OPENFABRICS ALLIANCE

Prototyping Byte-Addressable NVM Access

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11th ANNUAL INTERNATIONAL OPENFABRICS SOFTWARE DEVELOPERS' WORKSHOP

Agenda

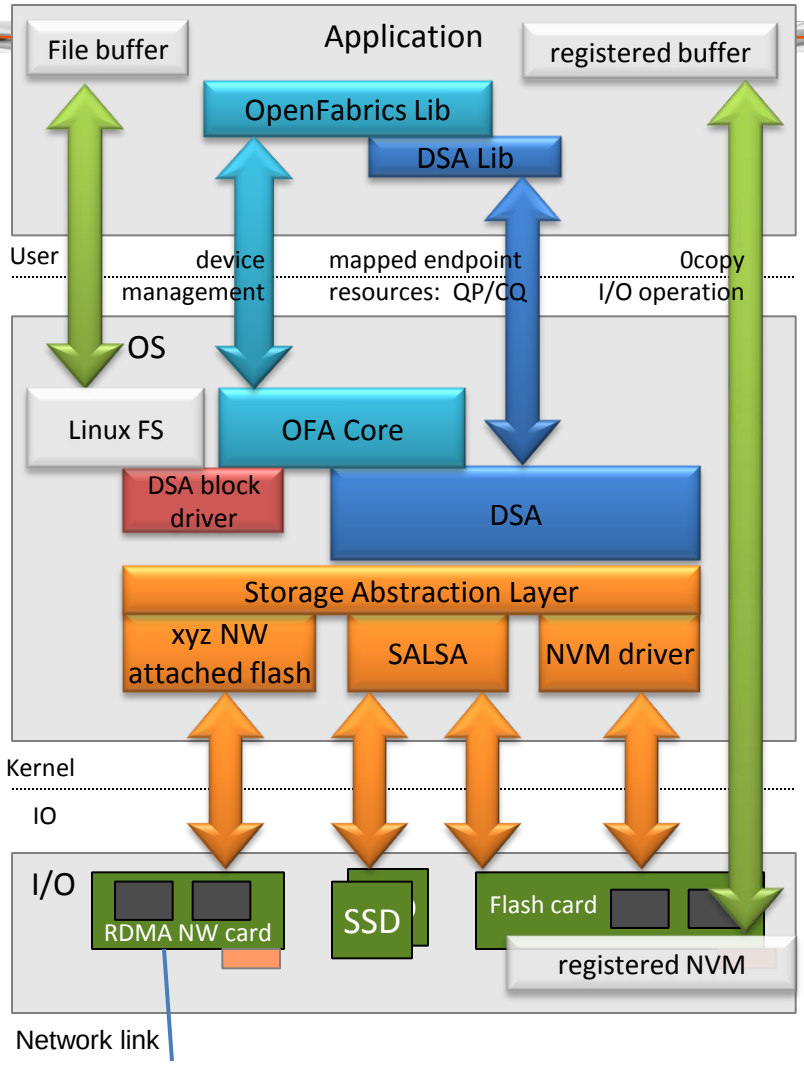
- NVM host integration
  - Status quo of DSA development
  - The Storage Abstraction Layer
  - OFA DSA user interfaces
  - Other user interfaces
- NVM/RDMA networking integration
  - Example prototypes
- Findings: New OFA interface requirements
- Outlook

Recap from 2014

- Idea: Use OFA stack for local NVM access
  - Integrate with OFA as just another verbs provider
- Benefits
  - ✓ Application private device channel (virtually unlimited number)
  - ✓ Deep request queues / async. operations
  - ✓ Byte-level I/O
  - ✓ OFA Verbs API: well established interface
- Issues
  - Inflexible memory registration/re-registration
  - RDMA network access

