Cuneiform

A Functional Workflow Language Implementation in Erlang

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A Functional Language for Large Scale Scientific Data Analysis

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- Black-box operator model

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  Wrapping in R, Matlab, Octave, Python, Lisp, Perl, Bash

- Automatic parallelization

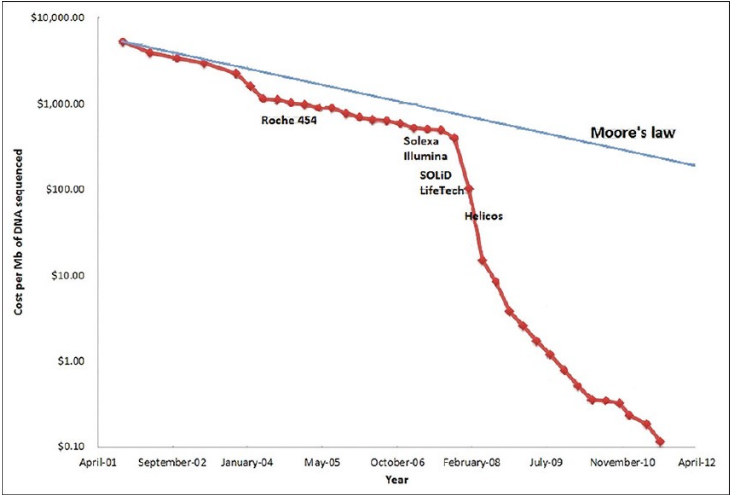
  Scalability with large data sets

Motivation

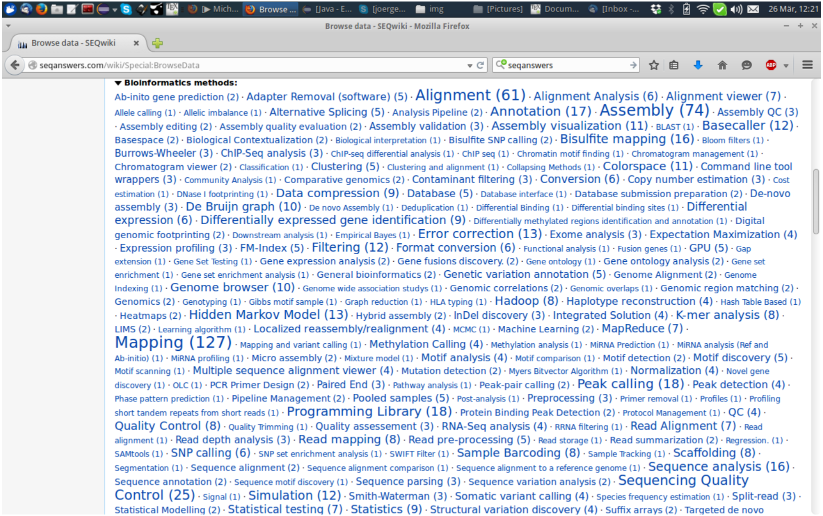
> "New hardware is increasingly parallel, so new programming languages must support concurrency or they will die."
>
> — Joe Armstrong

“New Hardware”

DNA Sequencing is becoming cheap



Decentralized software development



Scientific Workflow Systems

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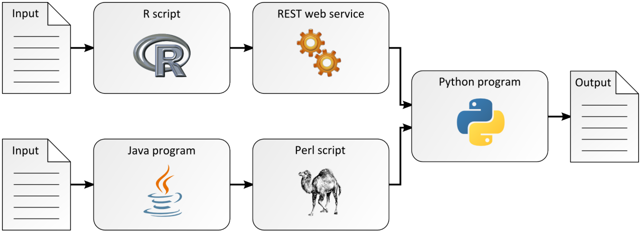
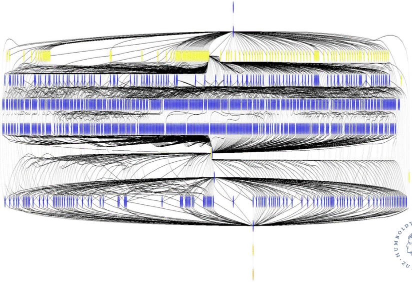


Workflows as DAGs

- Scientific Workflows are DAGs



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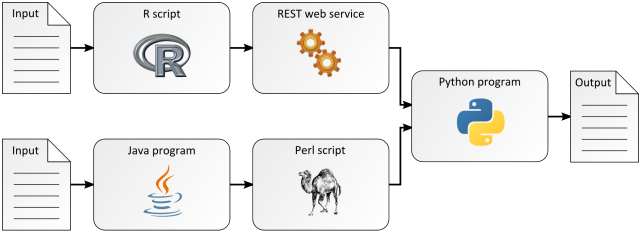

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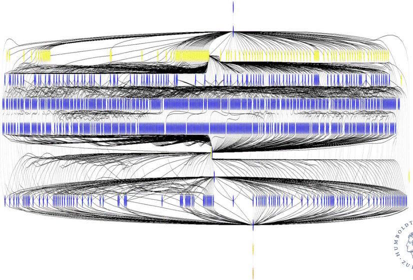
- Nodes are tasks



