River

A Foundation for the Rapid Development of Reliable Parallel Programming Systems

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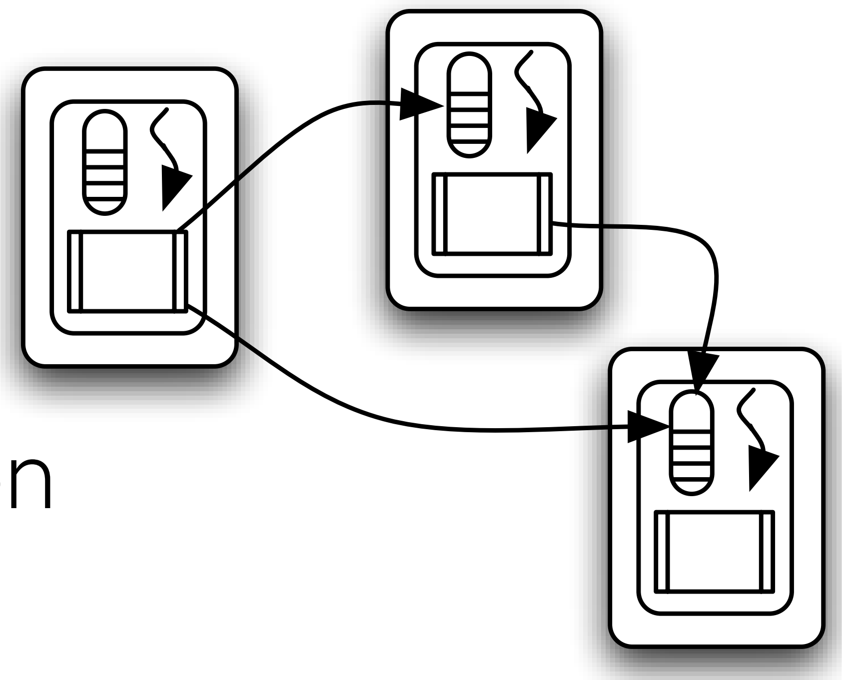
What is River?

- **R**eliable **V**irtual **R**esources
- A Python framework for parallel and distributed programming
  - Prototype parallel programming systems
  - Write parallel Python programs

River Overview



- River Core
  - Discovery
  - Process naming and creation
  - Message passing
  - State management
- River Extensions
  - RPC/RMI, Trickle, MPI, MapReduce

River Benefits

- Small, easy to use core interface
- Written entirely in Python
- Dynamic typing for rapid prototyping
- Python goodies
  - Heterogeneous (Use Python as a VM)
  - State capture at language VM level
    - Integrated checkpointing and migration

Motivation

- Parallel programming is still hard
- The future: more cores, larger clusters
- Apps will have to utilize multiple processors
- Apps will have to tolerate failures
- The quest:
  - Find the next set of programming models
  - Incrementally improve current models

Current Practice

- Design/development cycle (long)
  - Specify (perhaps by committee or group)
  - Prototype (Use C/C++/Java)
  - Use prototype to provide feedback
- Examples
  - MPI, X10, Fortress
- Early implementation decisions hard to undo

River Goals

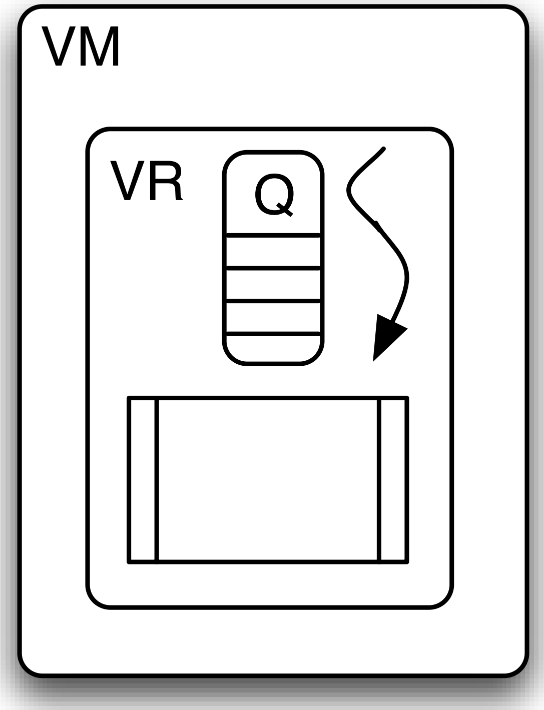
- Extend Python's rapid development capabilities to parallel systems
- Facilitate short design/implementation cycles
    - Open up design space
- Enable prototypes to run on real HW
- Demonstrate scalability/feasibility

