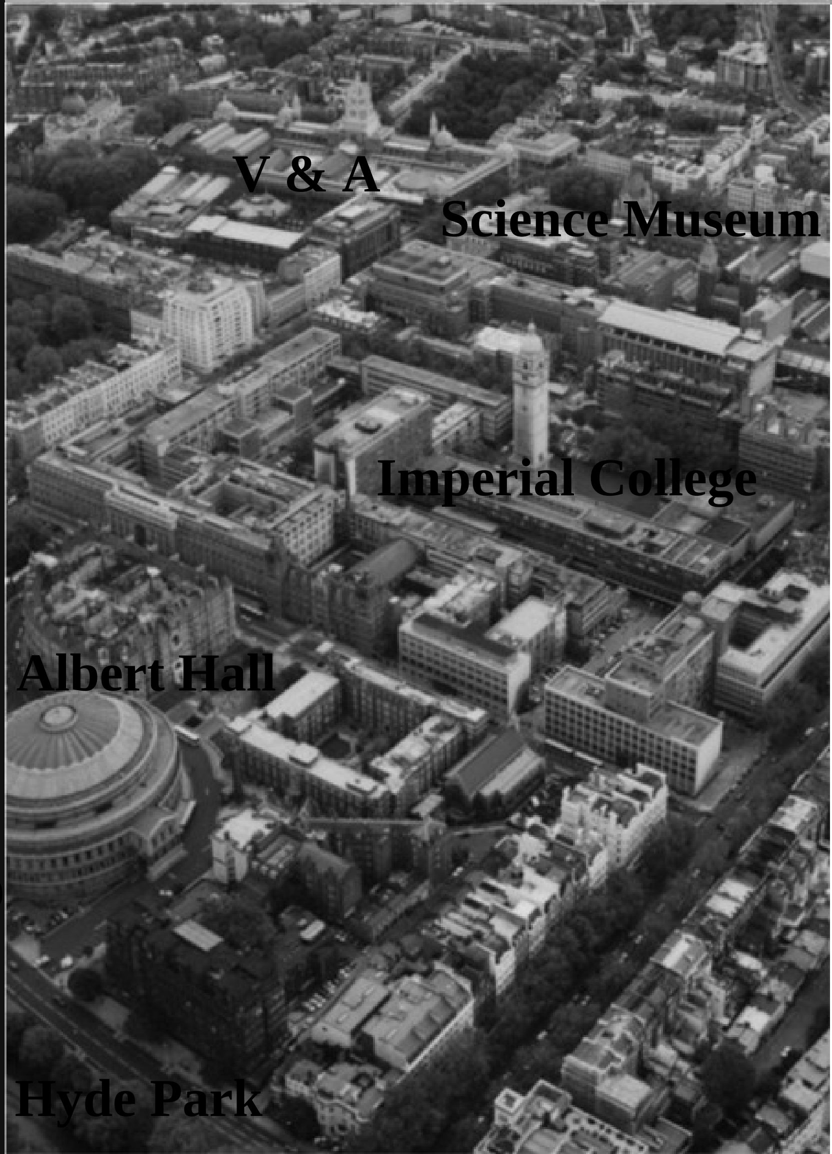
Distributed Java applications: dynamic instrumentation and automatic optimisation

Kwok Cheung Yeung
Paul H J Kelly
With contributions from Thomas Petrou, Tim Wiffen, Doug Brear, Sarah Bennett
Software Performance Optimisation group
Imperial College, London

Background…



- I lead the Software Performance Optimisation group at Imperial College, London
- Stuff I'd love to talk about another time:
  - Cross-component optimisation of scientific applications at run-time
  - Is Morton-order layout for 2D arrays competitive?
  - Bounds-checking for C, links with unchecked code
  - Dynamic instrumentation for the Linux kernel
  - Run-time specialisation in C++
  - Proxying in CC-NUMA cache-coherence protocols – adaptive randomisation and combining

Mission statement

- Extend optimising compiler technology to challenging contexts beyond scope of conventional compilers
- Component-based software: cross-component optimisation
- Distributed systems:
  - Across network boundaries
  - Between different security domains
  - Maintaining proper semantics in the event of failures

Software Performance Optimisation Group
Imperial College, London

This work…

- Virtual JVM, virtual JIT
  - Framework allows run-time manipulation of Java application's binary
  - Running on top of a standard JVM
- Two applications:
  - Message aggregation and related optimisations for RMI and EJB applications
    - Optimising Java applications across network boundaries
  - Dynamic instrumentation
    - Run-time binary patching

Software Performance Optimisation Group
Imperial College, London

Dynamic instrumentation for Java

- Dynamic instrumentation:
  - Run-time binary patching
  - Insert code into running application on the fly
  - Paradyn, DynInst for Sparc/Solaris, GILK for x86/Linux (www.doc.ic.ac.uk/~djp1/gilk)
- Dynamic instrumentation for Java:
  - Could be done inside JVM…
  - Could be done via debugging interface…
  - We did it by building a *virtual JVM*
  - Runs on standard JVMs, with full JIT optimisation

