Virtual Machine Aware Communication Libraries for High Performance Computing

Wei Huang, Matthew Koop, Qi Gao, and Dhabaleswar K. Panda

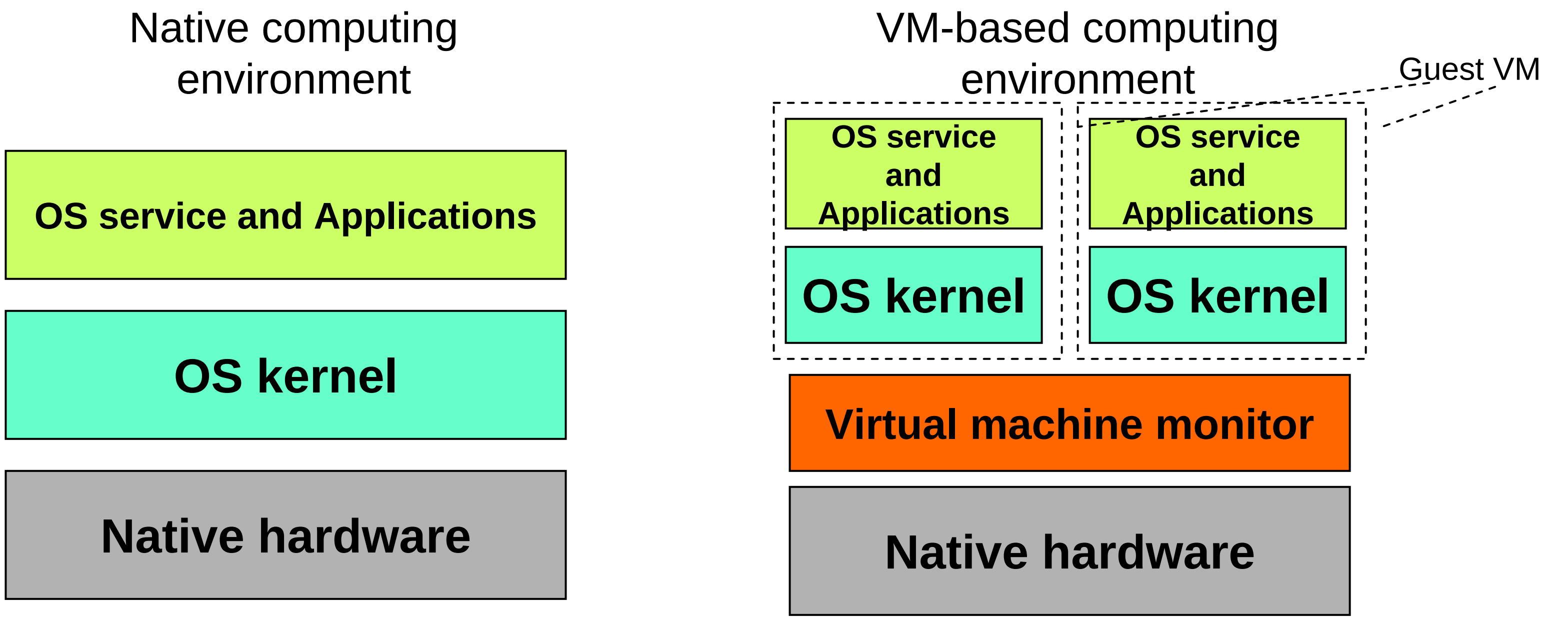
Network Based Computing Laboratory
The Ohio State University

SC'07 -- Nov 13th, 2007

In this presentation …

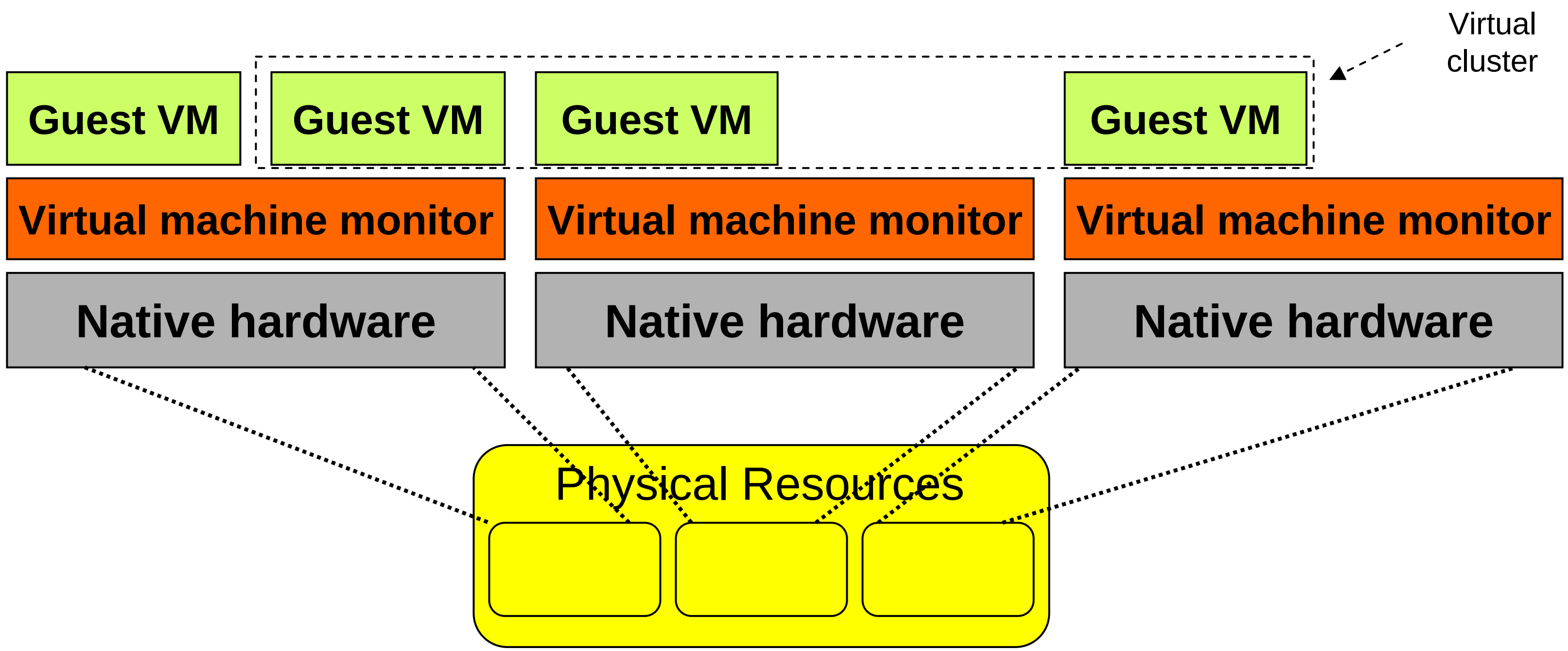
- We target high performance computing with virtual machines
- Why do we want to do this?
- What is missing?
  - Performance concerns
  - Efficient inter-VM communication
- What do we do?
  - IVC: Inter-VM Communication library
  - MPI: hiding the design complexities
  - Performance evaluation
- Conclusion

Virtual machine environment



- Virtual machine (VM) technologies allow running OSes on virtualized hardware instead of native hardware
- A wide adoption of VM environments:
  - Server consolidation: efficiently utilize the resources
  - Debugging and development: safety and efficiency

VM for HPC: how and why?