Remainder of Talk

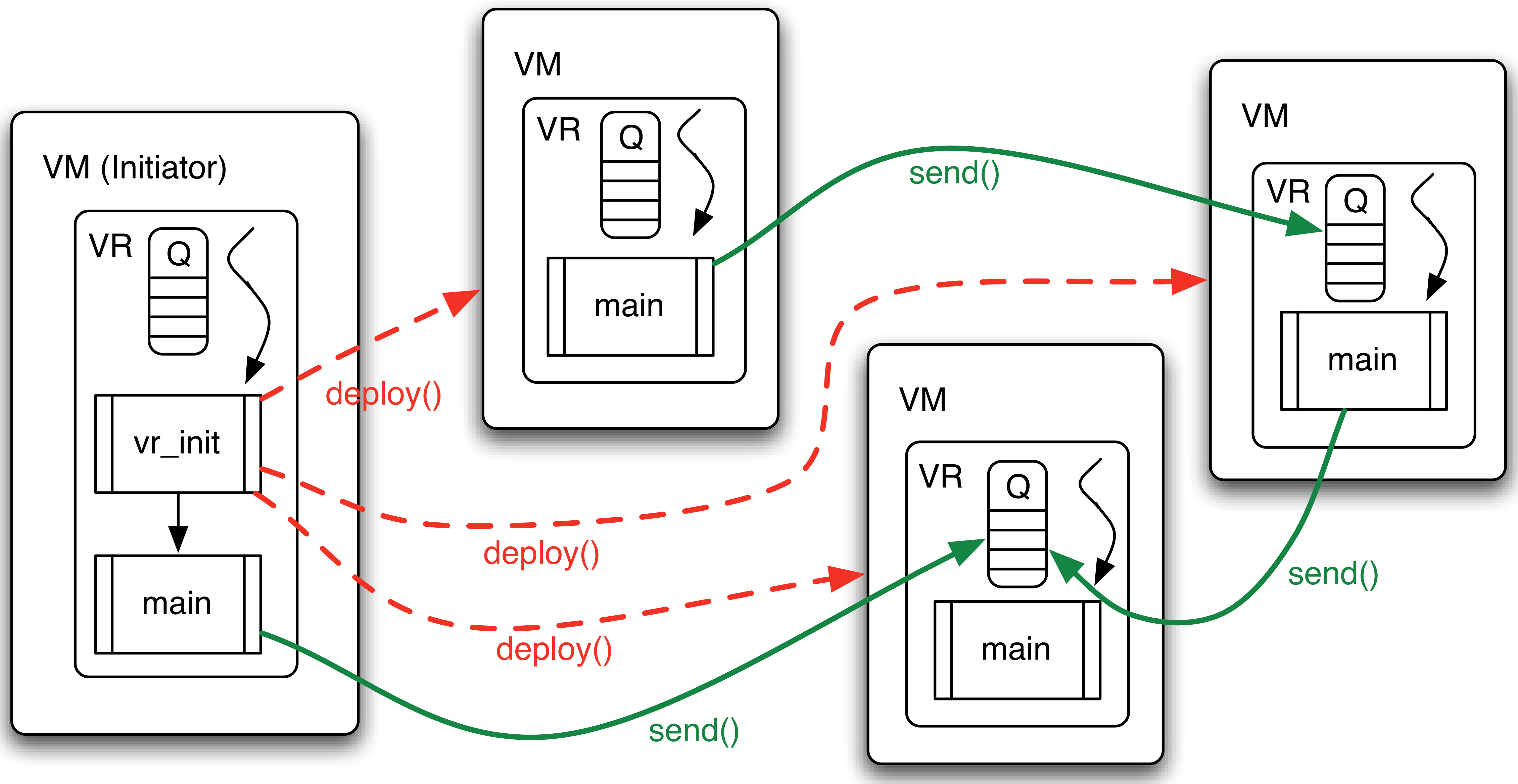
- River Core
- River Extensions
  - Remote Access and Invocation
  - Trickle (simple task farming language)
  - River MPI (rMPI)
- Related and Future Work