Software Performance Optimisation Group
Imperial College, London

A virtual virtual machine

- A VJVM is just a JVM written in Java, running on a Java JVM
- Our VJVM is carefully constructed…
  - To run fast
  - By running most of the application code directly – jump to corresponding bytecode (in some sense, a virtual JIT)
  - But the VJVM maintains control over execution by intercepting control flow
  - We can choose where to intercept control flow – method entry, basic blocks, back edges

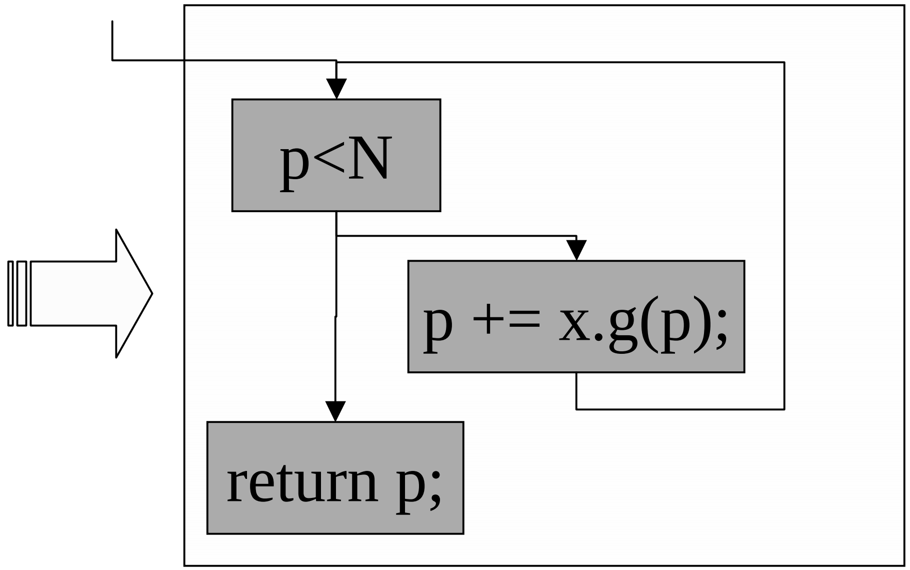
Software Performance Optimisation Group
Imperial College, London

Software Performance Optimisation Group
Imperial College, London

Method fragmentation

- Control flow is intercepted by *fragmenting* each method
- Fragmentation policy depends on application
- Example: basic block fragmentation

```
int f() {
  while (p<N)
    p += x.g(p);
  return p;
}
```



- Method body split into blocks
- Method entry replaced by “executor” loop: walks control-flow graph invoking each block in turn

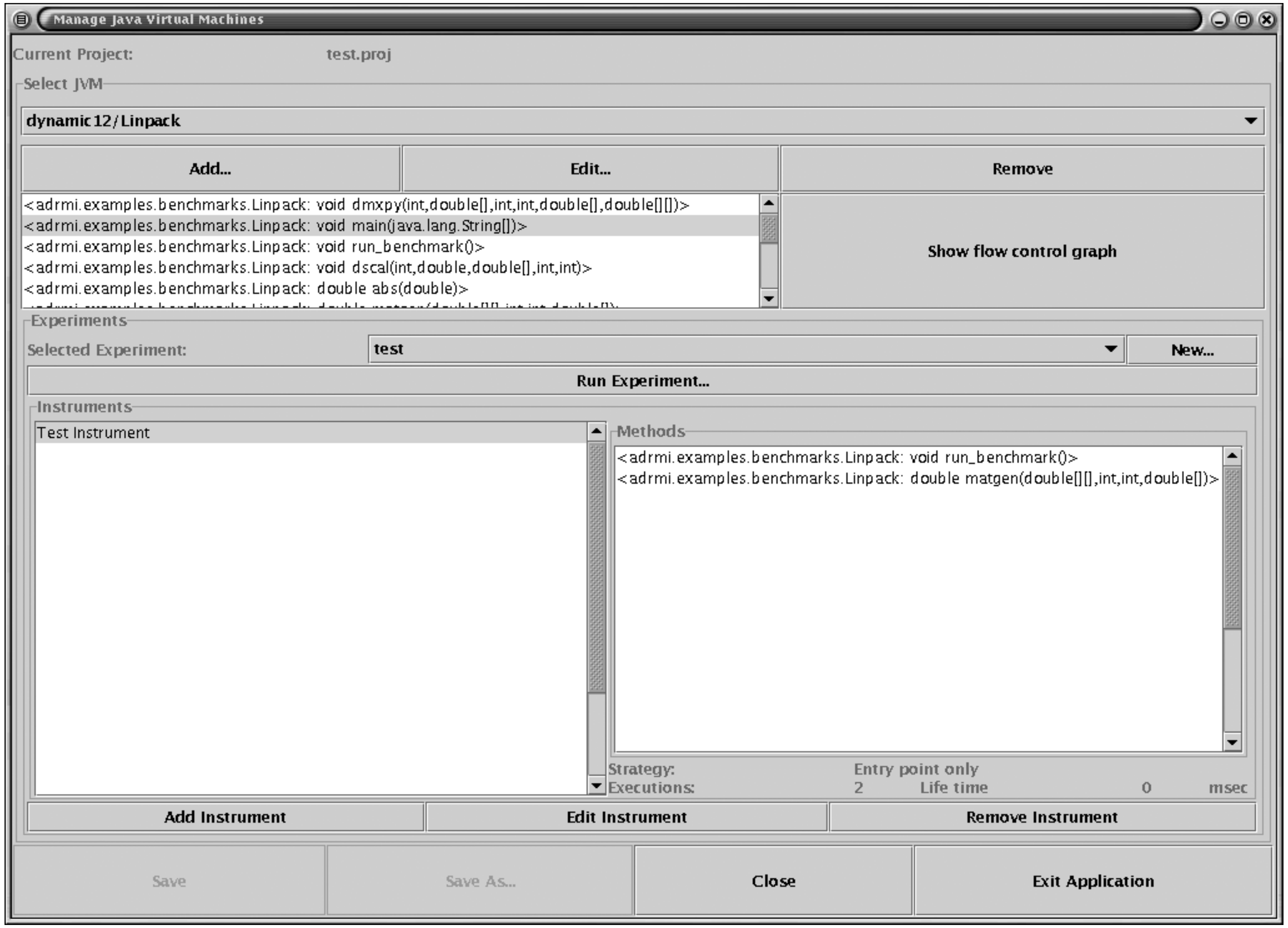
JUDI: Java utility for dynamic instrumentation

