# The GPars Framework - Reference Documentation

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1 Introduction

The world of mainstream computing is changing rapidly these days. If you open the hood and look under the covers of your computer, you'll most likely see a dual-core processor there. Or a quad-core one, if you have a high-end computer. We all now run our software on multi-processor systems. The code we write today and probably never run on a single processor system: parallel hardware has become standard. Not so with the software though, at least not yet. People still create single-threaded code, even though it will not be able to leverage the power of current and future hardware. Some developers experiment with low-level concurrency and locks or synchronized blocks. However, it has become obvious that the shared-memory multi-processor systems at the application level causes more trouble than it solves. Low-level concurrency handling is right, and it's not much fun either. With such a radical change in hardware, software inevitably has to change dramatically too. Higher-level concurrency and parallelism concepts like map/reduce, fork/join, actors provide natural abstractions for different types of problem domains while leveraging the multi-core processing power.

1.1 Enter GPars

Meet GPars - an open-source concurrency and parallelism library for Java and Groovy that gives high-level abstractions for writing concurrent and parallel code in Groovy (map/reduce, fork/join, actors, agents, dataflow concurrency and other concepts), which can make your Java and Groovy code concurrent and/or parallel with little effort. With GPars your Java and/or Groovy code can easily utilize all the available processors on the target system. You can run multiple calculations at the same time, request network resources in parallel, safely solve hierarchical divide-and-conquer problems, perform functional style map/reduce collection processing or build your applications around the actor or dataflow model.

The project is open sourced under the Apache 2 License. If you're working on a commercial, open-source, educational or any other type of software project in Groovy, download the binaries or integrate them from the Maven repository and get going. The way to writing highly concurrent and/or parallel Java and Groovy code is wide open.

1.2 Credits

This project could not have reached the point where it stands currently without all the great help and contribution of many individuals, who have devoted their time, energy and expertise to make GPars a solid product. First, it is the people in the core team who should be mentioned:

- Václav Pech
- Dierk Koenig
- Alex Tkachman
- Russel Winder
- Paul King
- Jon Kerridge

Over time, many people have contributed their ideas, provided useful feedback or helped GPars. There are many people in this group, too many to name them all, but let's list at least the most active.
Hamlet d'Arcy
Hans Dockter
Guillaume Laforge
Robert Fischer
Johannes Link
Graeme Rocher
Alex Miller
Jeff Gortatowsky
Jií Kropáek

Many thanks to everyone!
2 Getting Started

Let's set out a few assumptions before we get started:

1. You know and use Groovy and Java: otherwise you'd not be investing your valuable time studying a concurrency and parallelism library for Groovy and Java.
2. You definitely want to write your codes employing concurrency and parallelism using Groovy.
3. If you are not using Groovy for your code, you are prepared to pay the inevitable verbosity tax.
4. You target multi-core hardware with your code.
5. You appreciate that in concurrent and parallel code things can happen at any time, in any order, and more likely with than one thing happening at once.

With those assumptions in place, we get started.

It's becoming more and more obvious that dealing with concurrency and parallelism at the thread level, as provided by the JVM, is far too low a level to be safe and comfortable. Many high-level constructs such as actors and dataflow have been around for quite some time: parallel computers have been in use, centres if not on the desktop, long before multi-core chips hit the hardware mainstream. Now these higher-level abstractions in the mainstream software industry. This is what GPars enables Java languages, allowing Groovy and Java programmers to use higher-level abstractions and the developing concurrent and parallel software easier and less error prone.

The concepts available in GPars can be categorized into three groups:

1. **Code-level helpers** Constructs that can be applied to small parts of the code-base such as ir data structures without any major changes in the overall project architecture
   1. Parallel Collections
   2. Asynchronous Processing
   3. Fork/Join (Divide/Conquer)

2. **Architecture-level concepts** Constructs that need to be taken into account when designing th
   1. Actors
   2. Communicating Sequential Processes (CSP)
   3. Dataflow
   4. Data Parallelism

3. **Shared Mutable State Protection** Although about 95% of current use of shared mutable state proper abstractions, good abstractions are still necessary for the remaining 5% use cases, where state cannot be avoided
   1. Agents
   2. Software Transactional Memory (not fully implemented in GPars as yet)

2.1 Downloading and Installing
GPars is now distributed as standard with Groovy. So if you have a Groovy installation, you should have GPars already. The exact version of GPars you have will, of course, depend on which version of Groovy you have. If you do not have GPars, and you do have Groovy, then perhaps you should upgrade your Groovy!

If you do not have a Groovy installation, but get Groovy by using dependencies or just having the an old GPars-less Groovy you cannot upgrade, you will need to get GPars. The ways of getting GPars are:

- Download the artifact from a repository and add it and all the transitive dependencies manually.
- Specify a dependency in Gradle, Maven, or Ivy (or Gant, or Ant) build files.
- Use Grapes (especially useful for Groovy scripts).

If you're building a Grails or a Griffon application, you can use the appropriate plugins to fetch them.

### The GPars Artifact

As noted above, GPars is now distributed as standard with Groovy. If however, you have to manage this dependency manually, the GPars artifact is in the main Maven repository and in the Codehaus main and snapshots repositories. The released versions are in the Maven and Codehaus main repositories, the current development version (SNAPSHOT) is in the Codehaus snapshots repository. To use from Gradle or Grapes use the specification:

```
"org.codehaus.gpars:gpars:1.2.0"
```

for the release version, and:

```
"org.codehaus.gpars:gpars:1.2-SNAPSHOT"
```

for the development version. You will likely need to add the Codehaus snapshots repository manually in this latter case. Using Maven the dependency is:

```xml
<dependency>
  <groupId>org.codehaus.gpars</groupId>
  <artifactId>gpars</artifactId>
  <version>1.2.0</version>
</dependency>
```

or version 1.2-SNAPSHOT if using the latest snapshot.

### Transitive Dependencies

GPars as a library depends on Groovy version equal or greater than 2.0. Also, the Fork/Join concurrency (an artifact from the [JSR-166 Project](https://jsr166-mirror.github.io/jsr166y/)) must be on the classpath the programs, which use and execute. Released versions of this artifact are in the main Maven and Codehaus repositories, versions of the artifact are available in the Codehaus snapshots repository. Using Gradle or Grapes, the following dependency specification:

```
"org.codehaus.jsr166-mirror:jsr166y:1.7.0"
```

For Maven, the specification would be:
The development versions have version number 1.7.0-1-SNAPSHOT.

GPars defines this dependency in its own descriptor, so ideally all dependency management should automatically, if you use Gradle, Grails, Griffon, Maven, Ivy or other type of automatic dependency resolution tool.

Please visit the page Integration on the GPars website for more details.

2.2 A Hello World Example

Once you are setup, try the following Groovy script to test that your setup is functioning as it should:

```groovy
import static groovyx.gpars.actor.Actors.actor

/**
 * A demo showing two cooperating actors. The decryptor decrypts received messages
 * and replies them back. The console actor sends a message to decrypt, prints out
 * the reply and terminates both actors. The main thread waits on both actors to
 * finish using the join() method to prevent premature exit, since both actors use
 * the default actor group, which uses a daemon thread pool.
 * @author Dierk Koenig, Vaclav Pech
 */
def decryptor = actor {
    loop {
        react { message ->
            if (message instanceof String) reply message.reverse()
            else stop()
        }
    }
}
def console = actor {
    decryptor.send 'lellarap si yvoorG'
    react {
        println 'Decrypted message: ' + it
        decryptor.send false
    }
}
[decryptor, console]*.join()
```

You should get a message "Decrypted message: Groovy is parallel" printed out on the console when you run the code.

GPars has been designed primarily for use with the Groovy programming language. Of course all Java and Groovy programs are just bytecodes running on the JVM, so GPars can work with Java source. Despite being aimed at Groovy code use, the solid technical foundations and good performance characteristics, of GPars make it an excellent library for Java programmers. In fact most of GPars is written in Java, so there is no performance penalty for Java applications using GPars.

For details please refer to the Java API section.

To quick-test using GPars via the Java API, you can compile and run the following Java code:
import groovy.gpars.MessagingRunnable;
import groovy.gpars.actor.DynamicDispatchActor;

class StatelessActorDemo {
    public static void main(String[] args) throws InterruptedException {
        final MyStatelessActor actor = new MyStatelessActor();
        actor.start();
        actor.send("Hello");
        actor.sendAndWait(10);
        actor.sendAndContinue(10.0, new MessagingRunnable<String>() {
            @Override
            void doRun(final String s) {
                System.out.println("Received a reply "+ s);
            }
        });
    }
}

class MyStatelessActor extends DynamicDispatchActor {
    void onMessage(final String msg) {
        System.out.println("Received "+ msg);
        replyIfExists("Thank you");
    }
    void onMessage(final Integer msg) {
        System.out.println("Received a number "+ msg);
        replyIfExists("Thank you");
    }
    void onMessage(final Object msg) {
        System.out.println("Received an object "+ msg);
        replyIfExists("Thank you");
    }
}

Remember though that you will almost certainly have to add the Groovy artifact to the build as w artifact. GPars may well work at Java speeds with Java applications, but it still has some compila Groovy.

2.3 Code conventions

We follow certain conventions in the code samples. Understanding these may help you read and code samples better.

- The `leftShift` operator `<<` has been overloaded on actors, agents and dataflow expressions (I streams) to mean `send` a message or `assign` a value.

  ```java
  myActor << 'message'
  myAgent << {account -> account.add('5 USD')}
  myDataflowVariable << 120332
  ```

- On actors and agents the default `call()` method has been also overloaded to mean `send`. So an actor or agent may look like a regular method call.

  ```java
  myActor "message"
  myAgent {house -> house.repair()}
  ```

- The `rightShift` operator `>>` in GPars has the when bound meaning. So

  ```java
  myDataflowVariable >> {value -> doSomethingWith(value)}
  ```

In samples we tend to statically import frequently used factory methods:
○ GParsPool.withPool()
○ GParsPool.withExistingPool()
○ GParsExecutorsPool.withPool()
○ GParsExecutorsPool.withExistingPool()
○ Actors.actor()
○ Actors.reactor()
○ Actors.fairReactor()
○ Actors.messageHandler()
○ Actors.fairMessageHandler()
○ Agent.agent()
○ Agent.fairAgent()
○ Dataflow.task()
○ Dataflow.operator()

It is more a matter of style preferences and personal taste, but we think static imports make the code more compact and readable.

2.4 Getting Set Up in an IDE

Adding the GPars jar files to your project or defining the appropriate dependencies in pom.xml should be enough to get you started with GPars in your IDE.

GPars DSL recognition

IntelliJ IDEA in both the free Community Edition and the commercial Ultimate Edition will recognize specific languages, complete methods like `eachParallel()`, `reduce()` or `callAsync()` and validate the GroovyDSL mechanism, which teaches IntelliJ IDEA the DSLs as soon as the GPars jar file is added to the project.

2.5 Applicability of Concepts

GPars provides a lot of concepts to pick from. We’re continuously building and updating a page that helps users choose the right abstraction for their tasks at hands. Please, refer to the Concepts compared page for more information.

To briefly summarize the suggestions, below you can find the basic guide-lines:
1. You're looking at a collection, which needs to be *iterated* or processed using one of the many beautiful Groovy iterated collections method, like `each()`, `collect()`, `find()` and such. Proposing that processing each element of the collection is independent of the other items, using GPars *parallel collections* can be recommended.

2. If you have a *long-lasting calculation*, which may safely run in the background, use the *as invocation support* in GPars. Since the GPars asynchronous functions can be composed, you can parallelize complex functional calculations without having to mark independent calculations explicitly.

3. You need to *parallelize* an algorithm at hand. You can identify a set of *tasks* with their mutual dependencies. The *parallelize* tasks typically do not need to share data, but instead some tasks may need to wait for other tasks to finish before starting. You're ready to express these dependencies explicitly in code. With GPars *dataflow* internally sequential tasks, each of which can run concurrently with the others. Dataflow variables provide the tasks with the capability to express their dependencies and to exchange data safely.

4. You can't avoid using *shared mutable state* in your algorithm. Multiple threads will be accessing (some of them) modifying it. Traditional locking and synchronized approach feels too risky or unfamiliar. Go for *agents*, which will wrap your data and serialize all access to it.

5. You're building a system with high concurrency demands. Tweaking a data structure here or there won't cut it. You need to build the architecture from the ground up with concurrency in mind. *Message-passing* way to go.

1. *Groovy CSP* will give you highly deterministic and composable model for concurrent processes organized around the concept of *calculations* or *processes*, which run concurrently and through synchronous channels.

2. If you're trying to solve a complex data-processing problem, consider GPars *dataflow* a data flow network. The concept is organized around event-driven transformations wired into pipelines using asynchronous channels.

3. *Actors* and *Active Objects* will shine if you need to build a general-purpose, highly concurrent and scalable architecture following the object-oriented paradigm.

Now you may have a better idea of what concepts to use on your current project. Go and check them out in the User Guide.

### 2.6 What's New

The new GPars 1.2.0 release introduces several enhancements and improvements on top of the mainly in the dataflow area.

Check out the [JIRA release notes](http://jira.codehaus.org/README.txt).

#### Project changes

⚠️ See the [Breaking Changes listing](http://jira.codehaus.org/README.txt) for the list of breaking changes.

#### Asynchronous functions

#### Parallel collections
Fork / Join

Actors

- Annotated actor and actor factory methods with @DelegatesTo to enable use of actors inside Groovy code

Dataflow

- A thenForkAndJoin() method added to Promises to ease the creation of a fork/join algorithm
- Lazy tasks were added to simplify creation of asynchronous activities with execution delayed until their result is actually asked for
- Annotated operator factory methods with @DelegatesTo to enable use of dataflow operators statically compiled Groovy code

Agent

Stm

Other

- Replaced java.util.Timer with ScheduledExecutorService for timeout handling
- Proper shutdown of timers and thread-local variables added to the GParsConfig class

Renaming hints

2.7 Java API - Using GPars from Java

Using GPars is very addictive, I guarantee. Once you get hooked you won't be able to code with the force you to write code in Java, you will still be able to benefit from most of GPars features.

Java API specifics

Some parts of GPars are irrelevant in Java and it is better to use the underlying Java libraries directly:

- Parallel Collection - use jsr-166y library's Parallel Array directly
- Fork/Join - use jsr-166y library's Fork/Join support directly
- Asynchronous functions - use Java executor services directly

The other parts of GPars can be used from Java just like from Groovy, although most will miss their capabilities.
GPars Closures in Java API

To overcome the lack of closures as a language element in Java and to avoid forcing users to use Groovy closures directly through the Java API, a few handy wrapper classes have been provided to help you define body or dataflow tasks.

- `groovyx.gpars.MessagingRunnable` - used for single-argument callbacks or actor body
- `groovyx.gpars.ReactorMessagingRunnable` - used for ReactiveActor body
- `groovyx.gpars.DataflowMessagingRunnable` - used for dataflow operators' body

These classes can be used in all places GPars API expects a Groovy closure.

Actors

The `DynamicDispatchActor` as well as the `ReactiveActor` classes can be used just like in Groovy:

```java
import groovyx.gpars.MessagingRunnable;
import groovyx.gpars.actor.DynamicDispatchActor;
public class StatelessActorDemo {
    public static void main(String[] args) throws InterruptedException {
        final MyStatelessActor actor = new MyStatelessActor();
        actor.start();
        actor.send("Hello");
        actor.sendAndWait(10);
        actor.sendAndContinue(10.0, new MessagingRunnable<>() {
            @Override
            protected final String out.println("Received a reply " + s);
        });
    }
}

class MyStatelessActor extends DynamicDispatchActor {
    public void onMessage(final String msg) {
        System.out.println("Received " + msg);
        replyIfExists("Thank you");
    }
}

Although there are not many differences between Groovy and Java GPars use, notice, the callba MessagingRunnable class in place for a groovy closure.

```
Convenience factory methods

Obviously, all the essential factory methods to build actors quickly are available where you’d expect them.

```java
import groovy.lang.Closure;
import groovyx.gpars.ReactorMessagingRunnable;
import groovyx.gpars.actor.Actor;
import groovyx.gpars.actor.Actors;

public class ReactorDemo {
    public static final String handler = ReactorMessagingRunnable<
        Integer, Integer>() {
        final Integer return integer * 2;
    }
    final Actor actor = Actors.reactor(handler);
    System.out.println("Result: " + actor.sendAndWait(1));
    System.out.println("Result: " + actor.sendAndWait(2));
    System.out.println("Result: " + actor.sendAndWait(3));
}
```

Agents

```java
import groovyx.gpars.MessagingRunnable;
import groovyx.gpars.agent.Agent;

public class AgentDemo {
    public static void main(String[] args) throws InterruptedException {
        final Agent counter = new Agent<Integer>(0);
        counter.send(10);
        System.out.println("Current value: " + counter.getVal());
        counter.send(new MessagingRunnable<Integer>() {
            @Override
            protected void doRun(final Integer integer) {
                counter.updateValue(integer + 1);
            }
        });
        System.out.println("Current value: " + counter.getVal());
    }
}
```

Dataflow Concurrency

Both `DataflowVariables` and `DataflowQueues` can be used from Java without any hiccups. Just a overloaded operators and go straight to the methods, like `bind`, `whenBound`, `getVal` and other. Using dataflow `tasks` passing to them instances of `Runnable` or `Callable` just like `groovy Closure`.

```java
import groovyx.gpars.MessagingRunnable;
import groovyx.gpars.agent.Agent;

public class AgentDemo {
    public static void main(String[] args) throws InterruptedException {
        final Agent counter = new Agent<Integer>(0);
        counter.send(10);
        System.out.println("Current value: " + counter.getVal());
        counter.send(new MessagingRunnable<Integer>() {
            @Override
            protected void doRun(final Integer integer) {
                counter.updateValue(integer + 1);
            }
        });
        System.out.println("Current value: " + counter.getVal());
    }
}
```
import groovyx.gpars.MessagingRunnable;
import groovyx.gpars.dataflow.DataflowVariable;
import groovyx.gpars.group.DefaultPGroup;
import java.util.concurrent.Callable;

class DataflowTaskDemo {
    public static void main(final String[] args) throws InterruptedException {
        final DefaultPGroup group = new DefaultPGroup(10);
        final DataflowVariable a = new DataflowVariable();
        group.task(new Runnable() {
            @Override
            public void run() {
                a.bind(10);
            }
        });
        final Promise result = group.task(Callable() {
            public Object call() throws Exception {
                return (Integer)a.getVal() + 10;
            }
        });
        result.whenBound(MessagingRunnable<Integer>() {
            @Override
            public void doRun(final Integer integer) {
                System.out.println("arguments = "+ integer);
            }
        });
        System.out.println("result = "+ result.getVal());
    }
}

Dataflow operators

The sample below should illustrate the main differences between Groovy and Java API for dataflow operators:

1. Use the convenience factory methods accepting list of channels to create operators or selectors
2. Use DataflowMessagingRunnable to specify the operator body
3. Call getOwningProcessor() to get hold of the operator from within the body in order to e.g. bind output values

import groovyx.gpars.DataflowMessagingRunnable;
import groovyx.gpars.dataflow.DataflowQueue;
import groovyx.gpars.dataflow.DataflowProcessor;
import java.util.Arrays;
import java.util.List;

class DataflowOperatorDemo {
    public static void main(final String[] args) throws InterruptedException {
        final DataflowQueue stream1 = new DataflowQueue();
        final DataflowQueue stream2 = new DataflowQueue();
        final DataflowQueue stream3 = new DataflowQueue();
        final DataflowQueue stream4 = new DataflowQueue();

        final DataflowProcessor op1 = Dataflow.selector(Arrays.asList(stream1), Arrays.asList(stream2),
                new DataflowMessageProducer() {
                    @Override
                    public void doRun(final Object objects) {
                        getOwningProcessor().bindOutput(2*(Integer)objects[0]);
                    }
                });
        final List secondOperatorInput = Arrays.asList(stream2, stream3);

        final DataflowProcessor op2 = Dataflow.operator(secondOperatorInput, Arrays.asList(stream4),
                new DataflowMessageProducer() {
                    @Override
                    public void doRun(final Object objects) {
                        getOwningProcessor().bindOutput((Integer)objects[0] + (Integer)objects[1]);
                    }
                });
        stream1.bind(1);
        stream1.bind(2);
        stream1.bind(3);
        stream3.bind(100);
        stream3.bind(100);
        stream3.bind(100);
        System.out.println("Result: "+ stream4.getVal());
        op1.stop();
        op2.stop();
    }
}
Performance

In general, GPars overhead is identical irrespective of whether you use it from Groovy or Java. GPars actors, for example, can compete head-to-head with other JVM actor options, like Scala actors.

Since Groovy code in general runs slower than Java code, mainly due to dynamic method invocation, consider writing your code in Java to improve performance. Typically numeric operations or frequent fine-grained method calls within a task or actor body may benefit from a rewrite into Java.

Prerequisites

All the GPars integration rules apply to Java projects just like they do to Groovy projects. You only need to include the groovy distribution jar file in your project and all is clear to march ahead. You may also want to check out the sample Java Maven project to get tips on how to integrate GPars into a maven-based pure Java application.

Maven Project
3 Data Parallelism

Focusing on data instead of processes helps a great deal to create robust concurrent programs. Define your data together with functions that should be applied to it and then let the underlying machinery process the data. Typically a set of concurrent tasks will be created and then they will be submitted to a thread pool for processing.

In GPars the GParsPool and GParsExecutorsPool classes give you access to low-level data parallelism. While the GParsPool class relies on the jsr-166y Fork/Join framework and so offers greater functionality and better performance, the GParsExecutorsPool uses good old Java executors and so is easier to set up in restricted environments.

There are three fundamental domains covered by the GPars low-level data parallelism:

1. Processing collections concurrently
2. Running functions (closures) asynchronously
3. Performing Fork/Join (Divide/Conquer) algorithms

3.1 Parallel Collections

Dealing with data frequently involves manipulating collections. Lists, arrays, sets, maps, iterators other data types can be viewed as collections of items. The common pattern to process such coll elements sequentially, one-by-one, and make an action for each of the items in row.

Take, for example, the min() function, which is supposed to return the smallest element of a collection. When you call min() the method on a collection of numbers, the caller thread will create an accumulator or so-far-the-smallest-value initialized to the minimum value of the given type, let say to zero. And then the thread will iterate of the collection and compare them with the value in the accumulator. Once all elements have been processed, the minimum value is stored in the accumulator.

This algorithm, however simple, is **totally wrong** on multi-core hardware. Running the min() function on a dual-core chip can leverage at most 50% of the computing power of the chip. On a quad-core it would be at most 50% of the chip. This algorithm effectively wastes 75% of the computing power of the chip.

Tree-like structures proved to be more appropriate for parallel processing. The min() function in c need to iterate through all the elements in row and compare their values with the accumulator. V is relying on the multi-core nature of your hardware. A parallel_min() function could, for example, tuples of certain size) of neighboring values in the collection and promote the smallest value from round of comparison. Searching for minimum in different tuples can safely happen in parallel and round can be processed by different cores at the same time without races or contention among t

Meet Parallel Arrays

The jsr-166y library brings a very convenient abstraction called Parallel Arrays. GPars leverages implementation in several ways. The GParsPool and GParsExecutorsPool classes provide par common Groovy iteration methods like each(), collect(), findAll() and such.

```groovy
def selfPortraits = images.findAllParallel{it.contains me}.collectParallel {it.resize()}
```

It also allows for a more functional style map/reduce collection processing.
3.1.1 GParsPool

Use of GParsPool - the JSR-166y based concurrent collection processor

Usage of GParsPool

The GParsPool class enables a ParallelArray-based (from JSR-166y) concurrency DSL for collections.

Examples of use:

```groovy
// summarize numbers concurrently
GParsPool.withPool {
    final AtomicInteger result = new AtomicInteger(0)
    [1, 2, 3, 4, 5].eachParallel {result.addAndGet(it)}
    assert 15 == result
}
```

```groovy
// multiply numbers asynchronously
GParsPool.withPool {
    final List result = [1, 2, 3, 4, 5].collectParallel {it * 2}
    assert ([2, 4, 6, 8, 10].equals(result))
}
```

The passed-in closure takes an instance of a ForkJoinPool as a parameter, which can be then used inside the closure.

```groovy
// check whether all elements within a collection meet certain criteria
GParsPool.withPool(5) {ForkJoinPool pool ->
    assert [1, 2, 3, 4, 5].everyParallel {it > 0}
    assert ![1, 2, 3, 4, 5].everyParallel {it > 1}
}
```

The GParsPool.withPool() method takes optional parameters for number of threads in the created pool and an unhandled exception handler.

```groovy
withPool(10) {...}
withPool(20, exceptionHandler) {...}
```

The GParsPool.withExistingPool() method takes an already existing ForkJoinPool instance to reuse. The method returns only after all the worker threads have finished their tasks and the pool has been destroyed, returning back the return value of the associated block of code. The method doesn't wait for the pool threads to finish.

Alternatively, the GParsPool class can be statically imported import static groovyx.gpars.GParsPool allow omitting the GParsPool class name.

```groovy
withPool {
    assert [1, 2, 3, 4, 5].everyParallel {it > 0}
    assert ![1, 2, 3, 4, 5].everyParallel {it > 1}
}
```

The following methods are currently supported on all objects in Groovy:
Meta-class enhancer

As an alternative you can use the *ParallelEnhancer* class to enhance meta-classes of any classe instances with the parallel methods.

```groovy
import groovyx.gpars.ParallelEnhancer
def list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
ParallelEnhancer.enhanceInstance(list)
println list.collectParallel {it * 2 }
def animals = ['dog', 'ant', 'cat', 'whale']
ParallelEnhancer.enhanceInstance animals
println (animals.anyParallel {it ==~ /ant/} ? 'Found an ant' : 'No ants found')
println (animals.everyParallel {it.contains('a')} ? 'All animals contain a' : 'Some animals can live without a')
```

When using the *ParallelEnhancer* class, you're not restricted to a *withPool()* block with the use of The enhanced classed or instances remain enhanced till they get garbage collected.

**Exception handling**

If an exception is thrown while processing any of the passed-in closures, the first exception gets xxxParallel methods and the algorithm stops as soon as possible.
The exception handling mechanism of GParsPool builds on the one built into the Fork/Join framework. Since Fork/Join algorithms are by nature hierarchical, once any part of the algorithm fails, there’s usually little benefit from continuing the computation, since some branches of the algorithm will never return a result.

Bear in mind that the GParsPool implementation doesn’t give any guarantees about its behavior after a first unhandled exception occurs, beyond stopping the algorithm and re-throwing the first detected exception to the caller. This behavior, after all, is consistent with what the traditional sequential iteration methods do.

### Transparencly parallel collections

On top of adding new xxxParallel() methods, **GPars** can also let you change the semantics of the methods. For example, you may be passing a collection into a library method, which will process sequential way, let say using the `collect()` method. By changing the semantics of the `collect()` method you can effectively parallelize the library sequential code.

```groovy
GParsPool.withPool {
    //The selectImportantNames() will process the name collections concurrently
    assert ['ALICE', 'JASON'] == selectImportantNames(['Joe', 'Alice', 'Dave', 'Jason'].makeConcurrent())
}
```

```groovy
/**
 * A function implemented using standard sequential collect() and findAll() methods.
 */
def selectImportantNames(names) {
    names.collect {it.toUpperCase()}.findAll{it.size() > 4}
}
```

The `makeSequential()` method will reset the collection back to the original sequential semantics.

```groovy
import static groovyx.gpars.GParsPool.withPool

def list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
printn 'Sequential: '
list.each { print it + ',' }
printn()
withPool {
    printn 'Sequential: '
    list.each { print it + ',' }
    printn()
    list.makeConcurrent()
    printn 'Concurrent: '
    list.each { print it + ',' }
    printn()
    list.makeSequential()
    printn 'Sequential: '
    list.each { print it + ',' }
    printn()
}
```

The `asConcurrent()` convenience method will allow you to specify code blocks, in which the collection maintains concurrent semantics.
import static groovyx.gpars.GParsPool.withPool

def list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
println 'Sequential: '
list.each { print it + ',' } println()

withPool {
  println 'Sequential: '
  list.each { print it + ',' } println()
  list.asConcurrent {
    println 'Concurrent: '
    list.each { print it + ',' } println()
  }
  println 'Sequential: '
  list.each { print it + ',' } println()
}
println 'Sequential: '
list.each { print it + ',' } println()

Transparent parallelizm, including the makeConcurrent() , makeSequential() and asConcurrent() available in combination with ParallelEnhancer.

public static class makeConcurrent()
public static class makeSequential()
public static class asConcurrent()

import groovyx.gpars.ParallelEnhancer

def list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
println 'Sequential: '
list.each { print it + ',' } println()
ParallelEnhancer.enhanceInstance(list)
println 'Sequential: '
list.each { print it + ',' } println()
list.asConcurrent {
  println 'Concurrent: '
  list.each { print it + ',' } println()
}
list.makeSequential()
println 'Sequential: '
list.each { print it + ',' } println()

Avoid side-effects in functions

We have to warn you. Since the closures that are provided to the parallel methods like eachPara may be run in parallel, you have to make sure that each of the closures is written in a thread-safe must hold no internal state, share data nor have side-effects beyond the boundaries the single el been invoked on. Violations of these rules will open the door for race conditions and deadlocks, t enemies of a modern multi-core programmer.

Don't do this:
At least, you've been warned.

Because **GParsPool** uses a **Fork/Join** pool (with work stealing), threads may not be a waiting processing task even though they may appear idle. With a work-stealing algorithm, worker threads that run out of things to do can steal tasks from other threads that are still busy. If you use **GParsExecutorsPool**, which doesn't use **Fork/Join**, you get the thread allocation behavior that you would naively expect.

### 3.1.2 GParsExecutorsPool

**Use of GParsExecutorsPool - the Java Executors' based concurrent collection processor**

**Usage of GParsExecutorsPool**

The **GParsPool** class enables a Java Executors-based concurrency DSL for collections and objects.

The **GParsExecutorsPool** class can be used as a pure-JDK-based collection parallel processor. In contrast, **GParsExecutorsPool** doesn't require jsr-166y jar file, but leverages the standard JDK executors to parallelize closures processing a collection or an object iteratively. It needs to be states, however, that performs typically much better than **GParsExecutorsPool** does.

