System High Availability Architecture

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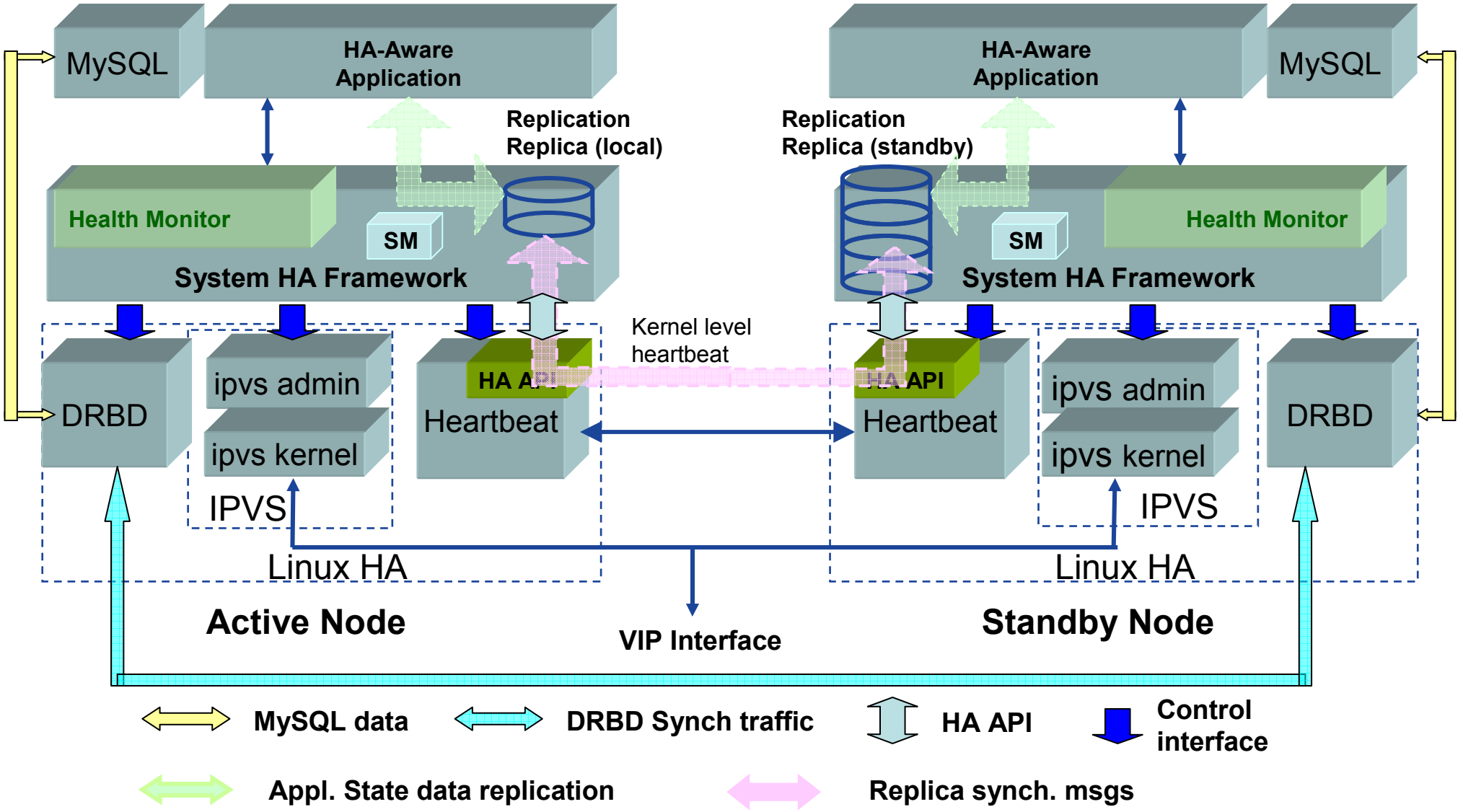
System HA Architecture



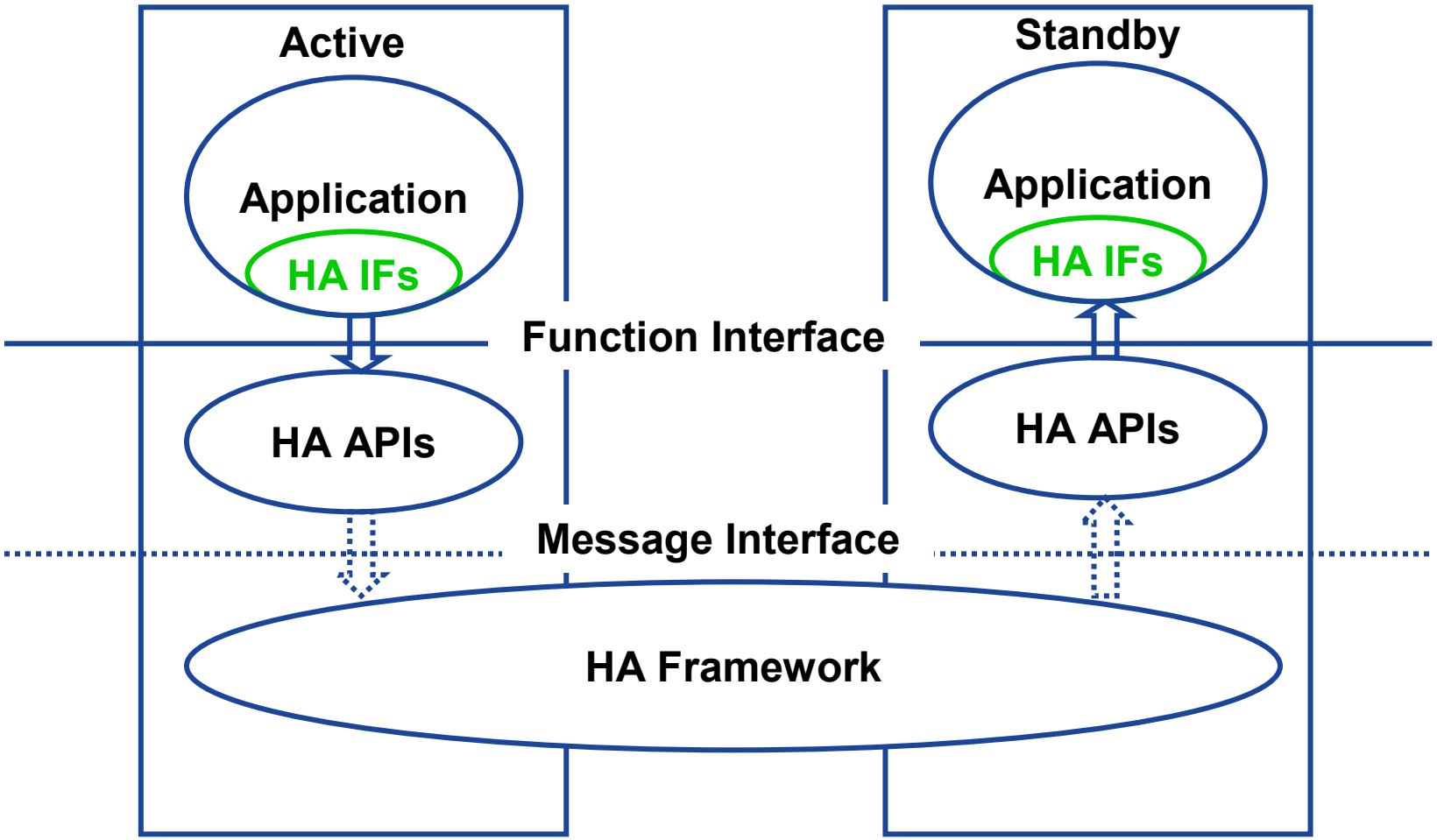
System HA Architecture

- **System HA Framework**
  - Replica: an in-memory, high speed data repository used by applications to store and replicate critical data for fault recovery and system failover
  - Health Monitor: An HA sub-component to monitor the healthiness of HA-aware application processes
  - HA State Machine: coordinates state changes between all the various components including IPVS, Heartbeat, management, node role arbitration etc.
  - Application APIs: interface between Application processes and HA framework for various HA service access
  - HA kernel module control interfaces: for HA framework to control all HA related linux kernel modules (DRBD, IPVS, Heartbeat etc.)

System HA Architecture

- **Linux HA kernel modules**
  - DRBD: Block devices designed as a building block to form high availability (HA) clusters
    - Buffer file system applications (e.g. MySQL) from the disc mount
    - Do whole block device mirroring via network
  - LVS: Linux virtual service
    - IPVS admin: control interface for controlling IPVS
    - IPVS kernel: Linux kernel module to perform the IPVS functions
  - Linux Heartbeat
    - A linux kernel module to provide cluster heart-beating functions
    - Also provides message delivery etc. functions
    - HA framework gains access to Linux heartbeat services via HA APIs

System HA Architecture



System HA Architecture

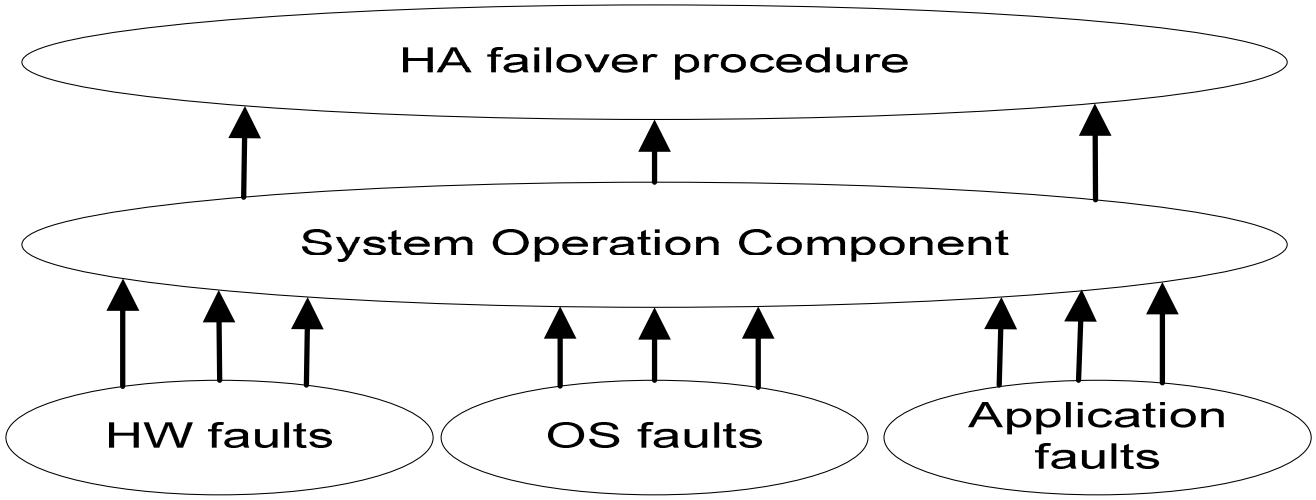
- **HA Framework Overview**
- **System Operation Component**
  - HA framework
- **System Operation Application Interface**
- **System Operation Agent**
- **System Operation Master**
- **Application HA Contexts**
- **Replication Checkpoints**
  - Application specific replication triggers
- **Replication Repertory**
  - In memory hashed replication data storage
- **HA APIs**
  - APIs for applications to access HA framework functionalities

