Do you wish you could hear the audio and read the transcription of this session?

Then come to JavaOne[SM] Online where this session is available in a multimedia tool with full audio and transcription synced with the slide presentation.

JavaOne Online offers much more than just multimedia sessions. Here are just a few benefits:

- 2003 and 2002 Multimedia JavaOne conference sessions
- Monthly webinars with industry luminaries
- Exclusive web-only multimedia sessions on Java technology
- Birds-of-a-Feather sessions online
- Classified Ads: Find a new job, view upcoming events, buy or sell cool stuff and much more!
- Feature articles on industry leaders, Q&A with speakers, etc.

For only $99.95, you can become a member of JavaOne Online for one year. Join today!

Visit http://java.sun.com/javaone/online for more details!

JavaOne℠

Sun's 2003 Worldwide Java Developer Conference

How to Write a Scalable Server

Mark Reinhold
Senior Staff Engineer
Sun Microsystems, Inc.

Outline

- Measuring Server Performance
- Server Architectures
  - From simple to complex
- Conclusion
  - Tuning
  - NIO Bugs Discovered
  - Lessons
- References

Measuring Server Performance

Measuring Server Performance

... is really really hard

- Real web servers do lots of stuff
  - CGI, JSP, SSL, database access, authentication, logging, session tracking, caching, ...
  - Essentially a very large distributed system
  - Hard to duplicate production environment in lab
  - Hard to measure a production system without interfering with it (cf. Heisenberg)

Measuring Server Performance

... is really really hard
... so we resort to microbenchmarks

- Microbenchmarks can be deceiving
  - Measure extreme cases, not real systems
- Microbenchmarks are much more practical
  - Still useful for exploring a design space
  - This is the approach taken here

Two Microbenchmarks

"Two tests in particular are simple, interesting, and hard." – Dan Kegel

- How many requests/second can you serve?
  - Small files (1KB)
  - Connections/second vs. requests/second
  - Response-time distribution
- How many slow (56kb) clients can you serve?
  - Large files (1MB)
  - Bytes/second vs. number of clients

Test Environment

- 3 Sun E450s
  - 4x480 MHz UltraSparc® II processors
  - 8MB cache/processor, 4GB main memory
  - Solaris™ 9 Operating Environment + patches
  - Two client machines, one server
- Point-to-point gigabit ethernet
  - Peak bandwidth: 76MB/s
  - Latency: Difficult to measure
- No bottlenecks
  - Except for the server itself

Test Methodology

- Each sample point measured separately
- Restart client and server programs
- Warm up server
  - 1000 small requests/second for 30 seconds
- Run test for five minutes
  - Experimentation showed no significant difference with longer durations
- Java™ runtime environment
  - Latest "Mantis" (1.4.2) build

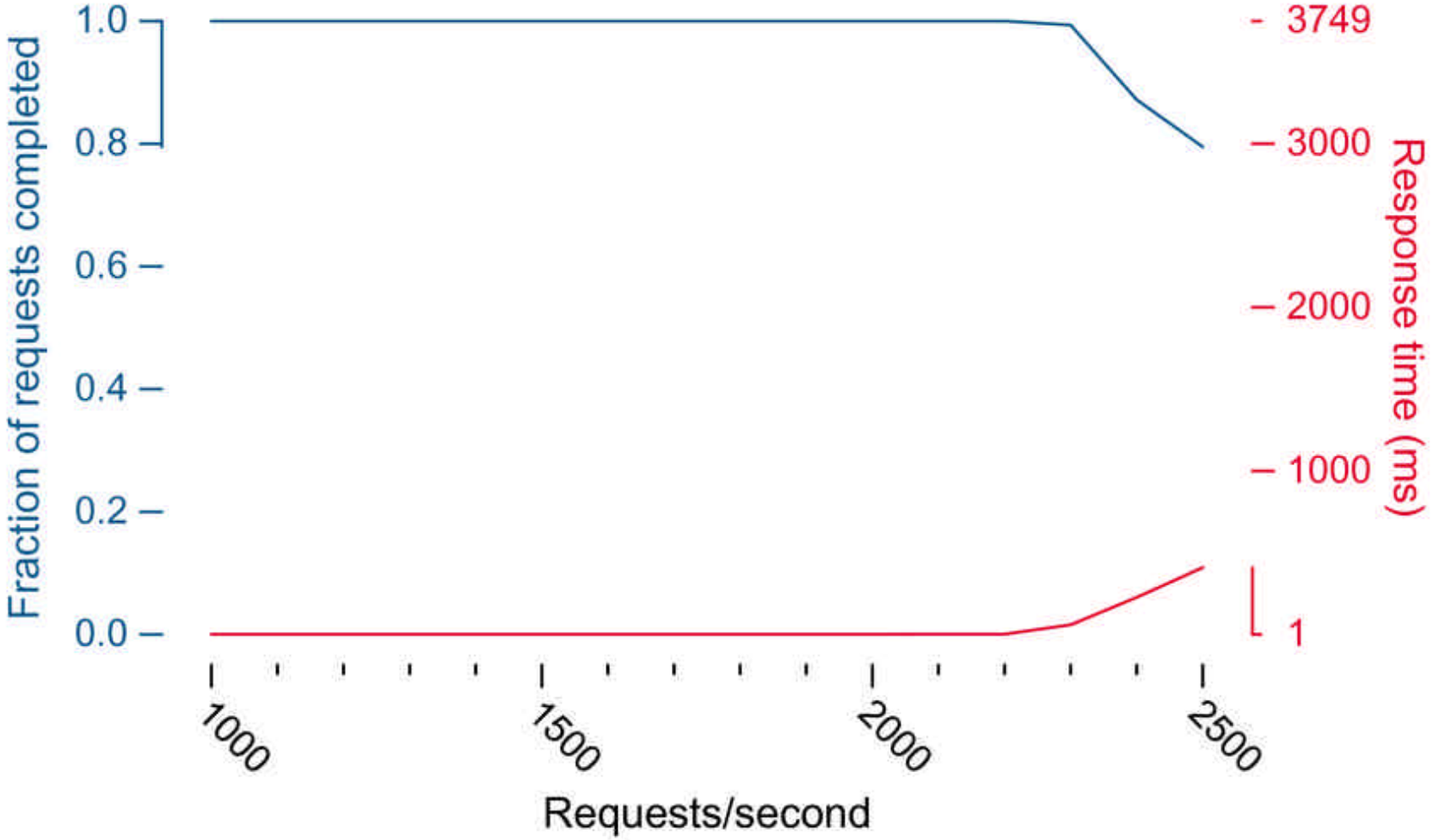
Baselines: Two Real Servers

- thttpd 2.20c
  - Jef Poskanzer @ Acme Laboratories
  - `http://www.acme.com/software/thttpd`
  - Small, fast, simple
  - Single-process, single-threaded, non-blocking
- Apache 2.0.42
  - Apache Software Foundation
  - `http://httpd.apache.org`
  - Larger, more complex, but still pretty fast
  - Multi-process, multi-threaded

Small-File Test

- Test tool: httperf
  - David Mosberger & Tai Jin @ HP Labs
  - `ftp://ftp.hpl.hp.com/pub/httperf`
  - Can generate and sustain overload
  - Can initiate requests at fixed or variable rates
  - Measures response-time distributions
- Test parameters
  - 1000 1KB files, requested randomly
  - 1000-2500 requests/second, fixed rate

