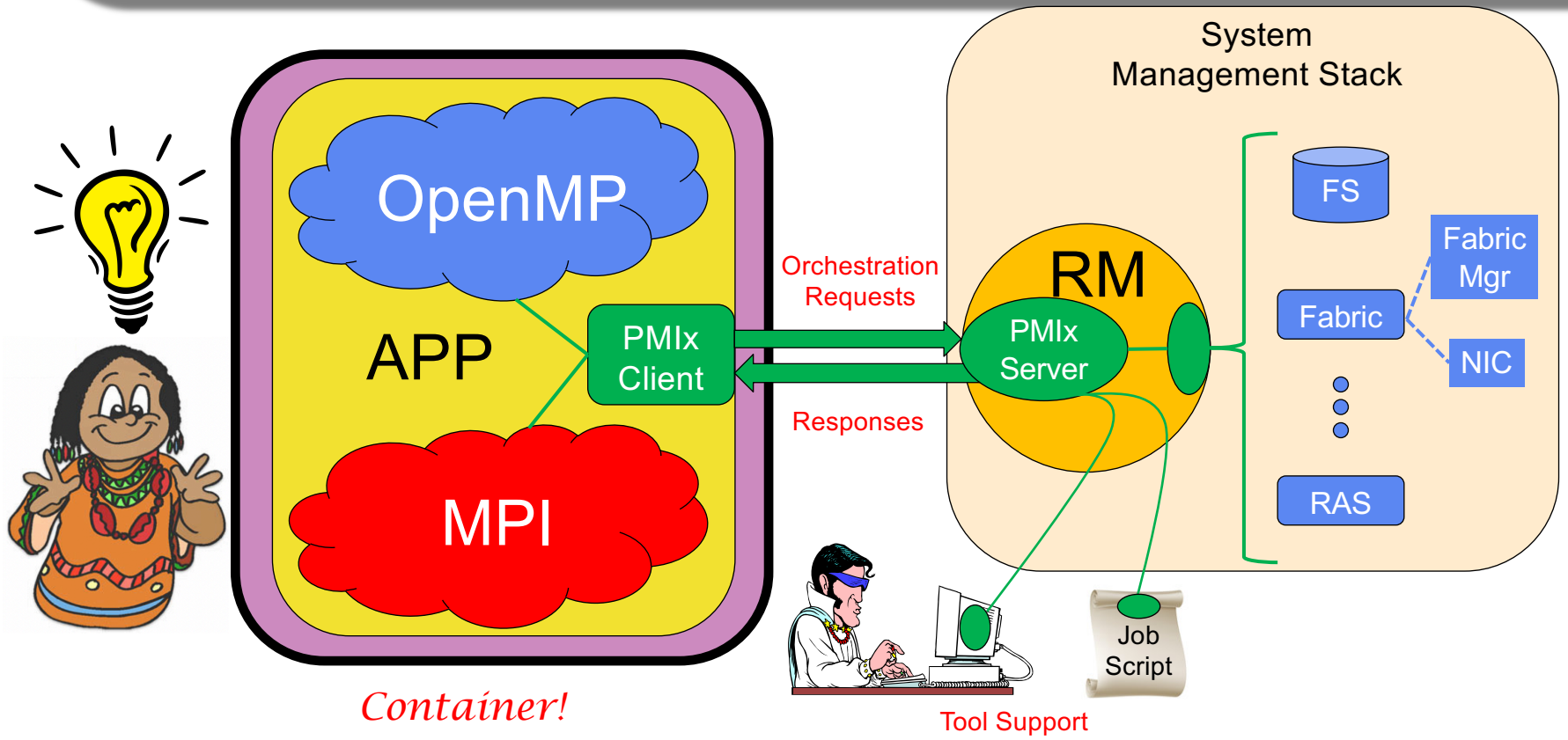
Sprinkle Some Magic Dust

- Allocation support
  - Dynamically add/remove/loan nodes
  - Register pre-emption acceptance, handshake
- Dynamic process groups
  - Async group construct/destruct
  - Notification of process departure/failure
- File system integration
  - Pre-cache files, specify storage strategies

PMIx-SMS Interactions



PMIx-SMS Interactions



Philosophy

- Generalized APIs
  - Few hard parameters
  - “Info” arrays to pass information, specify directives
- Easily extended
  - Add “keys” instead of modifying API
- Async operations
- Thread safe

Guiding Principles

- Messenger, not a Doer
  - There are some (very limited) exceptions
- No internal inter-node messaging support
  - Per RM request, all inter-node messaging provided by host environment
    - Minimizes connections and avoids yet another wireup procedure
  - Host environment required to know where things are
    - Where to send requests based on PMIx server type, info on a given proc
- “Not Supported”
  - Critical to RM adoption
  - Let the market drive support

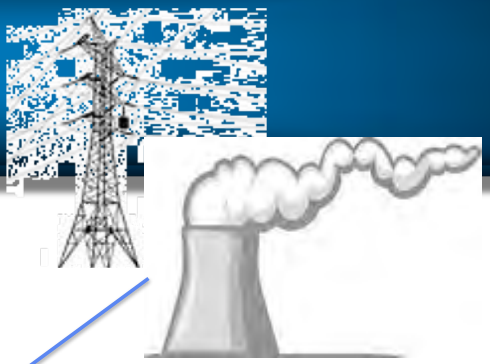
“Doer” Exceptions

- Interactions with non-PMIx systems
  - Fabric manager, credential subsystems, storage systems
- Aggregate local collective operations
  - Fence, connect/disconnect
- Environment “support”
  - Inventory collection, process monitoring, logging

PMIx Scope

- Wireup
  - Fence, put, get, commit
- Publication
  - Publish, lookup, unpublish
- Dynamics
  - Spawn, connect, disconnect, group construct/destruct
- Storage
  - Estimate retrieval times, set hot/warm/cold policy, data movement
- WLM
  - Inventory, comm costs, subsystem app resource allocations, allocation mgmt
- Fabric
  - QoS control, async updates
- Tools
  - Query, attach/detach, IO fwd
- Events (Async notification)
- Info
  - Query, logging

WLM/RTE ➡ Orchestrator



Network

File System

Prov. Agent

Monitoring

Console

DB

Day 1: Detail

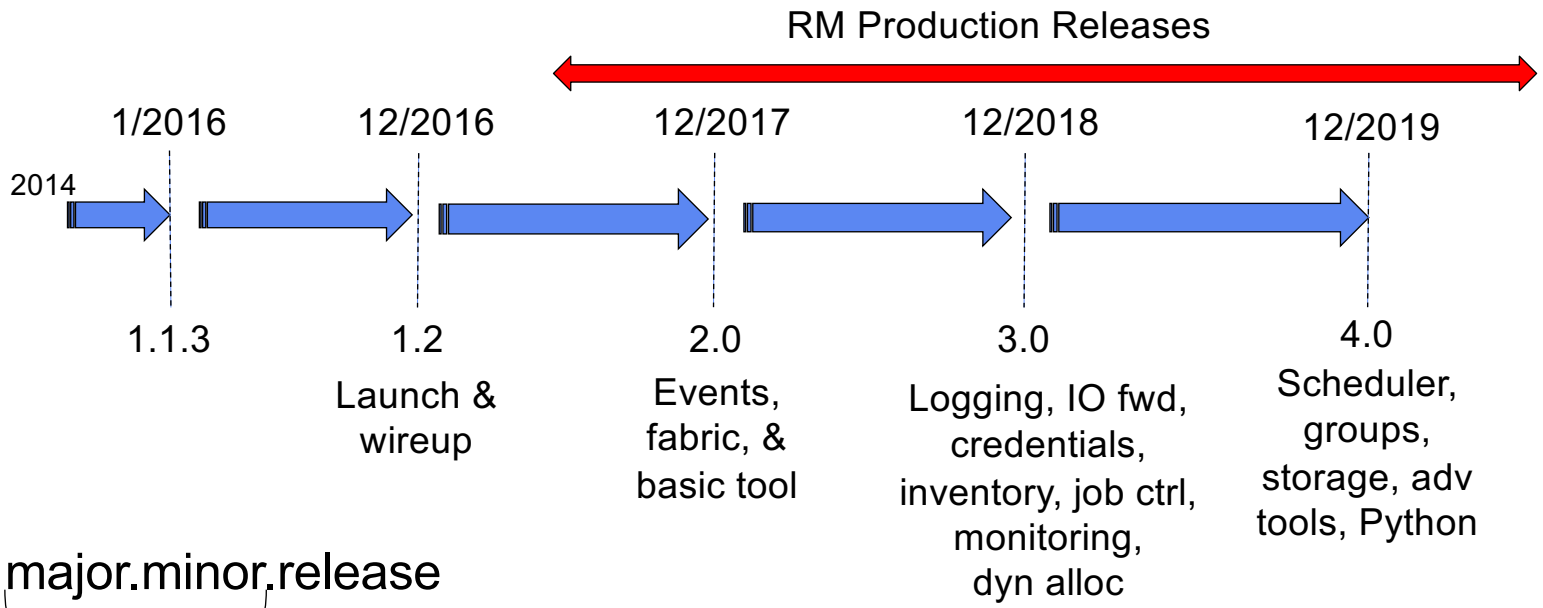
- Overview
- PMIx Reference Implementation
- Server Initialization
  - Exercise
- Launch Sequence
  - Exercise

Reference Implementation

https://github.com/pmix/pmix

- Objective
  - Ease adoption, validate proposed standard modifications/additions
- Written in C with some C++ like extensions (object classes)
- Plugin architecture
  - Internal APIs defined as “frameworks” with individual ”component” implementations
  - Components loaded as dll’s to allow for proprietary add-ons
- Python bindings
  - Utilize public PMIx APIs (not internal)
- Debugging fundamentals - Verbosity is your friend
  - Framework level spans components (e.g., ptl_base_verbose)
    - No separation between client and server
  - Functional level (pmix_iof_xxx_verbose), where xxx is either “client” or “server”

Releases

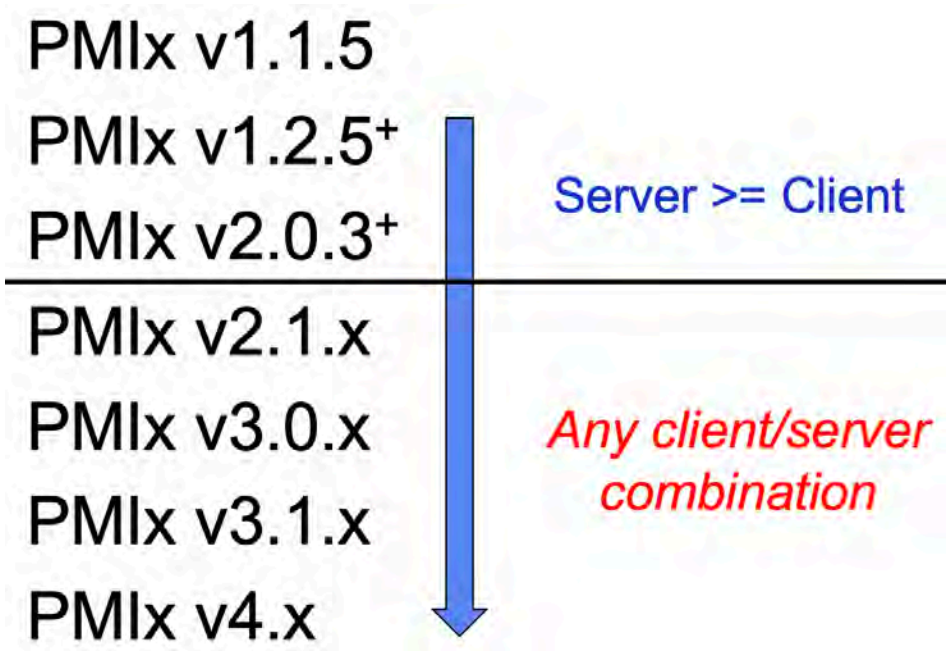


major.minor.release

Standard version

https://github.com/pmix/pmix/releases

Cross-Version Support



- Auto-negotiate messaging protocol
- Client starts
  - Envar indicates server capabilities
  - Select highest support in common
  - Convey selection in connection handshake
- Server follows client's lead
  - Per-client messaging protocol
  - Support mix of client versions

Process Types

- Client
  - Application process connected to local server
- Server
  - Client + server APIs + host function module
  - Subtypes: gateway, scheduler, default
- Tool
  - Client APIs with rendezvous
- Launcher
  - Tool + server APIs

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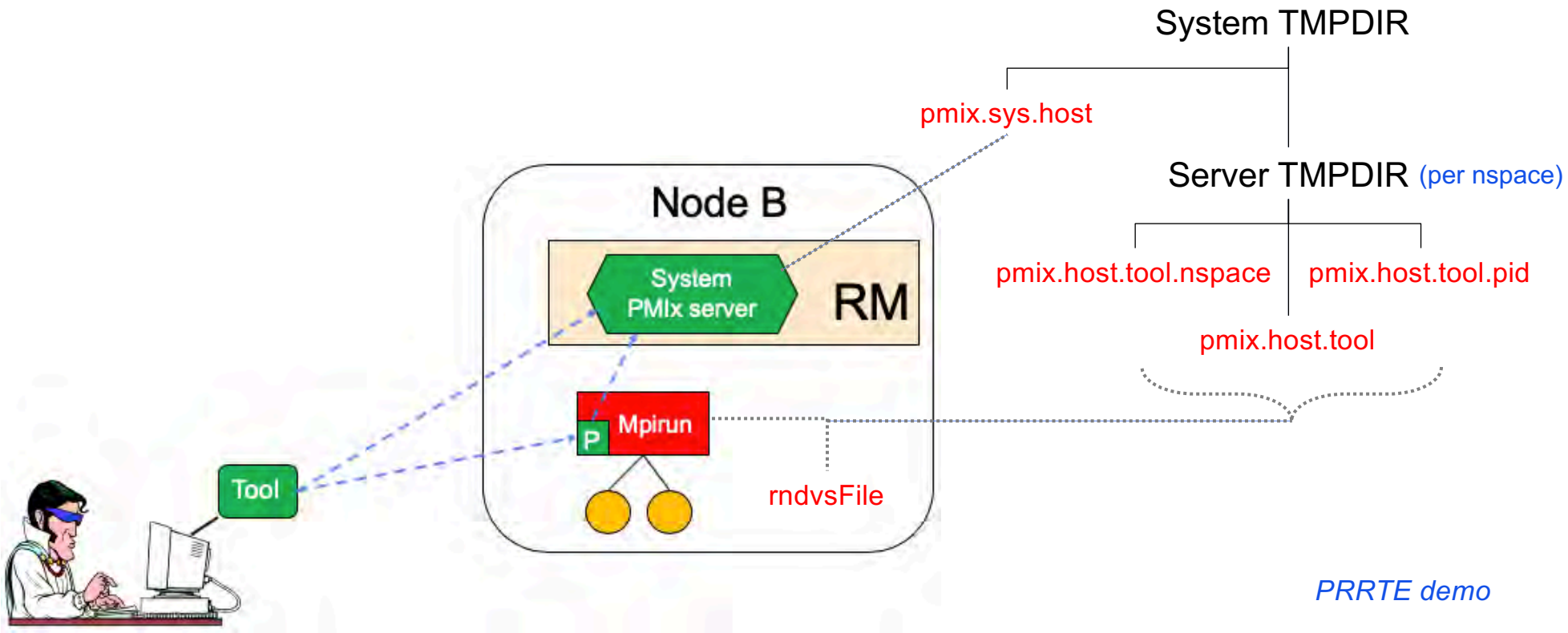
Server Initialization