- Fragmented method’s control-flow graph can be updated on the fly
- We built a prototype dynamic instrumentation tool JUDI:
  - Client GUI connects to set of remote (virtual) JVMs running fragmented code
  - Browse remote system’s classes, methods
  - Upload “instrument” to remote system and patch it into running code

Software Performance Optimisation Group
Imperial College, London

Software Performance Optimisation Group
Imperial College, London

JUDI: deploying instrumentation



- Select class and method to be instrumented
- Show fragmented control-flow graph to see where instrumentation could be applied
- Select instrument (an instrument is just a Java class file implementing the Instrument interface)
- Apply instruments to methods
- Select instrumentation strategy
- Select methods to which instrument is to be applied
- Execute experiment

- Construct “experiment” by applying instruments to methods
- Execute experiment: add requested instruments to each JVM
- Each instrument runs for given period or til trip count reached
- Client collects data logged from instruments for analysis
- Instruments removed from all JVMs when experiment is over

JUDI: not just for instrumentation

- Instruments are simple Java objects, which can be compiled and uploaded on the fly
- Instruments can:
  - Count, measure time
  - Access locals and parameters
  - Histogram values
  - Verify assertions
  - Modify values…
  - Impose/audit security policy
  - Trigger insertion/removal of further instrumentation

DESORMI: delayed-evaluation, self-optimising RMI

- Optimising Remote Method Invocation
- Another application for the VJVM

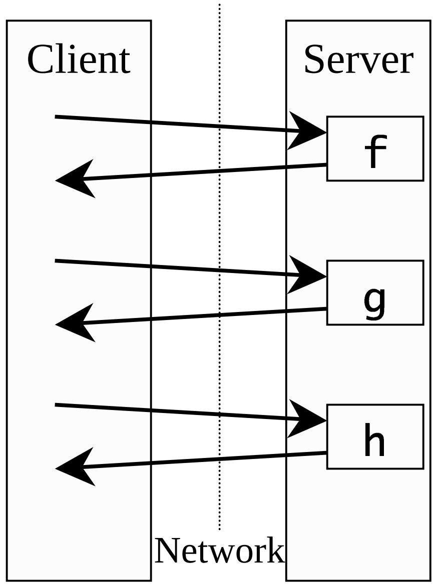
- Goal is to reduce amount of communication
- Thus, complementary to other work on faster RMI implementation

- RMI is a "heavyweight" operation: cost of an RMI call is large, so run-time optimisation can pay off even if slow(ish)

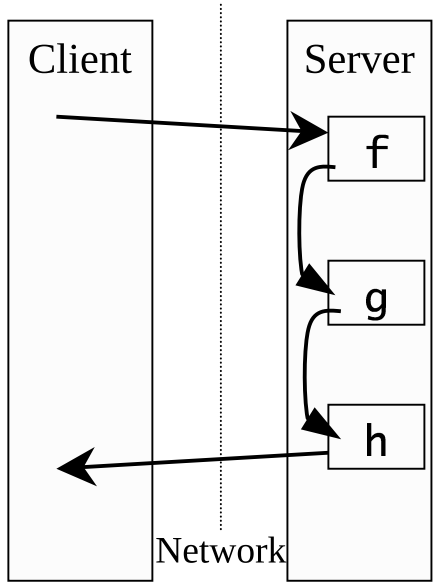
Software Performance Optimisation Group
Imperial College, London

Optimising distributed Java applications

```
void m(RemoteObject r, int a)
{
  int x = r.f(a);
  int y = r.g(a,x);
  int z = r.h(a,y);
  System.out.Println(z);
}
```