HA Framework Overview

- **Two functional layers**
  - Control layer: connectivity, self-maintenance
  - Service layer: services to applications
- **Functions and Services**
  - Aggregates system fault detections
  - Provides heart-beating mechanism in HA cluster
  - Provides HA replication mechanism to applications via APIs
  - Manages replication repertory
  - Controls failover procedures (restoration, activation auditing)
  - Provides logic addressing mechanism (address mapping) to all applications
- **Usage**
  - Register and use
  - Limited standard functions/methods to be implemented by application classes

HA framework – fault detection, classification and aggregation

- **Fault detection**
  - Error condition reporting: software breaks, signal capture, core dump
  - Operation status monitoring: keep-alive/heartbeat
- **Fault severity classification and aggregation**
  - Minor errors, log and keep going on
  - Major errors, restart the affected application process
  - Fatal errors, failover or reboot the affected node

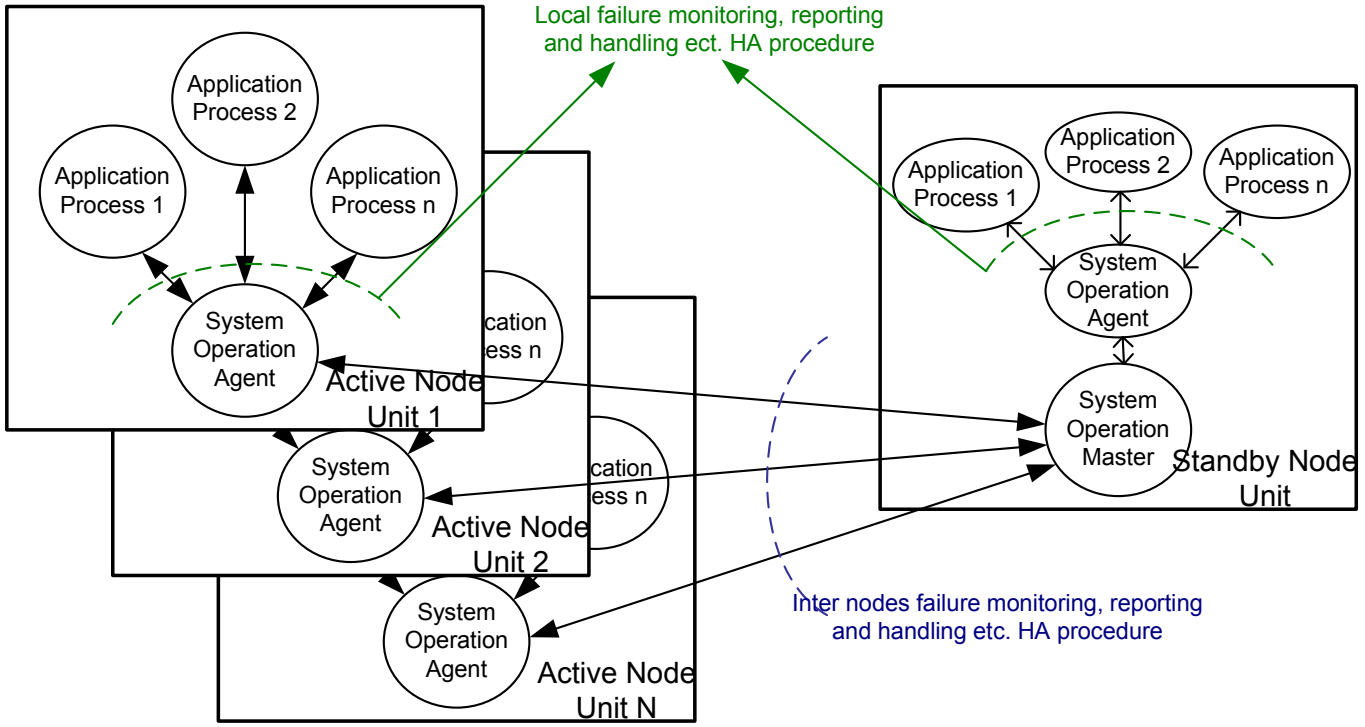


HA Framework – System Operation Component

- **The main control logic of the HA framework**
- **Provided functions like:**
  - Interface with the manufacture provided chassis manager to manage all chassis inventories and hardware failures if needed
  - Manage the chassis physical and logical addressing schemes for HA logic and inter-component communications
  - Monitor the overall system operation, process operation healthiness
  - Restart individual malfunctioned processes if HA failover is not necessary
  - Reboot / Restart node on fatal service interrupting failures if redundancy is not available
  - Detect the presence and absence of all nodes via heart-beating mechanism
  - Collect all hardware and software error conditions and translate them to appropriate failover triggers
  - Trigger the HA failover and control the failover timing, sequence and pace
  - Maintain system-wide inter-node, inter-component synchronization
  - Manage all system-wide global variables and provide access interfaces to other components
  - Provide transportation mechanism for data context replication.

HA Framework – System Operation Component

- **A distributed component**
  - Master process runs on standby node (FSM)
  - Agents process runs on active nodes (FSM)
  - Application interface functions runs in each monitored application process (FSM)

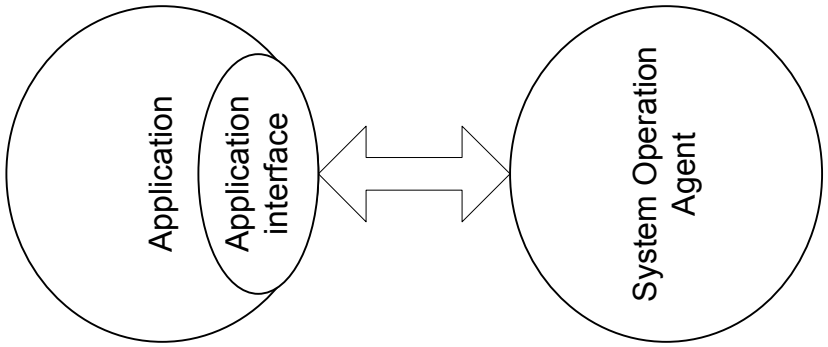


HA Framework – Replication Repertory

- **Hash indexed storage for HA replication data**
- **Implementation:**
  - Using private design, simple and efficient (preferred)
  - Using standard database, flexible, time saving
- **Repertory location**
  - On dedicated nodes (preferred)
    - Enables self-reboot non-interruption HA
    - Repertory persist on failover – no need to do batch replication when new standby node is available
    - No batch replication needed
    - Failover might be slow
    - Dedicated nodes needed to hold repertory
  - On standby node
    - Self-reboot non-interruption HA is not supported
    - Repertory not persist – replication data lost on failover
    - Large memory requirement on standby node
    - Fast failover can be achieved

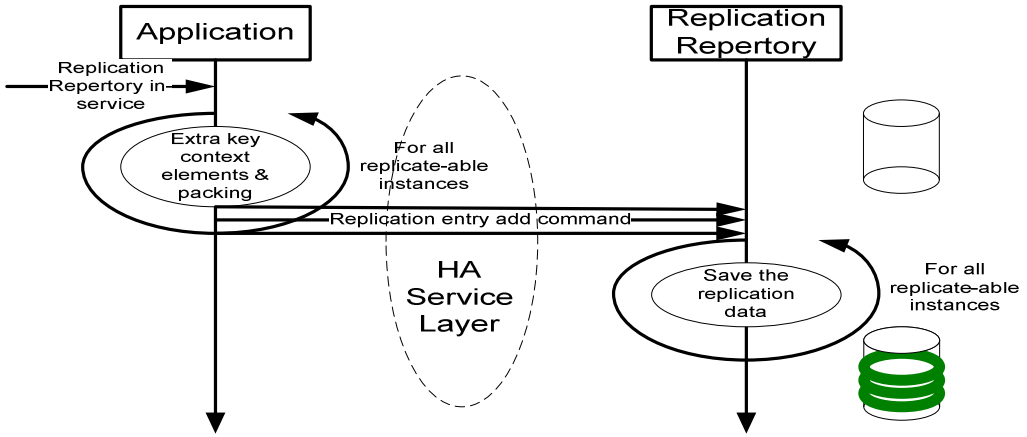
HA framework – Application APIs

- **Application interface class as a base class of subsystem class**
  - Provides application error reporting mechanism
  - Provides application heartbeat mechanism
  - Provides APIs to application for replication, restoration, activation and auditing
  - FSM implementation to interface with system operation agent for all HA related handlings