**Examples of use:**

//multiply numbers asynchronously
GParsExecutorsPool.withPool {
    Collection<Future> result = [1, 2, 3, 4, 5].collectParallel { it * 10 }
    assert new HashSet([10, 20, 30, 40, 50]) == new HashSet((Collection)result*.get())
}

//multiply numbers asynchronously using an asynchronous closure
GParsExecutorsPool.withPool {
    def closure = { it * 10 }
    def asyncClosure = closure.async()
    Collection<Future> result = [1, 2, 3, 4, 5].collect(asyncClosure)
    assert new HashSet([10, 20, 30, 40, 50]) == new HashSet((Collection)result*.get())
}

The passed-in closure takes an instance of a ExecutorService as a parameter, which can be then used freely inside the closure.

//find an element meeting specified criteria
GParsExecutorsPool.withPool(5) { ExecutorService service ->
    service.submit({ performLongCalculation() } as Runnable)
}

The **GParsExecutorsPool.withPool()** method takes optional parameters for number of threads in thread factory.

withPool(10) {...}
withPool(20, threadFactory) {...}
The `GParsExecutorsPool.withExistingPool()` takes an already existing executor service instance valid only within the associated block of code and only for the thread that has called the `withPool` method. The `withPool()` method returns only after all the worker threads have finished their tasks and service has been destroyed, returning back the return value of the associated block of code. The method doesn't wait for the executor service threads to finish.

Alternatively, the `GParsExecutorsPool` class can be statically imported `import static groovyx.gpars.GParsExecutorsPool.`*,` which will allow omitting the `GParsExecutorsPool` class.

```groovy
withPool {
    def result = [1, 2, 3, 4, 5].findParallel{Number number -> number > 2}
    assert result in [3, 4, 5]
}
```

The following methods on all objects, which support iterations in Groovy, are currently supported:

- `eachParallel()`
- `eachWithIndexParallel()`
- `collectParallel()`
- `findAllParallel()`
- `findParallel()`
- `allParallel()`
- `anyParallel()`
- `grepParallel()`
- `groupByParallel()`

### Meta-class enhancer

As an alternative you can use the `GParsExecutorsPoolEnhancer` class to enhance meta-classes individual instances with asynchronous methods.

```groovy
import groovyx.gpars.GParsExecutorsPoolEnhancer
def list = [1, 2, 3, 4, 5, 6, 7, 8, 9]
GParsExecutorsPoolEnhancer.enhanceInstance(list)
println list.collectParallel {it * 2 }
def animals = ['dog', 'ant', 'cat', 'whale']
GParsExecutorsPoolEnhancer.enhanceInstance animals
println (animals.anyParallel {it ==~ /ant/} ? 'Found an ant' : 'No ants found')
println (animals.allParallel {it.contains('a')} ? 'All animals contain a' : 'Some animals can live without an a')
```

When using the `GParsExecutorsPoolEnhancer` class, you're not restricted to a `withPool()` block with `GParsExecutorsPool` DSLs. The enhanced classed or instances remain enhanced till they get garbage collected.

### Exception handling

If exceptions are thrown while processing any of the passed-in closures, an instance of `AsyncException` the original exceptions gets re-thrown from the `xxxParallel` methods.

### Avoid side-effects in functions
Once again we need to warn you about using closures with side-effects effecting objects beyond single currently processed element or closures which keep state. Don't do that! It is dangerous to the xxxParallel() methods.

### 3.1.3 Memoize

The memoize function enables caching of function's return values. Repeated calls to the memoize same argument values will, instead of invoking the calculation encoded in the original function, retrieve from an internal transparent cache. Provided the calculation is considerably slower than retrieving the cache, this allows users to trade-off memory for performance. Checkout out the example, which multiple websites for particular content:

The memoize functionality of GPars has been contributed to Groovy in version 1.8 and if you run later, it is recommended to use the Groovy functionality. Memoize in GPars is almost identical, except that the memoize caches concurrently using the surrounding thread pool and so may give performance benefits in some scenarios.

⚠️ The GPars memoize functionality has been renamed to avoid future conflicts with the functionality in Groovy. GPars now calls the methods with a preceding letter `g`, such as `gmemoize()`.

### Examples of use

```groovy
gParsPool.withPool { 
    Closure download = {url -> println "Downloading $url" url.toURL().text.toUpperCase()}
    Closure cachingDownload = download.gmemoize()
    println 'Groovy sites today: ' + urls.findAllParallel {url -> cachingDownload(url).contains('GROOVY')}
    println 'Grails sites today: ' + urls.findAllParallel {url -> cachingDownload(url).contains('GRAILS')}
    println 'Griffon sites today: ' + urls.findAllParallel {url -> cachingDownload(url).contains('GRIFFON')}
    println 'Concurrency sites today: ' + urls.findAllParallel {url -> cachingDownload(url).contains('CONCURRE')
    println 'GPars sites today: ' + urls.findAllParallel {url -> cachingDownload(url).contains('GPARS')}
}
```

Notice closures are enhanced inside the `gParsPool.withPool()` blocks with a `memoize()` function, closure wrapping the original closure with a cache. In the example we're calling the `cachingDownload()` several places in the code, however, each unique url gets downloaded only once - the first time it is needed. The values are then cached and available for subsequent calls. And also to all threads, no matter which thread originally came first with a download request for the particular url and had to handle the actual calculation.

So, to wrap up, memoize shields a function by a cache of past return values. However, `memoize` some algorithms adding a little memory may have dramatic impact on the computational complexity. Let's look at a classical example of Fibonacci numbers.

### Fibonacci example

A purely functional, recursive implementation, following closely the definition of Fibonacci numbers:

```groovy
Closure fib = {n -> n > 1 ? call(n - 1) + call(n - 2) : n}
```
Try calling the \texttt{fib} function with numbers around 30 and you'll see how slow it is.

Now with a little twist and added memoize cache the algorithm magically turns into a linearly complex.

\begin{verbatim}
Closure fib
fib = {n -> n > 1 ? fib(n - 1) + fib(n - 2) : n}.gmemoize()
\end{verbatim}

The extra memory we added cut off all but one recursive branches of the calculation. And all sub
same \texttt{fib} function will also benefit from the cached values.

Also, see below, how the \texttt{memoizeAtMost} variant can reduce memory consumption in our exampl
e linear complexity of the algorithm.

\section*{Available variants}

\textbf{memoize}

The basic variant, which keeps values in the internal cache for the whole lifetime of the memoize
the best performance characteristics of all the variants.

\textbf{memoizeAtMost}

Allows the user to set a hard limit on number of items cached. Once the limit has been reached, values will eliminate the oldest value from the cache using the LRU (Last Recently Used) strateg.

So for our Fibonacci number example, we could safely reduce the cache size to two items:

\begin{verbatim}
Closure fib
fib = {n -> n > 1 ? fib(n - 1) + fib(n - 2) : n}.memoizeAtMost(2)
\end{verbatim}

Setting an upper limit on the cache size may have two purposes:

1. Keep the memory footprint of the cache within defined boundaries

2. Preserve desired performance characteristics of the function. Too large caches may take lor cached value than it would have taken to calculate the result directly.

\textbf{memoizeAtLeast}

Allows unlimited growth of the internal cache until the JVM's garbage collector decides to step in
SoftReferences, used by our implementation, from the memory. The single parameter value to thmethod specifies the minimum number of cached items that should be protected from gc eviction
shrink below the specified number of entries. The cache ensures it only protects the most recentl eviction using the LRU (Last Recently Used) strategy.

\textbf{memoizeBetween}
Combines memoizeAtLeast and memoizeAtMost and so allowing the cache to grow and shrink depending on available memory and the gc activity, yet the cache size upper size limit to preserve desired performance characteristics of the cache.

### 3.2 Map-Reduce

The Parallel Collection Map/Reduce DSL gives GPars a more functional flavor. In general, the Map/Reduce method can perform considerably faster, if you need to chain multiple methods to process a single collection in multiple steps:

```groovy
def myNumbers = (1..1000).parallel.filter{it % 2 == 0}.map{Math.sqrt it}.collection
```

#### Avoid side-effects in functions
Once again we need to warn you. To avoid nasty surprises, please, keep your closures, which you pass to the Map/Reduce functions, stateless and clean from side-effects.

**Availability**

This feature is only available when using in the Fork/Join-based *GParsPool*, not in *GParsExecutorsPool*.

**Classical Example**

A classical example, inspired by [http://github.com/thevery](http://github.com/thevery), counting occurrences of words in a string:

```java
import static groovyx.gpars.GParsPool.withPool

def words = "This is just a plain text to count words in"

print count(words)

def count(arg) {
    withPool {
        arg.parallel
        .map([it, 1])
        .groupBy{it[0]}.getParallel()
        .map {it.value=it.value.size();it}
        .sort{-it.value}.collection
    }
}
```

The same example, now implemented the more general *combine* operation:

```java
def words = "This is just a plain text to count words in"

print count(words)

def count(arg) {
    withPool {
        arg.parallel
        .map([it, 1])
        .combine(0) {sum, value -> sum + value}.getParallel()
        .sort{-it.value}.collection
    }
}
```

**Combine**

The *combine* operation expects on its input a list of tuples (two-element lists) considered to be key-value pairs such as 

```
combine[[key1, value1, key2, value2, key1, value3, key3, value4 ...]]
```

with potentially repeating keys. When invoked, `combine` merges the values for identical keys using the provided accumulator function and produces a map mapping the original (unique) keys to their accumulated values. E.g. `[a, b, c, d, a, e, c, f]` will be combined into `a: b+e, c: d+f`, while the `+` operation on the values needs to be provided by the user as the accumulation closure.

The *accumulation function* argument needs to specify a function to use for combining (accumulating) the values belonging to the same key. An *initial accumulator value* needs to be provided as well. Since the closure processes items in parallel, the *initial accumulator value* will be reused multiple times. Thus the parameter needs to specify a function that allows for reuse. It should be either a *cloneable* or *immutable* value or a *closure* returning a fresh value each time requested. Good combinations of accumulator functions and reusable initial values include:

```java
accumulator = {List acc, value -> acc << value} initialValue = []
accumulator = {List acc, value -> acc << value} initialValue = {[]}
accumulator = {Int sum, int value -> acc + value} initialValue = 0
accumulator = {Int sum, int value -> sum + value} initialValue = (0)
accumulator = {ShoppingCart cart, Item value -> cart.addItem(value)} initialValue = new ShoppingCart()
```
The return type is a map. E.g. ['he', 1, 'she', 2, 'he', 2, 'me', 1, 'she', 5, 'he', 1 with the initial value 0 will be combined into 'he' : 4, 'she' : 7, 'he' : 2, 'me' : 1.

The keys will be mutually compared using their equals and hashCode methods. Consider using @Canonical or @EqualsAndHashCode to annotate classes that you use as keys. Just as with all hash maps in Groovy, be sure you’re using a String not a GString as a key!

For more involved scenarios when you combine() complex objects, a good strategy here is to have used as a key for the common use cases and apply different keys for uncommon cases.

```java
import groovy.transform.ToString
import groovy.transform.TupleConstructor
import static groovyx.gpars.GParsPool.withPool

TupleConstructor ToString
class PricedCar implements Cloneable {
    String model
    String color
    Double price

    boolean equals(final o) {
        if (this == o) return true
        if (getClass() != o.getClass()) return false
        final PricedCar pricedCar = (PricedCar) o
        if (color != pricedCar.color) return false
        if (model != pricedCar.model) return false
        return true
    }

    int hashCode() {
        int result = (model != null ? model.hashCode() : 0)
        result = 31 * result + (color != null ? color.hashCode() : 0)
        return result
    }

    @Override
    protected Object clone() {
        return super.clone()
    }
}

def cars = [
    new PricedCar('F550', 'blue', 2342.223),
    new PricedCar('F550', 'red', 234.234),
    new PricedCar('Da', 'white', 2222.2),
    new PricedCar('Da', 'white', 1111.1)]

withPool {
    //Combine by model
    def result = cars.parallel.map {
        [it.model, it]
    }.combine(new PricedCar('', 'N/A', 0.0)) {sum, value ->
        sum.model = value.model
        sum.price += value.price
        sum
    }.values()
    println result

    //Combine by model and color (the PricedCar's equals and hashCode)
    result = cars.parallel.map {
        [it, it]
    }.combine(new PricedCar('', 'N/A', 0.0)) {sum, value ->
        sum.model = value.model
        sum.color = value.color
        sum.price += value.price
        sum
    }.values()
    println result
}
```

### 3.3 Parallel Arrays
As an alternative, the efficient tree-based data structures defines in JSR-166y can be used directly. The `parallelArray` property on any collection or object will return a `jsr166y.forkjoin.ParallelArray` instance holding the original collection, which then can be manipulated through the jsr166y API. Please refer to the jsr for the API details.

```java
import groovyx.gpars.extra166y.Ops

groovyx.gpars.GParsPool.withPool {
    assert 15 == [1, 2, 3, 4, 5].parallelArray.reduce((a, b -> a + b) as Ops.Reducer, 0)
    //summarize
    assert 55 == [1, 2, 3, 4, 5].parallelArray.withMapping((it ** 2) as Ops.Op).reduce((a, b -> a + b) as Ops.Reducer)
    //summarize squares
    assert 20 == [1, 2, 3, 4, 5].parallelArray.withFilter((it % 2 == 0) as Ops.Predicate)
    .withMapping((it ** 2) as Ops.Op)
    .reduce((a, b -> a + b) as Ops.Reducer, 0)
    assert 'aa:bb:cc:dd:ee' == 'abcde'.parallelArray
    //concatenate duplicated characters with separator
    .withMapping((it * 2) as Ops.Op)
    .reduce((a, b -> "$a:$b") as Ops.Reducer, "")
}
```

### 3.4 Asynchronous Invocation

Running long-lasting tasks in the background belongs to the activities, the need for which arises quite frequently. Your main thread of execution wants to initialize a few calculations, downloads, searches or such, however, the results may not be needed immediately. GPars gives the developers the tools to schedule the asynchronous processing in the background and collect the results once they're needed.

#### Usage of `GParsPool` and `GParsExecutorsPool` asynchronous processing

Both `GParsPool` and `GParsExecutorsPool` provide almost identical services in this domain, although different underlying machinery, based on which of the two classes the user chooses.

#### Closures enhancements

The following methods are added to closures inside the `GPars(Executors)Pool.withPool()` blocks:

- `async()` - Creates an asynchronous variant of the supplied closure, which when invoked returns a future for the potential return value
- `callAsync()` - Calls a closure in a separate thread supplying the given arguments, returning a future for the potential return value.

#### Examples:

```java
GParsPool.withPool() { 
    Closure longLastingCalculation = {calculate()}
    Closure fastCalculation = longLastingCalculation.async() //create a new closure, which starts the original thread
    Future result=fastCalculation()                           //returns almost immediately
    println result.get()                                    //do stuff while calculation performs ...
}

GParsPool.withPool() { 
    / * The callAsync() method is an asynchronous variant of the default call() method to invoke a closure. */
    assert 6 == {it * 2}.call(3)                             // it will return a Future for the result value.
    assert 6 == {it * 2}.callAsync(3).get()                 //...
}
```
Timeouts

The `callTimeoutAsync()` methods, taking either a long value or a Duration instance, allow the use of calculation cancelled after a given time interval.

```java
{->
    while(true) {
        Thread.sleep 1000  //Simulate a bit of interesting calculation
        if (Thread.currentThread().isInterrupted()) break;  //We've been cancelled
    }
}.callTimeoutAsync(2000)
```

In order to allow cancellation, the asynchronously running code must keep checking the `interrupt` thread and cease the calculation once the flag is set to true.

**Executor Service enhancements**

The ExecutorService and jsr166y.forkjoin.ForkJoinPool class is enhanced with the `<<` (leftShift) operator to submit tasks to the pool and return a `Future` for the result.

Example:

```
GParsExecutorsPool.withPool {ExecutorService executorService ->
    executorService << {println 'Inside parallel task'}
}
```

**Running functions (closures) in parallel**

The `GParsPool` and `GParsExecutorsPool` classes also provide handy methods `executeAsync()` a `executeAsyncAndWait()` to easily run multiple closures asynchronously.

Example:

```
GParsPool.withPool {
    assert [10, 20] == GParsPool.executeAsyncAndWait({calculateA()}, {calculateB()})  //waits for result
    assert [10, 20] == GParsPool.executeAsync({calculateA()}, {calculateB()}).get()  //returns Futures instead and doesn't wait for results to be calculated
}
```

**3.5 Composable Asynchronous Functions**

Functions are to be composed. In fact, composing side-effect-free functions is very easy. Much easier and reliable than composing objects, for example. Given the same input, functions always return the same result, their behavior unexpectedly nor they break when multiple threads call them at the same time.

**Functions in Groovy**

We can treat Groovy closures as functions. They take arguments, do their calculation and return a value. Provided you don't let your closures touch anything outside their scope, your closures are well-behaved pure functions that you can combine for a better good.

```
def sum = (0..100000).inject(0, (a, b -> a + b))
```
For example, by combining a function adding two numbers with the `inject` function, which iterates collection, you can quickly summarize all items. Then, replacing the `adding` function with a `comp.` immediately give you a combined function calculating maximum.

```java
def max = myNumbers.inject(0, {a, b -> a>b?a:b})
```

You see, functional programming is popular for a reason.

**Are we concurrent yet?**

This all works just fine until you realize you're not utilizing the full power of your expensive hardware. No parallelism in here. All but one processor core do nothing, they're idle, totally

⚠️ Those paying attention would suggest to use the *Parallel Collection* techniques described earlier and they would certainly be correct. For our scenario described here, where we have a collection, using those `parallel` methods would be the best choice. However, we're looking for a **generic way to create and combine asynchronous functions**, which help us not only for collection processing but mostly in other more generic cases, like right below.

To make things more obvious, here's an example of combining four functions, which are supposed particular web page matches the contents of a local file. We need to download the page, load the file, calculate hashes of both and finally compare the resulting numbers.

```java
Closure download = {String url ->
    url.toURL().text
}
Closure loadFile = {String fileName ->
    //load the file here
}
Closure hash = {s -> s.hashCode()}
Closure compare = {int first, int second ->
    first == second
}

def result = compare(hash(download('http://www.gpars.org')), hash(loadFile('/coolStuff/gpars/website/index.html')))
println "The result of comparison: " + result
```

We need to download the page, load up the file, calculate hashes of both and finally compare the results. Each of the functions is responsible for one particular job. One downloads the content, second loads the file, third calculates the hashes and finally the fourth one will do the comparison. Combining the functions is as simple as nesting their calls.

**Making it all asynchronous**

The downside of our code is that we don't leverage the independence of the `download()` and the `loadFile()` functions. Neither we allow the two hashes to be run concurrently. They could well run in parallel, but our way to combine them restricts any parallelism.

Obviously not all of the functions can run concurrently. Some functions depend on results of other before the other function finishes. We need to block them till their parameters are available. The `hash()` function needs a string to work on. The `compare()` function needs two numbers to compare.

So we can only parallelize some functions, while blocking parallelism of others. Seems like a challenge.

**Things are bright in the functional world**
Luckily, the dependencies between functions are already expressed implicitly in the code. There's no need to duplicate the dependency information. If one function takes parameters and the parameters need to be calculated by another function, we implicitly have a dependency here. The `hash()` function depends on the `loadFile()` function in our example. The `inject` function in our earlier example depends on the `download()` functions invoked gradually on all the elements of the collection.

However difficult it may seem at first, our task is in fact very simple. We only need to teach our functions to return `promises` of their future results. And we need to teach the other functions to accept those `promises` as parameters so that they wait for the real values before they work. And if we convince the functions to release the threads they hold while waiting for the values, we get directly to where the magic can happen.

In the good tradition of `GPars` we've made it very straightforward for you to convince any function of their future results. Call the `asyncFun()` function on a closure and you're asynchronous.

```groovy
withPool {
    def maxPromise = numbers.inject(0, (a, b -> a>b?a:b).asyncFun())
    println "Look Ma, I can talk to the user while the math is being done for me!"
    println maxPromise.get()
}
```

The `inject` function doesn't really care what objects are being returned from the `addition` function, surprised that each call to the `addition` function returns so fast, but doesn't moan much, keeps ite returns the overall result to you.

Now, this is the time you should stand behind what you say and do what you want others to do. Let's and just accepts that you got back just a promise. A `promise` to get the result delivered as soon as the calculation is done. The extra heat coming out of your laptop is an indication the calculation exploits natural parallelism in your functions and makes its best effort to deliver the result to you quickly.

The `promise` is a good old `DataflowVariable`, so you may query its status, register no hooks or make it an input to a `Dataflow` algorithm.

```groovy
withPool {
    def sumPromise = (0..100000).inject(0, {a, b -> a + b}.asyncFun())
    println "Are we done yet? " + sumPromise.bound
    sumPromise.whenBound {sum -> println sum}
}
```

The `get()` method has also a variant with a timeout parameter, if you want to avoid the waiting indefinitely.

Can things go wrong?

Sure. But you'll get an exception thrown from the result promise `get()` method.
try {
    sumPromise.get()
} catch (MyCalculationException e) {
    println "Guess, things are not ideal today."
}

This is all fine, but what functions can be really combined?

There are no limits. Take any sequential functions you need to combine and you should be able to combine asynchronous variants as well.

Back to our initial example comparing content of a file with a webpage, we simply make all the functions asynchronous by calling the `asyncFun()` method on them and we are ready to set off.

```java
Closure download = (String url) -> url.toURL().text .asyncFun()
Closure loadFile = (String fileName) -> ... // load the file here .asyncFun()
Closure hash = (s) -> s.hashCode() .asyncFun()
Closure compare = (int first, int second) -> first == second .asyncFun()

def result = compare(hash(download('http://www.gpars.org')), hash(loadFile('/coolStuff/gpars/website/index.html')))
println 'Allowed to do something else now'
else println + result.get() "The result of comparison: \$\{result\}"
```

Calling asynchronous functions from within asynchronous functions

Another very valuable characteristics of asynchronous functions is that their result promises can

```java
import static groovyx.gpars.GParsPool.withPool

withPool {
    Closure plus = (Integer a, Integer b) ->
        sleep 3000
        println 'Adding numbers'
        a + b
    .asyncFun()

    Closure multiply = (Integer a, Integer b) ->
        sleep 2000
        a * b
    .asyncFun()

    Closure measureTime = () ->
        sleep 3000
        4
    .asyncFun()

    Closure distance = (Integer initialDistance, Integer velocity, Integer time) ->
        plus(initialDistance, multiply(velocity, time))
    .asyncFun()

    Closure chattyDistance = (Integer initialDistance, Integer velocity, Integer time) ->
        println 'All parameters are now ready - starting'
        println 'About to call another asynchronous function'
        def innerResultPromise = plus(initialDistance, multiply(velocity, time))
        println 'Returning the promise for the inner calculation as my own result'
        return innerResultPromise
    .asyncFun()

    println "Distance = \$\{distance(100, 20, measureTime()).get() + ' m'\}"  println "ChattyDistance = \$\{chattyDistance(100, 20, measureTime()).get() + ' m'\}" }
```
If an asynchronous function (e.g. the `distance` function in the example) in its body calls another as (e.g. `plus`) and returns the the promise of the invoked function, the inner function's (`plus`) result with the outer function's (`distance`) result promise. The inner function (`plus`) will now bind its result function's (`distance`) promise, once the inner function (plus) finishes its calculation. This ability allows functions to cease their calculation without blocking a thread not only when waiting for parameters, but also whenever they call another asynchronous function anywhere in their body.

**Methods as asynchronous functions**

Methods can be referred to as closures using the `.&` operator. These closures can then be transformed into composable asynchronous functions just like ordinary closures.

```java
@AsyncFun
class DownloadHelper {
    String download(String url) {
        url.toURL().text
    }

    int scanFor(String word, String text) {
        text.findAll(word).size()
    }

    String lower(s) {
        s.toLowerCase()
    }
}
```

```java
withPool {
    DownloadHelper d = new DownloadHelper()
    Closure download = d.&download.asyncFun()
    Closure scanFor = d.&scanFor.asyncFun()
    Closure lower = d.&lower.asyncFun()
    //asynchronous processing
    def result = scanFor('groovy', lower(download('http://www.infoq.com')))  //synchronous processing
    println 'Allowed to do something else now'
    println result.get()
}
```

**Using annotation to create asynchronous functions**

Instead of calling the `asyncFun()` function, the `@AsyncFun` annotation can be used to annotate closures. The fields have to be initialized in-place and the containing class needs to be instantiated within a block.

```java
import static groovyx.gpars.GParsPool.withPool
import groovyx.gpars.AsyncFun

class DownloadingSearch {
    @AsyncFun Closure download = { String url ->
        url.toURL().text
    }

    @AsyncFun Closure scanFor = { String word, String text ->
        text.findAll(word).size()
    }

    @AsyncFun Closure lower = { s -> s.toLowerCase()}

    void scan() {
        def result = scanFor('groovy', lower(download('http://www.infoq.com')))  //synchronous processing
        println 'Allowed to do something else now'
        println result.get()
    }
}
```

**Alternative pools**
The `AsyncFun` annotation by default uses an instance of `GParsPool` from the wrapping `withPool` block. You may, however, specify the type of pool explicitly:

```java
@AsyncFun(GParsExecutorsPoolUtil) def sum6 = {a, b -> a + b }
```

### Blocking functions through annotations

The `AsyncFun` also allows the user to specify, whether the resulting function should have blocking (false - default) semantics.

```java
@AsyncFun(blocking = true)
def sum = {a, b -> a + b }
```

### Explicit and delayed pool assignment

When using the `GPars(Executors)PoolUtil.asyncFun()` function directly to create an asynchronous function, you have two additional options to assign a thread pool to the function.

1. The thread pool to use by the function can be specified explicitly as an additional argument at creation time.
2. The implicit thread pool can be obtained from the surrounding scope at invocation rather at creation.

When specifying the thread pool explicitly, the call doesn’t need to be wrapped in an `withPool()` block:

```java
Closure sPlus = {Integer a, Integer b ->
  a + b
}
Closure sMultiply = {Integer a, Integer b ->
  sleep 2000
  a * b
}
println "Synchronous result: " + sMultiply(sPlus(10, 30), 100)
final pool = new FJPool()
Closure aPlus = GParsPoolUtil.asyncFun(sPlus, pool)
Closure aMultiply = GParsPoolUtil.asyncFun(sMultiply, pool)
def result = aMultiply(aPlus(10, 30), 100)
println "Time to do something else while the calculation is running"
println "Asynchronous result: " + result.get()
```

With delayed pool assignment only the function invocation must be surrounded with a `withPool()` block:

```java
Closure aPlus = GParsPoolUtil.asyncFun(sPlus)
Closure aMultiply = GParsPoolUtil.asyncFun(sMultiply)
withPool {
  def result = aMultiply(aPlus(10, 30), 100)
  println "Time to do something else while the calculation is running"
  println "Asynchronous result: " + result.get()
}
```

On our side this is a very interesting domain to explore, so any comments, questions or suggestions on combining asynchronous functions or hints about its limits are welcome.

### 3.6 Fork-Join

Fork/Join or Divide and Conquer is a very powerful abstraction to solve hierarchical problems.
The abstraction

When talking about hierarchical problems, think about quick sort, merge sort, file system or gene such.

- Fork / Join algorithms essentially split a problem at hands into several smaller sub-problems the same algorithm to each of the sub-problems.
- Once the sub-problem is small enough, it is solved directly.
- The solutions of all sub-problems are combined to solve their parent problem, which in turn its parent problem.

⚠️ Check out the fancy interactive Fork/Join visualization demo, which will show you how cooperate to solve a common divide-and-conquer algorithm.

The mighty JSR-166y library solves Fork / Join orchestration pretty nicely for us, but leaves a corn which can hurt you, if you don't pay attention enough. You still deal with threads, pools or synchr

The GPars abstraction convenience layer

GPars can hide the complexities of dealing with threads, pools and recursive tasks from you, yet powerful Fork/Join implementation in jsr166y.

```groovy
import static groovyx.gpars.GParsPool.runForkJoin
import static groovyx.gpars.GParsPool.withPool

withPool() {
  println "***Number of files: ${}
  runForkJoin(new File("/src")) {file ->
    long count = 0
    file.eachFile {
      if (it.isDirectory()) {
        println "Forking a child task for $it"
        forkOffChild(it) //fork a child task
      } else {
        count++
      }
    }
  }
  return count + (childrenResults.sum(0))
  //use results of children tasks to calculate and store own result
}
```

The runForkJoin() factory method will use the supplied recursive code together with the provided hierarchical Fork/Join calculation. The number of values passed to the runForkJoin() method must expected parameters of the closure as well as the number of arguments passed into the forkOffC runChildDirectly() methods.

```groovy
def quicksort(numbers) {
  withPool {
    runForkJoin(0, numbers) {index, list ->
      def groups = list.groupBy {it <=> list[list.size().intdiv(2)]}
      if ((list.size() < 2) || (groups.size() == 1)) {
        return [index: index, list: list.clone()]
      }
      (-1..1).each {forkOffChild(it, groups[it] ?: [])}
      return [index: index, list: childrenResults.sort {it.index}.sum {it.list}]
    }
  }
}
```
The important piece of the puzzle that needs to be mentioned here is that `forkOffChild()` doesn't wait for the child to run. It merely schedules it for execution some time in the future. If a child fails by throwing an exception, you should not expect the exception to be fired from the `forkOffChild()` method itself. The exception is likely to happen long after the parent has returned from the call to the `forkOffChild()` method. It is the `getChildrenResults()` method that will re-throw exceptions that happened in the sub-tasks back to the parent task.

