Toward a Generic and Concurrency-Aware Pipes & Filters Framework

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Current State of Kieker

already optimized [Wa14]

Analysis component originally made for a modular offline analysis
⇒ Too slow for live analysis and more complex offline analysis
⇒ Not that modular anymore due to software erosion
Design Limitations of Kieker's Analysis Component

- Determination of target stage at runtime
  - Using Java's Reflection API
  - Causing unnecessary and high synchronization overhead
- Check for type safety on each deliver
  - Using annotation-based ports
- Only readers are executed in a separate thread
- Limited support for stage composition

pipes are no first-class entities [Shaw93]
Related P&F Frameworks

• ExplorViz’ trace processing component [FWBH13]
  – Tailored to trace processing
  – Not intended as generic P&F framework

• Java 8 streams [Oracle14]
  – No support for ports
  – Limited configuration options

• Akka [Akka14]
  – No direct support for ports
  – Less efficient due to its actor-based design
    • e.g., due to MpSc mailbox
Requirements

• Abstraction from platform/implementation details (Abs)
• Focus on efficiency and scalability (E&S)
• Type safety (TS)
• Compositional, reusable stages (CompS)
Agenda

• Motivation
• Proposal for a P&F Software Architecture
• Preliminary Performance Results
• Conclusion
Pipe as First-Class Entity

• Pros:
  – Encapsulates stage scheduling
  – Encapsulates synchronization
  – Allows the compiler to perform further optimizations

• Cons:
  – Increases runtime overhead due to delegation

Stage only defines its ports and logic
Stage Scheduling & Synchronization

- Unsynchronized
- Direct method call
- Backpressure technique

No additional global scheduler necessary: each thread decides for itself what to execute

- Lock-free SpSc queue\(^1\)
- All IPC protocols possible (e.g., asynch send + polling)

\(^1\) Java Concurrency Tools: https://github.com/JCTools/JCTools
Our sample pipeline using a hybrid thread assignment approach

- Flexible thread assignment: distinct [SQKP10], shared [SLY+11], and duplicated execution
- Minimal communication overhead by using intra- and inter-thread pipes
Stage Composition

A stage composed of multiple other stages
Basic, Reusable Stages

- **Distributor/Merger**
- **File system stages:**
  - Reader/writer, text file line processing
- **Generic stages:**
  - Repeater, delay, throughput, instanceOf
- **Further stages:**
  - Clock, word counter, en-/decryption, (de)compress
P&F Software Architecture

Toward a Generic and Concurrency-Aware Pipes & Filters Framework


AbstractStage

-logger : Logger
$id$ : String

inputPorts

consumerStages : List
finiteProducerStages : List

OutputPort<T>

+send(T)
+sendSignal(ISignal)

pipe

AbstractPort<T>

type : Class<T>

InputPort<T>

+receive() : T
+read() : T

AnalysisConfiguration

-consumerStages : List
-finiteProducerStages : List
-infiniteProducerStages : List

Analysis

+Analysis(AnalysisConfiguration)
+init()
+start() : Collection<Pair<Thread, Throwable>>

<<use>>

<<Interface>>

ISignal

+trigger(ISignal)

<<use>>

<<Interface>>

IStage

+execute()
+onSignal(ISignal, InputPort)

StartingSignal

ValidatingSignal

TerminatingSignal

<<use>>

<<use>>

<<Interface>>

IPipe

+insert(Object)
+remove() : Object
+insertSignal(ISignal)
+removeSignal() : ISignal

IntraThreadPipe

InterThreadPipe
## Preliminary Performance Evaluation

### Kieker’s analysis component

<table>
<thead>
<tr>
<th></th>
<th>Monitoring (S1)</th>
<th>TCP Reading (S2)</th>
<th>Reconstruction (S3)</th>
<th>Reduction (S4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>2.7370</td>
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</table>

### TeeTime

#### Performance results of Kieker’s analysis component with MooBench [Wa14] as load driver

<table>
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<th></th>
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<tbody>
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<td><strong>Ci95</strong></td>
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</table>

#### Performance results of TeeTime with MooBench [Wa14] as load driver

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<tr>
<td><strong>Mean</strong></td>
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<td>2.3995</td>
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<td><strong>Throughput</strong></td>
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<td>416748</td>
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#### Performance results of TeeTime with a faster load driver

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Conclusion

- **Flexible** P&F software architecture including an **open source implementation**
- **Optimized** in terms of abstraction, efficiency & scalability, type safety, and reusability
- **90-200x** performance increase w.r.t. Kieker’s current analysis component

Open source implementation *TeeTime*: https://sourceforge.net/p/teetime/

Future work:
- Further performance experiments
- Automatize as much as possible:
  - pipe instantiation, thread assignment, and exception handling
- Support for Kieker’s WebGUI via save/load of pipeline structures [E13]
- Migration of legacy P&F architectures [Wu14]
References


Two common thread assignment strategies:

- Assign each worker thread on a **distinct set** of stages [e.g., SQKP10]
- Assign each worker thread to **all** stages sharing the pipes [e.g., SLY+11]
Signal Concept

- Automatic passing of signals by the framework
- Signal encapsulates the logics
- Integrated signals for starting, validating, terminating
- Arbitrary signals possible
Example Stage

```java
public class Directory2FilesFilter extends ConsumerStage<File> {

    private final OutputPort<File> outputPort = this.createOutputPort();

    private FileFilter filter;
    private Comparator<File> fileComparator;

    // omitted constructors

    @Override
    protected void execute(final File inputDir) {
        final File[] inputFiles = inputDir.listFiles(this.filter);

        if (inputFiles == null) {
            this.logger.error("Directory \"" + inputDir + \\"does not exist or an I/O error occurred.");
            return;
        }

        if (this.fileComparator != null) {
            Arrays.sort(inputFiles, this.fileComparator);
        }

        for (final File file : inputFiles) {
            this.send(this.outputPort, file);
        }

        // omitted getter and setter

    }

    public OutputPort<File> getOutputPort() {
        return outputPort;
    }
}
```
Performance Evaluation - Setup

• Kieker (11.07.2014) vs. TeeTime (01.09.2014)
• Load: 2 resp. 200 million traces each with a depth of 10
• Four scenarios: S1-S4
• Single-threaded execution of the analysis side
More Efficient and Scalable

Static connection of ports
- No dynamic search of annotation-based ports

Single type check phase on initialization
- No dynamic type check on each delivery

Direct stage invocation
- No reflection call

Flexible thread assignment
- No limitation to readers