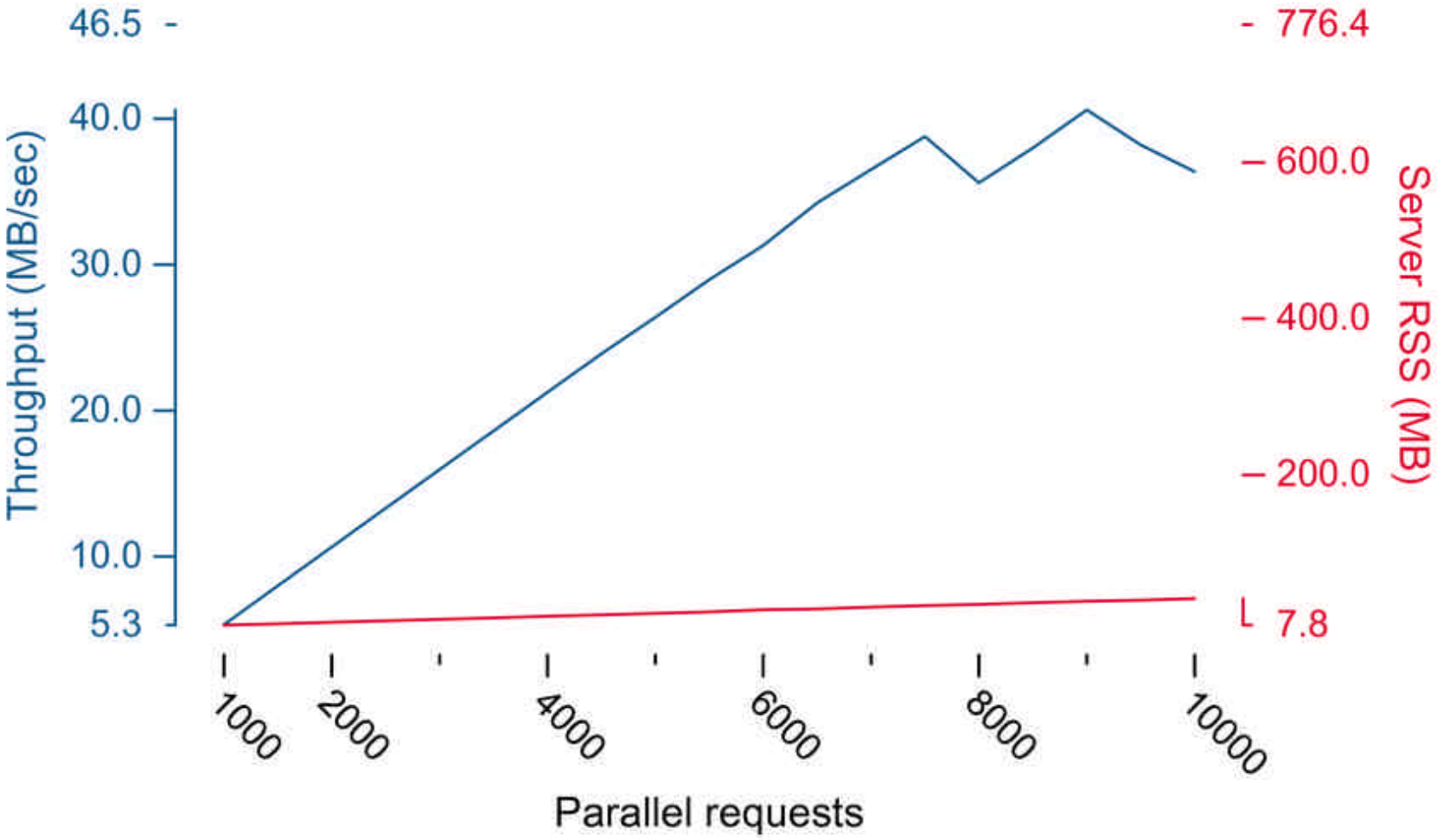
Small-File Test: Apache



Large-File Test

- Test tool: http_load
  - Also by Jef Poskanzer @ Acme Laboratories
  - `http://www.acme.com/software/thttpd`
  - Can open connections at fixed rate or with fixed parallelism
  - Can throttle bandwidth to simulate slow clients
- Test parameters
  - 100 different 1MB files, requested randomly
  - 1000-10000 parallel connections
  - Each connection throttled to 56kb/s

Large-File Test: thttpd



Server Architectures

Server Architectures

B1	Blocking	Single-Threaded
BN	Blocking	Multi-Threaded
BP	Blocking	Multi-Threaded, Pooled
N1	Non-Blocking	Single-Threaded
N2	Non-Blocking	Two Threads
N4	Non-Blocking	Four Threads

B1: Blocking, Single-Threaded

B1: Blocking, Single-Threaded

```
class B1 {
  private static int PORT = 8080;
  private static int BACKLOG = 1024;
  public static void main(String[] args)
    throws IOException
  {
    ServerSocketChannel ssc
      = ServerSocketChannel.open();
    ssc.socket().setReuseAddress(true);
    ssc.socket().bind(new InetSocketAddress(PORT),
                      BACKLOG);
    for (;;)
      service(ssc);
  }
}
```

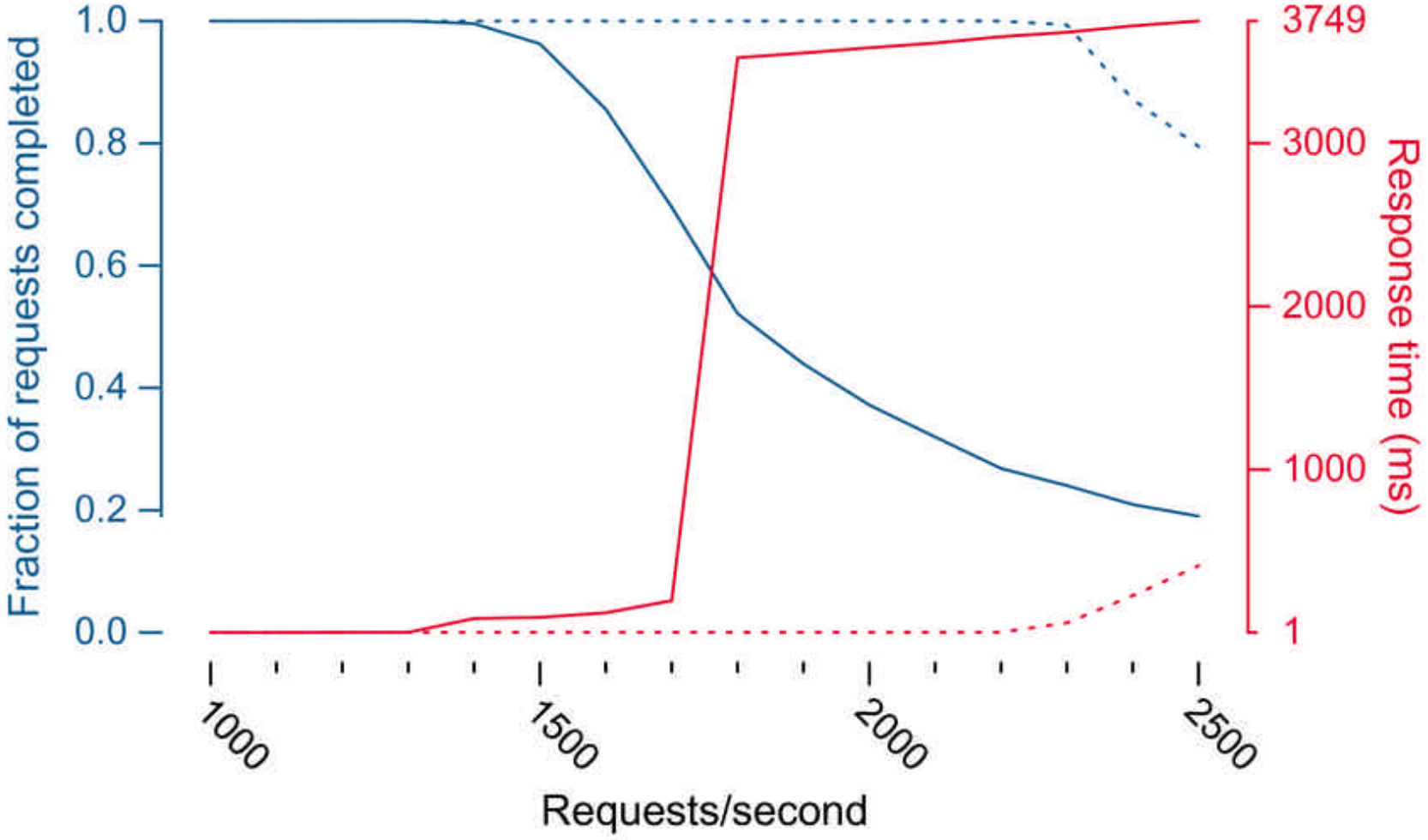
B1: Blocking, Single-Threaded

```
class B1 {
  private static int PORT = 8080;
  private static int BACKLOG = 1024;

  public static void main(String[] args)
    throws IOException
  {
    ServerSocketChannel ssc
      = ServerSocketChannel.open();
    ssc.socket().setReuseAddress(true);
    ssc.socket().bind(new InetSocketAddress(PORT),
                      BACKLOG);
    for (;;)
      service(ssc);
  }
}
```

B1: Blocking, Single-Threaded

```
class B1 {
  ...
  public static void main(String[] args) { ... }
  static void service(ServerSocketChannel ssc)
    throws IOException
  {
    SocketChannel sc = ssc.accept();      // Accept
    ByteBuffer rbb = receive(sc);         // Receive
    Request rq = Request.parse(rbb);      // Parse
    Reply rp = build(rq);                 // Build
    rp.send(sc);                          // Send
    sc.close();                           // Close
  }
}
```