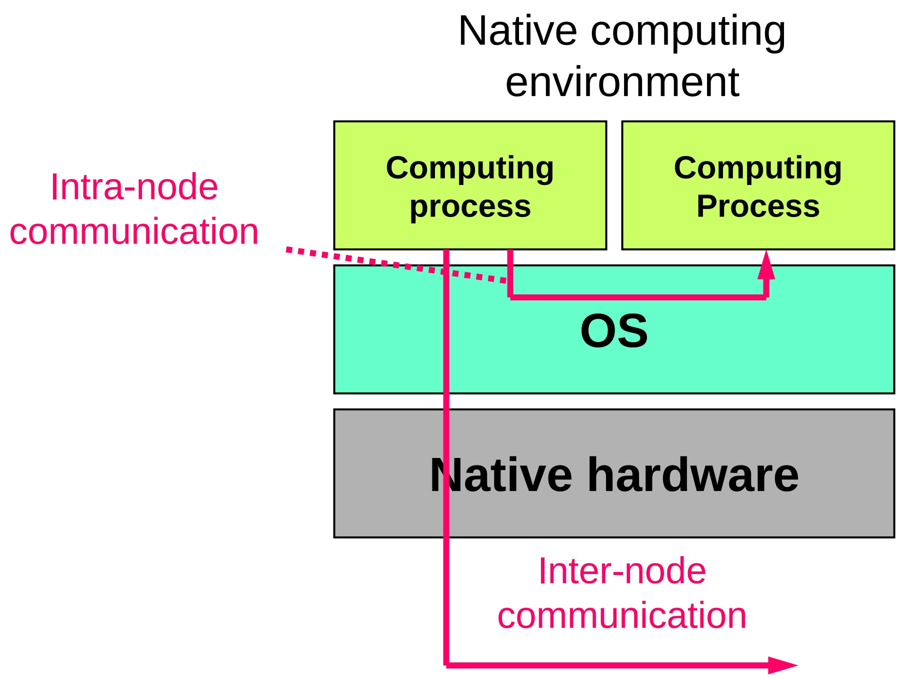


- Applications are running on virtual clusters consisting of multiple VMs
- VMs can be migrated among physical hosts
- Why VM based environments?
  - Management: hardware maintenance …
  - Fault tolerance
  - And many others: customized OSes, load balancing, performance isolation …

VM for HPC: why not?

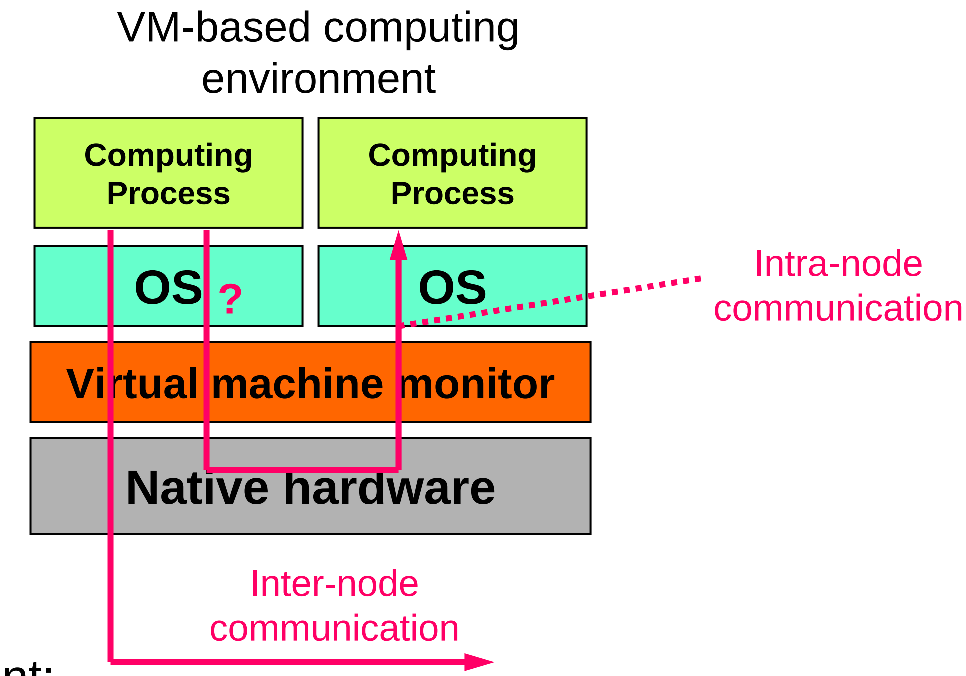
- Despite many promising features, VMs have not yet been widely used for HPC
- One of the most important reasons: perceived overhead from the virtualization layer
- Is this true?
  - CPU & memory virtualization:
    - Not really: HPC is full of non-privileged instructions, which can be executed natively
  - Communication I/O virtualization:
    - VMM-bypass I/O for network communication
    - Is that all?

