OFA Training Program

Writing Application Programs for RDMA using OFA Software

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Agenda – OFA Training Program

- Program Goals
- Instructors
- Programming course format
- Course requirements & syllabus
- UNH-IOL facilities & cluster equipment
- RDMA Benefits
- Programming course examples
- Future courses
- Course availability

OFA Training Program - Overall Goals

- Provide application developers with classroom instruction and hands on experience writing, compiling and executing an application using OFED verbs API
- Illustrate how RDMA programming is different from sockets programming and provide the rationale for using RDMA.
- Focus on the OFED API, RDMA concepts and common design patterns
- Opportunity to develop applications on the OFA cluster at the University of New Hampshire – includes the latest hardware from Chelsio, DDN, Intel, Mellanox, NetApp & QLogic

Instructors

- **Dr. Robert D. Russell**: Professor in the CS Department at UNH
  - Dr. Russell has been an esteemed member of the University of New Hampshire faculty for more than 30 years and has worked with the InterOperability Laboratory's iSCSI consortium, iWARP consortium and the OpenFabrics Interoperability Logo Program.
- **Paul Grun**: Chief Scientist for System Fabric Works
  - Paul has worked for more than 30 years on server I/O architecture and design, ranging from large scale disk storage subsystems to high performance networks. He served as chair of the IBTA's Technical Working Group, contributed to many IBTA specifications and chaired the working group responsible for creating the RoCE specification.
- **Rupert Dance:** Co-Chair of the OFA Interoperability Working Group
  - Rupert helped to form and has led both the IBTA Compliance and Interoperability and OFA Interoperability programs since their inception. His company, Software Forge, worked with the OFA to create and provide the OFA Training Program.

Programming Course Format

- Part One - Introduction to RDMA
  - I/O Architecture and RDMA Architecture
  - Address translation and network operations
  - Verbs Introduction and the OFED Stack
  - Introduction to wire protocols
- Part Two - Programming with RDMA
  - Hardware resources: HCAs, RNICs, etc
  - Protection Domains and Memory Registration keys
  - Connection Management
  - Explicit Queue Manipulation
  - Explicit Event Handling
  - Explicit Asynchronous Operation
  - Explicit Manipulation of System Data Structures

Programming Course Requirements

- Requirements
  - Knowledge of "C" programming including concepts such as structures, memory management, pointers, threads and asynchronous programming
  - Knowledge of Linux since this course does not include Windows programming
- Helpful
  - Knowledge of Event Handlers
  - Knowledge of sockets or network programming
  - Familiarity with storage protocols

Programming Course Syllabus

- Introduction to OFA architecture
  - Verbs and the verbs API
  - A Network perspective
  - RDMA Operations – SEND/RECEIVE, RDMA READ & WRITE
  - RDMA Services
  - Isolation and Protection Mechanisms
  - A brief overview of InfiniBand Management
  - A quick introduction to the OFED stack
  - Host perspective
    - Asynchronous processing
    - Channel vs. RDMA semantics
- Basic Data Structures
  - Connection Manager IDs
  - Connection Manager Events
  - Queue Pairs
  - Completion Queues
  - Completion Channels
  - Protection Domains
  - Memory Registration Keys
  - Work Requests
  - Work Completions

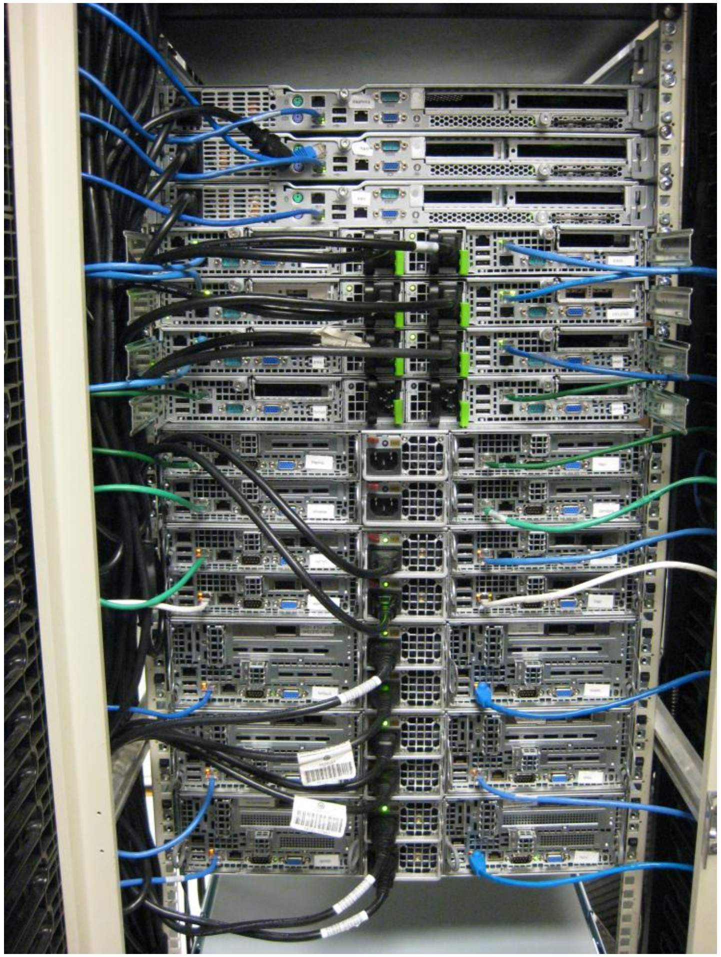
- Connection management basics
  - Establishing connections using RDMACM
  - RDMACM API
- Basic RDMA programming
  - Memory registration
  - Object creation
  - Posting requests
  - Polling
  - Waiting for completions using events
  - Common practices for implementing blocking wait
- Design patterns
  - Send-receive
  - RDMA cyclic buffers
  - Rendezvous
- Advanced topics
  - Work Request chaining
  - Multicast
  - Unsignaled Completions
- RDMA ecosystems
  - Native InfiniBand
  - iWARP
  - RoCE