Six messages



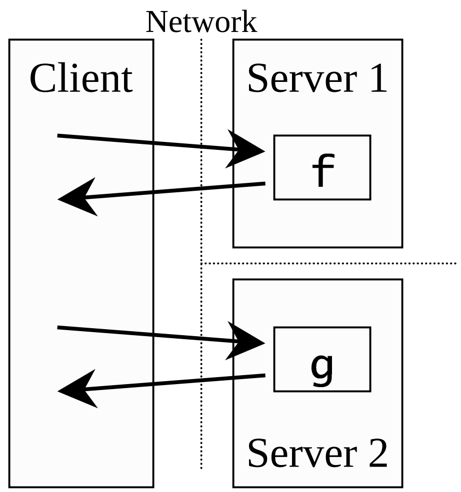
Two messages, no need to copy x and y

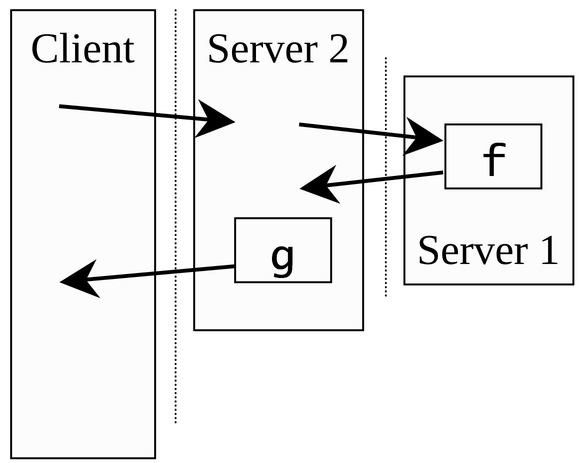
- Example: Aggregation
  - a sequence of calls to same server can be executed in a single message exchange
  - Reduce number of messages
  - Also reduce amount of data transferred
    - Common parameters
    - Results passed from one call to another

Software Performance Optimisation Group
Imperial College, London

Server forwarding

```
void m(RemoteObject r1,
       RemoteObject r2)
{
  Object a = r1.f();
  r2.g(a);
}
```

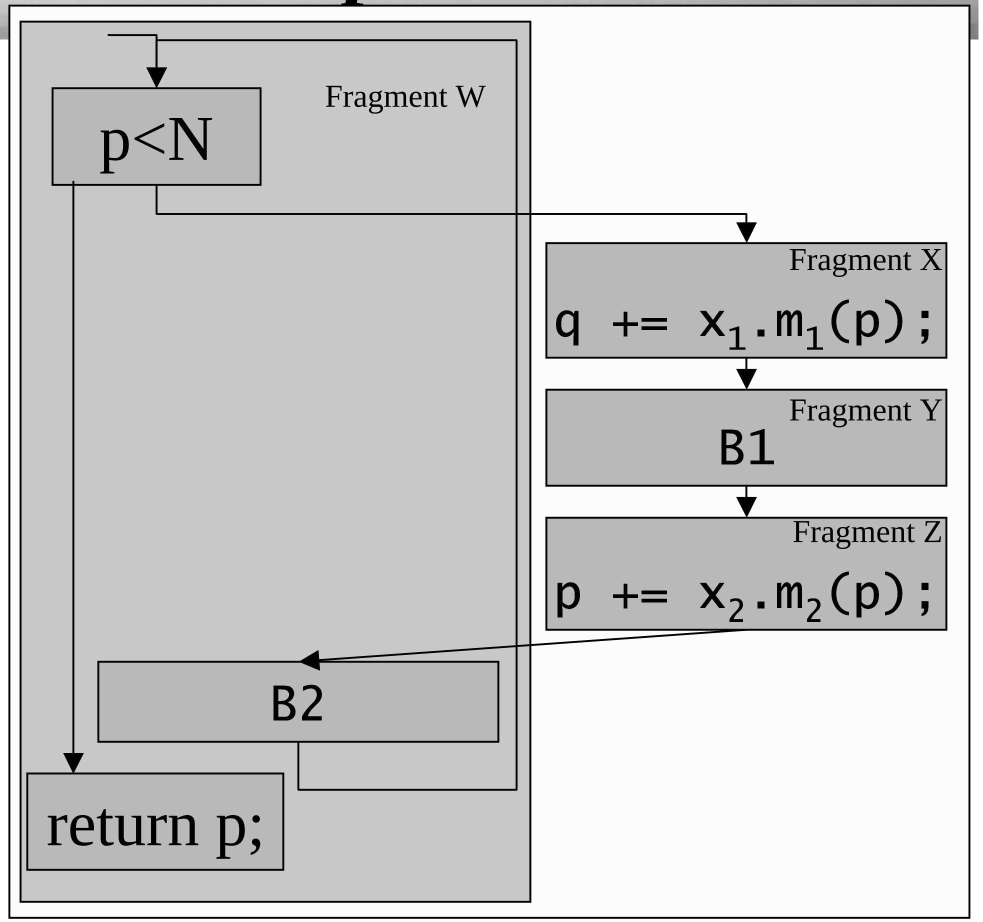




- Another example: Server Forwarding:
  - the result from a call on one remote server is passed as a parameter to a call on a second remote server
  - Avoids deserialisation/re-serialisation by client
  - Uses server-to-server network

Fragmentation to enable RMI optimisation

```
int m() {
  while (p<N) {
poss.remote ▷ q += x1.m1(p);
    B1  // non-remote code
poss.remote ▷ p += x2.m2(p);
    B2  // non-remote code
  }
  return p;
}
```

