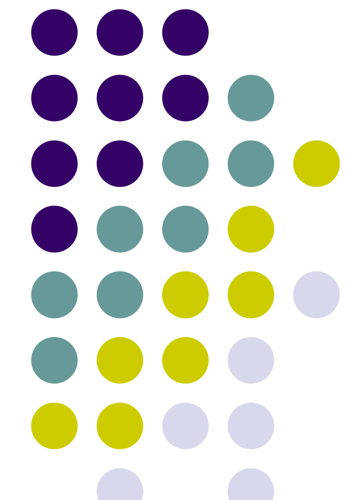
Incrementally Developing Parallel Applications with AspectJ



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João Luís Sobral
Departamento de Informática
Centro de Ciências e Tecnologias da Computação
Universidade do Minho
Braga - Portugal

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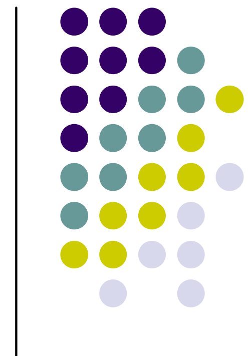
Developing Parallel Applications with AspectJ

Presentation Outline

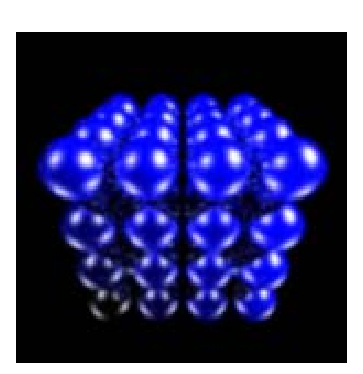
- Motivation for AOP in parallel computing
- AspectJ overview
- Developing modular parallel applications
- Performance results
- Developing reusable parallel modules
- Conclusions and future work

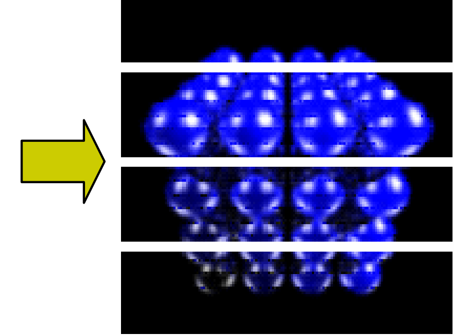


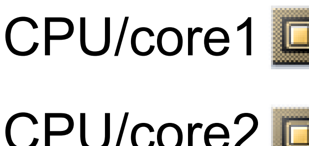
Motivation for AOP in Parallel Computing

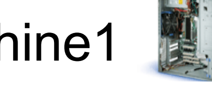
Parallel application development

- 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(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(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) { … }
```

Motivation for AOP in Parallel Computing

Parallel application development

- (Non modular) support to parallel application development

Goal:

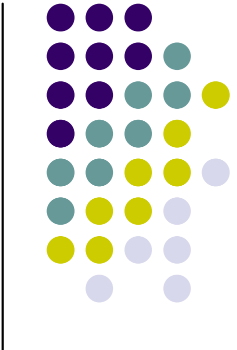
Modularise RayTracer / concurrency / distribution

- RayTracer
  - Sequential
  - Concurrent
  - Distributed

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

```
RayTracer rt[]=new RayTracer[4];