A closer look at communication I/O



- Native environment running MPI job:
  - Inter-node communication through high speed interconnect
  - Intra-node communication through shared memory
    - More efficient: no network contention
    - Supported by MVAPICH/MVAPICH2, OMPI, etc …

A closer look at communication I/O



- VM-based environment:
  - Computing processes are hosted on **separate** VMs for scheduling flexibility
  - Inter-node communication through high speed interconnect
    - Support from VMM-bypass I/O – native level performance
  - Intra-node communication has to go through loop back as well
    - **Extremely undesirable especially with the wide-spread adoption of multi-core architecture!**

* Jiuxing Liu, Wei Huang, Bulent Abali, and Dhabaleswar Panda. High Performance VMM-bypass I/O in Virtual Machines. In USENIX'06

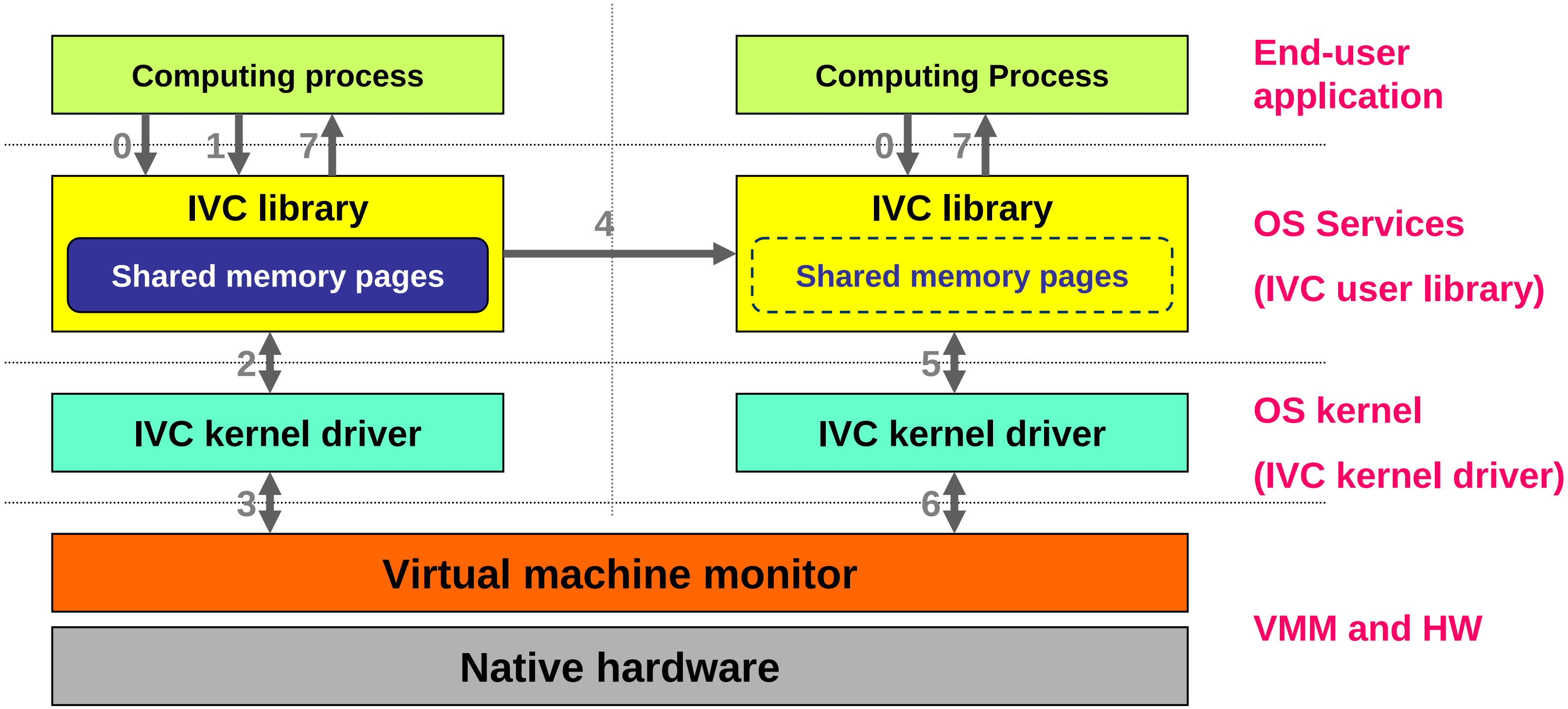
Our contributions

- Design IVC, an Inter-VM Communication library providing efficient intra-physical node communication through shared memory
- Hide all design complexities by designing MVAPICH2-ivc, a VM-aware MPI library
- Evaluate our design on multi-core computing systems, showing great potential for VM-based HPC

Inter-VM Communication

- Objectives
  - Providing efficient inter-VM (intra-physical node) communication through shared memory
    - How to setup shared memory region?
    - How to find peers on the same node?
  - Handling VM migration
    - How to tear-down/establish inter-VM communication?