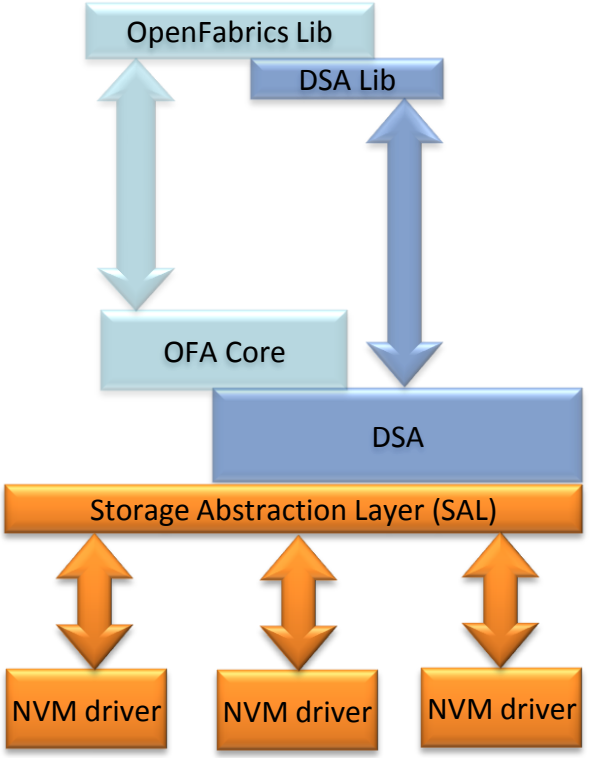
Host Integration: DSA

- Integrates with **OpenFabrics** industry standard environment
- **Direct Storage Access** Driver (**DSA**)
  - 'DSA' OFA module and 'libdsa' library
  - Provides RDMA API for access to all integrated flash resources at byte granularity
- **Storage Abstraction Layer**
  - Abstracts from device specifics
  - Exports flash partitions
  - Device I/O attached (local or network)
- **Block Layer** OFA kernel verbs client
  - Supports legacy block I/O to NVM devices



SAL: Storage Abstraction Layer

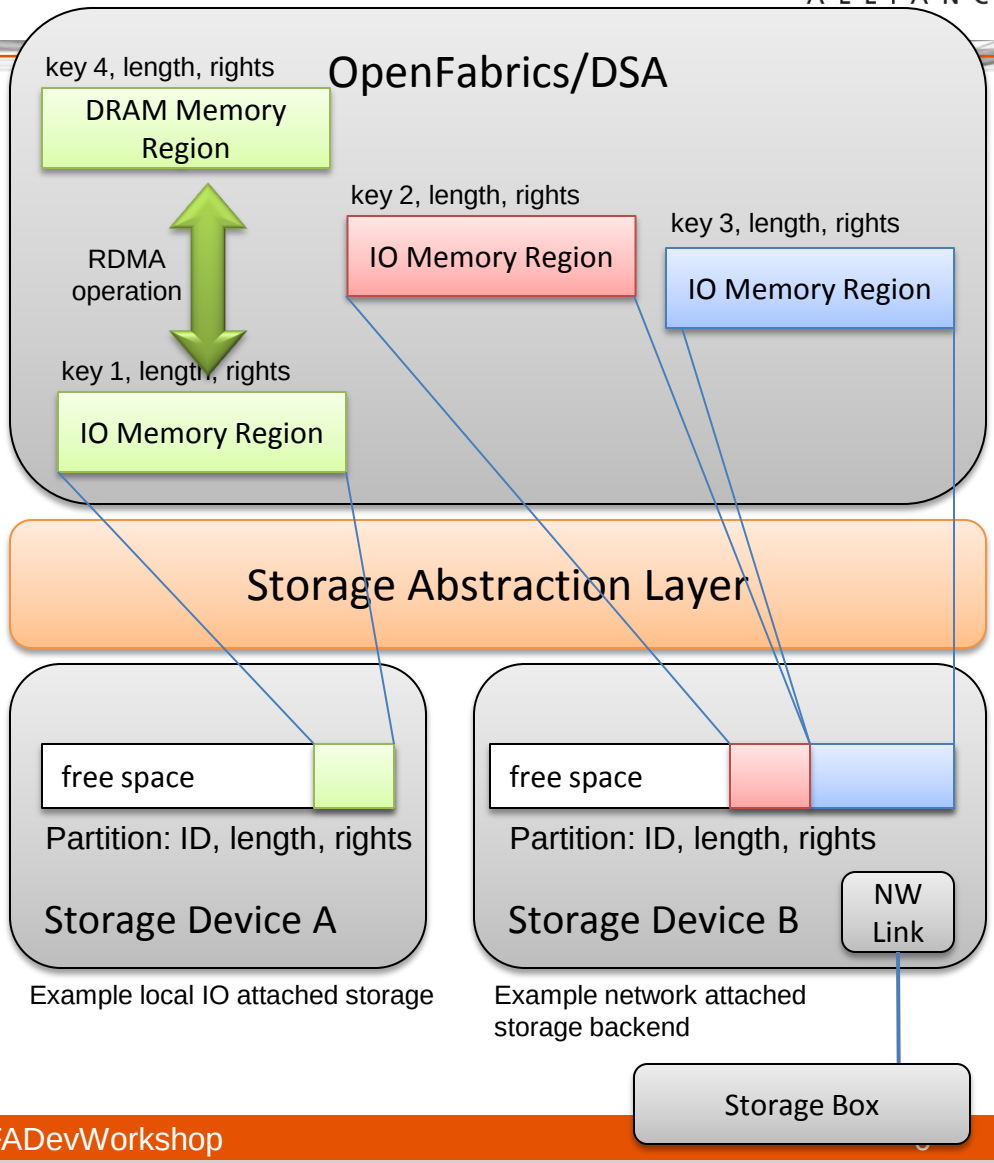
- Storage device interface
  - Upcalls:
    - register/unregister device
    - register/unregister/change partition
    - I/O and command completion(rv, *ctx)
    - publish_region(*part, *attrs)
  - Downcalls:
    - sal_write(*part, off, len, *sl, *ctx)
    - sal_read(*part, off, len, *sl, *ctx)
    - sal_trim(*part, off, len, flags, *ctx)
    - sal_reg_region(*part, *attrs)
    - sal_modify_region(*part, *attrs)
    - sal_dereg_region(*part)