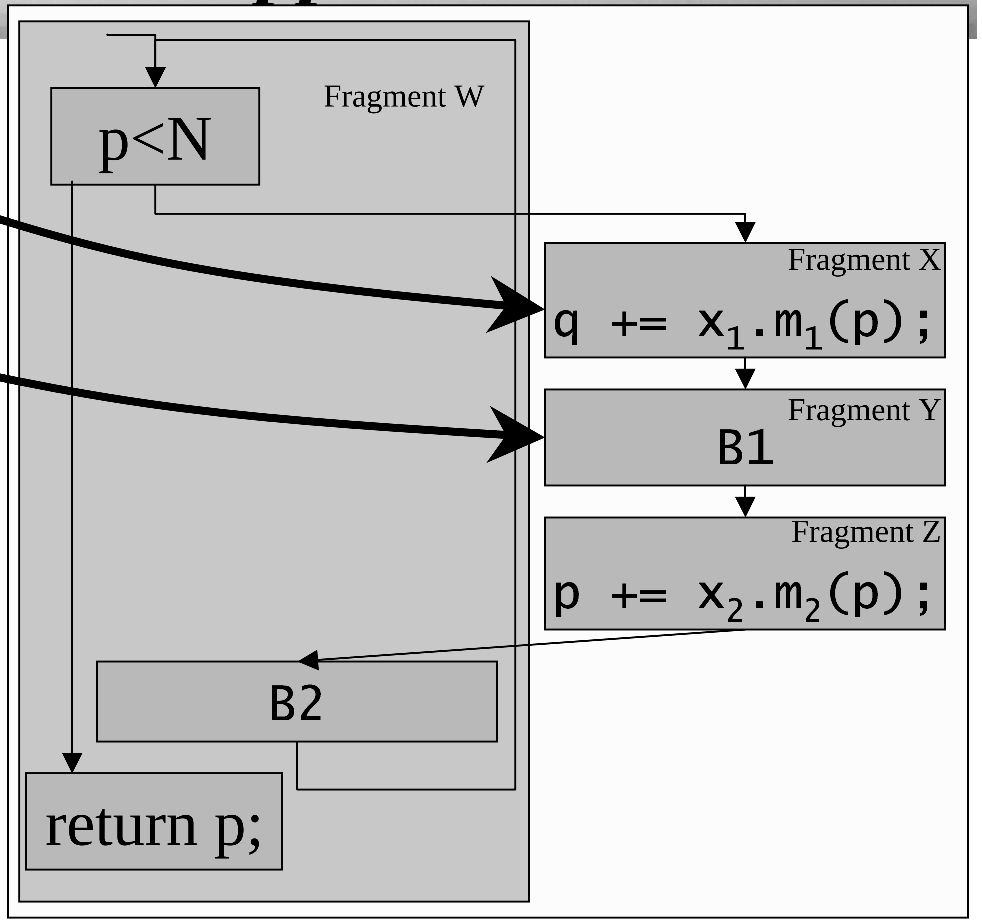


- Fragment at potential RMI call sites
- Potential RMI call sites are interface invocations with java.rmi.RemoteException on the throw list
- Whether a call is actually remote depends on the identity of the object – determined at run-time

Software Performance Optimisation Group
Imperial College, London

Optimising distributed Java applications

- Remote calls are delayed if possible
- Executor inspects local fragment following remote call
- Fragment carries def-use metadata
- If no data dependence, execute local fragment:
  - Defs(X) ∩ Uses(B1)
- If antidependence on RMI argument, copy first:
  - Uses(X) ∩ Defs(B1)