Shared memory setup: a client-server model

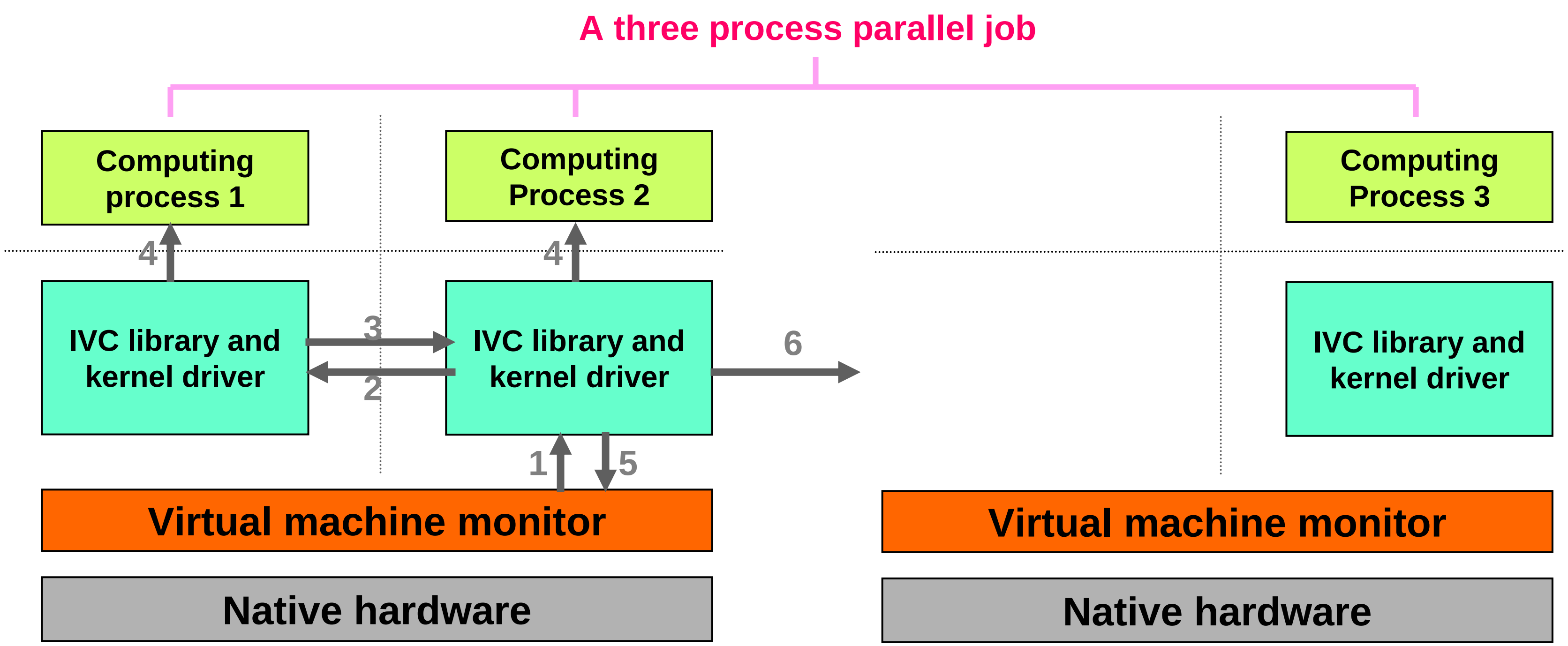


- Step 0: register – kernel drivers helps computing processes to find out peers on the same computing node
- Step 1: A user process initiates the setup process
  - Call into the IVC user communication library
- Step 2 & 3: IVC user library allocates shared memory space and grant page access to the remote VM through VMM
- Step 4: reference information is sent to the remote IVC library
- Step 5 & 6: Map the shared memory pages to process' address space
- Step 7: computing processes get notified

When VM migrates …

- IVC is a intra-node (physical node) communication library:
  - IVC connections to VMs on the original host must be torn down
  - IVC connections can be established to VMs on the new host
- Require peer coordination

When VM migrates ...



- Step 1: IVC kernel driver on the migrating VM receives a callback when VM is about to migrate
- Step 2 & 3: all peers stop send operations and acknowledge
- Step 4: computing processes get notified
- Step 5: return from callback
- Step 6: migrate to the new host and establish new IVC connection

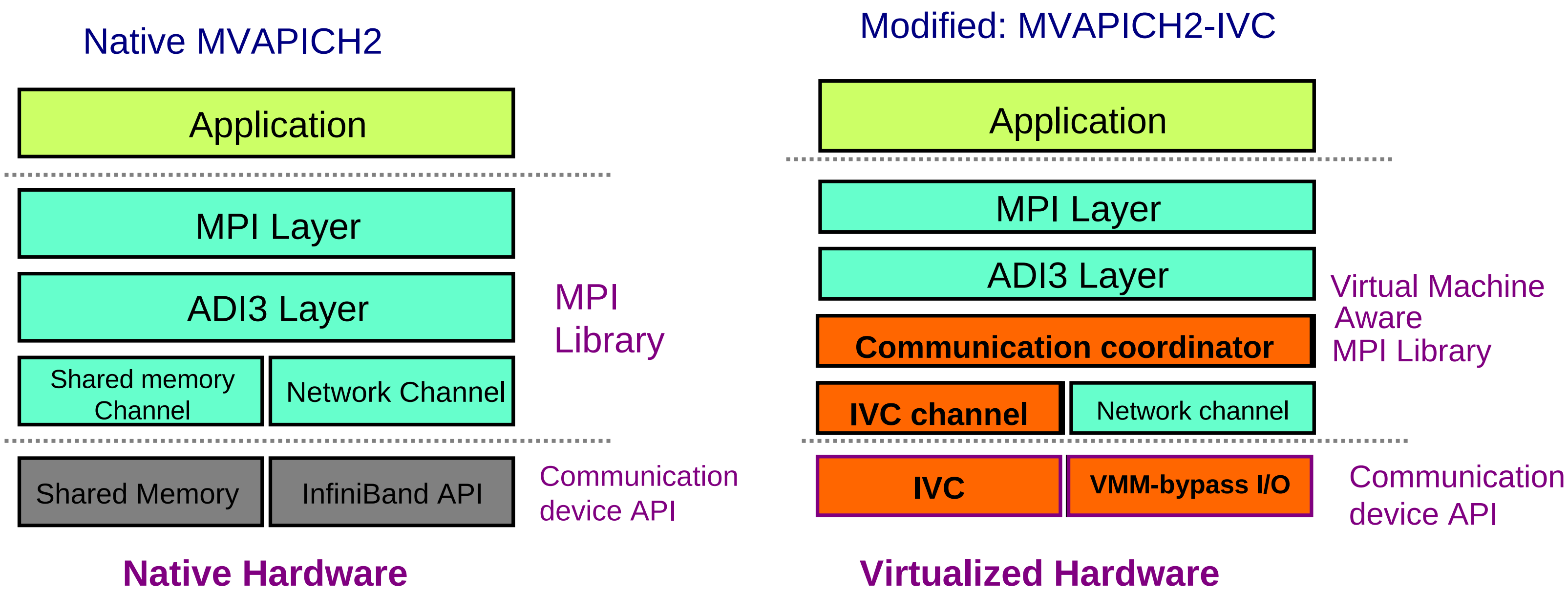
Now we have IVC …

- Benefits:
  - Application can have efficient communication over shared memory, even when the computing processes are not in the same guest VM
  - Possible to support VM migration
- Concerns: application needs to
  - Written with our API
  - Take care of both intra- and inter-node communication
- Not a big deal!
  - Most applications are written in standardized APIs, like MPI
  - We can integrate our design into those API implementations

MVAPICH2-ivc: hiding the complexities

- Choosing MPI: the *de facto* standard for parallel programming
- MVAPICH2: a popular MPI-2 library over InfiniBand from our lab, used by 580 organizations world wide
- MVAPICH2-ivc: extends MVAPICH2, automatically choosing between IVC or network (IB) communication
- Hiding the complexities of IVC-specific APIs – transparently benefits user applications

Architectural overview



MVAPICH2 (native)