  - All fast path operations share context with provider
    - Context with provider and caller private regions
    - Aim at cache and multi-core efficiency

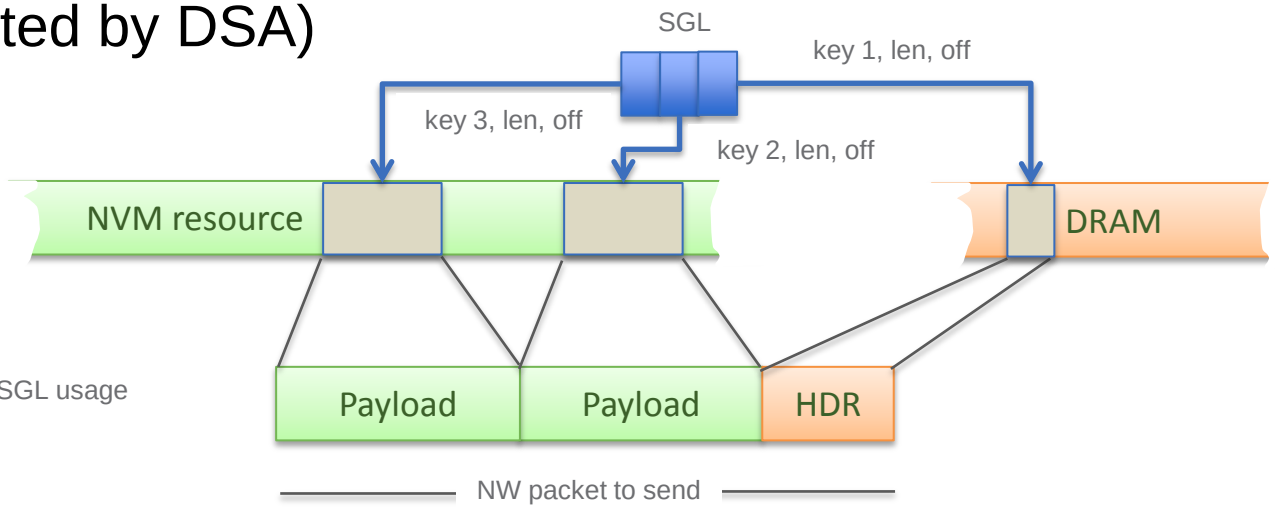
SAL: Maintaining NVM Resources

- All storage providers register with Storage Abstraction Layer
  - Provider resource representation: Partition [ID, length, rights]
  - SAL exposes resources at /sys fs
- Storage resource reserved with OFA subsystem: ibv_reg_mr() call
  - Same as local DRAM registration
  - Flash and local DRAM can be source or sink of any RDMA operation
  - Will allow for flash-to-flash read/write operations
- Kernel DSA clients have function call/RPC interface (not shown here)
- DSA/SAL maps between RDMA key, len, off and partition ID, off, len
  - During registration
  - On any data operation, enforces protection



DSA Application Interface: Referencing NVM resources

- Nothing different from DRAM access
  - NVM resource described by [key, off, len]
- Single key space shared with DRAM reservations
  - Both DRAM and (IO) NVM are registered with DSA
  - On the fast path, DSA detects memory type by key
  - SGL support: WR's with mixed SGL's possible (not yet supported by DSA)



Example mixed SGL usage

Register Memory with mmap()/VA


```
root@borus:/sys/class/infiniband# ls
dsa0
root@borus:/sys/class/infiniband# ibv_devices
    device                 node GUID
    ------              ----------------
    dsa0                6473613000000000
```

- DSA/SAL : Storage resources in /sys file system
- User
  - `fd = open(/sys/……/partitions/f1/memory, O_RDWR)`
  - `va1= mmap(NULL, 40960, PROT_NONE, fd, 0)`
  - Takes va1 to DSA OFA device for registration:
    `mr1 = ibv_reg_mr(dsa_pd, va1, …)`
  - Registers source/target va2 in DRAM:
    `mr2 = ibv_reg_mr(dsa_pd, va2, …)`
  - Makes and connects Queue Pair within DSA
  - Posts READ/WRITE RDMA operations: src=mr1, trgt=mr2
  - Reaps work completions
  - Persistent reservations can be replayed at system boot

- Extensible for
  - storage <-> storage transfers
  - Direct load/store into IO mem (work in progress)

```
root@borus:/sys/class/iomem/scm_0# find .
.
./ctrl_if
./power
./partitions
./partitions/f0
./partitions/f0/id
./partitions/f0/free
./partitions/f0/perm
./partitions/f0/size
./partitions/f0/type
./partitions/f0/areas
./partitions/f0/memory
./partitions/f1
./partitions/f1/id
./partitions/f1/free
./partitions/f1/perm
./partitions/f1/size
./partitions/f1/type
./partitions/f1/areas
./partitions/f1/areas/a0
./partitions/f1/areas/a0/id
./partitions/f1/areas/a0/pid
./partitions/f1/areas/a0/uid
./partitions/f1/areas/a0/perm
./partitions/f1/areas/a0/size
./partitions/f1/memory
./device
./subsystem
./uevent
./dev_desc
./dev_type
root@borus: more ./partitions/f1/areas/a0/size
40960
root@borus:
```