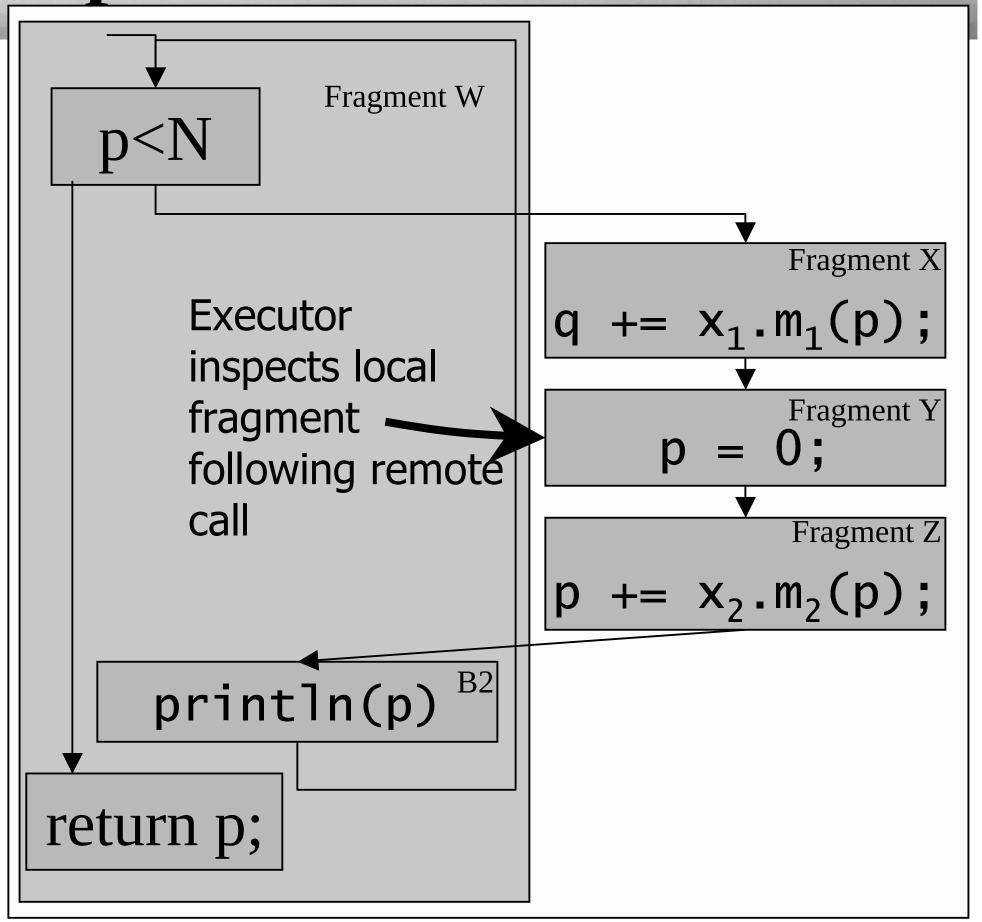


- Chain of delayed remote calls accumulates
- Until forced by dependence

Software Performance Optimisation Group
Imperial College, London

RMI aggregation - example

```
int m() {
  while (p<N) {
    q += x1.m1(p);
    p = 0;
    p += x2.m2(p);
    System.out.println(p);
  }
  return p;
}
```



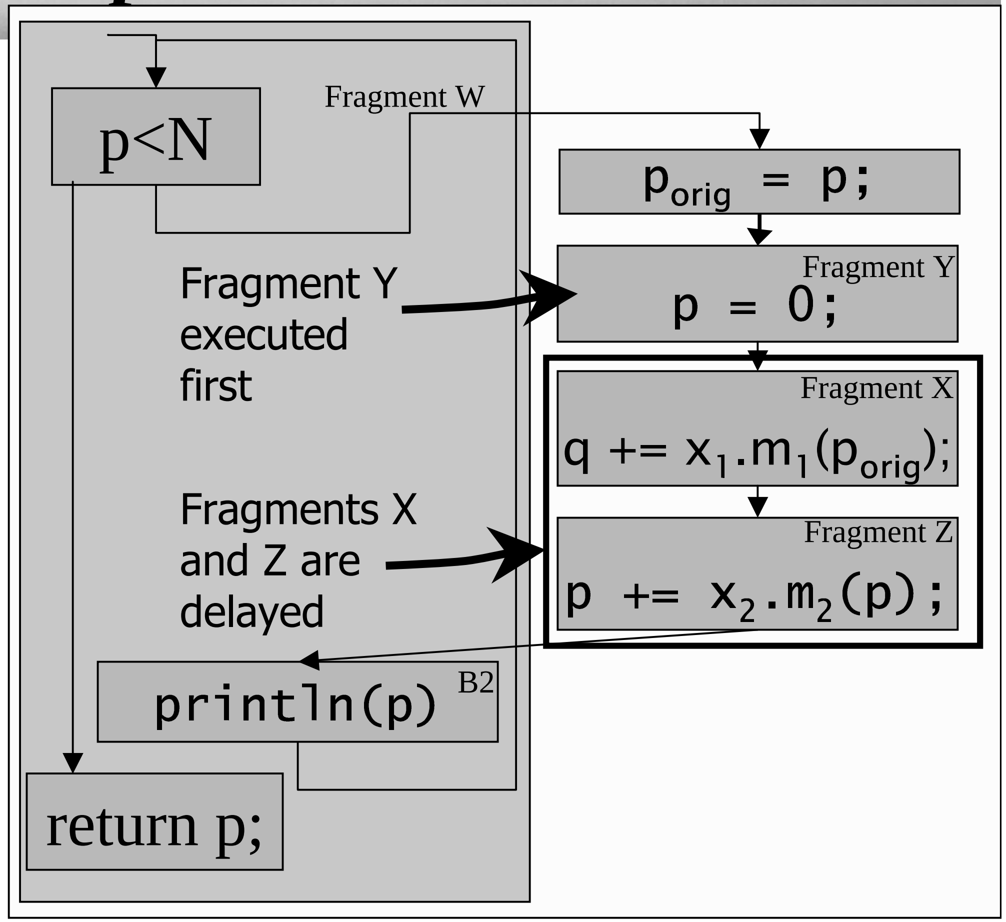
- Each fragment carries use/def and liveness info:

	X	Y	Z	B2
Defs	{q}	{p}	{p}	{}
Uses	{x_1,p,q}	{}	{x_2,p}	{p}

- Y can be executed before X, but p must be copied
- Z cannot be delayed because p is printed

RMI aggregation - example

- At this point, executor has collected a sequence of delayed remote calls (fragments X and Z)
- But execution is now forced by need to print
- Now, we can inspect delayed fragments and construct optimised execution plan



- If x_1 and x_2 are on same server, send aggregate call
- If x_1 and x_2 are on different servers, send execution plan to x_2's server, telling it to invoke $x_1.m_1(p_{orig})$ on x_1's server