**Alternative approach**

Alternatively, the underlying mechanism of nested Fork/Join worker tasks can be used directly. Custom-tailored workers can eliminate the performance overhead associated with parameter spreading imposed by the generic workers. Also, custom workers can be implemented in Java and so further increase the performance of the algorithm.

```java
public final class FileCounter extends AbstractForkJoinWorker<Long> {
    private final File file;
    def FileCounter(final File file) {
        this.file = file
    }

    @Override
    protected Long computeTask() {
        long count = 0;
        file.eachFile { it ->
            if (it.isDirectory()) {
                println "Forking a thread for $it";
                forkOffChild(new FileCounter(it))  //fork a child task
            } else {
                count++
            }
        }
        return count + ((childrenResults)?.sum() ?: 0)  //use results of children tasks to calculate and store own result
    }
}
```

The AbstractForkJoinWorker subclasses may be written both in Java or Groovy, giving you the option to easily optimize for execution speed, if row performance of the worker becomes a bottleneck.

**Fork / Join saves your resources**

Fork/Join operations can be safely run with small number of threads thanks to internally using the TaskBarrier class to synchronize the threads. While a thread is blocked inside an algorithm waiting for its sub-problem thread is silently returned to the pool to take on any of the available sub-problems from the task queue. Although the algorithm creates as many tasks as there are sub-directories and tasks wait for them to complete, as few as one thread is enough to keep the computation going and eventually result.

**Mergesort example**
import static groovyx.gpars.GParsPool.runForkJoin
import static groovyx.gpars.GParsPool.withPool

/**
 * Splits a list of numbers in half
 */
def split(List<Integer> list) {
    int listSize = list.size()
    int middleIndex = listSize / 2
    def list1 = list[0..<middleIndex]
    def list2 = list[middleIndex..<listSize - 1]
    return [list1, list2]
}

/**
 * Merges two sorted lists into one
 */
List<Integer> merge(List<Integer> a, List<Integer> b) {
    int i = 0, j = 0
    final int newSize = a.size() + b.size()
    List<Integer> result = new ArrayList<Integer>(newSize)
    while ((i < a.size()) && (j < b.size())) {
        if (a[i] <= b[j]) result << a[i++]
        else result << b[j++]
    }
    if (i < a.size()) result.addAll(a[i..-1])
    else result.addAll(b[j..-1])
    return result
}

def numbers = [1, 5, 2, 4, 3, 8, 6, 7, 3, 4, 5, 2, 9, 8, 7, 6, 7, 3, 4, 1, 4, 1, 7, 5, 8, 2, 3, 9, 5, 7, 4, 3]
withPool(3) {  //feel free to experiment with the number of fork/join threads in the pool
    println ""
    runForkJoin(numbers) {nums ->
        println "Thread \$currentThread(): Sorting $nums"
        switch (nums.size()) {
            case 0..1:
                return nums
            case 2:
                if (nums[0] <= nums[1]) return nums
                else return nums[-1..0]
            default:
                def splitList = split(nums)
                [splitList[0], splitList[1]].each {forkOffChild it}  //fork a child task
                merge(* childrenResults)      //use results of children tasks to calculate and store
        }
    }
    println ""
}

Mergesort example using a custom-tailed worker class
public final class SortWorker extends AbstractForkJoinWorker<List<Integer>> {
    private final List numbers
    
    def SortWorker(final List<Integer> numbers) {
        this.numbers = numbers.asImmutable()
    }

    /**
     * Splits a list of numbers in half
     */
    def split(List<Integer> list) {
        int listSize = list.size()
        int middleIndex = listSize / 2
        def list1 = list[0..<middleIndex]
        def list2 = list[middleIndex..<listSize - 1]
        return [list1, list2]
    }

    /**
     * Merges two sorted lists into one
     */
    List<Integer> merge(List<Integer> a, List<Integer> b) {
        Integer i = 0, j = 0
        Integer newSize = a.size() + b.size()
        List<Integer> result = new ArrayList<Integer>(newSize)
        while ((i < a.size()) && (j < b.size())) {
            if (a[i] <= b[j]) result << a[i++]
            else result << b[j++]
        }
        if (i < a.size()) result.addAll(a[i..-1])
        else result.addAll(b[j..-1])
        return result
    }

    /**
     * Sorts a small list or delegates to two children, if the list contains more than two elements.
     */
    @Override
    List<Integer> computeTask() {
        println "$currentThread.name[-1]: Sorting $numbers"
        switch (numbers.size()) {
            case 0..1: //store own result
                return numbers
                case 2:
                    if (numbers[0] <= numbers[1]) return numbers //store own result
                    else return numbers[1..0] //store own result
                    default:
                        def splitList = split(numbers)
                        new SortWorker(splitList[0]), new SortWorker(splitList[1]).each {forkOffChild it} //fork a c
                        def result = runChildDirectly(numbers[-1..0]) //use results of children tasks to calculate and store own
                        return merge(* childrenResults) //use results of children tasks to calculate and store own
                }
        }
    }

    final def numbers = [1, 5, 2, 4, 3, 8, 6, 7, 3, 4, 5, 2, 9, 8, 7, 6, 7, 8, 1, 4, 1, 7, 5, 8, 2, 3, 9, 5, 7, 4, 3]
    withPool(1) {  //feel free to experiment with the number of fork/join threads in the pool
        println "$Sorted numbers: $(runForkJoin(new SortWorker(numbers)))"
    }
}

Running child tasks directly

The `forkOffChild()` method has a sibling - the `runChildDirectly()` method, which will run the child task immediately within the current thread instead of scheduling the child task for asynchronous processing on the thread pool. Typically you’ll call `forkOffChild()` on all sub-tasks but the last, which you invoke directly without scheduling overhead.

```
Closure fib = {number ->
    if (number <= 2) {
        return 1
    }
    forkOffChild(number - 1)  // This task will run asynchronously, probably in a different thread
    def result = runChildDirectly(number - 2) // This task is run directly within the current thread
    return (Integer) getChildrenResults().sum() + result
}

assert 55 == runForkJoin(10, fib)
```

Availability
This feature is only available when using in the Fork/Join-based GParsPool, not in GParsExecutorsPool.

### 3.7 Parallel Speculations

With processor cores having become plentiful, some algorithms might benefit from brutal-force parallelization. Instead of deciding up-front about how to solve a problem, what algorithm to use or which location to connect to, you run all potential solutions in parallel.

**Parallel speculations**

Imagine you need to perform a task like e.g. calculate an expensive function or read data from a network. Luckily, you know of several good ways (e.g. functions or urls) to achieve your goal. However, they may take different amounts of time to complete and some of them may even fail (e.g. network issues). What's worse, you don't know which path gives you the solution first nor which paths lead to no solution at all. Shall I run quick sort or merge sort on my list? Which url will work best? Is this service available at its primary location or should I use the backup one?

GPars speculations give you the option to try all the available alternatives in parallel and so get the result from the fastest functional path, silently ignoring the slow or broken ones.

This is what the `speculate()` methods on GParsPool and GParsExecutorsPool() can do.

```groovy
def numbers = ...
def quickSort = ...
def mergeSort = ...
def sortedNumbers = speculate(quickSort, mergeSort)
```

Here we're performing both quick sort and merge sort concurrently, while getting the result of the fastest functional path, which of the two sorting algorithms would perform better on our data. Thus:

Similarly, downloading a document from multiple sources of different speed and reliability would look like this:

```groovy
import static groovyx.gpars.GParsPool.speculate
import static groovyx.gpars.GParsPool.withPool

def alternative1 = {
  'http://www.dzone.com/links/index.html'.toURL().text
}
def alternative2 = {
  'http://www.dzone.com/'.toURL().text
}
def alternative3 = {
  'http://www.dzzzzzone.com/'.toURL().text // wrong url
}
def alternative4 = {
  'http://dzone.com/'.toURL().text
}

withPool(4) {
  println speculate([alternative1, alternative2, alternative3, alternative4]).contains('groovy')
}
```

⚠️ Make sure the surrounding thread pool has enough threads to process all alternatives in parallel. The size of the pool should match the number of closures supplied.
Alternatives using dataflow variables and streams

In cases when stopping unsuccessful alternatives is not needed, dataflow variables or streams may be used to obtain the result value from the winning speculation.

Please refer to the Dataflow Concurrency section of the User Guide for details on Dataflow variables and streams.

```groovy
import groovy.gpars.dataflow.DataflowQueue
import static groovy.gpars.dataflow.Dataflow.task

def alternative1 = {
    'http://www.dzone.com/links/index.html'.toURL().text
}
def alternative2 = {
    'http://www.dzone.com/'.toURL().text
}
def alternative3 = {
    'http://www.dzzzzzone.com/'.toURL().text //will fail due to wrong url
}
def alternative4 = {
    'http://dzone.com/'.toURL().text
}

// Pick either one of the following, both will work:
final def result = new DataflowVariable()

[alternative1, alternative2, alternative3, alternative4].each {code ->
    task {
        try {
            result << code()
        } catch (ignore) { } //We deliberately ignore unsuccessful urls
    }
}

println result.val.contains('groovy')
```
4 Groovy CSP

The CSP (Communicating Sequential Processes) abstraction builds on independent composable exchange messages in a synchronous manner. GPars leverages the JCSP library developed at the University of Kent, UK.

Jon Kerridge, the author of the CSP implementation in GPars, provides exhaustive examples on his website:

⚠️ The GroovyCSP implementation leverages JCSP, a Java-based CSP library, which is licensed under LGPL. There are some differences between the Apache 2 license, which GPars uses, and LGPL. Please make sure your application conforms to the LGPL rules before enabling the use of JCSP in your code.

If the LGPL license is not adequate for your use, you might consider checking out the Dataflow Concurrency chapter of this User Guide to learn about tasks, selectors and operators, which may help you resolve concurrency similar to the CSP approach. In fact the dataflow and CSP concepts, as implemented in GPars, stand very close to each other.

⚠️ By default, without actively adding an explicit dependency on JCSP in your build file or downloading and including the JCSP jar file in your project, the standard commercial-software-friendly Apache 2 License terms apply to your project. GPars directly only depends on software licensed under licenses compatible with the Apache 2 License.

The CSP model principles

In essence, the CSP model builds on independent concurrent processes, which mutually communicate through channels using synchronous (i.e. rendezvous) message passing. Unlike actors or dataflow operators, which revolve around the event-processing pattern, CSP processes place focus on their activities (aka sequences of steps) and use communication to stay mutually in sync along the way.

Since the addressing is indirect through channels, the processes do not need to know about one another. They typically consist of a set of input and output channels and a body. Once a CSP process is started from a thread pool and starts processing its body, pausing only when reading from a channel or writing into a channel. Some implementations (e.g. GoLang) can also detach the thread from the CSP process when blocked on a channel.

CSP programs are deterministic. The same data on the program’s input will always generate the same output, irrespective of the actual thread-scheduling scheme used. This helps a lot when debugging CSP programs and analyzing deadlocks.

Determinism combined with indirect addressing result in a great level of composability of CSP processes. You can combine small CSP processes into bigger ones just by connecting their input and output channel with another, bigger containing process.

The CSP model introduces non-determinism using Alternatives. A process can attempt to read from multiple channels at the same time through a construct called Alternative or Select. The first value that becomes available in any of the channels involved in the Select will be read and consumed by the process. Since the order of messages received through a Select depends on unpredictable conditions during program run-time, the value is non-deterministic.
CSP with GPars dataflow

GPars provides all the necessary building blocks to create CSP processes.

- **CSP Processes** can be modelled through GPars tasks using a `Closure`, a `Runnable` or a `Callable` actual implementation of the process.
- **CSP Channels** should be modelled with `SyncDataflowQueue` and `SyncDataflowBroadcast`
- **CSP Alternative** is provided through the `Select` class with its `select` and `prioritySelect` methods.

Processes

To start a process simply use the `task` factory method.

```groovy
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool

group = new DefaultPGroup(new ResizeablePool(true))
def t = group.task {
    println "I am a process"
}
t.join()
```

⚠️ Since each process consumes a thread for its lifetime, it is advisable to use resizeable pools as in the example above.

A process can also be created from a Runnable or Callable object:

```groovy
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool

class MyProcess implements Runnable {
    @Override
    void run() {
        println "I am a process"
    }
}
def t = group.task new MyProcess()
t.join()
```

Using Callable allows for values to be returned through the `get()` method:

```groovy
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool
import java.util.concurrent.Callable

class MyProcess implements Callable<String> {
    @Override
    String call() {
        println "I am a process"
        return "CSP is great!"
    }
}
def t = group.task new MyProcess()
println t.get()
```
Channels

Processes typically need channels to communicate with the other processes as well as with the outside world:

```groovy
import groovy.transform.TupleConstructor
import groovyx.gpars.dataflow.DataflowReadChannel
import groovyx.gpars.dataflow.DataflowWriteChannel
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool
import java.util.concurrent.Callable
import groovyx.gpars.dataflow.SyncDataflowQueue

group = new DefaultPGroup(new ResizeablePool(true))

@TupleConstructor
class Greeter implements Callable<String> {
  DataflowReadChannel names
  DataflowWriteChannel greetings

  @Override
  String call() {
    while(!Thread.currentThread().isInterrupted()) {
      String name = names.val
      greetings << "Hello " + name
      return "CSP is great!"
    }
  }
}

def a = new SyncDataflowQueue()
def b = new SyncDataflowQueue()
group.task new Greeter(a, b)
a << "Joe"
a << "Dave"
println b.val
println b.val
```

⚠️ The CSP model uses synchronous messaging, however, in GPars you may consider using asynchronous channels as well as synchronous ones. You can also combine these two types of channels within the same process.

Composition

Grouping processes is then just a matter of connecting them with channels:
```java
@TupleConstructor
class Formatter implements Callable<String> {
    DataflowReadChannel rawNames
    DataflowWriteChannel formattedNames

    @Override
    String call() {
        while(!Thread.currentThread().isInterrupted()) {
            String name = rawNames.val
            formattedNames << name.toUpperCase()
        }
    }
}

@TupleConstructor
class Greeter implements Callable<String> {
    DataflowReadChannel names
    DataflowWriteChannel greetings

    @Override
    String call() {
        while(!Thread.currentThread().isInterrupted()) {
            String name = names.val
            greetings << "Hello " + name
        }
    }
}

def a = SyncDataflowQueue()
def b = SyncDataflowQueue()
def c = SyncDataflowQueue()

group.task new Formatter(a, b)
group.task new Greeter(b, c)
a << "Joe"
a << "Dave"
println c.val
println c.val
```

**Alternatives**

To introduce non-determinist GPars offers the `Select` class with its `select` and `prioritySelect` meth
import groovy.transform.TupleConstructor
import groovyx.gpars.dataflow.SyncDataflowQueue
import groovyx.gpars.dataflow.DataflowReadChannel
import groovyx.gpars.dataflow.DataflowWriteChannel
import groovyx.gpars.dataflow.Select
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool
import static groovyx.gpars.dataflow.Dataflow.select

@TupleConstructor
class Receptionist implements Runnable {
    DataflowReadChannel emails
    DataflowReadChannel phoneCalls
    DataflowReadChannel tweets
    DataflowWriteChannel forwardedMessages

    private final Select incomingRequests = select([phoneCalls, emails, tweets])  //prioritySelect() would give highest precedence to phone calls

    @Override
    void run() {
        while (!Thread.currentThread().isInterrupted()) {
            String msg = incomingRequests.select()
            forwardedMessages << msg.toUpperCase()
        }
    }
}

def a = new SyncDataflowQueue()
def b = new SyncDataflowQueue()
def c = new SyncDataflowQueue()
def d = new SyncDataflowQueue()

group.task new Receptionist(a, b, c, d)
a << "my email"
b << "my phone call"
c << "my tweet"
//The values come in random order since the process uses a Select to read its input

Components

CSP processes can be composed into larger entities. Suppose you already have a set of CSP pr Runnable/Callable classes), you can compose them into a larger process:

final class Prefix implements Callable {
    private final DataflowChannel inChannel
    private final DataflowChannel outChannel
    private final def prefix

    def Prefix(final inChannel, final outChannel, final prefix) {
        this.inChannel = inChannel;
        this.outChannel = outChannel;
        this.prefix = prefix
    }

    public def call() {
        outChannel << prefix
        while (true) {
            sleep 200
            outChannel << inChannel.val
        }
    }
}
```java
final class Copy implements Callable {
    private final DataflowChannel inChannel
    private final DataflowChannel outChannel1
    private final DataflowChannel outChannel2

    def Copy(final inChannel, final outChannel1, final outChannel2) {
        this.inChannel = inChannel;
        this.outChannel1 = outChannel1;
        this.outChannel2 = outChannel2;
    }

    def call() {
        public final PGroup group = Dataflow.retrieveCurrentDFPGroup()
        while (true) {
            def i = inChannel.val
            group.task {
                outChannel1 << i
                outChannel2 << i
            }.join()
        }
    }
}
```

```java
import groovyx.gpars.dataflow.DataflowChannel
import groovyx.gpars.dataflow.SyncDataflowQueue
import groovyx.gpars.group.DefaultPGroup

group = new DefaultPGroup(6)

def fib(DataflowChannel out) {
    group.task {
        def a = new SyncDataflowQueue()
        def b = new SyncDataflowQueue()
        def c = new SyncDataflowQueue()
        def d = new SyncDataflowQueue()
        [new Prefix(d, a, 0L), new Prefix(c, d, 1L), new Copy(a, b, out), new StatePairs(b, c)].each {
            group.t
        }
    }
    final SyncDataflowQueue ch = new SyncDataflowQueue()
    group.task new Print('Fibonacci numbers', ch)
    fib(ch)
    sleep 10000
```
5 Actors

The actor support in GPars was originally inspired by the Actors library in Scala, but has since gone beyond what Scala offers as standard.

Actors allow for a message passing-based concurrency model: programs are collections of independent active objects that exchange messages and have no mutable shared state. Actors can help developers avoid issues such as deadlock, live-lock and starvation, which are common problems for shared memory based approaches.

A nice article summarizing the key concepts behind actors was written recently by Ruben Vermeersch. Actors guarantee that at most one thread processes the actor's body at any one time and also, under the covers, that the memory gets synchronized each time a thread gets assigned to an actor so the actor's state can be modified by code in the body without any other extra (synchronization or locking) effort. Ideally actor be invoked directly from outside so all the code of the actor class can only be executed by the thread that received message and so all the actor's code is implicitly thread-safe. If any of the actor's methods is allowed to be directly called by other objects directly, the thread-safety guarantee for the actor's code and state are no longer valid.

Types of actors

In general, you can find two types of actors in the wild - ones that hold implicit state and those, you both options. Stateless actors, represented in GPars by the DynamicDispatchActor and the ReactiveActor classes, keep no track of what messages have arrived previously. You may think of these as flat which process messages as they come. Any state-based behavior has to be implemented by the user.

The stateful actors, represented in GPars by the DefaultActor class (and previously also by the AbstractPooledActor class), allow the user to handle implicit state directly. After receiving a message the actor moves into a new state with different ways to handle future messages. To give you an example, a freshly started actor may only accept some types of messages, e.g. encrypted messages for decryption, only after it has received the encryption keys. The stateful actors allow to encode such dependencies directly in the structure of the message-handling code. Implicit state management, however, comes at a slight performance cost, mainly due to the lack of continuations support on the JVM.

Actor threading model

Since actors are detached from the system threads, a great number of actors can share a relatively small thread pool. This can go as far as having many concurrent actors that share a single pooled thread. This architecture allows to avoid some of the threading limitations of the JVM. In general, while the JVM can only give you a limited number of threads (typically around a couple of thousands), the number of actors is only limited by the available memory. If an actor has no work to do, it doesn't consume threads.

Actor code is processed in chunks separated by quiet periods of waiting for new events (messages naturally modeled through continuations). As JVM doesn't support continuations directly, they have the actors frameworks, which has slight impact on organization of the actors' code. However, the advantages outweigh the difficulties.
import groovyx.gpars.actor.Actor
import groovyx.gpars.actor.DefaultActor

class GameMaster extends DefaultActor {
  int secretNum

  void afterStart() {
    secretNum = new Random().nextInt(10)
  }

  void act() {
    loop {
      react { int num ->
        if (num > secretNum)
          reply 'too large'
        else if (num < secretNum)
          reply 'too small'
        else {
          reply 'you win'
          terminate()
        }
      }
    }
  }
}

class Player extends DefaultActor {
  String name
  Actor server
  int myNum

  void act() {
    loop {
      myNum = new Random().nextInt(10)
      server.send myNum
      react {
        switch (it) {
          case 'too large': println "$name: $myNum was too large"; break
          case 'too small': println "$name: $myNum was too small"; break
          case 'you win': println "$name: I won $myNum"; terminate(); break
        }
      }
    }
  }
}

def master = new GameMaster().start()
def player = new Player(name: 'Player', server: master).start()
// this forces main thread to live until both actors stop
[master, player]*.join()

example by Jordi Campos i Miralles, Departament de Matemàtica Aplicada i Anàlisi, MAiA Facultat Universitat de Barcelona
Usage of Actors

Gpars provides consistent Actor APIs and DSLs. Actors in principal perform three specific operations - send messages, receive messages and create new actors. Although not specifically enforced by GPars, messages should be immutable or at least follow the hands-off policy when the sender never touches the messages after the message has been sent.

Sending messages

Messages can be sent to actors using the send() method.

```java
def passiveActor = Actors.actor{
    loop {
        react { msg -> println "Received: $msg"; }
    }
}
passiveActor.send 'Message 1'
passiveActor << 'Message 2' //using the << operator
passiveActor 'Message 3' //using the implicit call() method
```

Alternatively, the << operator or the implicit call() method can be used. A family of sendAndWait() to block the caller until a reply from the actor is available. The reply is returned from the sendAnd() return value. The sendAndWait() methods may also return after a timeout expires or in case of termination of the called actor.

```java
def replyingActor = Actors.actor{
    loop {
        react { msg ->
            println "Received: $msg"
            reply "I've got $msg"
        }
    }
}
def reply1 = replyingActor.sendAndWait('Message 4')
def reply2 = replyingActor.sendAndWait('Message 5', 10, TimeUnit.SECONDS)
use (TimeCategory) {
def reply3 = replyingActor.sendAndWait('Message 6', 10.seconds)
}
```

The sendAndContinue() method allows the caller to continue its processing while the supplied closure is waiting for a reply from the actor.

```java
friend.sendAndContinue 'I need money!', {money -> pocket money}
println 'I can continue while my friend is collecting money for me'
```

The sendAndPromise() method returns a Promise (aka Future) to the final reply and so allows the caller to continue its processing while the actor is handling the submitted message.

```java
Promise loan = friend.sendAndPromise 'I need money!'
println 'I can continue while my friend is collecting money for me'
loan.whenBound {money -> pocket money} //asynchronous waiting for a reply
println "Received ${loan.get()}") //synchronous waiting for a reply
```

All send(), sendAndWait() or sendAndContinue() methods will throw an exception if invoked on a non-active actor.

Receiving messages
Non-blocking message retrieval

Calling the `react()` method, optionally with a timeout parameter, from within the actor’s code will consume the next message from the actor’s inbox, potentially waiting, if there is no message to be processed immediately.

```java
println 'Waiting for a gift'
react {gift ->
    if (myWife.likes gift) reply 'Thank you!'
}
```

Under the covers the supplied closure is not invoked directly, but scheduled for processing by any thread in the thread pool once a message is available. After scheduling the current thread will then be detached from process any other actor, which has received a message already.

To allow detaching actors from the threads the `react()` method demands the code to be written in Continuation-style.

```java
Actors.actor {
    loop {
        println 'Waiting for a gift'
        react {gift ->
            if (myWife.likes gift) reply 'Thank you!'
            else
                reply 'Try again, please'
                react {anotherGift ->
                    if (myChildren.like gift) reply 'Thank you!'
                    }
        }
        println 'Never reached'
    }
    println 'Never reached'
}
```

The `react()` method has a special semantics to allow actors to be detached from threads when no message is available in their mailbox. Essentially, `react()` schedules the supplied code (closure) to be executed upon next message arrival and returns. The closure supplied to the `react()` methods is the code where the computation should continue.

Thus continuation style.

Since actor has to preserve the guarantee of at most one thread active within the actor’s body, the current message processing finishes. Typically, there shouldn’t be after calls to `react()`. Some actor implementations even enforce this, however, GPars does not for performance reasons. The `loop()` method allows iteration within the actor body. Unlike typical looping constructs, `loop()` cooperates with nested `react()` blocks and will ensure looping across subsequent messages.

Sending replies

The `reply/replyIfExists` methods are not only defined on the actors themselves, but for `AbstractPooledActor` available in `DefaultActor`, `DynamicDispatchActor` or `ReactiveActor` classes also on the processed messages themselves upon their reception, which is particularly handy when handling multiple messages in cases `reply()` invoked on the actor sends a reply to authors of all the currently processed messages whereas `reply()` called on messages sends a reply to the author of the particular message only.

See demo here

The sender property
Messages upon retrieval offer the sender property to identify the originator of the message. The property is available inside the Actor's closure:

```java
react {tweet ->
  if (isSpam(tweet)) ignoreTweetsFrom sender
  sender.send 'Never write me again!'
}
```

### Forwarding

When sending a message, a different actor can be specified as the sender so that potential replies will be forwarded to the specified actor and not to the actual originator.

```java
def decryptor = Actors.actor {
  react {message ->
    reply message.reverse() //An alternative way to send replies
    sender.send message.reverse()    //An alternative way to send replies
  }
}
def console = Actors.actor {  //This actor will print out decrypted messages, since the replies are forwarded
  react {
    println 'Decrypted message: ' + it
  }
}
decryptor.send 'lellarap si yvoorG', console  //Specify an actor to send replies to
console.join()
```

### Creating Actors

Actors share a pool of threads, which are dynamically assigned to actors when the actors need to send to them. The threads are returned to back the pool once a message has been processed and the actor is idle waiting for some more messages to arrive.

For example, this is how you create an actor that prints out all messages that it receives.

```java
def console = Actors.actor {
  loop {
    react {
      println it
    }
  }
}
```

Notice the `loop()` method call, which ensures that the actor doesn't stop after having processed the first message. Here's an example with a decryptor service, which can decrypt submitted messages and send them back to the originators.
**Undelivered messages**

Sometimes messages cannot be delivered to the target actor. When special action needs to be taken for undelivered messages, at actor termination all unprocessed messages from its queue have their `onDeliveryError()` method called. The `onDeliveryError()` method or closure defined on the message can, for example, send a notification back to the original sender of the message.
```
final DefaultActor me
me = Actors.actor {
    def message = 1

    message.metaClass.onDeliveryError = { ->
        //send message back to the caller
        me << "Could not deliver $delegate"
    }

    def actor = Actors.actor {
        react {
            //wait 2sec in order next call in demo can be emitted
            Thread.sleep(2000)
            //stop actor after first message
            stop()
        }
    }

    actor << message
    actor << message
    react {
        //print whatever comes back
        println it
    }
    me.join()
}
```

Alternatively the `onDeliveryError()` method can be specified on the sender itself. The method can dynamically

```
final DefaultActor me
me = Actors.actor {
    def message1 = 1
    def message2 = 2

    def actor = Actors.actor {
        react {
            //wait 2sec in order next call in demo can be emitted
            Thread.sleep(2000)
            //stop actor after first message
            stop()
        }
    }

    me.metaClass.onDeliveryError = {msg ->
        //callback on actor inaccessibility
        println "Could not deliver message $msg"
    }

    actor << message1
    actor << message2
    actor.join()
    me.join()
}
```

and statically in actor definition:

```
class MyActor extends DefaultActor {
    public void onDeliveryError(msg) {
        println "Could not deliver message $msg"
    }
}
```

**Joining actors**

Actors provide a `join()` method to allow callers to wait for the actor to terminate. A variant acceptor available. The Groovy `spread-dot` operator comes in handy when joining multiple actors at a time
def master = new GameMaster().start()
def player = new Player(name: 'Player', server: master).start()
[master, player]*.join()

**Conditional and counting loops**

The `loop()` method allows for either a condition or a number of iterations to be specified, optionally closure to invoke once the loop finishes - *After Loop Termination Code Handler*.

The following actor will loop three times to receive 3 messages and then prints out the maximum messages.

```java
final Actor actor = Actors.actor {
  def candidates = []
  def printResult = {-> println "The best offer is \${candidates.max()}"
  }
  loop(3, printResult) {
    react {
      candidates << it
    }
  }
  actor 10
  actor 30
  actor 20
  actor.join()
}
```

The following actor will receive messages until a value greater than 30 arrives.

```java
final Actor actor = Actors.actor {
  def candidates = []
  final Closure printResult = {-> println "Reached best offer - \${candidates.max()}"
  }
  loop({-> candidates.max() < 30}, printResult) {
    react {
      candidates << it
    }
  }
  actor 10
  actor 20
  actor 25
  actor 31
  actor 20
  actor.join()
}
```

⚠️ The *After Loop Termination Code Handler* can use actor's `react()` but not `loop()`.

⚠️ *DefaultActor* can be set to behave in a fair on non-fair (default) manner. Depending on the strategy chosen, the actor either makes the thread available to other actors sharing the parallel group (fair), or keeps the thread for itself until the message queue gets empty. Generally, non-fair actors perform 2-3 times better than fair ones. Use either the `fairActor()` factory method or the actor's `makeFair()` method.

**Custom schedulers**
Actors leverage the standard JDK concurrency library by default. To provide a custom thread scheduler when creating a parallel group (PGroup class), the supplied scheduler will orchestrate threads in the group’s thread pool.

Please also see the numerous Actor Demos.

### 5.1 Actors Principles

Actors share a pool of threads, which are dynamically assigned to actors when the actors need to react to messages sent to them. The threads are returned back to the pool once a message has been processed and waiting for some more messages to arrive. Actors become detached from the underlying threads, and a small thread pool can serve potentially unlimited number of actors. Virtually unlimited scalability is the main advantage of event-based actors, which are detached from the underlying physical threads.

Here are some examples of how to use actors. This is how you create an actor that prints out all messages it receives.

```java
import static groovyx.gpars.actor.Actors.actor

def console = actor {
    loop {
        react {
            println it
        }
    }
}
```

Notice the `loop()` method call, which ensures that the actor doesn't stop after having processed the first message.