River Concepts

- Virtual machines (VMs)
  - Python + River Core
- Virtual resources (VRs)
  - Named with UUIDs
  - Code, data, thread, and message queue
- Discover/allocate/deploy
- Flexible code execution



Executing VRs



Super Flexible Messaging

- Sending

```
send(dest=VRID, text='hello')
send(dest=VRID, tag='inputlist', items = [1, 2, 3, 4])

stk = Stack(); stk.push(1); stk.push(2)
send(dest=VRID, data=stk)
```

- Receiving (selective)

```
m = recv()                    # Any message
m = recv(tag='inputlist')     # Specific attr and value
print m.items

m = recv(tag='inputlist', items=(lambda x:len(x) > 1))
m = recv(src=VRID, data=ANY)
print m.data.pop()
```

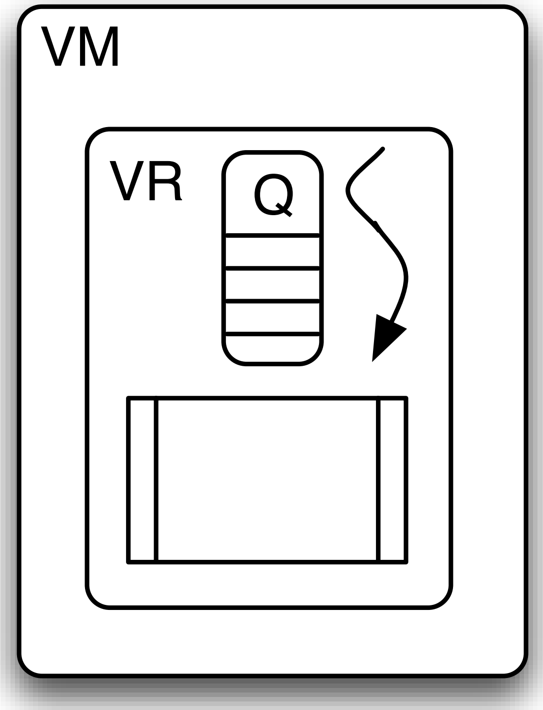
Simple River Program

```
from socket import gethostname
from river.core.vr import VR

class simple (VR):
    def vr_init(self):
        discovered = self.discover()
        allocated = self.allocate(discovered)
        deployed = self.deploy(allocated, module=self.__module__)
        self.vrlist = [vm.uuid for vm in deployed]
        return True

    def main(self):
        if self.parent is None:
            for vr in self.vrlist:
                m = self.recv(src=vr)
                print m.myname
        else:
            self.send(dest=self.parent, myname=gethostname())
```