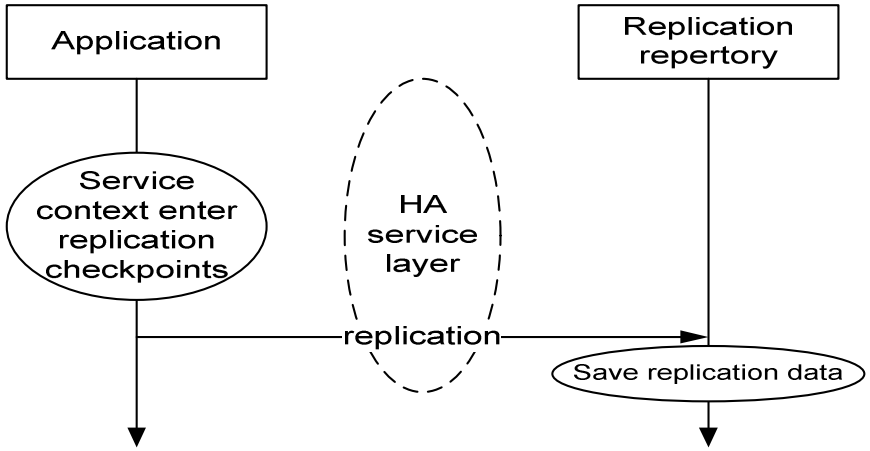


HA framework – replication procedure

- **Batch replication (not required in dedicated replication repertory case)**

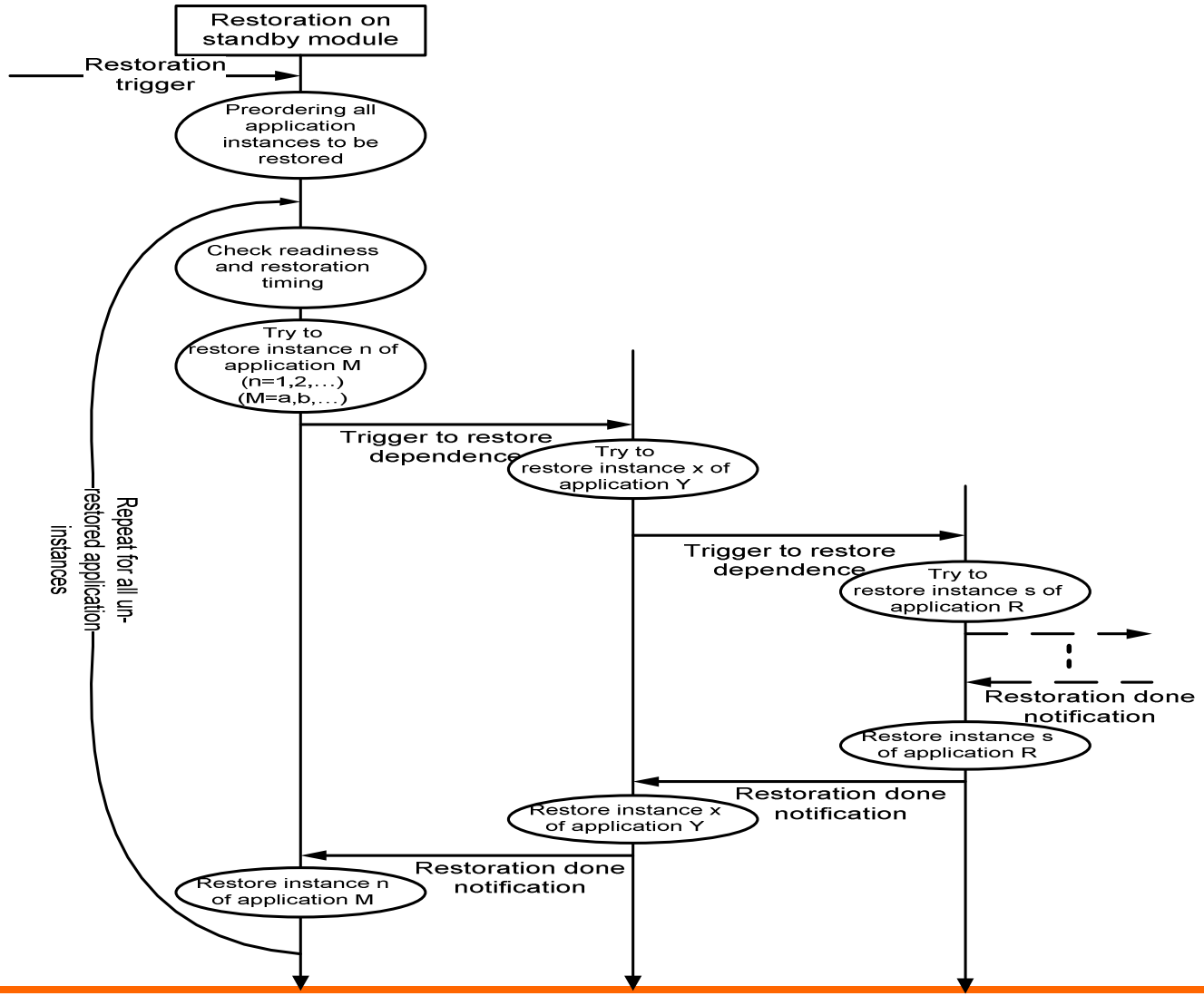


- **Incremental replication**



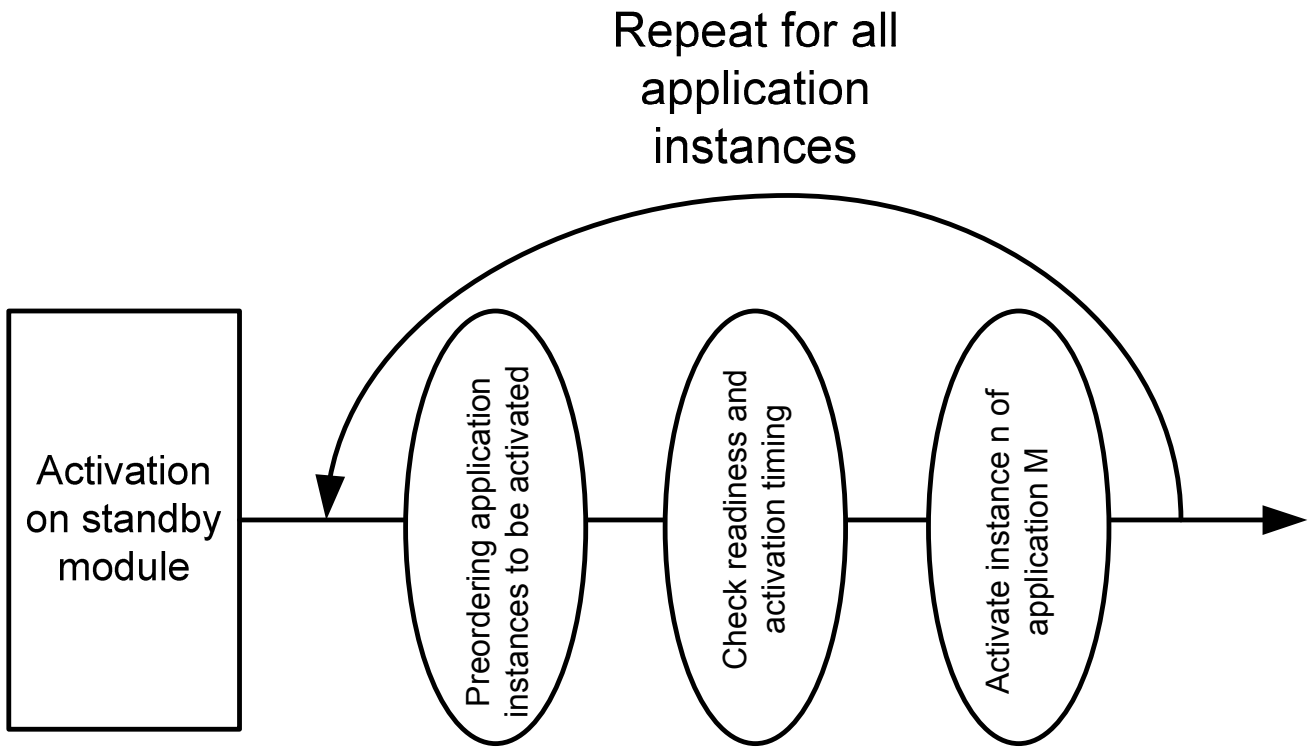
HA framework – restoration procedure

- **Restore service contexts into runtime condition from repertory on failover**



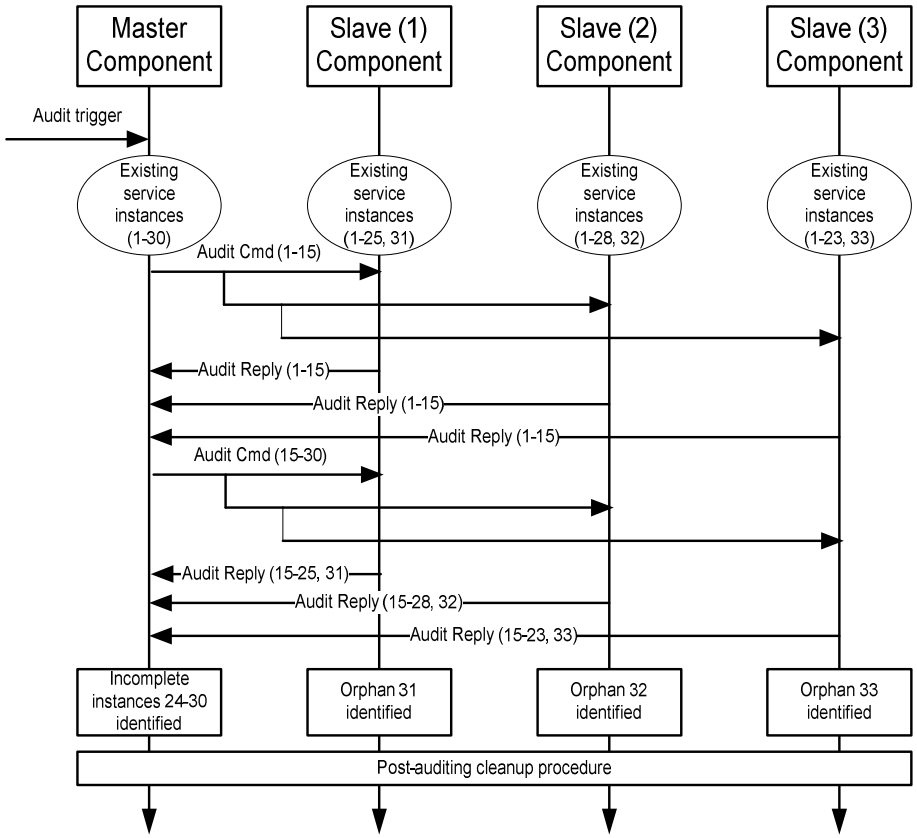
HA framework – activation procedure