- Declare server type
  - Gateway: acts as a gateway for PMIx requests that cannot be serviced on backend nodes (e.g., logging to email)
  - Scheduler: supports inventory and application resource allocations
  - Default: supports local PMIx clients and possibly tools
- Setup internal structures
- Create rendezvous file(s) for tool support
- Note: servers have access to all client, tool functions

Rendezvous File Locations



PRRTE demo

Server: Initialization Options

PMIx_server_init(pmix_server_module_t *module,
pmix_info_t info[], size_t ninfo)

- Process ID, system and server tmpdir
- Accept tool connections?
- Act as “system server” on that node?
- Server backend function module
  - Can be NULL or empty

Server Function Pointer Module

- Struct of function pointers (currently 26)
  - Provide access to host environment operations, info
  - Request support for inter-node ops
  - NULL or omitted => no support for that function
- Return rules
  - PMIX_SUCCESS: request accepted, cbfunc executed when complete
    - Cbfunc cannot be called prior to return from function
  - PMIX_OPERATION_SUCCEEDED: operation completed and successful, cbfunc will not be called
  - PMIx error code: problem with request, cbfunc will not be called

Module Functions

- Client_connected
  const pmix_proc_t *proc, void* server_object, pmix_op_cbfunc_t cbfunc, void *cbdata)
  - Client has connected to server, passing all internal security screenings
    - Matches expected uid/gid, psec plugin checks
  - Server response: indicate if connection is okay, host support ready
- Client_finalized
  const pmix_proc_t *proc, void* server_object, pmix_op_cbfunc_t cbfunc, void *cbdata)
  - Client has called PMIx_Finalize
  - Server response: allow client to leave PMIx

Module Functions

- Abort

  const pmix_proc_t *proc, void *server_object, int status, const char msg[], pmix_proc_t procs[], size_t nprocs, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Client requests that specified procs be terminated and provided status/msg be reported to user
    - NULL proc array => all members of requestor's nspace
    - Request does not automatically include requestor
- Fence_nb

  const pmix_proc_t procs[], size_t nprocs, const pmix_info_t info[], size_t ninfo, char *data, size_t ndata, pmix_modex_cbfunc_t cbfunc, void *cbdata

  - Execute inter-node barrier collecting any provided data
  - Array of participating procs indicates which nodes will participate
    - Host required to translate proc to node location
    - Forms op signature: multiple simultaneous ops allowed, only one per sig
  - Return all collected data to each participating server

Module Functions

- Direct_modex

  const pmix_proc_t *proc, const pmix_info_t info[], size_t ninfo,
  pmix_modex_cbfunc_t cbfunc, void *cbdata

  - Provide job-level data for nspace if rank=wildcard
  - Request any info “put” by the specified proc
  - Host required to:
    - Identify node where proc located
    - Pass request to PMIx server on that node
    - Return data response back to requesting PMIx server

Module Functions

- Publish
  `const pmix_proc_t *source, const pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata`
  - Publish information from source
  - Info array contains info + directives (range, persistence, etc.)
  - Duplicate keys in same range = error
- Lookup
  `const pmix_proc_t *proc, char **keys, const pmix_info_t info[], size_t ninfo, pmix_lookup_cbfunc_t cbfunc, void *cbdata`
  - Retrieve info published by publisher for provided keys (NULL -> all)
  - Info array contains directives (range)
- Unpublish
  `const pmix_proc_t *proc, char **keys, const pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata`
  - Delete data published by source for provided keys (NULL -> all)
  - Info array contains directives (range)

Module Functions

- Connect — const pmix_proc_t procs[], size_t nprocs, const pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata
  - Record specified procs as “connected”
    - Treat failure of any proc as reportable event
  - Collective operation
    - Array of procs => operation signature
    - Multiple simultaneous ops allowed, only one per signature
- Disconnect — const pmix_proc_t procs[], size_t nprocs, const pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata
  - Separate specified procs
  - Collective operation
    - Array of procs => operation signature
    - Multiple simultaneous ops allowed, only one per signature

Module Functions

- Register_events

  pmix_status_t *codes, size_t ncodes, const pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Request host provide notification of specified event codes using PMIx_Notify_event API
    - NULL => all
- Deregister_events

  pmix_status_t *codes, size_t ncodes, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Stop notifications for specified events
    - NULL => all
- Notify event

  pmix_status_t code, const pmix_proc_t *source, pmix_data_range_t range, pmix_info_t info[], size_t ninfo, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Request host notify all procs (within specified range) of given event code using PMIx_Notify_event

Module Functions

- Spawn

  const pmix_proc_t *proc, const pmix_info_t job_info[], size_t ninfo,
  const pmix_app_t apps[], size_t napps,
  pmix_spawn_cbfunc_t cbfunc, void *cbdata

  - Launch one or more applications on behalf of specified proc
  - Job-level directives apply to all apps, info provided to all procs
  - App-specific directives included in app object, info provided solely to app's procs
  - Can include allocation directivces
- Listener

  int listening_sd, pmix_connection_cbfunc_t cbfunc, void *cbdata

  - Host shall monitor provided socket for connection requests, harvest/validate them, and call cbfunc for PMIx server to init client setup

Module Functions

- Query

  pmix_proc_t *proct, pmix_query_t *queries, size_t nqueries,
  pmix_info_cbfunc_t cbfunc, void *cbdata

  - Request information from the host environment (e.g., queue status, active nspaces, proc table, time remaining in allocation)
- Tool_connected

  pmix_info_t *info, size_t ninfo,
  pmix_tool_connection_cbfunc_t cbfunc, void *cbdata

  - Tool has requested connection to server
    - Info contains uid/gid of tool plus optional service requests
  - Host can validate request, return proc ID for tool

Module Functions

- Log

  const pmix_proc_t *client, const pmix_info_t data[], size_t ndata,
  const pmix_info_t directives[], size_t ndirs, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Push the specified data to a persistent datastore or channel per directives
    - Syslog, email, text, system job log
- Allocate

  const pmix_proc_t *client, pmix_alloc_directive_t directive,
  const pmix_info_t data[], size_t ndata,
  pmix_info_cbfunc_t cbfunc, void *cbdata

  - Request modification to existing allocation
    - Extension (both time and resource), resource release, resource “lend”/”callback”
  - Request new allocation

Module Functions

- Job_control
  const pmix_proc_t *requestor, const pmix_proc_t targets[], size_t ntargets,
  const pmix_info_t directives[], size_t ndirs, pmix_info_cbfunc_t cbfunc, void *cbdata
  - Signal specified procs (pause, resume, kill, terminate, etc.)
  - Register files/directories for cleanup upon termination
  - Provision specified nodes with given image
  - Direct checkpoint of specified procs
- Monitor
  const pmix_proc_t *requestor, const pmix_info_t *monitor, pmix_status_t error,
  const pmix_info_t directives[], size_t ndirs, pmix_info_cbfunc_t cbfunc, void *cbdata
  - Monitor this process for ”signs of life”
    - File (size, access, modify), heartbeat, etc.
  - Failures reported as PMIx events

Module Functions

- Get_credential

  const pmix_proc_t *proc, const pmix_info_t directives[], size_t ndirs, pmix_credential_cbfunc_t cbfunc, void *cbdata

  - Request a credential
- Validate_credential

  const pmix_proc_t *proc, const pmix_byte_object_t *cred, const pmix_info_t directives[], size_t ndirs, pmix_validation_cbfunc_t cbfunc, void *cbdata

  - Validate a credential
- Group

  pmix_group_operation_t op, char grp[], const pmix_proc_t procs[], size_t nprocs, const pmix_info_t directives[], size_t ndirs, pmix_info_cbfunc_t cbfunc, void *cbdata

  - Perform a barrier op across specified procs
  - Perform any host tracking/cleanup operations
  - Return result of any special requests in directives
    - Assign unique context ID to group

Module Functions

- IOF_pull

  const pmix_proc_t procs[], size_t nprocs, const pmix_info_t directives[], size_t ndirs, pmix_iof_channel_t channels, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Request the specified IO channels be forwarded from the given array of procs to this server for local distribution
  - Stdin is *not* supported in this call

- Push_stdin

  const pmix_proc_t *source, const pmix_proc_t targets[], size_t ntargets, const pmix_info_t directives[], size_t ndirs, const pmix_byte_object_t *bo, pmix_op_cbfunc_t cbfunc, void *cbdata

  - Request the host transmit and deliver the provided data to stdin of the specified targets
    - Wildcard rank => all procs in that nspace
  - Source identifies the process whose stdin is being forwarded

Exercise 1: Create a Server

- Python or C – your choice
- Initialize a server
  - Start with an empty server module
  - Specify a “safe” tmpdir location
  - Indicate it should be a “system” server
- Have it hang around
- Use “pattrs” to find out what it supports
- Add job_control function to server module
  - Have it cause your server to exit
  - Use PRRTE’s ”prun --terminate” to trigger it

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Stage 0: Inventory Collection

- Objective
  - Gather a complete picture of all relevant hardware in the system
    - Utilizes HWLOC to obtain information
  - Allow each plugin to extract what is relevant to it
    - Fabric – NICs/HFIs plus distance matrix; topology, connectivity, and per-plane communication costs
    - Memory – available memory and hierarchy
- Two collection modes

Relevant Functions

- PMIx_server_collect_inventory

  pmix_info_t directives[], size_t ndirs,
  pmix_info_cbfunc_t cbfunc, void *cbdata

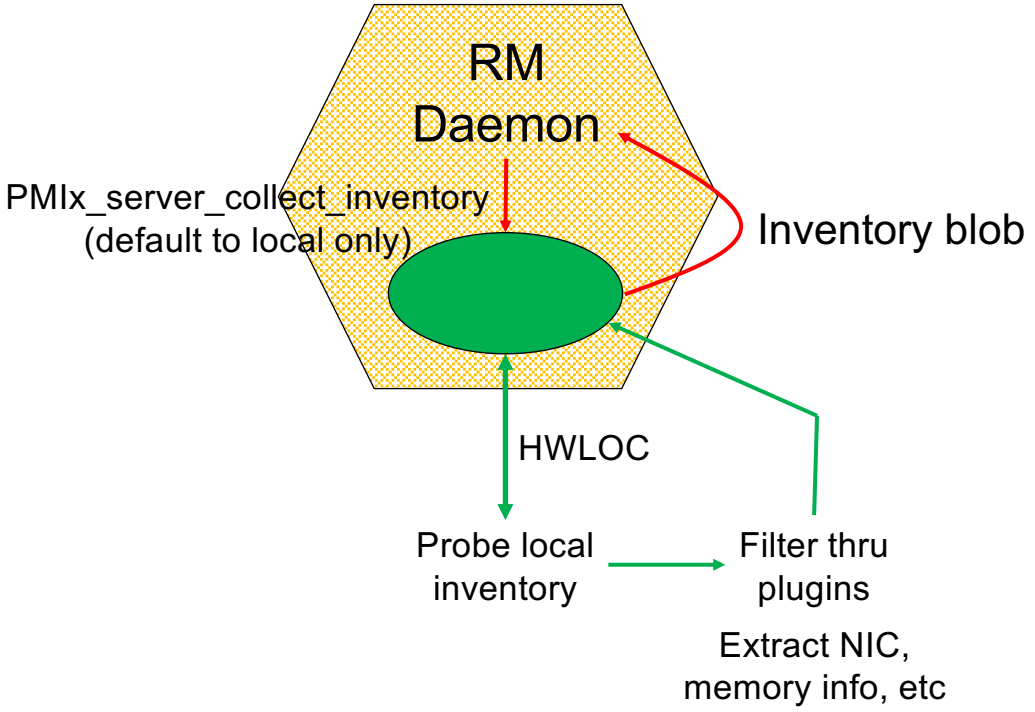
  - Collect inventory of local resources
  - Pass opaque blob back to host for transmission to WLM-based server
  - Info keys can specify types/level of detail of inventory to collect

- PMIx_server_deliver_inventory

  pmix_info_t info[], size_t ninfo,
  pmix_info_t directives[], size_t ndirs,
  pmix_op_cbfunc_t cbfunc, void *cbdata

  - Pass inventory blobs into PMIx server library for processing
  - Construct internal resource trackers