B1: Blocking, Single-Threaded



B1: Blocking, Single-Threaded

Problem: Cannot handle more than one connection at a time

Solution: Create a new thread for each connection

➥ BN: Blocking, *Multi*-Threaded

Server Architectures

BN: Blocking, Multi-Threaded

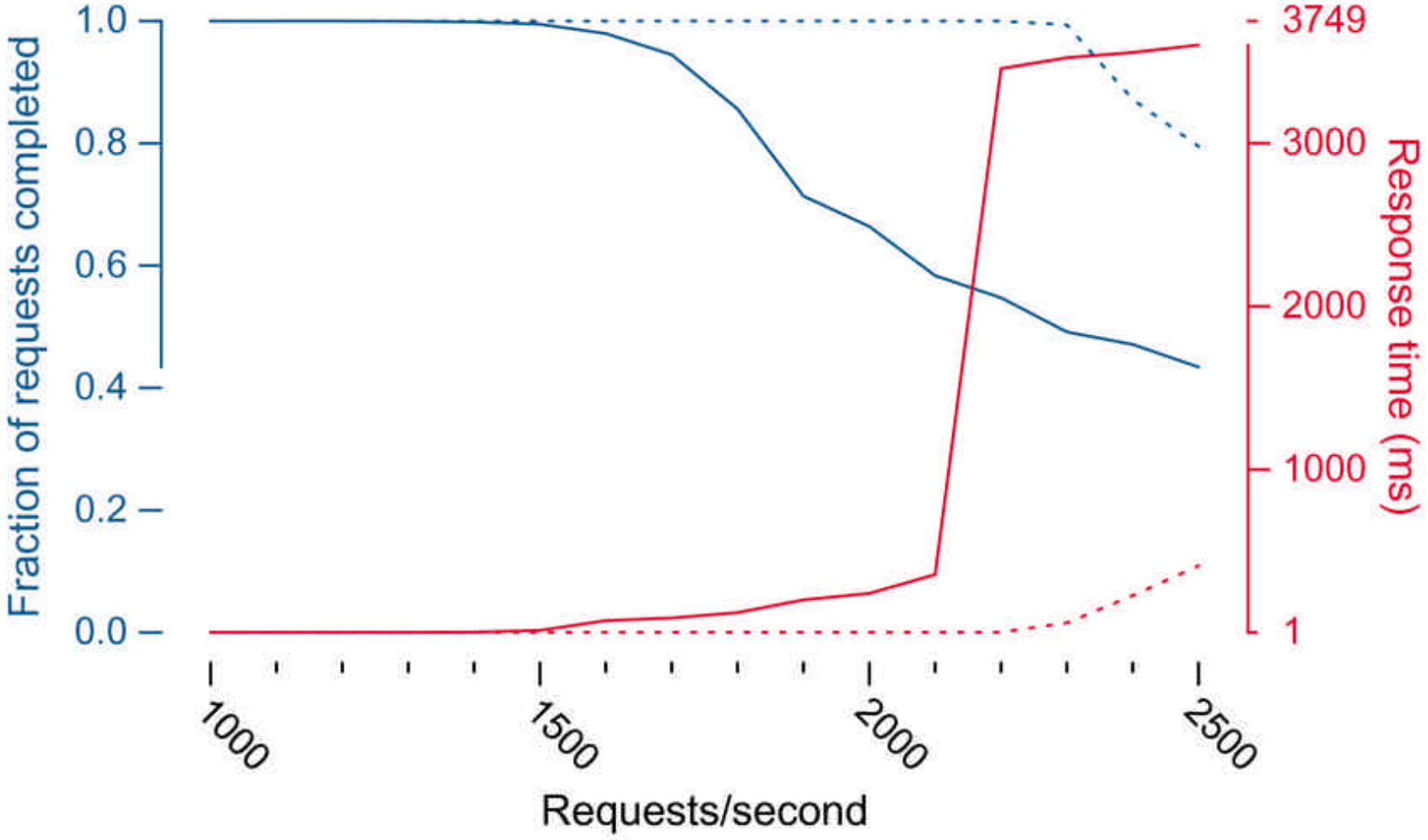
BN: Blocking, Multi-Threaded

```
class B1 {
  // Accept, receive, parse, build, send, close
  static void service(ServerSocketChannel ssc);

  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    for (;;)
      service(ssc);
  }

  static void service(ServerSocketChannel ssc) {
    SocketChannel sc = ssc.accept();     // Accept
    ByteBuffer rbb = receive(sc);        // Receive
    ...
  }
}
```

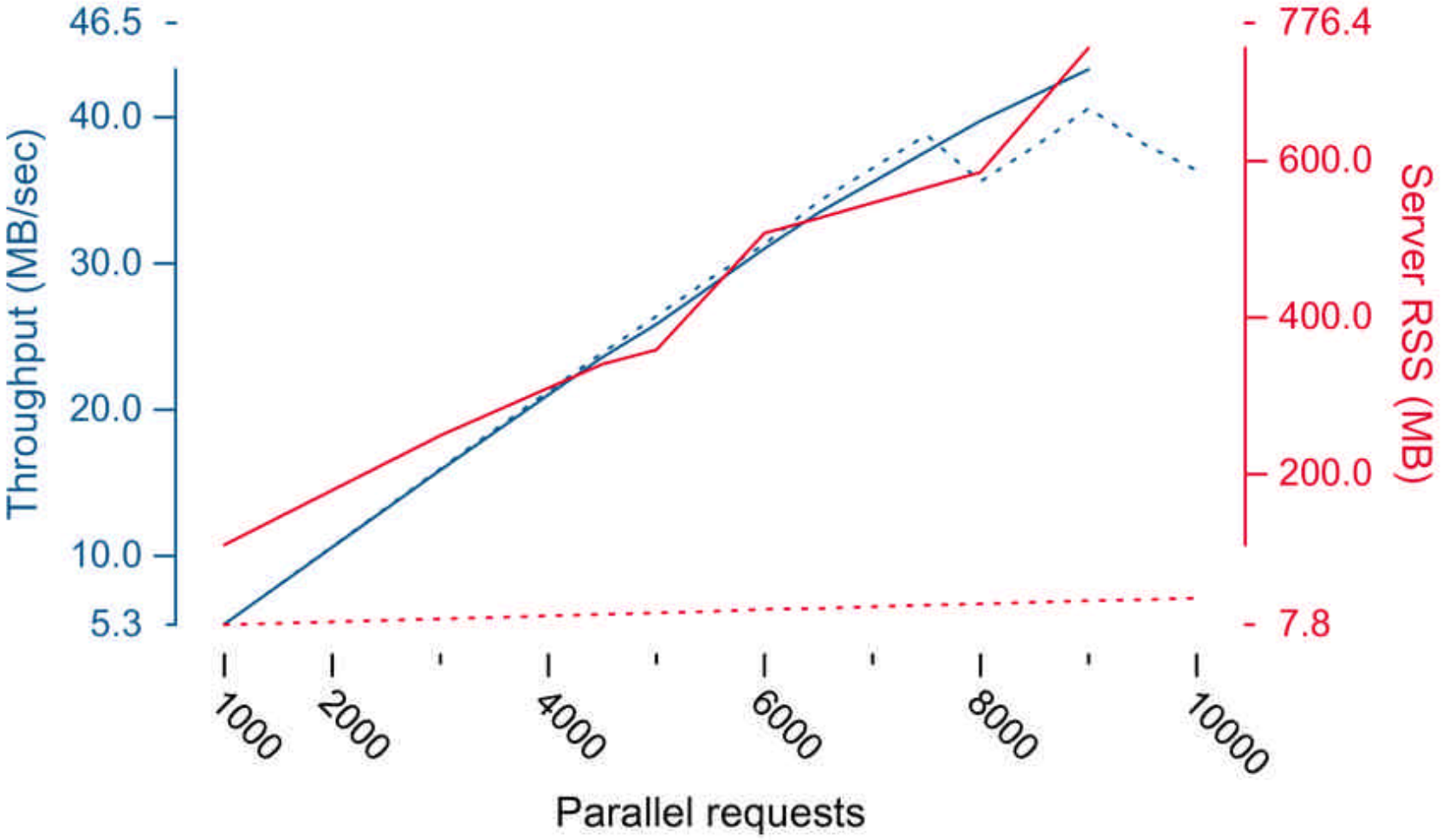
BN: Blocking, Multi-Threaded

```
class BN {
  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    for (;;) {
      SocketChannel sc = ssc.accept();
      new Thread(new Servicer(sc)).start();
    }
  }
}

class Servicer implements Runnable {
  Servicer(SocketChannel sc);
  void run();     // Receive, parse, build, send, close
}
```