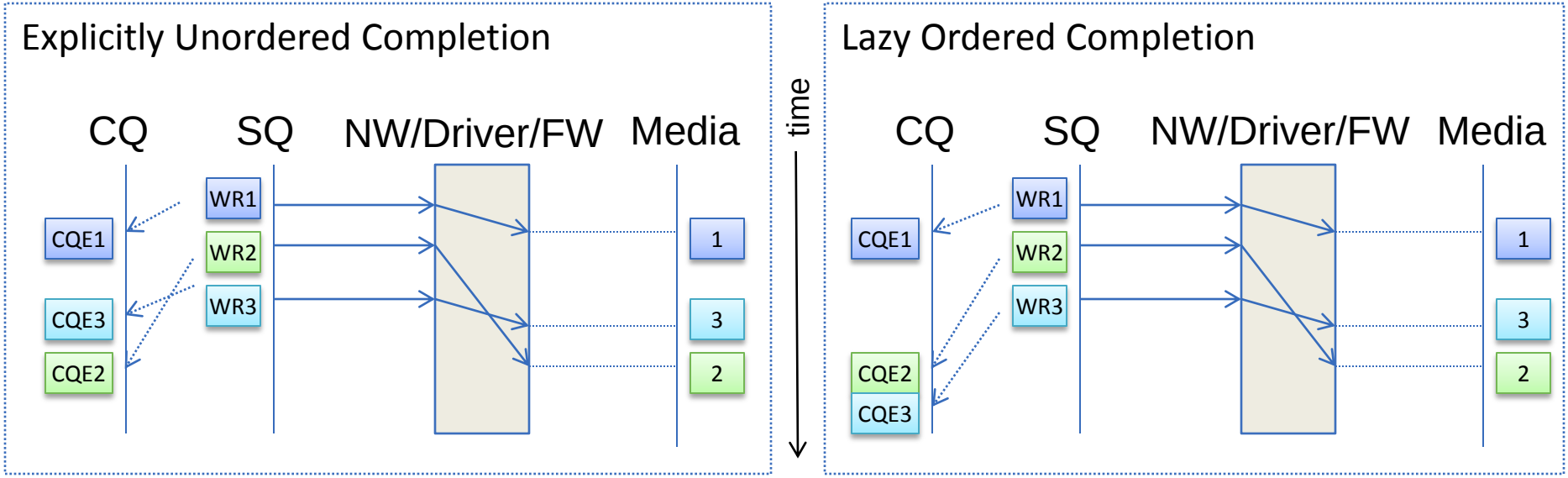
Register Memory w/o VA

Not maintaining a VA may have its merits

1. RPC protocol between application and SAL
   - post_send()/post_receive() between SAL and application
   - RPC's to discover NVM resources and make reservations
   - SAL translates into/from SAL device down calls/upcalls
   - Reservations visible in /sys file system as well
   - Reservation RPC returns key to be used with DSA
   - No VA: zero based addressing for given key
   - Used by kernel clients, supported also at user level
   - RPC mechanism shadows send/receive application usage, tagged mesages would help
2. Alternative: File handle (not VA) for registration
   - Needs extended memory registration semantics
   - `ibv_reg_mr(struct ibv_pd *pd, void *addr, size_t length, int access);`
   - `fi_mr_reg(…);`
   - Not supported yet

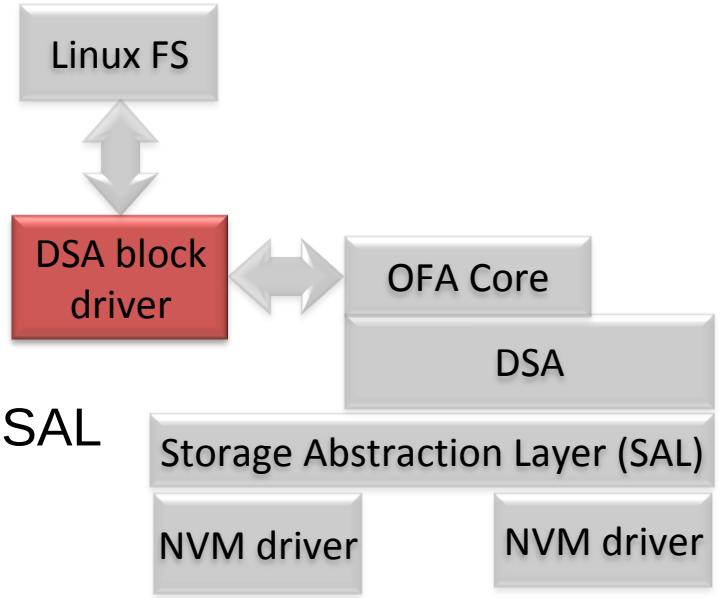
DSA Work Completion Semantics

- Strictly ordered I/O execution/completion:
  not supported by DSA/SAL: application or device duty
- ✓ Lazy Ordered completion: *default*
- ✓ Explicit unordered completion: *work in progress*