State Management



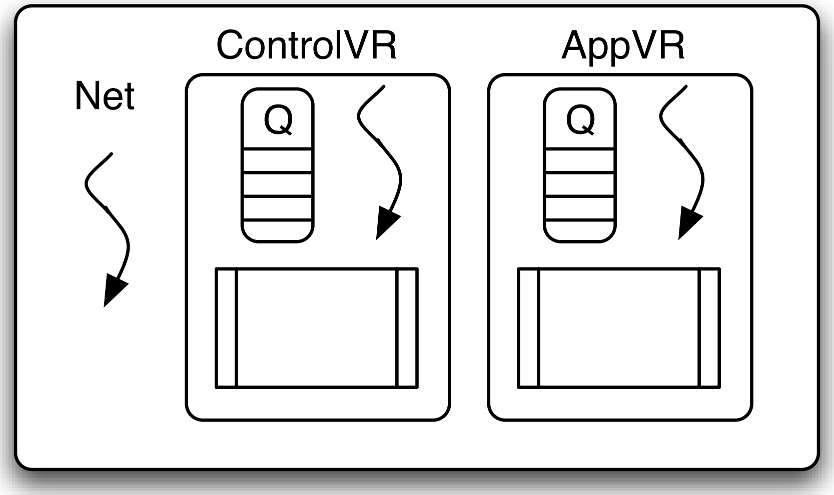
- Designed from the beginning
- Encapsulate local state in VR
  - Only hooks to outside UUIDs
- Per-VR queues hold in-transit messages
- Transparent migration and checkpointing
- Internal and external support

Coordinated Checkpointing

- Algorithm
  - Freeze all remote VRs (preemptively)
  - Allow in-flight messages to settle
  - Write frozen state (VR + queue)
  - Unfreeze all remote VRs
- Mechanism is extensible
  - State exclusion, diskless, app assisted, etc.

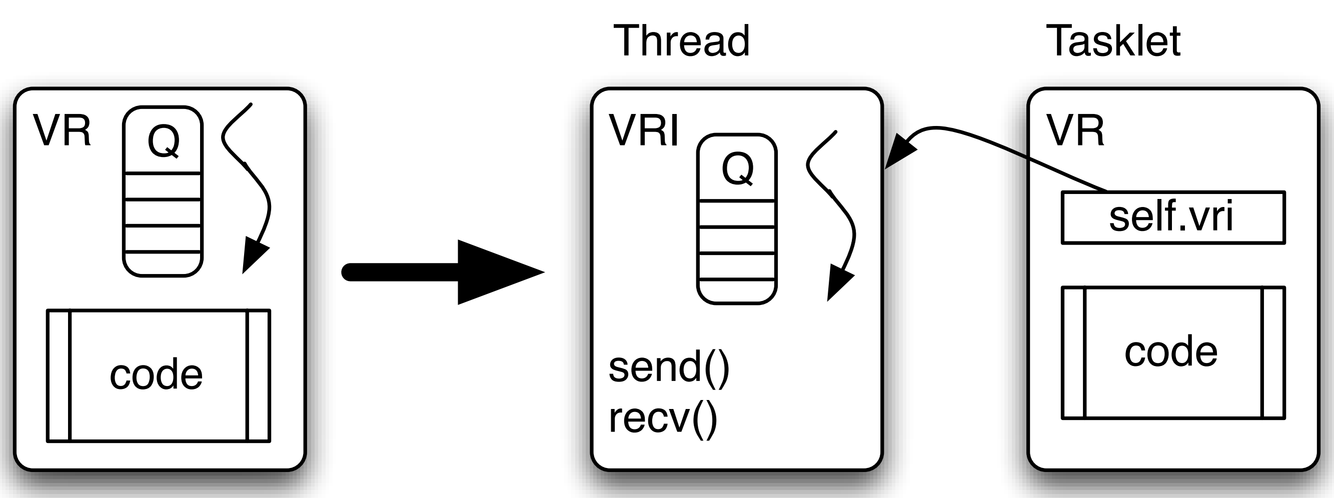
River Implementation

- One net thread, one Control VR
  - Control handles VR creation, state
- TCP-based, connection caching (scalable)
- Broadcast-based discovery
- Super Flexible Messaging
  - Queue matching
  - Serialization (Pickle)



State Implementation

- Keep *soft* VR state separate from *hard* VR state
  - Two VR classes: VR and VRI (internal)
  - VR has a reference to host VRI
- Stackless: run VR as a tasklet in a VRI thread
  - Generate *atomic* system calls (VRI calls)
  - State capture: unlink VRI reference from VR