BN: Blocking, Multi-Threaded



BN: Blocking, Multi-Threaded



BN: Blocking, Multi-Threaded

Problem: Creating threads is expensive

Solution: Pool threads for re-use

➥ BP: Blocking, Multi-Threaded, *Pooled*

Server Architectures

BP: Blocking, Pooled

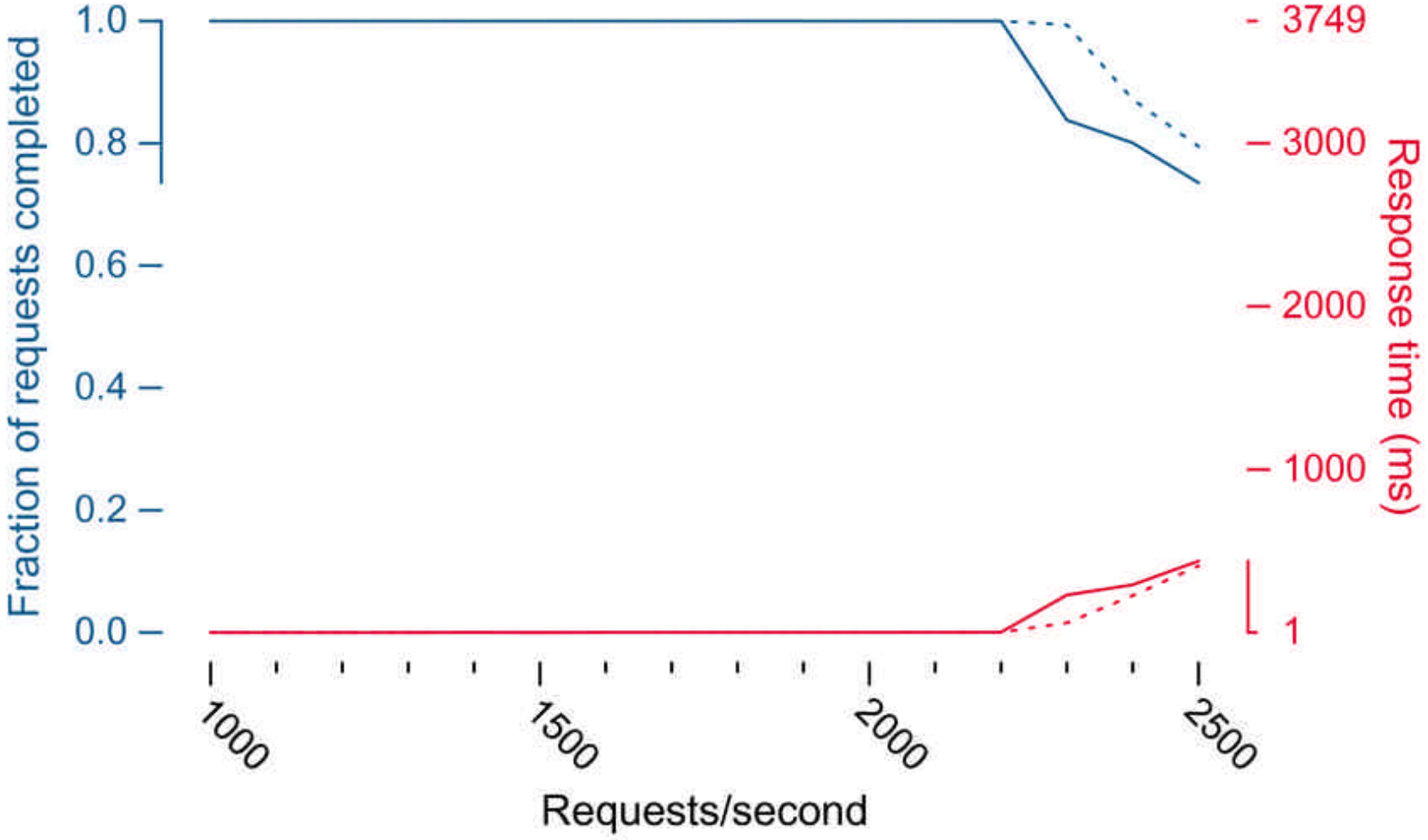
BP: Blocking, Pooled

```
class BN {
  ...
  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    for (;;) {
      SocketChannel sc = ssc.accept();
      new Thread(new Servicer(sc)).start();
    }
  }
}
```

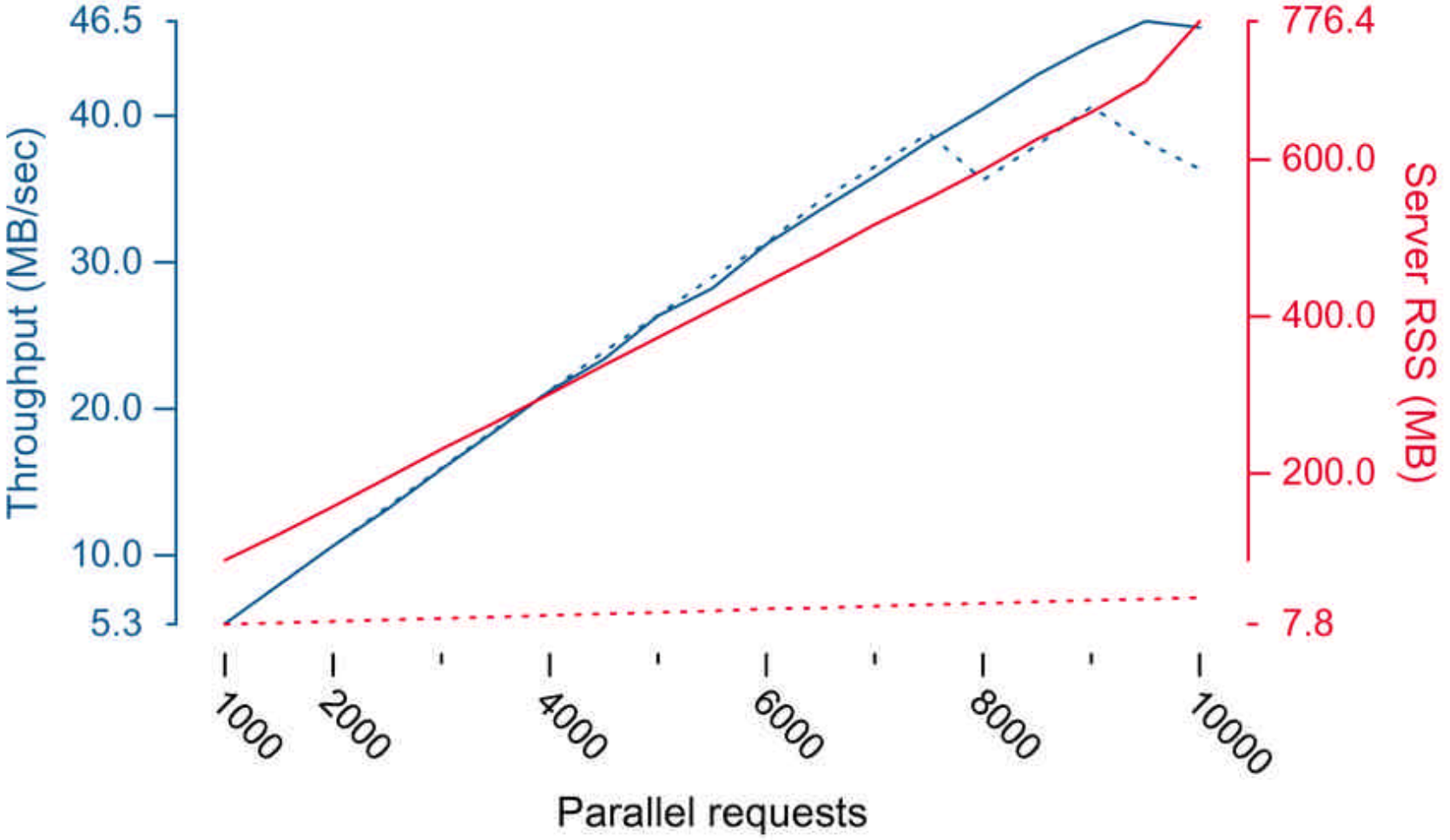
BP: Blocking, Pooled

```
class BP {
  ...
  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    Executor xec = new PooledExecutor();
    for (;;) {
      SocketChannel sc = ssc.accept();
      xec.execute(new Servicer(sc));
    }
  }
}
```

BP: Blocking, Pooled



BP: Blocking, Pooled



BP: Blocking, Pooled

Problem: Threads are expensive, even when pooled

Solution: Use non-blocking I/O operations

➥ N1: *Non*-Blocking, *Single*-Threaded

Server Architectures

N1: Non-Blocking, Single-Threaded

Digression

How to Use Selectors

How to Use Selectors

Selectable channel	=	A channel that can be multiplexed
Selector	=	A multiplexor of selectable channels
Selection key	=	A token representing the registration of a selectable channel with a selector

Selectors: Non-Blocking I/O

```
ByteBuffer bb = ByteBuffer.allocate(4096);
SocketChannel sc = SocketChannel.open(addr);

// Blocking read
return sc.read(bb);
```

Selectors: Non-Blocking I/O

```
ByteBuffer bb = ByteBuffer.allocate(4096);
SocketChannel sc = SocketChannel.open(addr);

// Blocking read
return sc.read(bb);

// Blocking read built from non-blocking ops
Selector sel = Selector.open();
sc.configureBlocking(false);
SelectionKey sk = sc.register(sel, SelectionKey.OP_READ);
sel.select();
return sc.read(bb);
```

Selectors: Hints Can Be Wrong

```
ByteBuffer bb = ByteBuffer.allocate(4096);
SocketChannel sc = SocketChannel.open(addr);

// Blocking read
return sc.read(bb);

// Blocking read built from non-blocking ops
Selector sel = Selector.open();
sc.configureBlocking(false);
SelectionKey sk = sc.register(sel, SelectionKey.OP_READ);
for (;;) {
  sel.select();
  int n = sc.read(bb);
  if (n > 0) return n;
}
```

Selectors: Multiplexing Channels

```
SelectionKey sk1
  = sc1.register(sel, SelectionKey.OP_READ);
SelectionKey sk2
  = sc2.register(sel, SelectionKey.OP_READ);
for (;;) {
  sel.select();
  if (sk1.readyOps() & SelectionKey.OP_READ != 0) {
    int n = sc1.read(bb);
    if (n > 0) return n;
  }
  if (sk2.readyOps() & SelectionKey.OP_READ != 0) {
    int n = sc2.read(bb);
    if (n > 0) return n;
  }
}
```

Selectors: The Selected-Key Set

```
sc1.register(sel, SelectionKey.OP_READ);
sc2.register(sel, SelectionKey.OP_READ);
for (;;) {
  sel.select();
  for (  Iterator i = sel.selectedKeys().iterator();
         i.hasNext();) {
      SelectionKey sk = (SelectionKey)i.next();
      i.remove();
      SocketChannel sc = (SocketChannel)sk.channel();
      int n = sc.read(bb);
      if (n > 0) return n;
    }
}
```

