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Enhanced Process APIs

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October 27, 2015

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Program Agenda

1. Creating and Working with Processes
2. Information about Processes
3. Asynchronous Process Management
4. Efficient Handling of Process Output
5. Summary

Many Use Cases

- Running arbitrary commands
  - Collecting, filtering, and redirecting output
  - Connecting heterogeneous commands and shells
- Test execution
  - Run a series of tests
  - Log the output
  - Clean up left over processes
- Monitoring
  - Monitor long running processes and re-spawn if they die
  - Collect usage statistics

ProcessBuilder – The basics

- ProcessBuilder Basics
  - Command and arguments
  - Environment variables and working directory
  - Redirection
    - Standard input, standard output, standard error
    - Inherit from invoking process or discard output
    - Send to or read from Files
    - Send to OutputStreams or read from InputStreams
- Create a process

```
Process p = new ProcessBuilder(“date”).start();
```

Process – Controls a spawned process

- waitFor(), waitFor(timeout, units) – wait for the process to exit
- isAlive(), getPid(), info(), exitValue() – information about the process
- Redirecting output and input to I/O Streams
  - getErrorStream(), getInputStream(), getOutputStream()
- children(), allChildren() – the direct and indirect children
- destroy(), destroyForcibly(), supportsNormalTermination()
- onExit() – a ComputableFuture for process exit

ProcessHandle – A native process

- allProcesses() – All OS processes*
- getCurrent(), of(pid), parent() – get ProcessHandles
- isAlive(), getPid(), info() – information about the process
- children(), allChildren() – streams of direct and indirect children
- destroy(), destroyForcibly()
- onExit() – a ComputableFuture for process exit

* Limited by the native system access controls

ProcessBuilder redirecting to a file

```
File outFile = new File("out.tmp");

Process p = new ProcessBuilder(“ls”, “-lt”)
    .directory(new File(“/home/duke”))
    .redirectOutput(outFile)
    .redirectError(Redirect.INHERIT)
    .start();

int status = p.waitFor();
if (status == 0) {
    p = new ProcessBuilder("cat" , outFile.toString())
            .inheritIO()
            .start();
    p.waitFor();
}
```

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ProcessBuilder can supply environment variables

```
ProcessBuilder pb = new ProcessBuilder("printenv", "horse", "dog“, “LANG”)
                        .inheritIO();

pb.environment().put("horse", "oats");
pb.environment().put("dog", "treats");

pb.start().waitFor();
```

Output from printenv

```
oats
treats
en_US.UTF-8
```

Information about Processes

ProcessHandle.Info

- Information about processes is controlled by the OS
- Values are wrapped in Optional to indicate if the value is not available
- The user – Optional<String>
- The command – Optional<String>
- The arguments – Optional<String[]>
- The start time – Optional<Instant>
- The cputime – Optional<Duration>

Information about Processes

```
    static void showProcess(ProcessHandle ph) {
        ProcessHandle.Info info = ph.info();
        log.printf(“pid: %d, parent: %s, user: %s, cmd: %s%n”,
            ph.getPid(), ph.getParent(),
            info.user().orElse(“none”), info.command().orElse(“none”);
    }
```

```
% showProcess(ProcessHandle.current());
pid: 2909, parent: Optional[2650], user: duke, cmd: /opt/jdk1.9.0/bin/java
```

Filter Processes using Streams

```
Optional<String> currUser = ProcessHandle.current().info().user();
ProcessHandle.allProcesses()
    .filter(p1 -> p1.info().user().equals(currUser))
    .sorted(CodeSamples::parentComparator)
    .forEach(CodeSamples::showProcess);


static int parentComparator(ProcessHandle p1, ProcessHandle p2) {
    return Long.compare(p1.parent().get().getPid(),
                        p2.parent().get().getPid());
}
```

Sensitive Process Information

- Process information may contain sensitive info, userids, paths, arguments to commands
- Process control is sensitive, destroying a process may be detrimental
- When running as a normal application a ProcessHandle has the same OS privileges to information about other processes as a native application; information about system processes may not be available
- When a SecurityManager is in use, security policy must grant
  - `RuntimePermission(“manageProcess”)`

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OnExit – Flexible handling of process exit