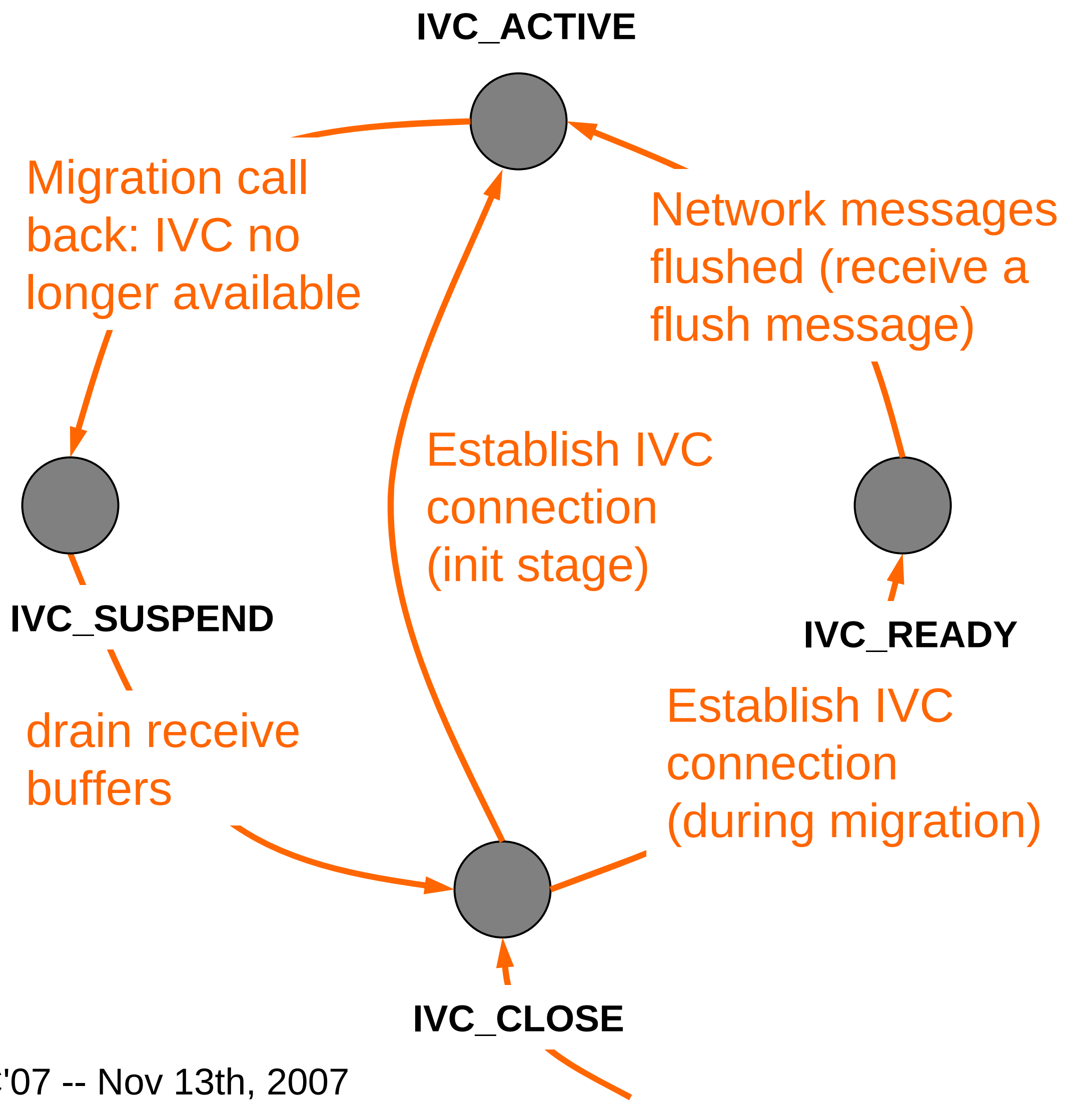
- ADI3 manages message delivery
- Shared memory and ADI3 channels are statically setup
- Shared memory channel communications over shared memory (OS provides mapping service)
- Network channel communicates over InfiniBand

MVAPICH2-ivc

- ADI3 manages message delivery
- Communication coordinator manages IVC and network channels setup (dynamic)
- IVC channel communicates of shared memory (IVC library/driver provide mapping)
- Network channel communicates over VMM-bypass over InfiniBand (transparent)

Handling VM migration

- **Key issue**: ensuring message in-order delivery when setting up and tearing down IVC connections during migration
- VC: virtual connections encapsulating communication mechanisms:
  - Network
  - IVC
- VC has four states:
  - ***IVC_CLOSE***: all VC start with this state
  - ***IVC_ACTIVE***: IVC connection is ready to use
  - ***IVC_SUSPEND***: IVC connection is being torn down
  - ***IVC_READY***: IVC connection is setup, but not ready to use due to in-flight message over network



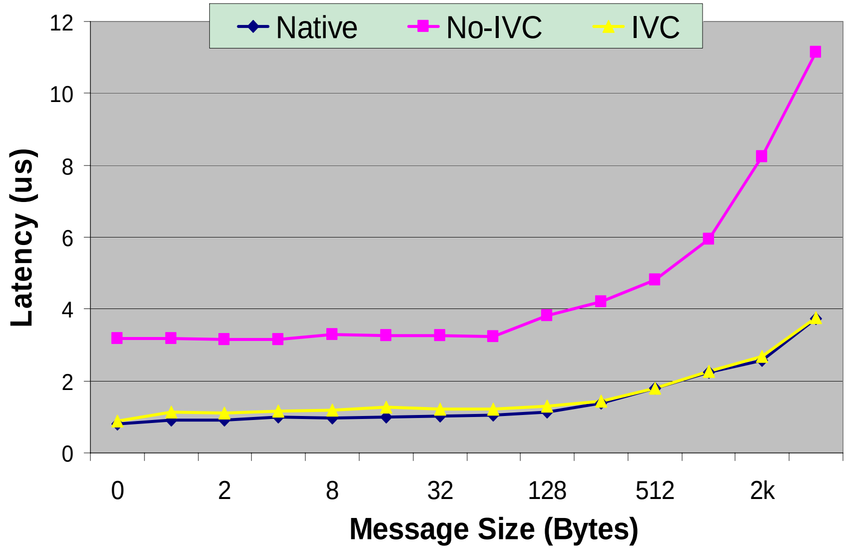
Now we have a MPI …

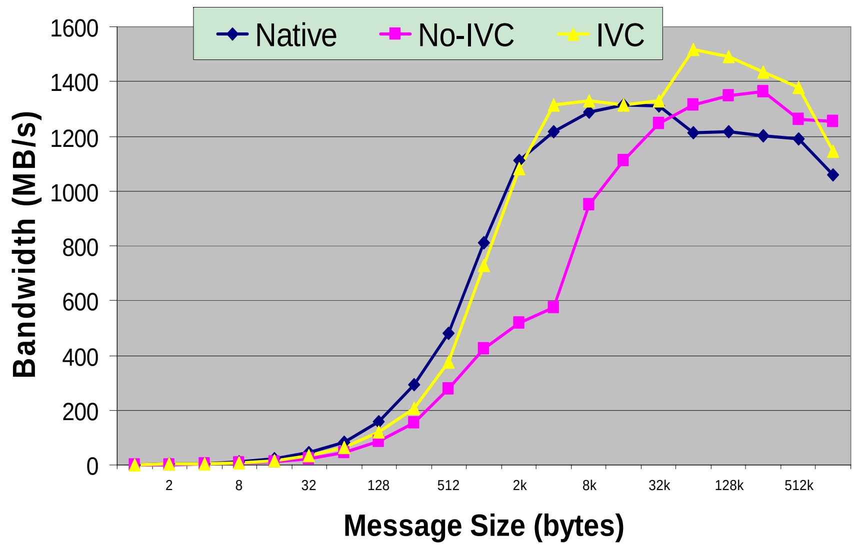
- Unmodified MPI applications can benefit from our design
- Regarding the performance concerns:
  - What's the benefit of IVC?
  - How does a VM-based environment with IVC compare with a native environment?