for(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 =  …
```

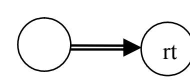
```
public interface IRayTracer  extends Remote {
    public int[] render(…)  throws RemoteException;
}
IRayTracer rt[]=new IRayTracer[4];
for(i=0; i<4; i++)
   try {  // rt[i] = new RayTracer();
            rt[i] = (IRayTracer)  PortableRemoteObject…
     } catch(Exception ex) { … }
 for(int i=0; i<4; i++)
      new Thread()  {
           void run() {
                try {
           res[i] = rt[i].render(/*sub-interval*/);
                } catch(Exception ex) { … }
           }
      }.start();
```

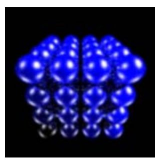


Modular parallel application development

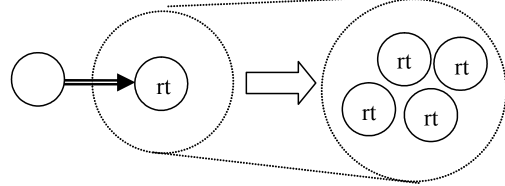
An (OO) incremental approach to develop parallel applications

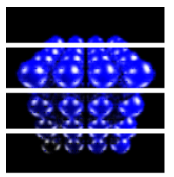
1. Develop core functionality (1 client - 1 server)



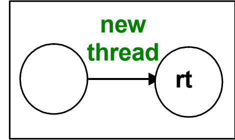


2. Partition work/data among serveral servers (1 client – several servers)

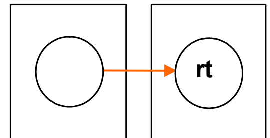




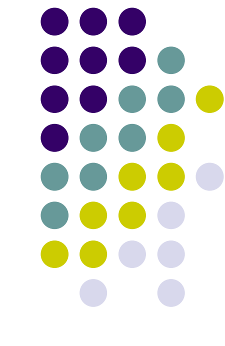
3. Include assynchronous method invocations (1 thread per method invocation)



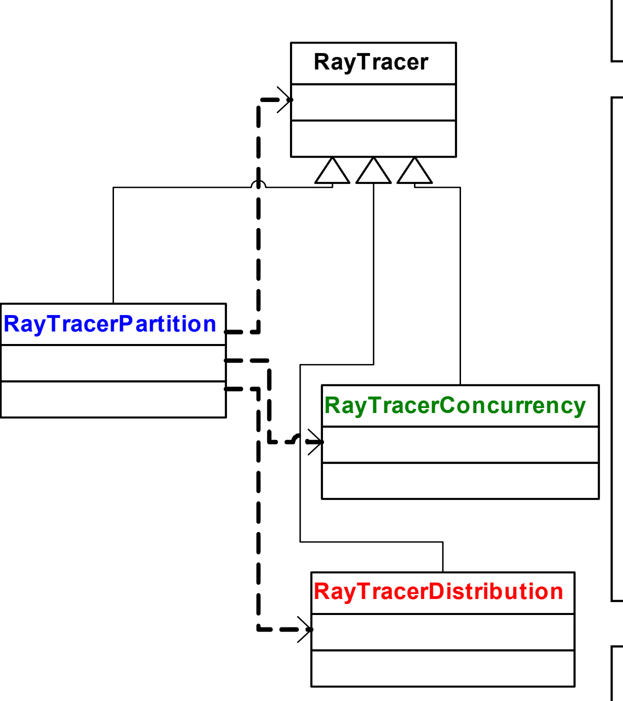
4. Distribute servers among available resources (e.g., RMI middleware)



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-intervalo*/) {
        for(int i=0; i<4; i++)
            res[i] = rt[i].render(/*sub-intervalo*/);

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

        return(result);
    }
}
```

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

```
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-intervalo*/) {
    try {
        result = rt.render(/*sub-intervalo*/);
    } catch(Exception ex) { … }
}
```

Drawbacks:

1. **Lack of flexibility to module composition**
2. **Code hard to reuse**

AO Support for Modular Parallel Computing

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

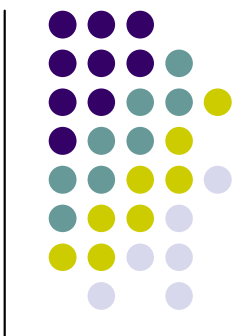
Benefits from using a fine-grained decomposition

- 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

AO Support for Modular Parallel Computing



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

```
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)

```
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);
        }
}
```

AO Support for Modular Parallel Computing

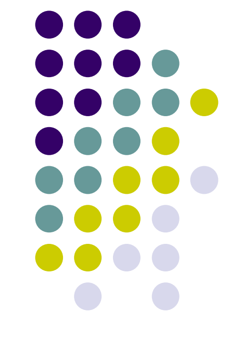
Developing modular parallel applications

- 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

AO Support for Modular Parallel Computing

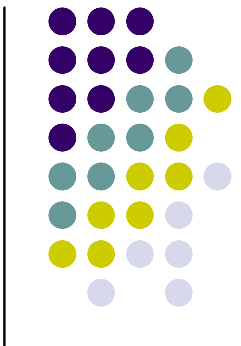


Supporting the approach with AOP

- **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**

AO Support for Modular Parallel Computing



JGF RayTracer whith 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]);
}
```