- onExit returns a ComputableFuture<Process>
- ComputableFuture is multi-faceted handle to the Process / ProcessHandle
- As a Future the use is synchronous
  - isDone(), get(), get(timeout, units)
- As a ComputableFuture can schedule actions when the process exits
  - thenApply, thenAccept, thenRun,
    thenApplyAsync, thenAcceptAsync, thenRunAsync, etc.
  - Actions run in a thread provided by the ForkJoinPool commonPool

Example using Process.onExit

- Set of commands to run repeatedly
- Parallelism – run <n> of them in parallel
- Keep track of the results

Start the process again

```
    Semaphore count = new Semaphore(11);
    CountDownLatch end = new CountDownLatch(1);

    static void start(ProcessBuilder pb, Semaphore count, CountDownLatch end) {
        try {
            if (count.tryAcquire()) {
                Process p = pb.start();
                p.onExit()
                        .thenAccept(CodeSamples::logExit)
                        .thenRun(() -> start(pb, count, end));
            } else {
                end.countDown();
            }
        } catch (IOException ioe) {
            throw new RuntimeException("Process start failed", ioe);
        }
    }

    static void logExit(Process p) {
        log.printf("exit: %d, status: %d%n", p.getPid(), p.exitValue());
    }
```

Count each run

```
Semaphore count = new Semaphore(11);
CountDownLatch end = new CountDownLatch(1);

static void start(ProcessBuilder pb, Semaphore count, CountDownLatch end) {
    try {
        if (count.tryAcquire()) {
            Process p = pb.start();
            p.onExit()
                    .thenAccept(CodeSamples::logExit)
                    .thenRun(() -> start(pb, count, end));
        } else {
            end.countDown();
        }
    } catch (IOException ioe) {
        throw new RuntimeException("Process start failed", ioe);
    }
}

static void logExit(Process p) {
    log.printf("exit: %d, status: %d%n", p.getPid(), p.exitValue());
}
```

Finish when all have been started

```
Semaphore count = new Semaphore(11);
CountDownLatch end = new CountDownLatch(1);

static void start(ProcessBuilder pb, Semaphore count, CountDownLatch end) {
    try {
        if (count.tryAcquire()) {
            Process p = pb.start();
            p.onExit()
                    .thenAccept(CodeSamples::logExit)
                    .thenRun(() -> start(pb, count, end));
        } else {
            end.countDown();
        }
    } catch (IOException ioe) {
        throw new RuntimeException("Process start failed", ioe);
    }
}

static void logExit(Process p) {
    log.printf("exit: %d, status: %d%n", p.getPid(), p.exitValue());
}
```

OnExit – Complete

```
Semaphore count = new Semaphore(11);
CountDownLatch end = new CountDownLatch(1);

static void start(ProcessBuilder pb, Semaphore count, CountDownLatch end) {
    try {
        if (count.tryAcquire()) {
            Process p = pb.start();
            p.onExit()
                    .thenAccept(CodeSamples::logExit)
                    .thenRun(() -> start(pb, count, end));
        } else {
            end.countDown();
        }
    } catch (IOException ioe) {
        throw new RuntimeException("Process start failed", ioe);
    }
}

static void logExit(Process p) {
    log.printf("exit: %d, status: %d%n", p.getPid(), p.exitValue());
}
```

Repeat command and wait for them to be done

```
void repeat(ProcessBuilder pb, int total, int parallelism) throws Exception {
    Semaphore count = new Semaphore(total);
    CountDownLatch end = new CountDownLatch(1);

    for (int i = 0; i < parallelism; i++)      // Start the first n
        start(pb1, count, end);

    end.await();                     // wait until there are no more to be started

    ProcessHandle.current()      // wait for each of the active children to exit
        .children().forEach(CodeSamples::waitForExit);
}

static void waitForExit(ProcessHandle p) {
    try { p.onExit().get();} catch (Exception e) { … }
}

repeat(new ProcessBuilder("sh", "-c", "sleep 1;exit 1"), 11, 2);
```

Process Diagnostics and Progressive cleanup

- Commands don’t always terminate when expected
- Before destroying the process it is helpful to log some diagnostics
- Simply requesting the process to terminate normally may not succeed
- Harsher measures may be needed