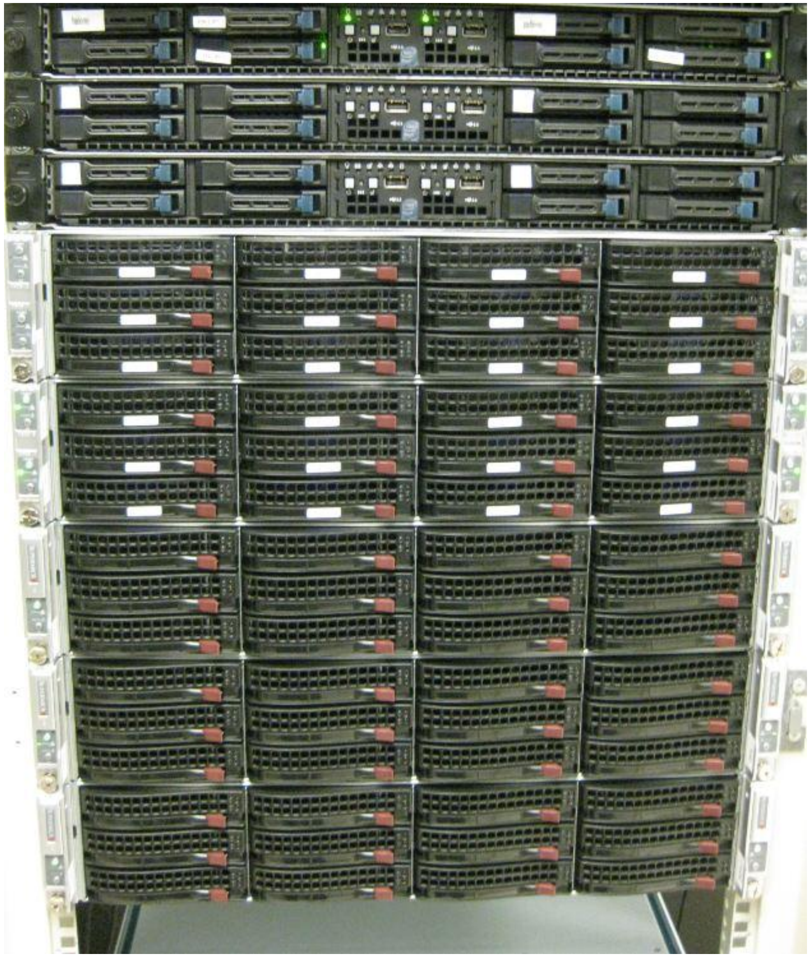
UNH Interoperability Lab

OFA Cluster at UNH-IOL

Linux

Windows





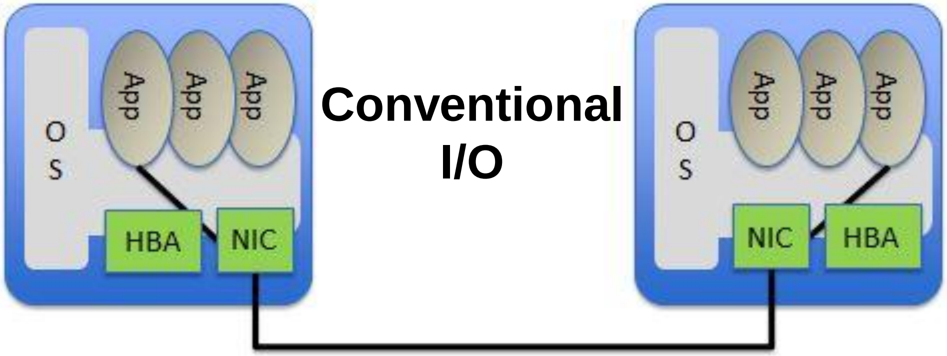
Thanks to AMD, Intel and OFA for the addition of 16 new nodes in October 2011

OFA Software Benefits

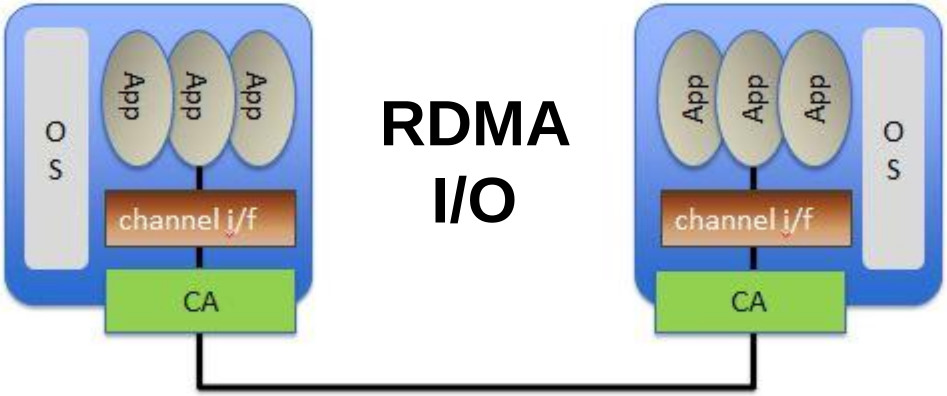
- Remote Direct Memory Access provides
  - Low latency – stack bypass and copy avoidance
  - Kernel bypass – reduces CPU utilization
  - Reduces memory bandwidth bottlenecks
  - High bandwidth utilization
- Cross Platform support
  - InfiniBand
  - iWARP
  - RoCE