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River Complexity

Component	LOC
River Core	3701
RAI (remote invocation)	531
Trickle (task farming)	375
rMPI	882
rMPI derived datatypes	246
rMPI non-blocking communication	441
rMPI optimized collectives	335
MapReduce	511

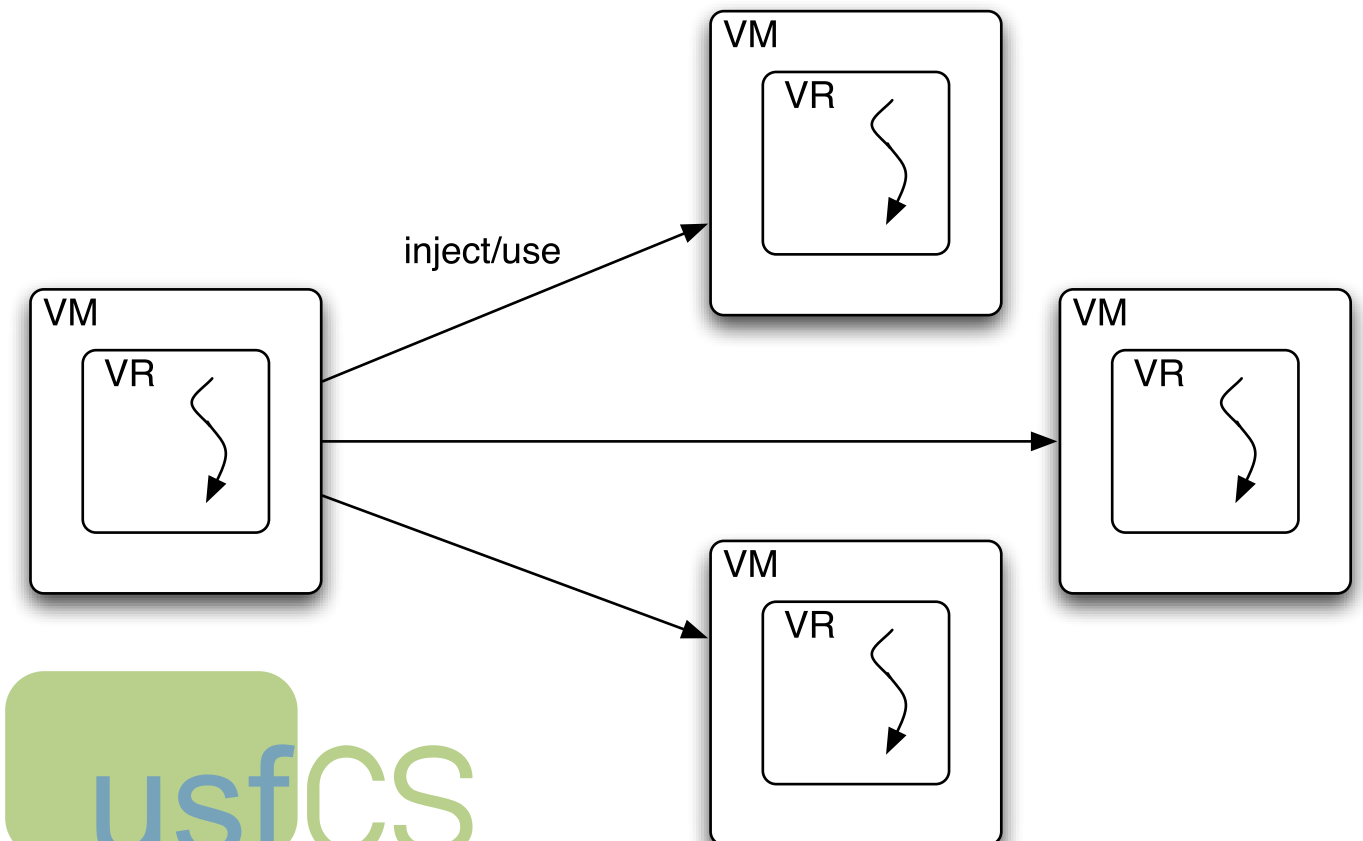
Remote Invocation

- Remote Access and Invocation (RAI)
  - RPC, RMI, and remote data access
- Create and access functions, objects, data on remote VRs
- Built on top of the River core
- Unrestricted mode

```
r = RemoteVR(server, self)
print r.add(1,2,3)
```