Monitor the last moments of the Process

```
class TimeoutMonitor implements Runnable {
    public static void schedule(Process process, int delay, int rate) {
        new TimeoutMonitor(process).scheduledFuture
           = timeoutExecutor.scheduleAtFixedRate(ts, delay, rate, TimeUnit.SECONDS);
    }
    public synchronized void run() {
        if (process.isAlive()) {
            log.printf("Timeout countdown: %d%n", --countdown);
            showProcess(process.toHandle());
            process.allChildren().forEach(CodeSamples::showProcess);
            if (countdown == 1) {
                log.printf("Destroy process: %d%n", process.getPid());
                process.destroy();
            } else if (countdown == 0) {
                log.printf("Forcibly destroy process: %d%n", process.getPid());
                process.allChildren().forEach(ProcessHandle::destroyForcibly);
                process.destroyForcibly();
            }
        } else {
            scheduledFuture.cancel(false);
        }
    }
}
```

Start monitor for timeout

```
    Semaphore count = new Semaphore(11);
    CountDownLatch end = new CountDownLatch(1);

    static void start(ProcessBuilder pb, Semaphore count, CountDownLatch end) {
        try {
            if (count.tryAcquire()) {
                Process p = pb.start();
                p.onExit()
                        .thenAccept(CodeSamples::logExit)
                        .thenRun(() -> start(pb, count, end));
                TimeoutMonitor.schedule(p, 120, 5);
            } else {
                end.countDown();
            }
        } catch (IOException ioe) {
            throw new RuntimeException("Process start failed", ioe);
        }
    }

    static void logExit(Process p) {
        log.printf("exit: %d, status: %d%n", p.getPid(), p.exitValue());
    }
```

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Pipeline Output between Processes

Candidate for JDK 9

- Pipelines are a familiar tool for shell users
- Previously, no direct way to send the output of one process to another
- New ProcessBuilder.startPipe(ProcessBuilder… builders)
  - Launches one process for each builder
  - The standard output of each is directed to the standard input of the next
  - Input to the first builder and output of the last builder can be redirected
  - Returns a List of the processes created

Pipelining Processes

```
ProcessBuilder pb1 = new ProcessBuilder("ls");
ProcessBuilder pb2 = new ProcessBuilder("fgrep", “duke")
                         .redirectOutput(Redirect.INHERIT);
List<Process> processes = ProcessBuilder.startPipe(pb1, pb2);

processes.forEach(p -> {
    try {
        int status = p.waitFor();
        log.printf("status: %d%n", status);
    } catch (InterruptedException ie) {
    }
});
```

Pipe Channels for Process Output

Candidate for JDK 9

- Handling output of Processes via IO streams requires a thread per process
- NIO Channels for Pipes support bulk data transfers
- Pipes Are SelectableChannels

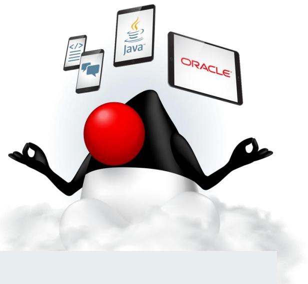
Copy Process Output via Pipe Channel to File

```
Process p = new ProcessBuilder("ls", "-ltGh")
               .redirectOutput(ProcessBuilder.Redirect.PIPE_CHANNEL)
               .start();

 // Copy from the channel to a file
 Path path = Paths.get("out.tmp");
 try (WritableByteChannel out = Files.newByteChannel(path, …  );
      Pipe.SourceChannel chan = p.getInputChannel()) {

     ByteBuffer bb = ByteBuffer.allocate(4096);
     while (chan.read(bb) > 0) {
         bb.flip();
         out.write(bb);
         bb.clear();
     }
 }
 p.waitFor();
```

NIO Selector can handle many channels in a Single Thread

- Create a Selector
- Associate a Channel specific function to consume the data
- Register Channel with the Selector
- Run the Selector to dispatch ready channels
- Wait for it to complete

Setup the Selector and Consumers of Process Output



```
Selector selector = Selector.open();

ProcessBuilder pb = new ProcessBuilder("ls", "-ltGh");
startTally(pb, selector);

ProcessBuilder pb2 = new ProcessBuilder("ls", "-l", "/tmp")
    .redirectOutput(ProcessBuilder.Redirect.PIPE_CHANNEL);
startTally(pb2, selector);

ProcessBuilder pb3 = new ProcessBuilder("ls", "-l", "/xxx")
        .redirectOutput(ProcessBuilder.Redirect.PIPE_CHANNEL);
startTally(pb3, selector);

runSelector(selector);
```