Conventional I/O versus RDMA I/O

OS involved in all operations



Conventional I/O



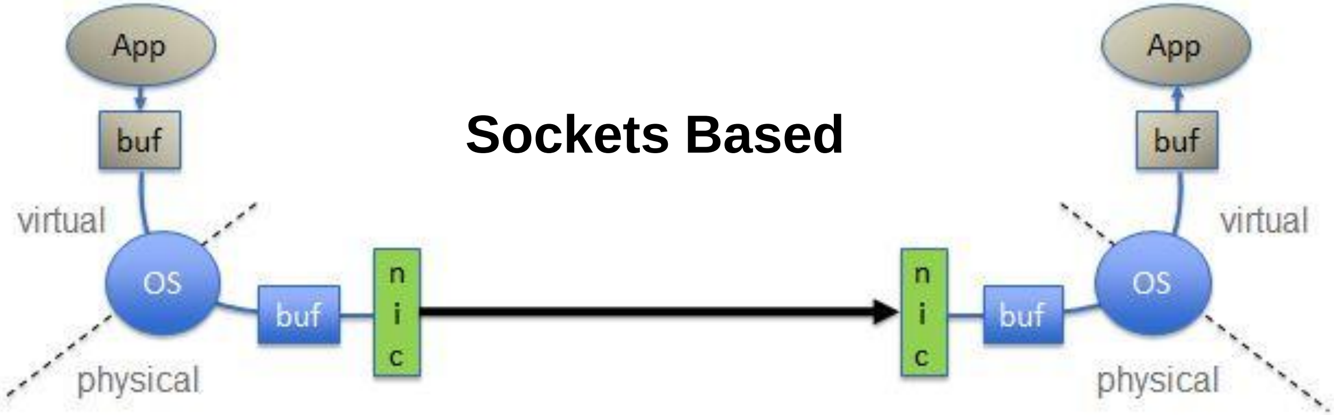
RDMA I/O

Channel interface runs in user space

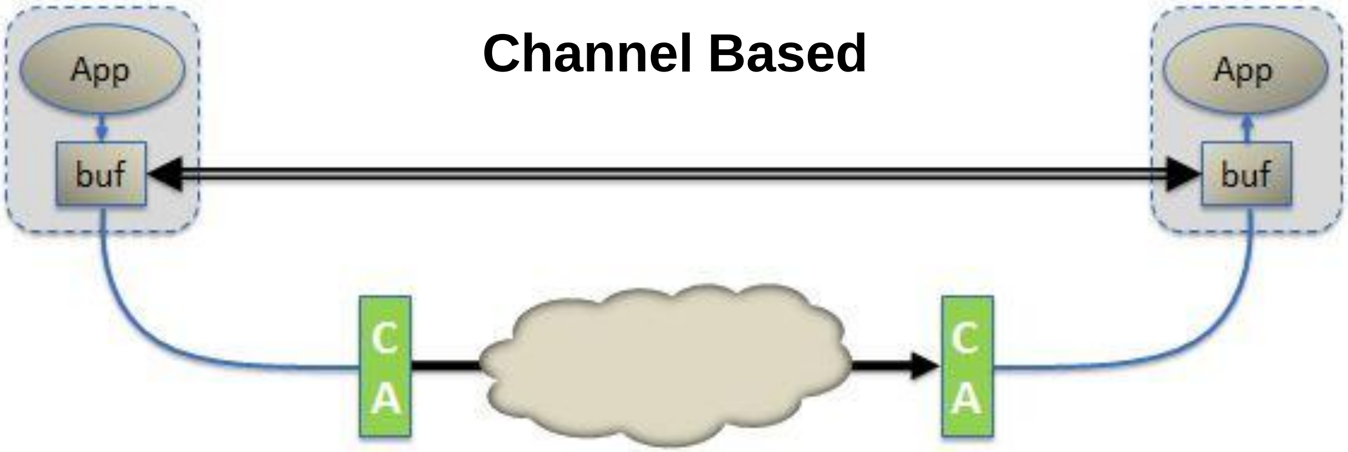
No need to access the kernel

Address Translation

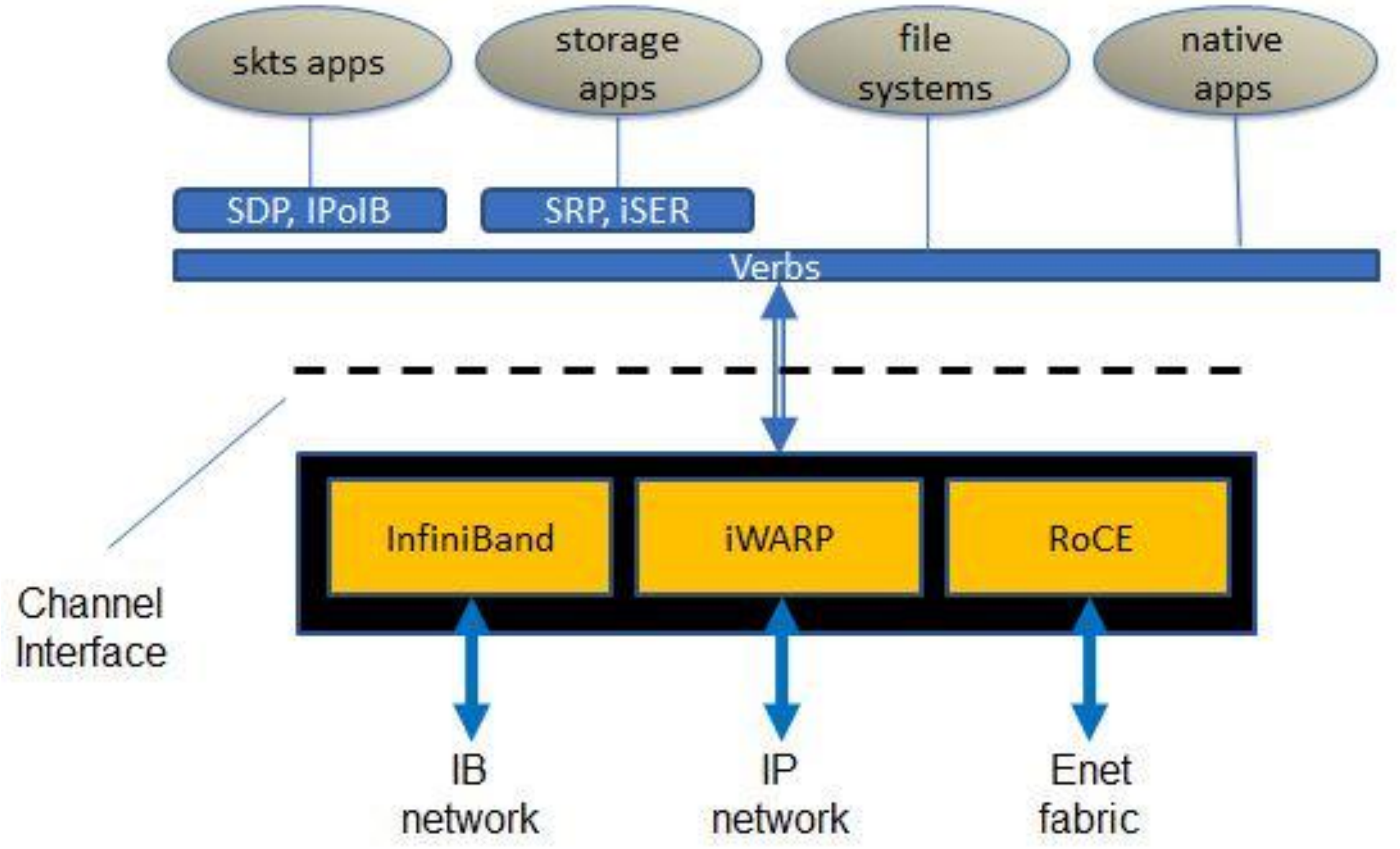
Sockets Based



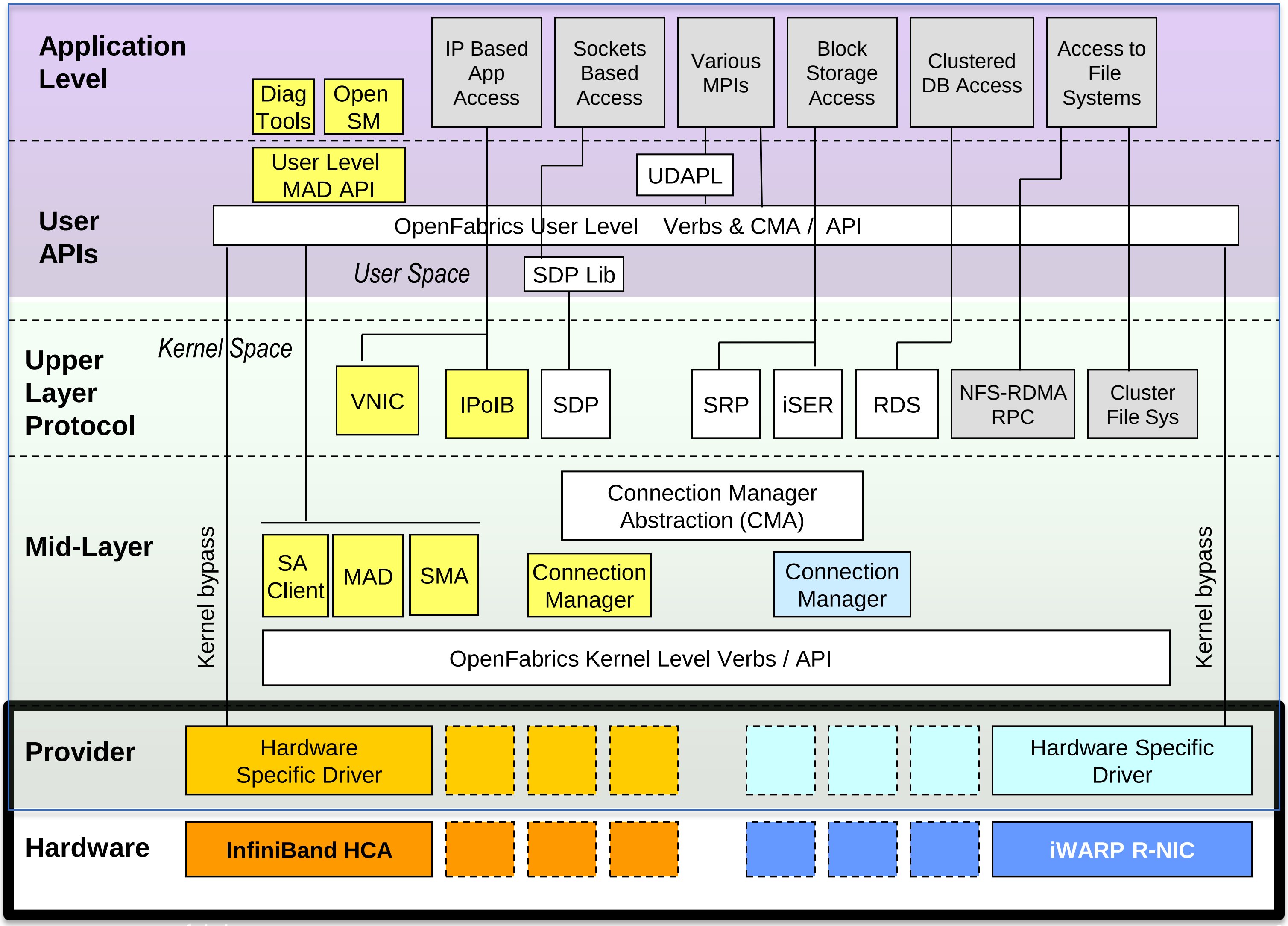
Channel Based



Many apps, one interface, three wires



OFED – the whole picture



Application Level

Diag Tools

Open SM

IP Based App Access

Sockets Based Access

Various MPIs

Block Storage Access

Clustered DB Access

Access to File Systems

User Level MAD API

UDAPL

User APIs

OpenFabrics User Level Verbs & CMA / API

User Space

SDP Lib

Kernel Space

Upper Layer Protocol

VNIC

IPoIB

SDP

SRP

iSER

RDS

NFS-RDMA RPC

Cluster File Sys

Mid-Layer

Kernel bypass

Connection Manager Abstraction (CMA)

SA Client

MAD

SMA

Connection Manager

Connection Manager

OpenFabrics Kernel Level Verbs / API

Kernel bypass

Provider

Hardware Specific Driver

Hardware Specific Driver

Hardware

InfiniBand HCA

iWARP R-NIC

SA	Subnet Administrator
MAD	Management Datagram
SMA	Subnet Manager Agent
PMA	Performance Manager Agent
IPoIB	IP over InfiniBand
SDP	Sockets Direct Protocol
SRP	SCSI RDMA Protocol (Initiator)
iSER	iSCSI RDMA Protocol (Initiator)
RDS	Reliable Datagram Service
VNIC	Virtual NIC
UDAPL	User Direct Access Programming Lib
HCA	Host Channel Adapter
R-NIC	RDMA NIC