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

new thread

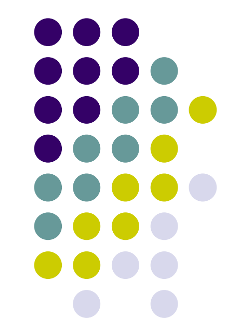
rt

```
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*/);
}
```

```
Image around() :  call (RayTracer.render()) {
  (new Thread() {
    public void run() {
    … .render(…)
    }
  }).start();
}
```

```
around() : call (*.render(...)) {
    … // redirect to remote node
    return(/*rendered image*/);
}
```

rt



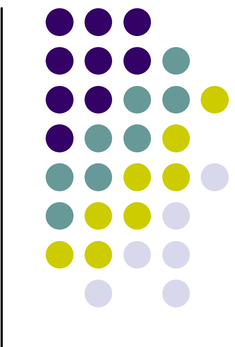
AO Support for Modular Parallel Computing

Supporting the approach with AOP

- Examples of deployable parallel applications

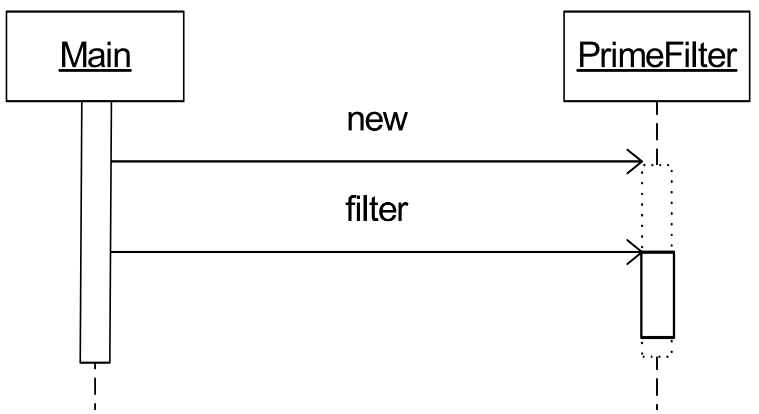
Partition module	Concurrency module	Distribution module	Purpose
No	No	No	Tidy up core functionality, debugging, single processor machines
Yes	No	No	Tidy up partition strategy, debugging
No / Yes	Yes	No	Shared memory parallel machines (SMP/Multi-core)
Yes	Yes	Yes	Distributed memory machines/Grids
No	No / Yes	Yes	Distributed application

Developing Parallel Applications with AspectJ



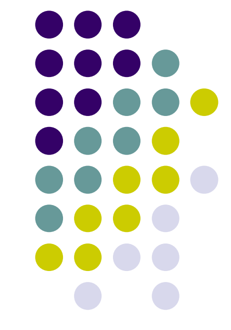
Example: Prime Filter – to find all prime numbers up to a pre-defined limit

- Core Functionality




```
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[]);
}

void 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
}
```

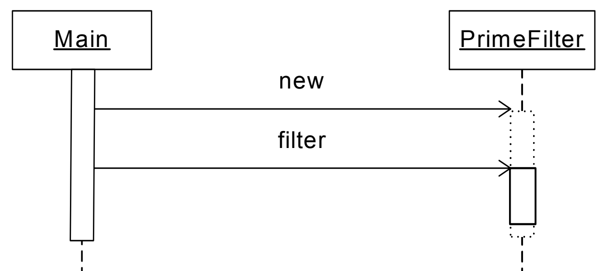
Developing Parallel Applications with AspectJ