Selectors: Attachments

```
sc1.register(sel, SelectionKey.OP_READ,
             ByteBuffer.allocate(4096));
sc2.register(sel, SelectionKey.OP_READ,
             ByteBuffer.allocate(4096));
for (;;) {
  sel.select();
  for (  Iterator i = sel.selectedKeys().iterator();
         i.hasNext();) {
      SelectionKey sk = (SelectionKey)i.next();
      i.remove();
      SocketChannel sc = (SocketChannel)sk.channel();
      ByteBuffer bb = (ByteBuffer)sk.attachment();
      int n = sc.read(bb);
      if (n > 0) return sk;
    }
}
```

Selectors: Handlers

```
interface Handler {
  void handle(SelectionKey sk);
}

class DataHandler implements Handler {
  DataHandler(SocketChannel sc);
  void handle(SelectionKey sk);
}

class LogHandler implements Handler {
  LogHandler(SocketChannel sc);
  void handle(SelectionKey sk);
}
```

Selectors: Handler Attachments

```
SelectionKey sk1
  = sc1.register(sel, SelectionKey.OP_READ,
                 new DataHandler(sc1));
SelectionKey sk1
  = sc2.register(sel, SelectionKey.OP_WRITE,
                 new LogHandler(sc2));
for (;;) {
  sel.select();
  for (  Iterator i = sel.selectedKeys().iterator();
         i.hasNext();) {
      SelectionKey sk = (SelectionKey)i.next();
      i.remove();
      Handler h = (Handler)sk.attachment();
      h.handle(sk);
    }
}
```

Server Architectures

N1: Non-Blocking, Single-Threaded

N1: Non-Blocking, Single-Threaded

```
sel.select();
for (  Iterator i = sel.selectedKeys().iterator();
       i.hasNext();)
{
  SelectionKey sk = (SelectionKey)i.next();
  i.remove();
  Handler h = (Handler)sk.attachment();
  h.handle(sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class Dispatcher {
  private Selector sel;
  void dispatch() {
    sel.select();
    for (  Iterator i = sel.selectedKeys().iterator();
           i.hasNext();)
    {
      SelectionKey sk = (SelectionKey)i.next();
      i.remove();
      Handler h = (Handler)sk.attachment();
      h.handle(sk);
    }
  }
}
```

N1: Non-Blocking, Single-Threaded

```
class Dispatcher {
  private Selector sel;
  void dispatch() {
    sel.select();
    ...
  }
  Dispatcher() {
    sel = Selector.open();
  }
}
```

N1: Non-Blocking, Single-Threaded

```
class Dispatcher {
  private Selector sel;
  void dispatch() {
    sel.select();
    ...
  }
  Dispatcher() {
    sel = Selector.open();
  }
  void register(SelectableChannel ch, int ops,
                Handler h)
  {
    ch.register(sel, ops, h);
  }
}
```

N1: Non-Blocking, Single-Threaded

```
class N1 {
  public static void main(String[] args) {
    ServerSocketChannel ssc
      = ServerSocketChannel.open();
    ...
    ssc.configureBlocking(false);
    Dispatcher d = new Dispatcher();
    d.register(ssc, SelectionKey.OP_ACCEPT,
               new AcceptHandler(ssc, d));
    for (;;)
      d.dispatch();
  }
}
```

N1: Non-Blocking, Single-Threaded

```
class AcceptHandler implements Handler {
  AcceptHandler(ServerSocketChannel ssc,
                Dispatcher d);
  void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class AcceptHandler implements Handler {
  private ServerSocketChannel ssc;
  private Dispatcher d;
  AcceptHandler(ServerSocketChannel ssc,
                Dispatcher d)
  {
    this.ssc = ssc;
    this.d = d;
  }
  void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class AcceptHandler implements Handler {
  private ServerSocketChannel ssc;
  private Dispatcher d;

  ...
  void handle(SelectionKey sk) {
    if (sk.readyOps() & SelectionKey.OP_ACCEPT == 0)
      return;
    SocketChannel sc = ssc.accept();
    if (sc == null)
      return;
    sc.configureBlocking(false);
    d.register(sc, SelectionKey.OP_READ,
                   new RequestHandler(sc));
  }
}
```

N1: Non-Blocking, Single-Threaded

```
class RequestHandler implements Handler {
  RequestHandler(SocketChannel sc);
  void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class RequestHandler implements Handler {
  private SocketChannel sc;
  RequestHandler(SocketChannel sc) {
    this.sc = sc;
  }
  void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class RequestHandler implements Handler {
   ...
   private ByteBuffer rbb = ByteBuffer.allocate(4096);
   private Request request = null;
   private Reply reply = null;
   void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
class RequestHandler implements Handler {
  ...
  private ByteBuffer rbb = ByteBuffer.allocate(4096);
  private Request request = null;
  private Reply reply = null;
  // Returns true when request is complete
  private boolean receive();
  // If okay, saves request and returns true
  private boolean parse();
  // Builds reply for request
  private void build();
  void handle(SelectionKey sk);
}
```

N1: Non-Blocking, Single-Threaded

```
void handle(SelectionKey sk) {
  if (request == null) {
    if (!receive())
      return;
    rbb.flip();
    if (parse())
      build();
    sk.interestOps(SelectionKey.OP_WRITE);
  } else {
    if (reply.send(sc))
      sc.close();
  }
}
```

N1: Non-Blocking, Single-Threaded

```
void handle(SelectionKey sk) {
  if (request == null) {
    if (!receive())
      return;
    rbb.flip();
    if (parse())
      build();
    if (!reply.send(sc))
      sk.interestOps(SelectionKey.OP_WRITE);
    else
      sc.close();
  } else {
    if (reply.send(sc))
      sc.close();
  }
}
```

N1: Non-Blocking, Single-Threaded

```
void handle(SelectionKey sk) {
  try {
    if (request == null) {
      if (!receive())
        return;
      ...
    } else {
      if (reply.send(sc))
        sc.close();
    }
  } catch (IOException x) {
    sc.close();
  }
}
```

N1: Non-Blocking, Single-Threaded

N1.main:

```
Dispatcher d = new Dispatcher();
d.register(ssc, SelectionKey.OP_ACCEPT,
           new AcceptHandler(ssc, d));
for (;;)
  d.dispatch();
```

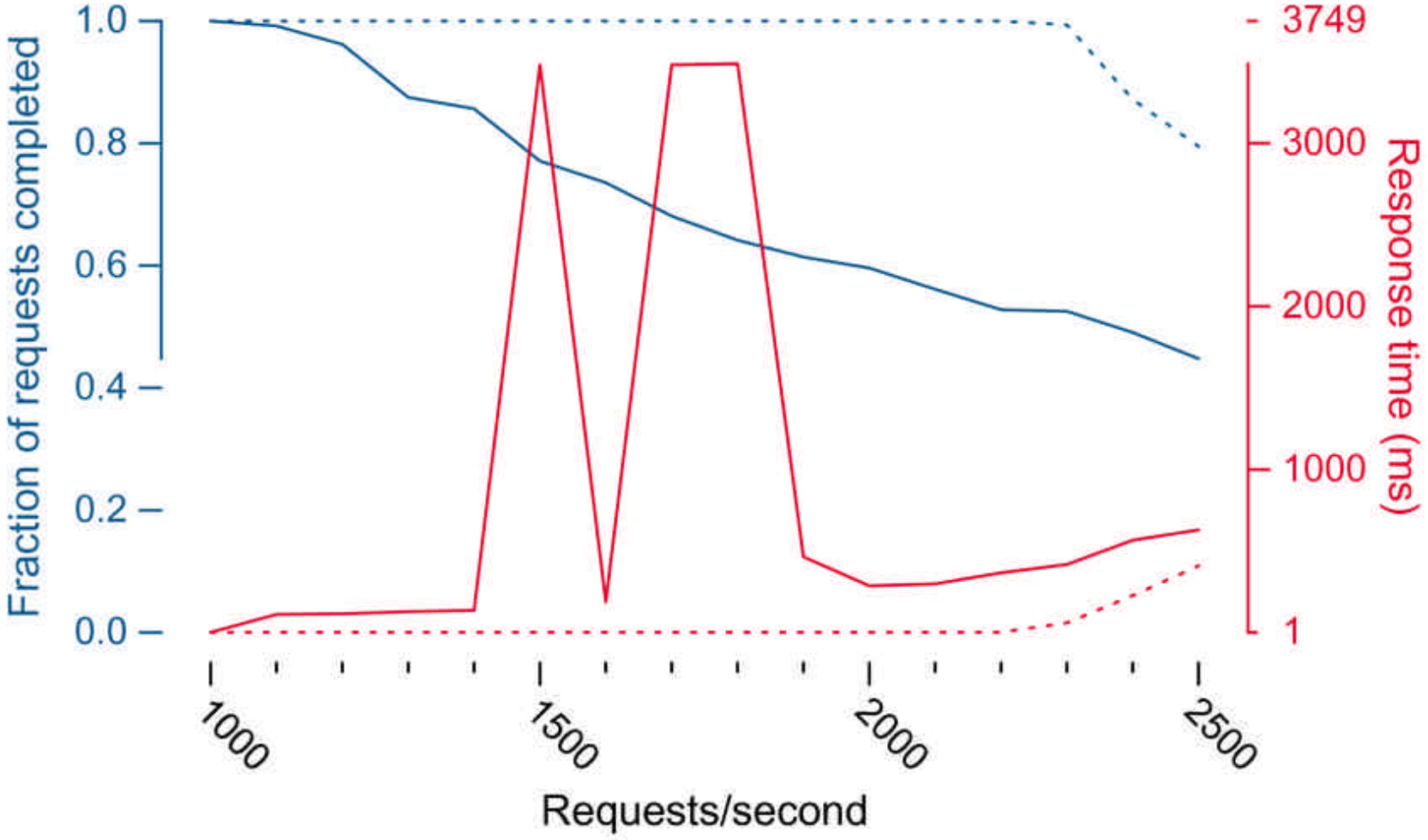
AcceptHandler:

```
SocketChannel sc = ssc.accept();
sc.configureBlocking(false);
d.register(sc, SelectionKey.OP_READ,
           new RequestHandler(sc));
```