Key

Common

InfiniBand

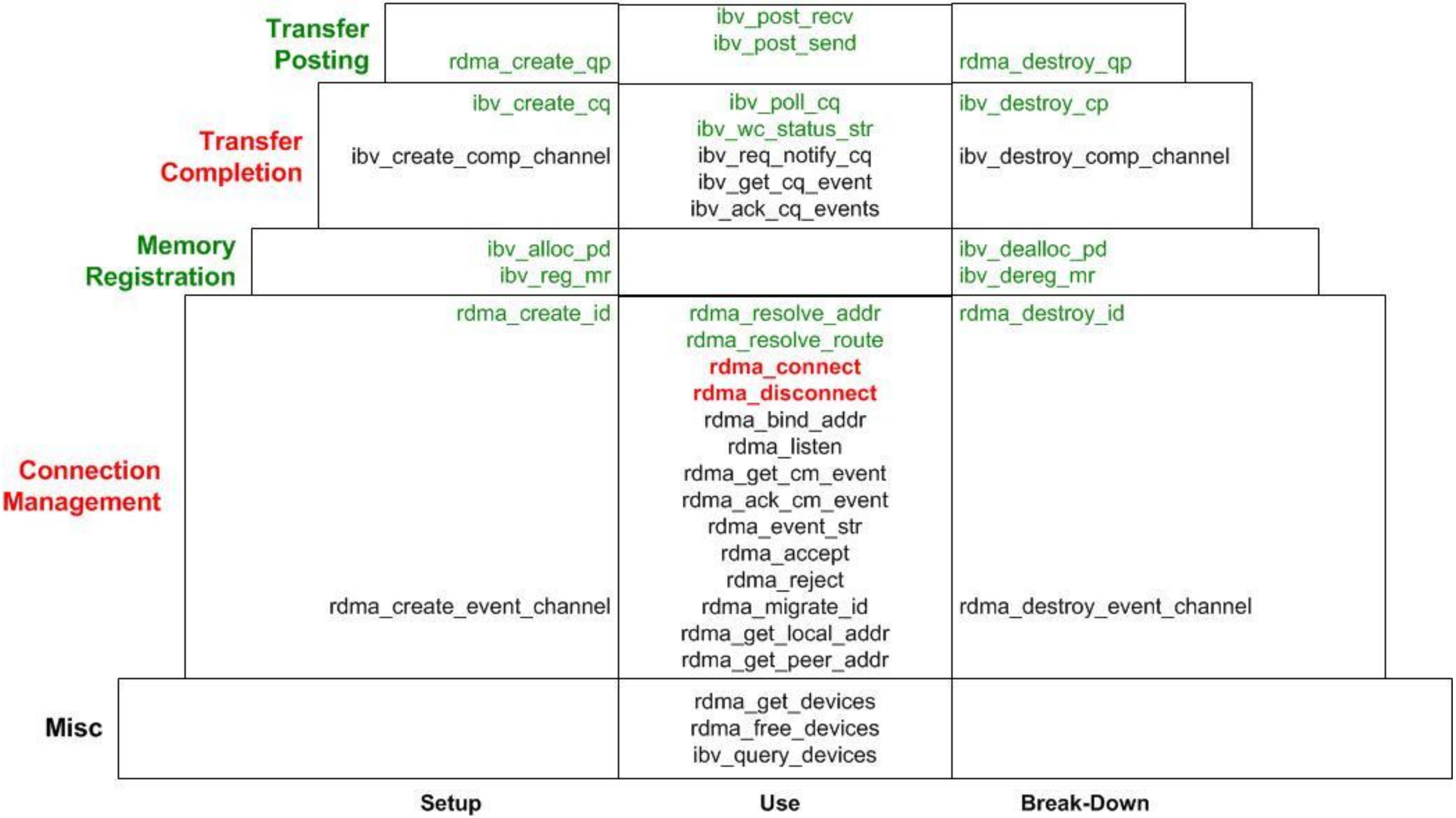
iWARP

Apps & Access Methods for using OF Stack

Programming Course Sample

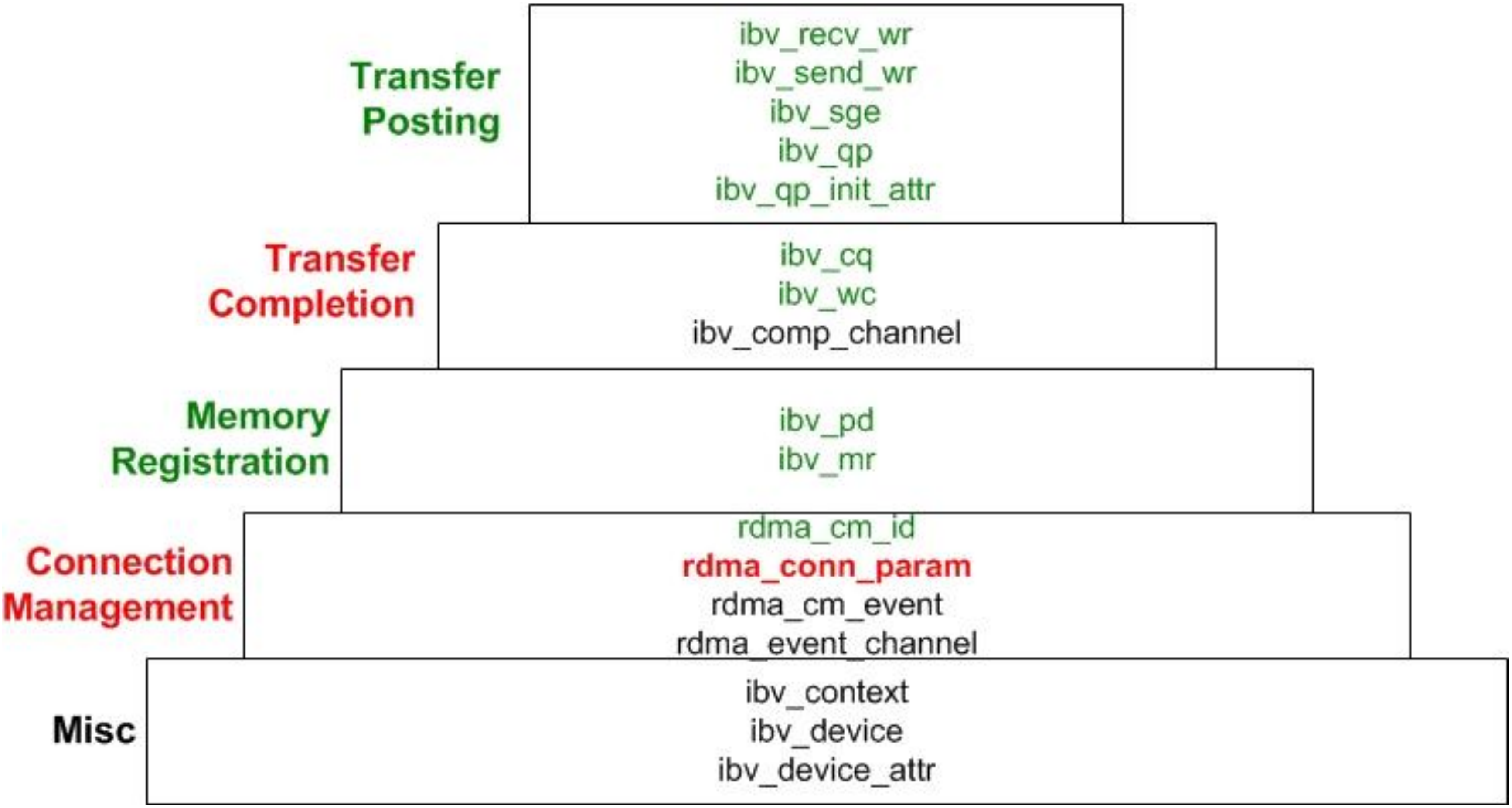
- Description of the verbs
- Description of the data structures
- Preparation for posting a send operation
- Create the work request
- Gathering data from memory
- Putting gathered elements on the wire
- The Big Picture

Programming Course - OFED Verbs



	Setup	Use	Break-Down
Transfer Posting	rdma_create_qp	ibv_post_recv ibv_post_send	rdma_destroy_qp
Transfer Completion	ibv_create_cq ibv_create_comp_channel	ibv_poll_cq ibv_wc_status_str ibv_req_notify_cq ibv_get_cq_event ibv_ack_cq_events	ibv_destroy_cp ibv_destroy_comp_channel
Memory Registration	ibv_alloc_pd ibv_reg_mr		ibv_dealloc_pd ibv_dereg_mr