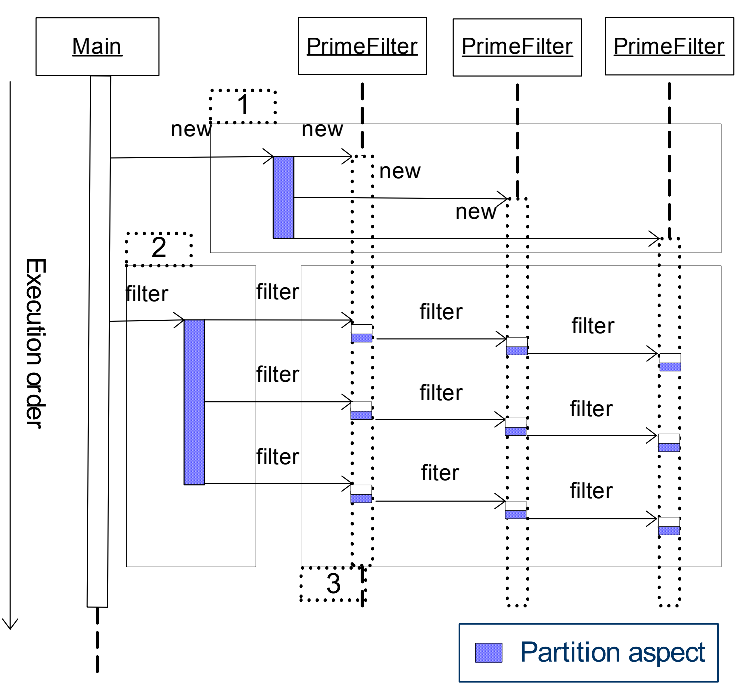


Example: Prime Filter (cont. 1)

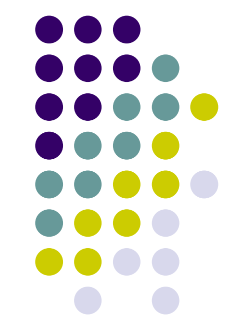
- Partition Aspect (pipeline)

1. **Create several prime filters**
2. **Split numbers to filter into tasks**
3. **Forward calls among elements**





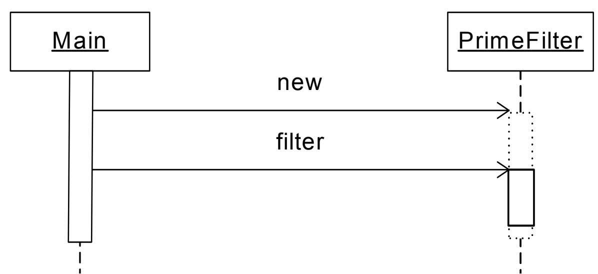
Developing Parallel Applications with AspectJ

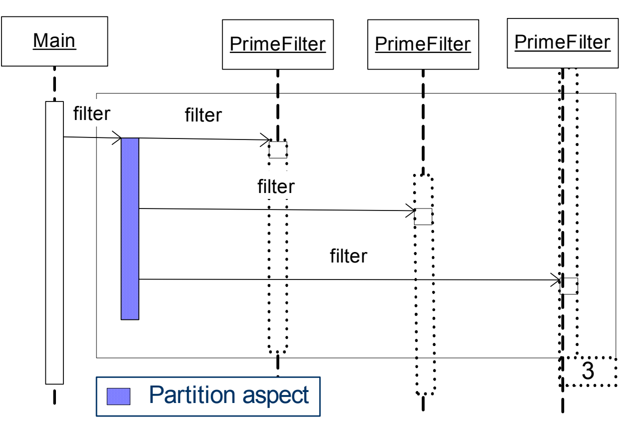


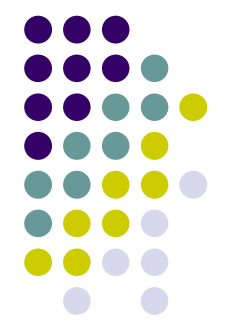
Example: Prime Filter (cont. 2)

- Partition Aspect (Farm)

1. **Create several prime filters**
2. **Split numbers to filter into tasks**
3. **Forward each call to one element**