As an alternative you can extend the `DefaultActor` class and override the `act()` method. Once you need to start it so that it attaches itself to the thread pool and can start accepting messages, you need to start it.

```java
class CustomActor extends DefaultActor {
    @Override
    protected void act() {
        loop {
            react {
                println it
            }
        }
    }
    
    def console = new CustomActor()
    console.start()
}
```

Messages can be sent to the actor using multiple methods:

```java
console.send('Message')
colse 'Message'

/Wait for a reply
```

Creating an asynchronous service
def decryptor = actor {
    loop {
        react { String message - >
            reply message.reverse()}
    }
}

def console = actor {
    decryptor.send 'lellarap si yvoorG'
    react {
        println 'Decrypted message: ' + it
    }
}

console.join()

As you can see, you create new actors with the `actor()` method passing in the actor's body as a closure parameter. Inside the actor's body you can use `loop()` to iterate, `react()` to receive messages and `reply()` to send a message to the actor, which has sent the currently processed message. The sender of the current message is accessible through the actor's `sender` property. When the decryptor actor doesn't find a message in its message queue, the `react()` method gives up the thread and returns it back to the thread pool for another message to be processed. Only after a new message arrives to the actor's message queue, the closure of the `react()` method gets scheduled for processing with the pool. Event-based actors internally simulate continuations - an actor's work is split into sequentially run chunks, which get invoked once a message is available in the inbox. Each chunk for a single actor is performed by a different thread from the thread pool.

Groovy flexible syntax with closures allows our library to offer multiple ways to define actors. For example, here's an example of an actor that waits for up to 30 seconds to receive a reply to its message. Actors allow the user to use the `TimeCategory` class to be used for timeout specification to the `react()` method, provided the user wraps the call within a `TimeCategory` use block.

When a timeout expires when waiting for a message, the `Actor.TIMEOUT` message arrives instead. Also the `onTimeout()` handler is invoked, if present on the actor:
def friend = Actors.actor {
    react {
        // this doesn't reply -> caller won't receive any answer in time
        println it
        // reply 'Hello' // uncomment this to answer conversation
        react {
            println it
        }
    }
}
def me = Actors.actor {
    friend.send('Hi')
    delegate.metaClass.onTimeout = {-
        friend.send('I see, busy as usual. Never mind.')
        stop()
    }
    // wait for answer lsec
    react(1000) {msg ->
        if (msg != Actor.TIMEOUT) {
            // continue conversation
            println "Thank you for $msg"
        }
    }
    me.join()
}

Notice the possibility to use Groovy meta-programming to define actor's lifecycle notification methods (e.g. `onTimeout`) dynamically. Obviously, the lifecycle methods can be defined the usual way when you decide to your actor.

```groovy
class MyActor extends DefaultActor {
    public void onTimeout() {
        --
    }
    protected void act() {
        --
    }
}
```

**Actors guarantee thread-safety for non-thread-safe code**

Actors guarantee that always at most one thread processes the actor's body at a time and also the memory gets synchronized each time a thread gets assigned to an actor so the actor's state can be modified by code in the body without any other extra (synchronization or locking) effort.

```groovy
class MyCounterActor extends DefaultActor {
    protected void act() {
        loop {
            react {
                counter++
            }
        }
    }
}
```

Ideally actor's code should **never be invoked** directly from outside so all the code of the actor class executed by the thread handling the last received message and so all the actor's code is implicit of the actor's methods is allowed to be called by other objects directly, the thread-safety guarantees and state are **no longer valid**.

**Simple calculator**
A little bit more realistic example of an event-driven actor that receives two numeric messages, sends the result to the console actor.

```java
import groovyx.gpars.group.DefaultPGroup
//not necessary, just showing that a single-threaded pool can still handle multiple actors
def group = new DefaultPGroup(1);

final def console = group.actor {
    loop {
        react {
            println 'Result: ' + it
        }
    }
}

final def calculator = group.actor {
    react {a ->
        react {b ->
            console.send(a + b)
        }
    }
}
calculator.send 2
calculator.send 3
calculator.join()
group.shutdown()
```

Notice that event-driven actors require special care regarding the `react()` method. Since event-driven actors split the code into independent chunks assignable to different threads sequentially and continuations supported on JVM, the chunks are created artificially. The `react()` method creates the next message handler. As soon as the current message handler finishes, the next message handler (continuation) gets scheduled.

**Concurrent Merge Sort Example**

For comparison I'm also including a more involved example performing a concurrent merge sort of a list of integers using actors. You can see that thanks to flexibility of Groovy we came pretty close to the Scala model, although I still miss Scala pattern matching for message handling.
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.actor.Actors.actor

Closure createMessageHandler(def parentActor) {
    return {
        react {List<Integer> message ->
            assert message != null
            switch (message.size()) {
                case 0..1:
                    parentActor.send(message)
                    break
                case 2:
                    if (message[0] <= message[1]) parentActor.send(message)
                    else parentActor.send(message[-1..0])
                    break
                default:
                    def splitList = split(message)
            }
        }
    }
}

def console = new DefaultPGroup(1).actor {
    new react {
        println "Sorted array:$it"
        System.exit 0
    }
}

def sorter = actor(createMessageHandler(console))
sorter.send([1, 5, 2, 4, 3, 8, 6, 7, 3, 9, 5, 3])
console.join()

def split(List<Integer> list) {
    Integer listSize = list.size()
    int middleIndex = listSize / 2
    def list1 = list[0..<middleIndex]
    def list2 = list[middleIndex..listSize - 1]
    return [list1, list2]
}

List<Integer> merge(List<Integer> a, List<Integer> b) {
    int i = 0, j = 0
    final int newSize = a.size() + b.size()
    List<Integer> result = new ArrayList<Integer>(newSize)
    while ((i < a.size()) && (j < b.size())) {
        if (a[i] <= b[j]) result << a[i++]
        else result << b[j++]
    }
    if (i < a.size()) result.addAll(a[i..-1])
    else result.addAll(b[j..-1])
    return result
}

Since actors reuse threads from a pool, the script will work with virtually any size of a thread pool, no matter how many actors are created along the way.

**Actor lifecycle methods**

Each Actor can define lifecycle observing methods, which will be called whenever a certain lifecycle event occurs.
- afterStart() - called right after the actor has been started.
- afterStop(List undeliveredMessages) - called right after the actor is stopped, passing in all the messages from the queue.
- onInterrupt(InterruptedException e) - called when the actor's thread gets interrupted. Thread in the stopping the actor in any case.
- onException(Throwable e) - called when an exception occurs in the actor's event handler. Actor will stop after return from this method.
- onTimeout() - called when no messages are sent to the actor within the timeout specified for the react method.

You can either define the methods statically in your Actor class or add them dynamically to the actor's metaclass:

```java
class MyActor extends DefaultActor {
    public void afterStart() {
        ...
    }
    public void onTimeout() {
        ...
    }
    protected void act() {
        ...
    }
}
```

```groovy
def myActor = actor {
    delegate.metaClass.onException = {
        log.error('Exception occurred', it)
    }
    ...
}
```

To help performance, you may consider using the silentStart() method instead of start() or a DynamicDispatchActor or a ReactiveActor. Calling silentStart() will by-pass the start-up machinery and as a result will also avoid calling the afterStart() method. Due to its stateful nature, DefaultActor cannot be started silently.

### Pool management

Actors can be organized into groups and as a default there's always an application-wide pooled group. And just like the Actors abstract factory can be used to create actors in the default group, custom abstract factories can be used to create new actors instances belonging to these groups.

```groovy
def myGroup = new DefaultPGroup()
def actor1 = myGroup.actor {
    ...
}
def actor2 = myGroup.actor {
    ...
}
```

The parallelGroup property of an actor points to the group it belongs to. It by default points to the which is Actors.defaultActorPGroup, and can only be changed before the actor is started.
class MyActor extends StaticDispatchActor<Integer> {  
    private static PGroup group = new DefaultPGroup(100)  
    MyActor(...) {  
        this.parallelGroup = group  
    }  
}

The actors belonging to the same group share the underlying thread pool of that group. The pc \( n + 1 \) threads, where \( n \) stands for the number of CPUs detected by the JVM. The pool size can either by setting the \( gpars.poolsize \) system property or individually for each actor group by specific constructor parameter.

def myGroup = new DefaultPGroup(10)  //the pool will contain 10 threads

The thread pool can be manipulated through the appropriate DefaultPGroup class, which delega interface of the thread pool. For example, the resize() method allows you to change the pool size resetDefaultSize() sets it back to the default value. The shutdown() method can be called when y finish all tasks, destroy the pool and stop all the threads in order to exit JVM in an organized man

As an alternative to the DefaultPGroup, which creates a pool of daemon threads, the NonDaemonGroup used when non-daemon threads are required.

def daemonGroup = new DefaultPGroup()  
def actor1 = daemonGroup.actor {  
    _  
}  
def nonDaemonGroup = new NonDaemonPGroup()  
def actor2 = nonDaemonGroup.actor {  
    _  
}  

class MyActor {  
    def MyActor() {  
        this.parallelGroup = nonDaemonGroup  
    }  
    void act() {...}  
}

Actors belonging to the same group share the underlying thread pool. With pooled actor group: actors to leverage multiple thread pools of different sizes and so assign resources to different com system and tune their performance.
def coreActors = new NonDaemonPGroup(5)  //5 non-daemon threads pool
def helperActors = new DefaultPGroup(1)  //1 daemon thread pool
def priceCalculator = coreActors.actor {
}
def paymentProcessor = coreActors.actor {
}
def emailNotifier = helperActors.actor {
}
def cleanupActor = helperActors.actor {
}
//increase size of the core actor group
coreActors.resize 6

//shutdown the group's pool once you no longer need the group to release resources
helperActors.shutdown()

Do not forget to shutdown custom pooled actor groups, once you no longer need them and their system resources.

The default actor group

Actors that didn't have their parallelGroup property changed or that were created through any of the Actors class share a common group Actors.defaultActorPGroup. This group uses a resizeAt an upper limit of 1000 threads. This gives you the comfort of having the pool automatically adjust actors. On the other hand, with a growing number of actors the pool may become too big and inefficient. It is advisable to group your actors into your own PGroups with fixed size thread pools for all but trivial applications.

Common trap: App terminates while actors do not receive messages

Most likely you're using daemon threads and pools, which is the default setting, and your main thread.join() on any, some or all of your actors would block the main thread until the actor terminates your actors running. Alternatively use instances of NonDaemonPGroup and assign some of your groups.

alternatively

```
def nonDaemonGroup = new NonDaemonPGroup()
def myActor = nonDaemonGroup.actor [...]```

Blocking Actors
Instead of event-driven continuation-styled actors, you may in some scenarios prefer using blocking actors. Blocking actors hold a single pooled thread for their whole life-time including the time when waiting for messages, some of the thread management overhead, since they never fight for threads after start, and also straight code without the necessity of continuation style, since they only do blocking message read method. Obviously the number of blocking actors running concurrently is limited by the number of the shared pool. On the other hand, blocking actors typically provide better performance compared to continuations actors, especially when the actor’s message queue rarely gets empty.

```groovy
def decryptor = blockingActor {
    while (true) { 
        receive { message ->
            if (message instanceof String) reply message.reverse()
            else stop()
        }
    }
}
def console = blockingActor {
    decryptor.send 'lellarap si yvoorG'
    println 'Decrypted message: ' + receive()
    decryptor.send false
}
[decryptor, console]*.join()
```

Blocking actors increase the number of options to tune performance of your applications. They make good candidates for high-traffic positions in your actor network.

5.2 Stateless Actors

Dynamic Dispatch Actor

The `DynamicDispatchActor` class is an actor allowing for an alternative structure of the message handling code. In general `DynamicDispatchActor` repeatedly scans for messages and dispatches arrived message: `onMessage(message)` methods defined on the actor. The `DynamicDispatchActor` leverages the method dispatch mechanism under the covers. Since, unlike `DefaultActor` descendants, a `DynamicDispatchActor` (discussed below) do not need to implicitly remember actor’s state between subsequent message receptions, they provide much better performance characteristics, generally comparable to other e.g. Scala Actors.

```groovy
import groovyx.gpars.actor.Actors
import groovyx.gpars.actor.DynamicDispatchActor
final class MyActor extends DynamicDispatchActor {
    void onMessage(String message) {
        println 'Received string'
    }
    void onMessage(Integer message) {
        println 'Received integer', reply 'Thanks!'
    }
    void onMessage(Object message) {
        println 'Received object', sender.send 'Thanks!'
    }
    void onMessage(List message) {
        println 'Received list', stop()
    }
}
final def myActor = new MyActor().start()
Actors.actor {
    myActor 1
    myActor *
    myActor 1.0
    myActor(new ArrayList())
    myActor.join()}.join()
```
In some scenarios, typically when no implicit conversation-history-dependent state needs to be preserved for the actor, the dynamic dispatch code structure may be more intuitive than the traditional one using nested if statements.

The `DynamicDispatchActor` class also provides a handy facility to add message handlers dynamically at construction time or any time later using the `when` handlers, optionally wrapped inside a `become` statement:

```java
final Actor myActor = new DynamicDispatchActor().become {
    when (String msg -> println 'A String'; reply 'Thanks')
    when (Double msg -> println 'A Double'; reply 'Thanks')
    when (msg -> println 'A something ...'; reply 'What was that?'; stop())
}
myActor.start()
Actors.actor {
    myActor 'Hello'
    myActor 1.0d
    myActor 10 as BigDecimal
    myActor.join()
}.join()
```

Obviously the two approaches can be combined:

```java
final class MyDDA extends DynamicDispatchActor {
    void onMessage(String message) {
        println 'Received string'
    }
    void onMessage(Integer message) {
        println 'Received integer'
    }
    void onMessage(Object message) {
        println 'Received object'
    }
    void onMessage(List message) {
        println 'Received list'
        stop()
    }
}

final def myActor = new MyDDA().become {
    when (BigDecimal num -> println 'Received BigDecimal')
    when (Float num -> println 'Got a float')
}.start()
Actors.actor {
    myActor 'Hello'
    myActor 1.0f
    myActor 10 as BigDecimal
    myActor.send([])
    myActor.join()
}.join()
```

The dynamic message handlers registered via `when` take precedence over the static `onMessage`.

**DynamicDispatchActor** can be set to behave in a fair or non-fair (default) manner. Depending on the strategy chosen, the actor either makes the thread available to other actors sharing the same parallel group (fair), or keeps the thread for itself until the message queue gets empty (non-fair). Generally, non-fair actors perform 2 - 3 times better than fair ones.

Use either the `fairMessageHandler()` factory method or the actor's `makeFair()` method:

```java
def fairActor = Actors.fairMessageHandler {...}
```

**Static Dispatch Actor**
While DynamicDispatchActor dispatches messages based on their run-time type and so pays extra performance penalty for each message, StaticDispatchActor avoids run-time message checks and dispatches based on the compile-time information.

```java
final class MyActor extends StaticDispatchActor<String> {
    void onMessage(String message) {
        println 'Received string ' + message
        switch (message) {
            case 'hello':
                reply 'Hi!
                break
            case 'stop':
                stop()
        }
    }
}
```

Instances of StaticDispatchActor have to override the onMessage method appropriate for the actor's declared type. The onMessage(T message) method is then invoked with every received message.

A shorter route towards both fair and non-fair static dispatch actors is available through the helper methods:

```java
final actor = staticMessageHandler {
    message ->
        println 'Received string ' + message
        switch (message) {
            case 'hello':
                reply 'Hi!
                break
            case 'stop':
                stop()
        }
    }
    println 'Reply: ' + actor.sendAndWait('hello')
    actor 'bye'
    actor 'stop'
    actor.join()
```

Although when compared to DynamicDispatchActor the StaticDispatchActor class is limited to a single handler method, the simplified creation without any when handlers plus the considerable performance benefits should make it your default choice for straightforward message handlers, when dispatching based on message run-time type is not necessary. For example, StaticDispatchActors make dataflow operators four times faster compared to when using DynamicDispatchActor.

**Reactive Actor**

The ReactiveActor class, constructed typically by calling Actors.reactor() or DefaultPGroup.reactor(), allow for more event-driven like approach. When a reactive actor receives a message, the supplied block of code making up the reactive actor’s body, is run with the message as a parameter. The result returned from the code
Here’s an example of an actor, which submits a batch of numbers to a `ReactiveActor` for processing and then prints the results gradually as they arrive.

```groovy
import groovy.gpars.actor.Actor
import groovy.gpars.actor.Actors
final def doubler = Actors.reactor {
    final 2 * it
}
Actor actor = Actors.actor {
    (1..10).each {doubler << it}
    i = 0
    loop {
        i += 1
        if (i > 10) stop()
        else {
            react {message ->
                println "Double of $i = $message"
                println "of $i = ${doubler.sendAndWait(i)}"
            }
        }
    }
}
actor.join()
doubler.stop()
doubler.join()
```

Essentially reactive actors provide a convenience shortcut for an actor that would wait for messages, process them, and send back the result. This is schematically how the reactive actor looks inside:

```groovy
public class ReactiveActor extends DefaultActor {
    Closure body
    void act() {
        loop {
            react {message ->
                reply body(message)
            }
        }
    }
}
```

`ReactiveActor` can be set to behave in a fair on non-fair (default) manner. Depending on the strategy chosen, the actor either makes the thread available to other actors sharing the parallel group (fair), or keeps the thread for itself until the message queue gets empty. Generally, non-fair actors perform 2 - 3 times better than fair ones. Use either the `fairReactor()` factory method or the actor’s `makeFair()` method.
5.3 Tips and Tricks

Structuring actor’s code

When extending the DefaultActor class, you can call any actor’s methods from within the act() method and use the react() or loop() methods in them.

```java
class MyDemoActor extends DefaultActor {
    protected void act() {
        handleA()
    }
    private void handleA() {
        react {a ->
            handleB(a)
        }
    }
    private void handleB(int a) {
        react {b ->
            println a + b
            reply a + b
        }
    }
    final def demoActor = new MyDemoActor()
    demoActor.start()
    Actors.actor {
        demoActor 10
        demoActor 20
        react {
            println "Result: $it"
        }
    }.join()
}
```

Bear in mind that the methods handleA() and handleB() in all our examples will only schedule the handlers to run as continuations of the current calculation in reaction to the next message arriving.

Alternatively, when using the actor() factory method, you can add event-handling code through the closures.

```java
Actor demoActor = Actors.actor {
    delegate.metaClass {
        handleA = {a ->
            react {a ->
                handleB(a)
            }
        }
        handleB = {a ->
            react {b ->
                println a + b
                reply a + b
            }
        }
        handleA()
    }
    Actors.actor {
        demoActor 10
        demoActor 20
        react {
            println "Result: $it"
        }
    }.join()
}
```

Closures, which have the actor set as their delegate can also be used to structure event-handling...
Closure handleB = {a ->
  react {b ->
    println a + b
    reply a + b
  }
}

Closure handleA = { ->
  react {a ->
    handleB(a)
  }
}

Actor demoActor = Actors.actor {
  handleA.delegate = delegate
  handleB.delegate = delegate
  handleA()
}

Actors.actor {
  demoActor 10
  demoActor 20
  react {
    println "Result: $it"
  }
}.join()

Event-driven loops

When coding event-driven actors you have to have in mind that calls to `react()` and `loop()` methods have slightly different semantics. This becomes a bit of a challenge once you try to implement any types of loops. On the other hand, if you leverage the fact that `react()` only schedules a continuation and returns, you can call methods recursively without fear to fill up the stack. Look at the examples below, which respectively use the three described techniques for structuring actor's code.

A subclass of `DefaultActor`

class MyLoopActor extends DefaultActor {
  protected void act() {
    outerLoop()
  }

  private void outerLoop() {
    react {a ->
      println 'Outer: ' + a
      if (a != 0) innerLoop()
      else println 'Done'
    }
  }

  private void innerLoop() {
    react {b ->
      println 'Inner: ' + b
      if (b == 0) outerLoop()
      else innerLoop()
    }
  }
}

def actor = new MyLoopActor().start()
actor 10
actor 20
actor 0
actor 0
actor.join()

Enhancing the actor's metaClass
Actor actor = Actors.actor {
    delegate.metaClass {
        outerLoop = {a ->
            react {a ->
                println 'Outer: ' + a
                if (a!=0) innerLoop()
                else println 'Done'
            }
        }
        innerLoop = {b ->
            println 'Inner ' + b
            if (b==0) outerLoop()
            else innerLoop()
        }
    }
    outerLoop()
}
actor 10
actor 20
actor 0
actor 0
actor.join()

Using Groovy closures

Closure innerLoop
Closure outerLoop = {a ->
    react {a ->
        println 'Outer: ' + a
        if (a!=0) innerLoop()
        else println 'Done'
    }
}
innerLoop = {b ->
    react {b ->
        println 'Inner ' + b
        if (b==0) outerLoop()
        else innerLoop()
    }
}
Actor actor = Actors.actor {
    outerLoop.delegate = delegate
    innerLoop.delegate = delegate
    outerLoop()
}
actor 10
actor 20
actor 0
actor 0
actor.join()

Plus don't forget about the possibility to use the actor’s loop() method to create a loop that runs until it terminates.
class MyLoopingActor extends DefaultActor {

    protected void act() {
        loop {
            outerLoop()
        }
    }

    private void outerLoop() {
        react {a ->
            println 'Outer: ' + a
            if (a != 0) innerLoop()
            else println 'Done for now, but will loop again'
        }
    }

    private void innerLoop() {
        react {b ->
            println 'Inner ' + b
            if (b == 0) outerLoop()
            else innerLoop()
        }
    }
}

final def actor = MyLoopingActor().start()
actor 10
actor 20
actor 0
actor 10
actor.stop()
actor.join()

5.4 Active Objects

Active objects provide an OO facade on top of actors, allowing you to avoid dealing directly with having to match messages, wait for results and send replies.

Actors with a friendly facade

import groovyx.gpars.activeobject.ActiveObject
import groovyx.gpars.activeobject.ActiveMethod
@ActiveObject
class Decryptor {
    @ActiveMethod
    def decrypt(String encryptedText) {
        return encryptedText.reverse()
    }
}

@ActiveMethod
definition Decryptor decrypt(int encryptedNumber) {
    return -1 * encryptedNumber + 142
}

final Decryptor decryptor = new Decryptor()
def part1 = decryptor.decrypt('noitcA ni yvoorG')
def part2 = decryptor.decrypt(140)
def part3 = decryptor.decrypt('noitide dn')
print part1.get()
print part2.get()
print part3.get()

You mark active objects with the @ActiveObject annotation. This will ensure a hidden actor instance of your class. Now you can mark methods with the @ActiveMethod annotation indicating the method to be invoked asynchronously by the target object's internal actor. An optional boolean b the @ActiveMethod annotation specifies, whether the caller should block until a result is available or whether the caller should only receive a promise for a future result in a form of a DataflowVariable and so be blocked waiting.

⚠️ By default, all active methods are set to be non-blocking. However, methods, which their return type explicitly, must be configured as blocking, otherwise the compiler will error. Only def, void and DataflowVariable are allowed return types for non-blocking
Under the covers, GPars will translate your method call to a **message being sent to the internal actor** eventually handle that message by invoking the desired method on behalf of the caller and once sent back to the caller. Non-blocking methods return promises for results, aka **DataflowVariables**

**But blocking means we're not really asynchronous, are we?**

Indeed, if you mark your active methods as **blocking**, the caller will be blocked waiting for the result doing normal plain method invocation. All we’ve achieved is being thread-safe inside the Active object access. Something the **synchronized** keyword could give you as well. So it is the **non-blocking** that drive your decision towards using active objects. Blocking methods will then provide the usual sync yet give the consistency guarantees across concurrent method invocations. The blocking method is useful when used in combination with non-blocking ones.

```groovy
import groovyx.gpars.activeobject.ActiveMethod
import groovyx.gpars.activeobject.ActiveObject
import groovyx.gpars.dataflow.DataflowVariable

@ActiveObject
class Decryptor {
    @ActiveMethod(blocking=true)
    String decrypt(String encryptedText) {
        encryptedText.reverse()
    }

    @ActiveMethod(blocking=true)
    Integer decrypt(Integer encryptedNumber) {
        -1*encryptedNumber + 142
    }
}

final Decryptor decryptor = new Decryptor()
print decryptor.decrypt(' noitcA ni yvoorG')
println decryptor.decrypt(140)
```

**Non-blocking semantics**

Now calling the non-blocking active method will return as soon as the actor has been sent a message and is now allowed to do whatever he likes, while the actor is taking care of the calculation. The state of the computation can be polled using the **bound** property on the promise. Calling the `get()` method on the returned promise will block the caller until a value is available. The call to `get()` will eventually return a value or throw an exception, depending on the outcome of the actual calculation.

⚠ **The `get()` method has also a variant with a timeout parameter, if you want to avoid the caller waiting indefinitely.**

**Annotation rules**

There are a few rules to follow when annotating your objects:
1. The `ActiveMethod` annotations are only accepted in classes annotated as `ActiveObject`.
2. Only instance (non-static) methods can be annotated as `ActiveMethod`.
3. You can override active methods with non-active ones and vice versa.
4. Subclasses of active objects can declare additional active methods, provided they are themselves annotated as `ActiveObject`.
5. Combining concurrent use of active and non-active methods may result in race conditions. Ideally design your active objects as completely encapsulated classes with all non-private methods marked as `ActiveMethod`.

### Inheritance

The `@ActiveObject` annotation can appear on any class in an inheritance hierarchy. The actor field in the top-most annotated class in the hierarchy, the subclasses will reuse the field.

```groovy
import groovyx.gpars.activeobject.ActiveObject
import groovyx.gpars.activeobject.ActiveMethod
import groovyx.gpars.dataflow.DataflowVariable

@ActiveObject
class A {
    @ActiveMethod
def fooA(value) {
        ...
    }
}

class B extends A {
    ...
}

@ActiveObject
class C extends B {
    @ActiveMethod
def fooC(value1, value2) {
        ...
    }
}
```

In our example the actor field will be generated into class `A`. Class `C` has to be annotated with `@ActiveObject` as it holds the `@ActiveMethod` annotation on method `fooC()`, while class `B` does not need the annotation since none of its methods is active.

### Groups

Just like actors can be grouped around thread pools, active objects can be configured to use threads from particular parallel groups.

```groovy
@ActiveObject("group1")
class MyActiveObject {
    ...
}
```

The `value` parameter to the `@ActiveObject` annotation specifies a name of parallel group to bind. Only threads from the specified group will be used to run internal actors of instances of the class. The groups need to be created and registered prior to creation of any of the active object instances belonging to that group. If not specified explicitly, an active object will use the default actor group - `Actors.defaultActorPGroup`.

```groovy
final DefaultPGroup group = new DefaultPGroup(10)
ActiveObjectRegistry.instance.register("group1", group)
```
Alternative names for the internal actor

You will probably only rarely run into name collisions with the default name for the active object's internalActiveObjectActor, use the actorName param @ActiveObject annotation.