Trickle

- Simple task farming language
- Put code/data on remote VMs
- Execute sequentially or in parallel




```
def foo(x):
    return x + 10

vmlist = connect()
inject(vmlist, foo)
results = [vm.foo(10) for vm in vmlist]
print results

$ trickle exsimple.py
[trickle: discovered 4 VMs]
[20, 20, 20, 20]
```

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Parallel Invocation

- Fork/join paradigm

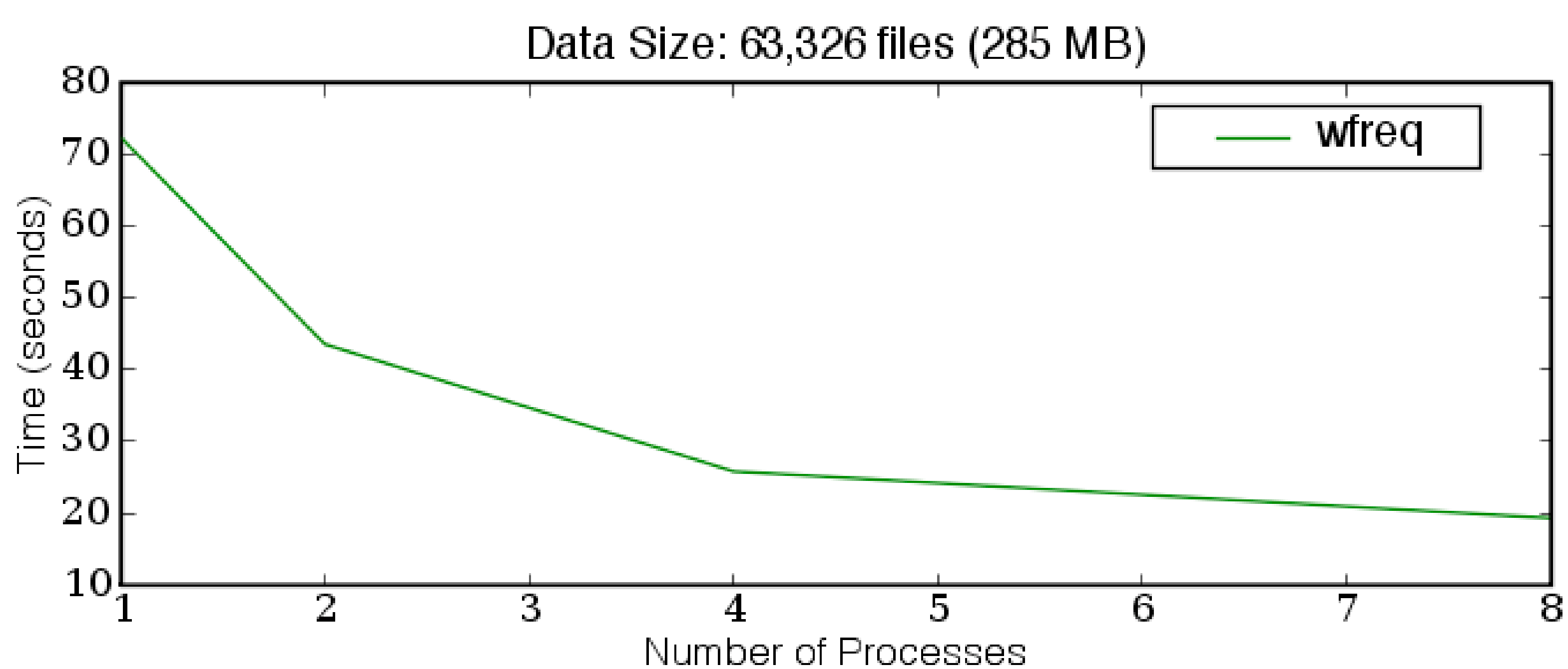
```
def foo(x):
    return x + 10

vmlist = connect()
inject(vmlist, foo)
hlist = fork(vmlist, foo, range(len(vmlist)))

print join(hlist)
```