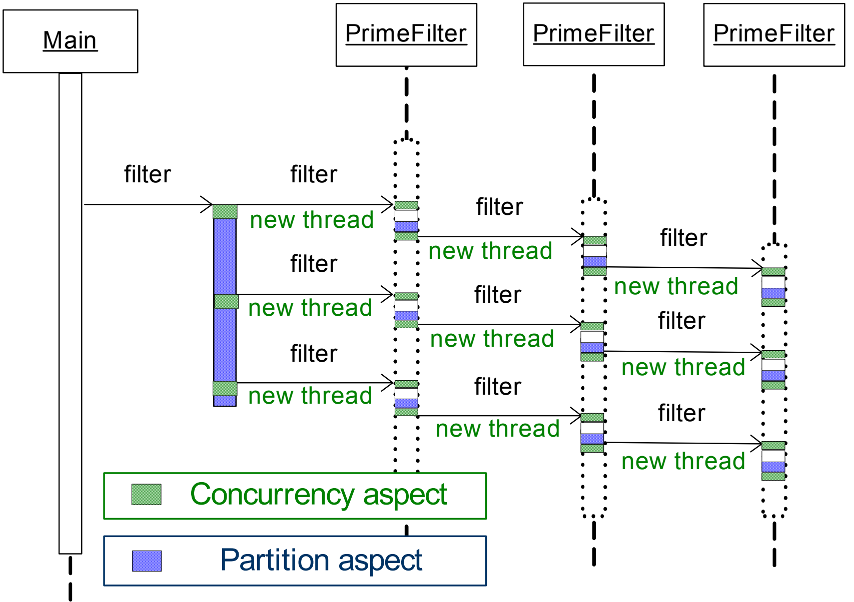


Developing Parallel Applications with AspectJ

Example: Prime Filter (cont. 3)

- Concurrency Aspect

1. **Spawn a new thread for each call**
2. **Synchronise access to prime filters**

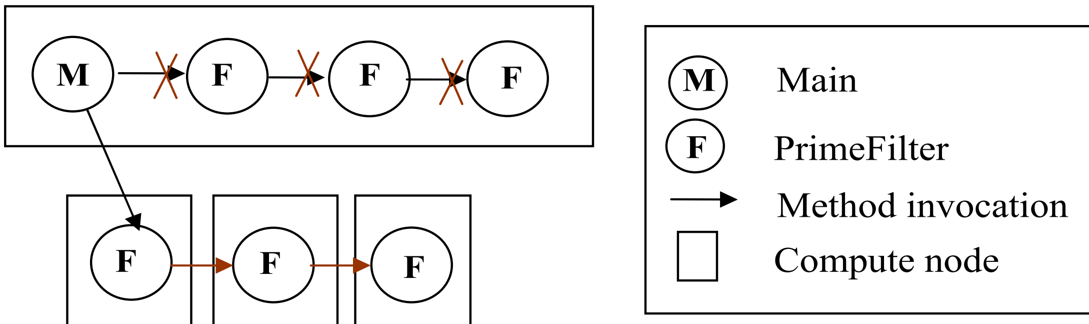


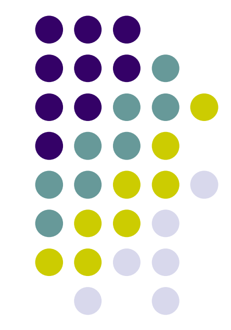
Developing Parallel Applications with AspectJ

Example: Prime Filter (cont. 3)

- Distribution Aspect

1. **Remotely instantiate prime filters**
2. **Redirect method call to remote nodes**

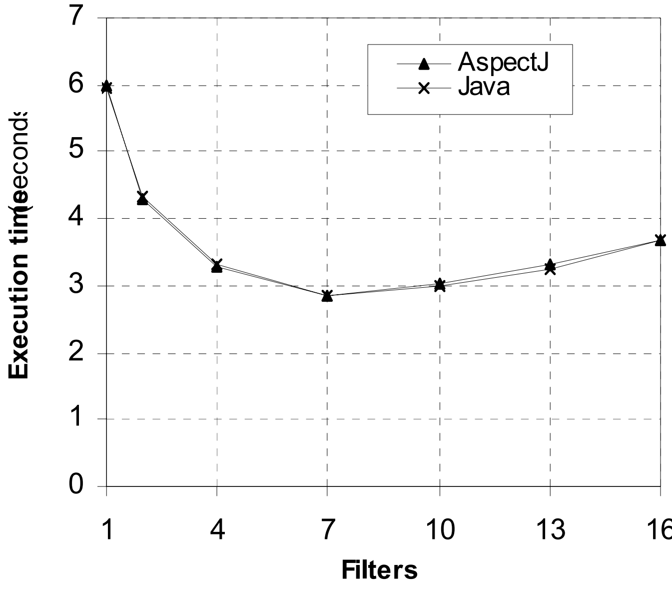




Developing Parallel Applications with AspectJ

Performance Results (Prime Sieve)