Create the consumer and register the channel

```
void startTally(ProcessBuilder pb, Selector selector) throws IOException {
    int[] tally = new int[1];

    pb.redirectOutput(ProcessBuilder.Redirect.PIPE_CHANNEL);

    Process p = pb.start();

    Consumer<SelectionKey> tallyFunc = (SelectionKey k) -> tallySize(k, p, tally);

    Pipe.SourceChannel chan = p.getInputChannel();
    chan.configureBlocking(false);
    chan.register(selector, SelectionKey.OP_READ, tallyFunc);
}
```

Run the Selector to dispatch ready channels

```
void runSelector(Selector selector) throws IOException {
    while (selector.selectNow() > 0 ||
            (selector.keys().size() > 0 && selector.select() > 0)) {

        Iterator<SelectionKey> it = selector.selectedKeys().iterator();
        while (it.hasNext()) {
            SelectionKey key = it.next();
            it.remove();

            ((Consumer<SelectionKey>) key.attachment())
                    .accept(key);              // Invoke the consumer
        }
    }
}
```

Channel Consumer to tally output size

```
void tallySize(SelectionKey key, Process p, int[] tally) {
    ReadableByteChannel chan = (ReadableByteChannel) key.channel();
    ByteBuffer bb = ByteBuffer.allocate(4096);
    try {
        int len;
        while ((len = chan.read(bb)) > 0) {
            tally[0] += len;
        }
        if (len < 0) {      // EOF
            log.printf("pid: %d, exit: %d, size: %d%n",
                              p.getPid(), p.exitValue(), tally[0]);
            closeChannel(chan);
        }
    } catch (IOException ioe) {
        closeChannel(chan);
    }
}
```

NIO Pipe Channel Summary

Candidate for JDK 9

- Create a Selector
- Register Channel and a Consumer with the Selector
- Run the Selector to dispatch ready channels
- Wait for everything to complete

Process and Process Handle Recap

- Information about native processes
  - Process id, user, command, arguments, cpu time, start time
- Monitor and Control
  - isAlive
  - destroy, destroyForcibly
- Process hierarchy
  - Streams of ProcessHandles
  - For all Processes, children and descendents

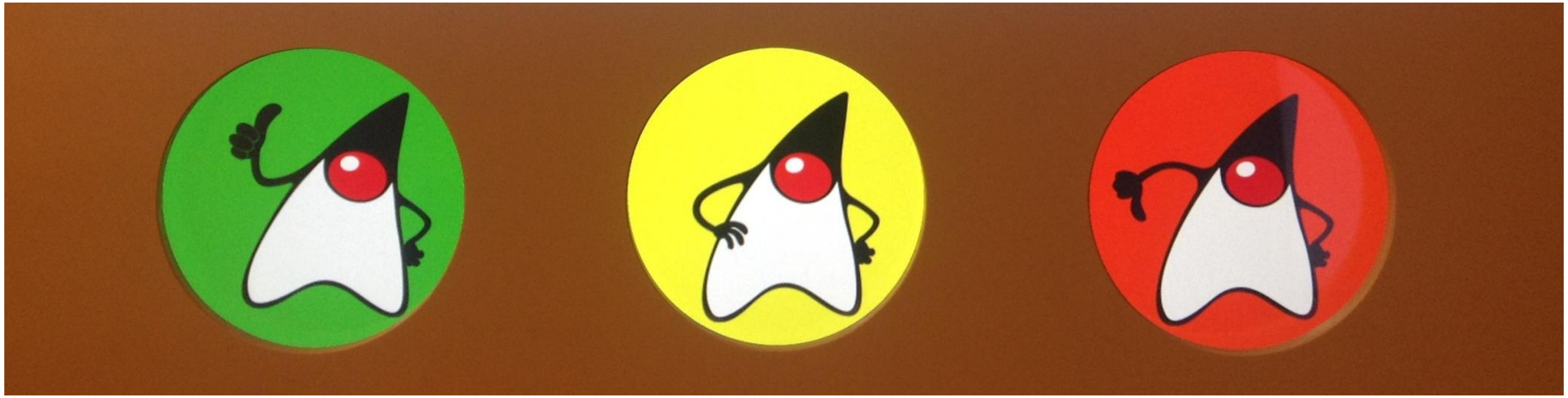
Process Enhancements Summary

- Monitoring process and task oriented results processing
  - onExit – Link tasks using ComputableFuture and the J.U.C. common pool
- Process handling of output
  - Pipeline output between processes *
  - Selectable Pipe Channels – scalable processing of output from processes *

* Candidate for JDK 9

Questions?

Comments!



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