Mode 1: Rollup



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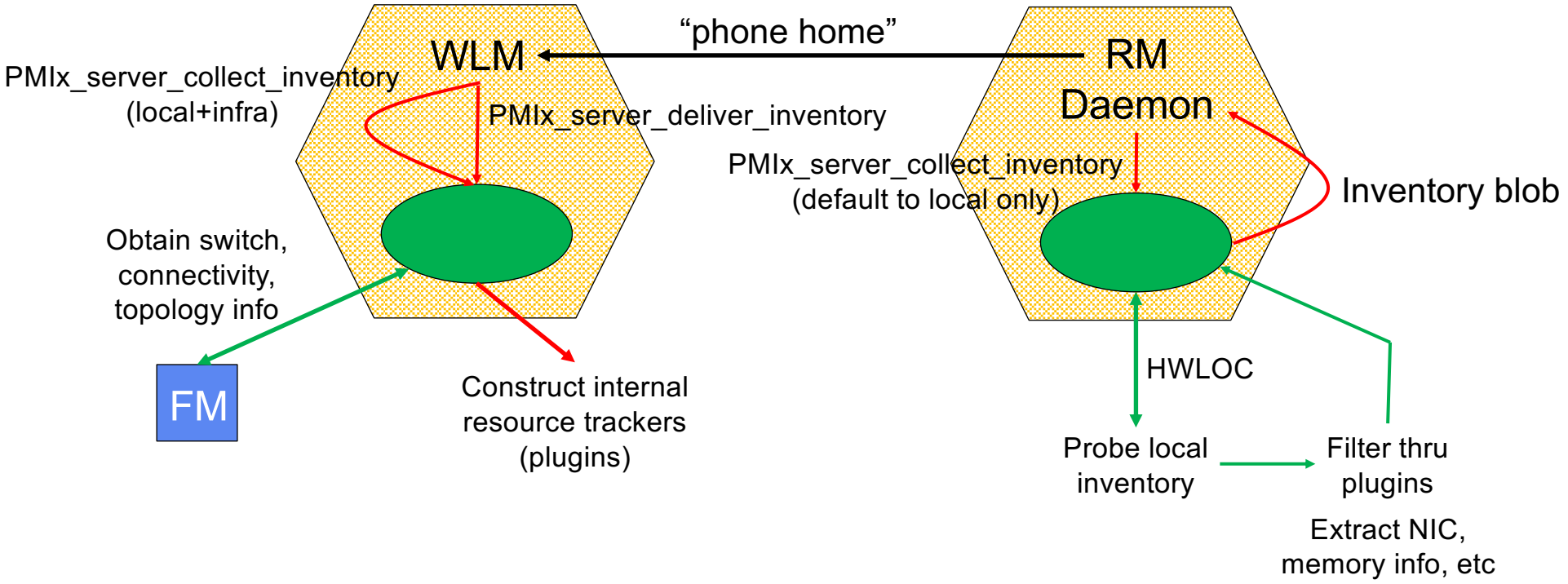
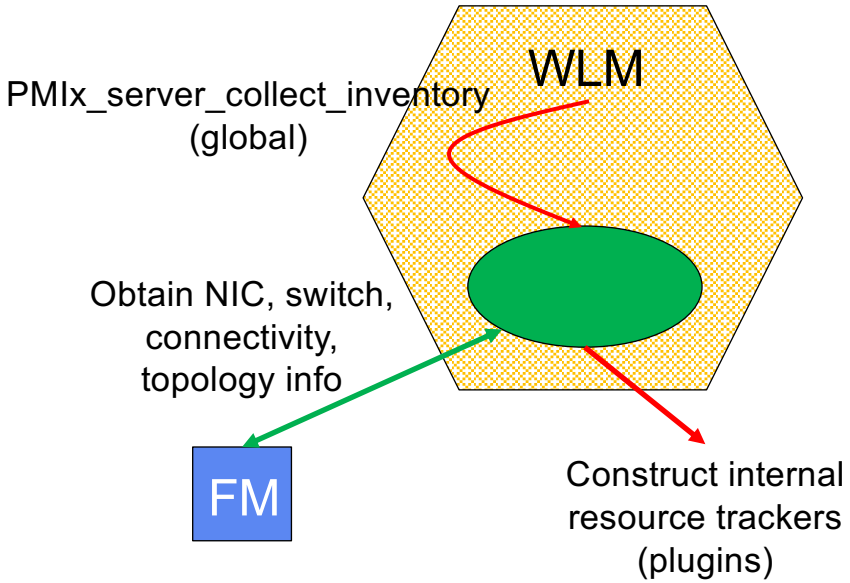


Mode 2: Central

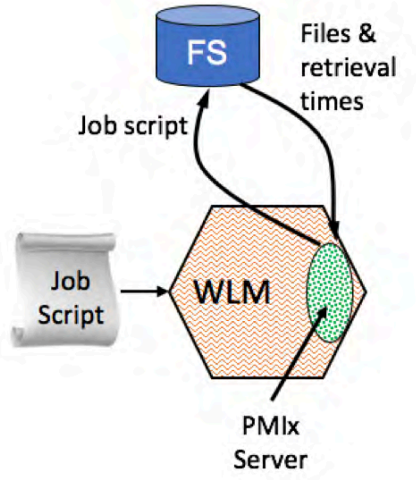


Only collects inventory accessible via centralized source (e.g., FM)

Option: WLM can request remote daemons respond with their local inventory

Stage 1: Scheduling

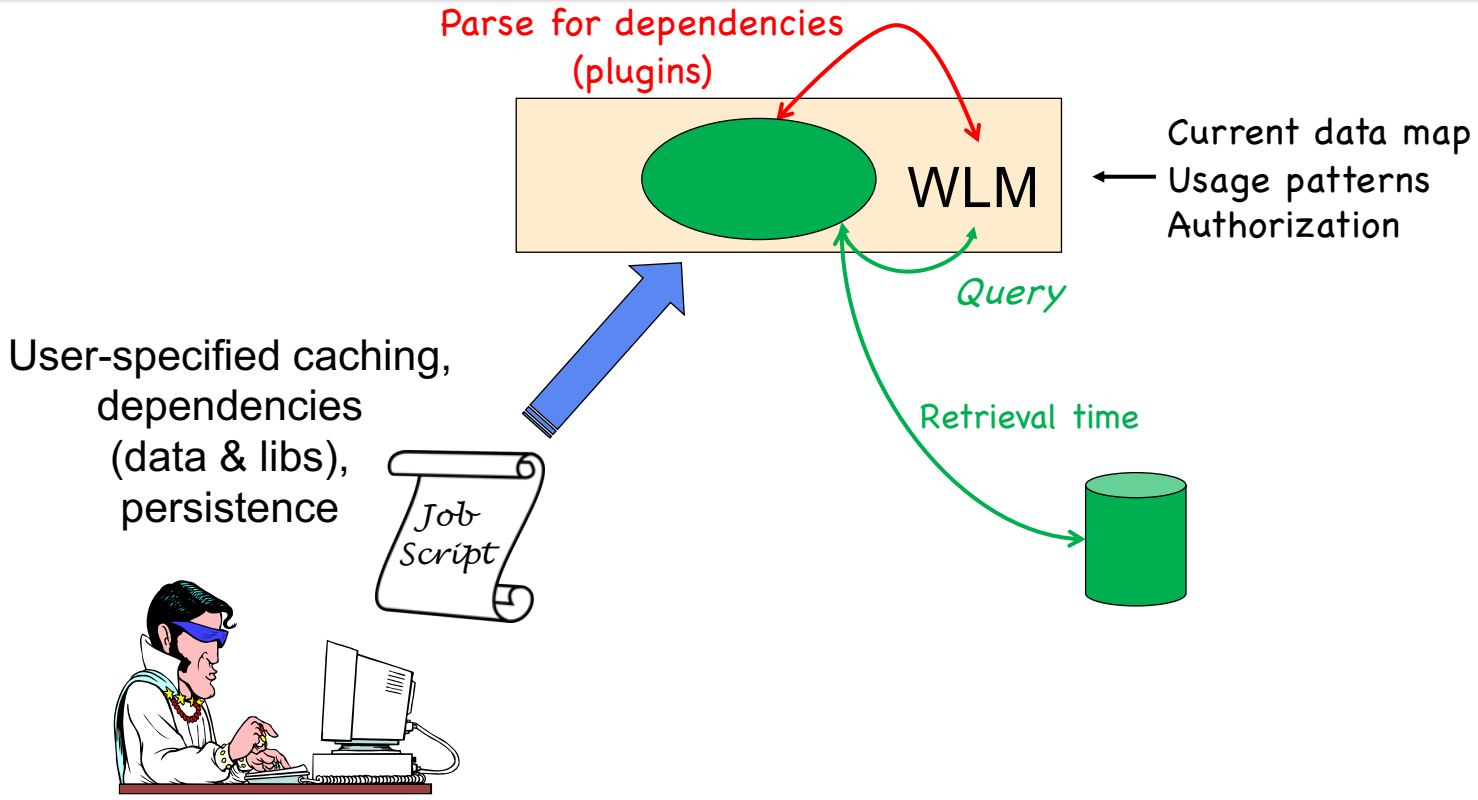
- Storage timing
  - Identify dependencies
  - Estimate caching/retrieval times
- Fabric considerations
  - Access relative communication costs
    - Asynchronously updated by FM events
  - Capabilities of each plane
    - Map user requests vs available planes



Baseline Storage Vision

- Tiered storage
  - Parallel file system
  - Caches at IO server, switches, cabinets, …
  - Caches hold images, files, executables, libraries, checkpoints
- Bits flow in all directions
  - Stage locations prior to launch
  - Movement in response to faults, dynamic workflow, computational stages

Estimate Retrieval Times



Relevant Storage Functions

(signatures TBD)

- Dependencies
  - Support multiple methods via plugins
  - Typical ldd-like checks, others are active area of research
- Accessibility
  - List of files and uid/gid or credential, return accessibility status for each file
  - Include temperature/location (e.g., hot/cached, warm/on disk), other metadata
- Scheduling data
  - Time/cost to move specified files to given target locations (nodes, caches, temp)
- Info queries
  - Available storage, unit of reservation (block size)
  - Storage strategies (striping patterns)
  - Capabilities (QoS levels, bandwidth, topology, co-located processes)

Relevant Fabric Functions

- PMIx_server_register_fabric
  pmix_fabric_t *fabric,
  const pmix_info_t directives[], size_t ndirs
  - Obtain a handle to a specific fabric plane
  - Can specify plane by characteristics or name
    - Obtain available names via PMIx_Query
- Pmix_server_deregister_fabric
  pmix_fabric_t *fabric
  - Release the fabric handle
- Terminology
  - Vertex: NIC or switch interface, can include metadata
  - Index: column or row in the cost matrix

Correspondence changes as interfaces fail, go offline, return as entire cost matrix is updated by FM!

Dealing With Updates

- Fabric plane handle tracks revision
- Matrix updates
  - Occur in thread-safe event
  - Increment matrix revision
- Functions that access cost data
  - Execute in thread-safe event
  - Check handle version against matrix version
  - Return PMIX_FABRIC_UPDATED if mismatch
- PMIx_server_update_fabric pmix_fabric_t *fabric
  - Syncs version level of handle to matrix

Relevant Fabric Functions

- PMIx_server_get_num_vertices pmix_fabric_t *fabric, uint32_t *nverts
  - Get number of vertices in the provided fabric plane
- PMIx_server_get_comm_cost pmix_fabric_t *fabric, uint32_t src, uint32_t dest, uint16_t *cost
  - Obtain relative communication cost for sending message from src to dest across provided plane
- PMIx_server_get_vertex_info pmix_fabric_t *fabric, uint32_t i, pmix_value_t *vertex, char **nodename
  - Given index, get interface metadata and name of node/switch hosting it
- PMIx_server_get_index pmix_fabric_t *fabric, pmix_value_t *vertex, uint32_t *i, char **nodename
  - Given vertex, get matrix index and name of node/switch hosting it

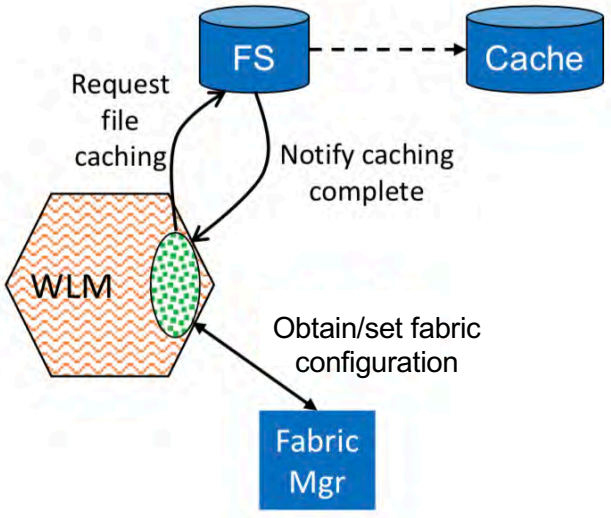
Open issue: query/return blocks of results – e.g., "give me 100 nodes with minimum relative comm cost"? May prove too complex a query due to number of constraint options.

Exercise 2: Scheduler Support

- Extend your previous server using the ”test” fabric component
  - PMIX_MCA_pnet=test
  - PMIX_MCA_pnet_test_nverts=nodes:5;plane:d:3
- Collect the inventory
- How many NICs are in the system?
- Print the communication costs between them
- What vertex info is available for index 3?
- What is the index of the 1st NIC on node “test001”?

Stage 2: Launch Prep

- Storage requests
  - Request pre-position/cache data
  - Allocate storage resources
- Fabric requests
  - Obtain fabric info for application
    - Endpoints, network coordinates, etc.
  - Set fabric configuration
    - Software-defined topologies, QoS, etc.
  - Obtain security credentials
- Collect envars to forward

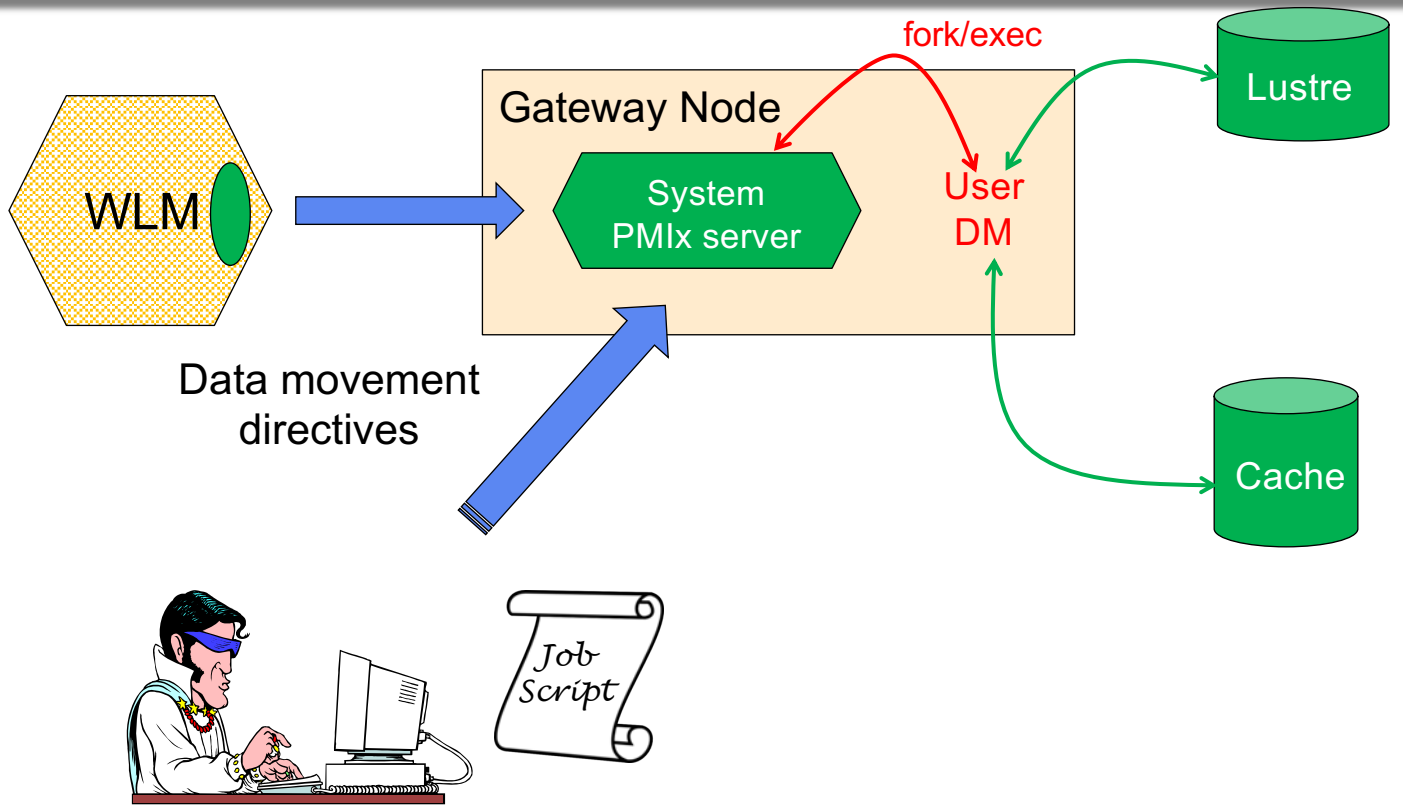


Storage Directives

(signatures TBD)

- Shift data
  - Move cache to parallel file system to clear room
  - Pre-position data from file system to cache
    - Gateway, network-near target nodes, on-node bulk memory
  - Async operation – callback upon completion
- Allocate storage resources
  - Manage cache allotments
  - Set storage strategy for job

Data Mover


fork/exec
Gateway Node
WLM
System
PMIx server
User
DM
Lustre
Cache
Data movement
directives
Job
Script

Setup Application

- PMIx_server_setup_application const pmix_nspace_t nspace, pmix_info_t info[], size_t ninfo, pmix_setup_application_cbfunc_t cbfunc, void *cbdata
  - Process mapping: What procs are on which nodes and where they are bound
  - Any directives regarding fabric settings (e.g., planes to be used, QoS), others
- Cycle across active components
  - Fabric plugins
    - Assign endpoints: info directives indicate how many per plane to assign to each proc, assignments provided in order of closest NIC to proc
    - Generate fabric credential(s) for job
    - Collect fabric-specific envars and settings for client libraries/drivers
  - Storage plugins
    - Alert job starting, retrieve storage settings for client libraries/drivers
- Pickup PMIx-specific envars
- Return info array for delivery to compute nodes

What About mpiexec?