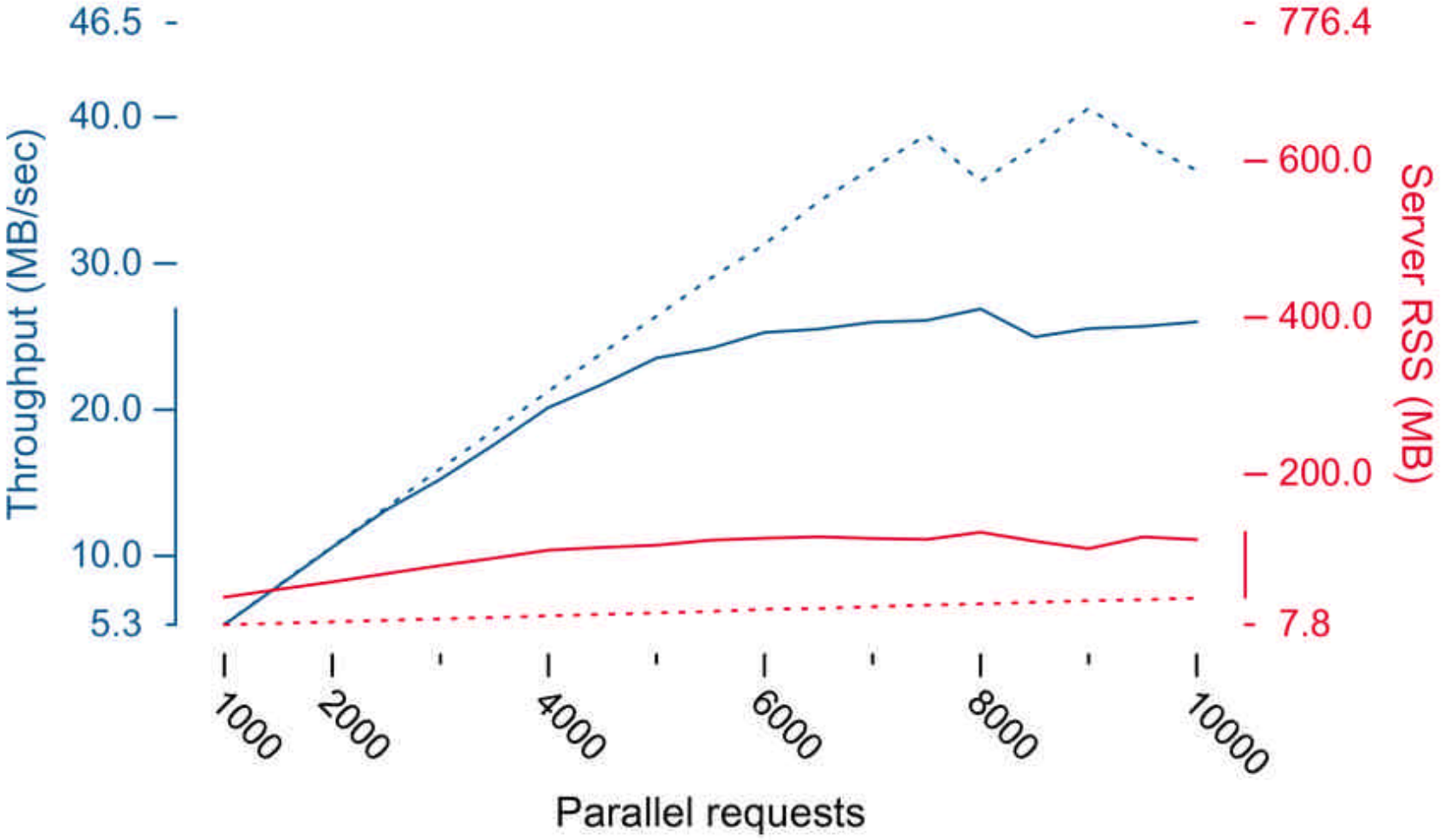
RequestHandler:

```
if (request == null) {
  if (!receive()) return;
  if (parse()) build();
  sk.interestOps(SelectionKey.OP_WRITE);
} else {
  if (reply.send(sc)) sc.close();
}
```

N1: Non-Blocking, Single-Threaded



N1: Non-Blocking, Single-Threaded



N1: Non-Blocking, Single-Threaded

Problem: Performance very poor

Solution: Use more threads

➥ N2: Non-Blocking, *Two* Threads

N2: Non-Blocking, Two Threads

N2: Non-Blocking, Two Threads

```
class Acceptor implements Runnable {
  Acceptor(ServerSocketChannel ssc, Dispatcher d);
  public void run();
}
```

N2: Non-Blocking, Two Threads

```
class Acceptor implements Runnable {
  private ServerSocketChannel ssc;
  private Dispatcher d;
  Acceptor(ServerSocketChannel ssc, Dispatcher d) {
    this.ssc = ssc;
    this.d = d;
  }
  public void run();
}
```

N2: Non-Blocking, Two Threads

```
class Acceptor implements Runnable {
  private ServerSocketChannel ssc;
  private Dispatcher d;

  ...
  public void run() {
    for (;;) {
      SocketChannel sc = ssc.accept();
      sc.configureBlocking(false);
      d.register(sc, SelectionKey.OP_READ,
                 new RequestHandler(sc));
    }
  }
}
```

N2: Non-Blocking, Two Threads

```
class Acceptor implements Runnable {
  ...
  public void run() {
    for (;;) {
      try {
        SocketChannel sc = ssc.accept();
        sc.configureBlocking(false);
        d.register(sc, SelectionKey.OP_READ,
                   new RequestHandler(sc));
      } catch (IOException x) {
        x.printStackTrace();
        break;
      }
    }
  }
}
```

N2: Non-Blocking, Two Threads

```
class N1 {
  public static void main(String[] args) {
    ServerSocketChannel ssc
      = ServerSocketChannel.open();
    ...
    ssc.configureBlocking(false);
    Dispatcher d = new Dispatcher();
    d.register(ssc, SelectionKey.OP_ACCEPT,
               new AcceptHandler(ssc, d));
    for (;;)
      d.dispatch();
  }
}
```

N2: Non-Blocking, Two Threads

```
class N2 {
  public static void main(String[] args) {
    ServerSocketChannel ssc
      = ServerSocketChannel.open();
    ...
    // DO NOT: ssc.configureBlocking(false);
    Dispatcher d = new Dispatcher();
    Acceptor a = new Acceptor(ssc, d);
    new Thread(a).start();
    for (;;)
      d.dispatch();
  }
}
```

N2: Non-Blocking, Two Threads

```
class Dispatcher {
  void dispatch() {
    sel.select();
    for (Iterator i = ...) { ... }
  }
  void register(SelectableChannel ch, int ops,
                Handler h)
  {
    ch.register(sel, ops, h);
  }
}
```