```java
@ActiveObject(actorName = "alternativeActorName")
class MyActiveObject {
    ...
}
```

Alternative names for internal actors as well as their desired groups cannot be overridden in subclasses. Make sure you only specify these values in the top-most active objects in the inheritance hierarchy. Obviously, the top most active object is still allowed to subclass other classes, just none of the predecessors must be an active object.

5.5 Classic Examples

A few examples on Actors use

Examples

- The Sieve of Eratosthenes
- Sleeping Barber
- Dining Philosophers
- Word Sort
- Load Balancer

The Sieve of Eratosthenes

Problem description
import groovyx.gpars.actor.DynamicDispatchActor
/**
 * Demonstrates concurrent implementation of the Sieve of Eratosthenes using actors
 * In principle, the algorithm consists of concurrently run chained filters,
 * each of which detects whether the current number can be divided by a single prime number.
 * (generate nums 1, 2, 3, 4, 5, ...) -> (filter by mod 2) -> (filter by mod 3) -> (filter by mod 5) -> (filter
 * by mod 11) -> (caution! Primes falling out here)
 * The chain is built (grown) on the fly, whenever a new prime is found.
 */

requestedPrimeNumberBoundary = 1000
final def firstFilter = new FilterActor(2).start()
/**
 * Generating candidate numbers and sending them to the actor chain
 */
(2..requestedPrimeNumberBoundary).each {
    firstFilter it
} firstFilter.sendAndWait 'Poison'
/**
 * Filter out numbers that can be divided by a single prime number
 */
final class FilterActor extends DynamicDispatchActor {
    final int myPrime
    private def follower
    def FilterActor(final myPrime) { this.myPrime = myPrime; }
    /**
     * Try to divide the received number with the prime. If the number cannot be divided, send it along the ch
     * If there's no-one to send it to, I'm the last in the chain, the number is a prime and so I will create
     * a new actor responsible for filtering by this newly found prime number.
     */ def onMessage(int value) {
        if (value % myPrime != 0) {
            if (follower) follower value
            else {
                println "Found $value"
                follower = new FilterActor(value).start()
            }
        } } /**
     * Stop the actor on poisson reception
     */
    def onMessage(def poisson) {
        follower.sendAndContinue(poisson, {
            if (follower) follower value
            else {
                //I am the last in the chain
                stop()
            } reply 'Done'
        })
    }
}

import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.actor.DefaultActor
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.actor.Actor
final def group = new DefaultPGroup()
final def barber = group.actor {
    final def random = Random()
    final loop {
        react {message ->
            switch (message) {
                case Enter:
                    message.customer.send new Start()
                    println "Barber: Processing customer ${message.customer.name}"
                    doTheWork(random)
                    message.customer.send new Done()
                    reply new Next()
                    break
                case Wait:
                    println "Barber: No customers. Going to have a sleep"
                    break
            }
        }
    }
}

Sleeping Barber

Problem description
private def doTheWork(Random random) {
    Thread.sleep(random.nextInt(10) * 1000)
}

final Actor waitingRoom

waitingRoom = group.actor {
    final int capacity = 5
    final List<Customer> waitingCustomers = []
    boolean barberAsleep = true

    loop {
        react {message ->
            switch (message) {
                case Enter:
                    if (waitingCustomers.size() == capacity) {
                        reply new Full()
                    } else {
                        waitingCustomers << message.customer
                        if (barberAsleep) {
                            assert waitingCustomers.size() == 1
                            barberAsleep = false
                            waitingRoom.send new Next()
                        } else reply new Wait()
                    }
                break
                case Next:
                    if (waitingCustomers.size()>0) {
                        def customer = waitingCustomers.remove(0)
                        barber.send new Enter(customer:customer)
                    } else barber.send new Wait()
                    barberAsleep = true
            }
        }
    }
}

class Customer extends DefaultActor {
    String name
    Actor localBarbers

    void act() {
        localBarbers << new Enter(customer:this)
        loop {
            react {message ->
                switch (message) {
                    case Full:
                        println "Customer: $name: The waiting room is full. I am leaving."
                        stop()
                    break
                    case Wait:
                        println "Customer: $name: I will wait."
                        break
                    case Start:
                        println "Customer: $name: I am now being served."
                        break
                    case Done:
                        println "Customer: $name: I have been served."
                        stop();
                        break
                }
            }
        }
    }
}

class Enter { Customer customer }
class Full {} class Wait {} class Next {} class Start {} class Done {}

def customers = []
customers << new Customer(name:'Joe', localBarbers:waitingRoom).start()
customers << new Customer(name:'Dave', localBarbers:waitingRoom).start()
customers << new Customer(name:'Alice', localBarbers:waitingRoom).start()
sleep 15000

customers << new Customer(name: 'James', localBarbers: waitingRoom).start()
sleep 5000

customers*.join()
barber.stop()
waitingRoom.stop()
import groovyx.gpars.actor.DefaultActor
import groovyx.gpars.actor.Actors
Actors.defaultActorPGroup.resize 5

final class Philosopher extends DefaultActor {
  private Random random = new Random()

  String name
  def forks = []

  void act() {
    assert 2 == forks.size()
    loop {
      think()
      forks*.send new Take()
      def messages = []
      react {a ->
        messages << [a, sender]
        react {b ->
          messages << [b, sender]
          if ((a, b).any {Rejected.isCase it}) {
            println "$name: tOops, can't get my forks! Giving up.
            final def accepted = messages.find {Accepted.isCase it[0]}
            if (accepted != null) accepted[1].send new Finished()
          } else {
            eat()
            reply new Finished()
            new
          }
        }
      }
    }
  }

  void think() {
    println "$name: tI'm thinking"
    Thread.sleep random.nextInt(3000)
    println "$name: tI'm done thinking"
  }

  void eat() {
    println "$name: tI'm EATING"
    Thread.sleep random.nextInt(2000)
    println "$name: tI'm done EATING"
  }
}

final class Fork extends DefaultActor {
  String name
  boolean available = true

  void act() {
    loop {
      react {message ->
        switch (message) {
          case Take:
            if (available) {
              available = false
              reply new Accepted()
            } else reply new Rejected()
            break
          case Finished:
            assert !available
            available = true
            break
          default: throw new IllegalStateException("Cannot process the message: $message")
        }
      }
    }
  }
}

final class Take {}
final class Accepted {}
final class Rejected {}
final class Finished {}

def forks = [
  new Fork(name:'Fork 1'),
  new Fork(name:'Fork 2'),
  new Fork(name:'Fork 3'),
  new Fork(name:'Fork 4'),
  new Fork(name:'Fork 5')
]

def philosophers = [
  new Philosopher(name:'Joe', forks:[forks[0], forks[1]]),
  new Philosopher(name:'Dave', forks:[forks[1], forks[2]]),
  new Philosopher(name:'Alice', forks:[forks[2], forks[3]]),
  new Philosopher(name:'James', forks:[forks[3], forks[4]]),
  new Philosopher(name:'Phil', forks:[forks[4], forks[0]])
]

forks*.start()
philosophers*.start()
sleep 10000
forks*.stop()
philosophers*.stop()}
Word sort

Given a folder name, the script will sort words in all files in the folder. The `SortMaster` actor creates `WordSortActors`, splits among them the files to sort words in and collects the results.

Inspired by Scala Concurrency blog post by Michael Galpin
Load Balancer

Demonstrates work balancing among adaptable set of workers. The load balancer receives tasks temporary task queue. When a worker finishes his assignment, it asks the load balancer for a ne
If the load balancer doesn't have any tasks available in the task queue, the worker is stopped. If the task queue exceeds certain limit, a new worker is created to increase size of the worker pool.
import groovyx.gpars.actor.Actor
import groovyx.gpars.actor.DefaultActor

/**
 * Demonstrates work balancing among adaptable set of workers.
 * The load balancer receives tasks and queues them in a temporary task queue.
 * When a worker finishes his assignment, it asks the load balancer for a new task.
 * If the load balancer doesn't have any tasks available in the task queue, the worker is stopped.
 * If the number of tasks in the task queue exceeds certain limit, a new worker is created
 * to increase size of the worker pool.
 */

final class LoadBalancer extends DefaultActor {
  int workers = 0
  List taskQueue = []
  private static final QUEUE_SIZE_TRIGGER = 10

  void act() {
    loop {
      react { message ->
        switch (message) {
          case NeedMoreWork:
            if (taskQueue.size() == 0) {
              println 'No more tasks in the task queue. Terminating the worker.'
              reply DemoWorker.EXIT
              workers -= 1
            } else reply taskQueue.remove(0)
            break
          case WorkToDo:
            taskQueue << message
            if ((workers == 0) || (taskQueue.size() >= QUEUE_SIZE_TRIGGER)) {
              println 'Need more workers. Starting one.'
              workers += 1
              new DemoWorker(this).start()
            }
        }
        println "Active workers=${workers}tTasks in queue=${taskQueue.size()}"
      }
    }
  }
}

final class DemoWorker extends DefaultActor {
  final EXIT = ()
  final static Object new Object()
  private static final Random random = Random()

  Actor balancer
  def DemoWorker(balancer) {
    this.balancer = balancer
  }

  void act() {
    loop {
      this.balancer << new NeedMoreWork()
      react {
        switch (it) {
          case WorkToDo:
            processMessage(it)
            break
          case EXIT: terminate()
        }
      }
    }
  }

  private void processMessage(message) {
    synchronized (random) {
      Thread.sleep random.nextInt(5000)
    }
  }
}

final class WorkToDo {}
final class NeedMoreWork {}
final Actor balancer = new LoadBalancer().start()

//produce tasks
for (i in 1..20) {
  Thread.sleep 100
  balancer << new WorkToDo()
}

//produce tasks in a parallel thread
Thread.start {
  for (i in 1..10) {
    Thread.sleep 1000
    balancer << new WorkToDo()
  }
}

Thread.sleep 35000  //let the queues get empty
balancer << new WorkToDo()
balancer << new WorkToDo()
Thread.sleep 10000
balancer.stop()
balancer.join()
6 Agents

The Agent class, which is a thread-safe non-blocking shared mutable state wrapper implementat in Clojure.

A lot of the concurrency problems disappear when you eliminate the need for Shared State with your architecture. Indeed, concepts like actors, CSP or dataflow concurren or isolate mutable state completely. In some cases, however, sharing mutable data is inevitable or makes the design more natural and understandable. Think, for example, shopping cart in a typical e-commerce application, when multiple AJAX requests may cart with read or write requests concurrently.

Introduction

In the Clojure programing language you can find a concept of Agents, the purpose of which is to that need to be shared across threads. Agents hide the data and protect it from direct access. Cli commands (functions) to the agent. The commands will be serialized and processed against the turn. With the commands being executed serially the commands do not need to care about conci assume the data is all theirs when run. Although implemented differently, GPars Agents, called Agent behave like actors. They accept messages and process them asynchronously. The messages, h- commands (functions or Groovy closures) and will be executed inside the agent. After reception I run against the internal state of the Agent and the return value of the function is considered to be of the Agent.

Essentially, agents safe-guard mutable values by allowing only a single agent-managed thread to them. The mutable values are not directly accessible from outside, but instead requests have at agent and the agent guarantees to process the requests sequentially on behalf of the callers. Ag sequential execution of all requests and so consistency of the values.

Schematically:

```java
agent = new Agent(0)  //created a new Agent wrapping an integer with initial value 0
agent.send {increment()}  //asynchronous send operation, sending the increment() function
//after some delay to process the message the internal Agent’s state has been updated
assert agent.val == 1
```

To wrap integers, we can certainly use AtomicXXX types on the Java platform, but when the stat- object we need more support.

Concepts

GPars provides an Agent class, which is a special-purpose thread-safe non-blocking implementa Agents in Clojure.

An Agent wraps a reference to mutable state, held inside a single field, and accepts code (closur messages, which can be sent to the Agent just like to any other actor using the '<<' operator, the implicit call() method. At some point after reception of a closure / command, the closure is invoke mutable field and can make changes to it. The closure is guaranteed to be run without interventic and so may freely alter the internal state of the Agent held in the internal data field.
The whole update process is of the fire-and-forget type, since once the message (closure) is sent to the Agent, the caller thread can go off to do other things and come back later to check the current value with `Agent.valAsync(closure)`.

**Basic rules**

- When executed, the submitted commands obtain the agent's state as a parameter.
- The submitted commands /closures can call any methods on the agent's state.
- Replacing the state object with a new one is also possible and is done using the `updateValue()` method.
- The return value of the submitted closure doesn't have a special meaning and is ignored.
- If the message sent to an `Agent` is not a closure, it is considered to be a new value for the
- The val property of an `Agent` will wait until all preceding commands in the agent's queue are safely return the value of the Agent.
- The `valAsync()` method will do the same without blocking the caller.
- The `instantVal` property will return an immediate snapshot of the internal agent's state.
- All Agent instances share a default daemon thread pool. Setting the `threadPool` property of an `Agent` will allow it to use a different thread pool.
- Exceptions thrown by the commands can be collected using the `errors` property.

**Examples**

**Shared list of members**

The Agent wraps a list of members, who have been added to the jug. To add a new member a member (add a member) has to be sent to the `jugMembers` Agent.

```groovy
import groovyx.gpars.agent.Agent
import java.util.concurrent.ExecutorService
import java.util.concurrent.Executors
/**
 * Create a new Agent wrapping a list of strings
 */
def jugMembers = new Agent<List<String>>(['Me']) //add Me
jugMembers.send {it.add 'James'} //add James

final Thread t1 = Thread.start {
  jugMembers.send {it.add 'Joe'} //add Joe
}

final Thread t2 = Thread.start {
  jugMembers << {it.add 'Dave'} //add Dave
  jugMembers {it.add 'Alice'} //add Alice (using the implicit call() method)
}

[t1, t2]*.join()
println jugMembers.val
jugMembers.valAsync {println "Current members: $it"}
jugMembers.await()
```

**Shared conference counting number of registrations**

The Conference class allows registration and un-registration, however these methods can only be called from the commands sent to the `conference` Agent.
import groovyx.gpars.agent.Agent

/**
 * Conference stores number of registrations and allows parties to register and unregister.
 * It inherits from the Agent class and adds the register() and unregister() private methods,
 * which callers may use it the commands they submit to the Conference.
 */

class Conference extends Agent<Long> {
    def Conference() { super() }
    private def register(long num) { data += num }
    private long def unregister(long num) { data -= num }
}

final Agent conference = new Conference() //new Conference created

/**
 * Three external parties will try to register/unregister concurrently
 */

final Thread t1 = Thread.start {
   conference << {register(10L)}               //send a command to register 10 attendees
}
final Thread t2 = Thread.start {
   conference << {register(5L)}                //send a command to register 5 attendees
}
final Thread t3 = Thread.start {
   conference << {unregister(3L)}              //send a command to unregister 3 attendees
}
[t1, t2, t3]*.join()
assert 12L == conference.val

Factory methods
Agent instances can also be created using the Agent.agent() factory method.

def jugMembers = Agent.agent ['Me']  //add Me

Listeners and validators
Agents allow the user to add listeners and validators. While listeners will get notified each time th changes, validators get a chance to reject a coming change by throwing an exception.

final Agent counter = new Agent()
counter.addListener {oldValue, newValue -> println "Changing value from $oldValue to $newValue"}
counter.addListener {agent, oldValue, newValue -> println "Agent $agent changing value from $oldValue to $newValue"}
counter.addValidator {oldValue, newValue -> oldValue > newValue} {IllegalArgumentException('Things can only go up in if throw new Groovy')}
counter.addValidator {agent, oldValue, newValue -> oldValue == newValue} {IllegalArgumentException('Things never stay the same for $agent')}

Both listeners and validators are essentially closures taking two or three arguments. Exceptions thrown will be logged inside the agent and can be tested using the hasErrors() method or retrieved through the errors property.
Validator gotchas

With Groovy being not very strict on data types and immutability, agent users should be aware of the road. If the submitted code modifies the state directly, validators will not be able to un-do the validation rule violation. There are two possible solutions available:

1. Make sure you never change the supplied object representing current agent state
2. Use custom copy strategy on the agent to allow the agent to create copies of the internal sta

In both cases you need to call `updateValue()` to set and validate the new state properly.

The problem as well as both of the solutions are shown below:

```groovy
//Create an agent storing names, rejecting 'Joe'
final Closure rejectJoeValidator = {oldValue, newValue -> if ('Joe' in newValue) throw new IllegalArgumentException('Joe is not allowed to enter our list.'))
Agent agent = new Agent([])
agent.addValidator rejectJoeValidator
agent {it << 'Dave'}                    //Accepted
agent {it << 'Joe'}                     //Erroneously accepted, since by-passes the validation mechanism
println agent.val

//Solution 1 - never alter the supplied state object
agent = new Agent([])
agent.addValidator rejectJoeValidator
agent {updateValue(['Dave', * it])}      //Accepted
agent {updateValue(['Joe', * it])}       //Rejected
println agent.val

//Solution 2 - use custom copy strategy on the agent
agent = new Agent([], {it.clone()})
agent.addValidator rejectJoeValidator
agent {updateValue it << 'Dave'}        //Accepted
agent {updateValue it << 'Joe'}         //Rejected, since 'it' is now just a copy of the internal agent's stat
println agent.val
```

Grouping

By default all Agent instances belong to the same group sharing its daemon thread pool. Custom groups can also create instances of Agent. These instances will belong to the group, which will share a thread pool. To create an Agent instance belonging to a group, call the `agent()` factory method on the `group`. This way you can organize and tune performance of agents.

```groovy
final def group = new NonDaemonPGroup(5)  //create a group around a thread pool
def jugMembers = group.agent(['Me'])  //add Me
```

⚠️ The default thread pool for agents contains daemon threads. Make sure that your custom thread pools either use daemon threads, too, which can be achieved either by using `DefaultPGroup` or by providing your own thread factory to a thread pool constructor, or in case your thread pools use non-daemon threads, such as when using the `NonDaemonPGroup` group class, make sure you shutdown the group or the thread pool explicitly by calling `shutdown()` method, otherwise your applications will not exit.
Direct pool replacement

Alternatively, by calling the `attachToThreadPool()` method on an Agent instance a custom thread pool for it.

```java
def jugMembers = new Agent<List<String>>(['Me']) //add Me
final ExecutorService pool = Executors.newFixedThreadPool(10)
jugMembers.attachToThreadPool(new DefaultPool(pool))
```

⚠️ Remember, like actors, a single Agent instance (aka agent) can never use more than one thread at a time

The shopping cart example

```java
import groovyx.gpars.agent.Agent

class ShoppingCart {
    def cartState = Agent([:])

    ----- methods below here ----------------------------------
    public void addItem(product, quantity) {
        cartState << {it[product] = quantity} //the << operator sends
        //a message to the Agent
    }
    public void removeItem(String product) {
        cartState << {it.remove(product)}
    }
    public Object listContent() {
        return cartState.val
    }
    public void clearItems() {
        cartState << performClear
    }

    ----- methods below here ----------------------------------

    private void changeQuantity(product, quantityChange, Map items) {
        items[product] = (items[product] ?: 0) + quantityChange
    }
    private Closure performClear = { it.clear() }

    ----- script code below here ---------------------------------

    ShoppingCart cart = new ShoppingCart()
    cart.addItem 'Pilsner', 10
    cart.addItem 'Budweisser', 5
    cart.addItem 'Staropramen', 20
    cart.removeItem 'Budweisser'
    cart.addItem 'Budweisser', 15
    println "Contents ${cart.listContent()}
    cart.increaseQuantity 'Budweisser', 3
    println "Contents ${cart.listContent()}
    cart.clearItems()
    println "Contents ${cart.listContent()}
```

You might have noticed two implementation strategies in the code.

1. Public methods may internally just send the required code off to the Agent, instead of executing the functionality directly

And so sequential code like

```java
public void addItem(String product, int quantity) {
    cartState[product]=quantity
}
```

becomes
2. Public methods may send references to internal private methods or closures, which hold the desired functionality to perform

```java
public void clearItems() {
    cartState << performClear
}
private Closure performClear = { it.clear() }
```

Currying might be necessary, if the closure takes other arguments besides the current internal the `increaseQuantity` method.

**The printer service example**

Another example - a not thread-safe printer service shared by multiple threads. The printer needs document and quality properties set before printing, so obviously a potential for race conditions if Callers don't want to block until the printer is available, which the fire-and-forget nature of actors:

```java
import groovyx.gpars.agent.Agent
/**
 * A non-thread-safe service that slowly prints documents on at a time
 */
class PrinterService {
    String document
    String quality

    public void printDocument() {
        println "Printing $document in $quality quality"
        Thread.sleep 5000
        println "Done printing $document"
    }
}
def printer = new Agent<PrinterService>(new PrinterService())
final Thread thread1 = Thread.start {
    for (num in (1..3)) {
        final String text = "document $num"
        printer << {printerService ->
            printerService.document = text
            printerService.quality = 'High'
            printerService.printDocument()
        }
        Thread.sleep 200
    }
    println 'Thread 1 is ready to do something else. All print tasks have been submitted'
}
final Thread thread2 = Thread.start {
    for (num in (1..4)) {
        final String text = "picture $num"
        printer << {printerService ->
            printerService.document = text
            printerService.quality = 'Medium'
            printerService.printDocument()
        }
        Thread.sleep 500
    }
    println 'Thread 2 is ready to do something else. All print tasks have been submitted'
}
[thread1, thread2]*.join()
printer.await()
```

For latest update, see the respective Demos.

**Reading the value**
To follow the clojure philosophy closely the Agent class gives reads higher priority than to writes. The `instantVal` property your read request will bypass the incoming message queue of the Agent and snapshot of the internal state. The `val` property will wait in the message queue for processing, just variant `valAsync(Clojure cl)`, which will invoke the provided closure with the internal state as a parameter.

You have to bear in mind that the `instantVal` property might return although correct, but randomly looking results, since the internal state of the Agent at the time of `instantVal` execution is non-deterministic and depends that have been processed before the thread scheduler executes the body of `instantVal`.

The `await()` method allows you to wait for processing all the messages submitted to the Agent before calling thread.

**State copy strategy**

To avoid leaking the internal state the Agent class allows to specify a copy strategy as the second constructor argument. With the copy strategy specified, the internal state is processed by the copy strategy closure and the output value of the copy strategy value is returned to the caller instead of the actual internal state. This applies to `val` as well as to `valAsync()`.

**Error handling**

Exceptions thrown from within the submitted commands are stored inside the agent and can be fetched from the `errors` property. The property gets cleared once read.

```clojure
def jugMembers = new Agent<List>()
    assert jugMembers.errors.empty
    jugMembers.send {throw new IllegalStateException('test1')}
    jugMembers.send {throw new IllegalArgumentException('test2')}
    jugMembers.await()

List errors = jugMembers.errors
assert 2 == errors.size()
assert errors[0] instanceof IllegalStateException
assert 'test1' == errors[0].message
assert errors[1] instanceof IllegalArgumentException
assert 'test2' == errors[1].message
assert jugMembers.errors.empty
```

**Fair and Non-fair agents**

Agents can be either fair or non-fair. Fair agents give up the thread after processing each message and keep a thread until their message queue is empty. As a result, non-fair agents tend to perform better. The default setting for all Agent instances is to be non-fair, however by calling its `makeFair()` method the instance can be made fair.

```clojure
def jugMembers = new Agent<List>({:'Me'})  //add Me
    jugMembers.makeFair()
```
7 Dataflow

Dataflow concurrency offers an alternative concurrency model, which is inherently safe and robust.

Introduction

Check out the small example written in Groovy using GPars, which sums results of calculations performed by three concurrently run tasks:

```groovy
import static groovyx.gpars.dataflow.Dataflow.task

final def x = new DataflowVariable()
final def y = new DataflowVariable()
final def z = new DataflowVariable()

task {
    z << x.val + y.val
}
task {
    x << 10
}
task {
    y << 5
}

println "Result: $z.val"
```

Or the same algorithm rewritten using the `Dataflows` class.

```groovy
import static groovyx.gpars.dataflow.Dataflow.task

final def df = new Dataflows()

task {
    df.z = df.x + df.y
}
task {
    df.x = 10
}
task {
    df.y = 5
}

println "Result: $df.z"
```

We start three logical tasks, which can run in parallel and perform their particular activities. The tasks data and they do so using **Dataflow Variables**. Think of Dataflow Variables as one-shot channel transferring data from producers to their consumers.

The Dataflow Variables have a pretty straightforward semantics. When a task needs to read a value from a `DataflowVariable` (through the val property), it will block until the value has been set by another task or thread (using the `<<` operator). Each `DataflowVariable` can be set only once in its lifetime. Notice that you do not need to order and synchronizing the tasks or threads and their access to shared variables. The values transferred among tasks at the right time without your intervention. The data flow seamlessly among tasks / threads without your intervention or care.

**Implementation detail:** The three tasks in the example do not necessarily need to be mapped to three physical threads. Tasks represent so-called "green" or "logical" threads and can be mapped under the covers to any number of physical threads. The actual mapping depends on the scheduler, but the outcome of dataflow algorithms does not depend on the actual scheduling.
The \textit{bind} operation of dataflow variables silently accepts re-binding to a value, which is an already bound value. Call \textit{bindUnique} to reject equal values on already-bound variables.

## Benefits

Here's what you gain by using Dataflow Concurrency (by, \textit{Jonas Bonér}):

- No race-conditions
- No live-locks
- Deterministic deadlocks
- Completely deterministic programs
- BEAUTIFUL code.

This doesn't sound bad, does it?
Concepts

Dataflow programming

Quoting Wikipedia

Operations (in Dataflow programs) consist of "black boxes" with inputs and outputs, all of which are defined. They run as soon as all of their inputs become valid, as opposed to when the program encounters them. Whereas a traditional program essentially consists of a series of statements saying "do this, now do this" in sequence, a dataflow program is more like a series of workers on an assembly line, who will do their assigned task as soon as the materials arrive. This is why dataflow languages are inherently parallel; the operations have no hidden state to keep track of, and the operations are all "ready" at the same time.

Principles

With Dataflow Concurrency you can safely share variables across tasks. These variables (in Groovy instances of the DataflowVariable class) can only be assigned (using the ‘<<’ operator) a value once in their lifetime. The values of the DataflowVariable variables, on the other hand, can be read multiple times (in Groovy through the val property), even before the value has been assigned. In such cases the reading task is suspended until the value is set by another task. Write your code for each task sequentially using Dataflow Variables and the underlying mechanics will make sure you get all the values you need in a thread-safe manner.

In brief, you generally perform three operations with Dataflow variables:

- Create a dataflow variable
- Wait for the variable to be bound (read it)
- Bind the variable (write to it)

And these are the three essential rules your programs have to follow:

- When the program encounters an unbound variable it waits for a value.
- It is not possible to change the value of a dataflow variable once it is bound.
- Dataflow variables makes it easy to create concurrent stream agents.

Dataflow Queues and Broadcasts

Before you go to check the samples of using Dataflow Variables, Tasks and Operators, you should have a full picture of Dataflow Concurrency. Except for dataflow variables, there are also the concepts of DataflowQueues and DataflowBroadcast that you can leverage in your code. You may use thread-safe buffers or queues for message transfer among concurrent tasks or threads. Check out a typical producer-consumer demo:
import static groovyx.gpars.dataflow.Dataflow.task

def words = ['Groovy', 'fantastic', 'concurrency', 'fun', 'enjoy', 'safe', 'GPars', 'data', 'flow']
final def buffer = new DataflowQueue()

task { for (word in words) {
  buffer << word.toUpperCase() //add to the buffer
}
}
task { //read from the buffer in a loop
  while(true) println buffer.val
}

Both DataflowBroadcasts and DataflowQueues, just like DataflowVariables, implement the DataflowChannel interface with common methods allowing users to write to them and read values from them. The ability to treat both types identically through the DataflowChannel interface comes in handy once you start using them to wire selectors together.

The DataflowChannel interface combines two interfaces, each serving its purpose:
  ○ DataflowReadChannel holding all the methods necessary for reading values from a channel - getVal(), getValAsync(), whenBound(), etc.
  ○ DataflowWriteChannel holding all the methods necessary for writing values into a channel - bind(), <<

You may prefer using these dedicated interfaces instead of the general DataflowChannel interface, to better express the intended usage.

Please refer to the API doc for more details on the channel interfaces.

Point-to-point communication

The DataflowQueue class can be viewed as a point-to-point (1 to 1, many to 1) communication channel. One or more producers send messages to one reader. If multiple readers read from the same DataflowQueue, each consume different messages. Or to put it a different way, each message is consumed by exactly one reader. You can easily imagine a simple load-balancing scheme built around a shared DataflowQueue with readers being added dynamically when the consumer part of your algorithm needs to scale up. This is also a useful default choice when connecting tasks or operators.

Publish-subscribe communication

The DataflowBroadcast class offers a publish-subscribe (1 to many, many to many) communication model. One or more producers write messages, while all registered readers will receive all the messages. Each message is consumed by all readers with a valid subscription at the moment when the message is being written.

Please refer to the API doc for more details on the channel interfaces.
Under the hood `DataflowBroadcast` uses the `DataflowStream` class to implement the message delivery.

**DataflowStream**

The `DataflowStream` class represents a deterministic dataflow channel. It is built around the concept of a functional queue and so provides a lock-free thread-safe implementation for message passing. Essentially, `DataflowStream` as a 1 to many communication channel, since when a reader consumes a message, other readers will still be able to read the same message. Also, all messages arrive to all readers in the same order. It is implemented as a functional queue, its API requires that users traverse the values in the stream one way, as a `1` to many communication channel, since when a reader consumes a message, other readers will still be able to read the same message. Also, all messages arrive to all readers in the same order. On the other hand `DataflowStream` offers handy methods for value filtering or transformation together with interesting performance characteristics.

The `DataflowStream` class, unlike the other communication elements, does not implement the `DataflowChannel` interface, since the semantics of its use is different. Use `DataflowStreamReadAdapter` and `DataflowStreamWriteAdapter` classes to wrap instances of `DataflowChannel` class in `DataflowReadChannel` or `DataflowWriteChannel` implementations.