Maintaining semantics

- Objective:
  - Optimised RMI/EJB application behaves in exactly the same way as original, but is more responsive and uses less resources
- Not that easy…what if…
  - the remote call overwrites its parameter?
  - aggregated call raises an exception?
  - the client is malicious?
  - a third JVM makes RMI calls on both client and server to observe sequence of actions?
  - aggregated call involves a call back to the client, which changes one of the parameters?
- All these problems can be solved, though in some cases at considerable cost

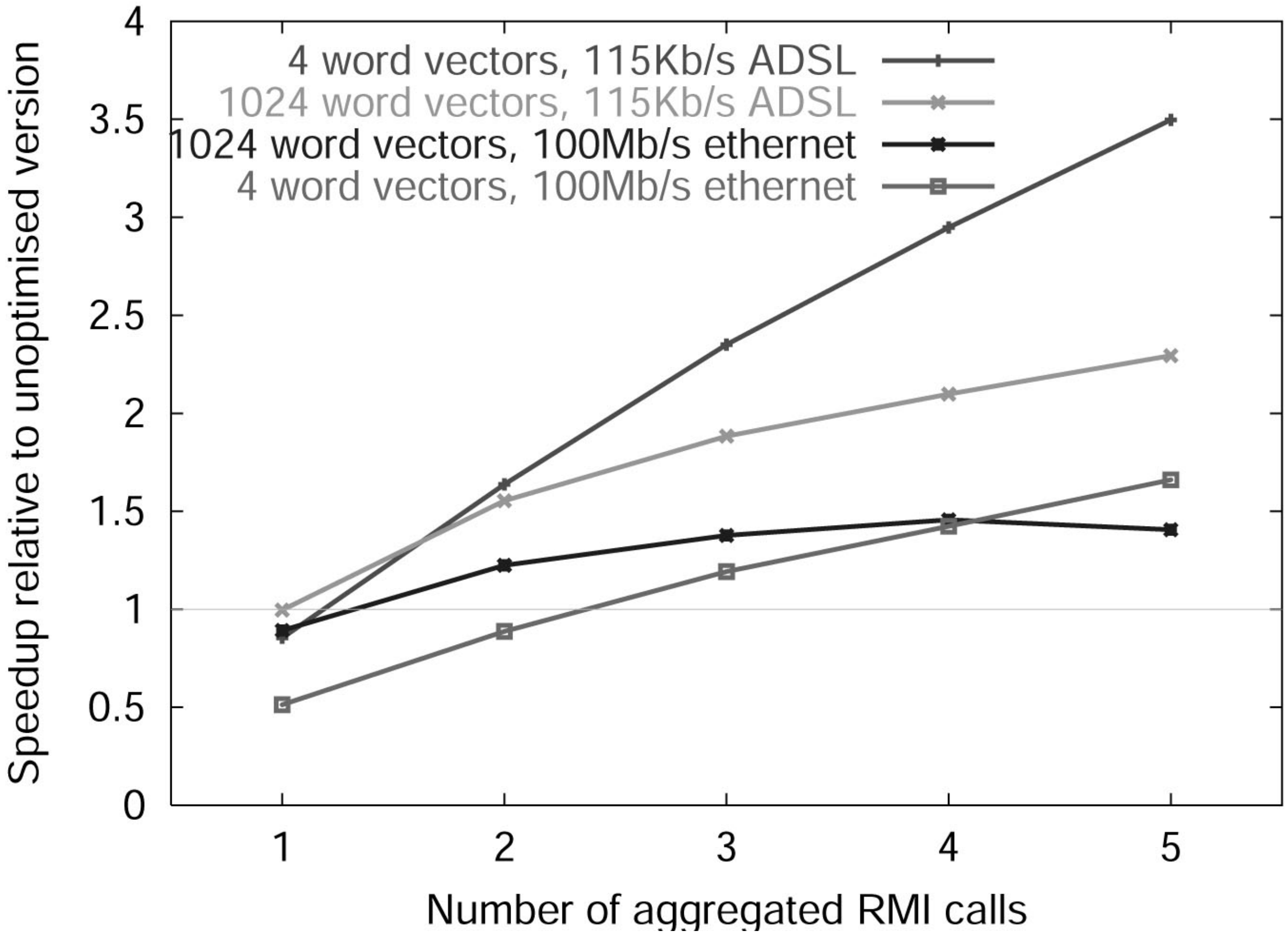
Microbenchmark results… aggregation

Software Performance Optimisation Group
Imperial College, London

- How much performance can be gained by aggregation?
- Substantial overheads
- Due to fragmentation
- Also due to transfer of execution plan
- Alleviated by caching