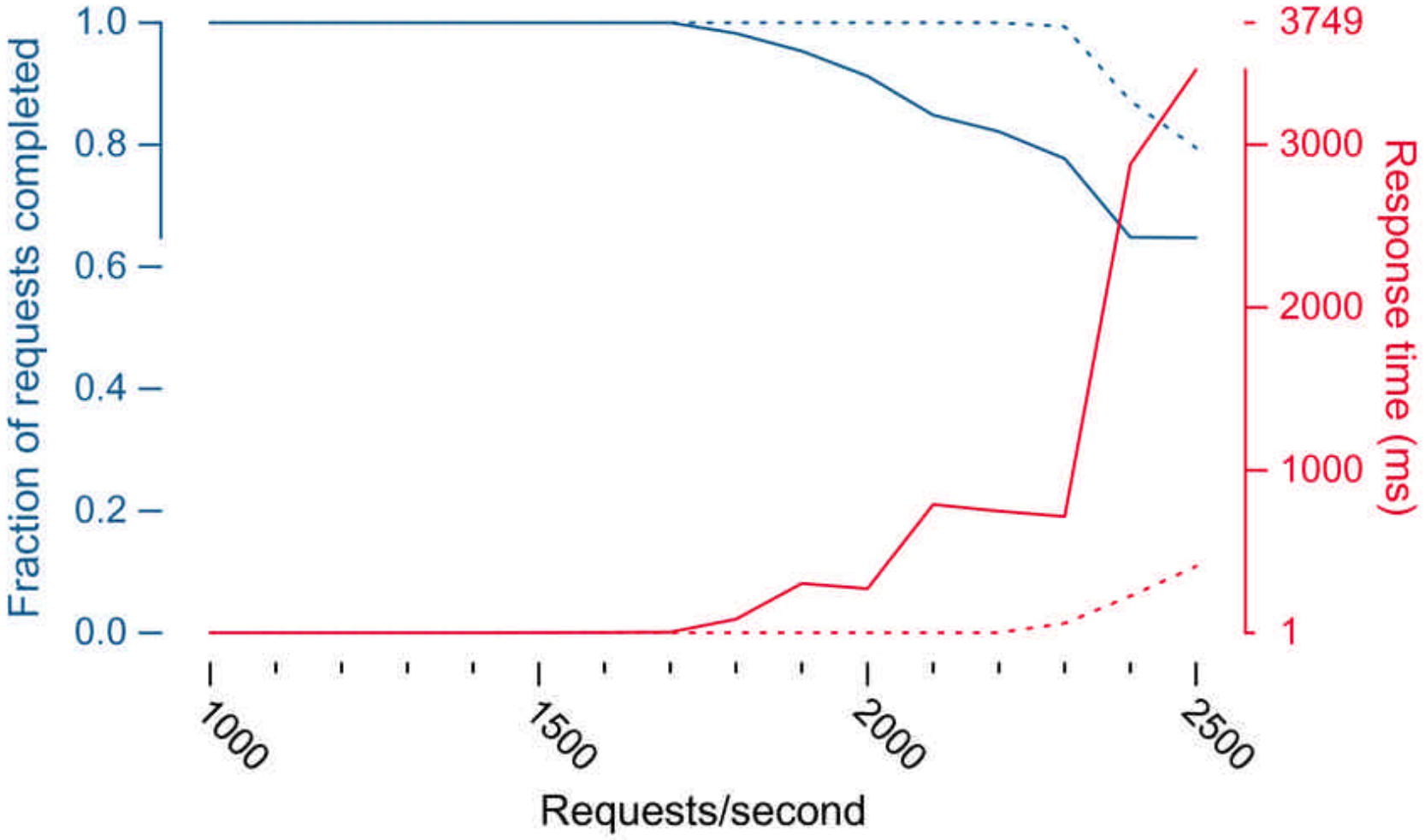
N2: Non-Blocking, Two Threads

```
class Dispatcher {
  void dispatch() {
    sel.select();
    for (Iterator i = ...) { ... }
  }
  void register(SelectableChannel ch, int ops,
                Handler h)
  {
    sel.wakeup();
    ch.register(sel, ops, h);
  }
}
```

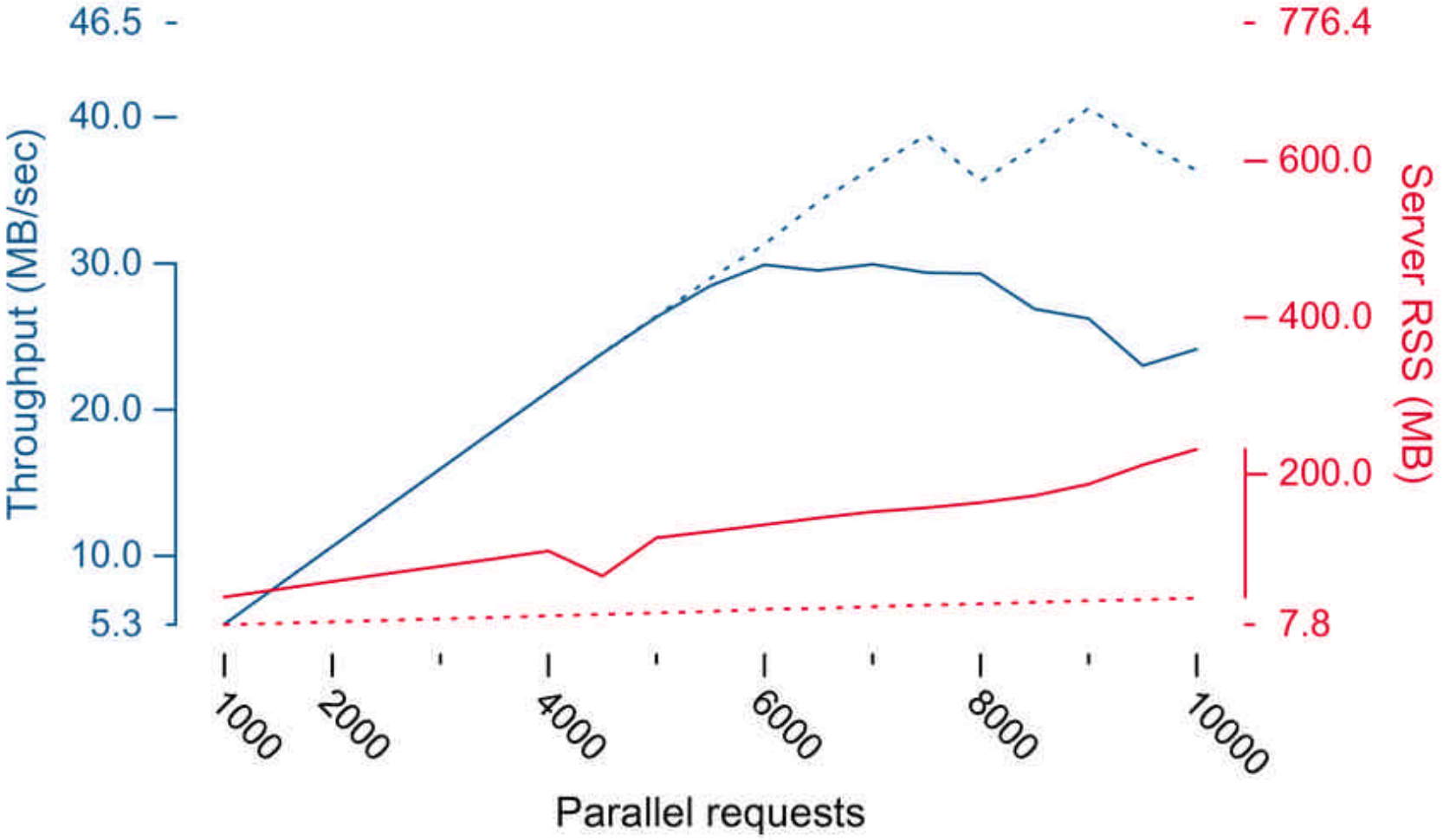
N2: Non-Blocking, Two Threads

```
class Dispatcher {
  private Object gate = new Object();
  void dispatch() {
    sel.select();
    for (Iterator i = ...) { ... }
    synchronized (gate) { }
  }
  void register(SelectableChannel ch, int ops,
                Handler h)
  {
    synchronized (gate) {
      sel.wakeup();
      ch.register(sel, ops, h);
    }
  }
}
```

N2: Non-Blocking, Two Threads



N2: Non-Blocking, Two Threads



N2: Non-Blocking, Two Threads

Problem: Small-file performance better, but large-file performance still pretty poor

Solution: Use even more threads

➥ N4: Non-Blocking, *Four* Threads

N4: Non-Blocking, Four Threads

N4: Non-Blocking, Four Threads

```
class N2 {
  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    Dispatcher d = new Dispatcher();
    Acceptor a = new Acceptor(ssc, d);
    new Thread(a).start();
    for (;;)
      d.dispatch();
  }
}
```

N4: Non-Blocking, Four Threads

```
class N4 {
  public static void main(String[] args) {
    ServerSocketChannel ssc = ...
    Dispatcher d1 = new Dispatcher();
    Dispatcher d2 = new Dispatcher();
    Acceptor a1 = new Acceptor(ssc, d1);
    Acceptor a2 = new Acceptor(ssc, d2);
    new Thread(d1).start();
    new Thread(d2).start();
    new Thread(a1).start();
    new Thread(a2).start();
  }
}
```