```groovy
import groovyx.gpars.dataflow.stream.DataflowStream
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.scheduler.ResizeablePool

/**
 * Demonstrates concurrent implementation of the Sieve of Eratosthenes using dataflow tasks
 * In principle, the algorithm consists of a concurrently run chained filters,
 * each of which detects whether the current number can be divided by a single prime number.
 * (generate nums 1, 2, 3, 4, 5, ...) -> (filter by mod 2) -> (filter by mod 3) -> (filter by mod 5) -> (filter by mod 11) ->
 * The chain is built (grown) on the fly, whenever a new prime is found
 *
 */

/**
 * We need a resizeable thread pool, since tasks consume threads while waiting blocked for values at DataflowQueue.val
 */

final int requestedPrimeNumberCount = 100

/**
 * Generating candidate numbers
 */

dataflowStream candidates = new DataflowStream()

group.task {
    candidates.generate(2, {it + 1}, {it < 1000})
}

/**
 * Chain a new filter for a particular prime number to the end of the Sieve
 * @param inChannel The current end channel to consume
 * @param prime The prime number to divide future prime candidates with
 * @return A new channel ending the whole chain
 */

def filter(DataflowStream inChannel, int prime) {
    inChannel.filter { number ->
        group.task {
            number % prime != 0
        }
    } return
}

/**
 * Consume Sieve output and add additional filters for all found primes
 */

def currentOutput = candidates

requestedPrimeNumberCount.times {
    int prime = currentOutput.first
    println "Found: $prime"
    currentOutput = filter(currentOutput, prime)
}
```
For convenience and for the ability to use DataflowStream with other dataflow constructs, like e.g. wrap it with DataflowReadAdapter for read access or DataflowWriteAdapter for write access. The stream is designed for single-threaded producers and consumers. If multiple threads are supposed to read the stream, their access to the stream must be serialized externally or the adapters should be used.

DataflowStream Adapters

Since the DataflowStream API as well as the semantics of its use are very different from the one Dataflow(Read/Write)Channel, adapters have to be used in order to allow DataflowStreams to be used with other dataflow elements. The DataflowStreamReadAdapter class will wrap a DataflowStream with necessary methods to read values, while the DataflowStreamWriteAdapter class will provide write methods around the DataflowStream.

It is important to mention that the DataflowStreamWriteAdapter is thread safe allowing multiple threads to add values to the wrapped DataflowStream through the adapter. On the other hand, DataflowStreamReadAdapter is designed to be used by a single thread.

To minimize the overhead and stay in-line with the DataflowStream semantics, the DataflowStreamReadAdapter class is not thread-safe and should only be used from within a single thread. If multiple threads need to read from a DataflowStream, they should each create their own wrapping DataflowStreamReadAdapter.

Thanks to the adapters DataflowStream can be used for communication between operators or selectors, which expect Dataflow(Read/Write)Channels:

```java
import groovyx.gpars.dataflow.DataflowQueue
import groovyx.gpars.dataflow.stream.DataflowStream
import groovyx.gpars.dataflow.stream.DataflowStreamReadAdapter
import groovyx.gpars.dataflow.stream.DataflowStreamWriteAdapter
import static groovyx.gpars.dataflow.DataflowSelector
import static groovyx.gpars.dataflow.DataflowOperator

/**
 * Demonstrates the use of DataflowStreamAdapters to allow dataflow operators to use DataflowStreams
 */

final DataflowStream a = new DataflowStream()
final DataflowStream b = new DataflowStream()
def aw = new DataflowStreamWriteAdapter(a)
def bw = new DataflowStreamWriteAdapter(b)
def ar = new DataflowStreamReadAdapter(a)
def br = new DataflowStreamReadAdapter(b)
def result = new DataflowQueue()
def op1 = operator(ar, bw) {
    bindOutput it
}
def op2 = selector([br], [result]) {
    result << it
}

aw << 1
aw << 2
aw << 3
assert([1, 2, 3] == [result.val, result.val, result.val])
op1.stop()
op2.stop()
op1.join()
op2.join()
```

Also the ability to select a value from multiple DataflowChannels can only be used through an ad

DataflowStream:
import groovyx.gpars.dataflow.Select
import groovyx.gpars.dataflow.stream.DataflowStream
import groovyx.gpars.dataflow.stream.DataflowStreamReadAdapter
import groovyx.gpars.dataflow.stream.DataflowStreamWriteAdapter
import static groovyx.gpars.dataflow.Dataflow.select
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * Demonstrates the use of DataflowStreamAdapters to allow dataflow select to select on DataflowStreams
 */

final DataflowStream a = new DataflowStream()
final DataflowStream b = new DataflowStream()
def aw = new DataflowStreamWriteAdapter(a)
def bw = new DataflowStreamWriteAdapter(b)
def ar = new DataflowStreamReadAdapter(a)
def br = new DataflowStreamReadAdapter(b)
final Select<?> select = select(ar, br)

Task task = { 
    aw << 1 
    aw << 2 
    aw << 3 
} 
assert 1 == select().value 
assert 2 == select().value 
assert 3 == select().value 

Task task = { 
    bw << 4 
    aw << 5 
    bw << 6 
} 
def result = (1..3).collect(select()).sort{it.value}
assert result*.value == [4, 5, 6]
assert result*.index == [1, 0, 1]
Promise bookingPromise = task {
    final data = collectData()
    return broker.makeBooking(data)
}
bookingPromise.whenBound {booking -> printAgenda booking}
bookingPromise.whenBound {booking -> sendMeAnEmailTo booking}
bookingPromise.whenBound {booking -> updateTheCalendar booking}

Dataflow variables and broadcasts are one of several possible ways to implement Parallel Speculations. For details, please check out Parallel Speculations in the Parallel Collections section of the User Guide.

Bind handlers grouping

When you need to wait for multiple DataflowVariables/Promises to be bound, you can benefit from the whenAllBound() function, which is available on the Dataflow class as well as on PGroup instance.

final group = new NonDaemonPGroup()
//Calling asynchronous services and receiving back promises for the reservations
Promise flightReservation = flightBookingService('PRG <-> BRU')
Promise hotelReservation = hotelBookingService('BRU:Feb 24 2009 - Feb 29 2009')
Promise taxiReservation = taxiBookingService('BRU:Feb 24 2009 10:31')

//when all reservations have been made we need to build an agenda for our trip
Promise agenda = group.whenAllBound(flightReservation, hotelReservation, taxiReservation) {flight, hotel, taxi ->
    "Agenda: $flight | $hotel | $taxi"
}

//since this is a demo, we will only print the agenda and block till it is ready
println agenda.val

If you cannot specify up-front the number of parameters the whenAllBound() handler takes, use a closure with one argument of type List :

Promise module1 = task {
    compile(module1Sources)
}
Promise module2 = task {
    compile(module2Sources)
}
//We don't know the number of modules that will be jarred together, so use a List
final jarCompiledModules = {List modules -> ...
whenAllBound([module1, module2], jarCompiledModules)

Bind handlers chaining

All dataflow channels also support the then() method to register a handler (a callback) that should be invoked when a value becomes available. Unlike whenBound() the then() method allows for chaining, giving you the option to pass result values between functions asynchronously.

Notice that Groovy allows us to leave out some of the dots in the then() method chain.
final DataflowVariable variable = new DataflowVariable()
final DataflowVariable result = new DataflowVariable()
variable.then {it * 2} then {it + 1} then {result << it}
variable << 4
assert 9 == result.val

This could be nicely combined with *Asynchronous functions*

final DataflowVariable variable = new DataflowVariable()
final DataflowVariable result = new DataflowVariable()
final doubler = {it * 2}
final adder = {it + 1}
variable.then doubler then adder then {result << it}
Thread.start {variable << 4}
assert 9 == result.val

or *ActiveObjects*

@ActiveObject
class ActiveDemoCalculator {
    @ActiveMethod
def doubler(int value) {
        value * 2
    }
    @ActiveMethod
def adder(int value) {
        value + 1
    }
}

final DataflowVariable result = new DataflowVariable()
final calculator = new ActiveDemoCalculator();
calculator.doubler(4).then {calculator.adder it}.then {result << it}
assert 9 == result.val
Chaining can save quite some code when calling other asynchronous services from within handlers. Asynchronous services, such as `whenBound()` or `active()`, return Promises for their results. To obtain the actual results your handlers either have to block to wait for the value to be bound, which would lock the current thread in an unproductive state,

```java
variable.whenBound {value ->
    Promise promise = asyncFunction(value)
    println promise.get()
}
```
or, alternatively, it would register another (nested) `whenBound()` handler, which would unnecessarily complex code.

```java
variable.whenBound {value ->
    asyncFunction(value).whenBound {
        println it
    }
}
```

For illustration compare the two following code snippets, one using `whenBound()` and `then()` chaining. They are both equivalent in terms of functionality and behavior.

```java
final DataflowVariable variable = new DataflowVariable()
final doubler = {it * 2}
final inc = {it + 1}
//Using whenBound()
variable.whenBound {value ->
    task {
        doubler(value)
    }.whenBound {doubledValue ->
        task {
            inc(doubledValue)
        }.whenBound {incrementedValue ->
            println incrementedValue
        }
    }
//Using then() chaining
variable.then doubler then inc then this.&println
Thread.start {variable << 4}
```

Chaining Promises solves both of these issues elegantly:

```java
variable >> asyncFunction >> println it
```

The `RightShift ( >> )` operator has been overloaded to call `then()` and so can be chained the same.

```java
final DataflowVariable variable = new DataflowVariable()
final DataflowVariable result = new DataflowVariable()
final doubler = {it * 2}
final adder = {it + 1}
variable >> doubler >> adder >> (result << it)
Thread.start {variable << 4}
assert 9 == result.val
```

Error handling for Promise chaining
Asynchronous operations may obviously throw exceptions. It is important to be able to handle them easily and with little effort. GPars promises can implicitly propagate exceptions from asynchronous calculations across:

1. Promises propagate result values as well as exceptions. The blocking `get()` method re-throw was bound to the Promise and so the caller can handle it.

2. For asynchronous notifications, the `whenBound()` handler closure gets the exception passed.

3. The `then()` method accepts two arguments - a **value handler** and an optional **error handler** depending on whether the result is a regular value or an exception. If noErrorHandler is specified, the exception is re-thrown to the Promise returned by `then()`.

4. Exactly the same behavior as for `then()` holds true for the `whenAllBound()` method, which lists Promises to get bound.

```java
Promise<Integer> initial = new DataflowVariable<Integer>();
    Promise<String> result = initial.then {it * 2} then {100 / it}  //Will throw exception for
    will be ignored //and silently re-thrown to the chain
    .then {println "Logging the value $it as it passes by"; return it} //Since no error handler is specified, if an exception is thrown, it will be ignored
    initial << 0
    println result.get()
```

ErrorHandler is a closure that accepts instances of `Throwable` as its only (optional) argument and should be bound to the result of the `then()` method call (the returned Promise). If an exception is an error handler, it is bound as an error to the resulting Promise.

```java
promise.then{(it+1)}  //Implicitly re-throws potential exception bound to promise
promise.then{(it+1), {e -> throw e}}  //Explicitly re-throws potential exception bound to promise
promise.then{(it+1), {e -> throw new RuntimeException('Error occurred', e)}}  //Explicitly re-throws a new exception wrapping a potential exception bound to promise
```

Just like with regular exception handling in Java with try-catch statements, this behavior of GPars asynchronous invocations gives the freedom to handle exceptions at the place where it is most convenient. You may ignore exceptions in your code and assume things just work, yet exceptions will not get accidentally swallowed.

```java
task {
    'gpars.codehaus.org'.toURL().text  //should throw MalformedURLException
    .then {page -> page.toUpperCase()}
    .then {page -> page.contains('GROOVY')}
    .then{mentionsGroovy -> println "Groovy found: $mentionsGroovy", {error -> println "Error: $error"}}.join()
}
```

**Handling concrete exception type**

You may be also more specific about the handled exception type:

```java
url.then(download)
    .then(calculateHash, {MalformedURLException e -> return 0})
    .then(formatResult)
    .then(printResult, printError)
    .then(sendNotificationEmail);
```

**Customer-site exception handling**
You may also leave the exception completely un-handled and let the clients (consumers) handle it:

```java
Promise<Object> result = url.then(download).then(calculateHash).then(formatResult).then(printResult);
try {
    result.get()
} catch (Exception e) {
    //handle exceptions here
}
```

Putting it together

By combining `whenAllBound()` and `then` (or `>>`) you can easily create large asynchronous scenarios in a convenient way:

```java
withPool {
    Closure download = {String url ->
        sleep 3000 //Simulate a web read
        'web content'
    }.asyncFun()
    Closure loadFile = {String fileName ->
        'file content' //simulate a local file read
    }.asyncFun()
    Closure hash = {s -> s.hashCode()}
    Closure compare = {int first, int second ->
        first == second
    }
    Closure errorHandler = {println
        "Error detected: $it"
    }
    def all = whenAllBound([
        download('http://www.gpars.org') >> hash,
        loadFile('/coolStuff/gpars/website/index.html') >> hash
    ], compare).then({println it}, errorHandler)
    all.join() //optionally block until the calculation is all done
}
```

Notice that only the initial action (function) needs to be asynchronous. The functions down the pipe will be invoked asynchronously by the promise even if the are synchronous.

Implementing the fork/join pattern with Promises

Promises are very flexible and can be used as an implementation vehicle for a lot of different scenarios. Here’s one additional handy capability of Promises. The `_thenForkAndJoin()` method triggers multiple activities once the current promise is bound and returns a promise that gets bound only after all the activities finish. Let’s see picture:

- `then()` - allows for chaining of activities, so that one is performed after another
- `whenAllBound()` - allows for joining multiple activities, so that a new activity is started only after all finish
- `task()` - allows to create (fork) multiple asynchronous activities
- `thenForkAndJoin()` - a short-hand for forking several activities and joining on them

So with `thenForkAndJoin()` you simply create multiple activities that should be triggered by a shared promise.
Once all the activities return a result, they get collected into a list and bound into the promise returned by `thenForkAndJoin()`.

```java
task { 2 }.thenForkAndJoin({ it ** 2 }, { it**3 }, { it**4 }, { it**5 }).then({ println it}).join()
```

### Lazy dataflow tasks and variables

Sometimes you may like to combine the qualities of dataflow variables with their lazy initialization.

```java
Closure<String> download = {url ->
    println "Downloading"  
    url.toURL().text
}
def pageContent = new LazyDataflowVariable(download.curry("http://gpars.codehaus.org"))
```

Instances of `LazyDataflowVariable` have an initializer specified at construction time, which only gets triggered when `LazyDataflowVariable` someone asks for its value, either through the blocking `get()` method or using any of the non-blocking callback methods, such as `then()`. Since `LazyDataflowVariables` preserve all the goodies of ordinary `DataflowVariables`, you can again chain them easily with other `lazy` or `ordinary` dataflow variables.

### Example

This deserves a more practical example. Taking inspiration from http://blog.jcoglan.com/2013/03/30/callbacks-are-imperative-promises-are-functional-nodes-biggest-missed-opportunity/ the following piece of code demonstrates use of `LazyDataflowVariables` to lazily and asynchronously load mutually dependent components into memory. The components (modules) will be loaded in the order of their dependencies and concurrently, if possible. Each module will only be loaded once, irrespective of the number of modules that depend on it. Thanks to laziness only the modules that are transitively needed will be loaded. Our example is a "diamond" dependency scheme:

- D depends on B and C
- C depends on A
- B depends on A

When loading D, A will get loaded first. B and C will be loaded concurrently once A has been loaded once both B and C have been loaded.
def moduleA = new LazyDataflowVariable({->
    println "Loading moduleA into memory"
    sleep 3000
    println "Loaded moduleA into memory"
    return "moduleA"
})

def moduleB = new LazyDataflowVariable({->
    moduleA.then {
        println "->Loading moduleB into memory, since moduleA is ready"
        sleep 3000
        println "  Loaded moduleB into memory"
        return "moduleB"
    }
})

def moduleC = new LazyDataflowVariable({->
    moduleA.then {
        println "->Loading moduleC into memory, since moduleA is ready"
        sleep 3000
        println "  Loaded moduleC into memory"
        return "moduleC"
    }
})

def moduleD = new LazyDataflowVariable({->
    whenAllBound(moduleB, moduleC) { b, c ->
        println "-->Loading moduleD into memory, since moduleB and moduleC are ready"
        sleep 3000
        println "   Loaded moduleD into memory"
        return "moduleD"
    }
})

println "Nothing loaded so far"
println "==================================================================="
println + moduleD.get()
println "Load module: 
println "==================================================================="
println "All requested modules loaded"

Making tasks lazy

The lazyTask() method is available alongside the task() method to give the users a task-oriented delayed activities. A Lazy Task returns an instance of LazyDataflowVariable (a Promise ) with th provided closure. As soon as someone asks for the value, the task will start asynchronously and value into the LazyDataflowVariable .

import groovyx.gpars.dataflow.Dataflow
def pageContent = Dataflow.lazyTask {
    println "Downloading".toURL().text
}

println "No-one has asked for the value just yet. Bound = ${pageContent.bound}"
sleep 1000
println "Now going to ask for a value"
println pageContent.get().size()
println "Repetitive requests will receive the already calculated value. No additional downloading."
println pageContent.get().size()

Dataflow Expressions

Look at the magic below:

def initialDistance = new DataflowVariable()
def acceleration = new DataflowVariable()
def time = new DataflowVariable()
task {
    initialDistance << 100
    acceleration << 2
    time << 10
}
def result = initialDistance + acceleration*0.5*time**2
println 'Total distance ' + result.val
We use DataflowVariables that represent several parameters to a mathematical equation calculating total distance of an accelerating object. In the equation itself, however, we use the DataflowVariables directly. We do not refer to the values they represent and yet we are able to do the math correctly. This shows that DataflowVariables can be very flexible.

For example, you can call methods on them and these methods will get dispatched to the bound values:

```groovy
def name = new DataflowVariable()
task {
    name << 'adam'
}
println name.toUpperCase().trim().val
```

You can pass other DataflowVariables as arguments to such methods and the real values will be passed instead:

```groovy
def title = new DataflowVariable()
def searchPhrase = new DataflowVariable()
task {
    title << 'Groovy in Action 2nd edition'
}
task {
    searchPhrase << '2nd'
}
println title.trim().contains(searchPhrase).val
```

And you can also query properties of the bound value using directly the DataflowVariable:

```groovy
def book = new DataflowVariable()
def searchPhrase = new DataflowVariable()
task {
    book << [
        title:'Groovy in Action 2nd edition',
        author:'Dierk Koenig',
        publisher:'Manning'
    ]
}
task {
    searchPhrase << '2nd'
}
book.title.trim().contains(searchPhrase).whenBound {println it}  //Asynchronous waiting
```

Please note that the result is still a DataflowVariable (DataflowExpression to be precise), which you can get the real value from both synchronously and asynchronously.

### Bind error notification

DataflowVariables offer the ability to send notifications to the registered listeners whenever a bind operation fails. The `getBindErrorManager()` method allows for listener to be added and removed. The listeners get notified in case of a failed attempt to bind a value (through bind(), bindSafely(), bindUnique() or leftShift()) or an error.
```java
final DataflowVariable variable = new DataflowVariable()
variable.getBindErrorManager().addBindErrorListener(new BindErrorListener() {
    @Override
    void onBindError(final Object oldValue, final Object failedValue, final boolean uniqueBind) {
        println "Bind failed!"
    }

    @Override
    void onBindError(final Object oldValue, final Throwable failedError) {
        println "Binding an error failed!"
    }

    public void onBindError(final Throwable oldError, final Object failedValue, final boolean uniqueBind) {
        println "Bind failed!"
    }

    @Override
    public void onBindError(final Throwable oldError, final Throwable failedError) {
        println "Binding an error failed!"
    }
});
```

This allows you to customize reactions to attempts to binding of already bound dataflow variables: `bindSafely()` you do not get bind exceptions fired to the caller, but instead a registered `BindErrorListener`.

### Further reading

- [Scala Dataflow library](https://github.com/jboner/scala-dataflow) by Jonas Bonér
- [JVM concurrency presentation slides](https://www.slideshare.net/jboner/concurrency-101) by Jonas Bonér
- [Dataflow Concurrency library for Ruby](https://github.com/jboner/ruby-dataflow)

### 7.1 Tasks

The **Dataflow tasks** give you an easy-to-grasp abstraction of mutually-independent logical tasks runs concurrently and exchange data solely through Dataflow Variables, Queues, Broadcasts and tasks with their easy-to-express mutual dependencies and inherently sequential body could also implementation of UML **Activity Diagrams**.

Check out the examples.

### A simple mashup example

In the example we’re downloading the front pages of three popular web sites, each in their own task: a separate task we’re filtering out sites talking about Groovy today and forming the output. The output automatically with the three download tasks on the three Dataflow variables through which the content is passed to the output task.
import static groovyx.gpars.GParsPool.withPool
import groovyx.gpars.dataflow.DataflowVariable
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * A simple mashup sample, downloads content of three websites
 * and checks how many of them refer to Groovy.
 */
def dzone = new DataflowVariable()
def jroller = new DataflowVariable()
def theserverside = new DataflowVariable()

task {
    println 'Started downloading from DZone'
    dzone << 'http://www.dzone.com'.toURL().text
    println 'Done downloading from DZone'
}

task {
    println 'Started downloading from JRoller'
    jroller << 'http://www.jroller.com'.toURL().text
    println 'Done downloading from JRoller'
}

task {
    println 'Started downloading from TheServerSide'
    theserverside << 'http://www.theserverside.com'.toURL().text
    println 'Done downloading from TheServerSide'
}

task {
    withPool {
        println "Number of Groovy sites today: "+
        ([dzone, jroller, theserverside].findAllParallel {
            it.val.toUpperCase().contains 'GROOVY'
        }).size()
    }
}.join()
usingGroup(group) {
    task {
        'http://gpars.codehaus.org'.toURL().text  \should throw MalformedURLException
        .then {page -> page.toUpperCase()}
        .then {page -> page.contains('GROOVY')}
        .then({mentionsGroovy -> println "Groovy found: $mentionsGroovy"}, {error -> println "Error: $error"}).join()
    }
}

You can always override the default group by being specific:

usingGroup(group) {
    anotherGroup.task {
        'http://gpars.codehaus.org'.toURL().text  \should throw MalformedURLException
        .then(anotherGroup) {page -> page.toUpperCase()}
        .then(anotherGroup) {page -> page.contains('GROOVY')}.then(anotherGroup) {println Dataflow.retrieveCurrentDFPGroup();it}
    }
}

A mashup variant with methods

To avoid giving you wrong impression about structuring the Dataflow code, here’s a rewrite of the with a downloadPage() method performing the actual download in a separate task and returning instance, so that the main application thread could eventually get hold of the downloaded content can obviously be passed around as parameters or return values.

package groovyx.gpars.samples.dataflow
import static groovyx.gpars.GParsExecutorsPool.withPool
import static groovyx.gpars.dataflow.DataflowVariable
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * A simple mashup sample, downloads content of three websites and checks how many of them refer to Groovy. 
*/
task {
    def pages = urls.collect { downloadPage(it) }
    withPool {
        println "of Groovy sites today: " +
        (pages.findAllParallel {
            it.val.toUpperCase().contains 'GROOVY'
        }).size()
    }
}.join()
def downloadPage(def url) {
    def page = new DataflowVariable()
    task {
        println "Started downloading from $url"
        page << url.toURL().text
        println "Done downloading from $url"
    }
    return page
}

A physical calculation example

Dataflow programs naturally scale with the number of processors. Up to a certain level, the more the faster the program runs. Check out, for example, the following script, which calculates param physical experiment and prints out the results. Each task performs its part of the calculation and calculated by some other tasks as well as its result might be needed by some of the other tasks. Concurrency you can split the work between tasks or reorder the tasks themselves as you like ar mechanics will ensure the calculation will be accomplished correctly.
import groovyx.gpars.dataflow.DataflowVariable
import static groovyx.gpars.dataflow.Dataflow.task

final def mass = new DataflowVariable()
final def radius = new DataflowVariable()
final def volume = new DataflowVariable()
final def density = new DataflowVariable()
final def acceleration = new DataflowVariable()
final def time = new DataflowVariable()
final def velocity = new DataflowVariable()
final def decelerationForce = new DataflowVariable()
final def deceleration = new DataflowVariable()
final def distance = new DataflowVariable()

def t = task {
  println "Calculating distance required to stop a moving ball."

  The ball has a radius of \$\{radius.val\} meters and is made of a material with \$\{density.val\} kg/m3 density, which means that the ball has a volume of \$\{volume.val\} m3 and a mass of \$\{mass.val\} kg.
  The ball has been accelerating with \$\{acceleration.val\} m/s2 from 0 for \$\{time.val\} seconds and so reached a velocity of \$\{velocity.val\} m/s.
  Given our ability to push the ball backwards with a force of \$\{decelerationForce.val\} N (Newton), we can cause a deceleration of \$\{deceleration.val\} m/s2 and so stop the ball at a distance of \$\{distance.val\} m.

  This example has been calculated asynchronously in multiple tasks using GPars Dataflow concurrency in Groovy.
  Author: \$\{author.val\}"
}

System.exit 0

} task {
  mass << volume.val * density.val
}

} task {
  volume << Math.PI * (radius.val ** 3)
}

} task {
  radius << 2.5
  density << 998.2071 //water
  acceleration << 9.80665 //free fall
  decelerationForce << 900
}

} task {
  println 'Enter your name:'
  def name = new InputStreamReader(System.in).readLine()
  author << (name?.trim()?.size()>0 ? name : 'anonymous')
}

} task {
  time << 10
  velocity << acceleration.val * time.val
}

} task {
  deceleration << decelerationForce.val / mass.val
}

} task {
  distance << deceleration.val * ((velocity.val/deceleration.val) ** 2) * 0.5
}

t.join()

Note: I did my best to make all the physical calculations right. Feel free to change the values and distance you need to stop the rolling ball.

**Deterministic deadlocks**

If you happen to introduce a deadlock in your dependencies, the deadlock will occur each time randomness allowed. That's one of the benefits of Dataflow concurrency. Irrespective of the actual scheme, if you don't get a deadlock in tests, you won't get them in production.
**Dataflows map**

As a handy shortcut the *Dataflows* class can help you reduce the amount of code you have to write to leverage Dataflow variables.

```groovy
def df = new Dataflows()
df.x = 'value1'
assert df.x == 'value1'
Dataflow.task {df.y = 'value2'}
assert df.y == 'value2'
```

Think of Dataflows as a map with Dataflow Variables as keys storing their bound values as appropriate map values. The semantics of reading a value (e.g. df.x) and binding a value (e.g. df.x = 'value') remain identical to plain Dataflow Variables (x.val and x <<= 'value' respectively).

**Mixing Dataflows and Groovy with blocks**

When inside a *with* block of a Dataflows instance, the dataflow variables stored inside the Dataflows instance can be accessed directly without the need to prefix them with the Dataflows instance identifier.

```groovy
new Dataflows().with {
    x = 'value1'
    assert x == 'value1'
    Dataflow.task {y = 'value2'}
    assert y == 'value2'
}
```

**Returning a value from a task**

Typically dataflow tasks communicate through dataflow variables. On top of that, tasks can also return values through a dataflow variable. When you invoke the *task()* factory method, you get back an instance of Promise (implemented as DataflowVariable), through which you can listen for the task’s return value, just like when using any other Promise or DataflowVariable.

```groovy
final Promise t1 = task {
    return 10
}
final Promise t2 = task {
    return 20
}
def results = [t1, t2]*.val
println 'Both sub-tasks finished and returned values: ' + results
```

Obviously the value can also be obtained without blocking the caller using the *whenBound()* method.

```groovy
def task = task {
    println 'The task is running and calculating the return value'
    return 30
}
task >> {value -> println "The task finished and returned $value"}
```

**h2. Joining tasks**

Using the *join()* operation on the result dataflow variable of a task you can block until the task finishes.

```groovy
final Promise t1 = task {
    return 10
}
final Promise t2 = task {
    return 20
}
def results = [t1, t2]*.val
println 'Both sub-tasks finished and returned values: ' + results
```

Obviously the value can also be obtained without blocking the caller using the *whenBound()* method.

```groovy
def task = task {
    println 'The task is running and calculating the return value'
    return 30
}
task >> {value -> println "The task finished and returned $value"}
```
task {
    final Promise t1 = task {
        println 'First sub-task running.'
    }
    final Promise t2 = task {
        println 'Second sub-task running'
    }
    [t1, t2]*.join()
    println 'Both sub-tasks finished'
}.join()
By default the Select blocks the caller until a value to read is available. The alternative selectToPromise() and prioritySelectToPromise() methods give you a way to obtain a promise for the value that will be selected in the future. Through the returned Promise you may register a callback to get invoked asynchronously whenever the next value is selected.

```groovy
def sel = select(a, b, c, d)
Promise result = sel.selectToPromise() //Random selection
Promise result = sel.selectToPromise([true, true, false, true]) //Random selection with guards specified
Promise result = sel.prioritySelectToPromise() //Priority selection
Promise result = sel.prioritySelectToPromise([true, true, false, true]) //Priority selection with guards specified
```

Alternatively, Select allows to have the value sent to a provided MessageStream (e.g. an actor) without blocking the caller.

```groovy
def handler = actor {...}
def sel = select(a, b, c, d)
```

Guards

Guards allow the caller to omit some input channels from the selection. Guards are specified as a List of boolean flags passed to the select() or prioritySelect() methods.

```groovy
def sel = select(leaders, seniors, experts, juniors)
def teamLead = sel([true, true, false, false]).value //Only 'leaders' and 'seniors' qualify for becoming teamLead
```

A typical use for guards is to make Selects flexible to adopt to the changes in the user state.

```groovy
import groovyx.gpars.dataflow.DataflowQueue
import static groovyx.gpars.dataflow.Dataflow.select
import static groovyx.gpars.dataflow.Dataflow.task
/**
 * Demonstrates the ability to enable/disable channels during a value selection on a select by providing boolean guards.
 */
final DataflowQueue operations = new DataflowQueue()
final DataflowQueue numbers = new DataflowQueue()
def t = task {
  final def select = select(operations, numbers)
  3.times {
    def instruction = select([true, false]).value
    def num1 = select([false, true]).value
    def num2 = select([false, true]).value
    final def formula = "$num1 $instruction $num2"
    println "formula = \${GroovyShell().evaluate(formula)}"
  }
}
task {
  operations << '+'
  operations << '+'
  operations << '*'
}
task {
  numbers << 10
  numbers << 20
  numbers << 30
  numbers << 40
  numbers << 50
  numbers << 60
}
t.join()
```
Priority Select

When certain channels should have precedence over others when selecting, the prioritySelect method should be used instead.

```groovy
/**
 * Shows a basic use of Priority Select, which monitors a set of input channels for values and makes these values available on its output irrespective of their original input channel.
 * Note that dataflow variables, queues and broadcasts can be combined for Select.
 * Unlike plain select method call, the prioritySelect call gives precedence to input channels with lower index.
 * Available messages from high priority channels will be served before messages from lower-priority channels.
 * Messages received through a single input channel will have their mutual order preserved.
 */
def critical = DataflowVariable()
def ordinary = DataflowQueue()
def whoCares = DataflowQueue()
task {
    ordinary << 'All working fine'
    whoCares << 'I feel a bit tired'
    ordinary << 'We are on target'
}
task {
    ordinary << 'I have just started my work. Busy. Will come back later...'
    sleep 5500
    ordinary << 'I am done for now'
}
task {
    whoCares << 'Huh, what is that noise'
    ordinary << 'Here I am to do some clean-up work'
    whoCares << 'I wonder whether unplugging this cable will eliminate that nasty sound.'
    critical << 'The server room goes on UPS!!'
    whoCares << 'The sound has disappeared'
}
def select = select([critical, ordinary, whoCares])
println 'Starting to monitor our IT department'
sleep 3000
10.times {println
    "Received: \${select.prioritySelect().value}"}
```

Collecting results of asynchronous computations

Asynchronous activities, no matter whether they are dataflow tasks, active objects' methods, functions, return Promises. Promises implement the SelectableChannel interface and so can be used together with other Promises as well as read channels. Similarly to Java's Completion future, Select enables you to obtain results of asynchronous activities as soon as each of them becomes available. You may employ Select to give you the first/fastest result of several computations running in parallel.

```groovy
import groovyx.gpars.dataflow.Promise
import groovyx.gpars.dataflow.Select
import groovyx.gpars.group.DefaultPGroup
/**
 * Demonstrates the use of dataflow tasks and selects to pick the fastest result of concurrently run calculations.
 */
final group = new DefaultPGroup()
group.with {
    Promise p1 = task {
        sleep(1000)
        10 * 10 + 1
    }
    Promise p2 = task {
        sleep(1000)
        5 * 20 + 2
    }
    Promise p3 = task {
        sleep(1000)
        1 * 100 + 3
    }
    final alt = new Select(group, p1, p2, p3)
    def result = alt.select()
    println "Result: \$\{result\}"}
```
Timeouts

The `Select.createTimeout()` method will create a DataflowVariable that gets bound to a value after a given time period. This can be leveraged in `Selects` so that they unblock after a desired delay, if none of the other `Selects` deliver a value before that moment. Just pass the `timeout channel` as another input channel to the `Select`.

```java
import groovyx.gpars.dataflow.Promise
import groovyx.gpars.dataflow.Select
import groovyx.gpars.group.DefaultPGroup

/**
 * Demonstrates the use of dataflow tasks and selects to pick the fastest result of concurrently run calculations.
 */
final group = new DefaultPGroup()
group.with {
    Promise p1 = task {
        sleep(1000)
        10 * 10 + 1
    }
    Promise p2 = task {
        sleep(1000)
        5 * 20 + 2
    }
    Promise p3 = task {
        sleep(1000)
        1 * 100 + 3
    }
    timeoutChannel = Select.createTimeout(500)
    final alt = Select(group, p1, p2, p3, timeoutChannel)
    final new def result = alt.select()
    println "Result: " + result
}
```

Cancellation

In case you need to cancel the other tasks once a value has been calculated or a timeout expires, set a flag that the tasks periodically monitor. There's intentionally no cancellation machinery built into `Tasks`.