- **Activate restored service contexts after failover**

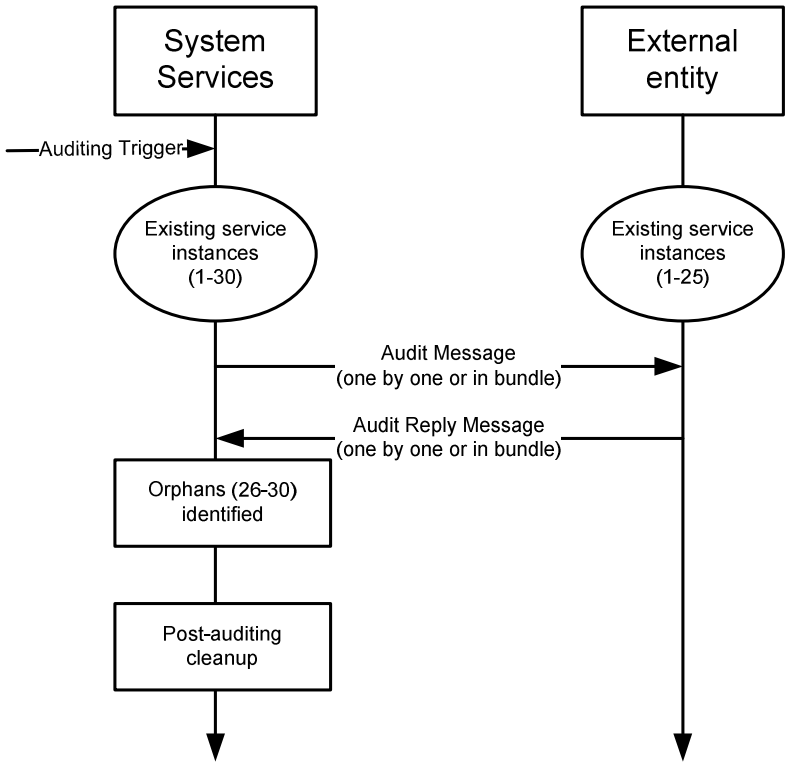


HA framework – auditing procedure

- **Auditing for consistency after failover**
  - **Internal auditing**

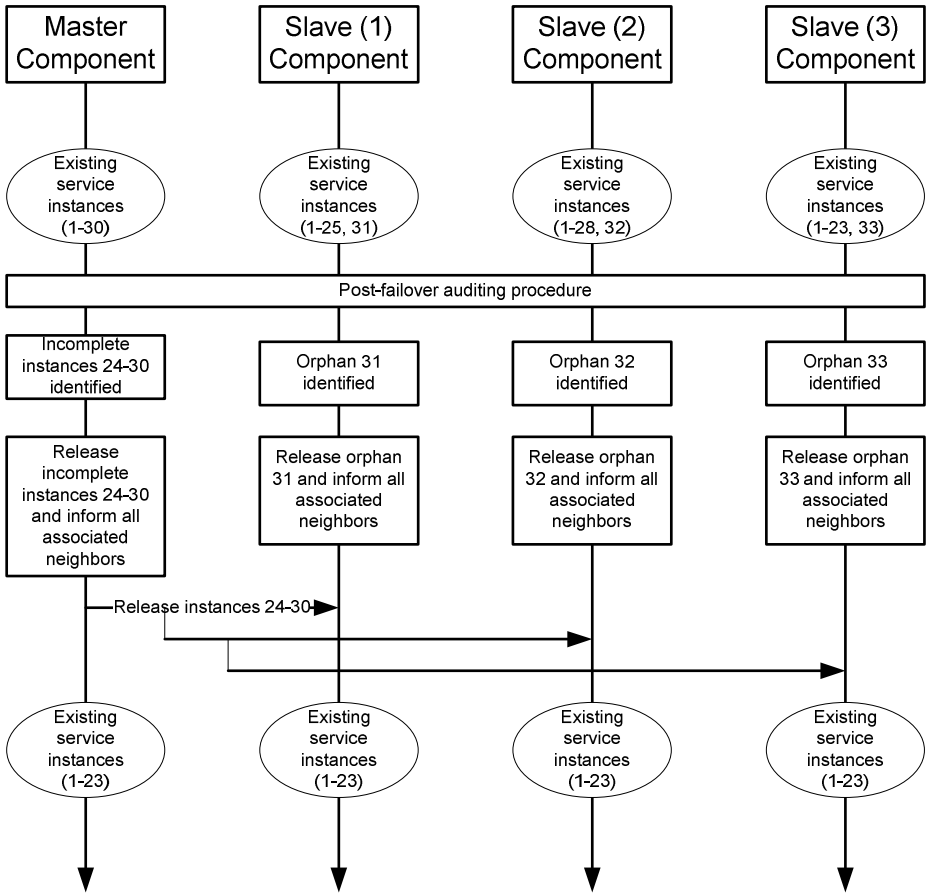


  - **External auditing (if applicable)**

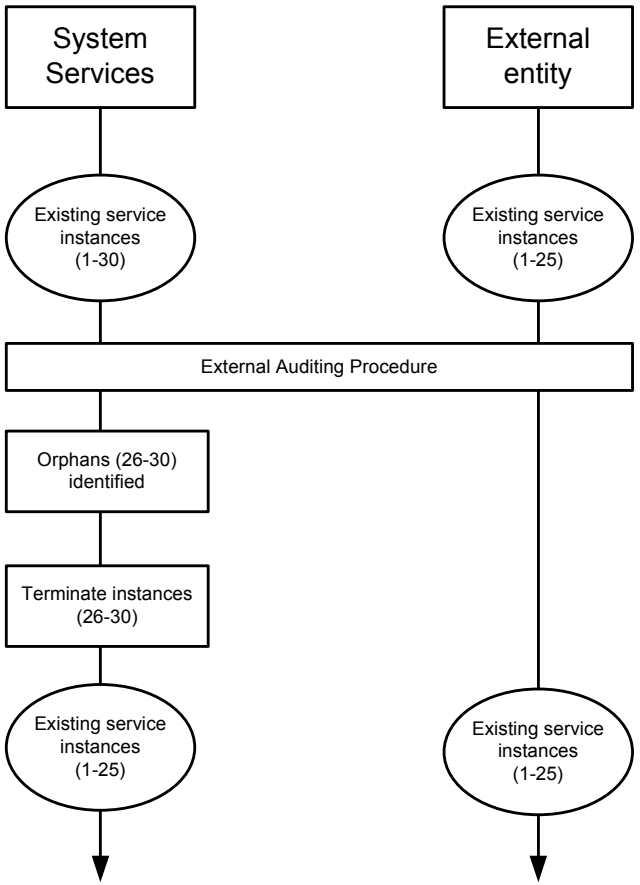


HA framework – post-failover cleanup procedure

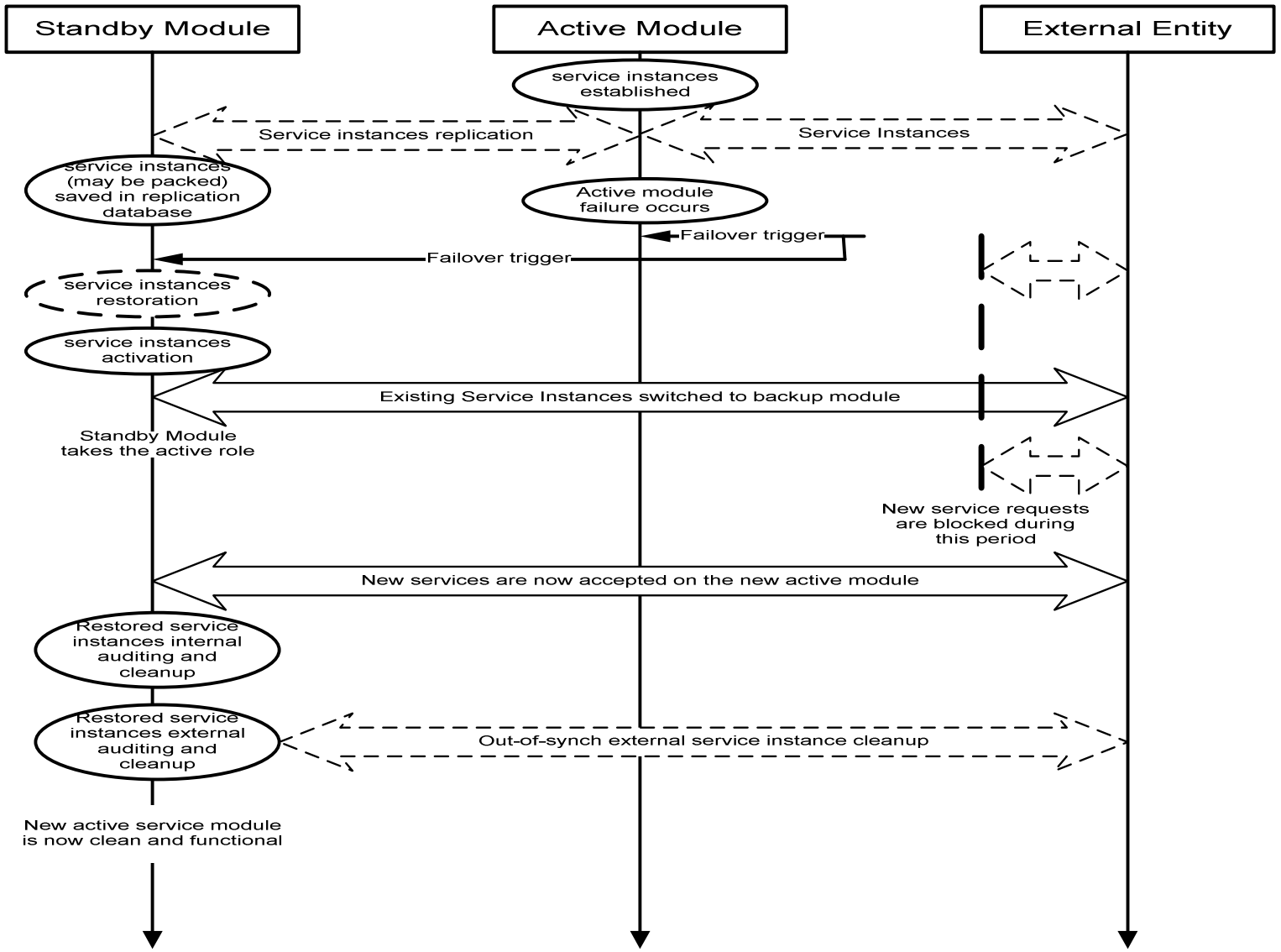
- Cleanup all orphan application contexts
  - Internal cleanup