Connection Management	rdma_create_id rdma_create_event_channel	rdma_resolve_addr rdma_resolve_route **rdma_connect** **rdma_disconnect** rdma_bind_addr rdma_listen rdma_get_cm_event rdma_ack_cm_event rdma_event_str rdma_accept rdma_reject rdma_migrate_id rdma_get_local_addr rdma_get_peer_addr	rdma_destroy_id rdma_destroy_event_channel
Misc		rdma_get_devices rdma_free_devices ibv_query_devices	

Programming Course – Data Structures

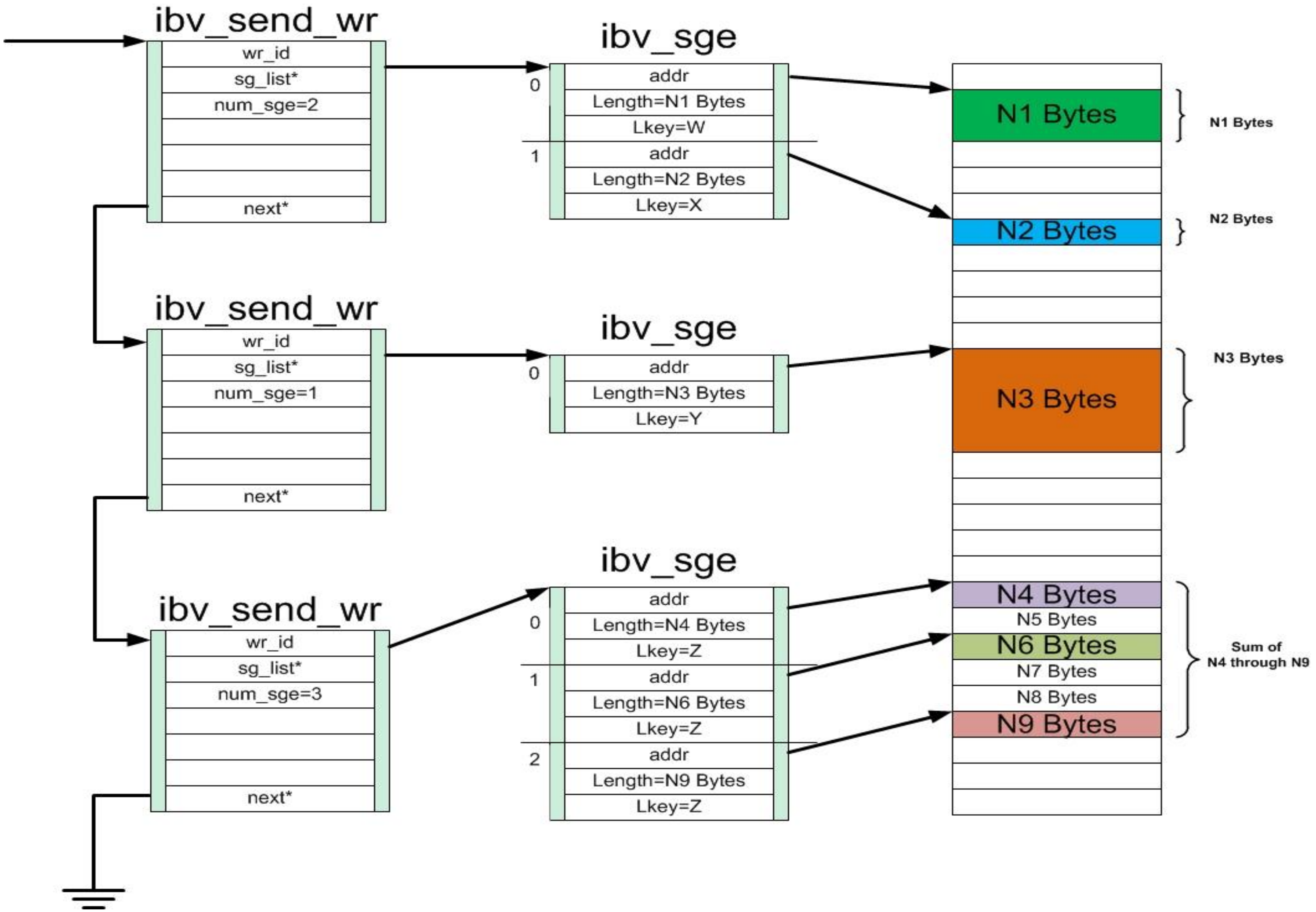


Transfer Posting	ibv_recv_wr ibv_send_wr ibv_sge ibv_qp ibv_qp_init_attr
Transfer Completion	ibv_cq ibv_wc ibv_comp_channel
Memory Registration	ibv_pd ibv_mr
Connection Management	rdma_cm_id **rdma_conn_param** rdma_cm_event rdma_event_channel
Misc	ibv_context ibv_device ibv_device_attr