- Launch its daemons on all nodes
  - Collect inventory from each
  - Proceed as before
- If inventory not available
  - PMIx_server_setup_application automatically requests info from scheduler
    - Provide URI for scheduler PMIx server
    - “Upcall” to RM for transmission

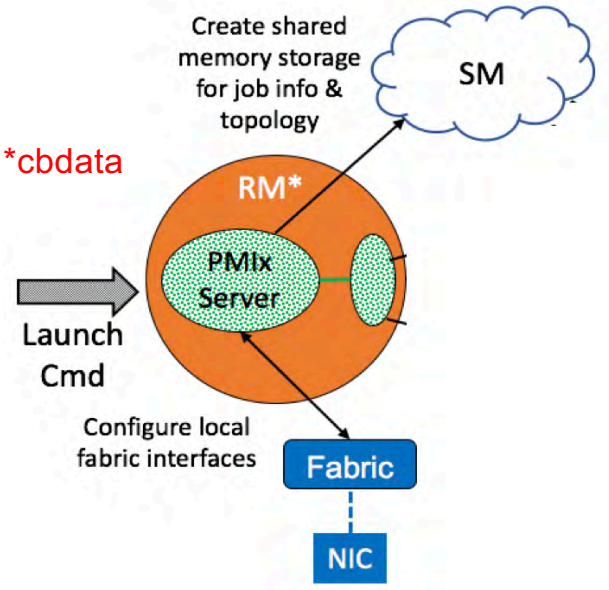
Exercise 3: Launch Prep

- Extend your previous server
  - PMIX_MCA_pnet=test
  - PMIX_MCA_pnet_test_nverts=nodes:5;plane:d:3
- Define an application (keep it simple)
  - Hosts: “test000,test001,test002”
  - Ppn: “0,1,2;3,4,5;6,7”
  - Remember to use the regex generators!
- Setup the application
  - Allocate network resources and security key
  - Pickup all related envars
  - Use the PNET verbosity parameter to see what it is doing
- Print out the result

Stage 3: Local Spawn Prep

- Extract setup array from launch msg
  - Check for job-level directives
    - Modify paths, set/unset envars
  - PMIx_server_setup_local_support
    - Pass input to all active components
    - Fabric plugins
      - Setup local drivers, prep address tables, …
    - Storage plugins
      - Setup local drivers, configure memory, …

const pmix_nspace_t nspace,
pmix_info_t info[], size_t ninfo,
pmix_op_cbfunc_t cbfunc, void *cbdata



- PMIx_server_register_nspace
  - Pass in job- and proc-level info for clients
  - Include setup array info, process map

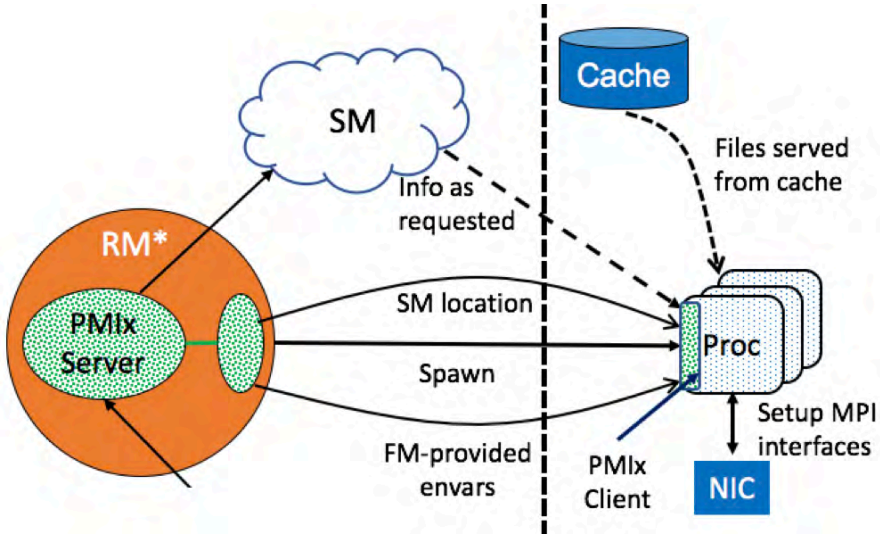
const pmix_nspace_t nspace, int nlocalprocs,
pmix_info_t info[], size_t ninfo,
pmix_op_cbfunc_t cbfunc, void *cbdata

Stage 4: Fork/Exec

- PMIx_server_register_client `const pmix_proc_t *proc, uid_t uid, gid_t gid, void *server_object, pmix_op_cbfunc_t cbfunc, void *cbdata`
  - Register each *local* proc for this nspace
  - Informs server of expected uid/gid of connecting client for security check
  - Server preps client support infrastructure
- PMIx_server_setup_fork `const pmix_proc_t *proc, char ***env`
  - Add PMIx server connection and support info to env
  - Add subsystem-specific envars for client libraries (e.g., fabric, storage)

Stage 5: Process Startup

- Handshake with server
  - Sets compatibility plugins
  - Server function module
    - Given chance to validate or reject connecting client
- Transfer data to client
  - Setup SM datastore
  - Send copy to client



Exercise 4: Fork/Exec Prep

- Extend your previous server
- Setup the local support
  - Pass in the data returned by setup application
  - Use the GDS and PNET verbosity parameters to see what it is doing
- Register the nspace
  - For now, just pass universe size and 3 local procs
- Register the local clients
- Setup the fork environment for each client
- Print out the results

Stage 6: Process Termination

- PMIx_server_deregister_client
  const pmix_nspace_t nspace,
  pmix_op_cbfunc_t cbfunc, void *cbdata
  - Called when local client terminates
    - Often called from within function module client_terminated entry
    - Both normal and abnormal termination
  - Provides server library with chance to cleanup
- Generate event
  - Abnormal termination only to avoid floods
    - Typically only upon request included with spawn directives
  - Notify anyone listening for PMIX_PROC_ABORTED event
    - Provide ID of affected proc, any provided text message and/or info
    - Target only nspace of affected proc unless otherwise directed
    - Target non-default handlers

Stage 7: Job Termination

- PMIx_server_deregister_nspace
  - Called when job completes
    - Note: PMIx cannot provide function module entry as it doesn't see multi-node job status
  - Provides server library with chance to cleanup
- Generate event
  - Notify anyone listening for PMIX_JOB_TERMINATED event
    - Optional to perform by default
  - Target non-default handlers
  - Provide exit status, any associated text message and/or info

Day 1: Detail

- Overview
- PMIx Reference Implementation
- Server Initialization
  - Exercise
- Launch Sequence
  - Exercise

Exercise: Scheduler

- Extend your server to support a scheduler
- Collect local inventory
- Poke around the comm cost matrix
  - Perhaps with ”pquery” tool?
- Define an application and set it up
  - Set pnet_base_verbose=100 to see what it does

Agenda

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Events

- Async notification
  - Proc failures, system issues, coordination requests, workflow orchestration
- Types of events
  - Job-specific: directly relate to executing job
    - Debugger attachment, proc failure, app-generated event
    - Always delivered to the PMIx server by host
  - Environment: indirectly relate to a job but not specifically targeting it
    - ECC errors, temperature excursions, …
    - Delivered only upon request to host
- Event codes
  - Any integer value
  - Host-specific values must be either positive or lie beyond PMIX_EXTERNAL_ERR_BASE

Registration

- Anyone can register
  - Host subsystem elements, apps, tools
- PMIx_Register_event_handler
  - Specify any number of codes (3 categories)
    - NULL => default handler for all codes
    - Single code, Multiple codes
  - Can provide string name for this handler
    - Used for ordering and debugging
  - Callback returns handler registration ID (deregister, returned in notifications)
  - Handlers not required to be unique (can register same function multiple times)
- Event caching
  - Job-specific events *required* to be cached and delivered in order
  - Environment events are *requested* to be cached

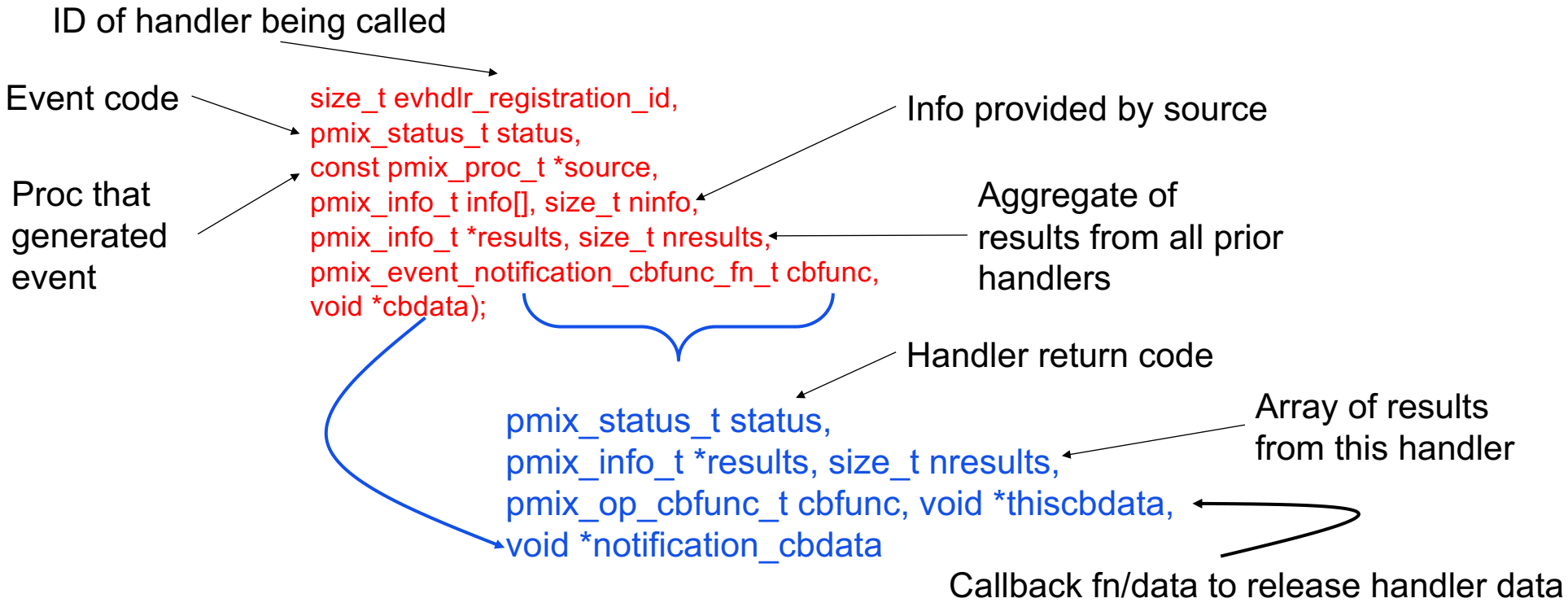
```
pmix_status_t codes[], size_t ncodes,
pmix_info_t info[], size_t ninfo,
pmix_notification_fn_t evhdlr,
pmix_hdlr_reg_cbfunc_t cbfunc,
void *cbdata
```

Handler Directives

- Specify ordering at time of registration
  - First => execute this handler before any others*
  - Last => execute this handler after all others have completed*
  - First in category => execute this handler before any others for the event category*
  - Last in category => execute after all handlers for the event category have completed*
  - Before – insert immediately before the named handler
  - After – insert immediately after the named handler
  - Prepend – add to the front of the list for this category
  - Append – add to the end of the list for this category
- Restrict interest
  - Pass array of specific affected procs we want to hear about
  - Events impacting all other procs will be ignored for that handler

**only one of each*

Handler Signature



Generation

- Anyone can generate an event
  - Application procs, tools, host
- PMIx_Notify_event
  - Report a single event code plus source that generated the event
  - Specify a delivery range
    - RM: solely to the host
    - Local: available to procs on local node only
    - Namespace: available to procs in same nspace only
    - Session: available to procs in same session only
    - Global: available to all procs
    - Proc_local: available only internally to the generating proc
    - Custom: array of specific target procs
  - Provide additional info
    - Affected proc(s), do not deliver to default event handlers

```
pmix_status_t status,
const pmix_proc_t *source,
pmix_data_range_t range,
const pmix_info_t info[], size_t ninfo,
pmix_op_cbfunc_t cbfunc, void *cbdata
```