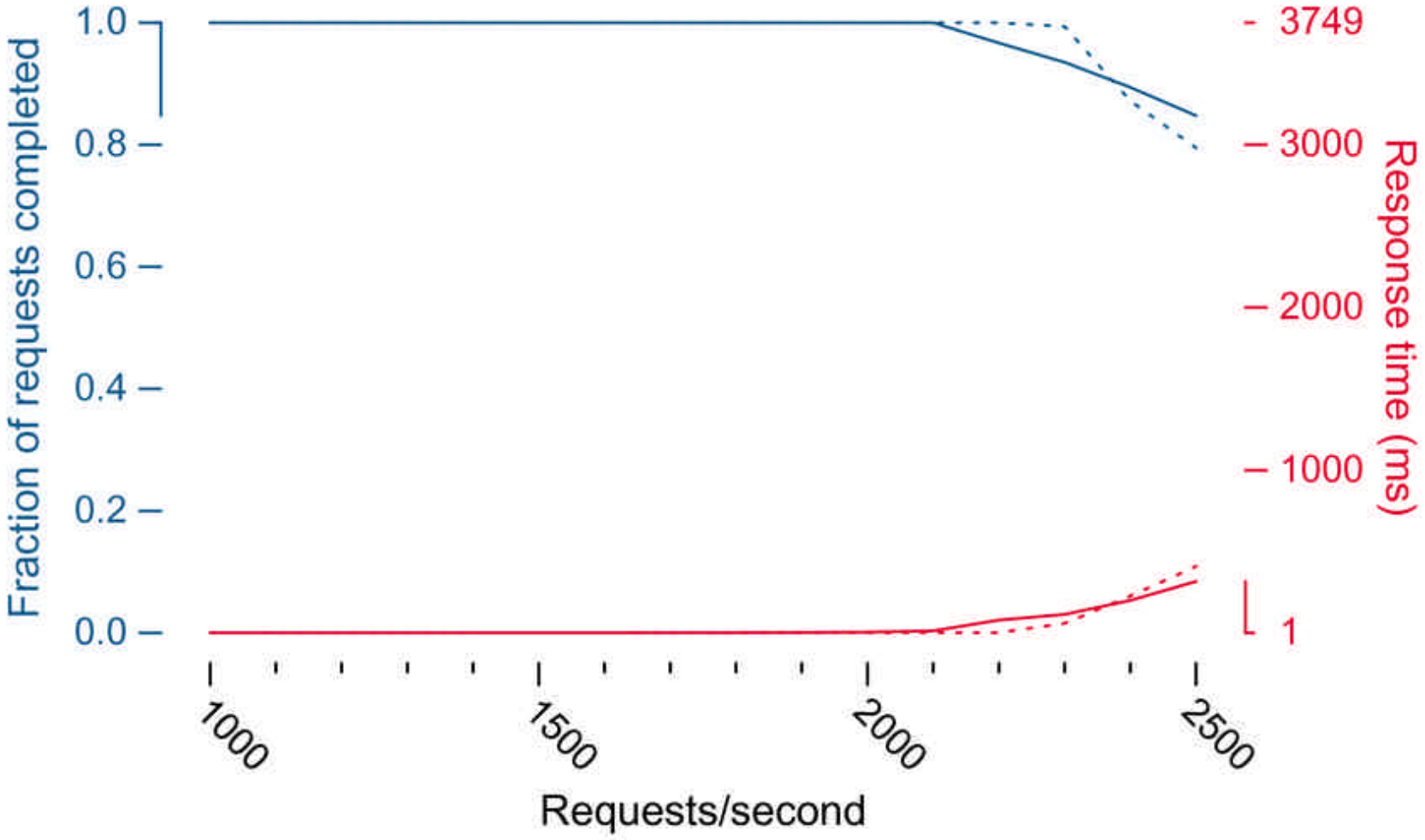
N4: Non-Blocking, Four Threads

```
class Dispatcher {
  void dispatch();
  void register(SelectableChannel ch, int ops,
                Handler h);
}
```

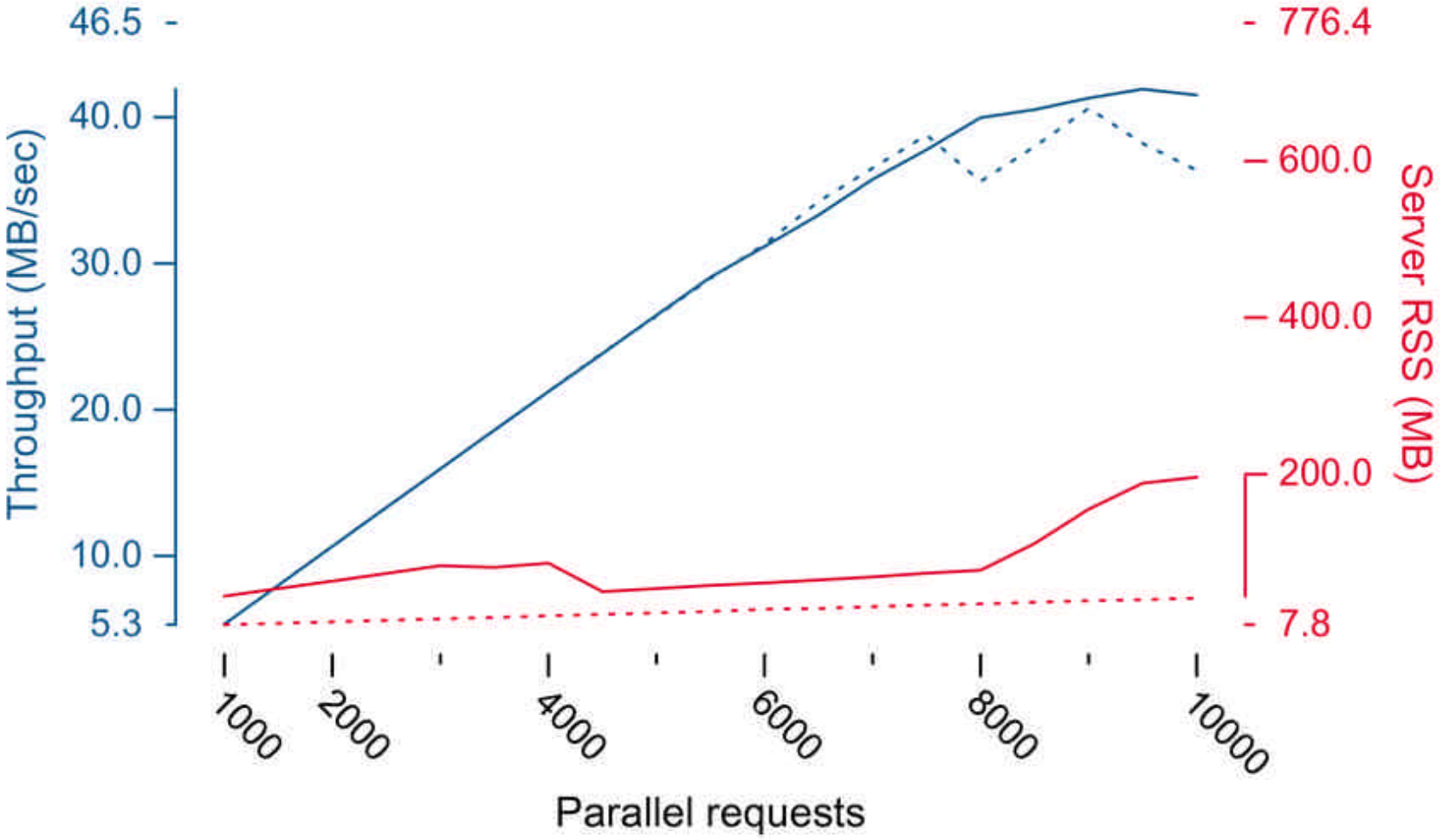
N4: Non-Blocking, Four Threads

```
class Dispatcher implements Runnable {
  void dispatch();
  void register(SelectableChannel ch, int ops,
                Handler h);
  public void run() {
    for (;;) {
      try {
        dispatch();
      } catch (IOException x) {
        x.printStackTrace();
        break;
      }
  }
  ...
}
```

N4: Non-Blocking, Four Threads



N4: Non-Blocking, Four Threads



Server Architectures

B1	Blocking	Single-Threaded
BN	Blocking	Multi-Threaded
BP	Blocking	Multi-Threaded, Pooled
N1	Non-Blocking	Single-Threaded
N2	Non-Blocking	Two Threads
N4	Non-Blocking	Four Threads

Conclusion

Tuning: Solaris

- Time wait interval 2 sec

```
$ ndd -set /dev/tcp tcp_time_wait_interval 2000
```

- Connection table size 32768

```
/etc/system: set tcp:tcp_conn_hash_size=32768
```

- File descriptor limits 65536

```
/etc/system: set rlim_fd_cur=65536
             set rlim_fd_max=65536
```

Tuning: Linux

- Local port range 1024–64000

```
$ echo 1024 64000 \
   >/proc/sys/net/ipv4/ip_local_port_range
```

- File descriptor limits 65536

```
/etc/security/limits.conf:
    * soft nofile 1024
    * hard nofile 65535
$ echo 65535 >/proc/sys/fs/file-max
$ ulimit -n unlimited
```

Tuning: VM

- Heap size 512MB

```
-Xms512M -Xmx512M
```

- New ratio 1

```
-XX:NewRatio=1
```

NIO Bugs Discovered

- New `FileChannel.transferTo` code broken
  - Only for some corner cases
  - Solaris docs are incomplete
- `/dev/poll` Selector code limits performance
  - Returns at most 20 events (!)
- Channel finalization is expensive
  - Removing it improves GC performance by 100x
  - Necessary to achieve final performance gains

These problems are fixed in 1.4.2

Lessons

- TCP is complicated
- VMs are complicated
- Non-blocking I/O is complicated
  - You don't always need it
- Finalization is evil
- Small multiprocessors are good
- NIO works pretty well
- Experiment!

References: Books

- *Unix Network Programming*
  W. Richard Stevens, Prentice Hall, 1998
- *Sun Performance and Tuning*
  Adrian Cockroft, Prentice Hall, 1998
- *JDK 1.4 Tutorial*
  Gregory M. Travis, Manning, 2002
- *Java NIO*
  Ron Hitchens, O'Reilly, 2002

References: Links

- *The C10K Problem*, Dan Kegel
  `http://kegel.com/c10k.html`
- `util.concurrent`, Doug Lea
  `http://gee.cs.oswego.edu/dl`
- Java HotSpot™ VM tuning pages
  `http://java.sun.com/docs/hotspot`
- Additional documentation & source code
  `http://java.sun.com/j2se/1.4/nio`
- Send us feedback!
  `java-io@java.sun.com`

References: Additional Showtimes

- J2SE “Ask the Experts” booth
  - Thursday, noon–3:00pm
- BOFs: Thursday, Argent, Metropolitan III
  - New I/O: Scanning and Formatting (6:30pm)
  - New I/O: General Q&A (7:30pm)

JavaOne℠

Sun's 2003 Worldwide Java Developer Conference℠

java.sun.com/javaone/sf