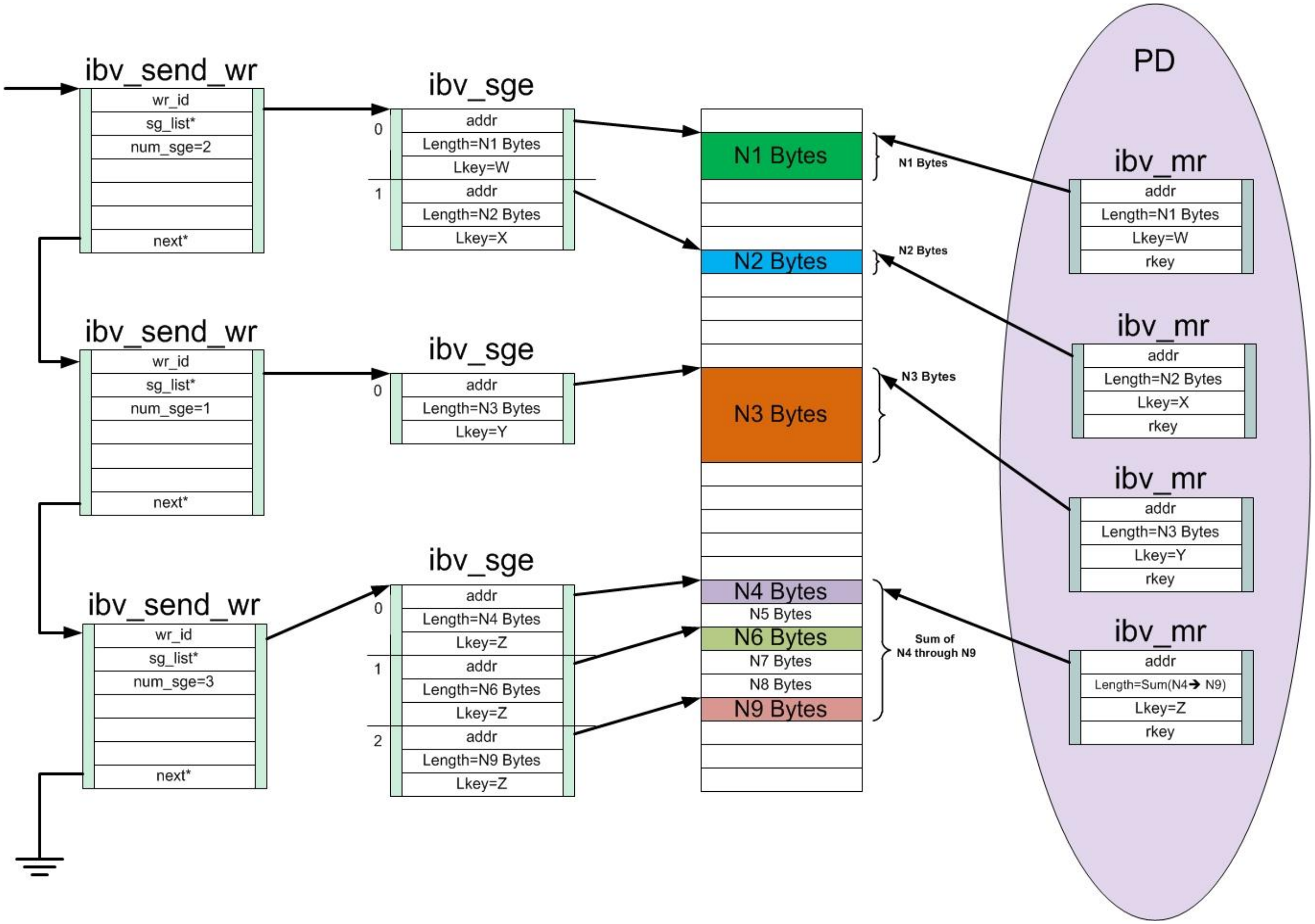
Bottom-up client setup phase

- **rdma_create_id()** - create **struct rdma_cm_id** – identifier
- **rdma_resolve_addr()** - bind **struct rdma_cm_id** to local device
- **rdma_resolve_route()** - resolve route to remote server
- **ibv_alloc_pd()** - create **struct ibv_pd** – protection domain
- **ibv_create_cq()** - create **struct ibv_cq** – completion queue
- **rdma_create_qp()** - create **struct ibv_qp** – queue pair
- **ibv_reg_mr()** - create **struct ibv_mr** – memory region
- **rdma_connect()** - create connection to remote server

Creating Scatter Gather Elements



Protection Domains – Memory Regions



ibv_send_wr
wr_id
sg_list*
num_sge=2
next*

ibv_sge
0
addr
Length=N1 Bytes
Lkey=W
1
addr
Length=N2 Bytes
Lkey=X

ibv_send_wr
wr_id
sg_list*
num_sge=1
next*

ibv_sge
0
addr
Length=N3 Bytes
Lkey=Y

ibv_send_wr
wr_id
sg_list*
num_sge=3
next*

ibv_sge
0
addr
Length=N4 Bytes
Lkey=Z
1
addr
Length=N6 Bytes
Lkey=Z
2
addr
Length=N9 Bytes
Lkey=Z