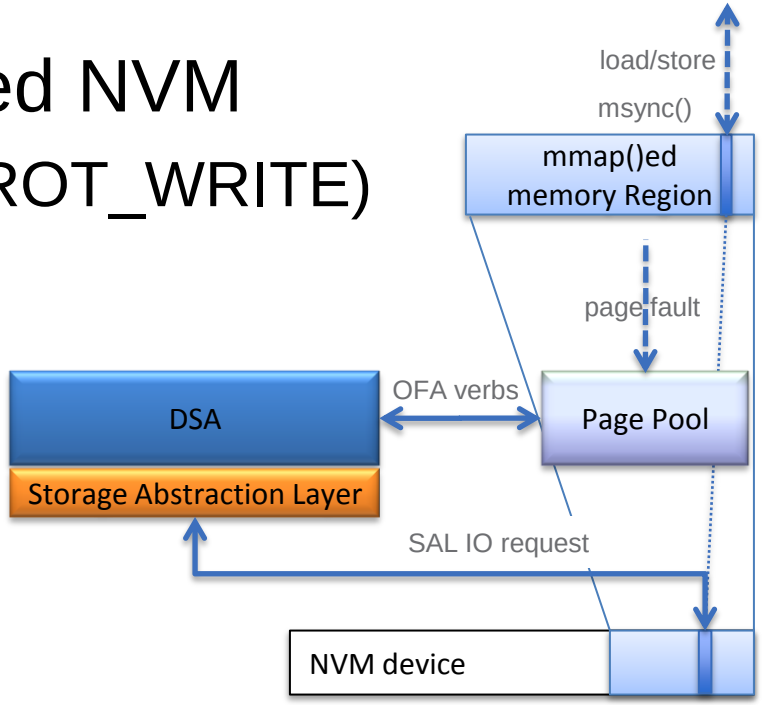
Legacy File I/O Integration: Block IO

- Block Driver: Kernel Verbs client
- Integrates DSA with Linux file system
- Multiple DSA QP's for efficient multi-core support
  - Similar to Multi-Q-BIO
- Memory reservation via RPC protocol with SAL
  - Send/Receive work requests with SAL peer
  - Resource discovery (devices and partitions)
  - Resource reservation (whole partition only)
  - Reservations visible in /sys file system
- I/O throughput similar to user level verbs
- TRIM command supported
  - dsa_rpc_trim(key, flags, length, offset) : currently send WR
  - Asynchronous completion: currently RPC interface: receive WR



DSA: Supporting Load/Store to NVM

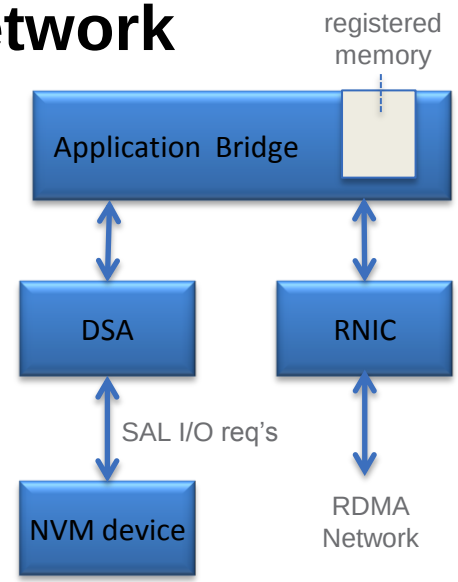
- ✓ File I/O
  - ✓ Supported via DSA block device
- Load/store to mmap()'ed NVM
  - mmap(PROT_READ|PROT_WRITE)
  - Handling page faults
  - Own page pool
  - OFA kernel client
  - Work in progress