```java
import groovyx.gpars.dataflow.Promise
import groovyx.gpars.dataflow.Select
import groovyx.gpars.group.DefaultPGroup
import java.util.concurrent.atomic.AtomicBoolean

/**
 * Demonstrates the use of dataflow tasks and selects to pick the fastest result of concurrently run calculations.
 * It shows a way to cancel the slower tasks once a result is known.
 */
final group = new DefaultPGroup()
final done = new AtomicBoolean()
group.with {
    Promise p1 = task {
        sleep(1000)
        if (done.get()) return
        10 * 10 + 1
    }
    Promise p2 = task {
        sleep(1000)
        if (done.get()) return
        5 * 20 + 2
    }
    Promise p3 = task {
        sleep(1000)
        if (done.get()) return
        1 * 100 + 3
    }
    alt = new Select(group, p1, p2, p3, Select.createTimeout(500))
    def result = alt.select()
    done.set(true)
    println "Result: " + result
}```
7.3 Operators

Dataflow Operators and Selectors provide a full Dataflow implementation with all the usual ceremony.

Concepts

Full dataflow concurrency builds on the concept of channels connecting operators and selectors, values coming through input channels, transform them into new values and output the new value channels. While *Operators* wait for **all** input channels to have a value available for read before they start processing, *Selectors* are triggered by a value available on any of the input channels.

```java
operator(inputs: [a, b, c], outputs: [d]) {x, y, z ->
  bindOutput 0, x + y + z
}
```

```java
/**
 * CACHE
 *
 * Caches sites' contents. Accepts requests for url content, outputs the content. Outputs requests for downloading if the site is not in cache yet.
 */
operator(inputs: [urlRequests], outputs: [downloadRequests, sites]) {request ->
  if (!request.content) {
    if (content) {
      println "[Cache] Found in cache"
      bindOutput 1, [site: request.site, word:request.word, content: content]
    } else {
      def downloads = pendingDownloads[request.site]
      if (downloads != null) {
        println "[Cache] Awaiting download"
        downloads << request
      } else {
        pendingDownloads[request.site] = []
        println "[Cache] Asking for download"
        bindOutput 0, request
      }
    }
  } else {
    println "[Cache] Caching ${request.site}"
    cache[request.site] = request.content
    bindOutput 1, request
    def downloads = pendingDownloads[request.site]
    if (downloads != null) {
      for (downloadRequest in downloads) {
        println "[Cache] Waking up"
        bindOutput 1, [site: downloadRequest.site, word:downloadRequest.word, content: request.content]
      }
      pendingDownloads.remove(request.site)
    }
  }
}
```
The standard error handling will print out an error message to the standard error output and terminate the operator in case an uncaught exception is thrown from within the operator's body. To alter the behavior, you can register your own event listener:

```java
def listener = new DataflowEventAdapter() {
    @Override
    boolean onException(DataflowProcessor processor, Throwable e) {
        logChannel << e
        return false //Indicate whether to terminate the operator or not
    }
}

op = group.operator(inputs: [a, b], outputs: [c], listeners: [listener]) {x, y ->
    ...
}
```

See the **Operator lifecycle** section for more details.

### Types of operators

There are specialized versions of operators serving specific purposes:

- **operator** - the basic general-purpose operator
- **selector** - operator that is triggered by a value being available in any of its input channels
- **prioritySelector** - a selector that prefers delivering messages from lower-indexed input channels over higher-indexed ones
- **splitter** - a single-input operator copying its input values to all of its output channels

### Wiring operators together

Operators are typically combined into networks, when some operators consume output by other operators:

```java
operator(inputs:[a, b], outputs:[c, d]) {...}
splitter(c, [e, f])
selector(inputs:[e, d]: outputs:[]) {...}
```

You may alternatively refer to output channels through operators themselves:

```java
def op1 = operator(inputs:[a, b], outputs:[c, d]) {...}
def spl1 = splitter(op1.outputs[0], [e, f])                            //takes the first output of op1
def sel = selector(inputs:[spl1.outputs[0], op1.outputs[1]): outputs:[])   //takes the first output of spl1 and the second output of op1
```

### Grouping operators

Dataflow operators can be organized into groups to allow for performance fine-tuning. Groups provide a handy factory method to create tasks attached to the groups.
The default thread pool for dataflow operators contains daemon threads, which means your application will exit as soon as the main thread finishes and won't wait for all tasks to complete. When grouping operators, make sure that your custom thread pools either use daemon threads, too, which can be achieved by using DefaultPGroup or by providing your own thread factory to a thread pool constructor, or in case your thread pools use non-daemon threads such as when using the NonDaemonPGroup group class, make sure you shutdown the group or the thread pool explicitly by calling its shutdown() method, otherwise your application will not exit.

You may selectively override the default group used for tasks, operators, callbacks and other dataflow elements inside a code block using the `Dataflow.usingGroup()` method:

```groovy
Dataflow.usingGroup(group) {
    operator(inputs: [a, b, c], outputs: [d]) {x, y, z ->
        bindOutput 0, x + y + z
    }
}
```

You can always override the default group by being specific:

```groovy
Dataflow.usingGroup(group) {
    anotherGroup.operator(inputs: [a, b, c], outputs: [d]) {x, y, z ->
        bindOutput 0, x + y + z
    }
}
```

### Constructing operators

The construction properties of an operator, such as `inputs`, `outputs`, `stateObject` or `maxForks` cannot be modified once the operator has been built. You may find the `groovyx.gpars.dataflow.ProcessingNode` class helpful when gradually collecting channels and values into lists before you finally build an operator.
import groovyx.gpars.dataflow.Dataflow
import groovyx.gpars.dataflow.DataflowQueue
import static groovyx.gpars.dataflow.ProcessingNode.node

/**<n* Shows how to build operators using the ProcessingNode class</n*/
final DataflowQueue aValues = new DataflowQueue()
final DataflowQueue bValues = new DataflowQueue()
final DataflowQueue results = new DataflowQueue()

//Create a config and gradually set the required properties - channels, code, etc.
def adderConfig = node {valueA, valueB ->
  bindOutput valueA + valueB
}
adderConfig.inputs << aValues
adderConfig.inputs << bValues
adderConfig.outputs << results

//Build the operator
final adder = adderConfig.operator(Dataflow.DATA_FLOW_GROUP)

//Now the operator is running and processing the data
aValues << 10
aValues << 20
bValues << 1
bValues << 2
assert [11, 22] == (1..2).collect {
  results.val
}

State in operators

Although operators can frequently do without keeping state between subsequent invocations, GPars allows operators
to maintain state, if desired by the developer. One obvious way is to leverage the Groovy closure capabilities to
close-over their context:

```groovy
int counter = 0
operator(inputs: [a], outputs: [b]) {value ->
  counter += 1
}
```

Another way, which allows you to avoid declaring the state object outside of the operator definitic
object into the operator as a stateObject parameter at construction time:

```groovy
operator(inputs: [a], outputs: [b], stateObject: [counter: 0]) {value ->
  stateObject.counter += 1
}
```

Parallelize operators

By default an operator's body is processed by a single thread at a time. While this is a safe settin
operator's body to be written in a non-thread-safe manner, once an operator becomes "hot" and i
accumulate in the operator's input queues, you might consider allowing multiple threads to run th concurrently. Bear in mind that in such a case you need to avoid or protect shared resources f or access. To enable multiple threads to run the operator's body concurrently, pass an extra maxForks
creating an operator:

```groovy
def op = operator(inputs: [a, b, c], outputs: [d, e], maxForks: 2) {x, y, z ->
  bindOutput 0, x + y + z
  bindOutput 1, x * y * z
}
```
The value of the *maxForks* parameter indicates the maximum of threads running the operator concurrently. Positive numbers are allowed with value 1 being the default.

Please always make sure the group serving the operator holds enough threads to support all requested forks. Using groups allows you to organize tasks or operators around different pools (wrapped inside the group). While the Dataflow.task() command schedules the default thread pool (java.util.concurrent.Executor, fixed size=#cpu+1, daemon threads), you may prefer being able to define your own thread pool(s) to run your tasks.

```java
def group = new DefaultPGroup(10)
group.operator((inputs: [a, b, c], outputs: [d, e], maxForks: 5) {x, y, z -> ...
```

The default group uses a resizeable thread pool as so will never run out of threads.

**Synchronizing the output**

When enabling internal parallelization of an operator by setting the value for *maxForks* to a value greater than 1, it is important to remember that without explicit or implicit synchronization in the operators’ body race conditions may occur. Especially bear in mind that values written to multiple output channels are not guaranteed to be written in the same order to all the channels.

```java
operator(inputs:[inputChannel], outputs:[a, b], maxForks:5) {msg ->
  bindOutput 0, msg
  bindOutput 1, msg
}
```

May result in output channels having the values mixed-up something like:

- a → 1, 3, 2, 4, 5
- b → 2, 1, 3, 5, 4

Explicit synchronization is one way to get correctly bound all output channels and protect operator state:

```java
def lock = new Object()
operator(inputs:[inputChannel], outputs:[a, b], maxForks:5) {msg ->
  doStuffThatIsThreadSafe()
  synchronized(lock) {
    doSomethingThatMustNotBeAccessedByMultipleThreadsAtTheSameTime()
    bindOutput 0, msg
    bindOutput 1, 2*msg
  }
}
```

Obviously you need to weight the pros and cons here, since synchronization may defeat the purpose of setting *maxForks* to a value greater than 1.

To set values of all the operator’s output channels in one atomic step, you may also consider calling the `bindAllOutputsAtomically` method, passing in a single value to write to all output channels or the `bindAllOutputsAtomically` method, which takes a multiple values, each of which will be written to the same position index.
```
operator(inputs:[inputChannel], outputs:[a, b], maxForks:5) {msg ->
  doStuffThatIsThreadSafe()
  bindAllOutputValuesAtomically(msg, 2*msg)
}
```

Using the `bindAllOutputs` or the `bindAllOutputValues` methods will not guarantee atomicity of writes across all the output channels when using internal parallelism. If preserving the messages in multiple output channels is not an issue, `bindAllOutputs` as well as `bindAllOutputValues` will provide better performance over the atomic variants.

**Operator lifecycle**

Dataflow operators and selectors fire several events during their lifecycle, which allows the interested parties to obtain notifications and potentially alter operator's behavior. The `DataflowEventListener` interface offers a couple of callback methods:
public interface DataflowEventListener {
    /**
     * Invoked immediately after the operator starts by a pooled thread before the first message is obtained
     * @param processor The reporting dataflow operator/selector
     */
    void afterStart(DataflowProcessor processor);

    /**
     * Invoked immediately after the operator terminates
     * @param processor The reporting dataflow operator/selector
     */
    void afterStop(DataflowProcessor processor);

    /**
     * Invoked if an exception occurs. If any of the listeners returns true, the operator will terminate.
     * Exceptions outside of the operator's body or listeners' messageSentOut() handlers will terminate the operator irrespective of the listeners' votes.
     * @param processor The reporting dataflow operator/selector
     * @param e The thrown exception
     */
    boolean onException(DataflowProcessor processor, Throwable e);

    /**
     * Invoked when a message becomes available in an input channel.
     * @param processor The reporting dataflow operator/selector
     * @param channel The input channel holding the message
     * @param index The index of the input channel within the operator
     * @param message The incoming message
     */
    Object messageArrived(DataflowProcessor processor, DataflowReadChannel<Object> channel, int index, Object);

    /**
     * Invoked when a control message (instances of ControlMessage) becomes available in an input channel.
     * @param processor The reporting dataflow operator/selector
     * @param channel The input channel holding the message
     * @param index The index of the input channel within the operator
     * @param message The incoming message
     */
    Object controlMessageArrived(DataflowProcessor processor, DataflowReadChannel<Object> channel, int index, Object);

    /**
     * Invoked when a message is being bound to an output channel.
     * @param processor The reporting dataflow operator/selector
     * @param channel The output channel to send the message to
     * @param index The index of the output channel within the operator
     * @param message The message to send
     */
    Object messageSentOut(DataflowProcessor processor, DataflowWriteChannel<Object> channel, int index, Object);

    /**
     * Invoked when all messages required to trigger the operator become available in the input channels.
     * @param processor The reporting dataflow operator/selector
     * @param messages The incoming messages
     */
    List<Object> beforeRun(DataflowProcessor processor, List<Object> messages);

    /**
     * Invoked when the operator completes a single run
     * @param processor The reporting dataflow operator/selector
     * @param messages The incoming messages that have been processed
     */
    void afterRun(DataflowProcessor processor, List<Object> messages);

    /**
     * Invoked when the fireCustomEvent() method is triggered manually on a dataflow operator/selector
     * @param processor The reporting dataflow operator/selector
     * @param data The custom piece of data provided as part of the event
     */
    Object customEvent(DataflowProcessor processor, Object data);
}

A default implementation is provided through the DataflowEventAdapter class.
Listeners provide a way to handle exceptions, when they occur inside operators. A listener may typically log such exceptions, notify a supervising entity, generate an alternative output or perform any steps required to recover from the situation. If there’s no listener registered or if any of the listeners returns `true` the operator will terminate, preserving the true contract of `afterStop()`. Exceptions that occur outside the actual operator’s body, i.e. at the parameter preparation phase before the body is triggered or at the clean-up and channel subscription phase, after the body finishes, always lead to operator termination.

The `fireCustomEvent()` method available on operators and selectors may be used to communicate between operator’s body and the interested listeners:

```java
class DataflowEventAdapter {
    @Override
    public Object customEvent(DataflowProcessor processor, Object data) {
        System.out.println("Log: Getting quite high on the scale $data");
        return 100 }//The value to use instead
    }
}

final listener = new DataflowEventAdapter() {
    @Override
    public Object customEvent(DataflowProcessor processor, Object data) {
        System.out.println("Log: Getting quite high on the scale $data");
        return 100 }//The value to use instead
    }
}

op = group.operator(inputs: [a, b], outputs: [c], listeners: [listener]) {x, y ->
    final sum = x + y
    if (sum > 100) bindOutput(fireCustomEvent(sum)) //Reporting that the sum is too high, binding the lowered
    else bindOutput sum
}
```

**Selectors**

Selector’s body should be a closure consuming either one or two arguments.

```java
selector (inputs : [a, b, c], outputs : [d, e]) {value ->
    ....
}
```

The two-argument closure will get a value plus an index of the input channel, the value of which is currently being processed. This allows the selector to distinguish between values coming through different input channels.

```java
selector (inputs : [a, b, c], outputs : [d, e]) {value, index ->
    ....
}
```

**Priority Selector**

When priorities need to be preserved among input channels, a `DataflowPrioritySelector` should be used.

```java
prioritySelector(inputs : [a, b, c], outputs : [d, e]) {value, index ->
    ....
}
```

The priority selector will always prefer values from channels with lower position index over values coming through channels with higher position index.

**Join selector**

A selector without a body closure specified will copy all incoming values to all of its output channels.

```java
def join = selector (inputs : [programmers, analysis, managers], outputs : [employees, colleagues])
```
Internal parallelism

The `maxForks` attribute allowing for internal selectors parallelism is also available.

```groovy
selector (inputs : [a, b, c], outputs : [d, e], maxForks : 5) {value ->
  ....
}
```

Guards

Just like Selects, Selectors also allow the users to temporarily include/exclude individual input of the guards input property can be used to set the initial mask on all input channels and the `setGuards` methods are then available in the selector’s body.

```groovy
import groovyx.gpars.dataflow.DataflowQueue
import static groovyx.gpars.dataflow.Dataflow.selector
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * Demonstrates the ability to enable/disable channels during a value selection on a select by providing boolean
 */
final DataflowQueue operations = new DataflowQueue()
final DataflowQueue numbers = new DataflowQueue()
def instruction
def nums = []
selector(inputs: [operations, numbers], outputs: [], guards: [true, false]) {value, index -> //initial guard
  if (index == 0) {
    if (instruction = value
      setGuard(0, false) //setGuard() used here
      setGuard(1, true)
    }
    else nums << value
  }
  if (nums.size() == 2) {
    if (setGuards([true, false])) //setGuards() used here
      final def formula = "${nums[0]} $instruction ${nums[1]}"
      println "$formula = ${new GroovyShell().evaluate(formula)}"
      nums.clear()
  }
}
task {
  operations << '+'
  operations << '+'
  operations << '+'
}
task {
  numbers << 10
  numbers << 20
  numbers << 30
  numbers << 40
  numbers << 50
  numbers << 60
}
```

Avoid combining `guards` and `maxForks` greater than 1. Although the Selector is thread-safe and guards won't be damaged in any way, the guards are likely not to be set the way you expect. Multiple threads running selector’s body concurrently will tend to over-write each-other’s settings to the `guards` property.

7.4 Shutting Down Dataflow Networks

Shutting down a network of dataflow processors (operators and selectors) may sometimes be a rather non-trivial task, especially if you need a generic mechanism that will not leave any messages unprocessed.

Dataflow operators and selectors can be terminated in three ways:
1. by calling the terminate() method on all operators that need to be terminated
2. by sending a poisson message
3. by setting up a network of activity monitors that will shutdown the network after all messages

Check out the details on the ways that GPars provides.

Shutting down the thread pool

If you use a custom PGroup to maintain a thread pool for your dataflow network, you forget to shutdown the pool once the network is terminated. Otherwise the thread pool will consume system resources and, in case of using non-daemon threads, it will prevent exit.

Emergency shutdown

You can call terminate() on any operator/selector to immediately shut it down. Provided you keep processors, perhaps by adding them to a list, the fastest way to stop the network would be:

allMyProcessors*.terminate()

This should, however, be treated as an emergency exit, since no guarantees can be given regarding processed nor finished work. Operators will simply terminate instantly leaving work unfinished and messages in the input channels. Certainly, the lifecycle event listeners hooked to the operators/s afterStop() event handlers invoked in order to, for example, release resources or output a note in

Stopping operators gently

 Operators handle incoming messages repeatedly. The only safe moment for stopping an operator is right after the operator has finished processing messages and is just about to look for more messages in its incoming pipes. This is exactly what the terminateAfterNextRun() method does. I operator for shutdown after the next set of messages gets handled.
The unprocessed messages will stay in the input channels, which allows you to handle them later, perhaps with a different operator/selector or in some other way. Using `terminateAfterNextRun()` you will not loose any input messages. This may be particularly handy when you use a group of operators/selectors to load-balance messages coming from a channel. Once the work-load decreases, the `terminateAfterNextRun()` method may be used to safely reduce the pool of load-balancing operators.

### Detecting shutdown

Operators and electors offer a handy `join()` method for those who need to block until the operator terminates.

```java
allMyProcessors*.join()
```

This is the easiest way to wait until the whole dataflow network shuts down, irrespective of the shutdown method used.

### PoisonPill

`PoisonPill` is a common term for a strategy that uses special-purpose messages to stop entities. It offers the `PoisonPill` class, which has exactly such effect or operators and selectors. Since `PoisonPill` is invisible to operator's body and custom code does not need to handle it in `DataflowEventListeners` may react to `ControlMessages` through the `controlMessageArrived()` handler method.

```java
def op1 = operator(inputs: [a, b, c], outputs: [d, e]) {x, y, z -> }
def op2 = selector(inputs: [d], outputs: [f, out]) { }
def op3 = prioritySelector(inputs: [e, f], outputs: [b]) {value, index -> }
a << PoisonPill.instance  //Send the poison
op1.join()
op2.join()
op3.join()
```

After receiving a poison an operator terminates, right after it finishes the current calculation and poison is sent to all its output channels, so that the poison can spread to the connected operators. Typically, operators wait for all inputs to have a value, in case of `PoisonPill`, the operator will terminate immediately as soon as a `PoisonPill` appears on any of its inputs. The values already obtained from the other channels can be considered an error in the design of the network, if these messages were supposed to be treated as a proper value as their peer and not a PoisonPill in order to be processed normally.

Selectors, on the other hand, will patiently wait for `PoisonPill` to be received from all their input channels. This prevents networks containing `feed-back loops` from being shutdown using `PoisonPill`. A selector would never receive a `PoisonPill` from the channel behind the selector. A different shutdown strategy should be used for such networks.

Given the potential variety of operator networks and their asynchronous nature, a good termination strategy is that operators and selectors should only ever terminate themselves. Ways of terminating them from outside (either by calling the `terminate()` method or by poisson down the stream) may result in messages being lost somewhere in the pipes, reading operators terminate before they fully handle the messages waiting in their input channels.
Immediate poison pill

Especially for selectors to shutdown immediately after receiving a poison pill, a notion of immediate poison pill has been introduced. Since normal, non-immediate poison pills merely close the input channel leaving at least one input channel remains open, the immediate poison pill closes the selector instantly. Unprocessed messages from the other selector's input channels will not be handled by the selector.

With immediate poison pill you can safely shutdown networks with selectors involved in feedback loops.

```java
def op1 = selector(inputs: [a, b, c], outputs: [d, e]) {value, index -> }
def op2 = selector(inputs: [d], outputs: [f, out]) {}
def op3 = prioritySelector(inputs: [e, f], outputs: [b]) {value, index -> }
a << PoisonPill.immediateInstance
[op1, op2, op3]*.join()
```

Poison with counting

When sending a poison pill down the operator network you may need to be notified when all the specified number of them have been stopped. The CountingPoisonPill class serves exactly this purpose:

```java
operator(inputs: [a, b, c], outputs: [d, e]) {x, y, z -> }
selector(inputs: [d], outputs: [f, out]) {}
prioritySelector(inputs: [e, f], outputs: [b]) {value, index -> }
//Send the poison indicating the number of operators than need to be terminated before we can continue
final pill = new CountingPoisonPill(3)
a << pill
//Wait for all operators to terminate
pill.join()
//At least 3 operators should be terminated by now
```

The termination property of the CountingPoisonPill class is a regular Promise<Boolean> and so I properties.

```java
//Send the poison indicating the number of operators than need to be terminated before we can continue
final pill = new CountingPoisonPill(3)
pill.termination.whenBound {println "Reporting asynchronously that the network has been stopped"} a << pill
//Wait for all operators to terminate
pill.join()
//At least 3 operators should be terminated by now
```

An immediate variant of CountingPoisonPill is also available - ImmediateCountingPoisonPill.

```java
def op1 = selector(inputs: [a, b, c], outputs: [d, e]) {value, index -> }
def op2 = selector(inputs: [d], outputs: [f, out]) {}
def op3 = prioritySelector(inputs: [e, f], outputs: [b]) {value, index -> }
final pill = new ImmediateCountingPoisonPill(3)
a << pill
pill.join()
```

ImmediateCountingPoisonPill will safely and instantly shutdown dataflow networks even selectors involved in feedback loops, which normal non-immediate poison pill would not to.
Poison strategies

To correctly shutdown a network using PoisonPill you must identify the appropriate set of channels to send PoisonPill to will be those that serve as data sources for the network. to achieve for general cases or for complex networks. On the other hand, for networks with a predefined message flow PoisonPill provides a very straightforward way to shutdown the whole network gracefully.

Load-balancing architectures, which use multiple operators reading messages off a single channel (queue), will also prevent poison shutdown to work properly, since only one of the reading operators will get to read the poison message. You may consider using forking operators instead, by setting the maxForks property to a value greater than 1. Another alternative is to manually split the message stream into multiple channels, each of which be consumed by one of the original operators.

Termination tips and tricks

Notice that GPars tasks return a DataflowVariable, which gets bound to a value as soon as the termination operator below leverages the fact that DataflowVariables are implementations of the DataflowReadChannel interface and thus can be consumed by operators. As soon as both tasks finish, the operator will send a PoisonPill down the channel to stop the consumer as soon as it processes all data.

```groovy
import groovyx.gpars.dataflow.DataflowQueue
import groovyx.gpars.group.NonDaemonPGroup

def group = new NonDaemonPGroup()
final DataflowQueue q = new DataflowQueue()

// big producer
def green = group.task {
    (1..100).each { q << 'green channel ' + it
        sleep 10
    }
}

// little producer
def red = group.task {
    (1..10).each { q << 'red channel ' + it
        sleep 15
    }
}

def terminator = group.operator(inputs: [green, red], outputs: []) { t1, t2 ->
    q << PoisonPill.instance
}

customs.join()
group.shutdown()
```

Keeping PoisonPill inside a given network

If your network passed values through channels to entities outside of it, you may need to stop the data flow on the network boundaries. This can be easily achieved by putting a single-input single-output filter on such channel.
The **Pipeline DSL** may be also helpful here:

```kotlin
networkLeavingChannel.filter { !(it instanceOf PoisonPill) } into otherNetworkEnteringChannel
```

⚠️ Check out the **Pipeline DSL** section to find out more on pipelines.

### Graceful shutdown

GPars provides a generic way to shutdown a dataflow network. Unlike the previously mentioned approach will keep the network running until all the messages get handled and than gracefully shutting you know when this happens. You have to pay a modest performance penalty, though. Thus we need to keep track of what’s happening inside the network.

```kotlin
import groovyx.gpars.dataflow.DataflowBroadcast
import groovyx.gpars.dataflow.DataflowQueue
import groovyx.gpars.dataflow.operator.component.GracefulShutdownListener
import groovyx.gpars.dataflow.operator.component.GracefulShutdownMonitor
import groovyx.gpars.group.DefaultPGroup
import groovyx.gpars.group.PGroup

PGroup group = new DefaultPGroup(10)
final a = new DataflowQueue()
final b = new DataflowQueue()
final c = new DataflowQueue()
final d = new DataflowQueue<Object>()
final e = new DataflowBroadcast<Object>()
final f = new DataflowQueue<Object>()
final result = new DataflowQueue()
final monitor = new GracefulShutdownMonitor(100);

def op1 = group.operator(inputs: [a, b], outputs: [c], listeners: [new GracefulShutdownListener(monitor)]) {x, y ->
  sleep 5
  bindOutput x + y
}

def op2 = group.operator(inputs: [c], outputs: [d, e], listeners: [new GracefulShutdownListener(monitor)]) {x ->
  sleep 10
  bindAllOutputs 2*x
}

def op3 = group.operator(inputs: [d], outputs: [f], listeners: [new GracefulShutdownListener(monitor)]) {x ->
  sleep 5
  bindOutput x + 40
}

def op4 = group.operator(inputs: [e.createReadChannel(), f], outputs: [result], listeners: [new GracefulShutdownListener()]) {x, y ->
  sleep 5
  bindOutput x + y
}

100.times{a << 10}
100.times{b << 20}

final shutdownPromise = monitor.shutdownNetwork()

100.times{assert 160 == result.val}

shutdownPromise.get()
[op1, op2, op3, op4]*/.join()

group.shutdown()
```

First, we need an instance of **GracefulShutdownMonitor**, which will orchestrate the shutdown process. Instances of **GracefulShutdownListener** attached to all operators/selectors. These listeners observe processors together with their input channels and report to the shared **GracefulShutdownMonitor.shutdownNetwork()** is called on **GracefulShutdownMonitor**, it will periodically check for reported state of operators as well as the number of messages in their input channels.
Please make sure that no new messages enter the dataflow network after the shutdown has been initiated, since this may cause the network to never terminate. The shutdown process should only be started after all data producers have ceased sending additional messages to the monitored network.

The `shutdownNetwork()` method returns a `Promise` so that you can do the usual set of tricks with the network to terminate using the `get()` method, register a callback using the `whenBound()` method or make a whole set of activities through the `then()` method.

### Limitations of graceful shutdown

1. For `GracefulShutdownListener` to work correctly, its `messageArrived()` event handler must see the original value that has arrived through the input channel. Since some event listeners may alter the messages as they pass through the listeners it is advisable to add the `GracefulShutdownListener` first to the list of listeners on each dataflow processor.

2. Also, graceful shutdown will not work for those rare operators that have listeners, which turn control messages into plain value messages in the `controlMessageArrived()` handler.

3. Third and last, load-balancing architectures, which use multiple operators reading messages off a shared channel (queue), will also prevent graceful shutdown to work properly. You may consider using forked operators instead, by setting the `maxForks` property to a value greater than 1. Another alternative is to manually split the message stream into multiple channels, each of which would be consumed by one of the original operators.

### 7.5 Application Frameworks

Dataflow Operators and Selectors can be successfully used to build high-level domain-specific frameworks for problems that naturally fit the flow model.

**Building flow frameworks on top of GPars dataflow**

GPars dataflow can be viewed as bottom-line language-level infrastructure. Operators, selectors, listeners can be very useful at language level to combine, for example, with actors or parallel collections. Whenever a need comes for asynchronous handling of events that come through one of more channels, a dataflow network could be a very good fit. Unlike tasks, operators are lightweight and release threads when there’s no message to process. Unlike actors, operators are addressed indirectly through channels to combine messages from multiple channels into one action.

Alternatively, operators can be looked at as continuous functions, which instantly and repeatedly transform input values into output. We believe that a concurrency-friendly general-purpose programming language type of abstraction.

At the same time, dataflow elements can be easily used as building blocks for constructing domain workflow-like frameworks. These frameworks can offer higher-level abstractions specialized to a domain, which would be inappropriate for a general-purpose language-level library. Each of the then mapped to (potentially several) GPars concepts.
For example, a network solving data-mining problems may consist of several data sources, data categorization nodes, reporting nodes and others. Image processing network, on the other hand, specialized in image compression and format transformation. Similarly, networks for data encryption work-flow management as well as many other domains that would benefit from dataflow-based solutions - the type of nodes in the network, the type and frequency of events, the load-balance potential constraints on branching, the need for visualization, debugging and logging, the way us networks and interact with them as well as many others.