N1 Bytes
N2 Bytes
N3 Bytes
N4 Bytes
N5 Bytes
N6 Bytes
N7 Bytes
N8 Bytes
N9 Bytes

N1 Bytes
N2 Bytes
N3 Bytes
Sum of
N4 through N9

PD

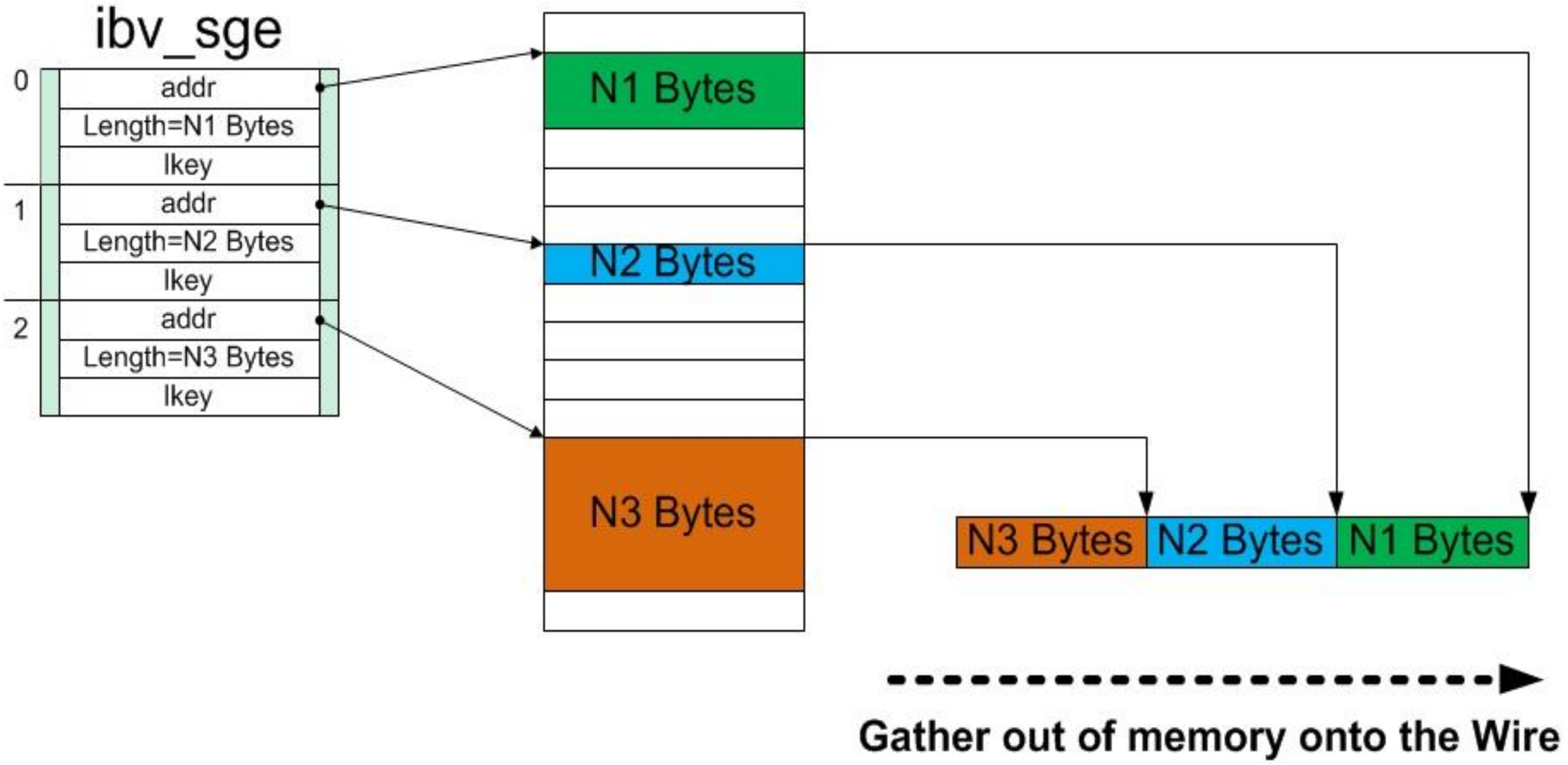
ibv_mr
addr
Length=N1 Bytes
Lkey=W
rkey

ibv_mr
addr
Length=N2 Bytes
Lkey=X
rkey

ibv_mr
addr
Length=N3 Bytes
Lkey=Y
rkey

ibv_mr
addr
Length=Sum(N4→ N9)
Lkey=Z
rkey

Gather during ibv_post_send()



Send Work Request (SWR)

- Purpose: tell network adaptor what data to send
- Data structure: **struct ibv_send_wr**
- Fields visible to programmer:

next	pointer to next SWR in linked list
wr_id	user-defined identification of this SWR
sg_list	array of scatter-gather elements (SGE)
opcode	**IBV_WR_SEND**
num_sge	number of elements in **sg_list** array
send_flags	**IBV_SEND_SIGNALED**

- Programmer must fill in these fields before calling **ibv_post_send()**

Posting to send data

- Verb: **ibv_post_send()**
- Parameters:
  - Queue Pair - QP
  - Pointer to linked list of Send Work Requests – SWR
  - Pointer to bad SWR in list in case of error
- Return value:

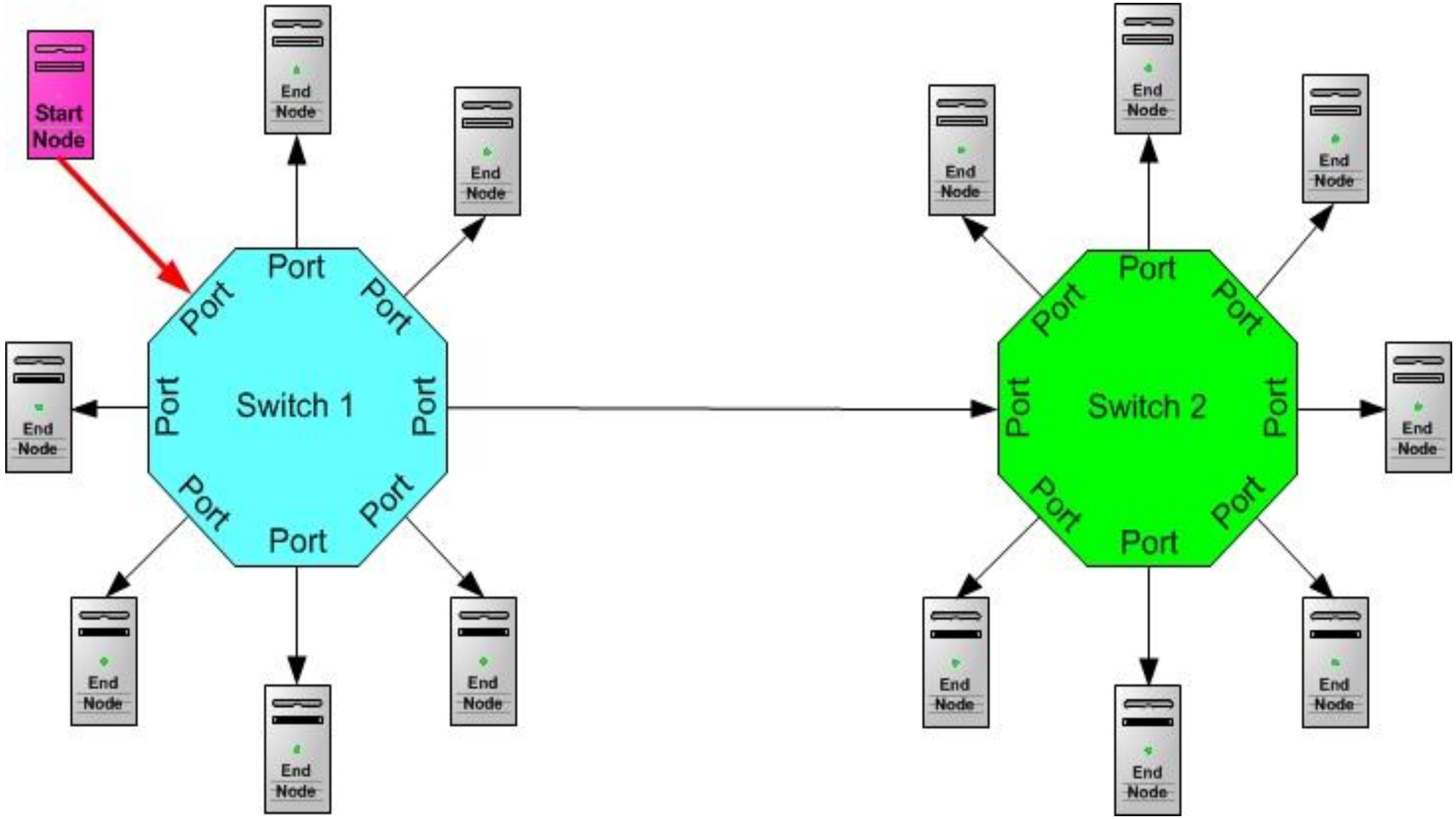
  == 0 all SWRs successfully added to send queue (SQ)