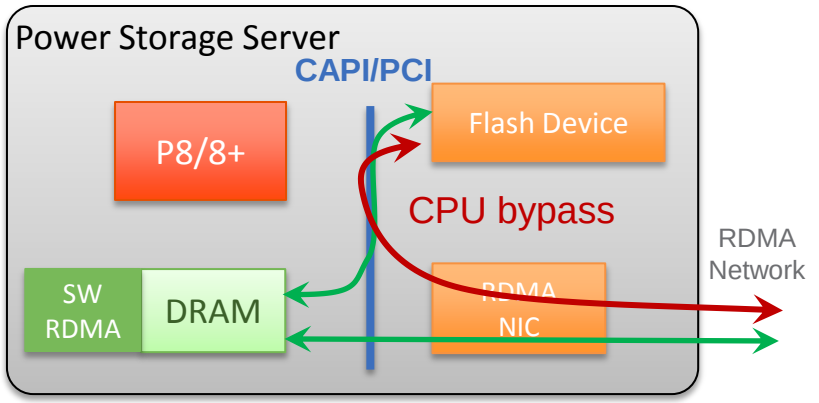
Prototype NVM - RDMA Network Integration

Some ways to integrate NVM with RDMA network

1. Bridging application
   (Breaks end-to-end RDMA semantic)
   1. User- or kernel-level verbs client
      - DRAM buffer registered with DSA and RNIC
      - Tolerable latency (user level app:
        some I/O 65us + RDMA Read 3us + appl. 7us)
   2. read/write mmap'ed file, register with RNIC
      - Would bring in all pages