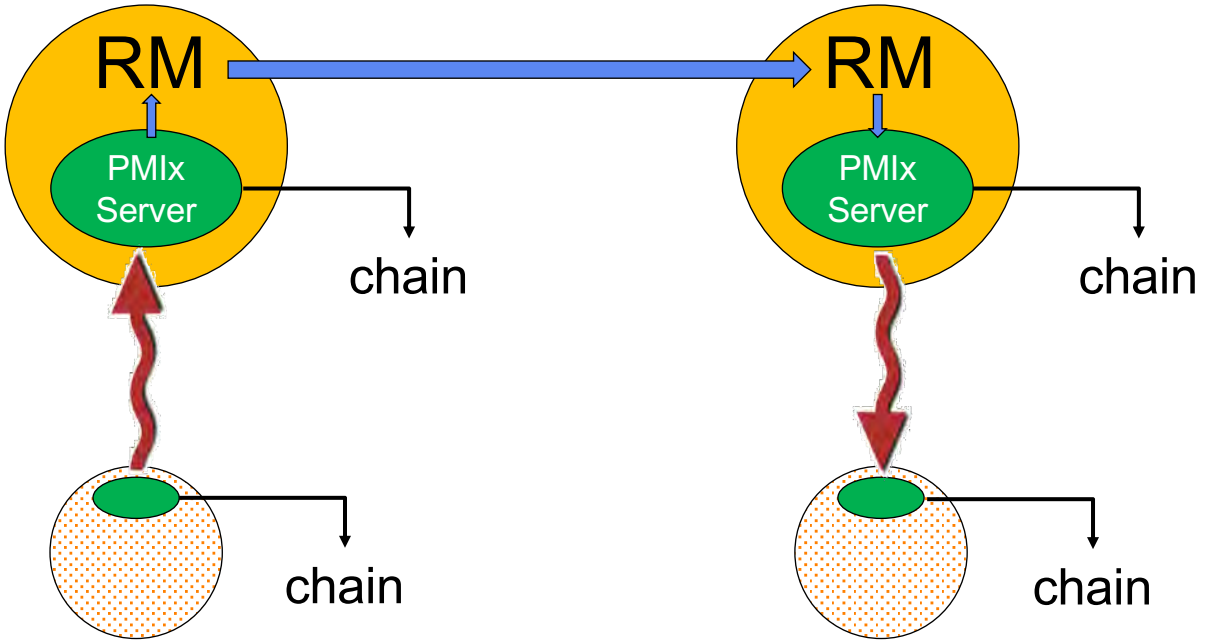
Event Handling

- Precedence order
  - First
  - Single code -> Multi-code -> Default handlers
    - First/last called in each category
  - Last
- Results “chained”
  - Results returned by each handler are added to end of results array passed to next handler
- Each handler *must* call event handler completion function
  - All processing stops upon return of PMIX_EVENT_ACTION_COMPLETE
  - Not allowed to perform any blocking operation during handler

Event Notes

- Last handler is called after all registered default handlers matching specified range
  - Ensure no default handler aborts process before it
- Events cannot be delivered back to the process that generated them
  - Host cannot pass event back to its PMIx server library
  - Server library cannot pass event back to generating client
- Keep event handlers short
  - PMIx server library is “blocked” until completion

Event Processing

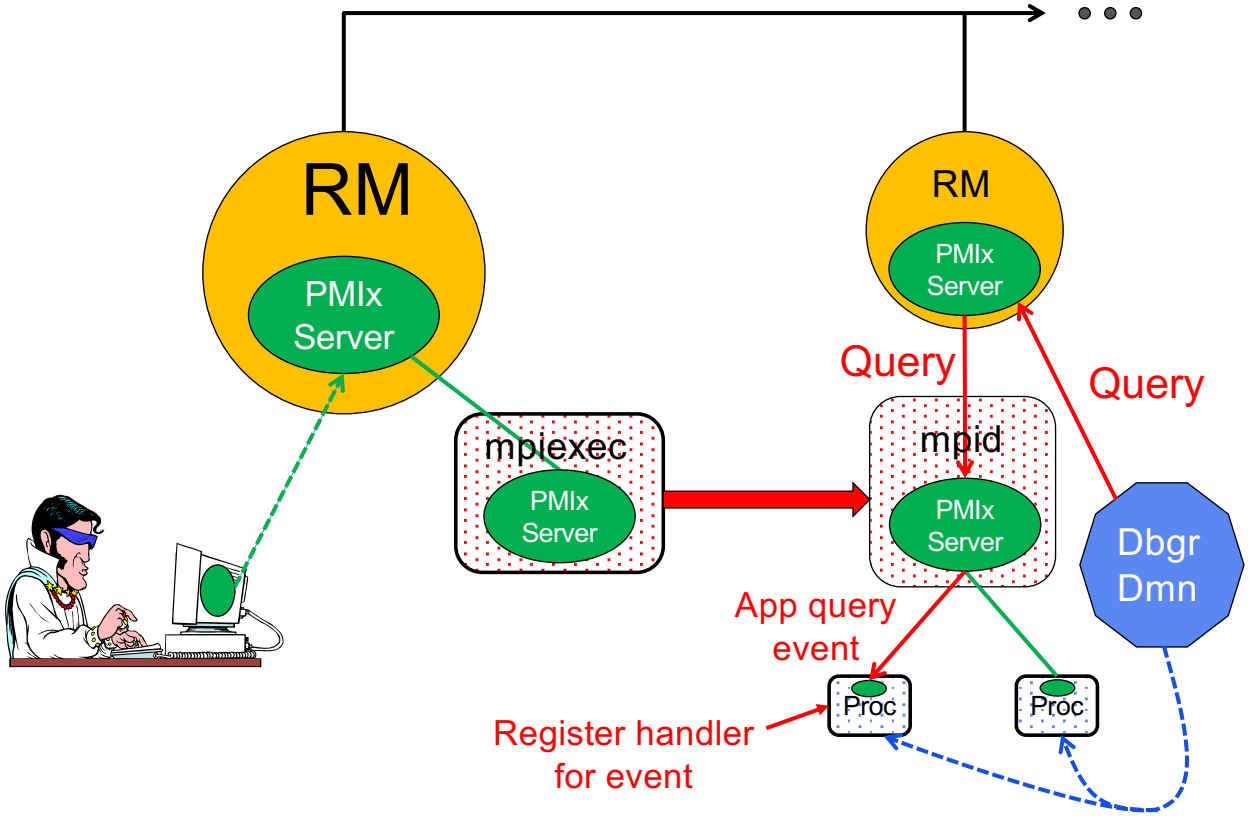


Send and then internally process

Example Uses

- Hybrid applications
  - Notify programming libraries of each others existence, operations
  - OpenMP + MPI: coordinate programming blocks
  - Notification strictly within the individual proc
- Fault tolerance: ULFM
  - Notification of process failure
- Tools
  - Notification of job completion
  - Debugger attachment handshake

Query App Info



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PMIx Scope: Client

- Wireup
  - Fence, put, get, commit
- Publication
  - Publish, lookup, unpublish
- Dynamics
  - Spawn, connect, disconnect, group construct/destruct
- Storage
  - Estimate retrieval times, set hot/warm/cold policy, data movement
- WLM
  - Inventory, comm costs, subsystem app resource allocations, allocation mgmt
- Fabric
  - QoS control, async updates
- Tools
  - Query, attach/detach, IO fwd
- Events (async notification)
- Info
  - Query, logging

Wireup

- PMIx_Put
  pmix_scope_t scope,
  const pmix_key_t key,
  pmix_value_t *val
  - Adds provided key-value pair to internal cache
  - Duplicate keys are overwritten
- PMIx_Commit
  - Sends all added/modified key-value pairs since last commit to local PMIx server
  - Server required to store keys on per-proc basis – i.e., procs can post the identical key without overwrite
- Fence
  const pmix_proc_t procs[], size_t nprocs,
  const pmix_info_t info[], size_t ninfo
  - Barrier operation
  - Data collection optional
- Get
  const pmix_proc_t *proc, const char key[],
  const pmix_info_t info[], size_t ninfo,
  pmix_value_t **val
  - Retrieve key for a given proc
    - PMIX_RANK_UNDEF: retrieve globally unique key (legacy support)
  - Check internal/shmem first
  - Request from server
    - Obtain from remote server hosting specified proc if data not exchanged

Key-Value "Scope"

Who can "Get" this key-value pair?

- Specified by source process at time of "put"
- Controls access by other procs
  - "internal": only available to the source proc
  - "local": only accessible by other procs on same node
  - "remote": only available to procs on other nodes
  - "global": available to everyone
- Only remote and global scope included in data exchanges during "fence"

Publication

- PMIx_Publish const pmix_info_t info[], size_t ninfo
  - Publish data in info array to specified range (default: session)
  - Keys must be unique within given range
    - Not indexed by source proc!
    - First published “wins” – followers return error
  - Persistence instructs server as to how long data is retained (default: app)
- PMIx_Unpublish char **keys, const pmix_info_t info[], size_t ninfo
  - Delete data for specified keys
  - NULL => delete all data published by this process
- PMIx_Lookup pmix_pdata_t data[], size_t ndata, const pmix_info_t info[], size_t ninfo
  - Retrieve published data
  - Constrained to data published by current uid/gid
  - Returns error if not found
    - Optional: wait for first found data, wait for all data, timeout
  - “non-found” data will have PMIX_UNDEF datatype

Range & Persistence

- Range: who has access to data
  - “proc_local”: only within the proc itself (e.g., across threads)
  - ”local”: only procs on local node
  - “namespace”: only procs within same nspace (job) as publisher
  - “session”: only procs within same session (allocation) as publisher
  - “global”: any process
  - “custom”: only specified processes
  - “rm”: only the host environment
- Persistence: when data shall automatically be deleted
  - “first_read”: delete after first access
  - “proc”: retain until publisher terminates
  - “app”: delete when publisher’s application terminates
  - “namespace”: delete when publisher’s nspace (job) terminates
  - “session”: delete when publisher’s session (allocation) terminates
  - “indef”: retain until specifically deleted

Dynamics: Basic

- Spawn
  - Spawn new job
    - Job_info specifies directives and info for all apps
    - Apps array contains info for each individual app
  - Namespace returned upon spawn complete
  - Variety of notification options
    - Job launched, job terminated, app terminated, proc terminated
- Connect
  - Mark the specified procs as “connected”
  - All procs to receive
    - Job-level info for nspaces of all participants
    - “put” info from participants, filtered by scope
- Disconnect
  - Remove “connected” specification for given procs
  - Return error if not connected

Dynamics: Groups vs Basic

- Relation to RM
  - Connect: passed to RM, no new ID assigned
  - Group: handled by PMIx server, each proc assigned new “group rank”, translate group IDs to global IDs for RM operations
- Construction
  - Connect: bulk synchronous only
  - Group: can be dynamic, invite/join as well as nonblocking
- Destruction
  - Disconnect: bulk synchronous only
  - Group: can be dynamic, members notified as procs leave

Allocation Management

- PMIx_Allocation_request
  pmix_alloc_directive_t directive,
  pmix_info_t *info, size_t ninfo
  - Request allocation of new resources
  - Extend current reservation on specified resources
  - Release current specified resources
  - “Lend” resources back, mark for return on request or after specified time
    - Return requested by passing PMIX_ALLOC_REAQUIRE directive
- RM can notify of resource changes
  - Registration for event required

Job Control & Monitoring

- PMIx_Job_control
  - Include string ID with request
    - Allows later query for status, cancellation of request
  - Signal, kill, politely terminate
  - Direct targets to checkpoint
    - PMIx event, signal, etc
  - Provision specified nodes with indicated image
  - Register files and directories for cleanup after termination
  - Register willingness to be preempted
- PMIx_Process_monitor
  - Monitor file changes(access, mod, size)
  - Heartbeat

Information

- PMIx_Resolve_nodes
  - Given nspace, return comma-delimited list of nodes hosting procs within it
- PMIx_Resolve_peers
  - Given node, return array of procs within given nspace on it (NULL => all)
- Query
  - Request supported APIs, attributes
  - Executing jobs, process tables, queue status
  - Psets, groups, available resources
- Log
  - Deliver provided message to one or more logging channels
  - Syslog (local, global), email, text, global data store, job record

Security & Storage

- Get/validate credential
  - Some built-in support for credential services
    - Munge, Cray DRC
  - Others passed to host for servicing
- Storage
  - Data movement, storage strategies, availability and location

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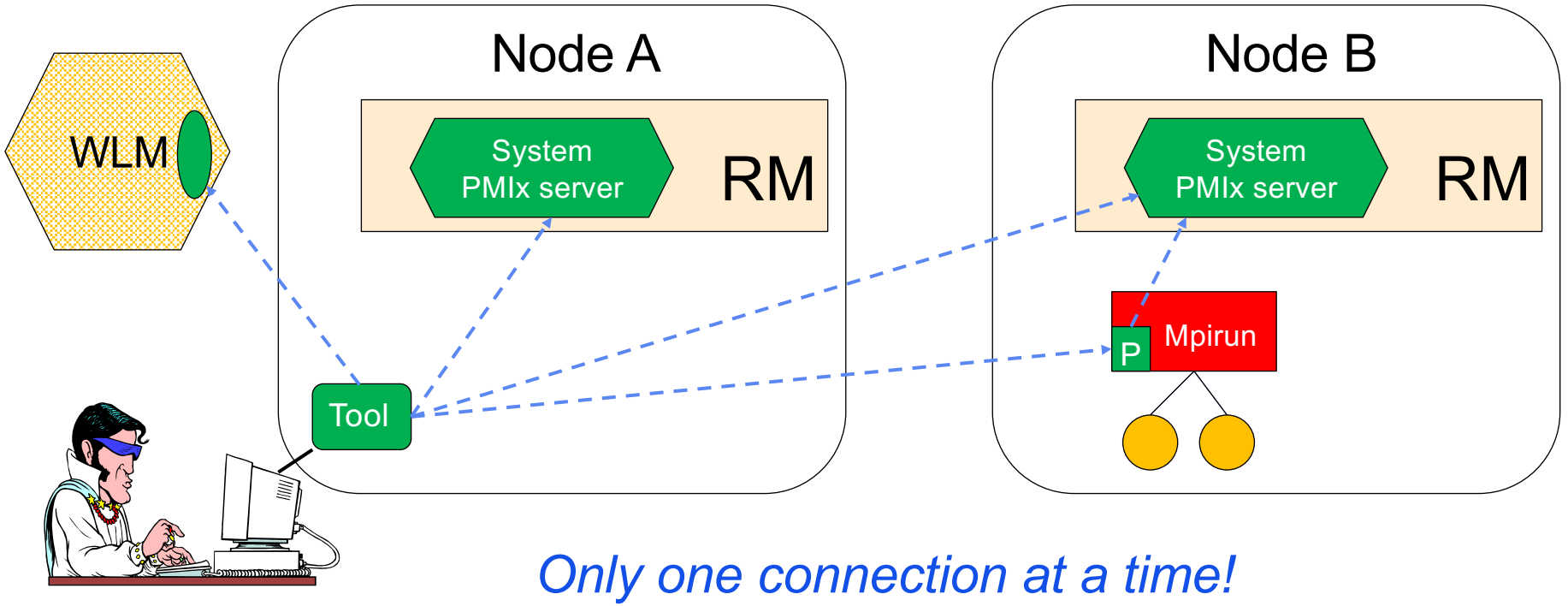
Tool Support Examples

- Query
  - Network topology
    - Array of proc network-relative locations
    - Overall topology (e.g., “dragonfly”)
  - Running jobs
    - Currently executing job namespaces
    - Array of proc location, status, PID
  - Resources
    - Available system resources
    - Array of proc location, resource utilization (ala “top”)
  - Queue status
    - Current scheduler queue backlog
- Event injection
  - Async directives to running jobs
- Storage directives
  - Move/delete files between storage locations
- Job submission
- Debuggers
  - Portable attach, query mechanism