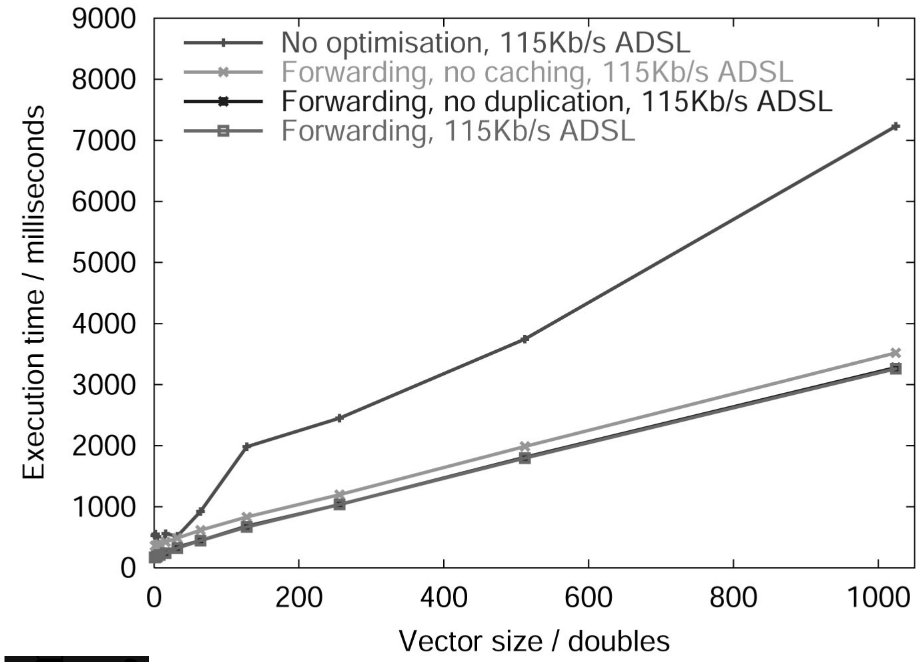
- Server adds vectors of doubles
- Client code:

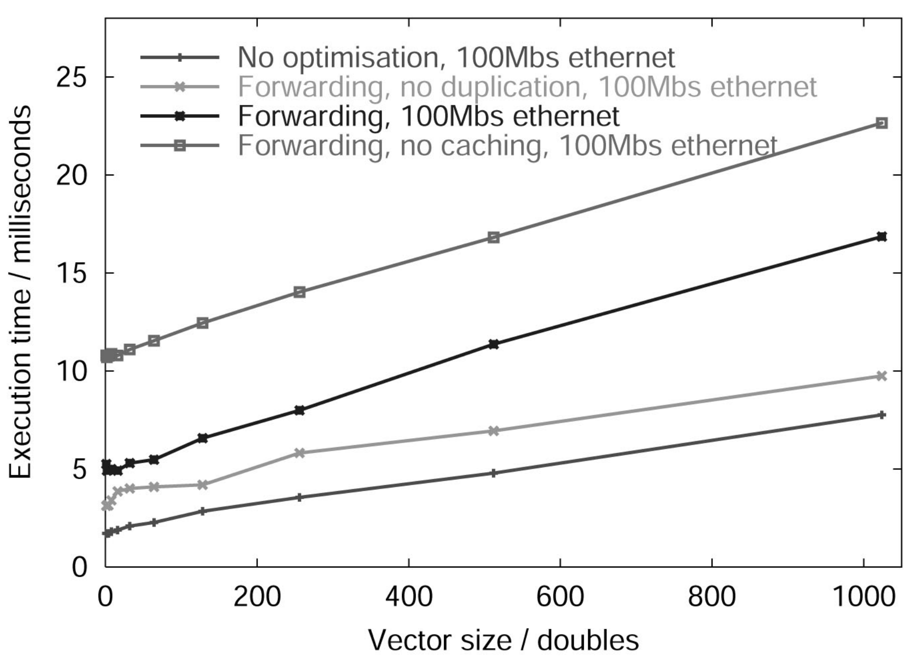
  Result = r.add(r.add(…r.add(v_1,v_2),v_3)…),v_n);



Microbenchmark results… forwarding

- How much performance can be gained by server forwarding?
- Client code: `Result = r1.add(r2.add(v1,v2),v3);`





- Servers holding remote objects r1 and r2 connected by fast ethernet
- In optimised code, vector result is passed directly from r2 to r1
- If client has slow connection, speedup even for short messages
- If client also has fast connection, no speedup yet possible
- Caching of execution plans is essential
- It would be really good not to have to duplicate parameters

Software Performance Optimisation Group
Imperial College, London

Real-world benchmarks…

- Simple example: Multi-user Dungeon (from Flanagan's Java Examples in a Nutshell)
- "Look" method:

```
String mudname = p.getServer().getMudName();
String placename = p.getPlaceName();
String description = p.getDescription();
Vector things = p.getThings();
Vector names = p.getNames();
Vector exits = p.getExits();
```

- Seven aggregated calls:
- Prototype implementation, more results soon!

Time taken to execute "look":	Ethernet	ADSL
Without call aggregation:	6.38ms	803.5ms
With call aggregation:	5.45ms	434.1ms
Speedup:	**1.164**	**1.851**

Conclusions and future directions

- Virtual JVM/JIT provides extremely powerful, flexible tool
  - Dynamic instrumentation, automatic bottleneck search, dynamic "aspect weaver"
  - Research vehicle to study how to combine static analysis with run-time information
  - Currently rather slow… faster soon!
- RMI optimisation
  - Extremely challenging, due to complex dependences
  - Prototype works for simple examples
  - Currently being extended:
    - More sophisticated dependence analysis
    - EJB
  - Many more optimisations:
    - Object replication and caching
    - Cross-network code motion ("code motion for mobile code")