- Dynamic scheduling

```
def foo(x):
    return sum(x)

vmlist = connect()
inject(vmlist, foo)
results = forkwork(vmlist, foo, range(100), chunksize=10)

print sum(results)
```

Word Frequency

```
def wordcount(files):
     # count words in given files (13 lines)
def mergecounts(dlist):
     # merge resulting count dictionaries (8 lines)

# Command line processing (9 lines)

vmlist = connect(n)
inject(vmlist, wordcount)
rlist = forkwork(vmlist, wordcount, files, chunksize=cs)
final = mergecounts(rlist)
```



Penguin Cluster

AMD Opterons
(Dual dual-core) 2.0GHz
4 GB RAM, GigE

One VM per node

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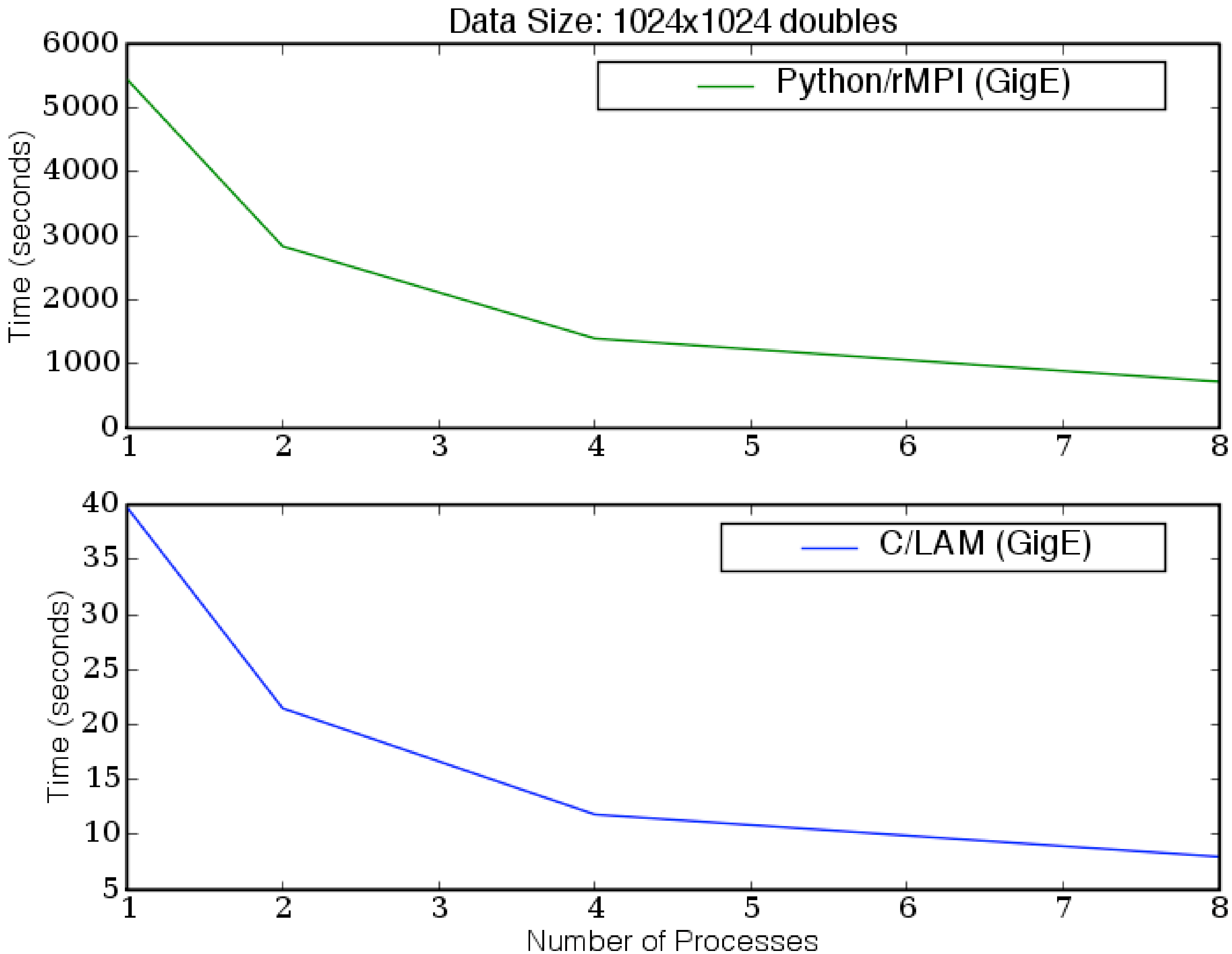
River MPI (rMPI)