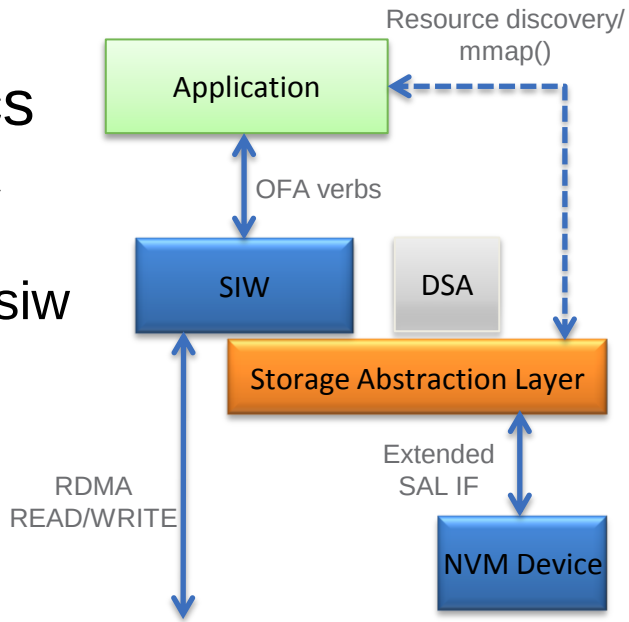


2. Fusing with RDMA NW stack
   1. RDMA/NVM Appliance
   2. In-kernel fusing with software RDMA stack (see next page)



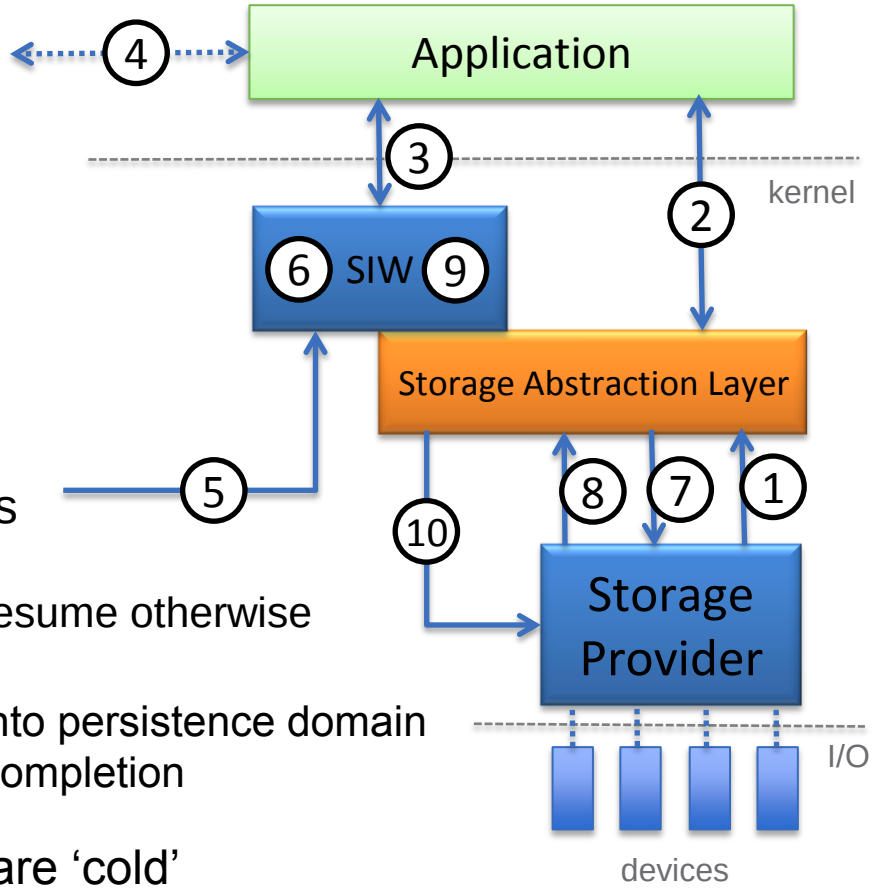
NVM - RDMA Network Integration Prototype

- Splice SoftiWarp with NVM access
- Preserves RDMA end-to-end semantics
  - Application reserves IO memory for RDMA
  - Peer directly accesses via reservation key
  - Direct remote READ/WRITE execution by siw
- Needs extensions
  - RDMA provider (siw)
    - IO memory registration similar to DSA
    - rx + tx path: resolve IO memory, bail/resume
  - SAL interface additions
    - **Downcalls**
      inbound READ/WRITE: `get_iomem(part, off, size, op, *ctx)`
      after read/write finished: `sync()`
      if not longer referenced: `put_iomem_page()`
    - **Upcall**
      complete `get_iomem()`: `get_iomem_callback(err, off, *page, *ctx)`



Example Operation (WRITE)

1. Resource registration with SAL
2. Application mmap() of resource
3. ibv_reg_mr()
4. Resource key passed to peer
5. Peer WRITE access
6. SIW resolves IO mem
7. SAL request get_iomem(), siw bail-out
8. SAL upcalls with IO pages
9. SIW resumes placing data into IO pages
10. sync() with storage provider & put_iomem_page()



- SIW requests/maintains current IO pages
  - Pre-fetching if signaled by DDP
  - Direct placement if page available, stall/resume otherwise
- Local Completion semantics
  - Data 'visible' in provider, or data placed into persistence domain
  - Currently completion if 'visible' since no completion semantics selectable
- Head of line blocking if some I/O pages are 'cold'
  - RDMA UC Service: SIW/UDP version ready to be tested

Findings

- OFA infrastructure good fit for NVM access
- Incomplete wish list of API extensions
  - Re-registration of persistent memory objects
  - Selectable NVM access completion semantics
  - Selectable NVM access completion ordering
  - Registration of NVM w/o VA
  - Zero based addressing from user space
  - Larger key space (currently just 24 bit) preferred
  - Command interface (e.g. explicit Trim support etc.)

Outlook

- NVM integration part of Zurich IBM Research effort for cloud stack optimization (jVerbs, DaRPC, siw, HyV, Peregrine, …)
- DSA open sourcing
  - Will come with example storage provider (fakes NVM device/partitions in DRAM)
  - We will add NVMe/SAL integration
  - Working on load/store interface
- Further work towards NVM/network integration
  - Consider open sourcing siw extensions
  - Experiments with UC RDMA Flash access (UDP based siw/NVM integration as already prototyped for radio-astronomic SKA project)

Thank You

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