Experimental setup

- Testbed A: dual socket Intel Clovertown (Quad-core) processors, 4 GB memory, PCI-Express InfiniBand HCA
- Testbed B: 64 node dual socket single core cluster (32 Xeon and 32 Opteron), 2GB memory, PCI-Express InfiniBand HCA
- Xen-3.0, dom0 running RHEL 4
- DomU using ttylinux (tiny linux distribution)
- Configurations:
  - IVC: mvapich2-ivc running in VM-based environment
  - No-IVC: unmodified mvapich2 in VM-based environment
  - Native: unmodified mvapich2 in native Linux environment

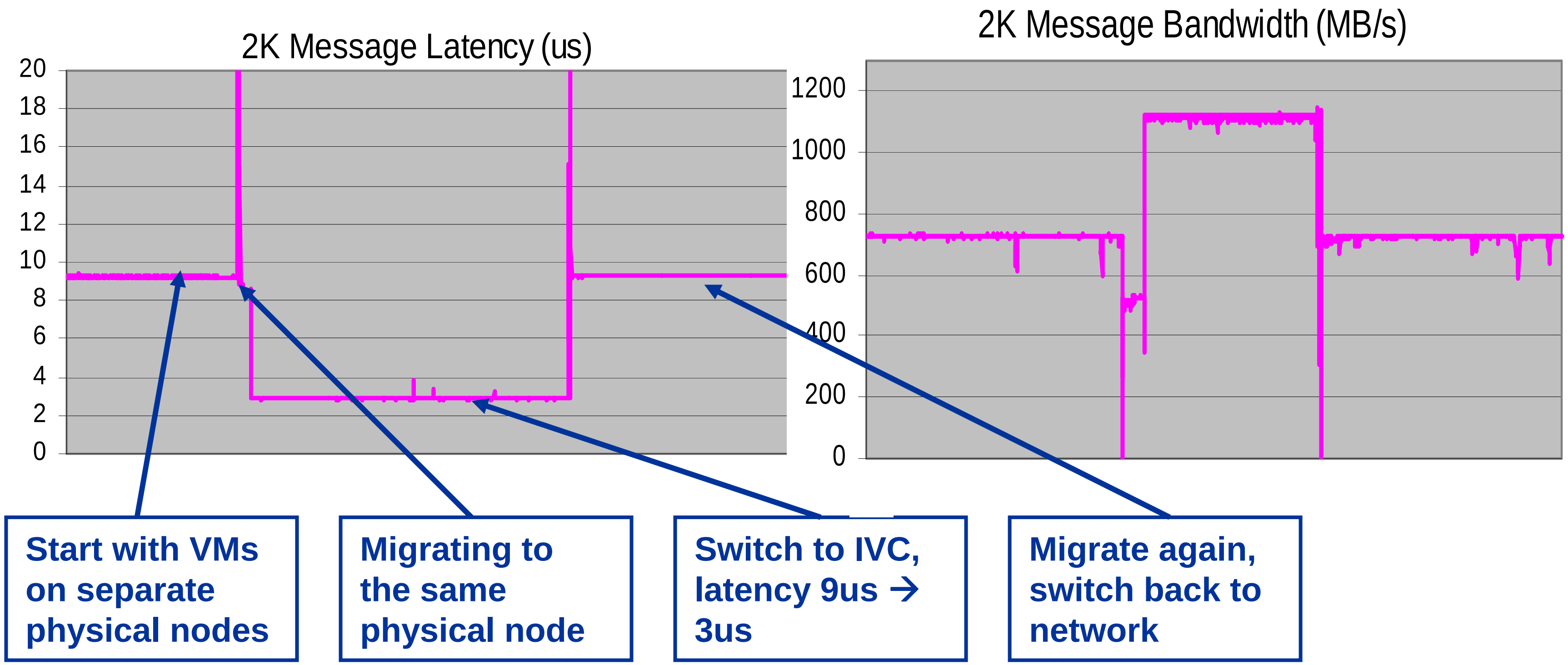
Latency and bandwidth





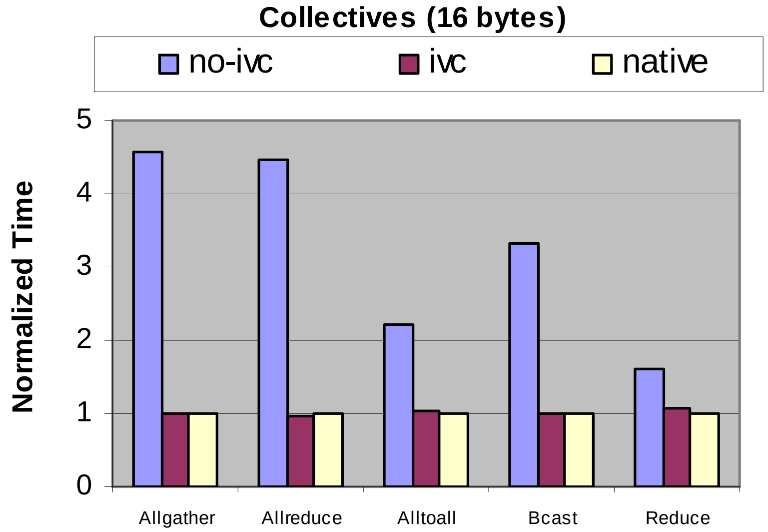
	Native	No-IVC	IVC
Latency	Sub-1us through Shared memory	~3.2us through IB loopback	Very close to native
Bandwidth	Much higher for mid-size messages	Getting better for large messages	Native-level performance