  != 0 error code

Bottom-up client break-down phase

- **rdma_disconnect()** - destroy connection to remote server
- **ibv_dereg_mr()** - destroy **struct ibv_mr** – memory region
- **rdma_destroy_qp()** - destroy **struct ibv_qp** – queue pair
- **ibv_destroy_cp()** - destroy **struct ibv_cq** – completion queue
- **ibv_dealloc_pd()** - deallocate **struct ibv_pd** – protection domain
- **rdma_destroy_id()** - destroy **struct rdma_cm_id** – identifier

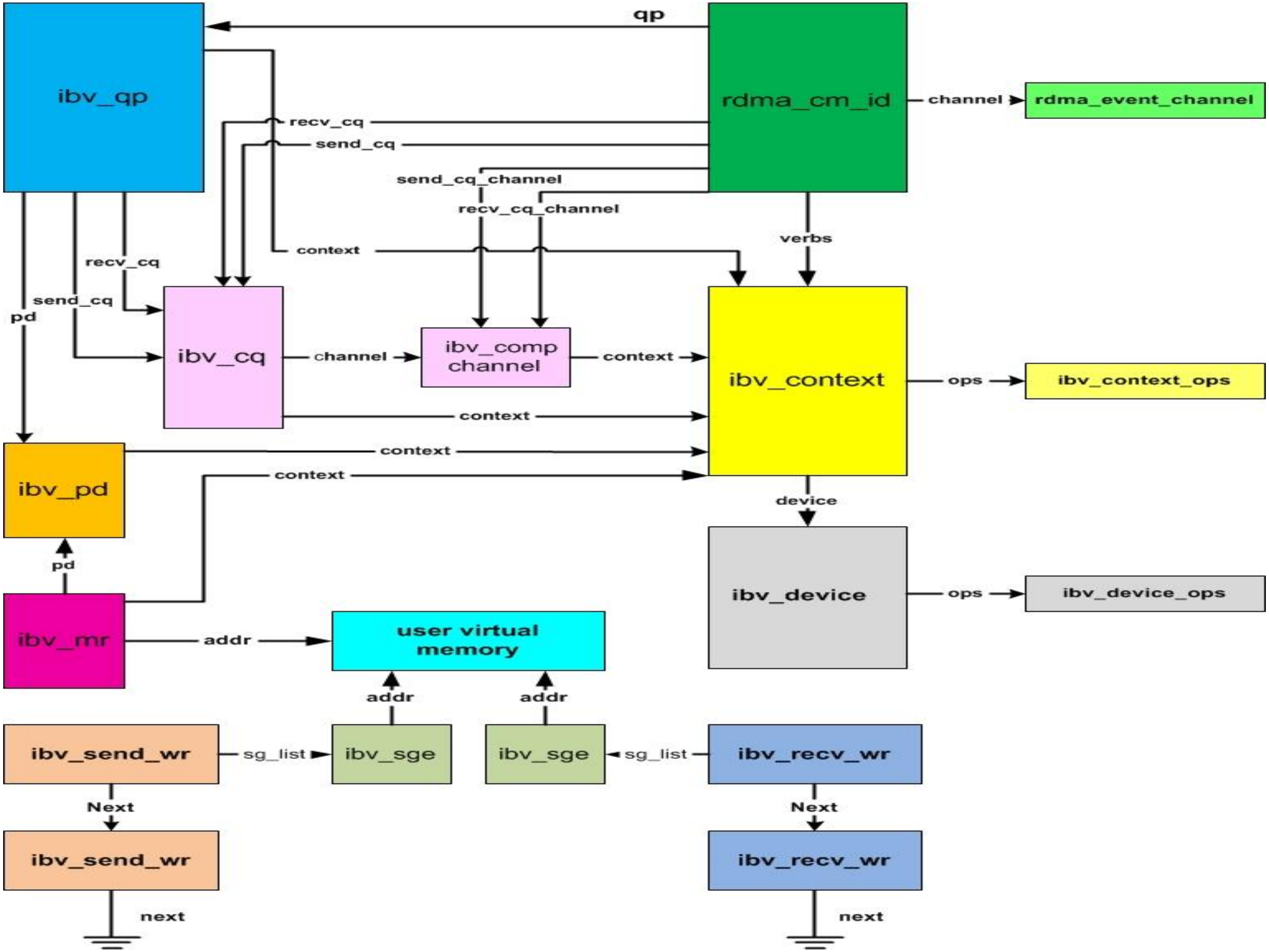
Multicast concept



Multicast

- Optional to implement in IB CAs and switches
- Uses **Unreliable Datagram (UD)** mode
  - Only **Send/Recv** operations allowed
  - Both sides must actively participate in data transfers
- Receiver must have RECV posted for next SEND
- Receiver must process each RECV completion
- Only possible with IB, not iWARP

Programming Course – The Big Picture



Future OFA Software Training Course

- System Administration
  - System configuration
  - Cluster optimization
- Advanced Programming topics
  - Kernel level programming
- ULP Training
  - MPI
  - RDS
  - SRP

OFA Programming Course Availability

- Available quarterly at the University of New Hampshire Interoperability Lab (UNH-IOL)
  - January 18-19, 2012 – OFA Programming Course
    - January 20th, 2012 – Free Ski Trip to Loon Mountain
  - March 14-15 2012 – OFA Programming Course
  - Registration: https://www.openfabrics.org/resources/training/training-offerings.html
- The course can be presented at your company location
  - Additional fees apply for travel and equipment required to support the training materials and exercises.
  - Minimum of 8 attendees required
  - Europe and Asia supported in addition to USA
- New for 2012, the course will be made available via Webinar
  - This is a 4 day course made available for developers in Asia and other countries requiring extensive travelling
  - Minimum of 8 attendees required
- For more information contact: rsdance@soft-forge.com

Backup

our_setup_send_wr() code snippet

```
static void
our_setup_send_wr(struct our_control  *conn,  struct ibv_sge  *sg_list,
                  enum ibv_wr_opcode  opcode,  int  n_sges,
                  struct ibv_send_wr  *send_work_request)
{
         /* set the user's identification to be pointer to itself */
         send_work_request->wr_id = (uint64_t)send_work_request;

         /* not chaining this work request to other work requests */
         send_work_request->next = NULL;

         /* point at array of scatter-gather elements for this send */
         send_work_request->sg_list = sg_list;

         /* number of scatter-gather elements in array actually being used */
         send_work_request->num_sge = n_sges;

         /* the type of send */
         send_work_request->opcode = opcode;

         /* set SIGNALED flag so every send generates a completion */
         send_work_request->send_flags = IBV_SEND_SIGNALED;

         /* not sending any immediate data */
         send_work_request->imm_data = 0;
}        /* our_setup_send_wr */
```

ibv_post_send() code snippet

```
int
our_post_send(struct our_control  *conn, struct ibv_send_wr  *send_work_request,
          struct our_options  *options)
{
struct ibv_send_wr      *bad_wr;
int   ret;

errno = 0;
ret = ibv_post_send(conn->queue_pair,  send_work_request,  &bad_wr);
If (ret != 0) {
    if (our_report_wc_status(ret,  "ibv_post_send",  options) != 0)  {
        our_report_error(ret,  "ibv_post_send",  options);
    }
}
return ret;
}     /* our_post_send */
```