  - External cleanup



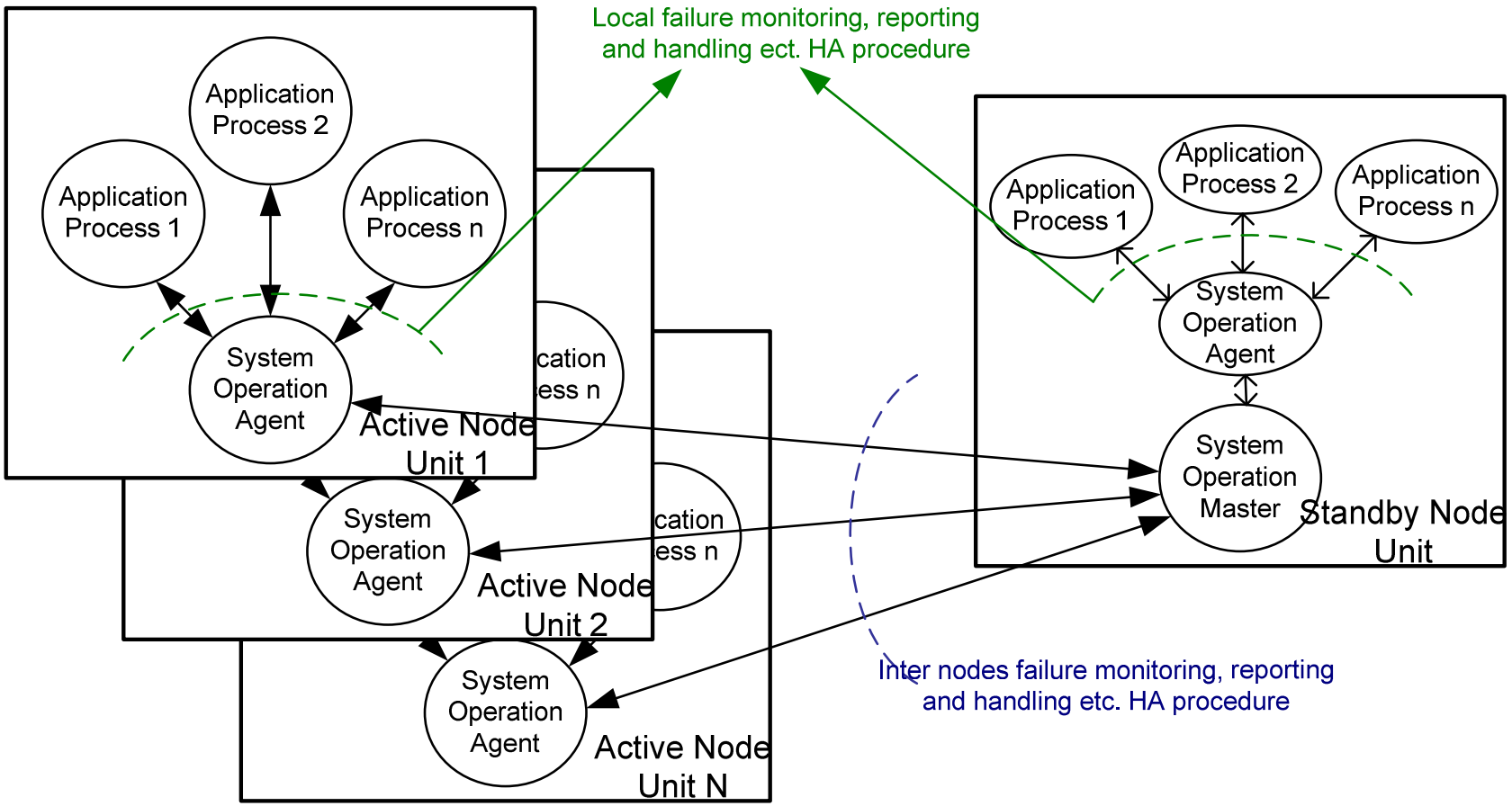
HA framework – procedures overview



System Operation Component

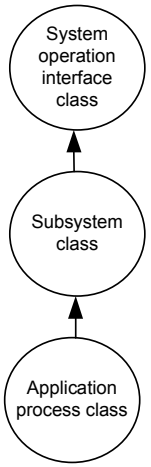
- **HA framework functions**
  - Error condition reporting interface
  - Local application process operation status monitoring
    - Heartbeat (Application ←→ system operation agent)
  - HA data replication interface
  - HA control
    - Heartbeat (Active ←→ standby nodes)
    - Process restart on failure
    - node restart / reboot
    - Failover control
    - Standby role relay
  - Replication data transportation and storage
- **A distributed component**
  - Application interface (part of each application process)
  - System Operation Agent (process running in active nodes)
  - System Operation Master (process running in standby node)
- **Provide generic HA services to applications via APIs**

System Operation Component

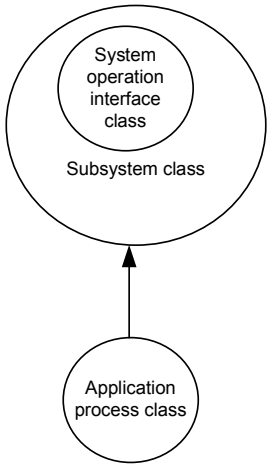


System Operation Application Interface

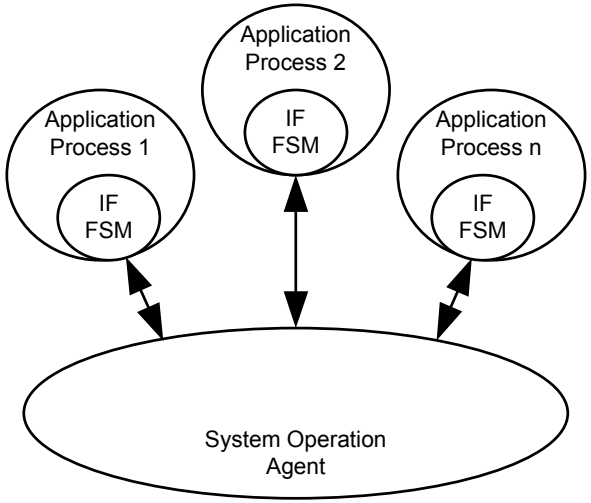
- **Generic HA interface class**
  - Provide all HA APIs to application processes
  - Implementation
    - Base class of subSystem class or
    - A class member of subSystem class
  - FSM core
    - Interface with local System Operation Agent to monitor application operation status
    - Transport application operation status reports and replication data
    - Execute HA control commands



System operation interface class as the base class of subsystem class



System operation interface class as a member of subsystem class



System Operation Application Interface

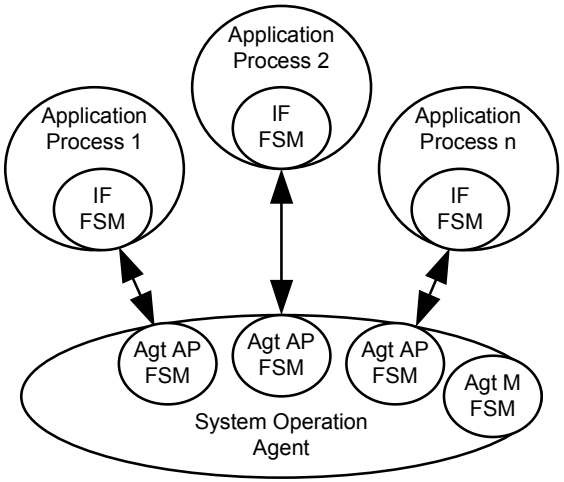
- **Functions**
  - Aggregates local operation status of the monitored application process and reports to the controlling system operation agent.
  - Provides heartbeat mechanism between application process and its controlling system operation agent process, responses to requests from the controlling agent.
  - Replicates application process data to standby node via its controlling agent.
  - Reacts to various commands from the controlling agent, such as
    - Application process stop. This command will force the application process to exit.
    - Application process restart. This command will force the application process to restart.
    - System operation interface role setting. This command will set the active/standby role of the system operation interface.
    - Switchover. This command can be triggered by either a manual switchover request or a failure caused failover, and will suspend all application process data replication in an active node and start the switchover procedure in the standby node.

System Operation Application Interface

- **Application Interface FSM**
  - States definitions
    - SO_IF_ST_NULL: system operation interface NULL state.
    - SO_IF_ST_CONNECTED: IPC connection to the controlling system operation agent established
    - SO_IF_ST_ASSOCIATED: system operation master-agent association establishment notification received.
    - SO_IF_ST_ACTIVE: role setting request (ACTIVE) received from the agent
    - SO_IF_ST_STANDBY: system operation interface is in full functional state but plays the standby role
    - SO_IF_ST_SWITCHING: in process of switching from standby role to active role.
    - SO_IF_ST_SWITCHED: switch-over done, waiting for passing standby role on
  - Events definitions
    - SO_IF_EV_AGT_CONNECT: system operation agent IPC connection event.
    - SO_IF_EV_AGT_DISCONNECT: system operation agent IPC disconnection event.
    - SO_IF_EV_AGT_ASSOC_UP: system operation agent-master association establishment notification event
    - SO_IF_EV_AGT_ASSOC_DOWN: system operation agent-master association breakdown notification event
    - SO_IF_EV_AGT_STATUS_REQ: application process operation status request from system operation agent
    - SO_IF_EV_AGT_STOP_REQ: application process stop request received from system operation agent. This event will cause the application process to exit.
    - SO_IF_EV_AGT_RESTART_REQ: application process operation restart request received from system operation agent. This event will cause the application process to restart.
    - SO_IF_EV_AGT_REPLICATION_RSP: replication response received from the system operation agent.
    - SO_IF_EV_AGT_ROLE_REQ: role setting request received from system operation agent.
    - SO_IF_EV_AGT_SWITCHOVER_UREQ: unacknowledged failover/switchover request received from system operation agent (can be of restoration, activation, auditing and cleanup etc. different action types)
    - SO_IF_EV_AGT_SWITCHOVER_DONE: failover/switchover done notification received from system operation agent.
    - SO_IF_EV_REPLICATION_TO: application process replication timeout event.
    - SO_IF_EV_ERROR_TO: application process error report timeout event.
    - SO_IF_EV_HEARTBEAT_TO: application process heartbeat timeout event