- Partial implementation of MPI 1.2 in River
- Most p-to-p and collectives
- Easy to read and understand
- Models C MPI interface
- Experiment with different algorithms
- Use inheritance to add functionality
  - Derived data types, non-blocking comm

rMPI Hello World

```
from mpi import *

class Hello(mpi):

    def main(self):
        self.MPI_Init()
        rank = mpi_Rank()
        np   = mpi_Size()
        self.MPI_Comm_rank( MPI_COMM_WORLD, rank )
        self.MPI_Comm_size( MPI_COMM_WORLD, np )
        status = MPI_Status()

        recvbuf = [ 0.0 ]
        sendbuf = [ rank.value * 100.0 ]

        print 'Hello from rank %d' % ( rank.value )

        if rank.value == 0:
            for i in xrange( 1, np.value ):
                self.MPI_Recv( recvbuf, 1, MPI_FLOAT, i, 0, MPI_COMM_WORLD, status )
                print 'From rank %d: %f' % ( i, recvbuf[0] )
        else:
            # if not rank 0, send value to rank 0
            print 'Rank %d sending %f' % ( rank.value, sendbuf[0] )
            self.MPI_Send( sendbuf, 1, MPI_FLOAT, 0, 0, MPI_COMM_WORLD )

        self.MPI_Finalize()
```

rMPI Conjugate Gradient



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One VM/Process per node

Dissemination Barrier

```
def MPI_Barrier(self, comm):

    root = mpi_Rank(0)
    sendbuf = [1]; recvbuf = [0]
    msgUid = self.getMsgUid()
    status = MPI_Status()

    i = self.rank.value
    p = comm.size()
    steps = int(math.ceil(math.log(p, 2)))
    for k in xrange(steps):
        dest = (i + 2**k) % p
        src = (i - 2**k + p) % p
        self.MPI_Send(sendbuf, 1, MPI_INT, mpi_Rank(dest), msgUid, comm)
        self.MPI_Recv(recvbuf, 1, MPI_INT, mpi_Rank(src), msgUid, comm, status)
    return MPI_SUCCESS
```

Experience

- Trickle
  - Design: about 2 days
  - First implementation: about 1 evening
  - Refinements: easy (e.g., dynamic scheduling)
- rMPI
  - First implementation: about 1 month
  - Used in a grad parallel computing class

Related Work

- Python
  - PyMPI, MYMPI, PYRO, Twisted, others
  - IPython (Trickle-like functionality)
- VM level checkpointing and migration
  - Many Java-based implementations

Future Work

- Refine the River Core
- Further experimentation with rMPI and Trickle
- Evaluate different checkpointing schemes
- Develop new extensions: GAS-like language
- Automate the translation of a River implementation into a C/Java implementation

River Website and Release

http://www.cs.usfca.edu/river

- River papers
  - River overview
  - Super Flexible Messaging (SFM)
  - Trickle
- Download River and Extensions