Tool Basics

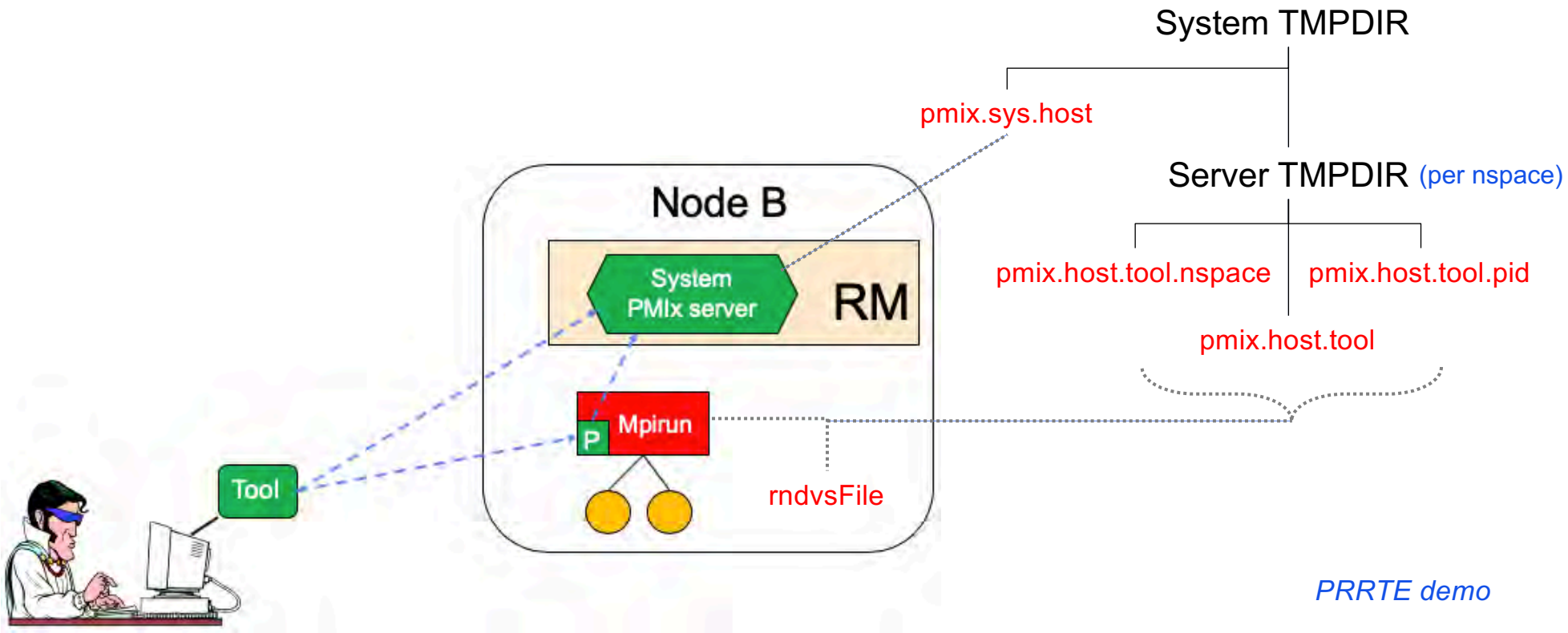
- Two types
  - Client
    - Launched by a PMIx server – has identifier
  - Launcher
    - Will be spawning processes – e.g., “mpiexec”
    - May or may not also be client
- Servers must “opt in” for tool connection support
  - PMIX_SERVER_TOOL_SUPPORT – allow support
  - PMIX_SERVER_REMOTE_CONNECTIONS – allow remote connections
  - PMIX_SERVER_SYSTEM_SUPPORT - system server (max one/node)
  - Job-specific server (default)

Tool Connections



Only one connection at a time!

Rendezvous File Locations



PRRTE demo

Tool Initialization

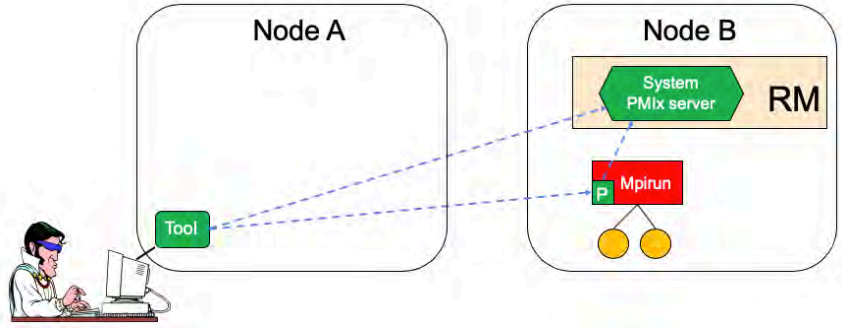
- PMIx_tool_init pmix_proc_t *proc, pmix_info_t info[], size_t ninfo
  - Type of tool
  - Connection options
    - Do not connect
    - Connect via precedence rules
- PMIx_tool_connect_to_server pmix_proc_t *proc, pmix_info_t info[], size_t ninfo
  - If connected, disconnect from current server
  - Connect to new server per precedence rules

Connection Precedence

- Given specific URI or filename
  - Special names found in configuration file (MCA param)
    - PMIX_CONNECT_TO_SCHED
- System server
  - If system-server-only, then return error if not found
- Scan server tmpdir's
  - Given server PID or nspace
    - Returns error if not found or not allowed to access
  - First generic tool uid/gid allowed to access

Tool Connections: Remote

- Query local server for URI
  - Reconnect to returned URI
  - System and job-level servers
- Compute from configuration, given target node
  - MCA param for static socket of system servers
- Spawn proxy to scan
  - Assumes permissions and mechanism for spawn



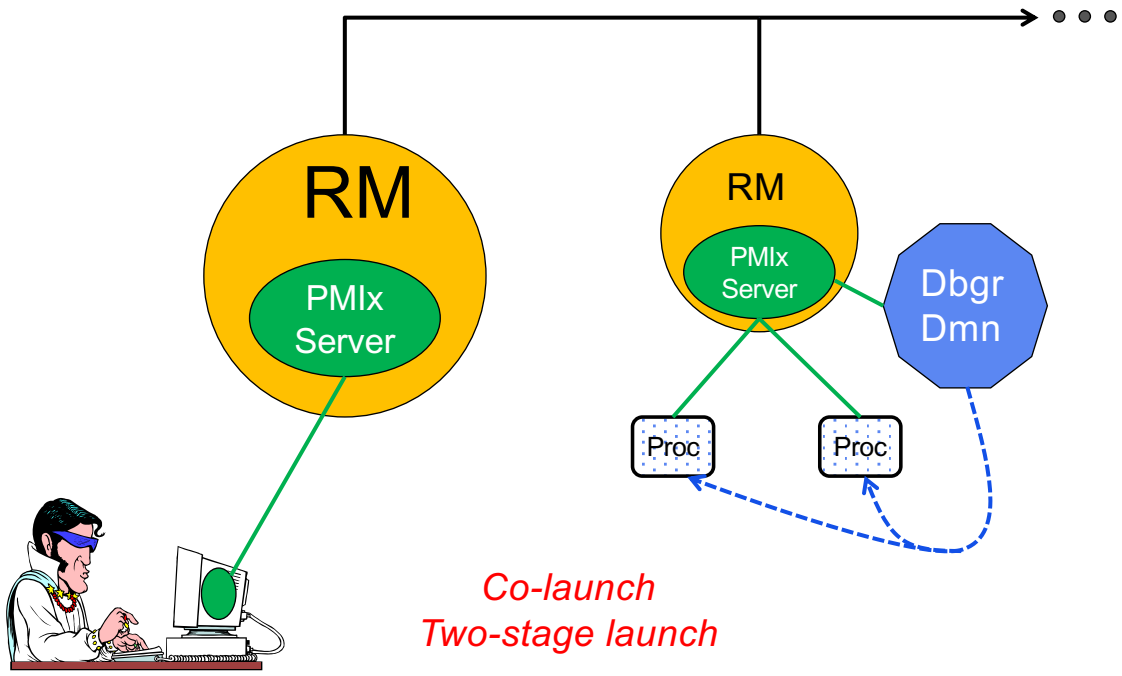
General Capabilities

- Query RM or launcher for support
  - Mechanisms for “hold” and “release”
  - Daemon co-launch capabilities
  - IO forwarding support
- Specify app release mechanism
  - PMIx event, signal, …
- Register for events
  - Termination of debugger job and/or daemons
  - Termination of app job and/or procs
  - Request debugger start on event from app

Debugger/Tool Features

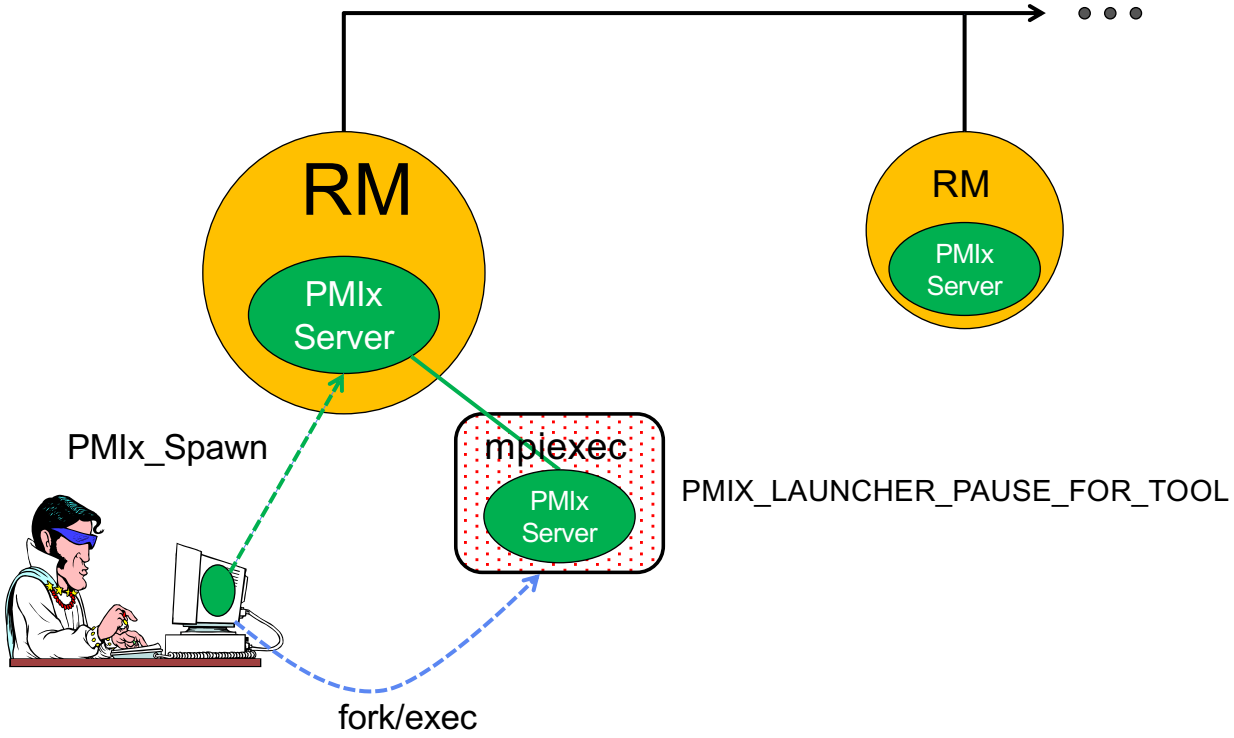
- Co-launch/co-location of daemons
  - At initial app spawn
    - Co-launch
  - Upon attach
    - Spawn w/co-location
- Launch control
  - Stop-on-exec, stop-in-init, stop-in-app
  - Release method to be used
- Forwarding of IO
  - To/from debugger daemons
  - To/from app being debugged
- Query app info
  - Global and local proctable
  - Application internal metadata
- Direct/indirect launch support
  - Forward, set/unset/modify envars (e.g., LD_PRELOAD)
  - Launcher directives
    - Modify local fork/exec agent
    - Replace launcher daemons
- Local launcher fork/exec option
  - If PMIx_Spawn not available or if desired