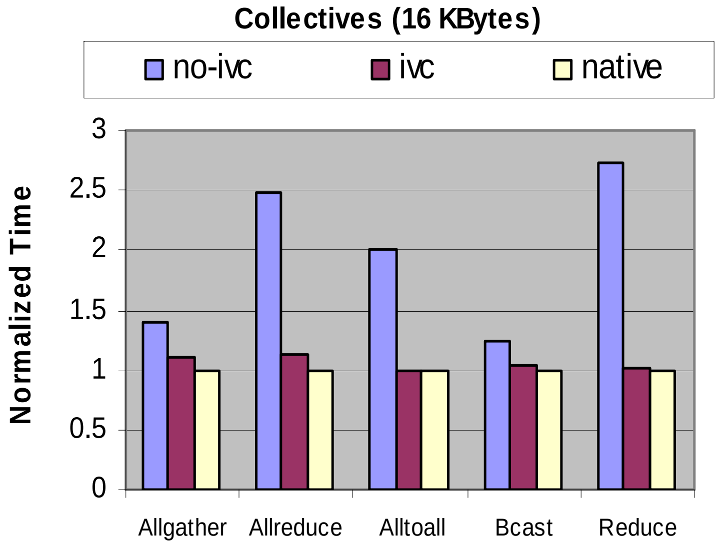
VM migration

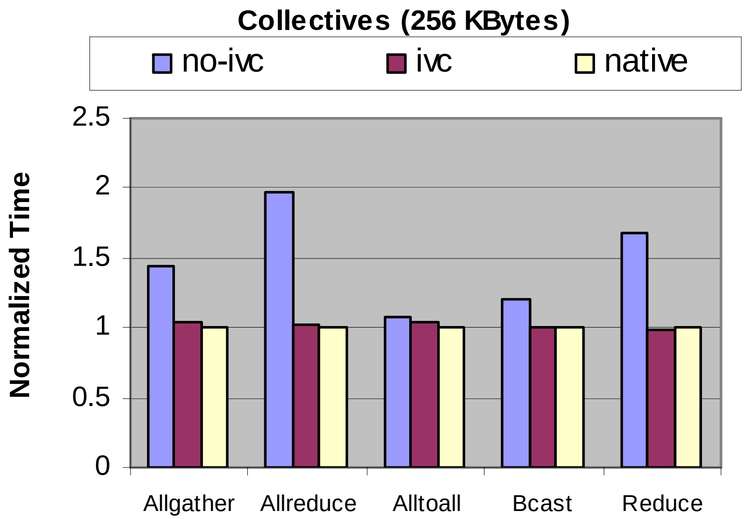


- MVAPICH2-ivc automatically switches to IVC whenever the target peers are on the same physical nodes
- Above two graphs show decreased latency and increased bandwidth when two processes in separate VMs are migrated to the same physical nodes