- Less than 5% overhead in this application

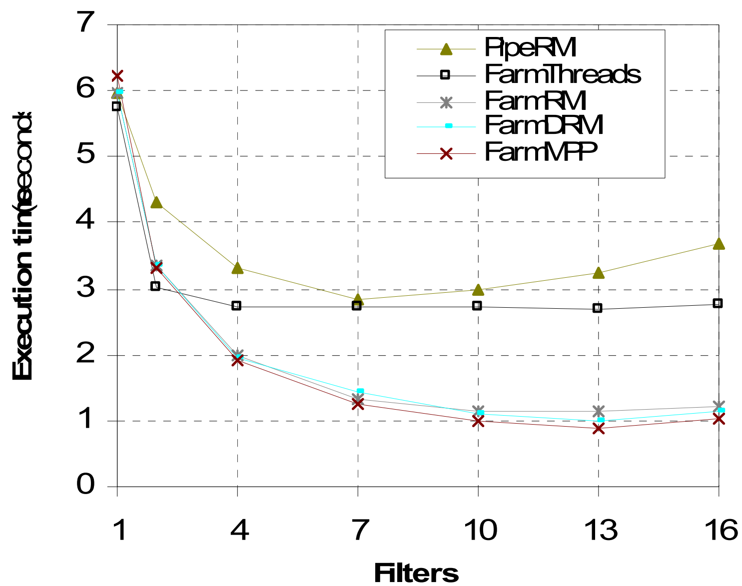


Developing Parallel Applications with AspectJ

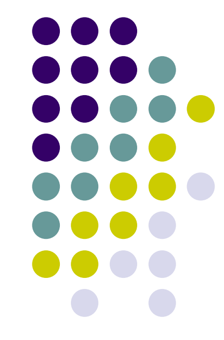
Performance Results (Prime Sieve – cont.)

- Tested combinations of modules

	Partition	Concurrency	Distribution
FarmThreads	Farm	Yes	No
PipeRMI	Pipeline	Yes	RMI
FarmRMI	Farm	Yes	RMI
FarmDRMI	Dynamic Farm		RMI
FarmMPP	Farm	Yes	MPP

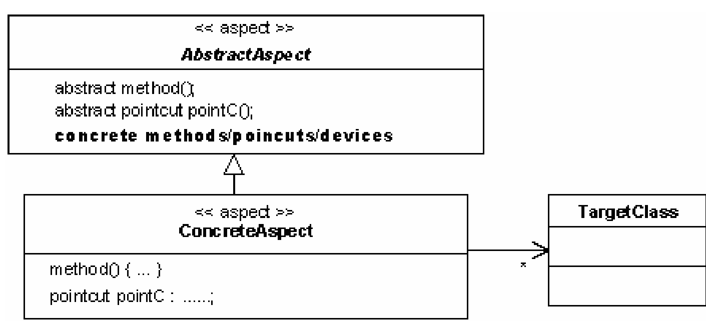


Developing reusable modules



How to implement reusable modules?

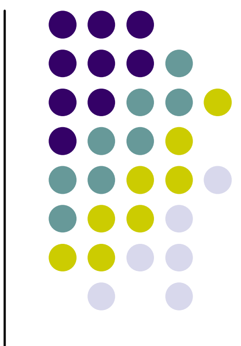
- **Marker interfaces**
- **Abstract pointcuts**



Concurrency modules

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

```
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

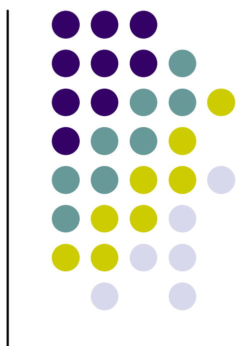
```
public abstract aspect GridProtocol {

    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));
    }
}
```

JGF RayTracer with reusable modules

RayTracer rt = new RayTracer();	aspect Partition extends GridProtocol { declare parents: RayTracer implements Grid;	

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);
	}
	pointcut scatterCall(..) : call (RayTracer.render(..));
	}
		public aspect Future extends FutureProtocol {
		protected pointcut futureMethodExecution() :
		(execution(* RayTracer.render(..)));

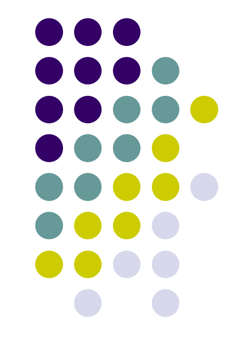
AO Support for Modular Parallel Computing



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

AO Support for Modular Parallel Computing



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