System Operation Agent

- **A process running in every node**
  - Both active and standby
  - Aggregate local operation status and report to system operation master
  - Deliver application replication data to replication repertory
  - Pass HA related commands from system operation master to application processes
- **Implementation**
  - Dual FSMs – to simplify the control logic
  - Application side FSM interfaces with application interface FSM
  - Master side FSM interfaces with system operation master



System Operation Agent

- **System Operation Agent Application Side FSM**
  - States definitions
    - SO_AGT_APP_ST_NULL: the very initial state
    - SO_AGT_APP_ST_ACTIVE: the system operation agent application side state-machine instance has established the IPC connection with the corresponding application process
  - Events definitions
    - SO_AGT_APP_EV_CONNECT: IPC connection to managed application process established.
    - SO_AGT_APP_EV_DISCONNECT: IPC connection to managed application process torn down.
    - SO_AGT_APP_EV_START_IND: start indication received from application process
    - SO_AGT_APP_EV_STATUS: status update received from application process. This message also serves as the heartbeat message.
    - SO_AGT_APP_EV_ERROR: error report received from application process
    - SO_AGT_APP_EV_STATUS_CFM: status confirmation reply received from application process.
    - SO_AGT_APP_EV_STOP_UIND: unacknowledged stop indication received from application process
    - SO_AGT_APP_EV_RESTART_UIND: unacknowledged restart indication received from application process
    - SO_AGT_APP_EV_STOP_CFM: stop confirmation reply received from application process
    - SO_AGT_APP_EV_RESTART_CFM: restart confirmation reply received from application process
    - SO_AGT_APP_EV_ROLE_CFM: role set confirmation received from application process
    - SO_AGT_APP_EV_REPLICATION_IND: replication request received from application process
    - SO_AGT_APP_EV_REQUEST: request sent to application process
    - SO_AGT_APP_EV_REQUEST_TO: request timeout event
    - SO_AGT_APP_EV_HEARTBEAT_TO: heartbeat timeout event

System Operation Agent

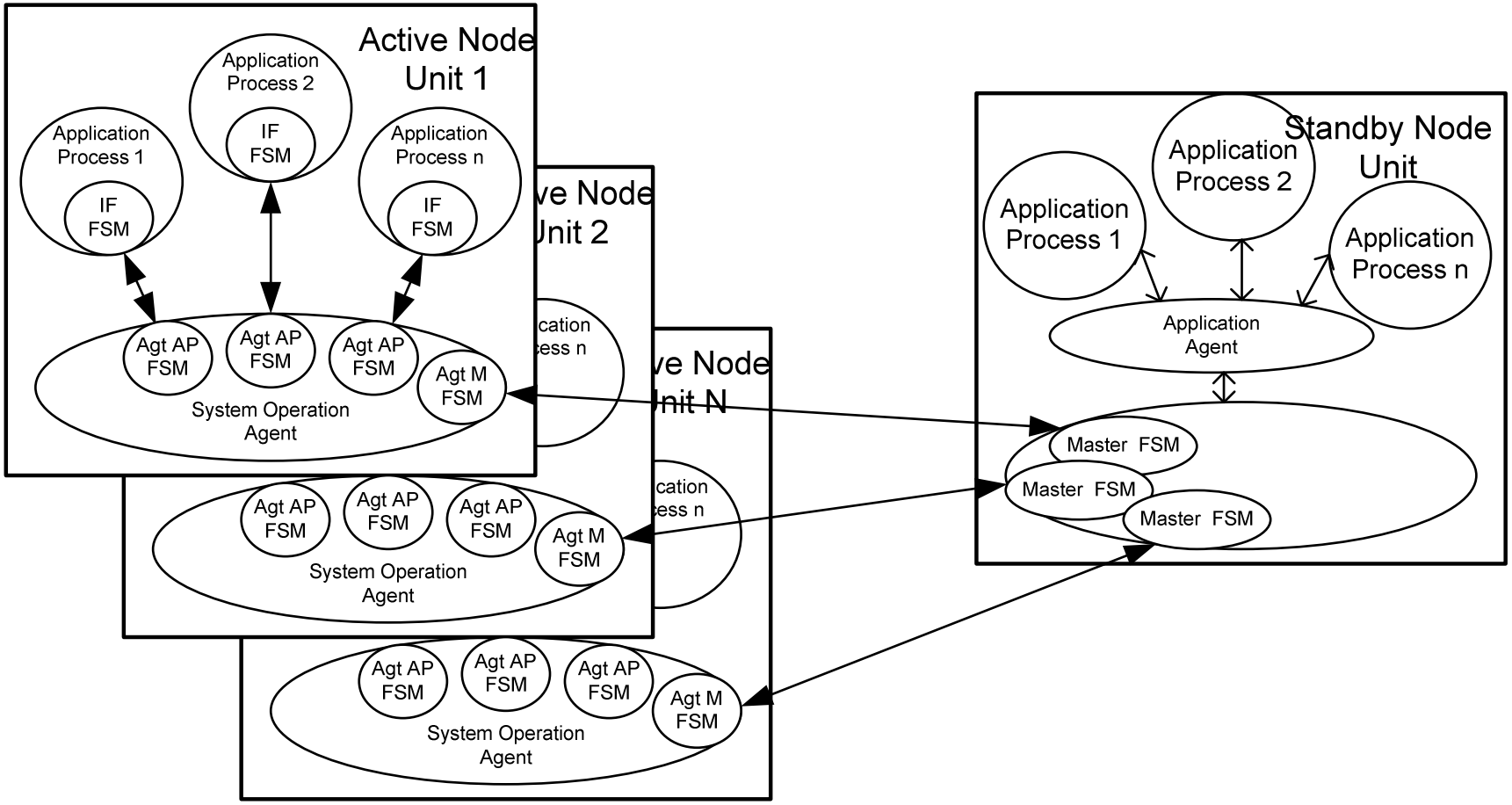
- **System Operation Agent Master Side FSM**
  - **States definitions**
    - SO_AGT_MST_ST_NULL: the very initial state
    - SO_AGT_MST_ST_ASSOCIATED: IPC connection to system operation master established
    - SO_AGT_MST_ST_ACTIVE: “active” role setting command received from system operation master
    - SO_AGT_MST_ST_STANDBY: “standby” role setting command received from system operation master
    - SO_AGT_MST_ST_SWITCHING: system operation agent is in failover/switchover process
    - SO_AGT_MST_ST_SWITCHED: switchover done, waiting for pass standby role on to new standby unit
  - **Events definitions**
    - SO_AGT_MST_EV_CONNECT: IPC connection to system operation master established.
    - SO_AGT_MST_EV_DISCONNECT: IPC connection to system operation master broken.
    - SO_AGT_MST_EV_STATUS_REQ: operation status request from system operation master
    - SO_AGT_MST_EV_STOP_REQ: stop request received from system operation master. This event will cause the node to shutdown.
    - SO_AGT_MST_EV_RESTART_REQ: restart request received from system operation master. This event will cause the node to reboot/restart.
    - SO_AGT_MST_EV_REPLICATION_RSP: replication response received from system operation master
    - SO_AGT_MST_EV_BATCHREP_REQ: batch replication start request received from system operation master
    - SO_AGT_MST_EV_ROLE_REQ: role setting request received from the system operation master.
    - SO_AGT_APP_EV_SWITCHOVER_UREQ: unacknowledged switchover request from system operation master.
    - SO_AGT_APP_EV_SWITCHOVER_DONE: failover/switchover done event
    - SO_AGT_APP_EV_REPLICATION_IND: replication indication received from the application side
    - SO_AGT_MST_EV_HEARTBEAT_TO: heartbeat timeout event

System Operation Master

- **A process running on standby node**
  - Monitors the operation status and healthiness of all active nodes within the redundancy cluster
  - Aggregates service context replication data from all active node and save into the replication repertory
  - Manages replication repertory functions, including
    - Replication data record addition, deletion, modification etc.
    - Replication data compression or decompression if necessary
  - Initiates the failover procedure on active node failure event
  - Terminates and handles administrative commands from network administrator
    - Shutdown a node within the redundancy cluster
    - Restart a node within the redundancy cluster
    - Trigger a manual switchover between the standby node and any one of the active nodes within the redundancy cluster
  - Executes and controls failover/switchover procedure
    - Restoration
    - Activation
    - Auditing
    - Cleanup
  - Passes the standby role to new standby node after failover/switchover

System Operation Master

- **An FSM core**
  - Interface with all system operation agents in the HA cluster