Collectives

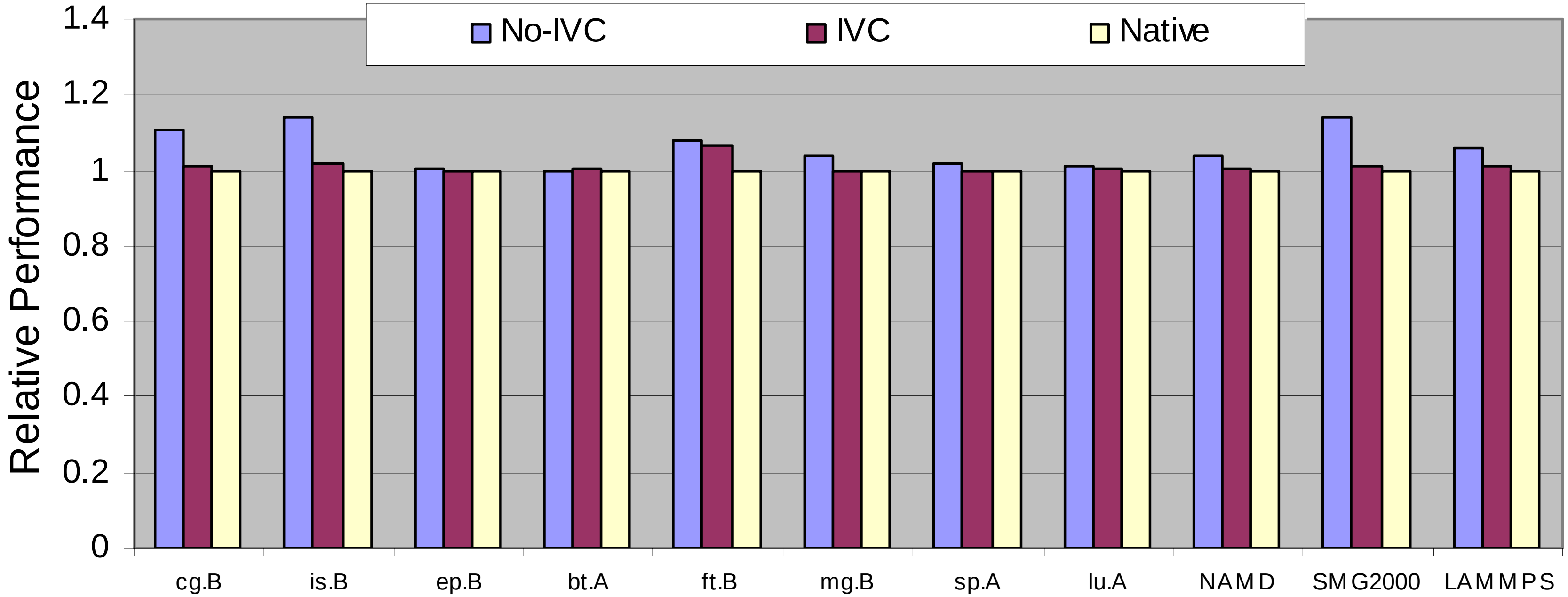






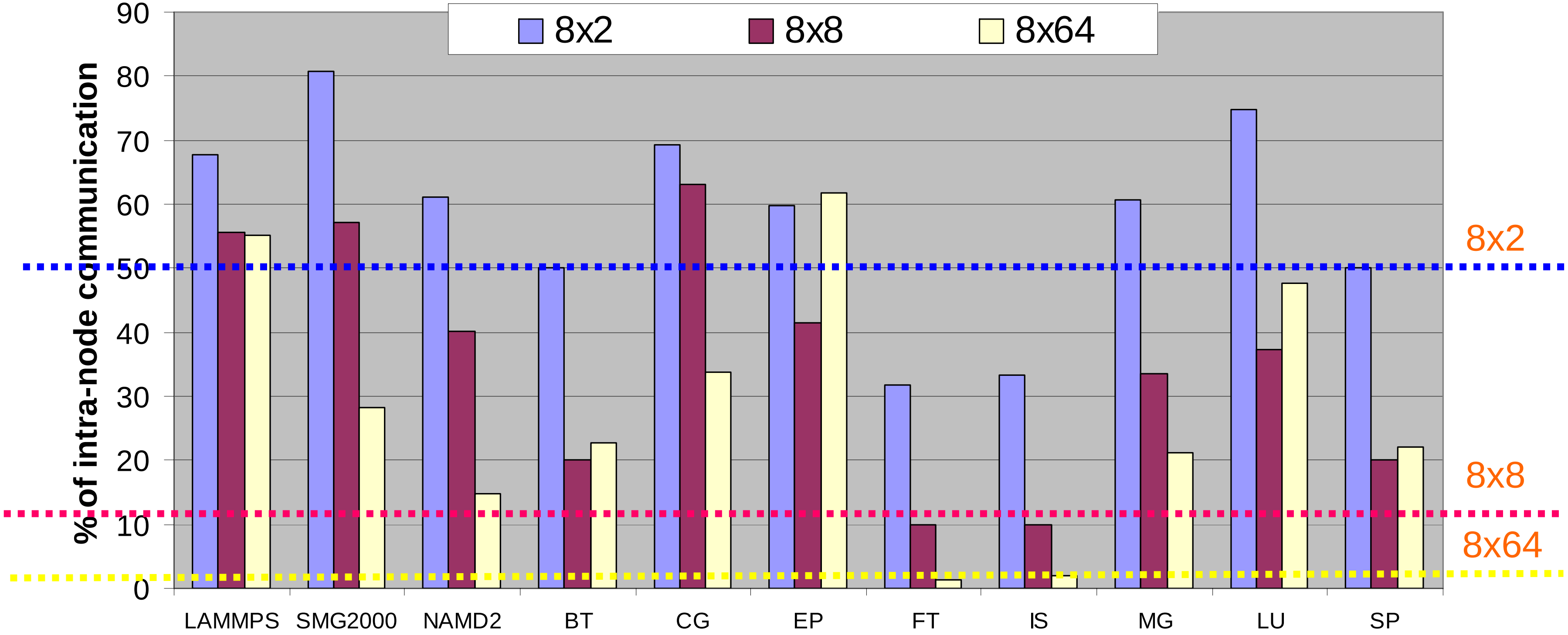
- With inter-VM communication, mvapich2-ivc largely closes the gap between native and VM based environments
- Results collected on 8-core systems using Intel MPI Benchmarks (IMB) (8x2)

Application-level benchmarks



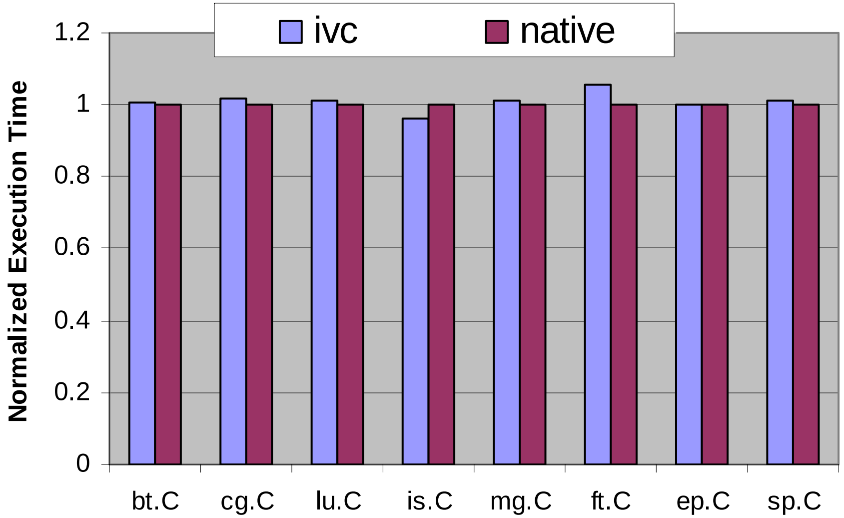
- Number taken on 16 processes
- Benefits of IVC show for several benchmarks, e.g. IS (11%), CG (9%), LAMMPS (5.9%), SMP2000 (11.8%), and NAMD (3.4%)

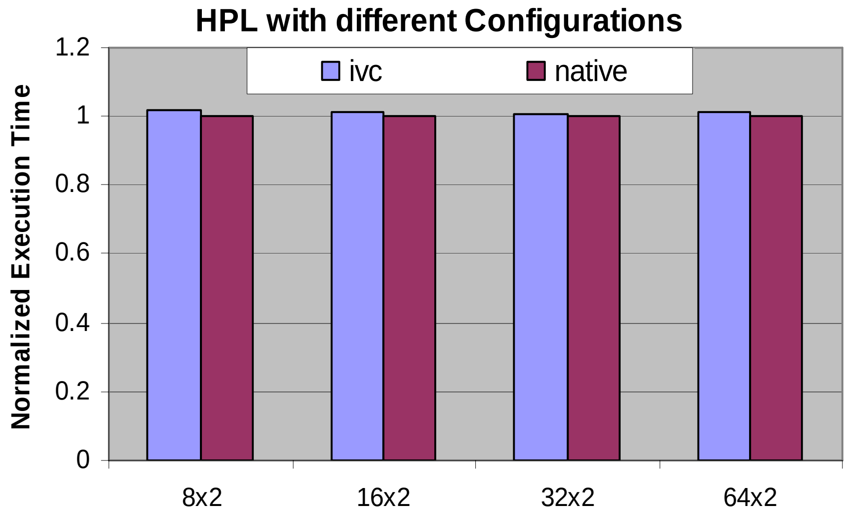
Larger scale?



- Based on individual benchmarks, intra-node communication is still an important part!
- Percentage of intra-node communication is well above average

Overheads on 64 node cluster





- Performance comparison on a 64 node dual processor cluster
- We do see very close performance (~1%)
- NAS-FT shows around 5% overhead with its large message all-to-all communication pattern

Conclusion

- We propose Inter-VM communication (IVC), allowing efficient shared memory communication between VMs
- We modify MVAPICH2 to hide all complexities and allow user applications to benefit transparently
- With our evaluation, we show: virtualization is NOT introducing much overhead
- With its benefits for system management, VMs are an attractive solution for HPC!

Future work

- More optimizations can be made to improve the performance of Inter-VM communication
  - Dynamically map user buffers to achieve one-copy communication
- Looking more into management frameworks for VM-based computing environments (load balancing, fault-tolerance …)

Acknowledgements

Our research at the Ohio State University is supported by the following organizations:

- Current Funding support by

- Current Equipment support by

Thank you!

Network-Based Computing Laboratory

http://nowlab.cse.ohio-state.edu/