Direct Launch

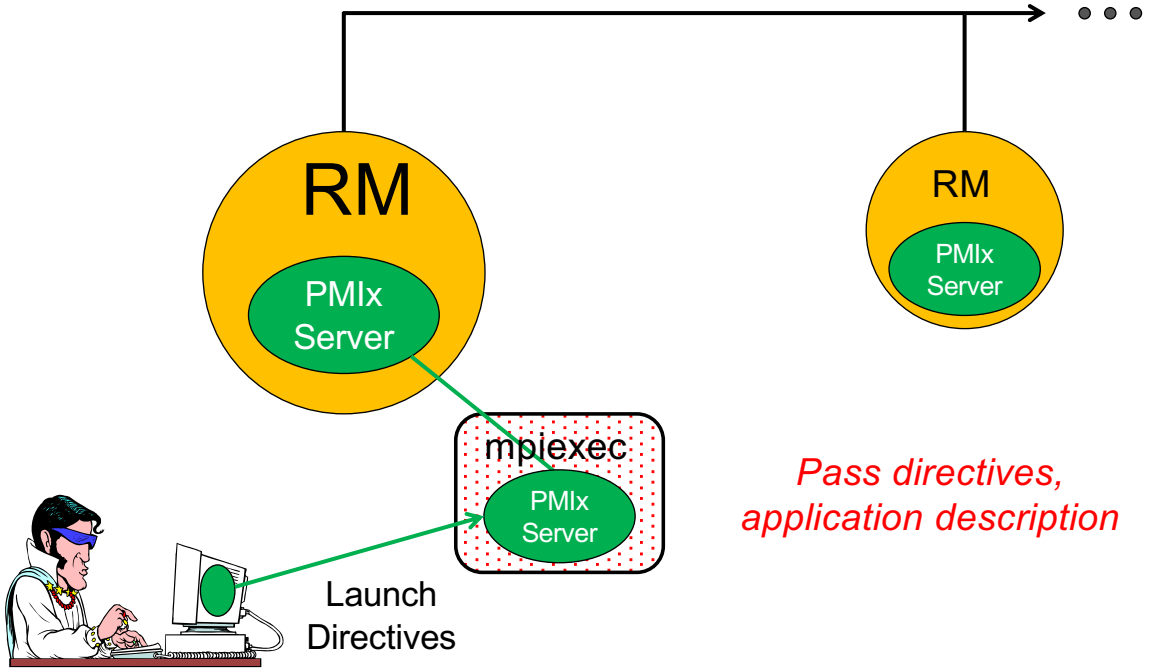


Co-launch
Two-stage launch

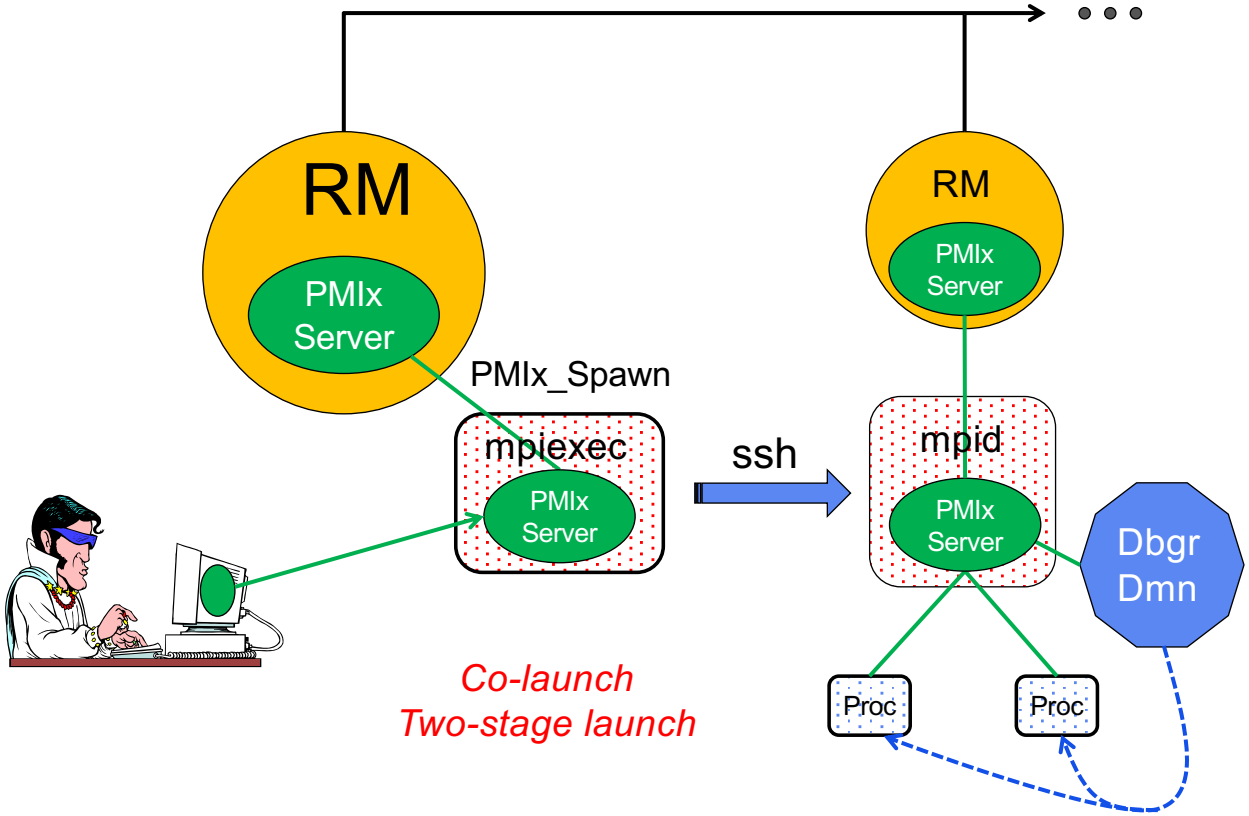
Indirect Launch



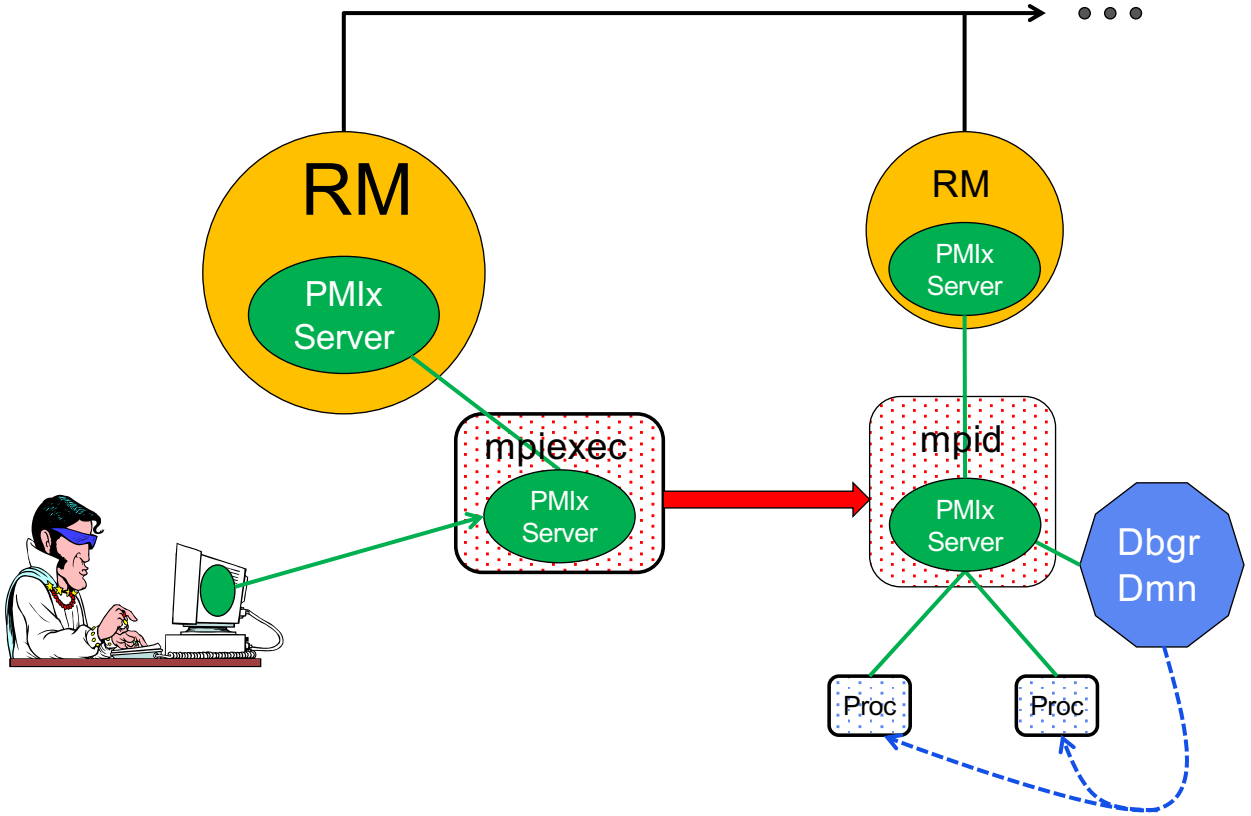
Indirect Launch



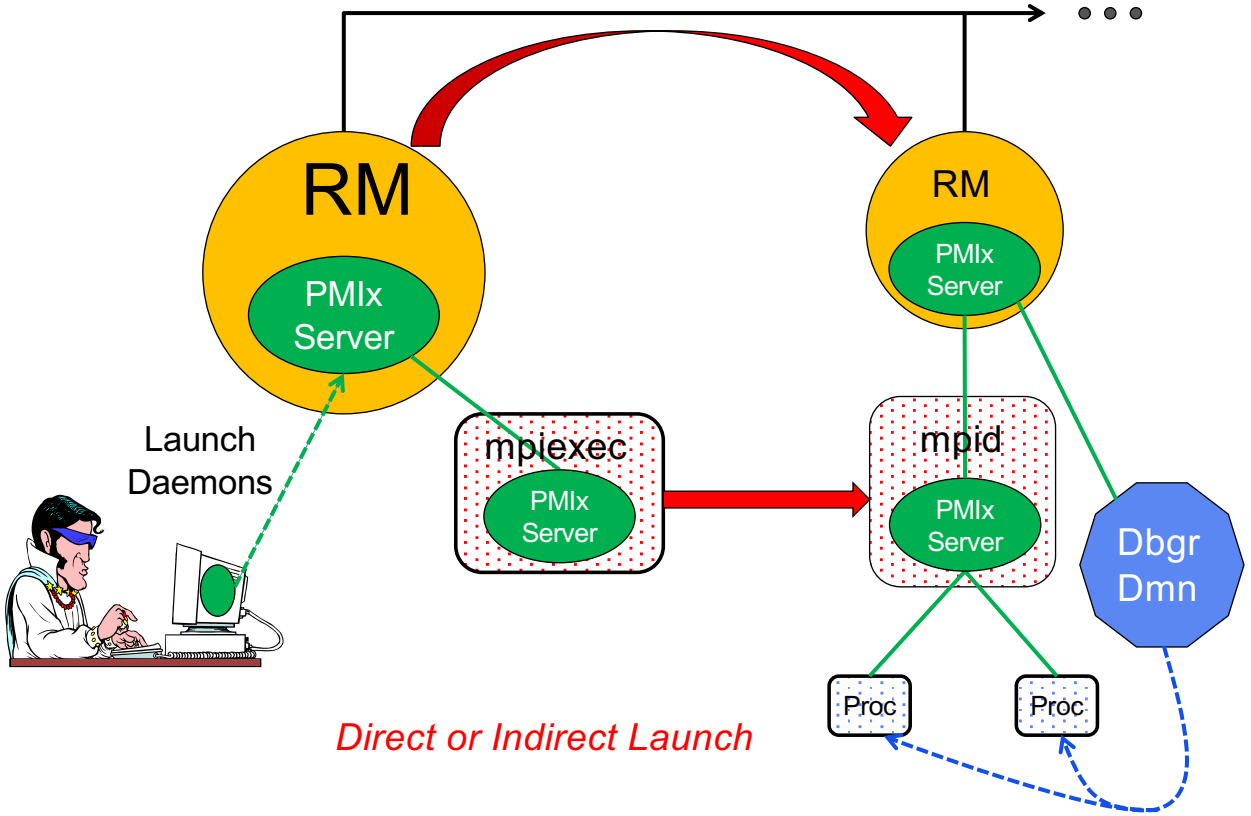
Indirect Launch



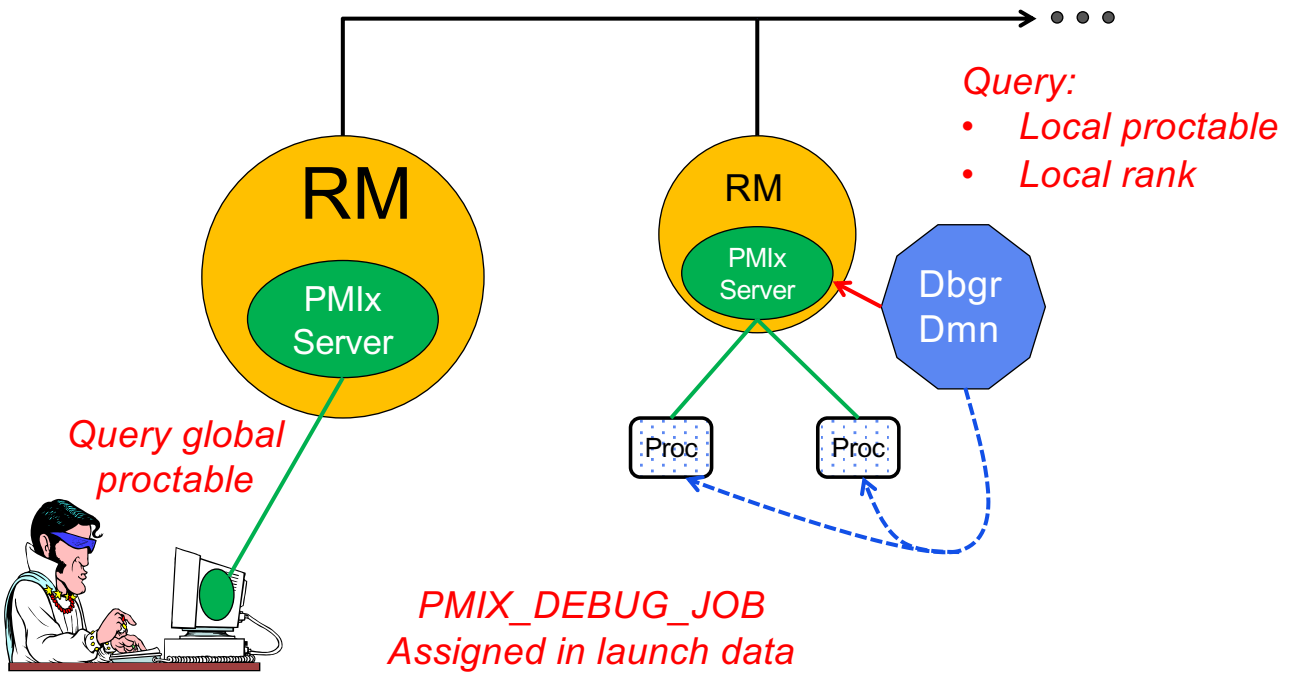
Attach to Running Job



Attach to Running Job



Assigning Procs->Daemons



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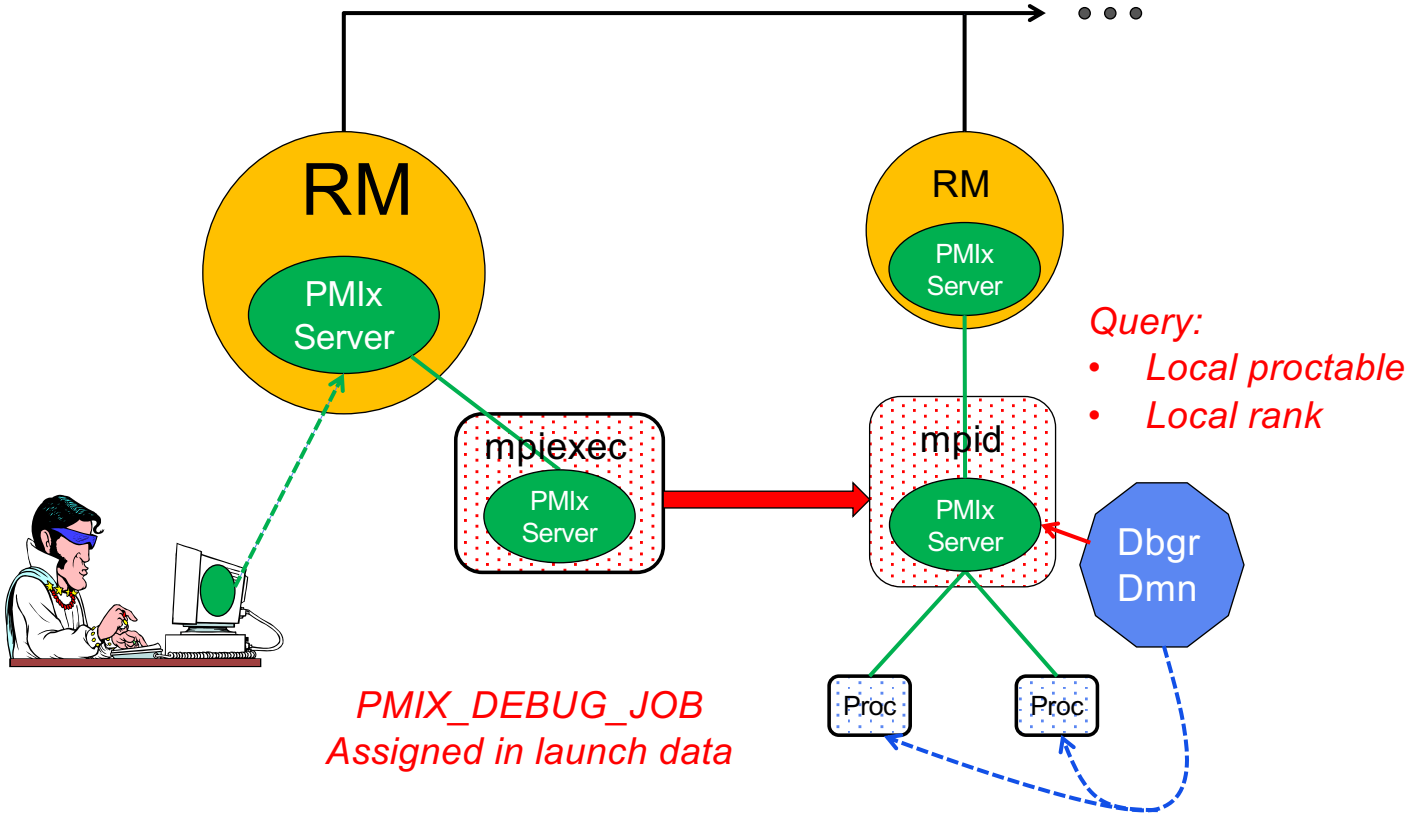