System Operation Master

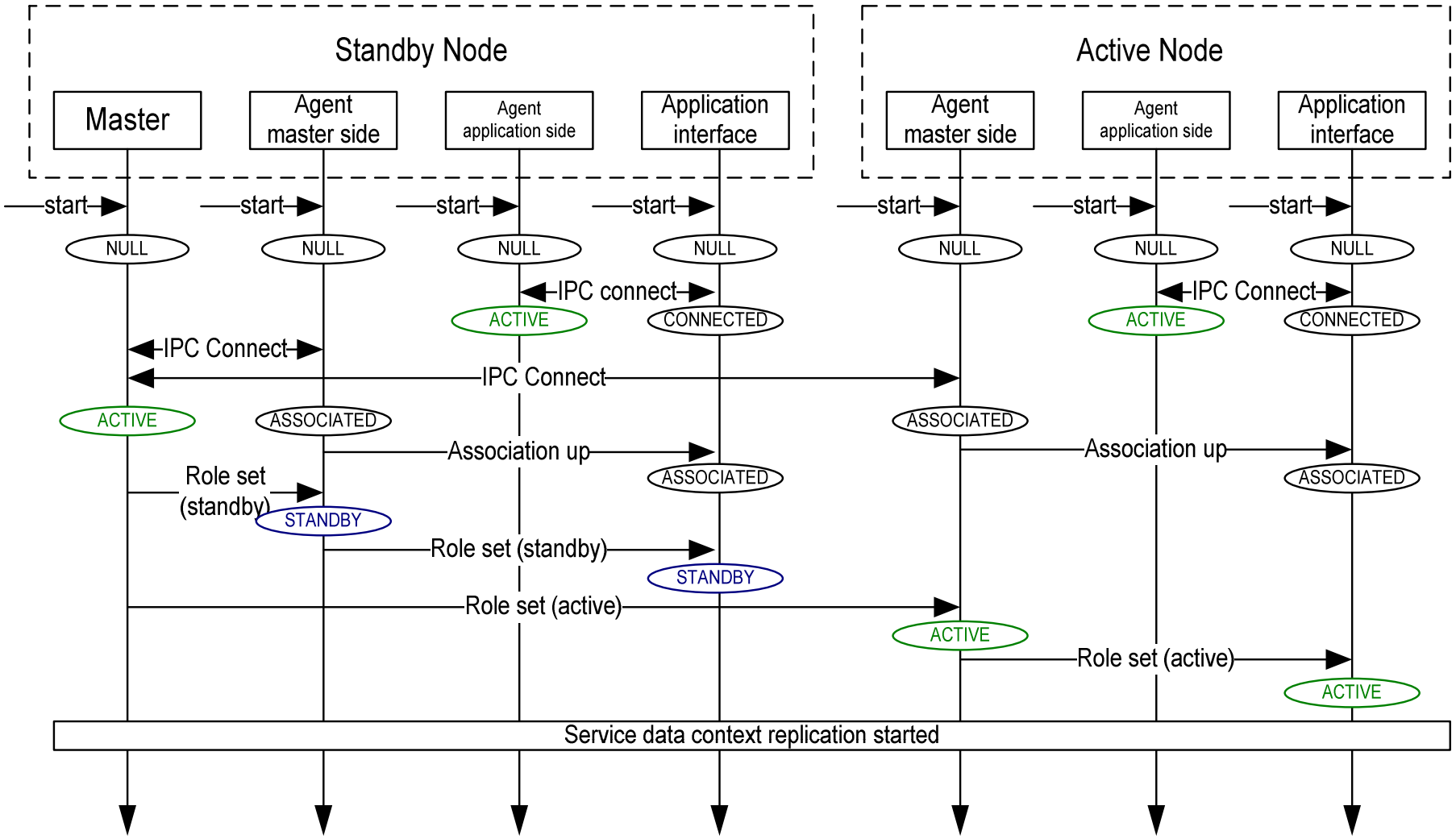
- **System Operation Master FSM**
  - States definitions
    - SO_MST_ST_NULL: the very initial state
    - SO_MST_ST_ACTIVE: system operation master instance has connected with the corresponding agent and is ready to act all designed functions.
    - SO_MST_ST_SWITCHING: in process of failover/switchover
    - SO_MST_ST_ SWITCHED: the post-failover/switchover state, waiting for passing control to the new system operation master in the new standby node when available

System Operation Master

- **System Operation Master FSM**
  - **Events definitions**
    - SO_MST_EV_CONNECT: IPC connection to agent established
    - SO_MST_EV_DISCONNECT: IPC connection to agent down.
    - SO_MST_EV_START_IND, start indication received from the agent
    - SO_MST_EV_STATUS: status update received from the agent, this is the heartbeat message from the agent
    - SO_MST_EV_ERROR: error report received from the agent
    - SO_MST_EV_STATUS_CFM: status confirmation received from the agent, this is the reply to a master issued status request.
    - SO_MST_EV_STOP_UIND: unacknowledged agent stop indication received. This is an indication from the agent on the shutting down.
    - SO_MST_EV_RESTART_UIND: unacknowledged agent restart indication received. This is an indication from the agent on the rebooting.
    - SO_MST_EV_STOP_CFM: agent stop confirmation received. This is the reply to a master issued stop request.
    - SO_MST_EV_RESTART_CFM: agent restart confirmation received. This is the reply to a master issued restart request.
    - SO_MST_EV_AGT_ROLE_CFM: setting role confirmation received from system operation agent. This is the agent reply to a master issued role setting request.
    - SO_MST_EV_REPLICATION_IND: agent replication indication received. This is the message containing the replication data.
    - SO_MST_EV_STOP_AGT_REQ: high level request to stop an agent. This request will cause the targeted node to shut down.
    - SO_MST_EV_RESTART_AGT_REQ: high level request to restart an agent. This request will cause the targeted node to reboot/restart.
    - SO_MST_EV_SWITCHOVER_REQ: high level switchover request. This request will trigger a failure caused failover or a manual switchover.
    - SO_MST_EV_SWITCHOVER_DONE: switchover done event.
    - SO_MST_EV_HEARTBEAT_TO: heartbeat timeout event
    - SO_MST_EV_REQUEST_TO: request timeout event

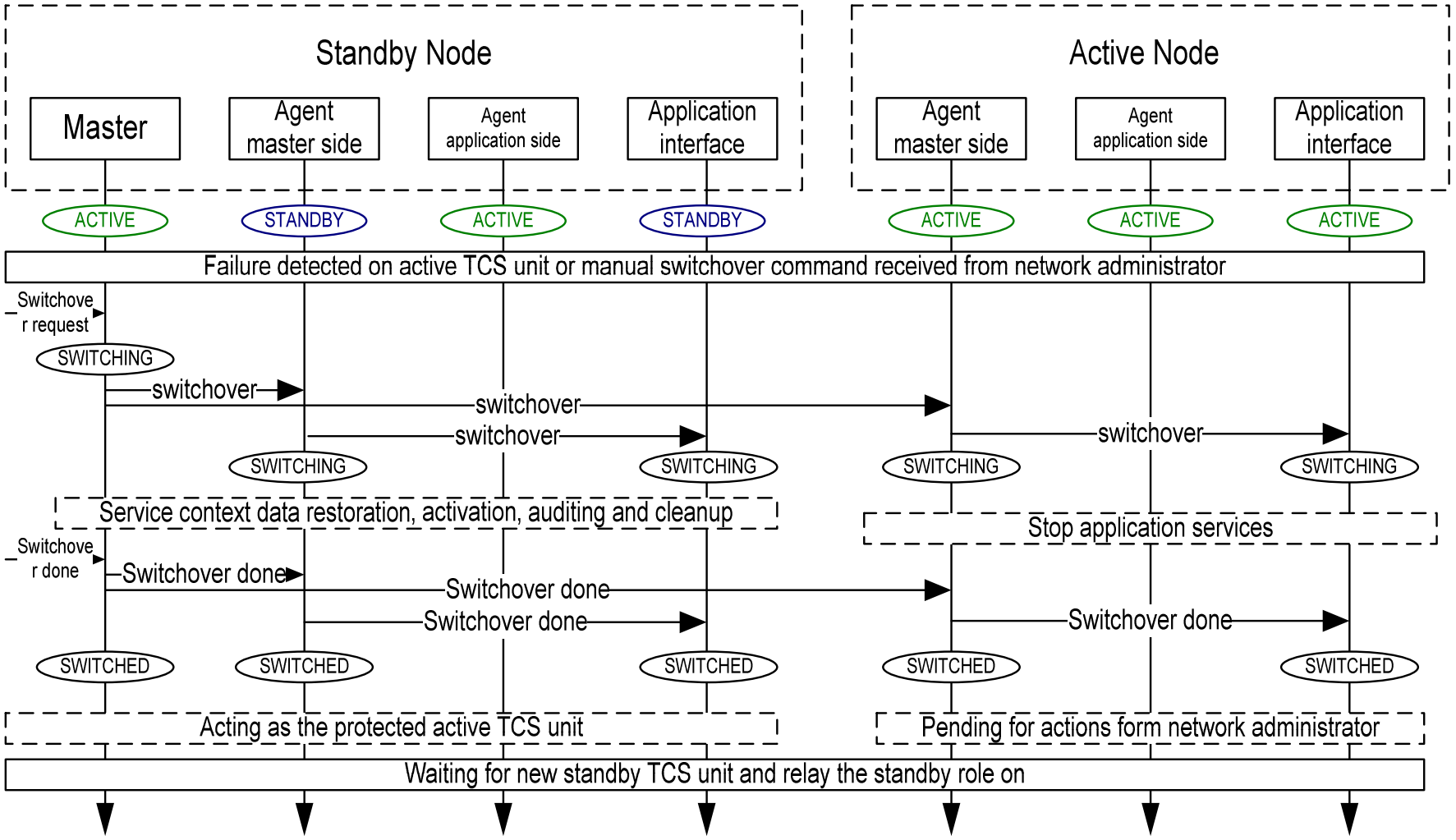
System Operation Component Interaction Overview