The higher-level application-specific frameworks should put effort into providing abstractions best domain and hide GPars complexities. For example, the visual graph of the network that the user screen should typically not show all the channels that participate in the network. Debugging or logs rarely contribute to the core of the solution, are among the first good candidates to consider for exclusion. Channels and lifecycle-event listeners, which orchestrate aspects such as load balancing or graceful shutdown, will probably be not exposed to the user, although they will be part of the generated and executed network. Single channel in the domain-specific model will in reality translate into multiple channels perhaps logging/transforming/filtering operators connecting them together. The function associated with a be wrapped with some additional infrastructural code to form the operator's body.

GPars gives you the underlying components that the end user may be abstracted away complete application-specific framework. This keeps GPars domain-agnostic and universal, yet useful at the implementation level.

7.6 Pipeline DSL

A DSL for building operators pipelines

Building dataflow networks can be further simplified. GPars offers handy shortcuts for the common scenario of building (mostly linear) pipelines of operators.

```java
def toUpperCase = {s -> s.toUpperCase()}
final encrypt = new DataflowQueue()
final DataflowReadChannel encrypted = encrypt | toUpperCase | (it.reverse()) | {'###encrypted###' + it + '###'}
encrypt << "I need to keep this message secret!"
encrypt << "GPars can build linear operator pipelines really easily"
print encrypted.val
print encrypted.val
```

This saves you from directly creating, wiring and manipulating all the channels and operators that pipeline. The `pipe` operator lets you hook an output of one function/operator/process to the input like chaining system processes on the command line.

The `pipe` operator is a handy shorthand for a more generic `chainWith()` method:

```java
def toUpperCase = {s -> s.toUpperCase()}
final encrypt = new DataflowQueue()
final DataflowReadChannel encrypted = encrypt.chainWith toUpperCase chainWith (it.reverse()) chainWith ('###encrypted###')
encrypt << "I need to keep this message secret!"
encrypt << "GPars can build linear operator pipelines really easily"
print encrypted.val
print encrypted.val
```

Combining pipelines with straight operators
Since each operator pipeline has an entry and an exit channel, pipelines can be wired into more complex operator networks. Only your imagination can limit your ability to mix pipelines with channels and operator definitions.

```groovy
def toUpperCase = {s -> s.toUpperCase()}
def save = {text ->
  //Just pretending to be saving the text to disk, database or whatever
  println 'Saving ' + text
}

final toEncrypt = new DataflowQueue()
final DataflowReadChannel encrypted = toEncrypt.chainWith toUpperCase chainWith {it.reverse()} chainWith {'###' + it + '###'}

final DataflowQueue fork1 = new DataflowQueue()
final DataflowQueue fork2 = new DataflowQueue()
final splitter(encrypted, [fork1, fork2])  //Split the data flow
fork1.chainWith save  //Hook in the save operation

final toEncrypt = "I need to keep this message secret!"
toEncrypt << "GPars can build operator pipelines really easy"

println decrypted.val
println decrypted.val
```

The type of the channel is preserved across the whole pipeline. E.g. if you start chaining synchronous channels, all the channels in the pipeline will be synchronous. In that case obviously, the whole chain blocks, including the writer who writes into the channel at the head, until someone reads data off the tail of the pipeline.

```
final SyncDataflowQueue queue = new SyncDataflowQueue()
final result = queue.chainWith {it * 2}.chainWith {it + 1} chainWith {it * 100}

Thread.start {
  5.times {
    println result.val
  }
}
queue << 1
queue << 2
queue << 3
queue << 4
queue << 5
```

Joining pipelines

Two pipelines (or channels) can be connected using the `into()` method:

```
final encrypt = new DataflowQueue()
final DataflowWriteChannel messagesToSave = new DataflowQueue()
encrypt.chainWith toUpperCase chainWith {it.reverse()} into messagesToSave

task {
  encrypt << "I need to keep this message secret!"
  encrypt << "GPars can build operator pipelines really easy"
}

task {
  2.times {
    println "Saving " + messagesToSave.val
  }
}
```

The output of the `encryption` pipeline is directly connected to the input of the `saving` pipeline (a synchronous case).
Forking the data flow

When a need comes to copy the output of a pipeline/channel into more than one following pipeline method will help you:

```java
final encrypt = new DataflowQueue()
final DataflowWriteChannel messagesToSave = new DataflowQueue()
final DataflowWriteChannel messagesToLog = new DataflowQueue()
encrypt.chainWith toUpperCase chainWith {it.reverse()}.split(messagesToSave, messagesToLog)
```

Tapping into the pipeline

Like `split()` the `tap()` method allows you to fork the data flow into multiple channels. Tapping, however, is convenient in some scenarios, since it treats one of the two new forks as the successor of the pipi:

```java
queue.chainWith {it * 2}.tap(logChannel).chainWith{it + 1}.tap(logChannel).into(PrintChannel)
```

Merging channels

Merging allows you to join multiple read channels as inputs for a single dataflow operator. The function passed as the second argument needs to accept as many arguments as there are channels being merged - each the corresponding channel.

```java
maleChannel.merge(femaleChannel) {m, f -> m.marry(f)}.into(mortgageCandidatesChannel)
```

Separation

`Separation` is the opposite operation to `merge`. The supplied closure returns a list of values, each output into an output channel with the corresponding position index.

```java
queue1.separate([queue2, queue3, queue4]) {a -> [a-1, a, a+1]}
```

Choices

The `binaryChoice()` and `choice()` methods allow you to send a value to one out of two (or many) indicated by the return value from a closure.

```java
queue1.binaryChoice(queue2, queue3) {a -> a > 0}
queue1.choice([queue2, queue3, queue4]) {a -> a % 3}
```

Filtering

The `filter()` method allows to filter data in the pipeline using boolean predicates.
null values

If a chained function returns a null value, it is normally passed along the pipeline as a valid value operator that no value should be passed further down the pipeline, a NullObject.nullObject instance.

customizing the thread pools

All of the Pipeline DSL methods allow for custom thread pools or PGroups to be specified:
Overriding the default PGroup

To avoid the necessity to specify PGroup for each Pipeline DSL method separately you may override the default Dataflow PGroup.

```java
Dataflow.usingGroup(group) {
    channel.choice(branches)
}
//Is identical to
channel.choice(group, branches)
```

The `Dataflow.usingGroup()` method resets the value of the default dataflow PGroup for the given value specified.

The pipeline builder

The `Pipeline` class offers an intuitive builder for operator pipelines. The greatest benefit of using it compared to chaining the channels directly is the ease with which a custom thread pool/group can be applied to all the operators along the constructed chain. The available methods and overloaded operators are identical to the ones available on channels directly.

```java
import groovyx.gpars.dataflow.DataflowQueue
import groovyx.gpars.dataflow.operator.Pipeline
import groovyx.gpars.scheduler.DefaultPool
import groovyx.gpars.scheduler.Pool

final DataflowQueue queue = new DataflowQueue()
final DataflowQueue result1 = new DataflowQueue()
final DataflowQueue result2 = new DataflowQueue()
final Pool pool = new DefaultPool(false, 2)
final negate = {-it}

final Pipeline pipeline = new Pipeline(pool, queue)
pipeline | {it * 2} | {it + 1} | negate
pipeline.split(result1, result2)
queue << 1
queue << 2
queue << 3
assert -3 == result1.val
assert -5 == result1.val
assert -7 == result1.val
assert -3 == result2.val
assert -5 == result2.val
assert -7 == result2.val
pool.shutdown()
```

Passing construction parameters through the Pipeline DSL

You are likely to frequently need the ability to pass additional initialization parameters to the operators to attach or the value for `maxForks`. Just like when building operators directly, the Pipeline accept an optional map of parameters to pass in.

```java
new Pipeline(group, queue1).merge([maxForks: 4, listeners: [listener]], queue2) (a, b -> a + b).into queue3
```

7.7 Implementation
The Dataflow Concurrency in GPars builds on the same principles as the actor support. All of the tasks share a thread pool and so the number threads created through `Dataflow.task()` factory method don’t need to correspond to the number of physical threads required from the system. The `PGroup.task()` factory method can create a task to a group. Since each group defines its own thread pool, you can easily organize tasks around different thread pools just like you do with actors.

### Combining actors and Dataflow Concurrency

The good news is that you can combine actors and Dataflow Concurrency in any way you feel fit for your particular problem at hands. You can freely use Dataflow Variables from actors.

```java
final DataflowVariable a = new DataflowVariable()
final Actor doubler = Actors.actor {
  react {message->
    a << 2 * message
  }
}
final Actor fakingDoubler = actor {
  react {
    doubler.send it  //send a number to the doubler
    println "Result: \${a.val}"  //wait for the result to be bound to 'a'
  }
}
fakingDoubler << 10
```

In the example you see the "fakingDoubler" using both messages and a `DataflowVariable` to communicate with the `doubler` actor.

### Using plain java threads

The `DataflowVariable` as well as the `DataflowQueue` classes can obviously be used from any thread not only from the tasks created by `Dataflow.task()` . Consider the following example:

```java
import groovyx.gpars.dataflow.DataflowVariable
final DataflowVariable a = new DataflowVariable<String>()
final DataflowVariable b = new DataflowVariable<String>()
Thread.start {
  println "Received: \${a.val}"
  Thread.sleep 2000
  b << 'Thank you'
}
Thread.start {
  Thread.sleep 2000
  a << 'An important message from the second thread'
  println "Reply: \${b.val}"}
```

We’re creating two plain `java.lang.Thread` instances, which exchange data using the two data flows, neither the actor lifecycle methods, nor the send/react functionality or thread pooling take effect.

### 7.8 Synchronous Variables and Channels
When using asynchronous dataflow channels, apart from the fact that readers have to wait for a value to be available for consumption, the communicating parties remain completely independent. Writers don't wait for their messages to get consumed. Readers obtain values immediately as they come and ask. Synchronous channels can synchronize writers with the readers as well as multiple readers among themselves. This is particularly useful when you need to increase the level of determinism. The writer-to-reader partial ordering imposed by a communication is complemented with reader-to-writer partial ordering, when using synchronous channels. In other words, you are guaranteed that whatever the reader did before reading a value from a synchronous channel preceded whatever the writer did after writing the value. Also, with synchronous communication writers can never get too far ahead of readers, which simplifies reasoning about the system and reduces the need to manage data production speed in order to avoid system overload.

### Synchronous dataflow queue

The `SyncDataflowQueue` class should be used for point-to-point (1:1 or n:1) communication. Each message written to the queue will be consumed by exactly one reader. Writers are blocked until their message is consumed until there's a value available for them to read.

```groovy
import groovyx.gpars.dataflow.SyncDataflowQueue
import groovyx.gpars.group.NonDaemonPGroup
/**
 * Shows how synchronous dataflow queues can be used to throttle fast producer when serving data to a slow consumer.
 * Unlike when using asynchronous channels, synchronous channels block both the writer and the readers until a message is exchanged.
 */
def group = new NonDaemonPGroup()
final SyncDataflowQueue channel = new SyncDataflowQueue()
def producer = group.task {
    (1..30).each {
        channel << it
        println "Just sent $it"
    }
    channel << -1
}
def consumer = group.task {
    while (true) {
        sleep 500 // simulating a slow consumer
        final Object msg = channel.val
        if (msg == -1) return
        println "Received $msg"
    }
}
consumer.join()
group.shutdown()
```

### Synchronous dataflow broadcast

The `SyncDataflowBroadcast` class should be used for publish-subscribe (1:n or n:m) communication. Each message written to the broadcast will be consumed by all subscribed readers. Writers are blocked until the message is consumed by all readers, readers are blocked until there's a value available for them to read and subscribed readers ask for the message as well. With `SyncDataflowBroadcast` you get all readers message at the same time and waiting for one-another before getting the next one.
Synchronous dataflow variable

Unlike `DataflowVariable`, which is asynchronous and only blocks the readers until a value is bound to the variable, the `SyncDataflowVariable` class provides a one-shot data exchange mechanism that blocks the write a specified number of waiting parties is reached.

7.9 Kanban Flow

APIs: [KanbanFlow](#) | [KanbanLink](#) | [KanbanTray](#) | [ProcessingNode](#)
**KanbanFlow**

A *KanbanFlow* is a composed object that uses dataflow abstractions to define dependencies between concurrent producer and consumer operators.

Each link between a producer and a consumer is defined by a *KanbanLink*.

Inside each KanbanLink, the communication between producer and consumer follows the Kanban pattern described in [The KanbanFlow Pattern](#) (recommended read). They use objects of type *KanbanTray* downstream and signal requests for further products back to the producer.

The figure below shows a *KanbanLink* with one producer, one consumer and five trays numbered 0 to 4. Tray number 0 has been used to take a product from producer to consumer, has been emptied by the consumer and is now sent back to the producer’s input queue. Trays 1 and 2 wait to carry products waiting for consumption, trays 3 and 4 wait to be used by producers.

A *KanbanFlow* object links producers to consumers thus creating *KanbanLink* objects. In the course of this activity, a second link may be constructed where the producer is the same object that acted as the consumer in a formerly created link such that the two links become connected to build a chain.

Here is an example of a *KanbanFlow* with only one link, e.g. one producer and one consumer. The producer always sends the number 1 downstream and the consumer prints this number.

```groovy
import static groovyx.gpars.dataflow.ProcessingNode.node
import groovyx.gpars.dataflow.KanbanFlow
def producer = node { down -> down 1 }
def consumer = node { up   -> println up.take() }
new KanbanFlow().with {
  new link producer to consumer
  start()
  // run for a while
  stop()
}
```

For putting a product into a tray and sending the tray downstream, one can either use the *send* operator, or use the tray as a method object. The following lines are equivalent:

```groovy
node { down -> down.send 1 }
node { down -> down << 1 }
node { down -> down 1 }
```

When a product is taken from the input tray with the *take()* method, the empty tray is automatically released. You should call *take()* only once!

If you prefer to not using an empty tray for sending products downstream (as typically the case when *ProcessingNode* acts as a filter), you must release the tray in order to keep it in play. Otherwise, the system decreases. You can release a tray either by calling the *release()* method or by using the *~* operator (think “shake it off”). The following lines are equivalent:

```groovy
node { down -> down.release() }
node { down -> ~down }
```
Trays are automatically released, if you call any of the `take()` or `send()` methods.

Various linking structures

In addition to a linear chains, a `KanbanFlow` can also link a single producer to multiple consumer producers to a single consumer (collector) or any combination of the above that results in a directed acyclic graph (DAG).

The `KanbanFlowTest` class has many examples for such structures, including scenarios where a delegates work to multiple consumers with

- a **work-stealing** strategy where all consumers get their pick from the downstream,
- a **master-slave** strategy where a producer chooses from the available consumers, and
- a **broadcast** strategy where a producer sends all products to all consumers.

Cycles are forbidden by default but when enabled, they can be used as so-called generators. A producer can even be his own consumer that increases a product value in every cycle. The generator itself remains state-free since the value is only stored as a product riding on a tray. Such a generator can be used for e.g. lazy sequence “heartbeat” of a subsequent flow.

The approach of generator "loops" can equally be applied to collectors, where a collector does not maintain any internal state but sends a collection onto itself, adding products at each call.

Generally speaking, a `ProcessingNode` can link to itself for exporting state to the tray/product that Access to the product is then **thread-safe by design**.

Composing KanbanFlows

Just as `KanbanLink` objects can be chained together to form a `KanbanFlow`, flows themselves can be composed to form new greater flows from existing smaller ones.

```java
def firstFlow = new KanbanFlow()
def producer  = node(counter)
def consumer  = node(repeater)
firstFlow.link(producer).to(consumer)
def secondFlow = new KanbanFlow()
def producer2 = node(repeater)
def consumer2 = node(reporter)
secondFlow.link(producer2).to(consumer2)
flow = firstFlow + secondFlow
flow.start()
```

Customizing concurrency characteristics

The amount of concurrency in a kanban system is determined by the number of trays (sometimes called WIP = work in progress). With no trays in the streams, the system does nothing.

- With one tray only, the system is confined to sequential execution.
- With more trays, concurrency begins.
- With more trays than available processing units, the system begins to waste resources.
The number of trays can be controlled in various ways. They are typically set when starting the flow:

```java
flow.start(0) // start without trays
flow.start(1) // start with one tray per link in the flow
flow.start()  // start with the optimal number of trays
```

In addition to the trays, the KanbanFlow may also be constrained by its underlying ThreadPool. For example, a pool of size 1 for the KanbanFlow example will not allow much concurrency.

KanbanFlows use a default pool that is dimensioned by the number of available cores. This can be customized by setting the pooledGroup property.

Test:
KanbanFlowTest

Demos:
DemoKanbanFlow
DemoKanbanFlowBroadcast
DemoKanbanFlowCycle
DemoKanbanLazyPrimeSequenceLoops

### 7.10 Classic Examples

The Sieve of Eratosthenes implementation using dataflow tasks

```java
import groovyx.gpars.dataflow.DataflowQueue
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * Demonstrates concurrent implementation of the Sieve of Eratosthenes using dataflow tasks
 */
final int requestedPrimeNumberCount = 1000
final DataflowQueue initialChannel = new DataflowQueue()

/**
 * Generating candidate numbers
 */
task {
    (2..10000).each {
        initialChannel << it
    }
}

/**
 * Chain a new filter for a particular prime number to the end of the Sieve
 * @param inChannel The current end channel to consume
 * @param prime The prime number to divide future prime candidates with
 * @return A new channel ending the whole chain
 */
def filter(inChannel, int prime) {
    def outChannel = new DataflowQueue()
    task {
        while (true) {
            def number = inChannel.val
            if (number % prime != 0) {
                outChannel << number
            }
        }
        return outChannel
    }
}

/**
 * Consume Sieve output and add additional filters for all found primes
 */
def currentOutput = initialChannel
requestedPrimeNumberCount.times {
    int prime = currentOutput.val
    println "Found: $prime"
    currentOutput = filter(currentOutput, prime)
}
```
The Sieve of Eratosthenes implementation using a combination of dataflow operators

```java
import groovyx.gpars.dataflow.DataflowQueue
import static groovyx.gpars.dataflow.Dataflow.operator
import static groovyx.gpars.dataflow.Dataflow.task

/**
 * Demonstrates concurrent implementation of the Sieve of Eratosthenes using dataflow tasks and operators
 */

final int requestedPrimeNumberCount = 100
final DataflowQueue initialChannel = new DataflowQueue()

/**
 * Generating candidate numbers
 */
task {
    (2..1000).each {
        initialChannel << it
    }
}

/**
 * Chain a new filter for a particular prime number to the end of the Sieve
 * @param inChannel The current end channel to consume
 * @param prime The prime number to divide future prime candidates with
 * @return A new channel ending the whole chain
 */
def filter(inChannel, int prime) {
    def outChannel = new DataflowQueue()
    new (inputs: [inChannel], outputs: [outChannel]) {
        operator {it % prime != 0} {
            bindOutput it
        }
    }
    return outChannel
}

/**
 * Consume Sieve output and add additional filters for all found primes
 */
def currentOutput = initialChannel
requestedPrimeNumberCount.times {
    prime = currentOutput.val
    println "Found: $prime"
    currentOutput = filter(currentOutput, prime)
}
```

STM

Software Transactional Memory (STM) gives developers transactional semantics for accessing in-memory data. When multiple threads share data in memory, by marking blocks of code as transactional (atomic) the responsibility for data consistency is delegated to the Stm engine. GPars leverages the Multiverse Stm engine. Check out more details on the transactional engine at the Multiverse site.

Running a piece of code atomically

When using Stm, developers organize their code into transactions. A transaction is a piece of code - either all the code is run or none at all. The data used by the transactional code remains atomically consistent irrespective of whether the transaction finishes normally or abruptly. While running inside a transaction, given an illusion of being isolated from the other concurrently run transactions so that changes to transaction are not visible in the other ones until the transactions commit. This gives us the ACID characteristics of database transactions. The durability transactional aspect so typical for database transactions is not mandated for Stm.

GPars allows developers to specify transaction boundaries by using the atomic closures.

```java
import groovyx.gpars.stm.GParsStm
import org.multiverse.api.references.TxnInteger
import static org.multiverse.api.StmUtils.newTxnInteger

public class Account {
    private final TxnInteger amount = newTxnInteger(0);
    public void transfer(final int a) {
        GParsStm.atomic {
            amount.increment(a);
        }
    }
    public int getCurrentAmount() {
        GParsStm.atomicWithInt {
            amount.get();
        }
    }
}
```

There are several types of atomic closures, each for different type of return value:

- atomic - returning Object
- atomicWithInt - returning int
- atomicWithLong - returning long
- atomicWithBoolean - returning boolean
- atomicWithDouble - returning double
- atomicWithVoid - no return value

Multiverse by default uses optimistic locking strategy and automatically rolls back and retries colliding transactions. Developers should thus restrain from irreversible actions (e.g. writing to the console, sending an email, launching a missile, etc.) in their transactional code. To increase flexibility, the default Multiverse settings can be customized through custom atomic blocks.

Customizing the transactional properties
Frequently it may be desired to specify different values for some of the transaction properties (e.g., read-only transactions, locking strategy, isolation level, etc.). The `createAtomicBlock` method will create a `AtomicBlock` configured with the supplied values:

```java
import groovyx.gpars.stm.GParsStm
import org.multiverse.api.AtomicBlock
import org.multiverse.api.PropagationLevel

final TxnExecutor block = GParsStm.createTxnExecutor(maxRetries: 3000, familyName: 'Custom', PropagationLevel: PropagationLevel.Requires, interruptible: false)
assert GParsStm.atomicWithBoolean(block) {
    true
}
```

The customized `AtomicBlock` can then be used to create transactions following the specified settings. `AtomicBlock` instances are thread-safe and can be freely reused among threads and transactions.

## Using the `Transaction` object

The atomic closures are provided the current `Transaction` as a parameter. The `Txn` objects can then be used to manually control the transaction. This is illustrated in the example below, where we use the `retry()` method to block the current transaction until the counter reaches the desired value:

```java
import groovyx.gpars.stm.GParsStm
import org.multiverse.api.PropagationLevel
import org.multiverse.api.TxnExecutor
import static org.multiverse.api.StmUtils.newTxnInteger

final TxnExecutor block = GParsStm.createTxnExecutor(maxRetries: 3000, familyName: 'Custom', PropagationLevel: PropagationLevel.Requires, interruptible: false)
def counter = newTxnInteger(0)
final int max = 100
Thread.start {
    while (counter.atomicGet() < max) {
        counter.atomicIncrementAndGet(1)
        sleep 10
    }
}
assert max + 1 == GParsStm.atomicWithInt(block) { tx ->
    if (counter.get() == max) return counter.get() + 1
    tx.retry()
}
```

## Data structures

You might have noticed in the code examples above that we use dedicated data structures to hold values. Normal Java classes do not support transactions and thus cannot be used directly, since Multiverse would not be able to share them safely among concurrent transactions, commit them nor roll them back. We need to use data that knows about transactions:

- `TxnIntRef`
- `TxnLongRef`
- `TxnBooleanRef`
- `TxnDoubleRef`
- `TxnRef`

You typically create these through the factory methods of the `org.multiverse.api.StmUtils` class.

## More information
We decided not to duplicate the information that is already available on the Multiverse website. Please visit the Multiverse site and use it as a reference for your further Stm adventures with GPars.
9 Google App Engine Integration

GPars can be run on the Google App Engine (GAE). It can be made part of Groovy and Java G as a plugged into Gaelyk. The small GPars App Engine integration library provides all the necessary infrastructure to hook GAE services into GPars. Although you'll be running on GAE threads and leveraging GAE's high-level abstractions remain the same. With a few restrictions you can still use GPars actors, parallel collections and other handy concepts.

Please refer to the GPars App Engine library documentation for details on how to proceed with G
10 Tips

General GPars Tips

Grouping

High-level concurrency concepts, like Agents, Actors or Dataflow tasks and operators can be grouped around shared thread pools. The `Group` class and its sub-classes represent convenient GPars wrappers around thread pools. Objects created using the group's factory methods will share the group's thread pool.

```groovy
def group1 = new DefaultPGroup()
def group2 = new NonDaemonPGroup()
group1.with {
task {...}
task {...}
def op = operator(...) {...}
def actor = actor({...})
def anotherActor = group2.actor({...}) // will belong to group2
def agent = safe(0)
}
```

When customizing the thread pools for groups, consider using the existing GPars implementations - the `DefaultPool` or `ResizablePool` classes. Or you may create your own implementation of the `groovyx.gpars.scheduler.Pool` interface to pass to the `DefaultPGroup` or `NonDaemonPGroup` constructors.

Java API

Most of GPars functionality can be used from Java just as well as from Groovy. Checkout the 2.6 *GPars from Java* section of the User Guide and experiment with the maven-based stand-alone J. Take GPars with you wherever you go!

10.1 Performance

Your code in Groovy can be just as fast as code written in Java, Scala or any other programing language. This should not be surprising, since GPars is technically a solid tasty Java-made cake with a Groovy DSL cream on it. Unlike in Java, however, with GPars, as well as with other DSL-friendly languages, you are very likely to experience a useful kind of code speed-up for free, a speed-up coming from a better and cleaner design of your with a concurrency DSL will give you smaller code-base with code using the concurrency primitive constructs. So it is much easier to build robust concurrent applications, identify potential bottle-necks or errors and eliminate them.

While this whole User Guide is describing how to use Groovy and GPars to create beautiful and robust concurrent code, let's use this chapter to highlight a few places, where some code tuning or minor design compromises could give you interesting performance gains.

Parallel Collections
Methods for parallel collection processing, like `eachParallel()`, `collectParallel()` and such use `Par` tree-like data structure behind the scenes. This data structure has to be built from the original collection any of the parallel collection methods. Thus when chaining parallel method calls you might consider using the `ParallelArray` API instead or resort to using the `ParallelArray` API directly, to avoid the `ParallelArray` creation overhead.

```java
GParsPool.withPool {
  people.findAllParallel{it.isMale()}.collectParallel{it.name}.any{it == 'Joe'}
  people.parallel.filter{it.isMale()}.map{it.name}.filter{it == 'Joe'}.size() > 0
  people.parallelArray.withFilter({it.isMale()} as Predicate).withMapping({it.name} as Mapper).any{it == 'Joe'}
}
```

In many scenarios changing the pool size from the default value may give you performance benefits. Especially if your tasks perform IO operations, like file or database access, networking and such, increasing the number of threads in the pool is likely to help performance.

```java
GParsPool.withPool(50) {
  ...
}
```

Since the closures you provide to the parallel collection processing methods will get executed concurrently, you may further slightly benefit from turning them into Java.

**Actors**

GPars actors are fast. `DynamicDispatchActors` and `ReactiveActors` are about twice as fast as the `DynamicDispatchActors` in performance with actors in `Scala`, which you can hardly hear of as being slow.

If top performance is what you're looking for, a good start is to identify the following patterns in your actor code:

```java
actor {
  loop {
    react {msg ->
      switch (msg) {
        case String:...
        case Integer:...
      }
    }
  }
}
```

and replace them with `DynamicDispatchActor`:

```java
messageHandler {
  when(String msg -> ...) {
    when(Integer msg -> ...)
  }
}
```

The `loop` and `react` methods are rather costly to call.

Defining a `DynamicDispatchActor` or `ReactiveActor` as classes instead of using the `messageHandler` factory methods will also give you some more speed:

```java
class MyHandler extends DynamicDispatchActor {
  public void handleMessage(String msg) {
    ...
  }

  public void handleMessage(Integer msg) {
    ...
  }
}
```
Now, moving the *MyHandler* class into Java will squeeze the last bit of performance from GPars.

**Pool adjustment**

GPars allows you to group actors around thread pools, giving you the freedom to organize actors always worthwhile to experiment with the actor pool size and type. *FJPool* usually gives better characteristics than *DefaultPool*, but seems to be more sensitive to the number of threads in the pool. Sometimes using a *ResizeablePool* could help performance by automatic eliminating unneeded threads.

```groovy
def attackerGroup = new DefaultPGroup(new ResizeableFJPool(10))
def defenderGroup = new DefaultPGroup(new DefaultPool(5))
def attacker = attackerGroup.actor {...}
def defender = defenderGroup.messageHandler {...}
...```

**Agents**

GPars *Agents* are even a bit faster in processing messages than actors. The advice to group agents around thread pools and tune the pool sizes and types applies to agents as well as to actors. With agent benefit from submitting Java-written closures as messages.

**Share your experience**

The more we hear about GPars uses in the wild the better we can adapt it for the future. Let us know how you use GPars and how it performs. Send us your benchmarks, performance comparisons or profiling reports to help us tune GPars for you.

**10.2 Integration into hosted environment**

Hosted environments, such as Google App Engine, impose additional restrictions on threading. For these environments better, the default thread factory and timer factory can be customized. The `GPars_Config` class provides static initialization methods allowing third parties to register their own implementations of the `PoolFactory` and `TimerFactory` interfaces, which will then be used to create default pools and timers for Actors, Dataflow and PGroups.

```java
public final class GParsConfig {
    private static volatile PoolFactory poolFactory;
    private static volatile TimerFactory timerFactory;
    public static void setPoolFactory(final PoolFactory pool)
    public static PoolFactory getPoolFactory()
    public static Pool retrieveDefaultPool()
    public static void setTimerFactory(final TimerFactory timerFactory)
    public static TimerFactory getTimerFactory()
    public static GeneralTimer retrieveDefaultTimer(final String name, final boolean daemon)
    public static void shutdown()
}
```

The custom factories should be registered immediately after the application startup in order for Actors to be able to use them for their default groups.
Shutdown

The `GParsConfig.shutdown()` method can be used in managed environments to properly shutdown run timers and free the memory from all thread-local variables. After the call to this method the GPars library will no longer provide the declared services.

Compatibility

Some further compatibility problems may occur when running GPars in a hosted environment. This is probably the lack of ForkJoinThreadPool (aka jsr-166y) support in GAE. Functionality such as `GParsPool` may thus not be available on some services as a result. However, `GParsExecutorsPool`, `Agents` and `Stm` should work normally even when using managed non-Java SE thread pools.
11 Conclusion

This was quite a wild ride, wasn't it? Now, after going through the User Guide, you're certainly ready to build fast, robust and reliable concurrent applications. You've seen that there are many concepts you can choose from and each has its own areas of applicability. The ability to pick the right concept to apply to a given problem is key to being a successful developer. If you feel you can do this with GPars, the mission of the User Guide has been accomplished.

Now, go ahead, use GPars and have fun!