Incrementally Developing Parallel Applications with AspectJ

20th International Parallel & Distributed Processing Symposium (IPDPS’06)

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Rhodes, 28 April 2006
Developing Parallel Applications with AspectJ

Presentation Outline

- Motivation for AOP in parallel computing
- AspectJ overview
- Developing modular parallel applications
- Performance results
- Developing reusable parallel modules
- Conclusions and future work
Motivation for AOP in Parallel Computing

Parallel application development

- JGF RayTracer implemented with Java concurrency/distribution mechanisms

Sequential

RayTracer rt = new RayTracer();
Image result = rt.render(0,500);

Multicore/SMP

RayTracer rt[]=new RayTracer[4];
for(int i=0; i<4; i++)
    rt[i] = new RayTracer();

for(int i=0; i<4; i++)
    new Thread() {
        void run() {
            res[i] = rt[i].render("sub-interval");
        }
    }.start();

for(int i=0; i<4; i++)
    result = ...

MPP/Cluster/Grid

public interface IRayTracer extends Remote {
    public int[] render(...) throws RemoteException;
}
IRayTracer rt[]=new IRayTracer[4];
for(int i=0; i<4; i++)
    try { // rt[i] = new RayTracer();
        rt[i] = (IRayTracer) PortableRemoteObject...
    } catch(Exception ex) { ...

for(int i=0; i<4; i++)
    new Thread() {
        void run() {
            try {
                res[i] = rt[i].render("sub-interval");
            } catch(Exception ex) { ...

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Motivation for AOP in Parallel Computing

Parallel application development

- (Non modular) support to parallel application development

Goal:

Modularise RayTracer / concurrency / distribution
Modular parallel application development

An (OO) incremental approach to develop parallel applications

1. Develop core functionality (1 client - 1 server)

2. Partition work/data among severa! servers (1 client – several servers)

3. Include assynchronous method invocations (1 thread per method invocation)

4. Distribute servers among available resources (e.g., RMI middleware)
Modular parallel application development

Implementing the approach with (OO) inheritance/composition

```
RayTracer rt = new RayTracer();
Image result = rt.render(0, 500);

RayTracerPartition extends RayTracer
{
    RayTracer[] rt = new RayTracer[4];
    public RayTracerPartition()
    {
        for (i = 0; i < 4; i++)
            rt[i] = new RayTracer();
    }
    public Image render(/*sub-interval*/) {
        for (int i = 0; i < 4; i++)
            res[i] = rt[i].render(/*sub-interval*/);
        for (int i = 0; i < 4; i++)
            result = ...
        return (result);
    }
}

public interface IRayTracer extends Remote {
    public Image render(...) throws RemoteException;
}

RayTracerDistribution extends RayTracer
{
    IRayTracer rt;
    public RayTracerDistribution()
    {
        try { rt[i] = new RayTracer();
            rt = (IRayTracer) PortableRemoteObject...
            } catch (Exception ex) { ... }
    }
    public Image render(/*sub-interval*/) {
        try {
            result = rt.render(/*sub-interval*/);
            } catch (Exception ex) { ... }
    }
}

RayTracerConcurrency extends RayTracer
{
    public Image render(/*sub-interval*/) {
        new Thread() {
            void run() {
                result = super.render(/*sub-interval*/);
            }
        }.start();
    }
}
```

Drawbacks:

1. Lack of flexibility to module composition
2. Code hard to reuse
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Benefits from modularising core functionality and parallelisation strategy

- Core functionality and parallelisation strategy easier to understand
- Core functionality and parallel code can evolve simultaneously
- Ability to plug or unplug parallel code for profiling and debugging

Benefits from using a fine-grained decomposition

- More incremental application development
- Ability to swap/unplug parallelisation modules
- Increased reuse potential

Motivation for using AOP

- Parallelisation concerns are typically crosscutting
- Enables new ways to build modular parallelisation concerns, promising to attain higher reuse than traditional OOP
AspectJ Overview

- Extension to Java designed to deal with crosscutting concerns
  - **Static crosscutting**
    - Introduce a method or an instance variable into a class
    - Implement a subclass or an interface
      ```java
      public aspect Static {
        declare parents: Point implements Serializable;
        public void Point.migrate(String node) { System.out.println("Migrate to node" + node); }
      }
      ```
  - **Dynamic crosscutting**
    - Intercept an object creation, method call or instance variable access and specify a new behaviour, before, after or instead (around)
      ```java
      public aspect Logging {
        void around(Point obj, int disp) : call(* *.move*(..)) && target(obj) && args(disp) {
          System.out.println("Move called: target object = " + obj + " Displacement " + disp);
          proceed(obj,disp);
        }
      }
      ```
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Developing modular parallel applications

- Use one or several modules to implement the parallelisation strategy?
- How to deal with intrinsically parallel applications?
- What are parallelisation concerns?
- How to reuse parallelisation concerns?

Supporting the approach with AOP

1. Implement core functionality with OOP techniques (i.e., domain specific code)
2. Implement partition, concurrency and distribution concerns with AOP
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Supporting the approach with AOP

- **Partition** modules (i.e., aspects) transparently replicate objects, distribute data among these objects and manage method calls to these objects
- **Concurrency** modules implement asynchronous method calls and synchronisation requirements
- **Distribution** modules implement object distribution and remote method invocations

**Benefits**
- More flexibility to compose these modules
- Higher reuse potential
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JGF RayTracer with aspects for partition, concurrency and distribution

RayTracer rt = new RayTracer();

RayTracer farm[] = new RayTracer[4];

RayTracer around() : call (RayTracer.new()) {
    for(i=0; i<4; i++)
        farm[i] = new RayTracer();
    return(farm[0]);
}

Image result = rt.render(0,500);