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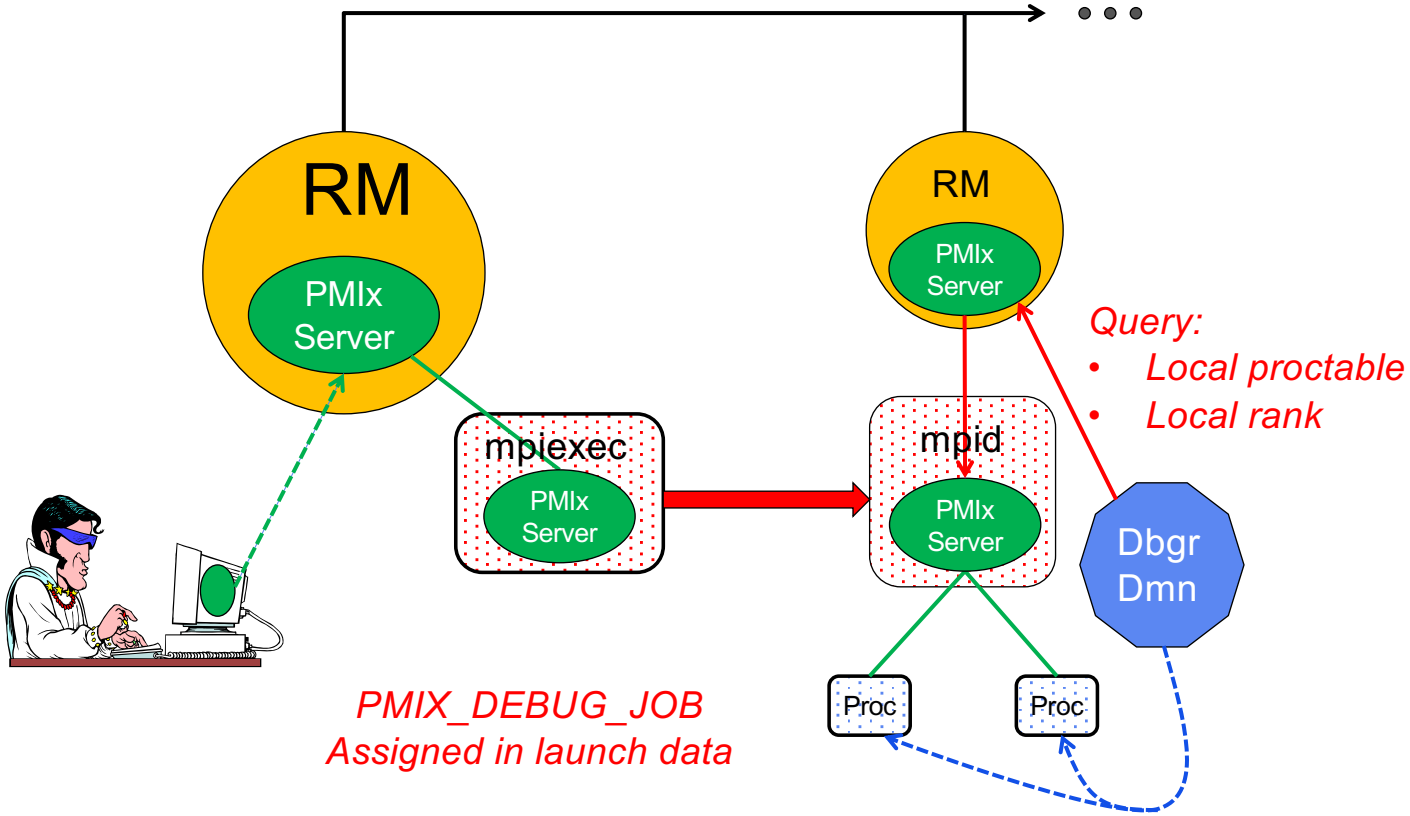
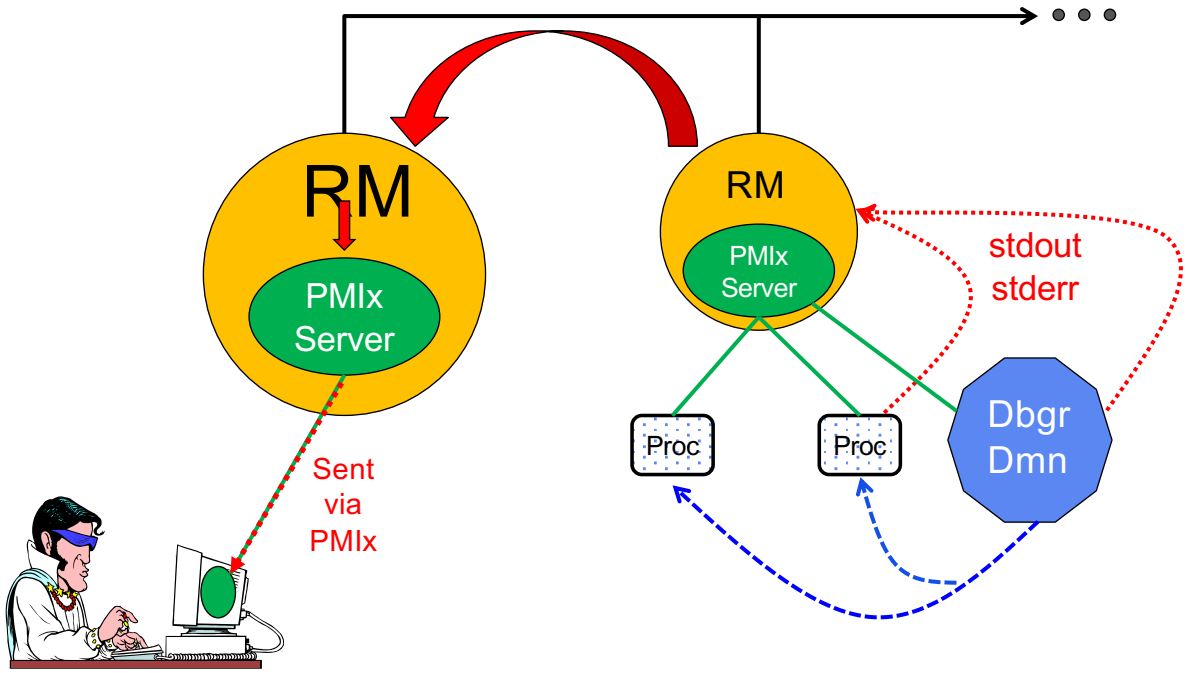
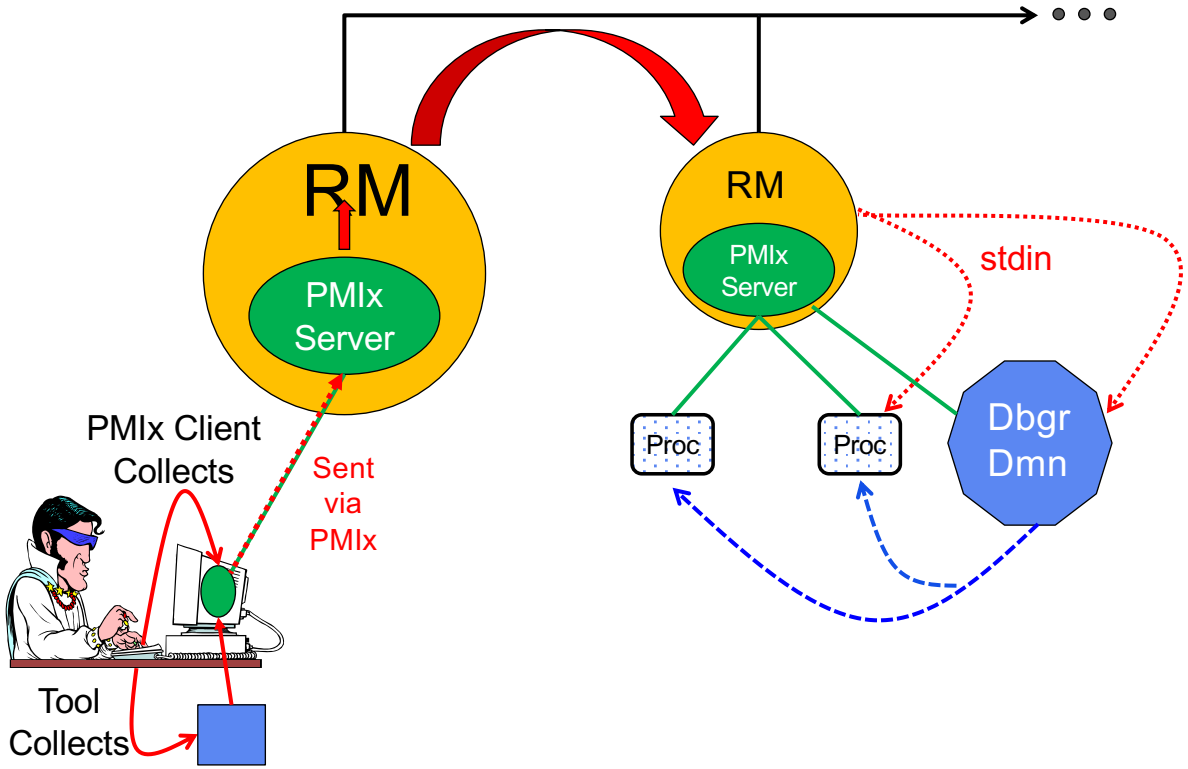


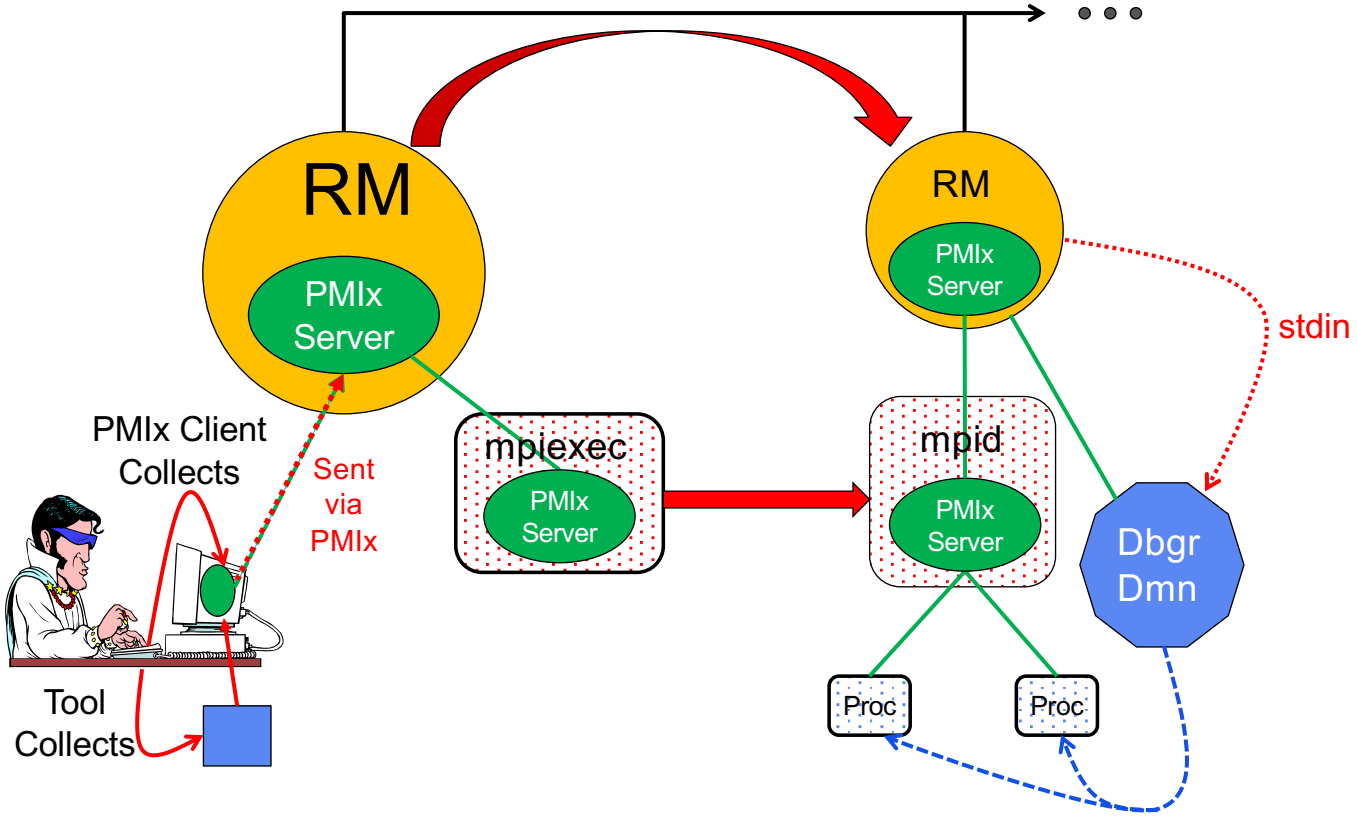
Forwarding of Output



Forwarding Stdin



Forwarding Stdin



Wrap-Up

- Covered a lot of ground
  - Primary focus on scheduler
- Implementation status
  - Client & basic server: in production
  - Scheduler & fabric: alpha
  - Storage: in definition
- Expected completion
  - Release v4.0 in 2Q2020

Thank You!