- ## System Operation Component Startup Procedure



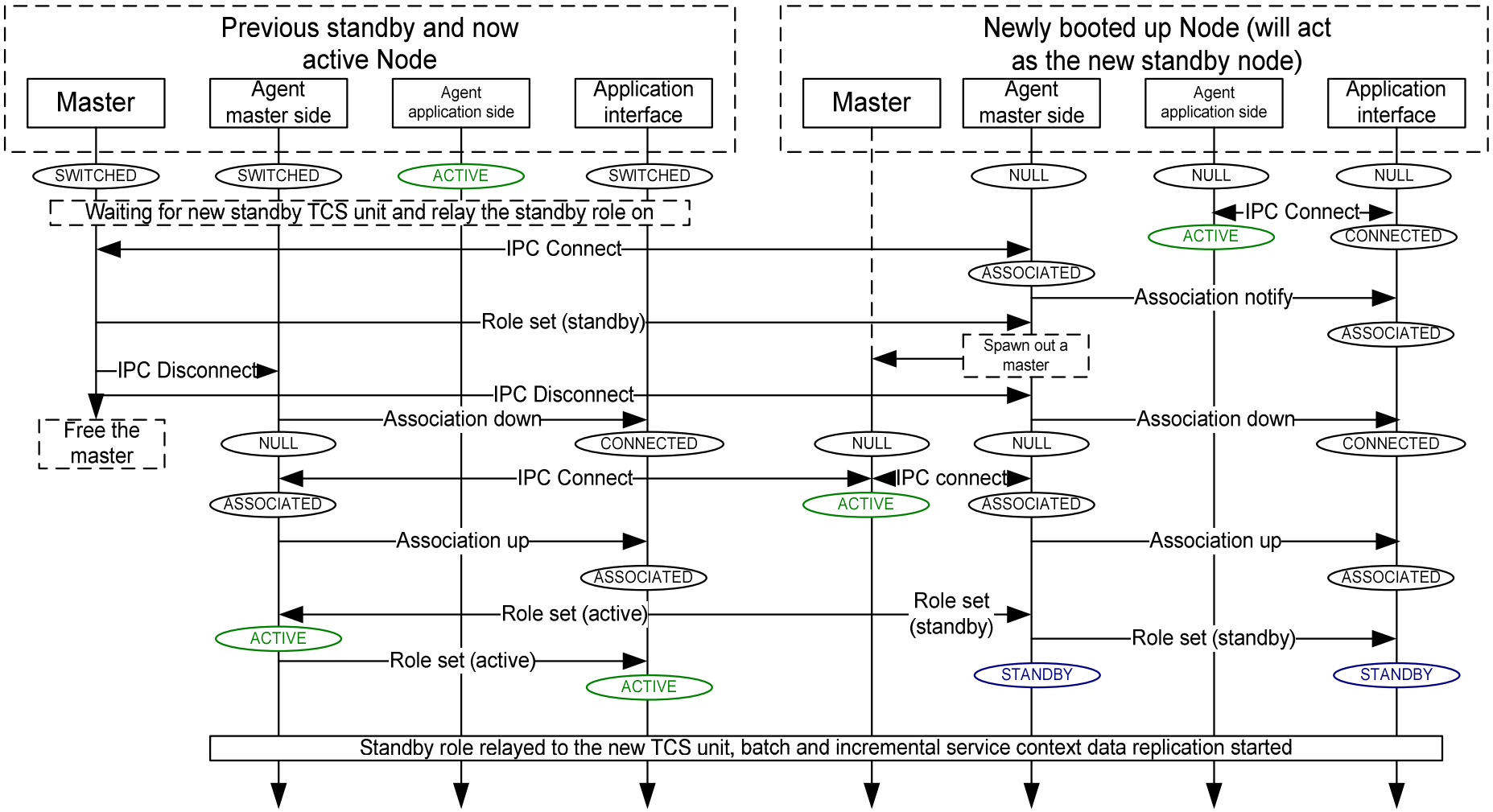
System Operation Component Interaction Overview

- **Switchover/failover procedure**



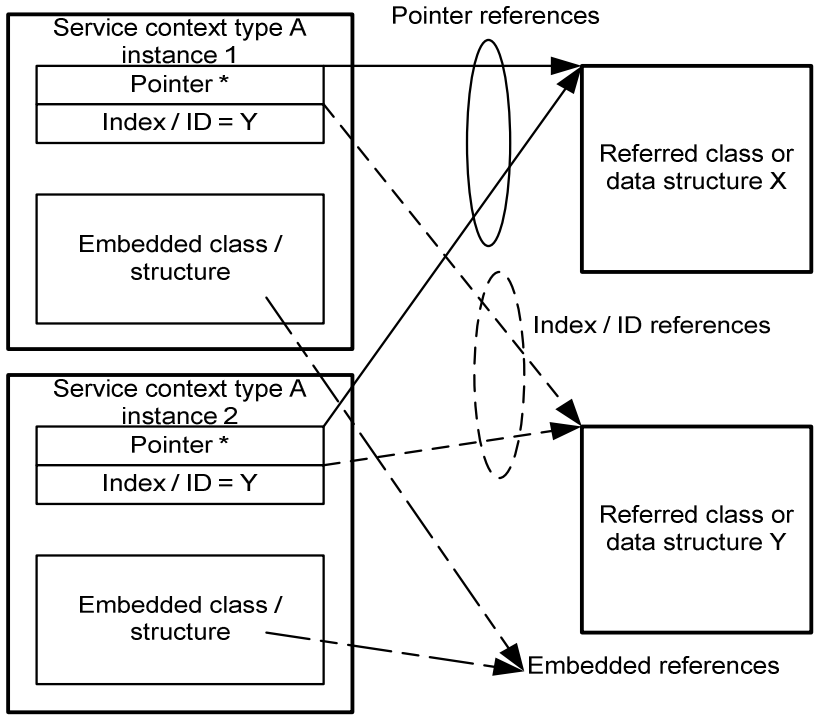
System Operation Component Interaction Overview

- **Standby role relay procedure**



System Application Contexts

- **Application Specific Contexts need to be preserved for HA**
  - SIP subscriber contexts
  - SIP call control contexts
    - Regular calls
    - Emergency calls
  - SMS contexts (??)
  - CMonitor and CDR contexts
  - Diameter Base Node Contexts
    - Stateful sessions: session state context
    - Stateless sessions: pending request queue
  - SS7 VLR contexts
    - Request queue
    - Subscriber ID map
    - Device ID map
- **Referenced Context replication**
  - Handlings of reference pointers
  - Handlings of reference indexes
  - Handlings of embedded contexts
  - Separate from the replication of referencing contexts
- **Applications to make decisions on**
  - What are to be replicated
  - Definition of replication data structure
- **Replication coordination and synchronization**

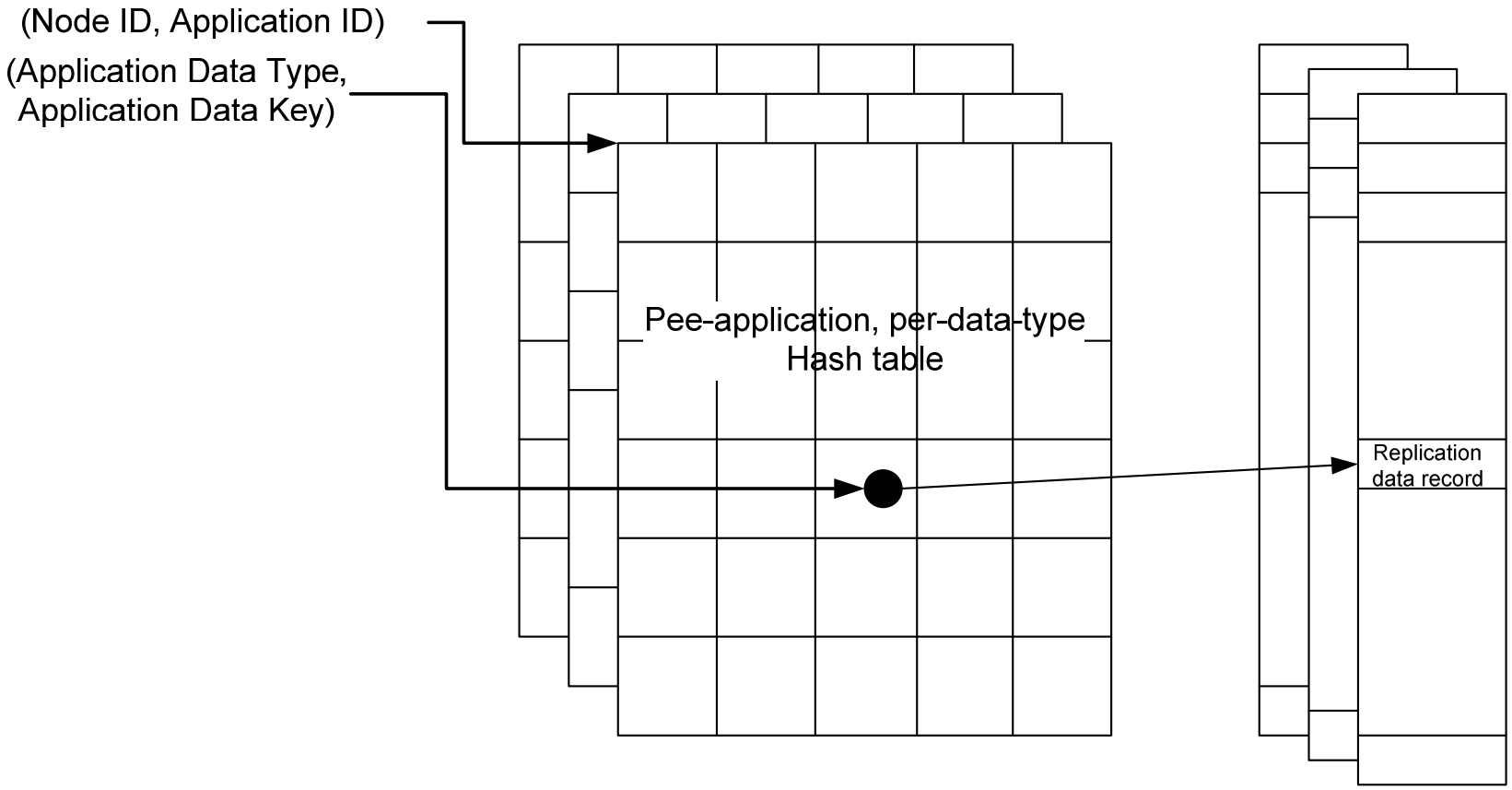


System Replication Checkpoints

- **General roles are**
  - Add replication when entering “stable” state(s)
  - Delete replication when leaving ‘stable” state(s)
  - Modify replication only when necessary (optional)
- **Stable states definitions are very component specific**
- **Special replication handling**
  - Emergency call context replication
- **System application specific checkpoints**
  - Subscriber: stable state “registered”
  - Call control: stable state “active”
  - Diameter Base Node
    - Stateless session: request queue
    - Stateful session: session state
  - VLR

Replication Repertory

- **Multiple Hash tables**
  - Node ID and application ID are used to index to the hash table
  - Application data type and data key are used as hash key



HA APIs

- **Implemented in System operation application interface class**
- **For applications to access HA framework services**
- **APIs**
  - HA registration API. Used for application to register with the HA framework for HA services
  - HA replication API. A generic API called at application checking points to deliver application specific replication data to HA framework for replication
    - Addition, Deletion, Modification
  - HA error report API. An API to be called by application to reported the encountered error condition to the HA framework
  - HA command handler API. An API for HA framework to deliver command to applications.
  - HA failover/switchover API: an API used by HA framework to trigger the application specific failover/switchover procedures on the standby node.