Image around/* ... */) : call (*.render(..)) {
    for(int i=0; i<4; i++)
        res[i] = farm[i].render/* subinterval*/();
    ... //join sub-images saved in res array
    return/*merged subimages*/();
}

RayTracer around() : call (RayTracer.new()) {
    ... // request object creation to remote factory
    ... // associate remote object to local fake
    return/*fake local object*/;
}

Image around() : call (RayTracer.render()) {
    (new Thread() {
        public void run() {
            around() : call (*.render(...)) {
                ... // redirect to remote node
                return/*rendered image*/;
            }
        }
    }).start();
}

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Supporting the approach with AOP

Examples of deployable parallel applications

<table>
<thead>
<tr>
<th>Partition module</th>
<th>Concurrency module</th>
<th>Distribution module</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Tidy up core functionality, debugging, single processor machines</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Tidy up partition strategy, debugging</td>
</tr>
<tr>
<td>No / Yes</td>
<td>Yes</td>
<td>No</td>
<td>Shared memory parallel machines (SMP/Multi-core)</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Distributed memory machines/Grids</td>
</tr>
<tr>
<td>No</td>
<td>No / Yes</td>
<td>Yes</td>
<td>Distributed application</td>
</tr>
</tbody>
</table>

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Example: Prime Filter – to find all prime numbers up to a pre-defined limit

- Core Functionality

```java
public class PrimeFilter {
    // calculates primes between [pmin,pmax]
    public PrimeFilter(int pmin, int pmax);

    // remove non-primes from num list
    public void filter(int num[]);
}

public static void main(String[] arg) {
    int list[] = ... // place numbers in the list
    PrimeFilter p = new PrimeFilter(2, sqrt(Max) );
    p.filter(list); // filters the list
}
```
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Example: Prime Filter (cont. 1)

- Partition Aspect (pipeline)
  1. Create several prime filters
  2. Split numbers to filter into tasks
  3. Forward calls among elements
Example: Prime Filter (cont. 2)

- **Partition Aspect (Farm)**
  1. Create several prime filters
  2. Split numbers to filter into tasks
  3. Forward each call to one element

```
new PrimeFilter
```

![Diagram of Prime Filter partition aspect](image)
Example: Prime Filter (cont. 3)

- **Concurrency Aspect**

  1. Spawn a new thread for each call
  2. Synchronise access to prime filters
Example: Prime Filter (cont. 3)

- **Distribution Aspect**
  1. Remotely instantiate prime filters
  2. Redirect method call to remote nodes
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Performance Results (Prime Sieve)

- Less than 5% overhead in this application
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Performance Results (Prime Sieve – cont.)

- Tested combinations of modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Partition</th>
<th>Concurrency</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>FarmThreads</td>
<td>Farm</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PipeRMI</td>
<td>Pipeline</td>
<td>Yes</td>
<td>RMI</td>
</tr>
<tr>
<td>FarmRMI</td>
<td>Farm</td>
<td>Yes</td>
<td>RMI</td>
</tr>
<tr>
<td>FarmDRMI</td>
<td>Dynamic Farm</td>
<td>Yes</td>
<td>RMI</td>
</tr>
<tr>
<td>FarmMPP</td>
<td>Farm</td>
<td>Yes</td>
<td>MPP</td>
</tr>
</tbody>
</table>
Developing reusable modules

How to implement reusable modules?

- Marker interfaces
- Abstract pointcuts

Concurrency modules

- Common concurrency mechanism and patterns (oneway, futures, barrier, synchronisation, read/write lock, etc)
- Example:

```java
public abstract aspect OnewayProtocol {
    pointcut onewayMethodExecution();

    void around(): onewayMethodExecution() {
        Thread t = new Thread() {
            public void run() {
                proceed();
            }
        };
        t.start();
    }
}
```
Developing reusable modules

Partition modules

- Marker interfaces specify objects to replicate
- Abstract pointcuts to specify method calls to broadcast, scatter, reduce among replicated objects (a.k. GMI and Concurrent Aggregates)
- Abstract methods to provide call-specific parameters

### JGF RayTracer with reusable modules

```java
RayTracer rt = new RayTracer();
Image result = rt.render(0,500);

// calculates parameters of each scatterCall
Vector scatter(Object arg) {
    Vector v = new Vector();
    // splits args into sub-intervals
    return(v);
}

aspect Partition extends GridProtocol {
    declare parents: RayTracer implements Grid;

    // calculates parameters of each scatterCall
    Vector scatter(Object arg) {
        Vector v = new Vector();
        // splits args into sub-intervals
        return(v);
    }

    pointcut scatterCall(..) : call (RayTracer.render(..));
}

public abstract aspect GridProtocol {
    public interface Grid {};
    Vector elem = new Vector();

    Object around() : call(Grid+.new()) {
        for(int i=0; i<workers; i++) {
            elem.add(proceed());
        }
        return(elem.get(0));
    }
}

public abstract aspect Future extends FutureProtocol {
    protected pointcut futureMethodExecution() : (execution("RayTracer.render(..)");
```
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Conclusions

- AOP offers an alternative to modularise parallel applications
- Successfully modularised several types of parallel algorithms
  - Heartbeat, farming, pipeline and divide and conquer
- Parallel applications can be developed by composing parallelisation modules
- Easy to swap the parallelisation (e.g., farm, pipeline) and the middleware (e.g., MPI, RMI, Grid)
- Higher reuse potential, but more design effort required
- Performance is close to OOP (when weaving can achieve similar parallel code)
- Composing reusable modules requires more fine-grained control over the scope of an aspect
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Current and Future Work

- Apply the approach “in the large”
- Develop reusable modules for distribution and optimisation on distributed systems
- Develop a model of composition of reusable aspects