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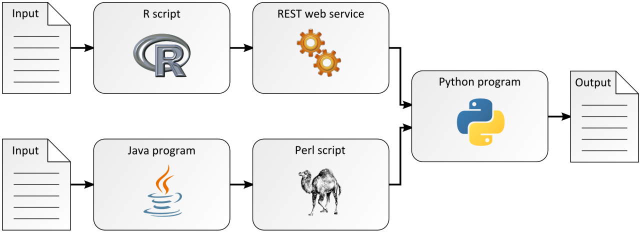
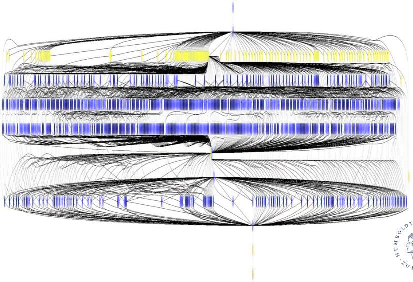
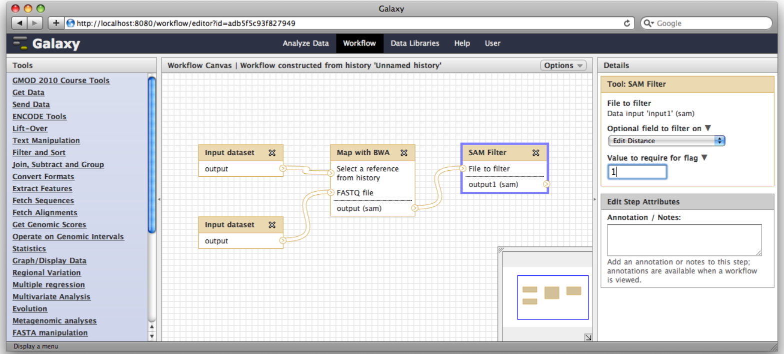


Workflows as DAGs

- Scientific Workflows are DAGs
- Nodes are tasks
- Edges are data dependencies



Example: Galaxy Workflow System



Focus on

- Usability

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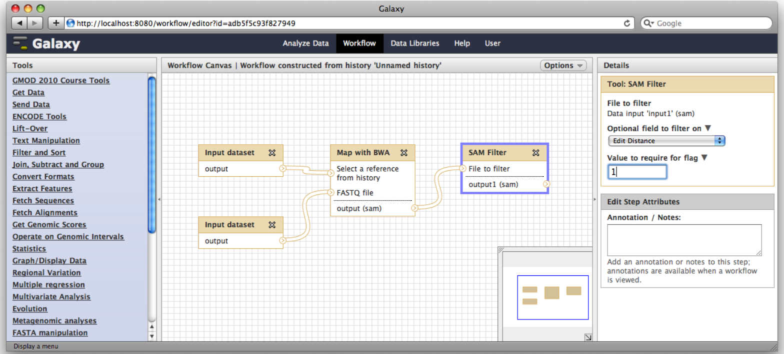

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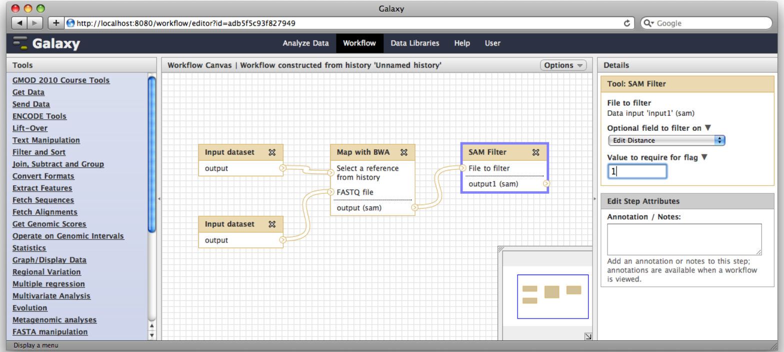

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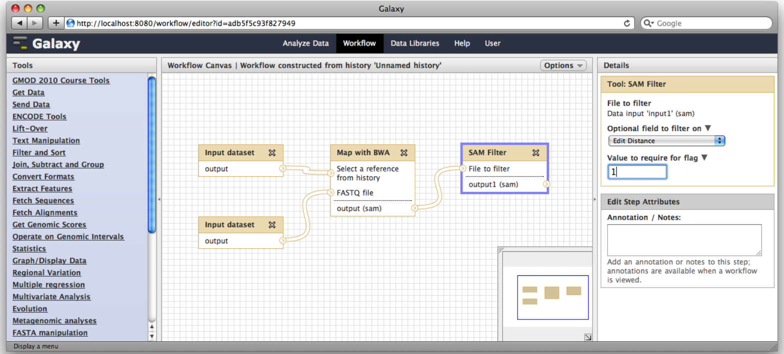

Focus on

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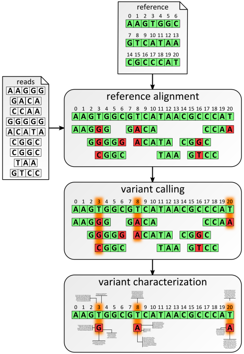
- Systematic documentation
- Reproducibility

The Next Generation Sequencing use case



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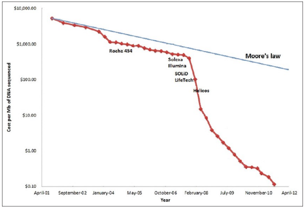

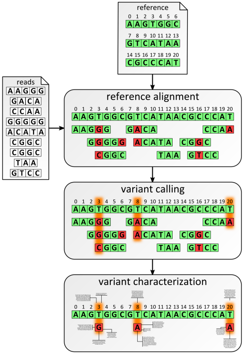

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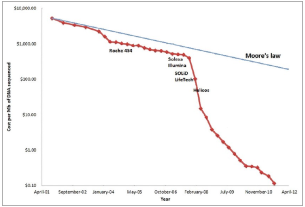

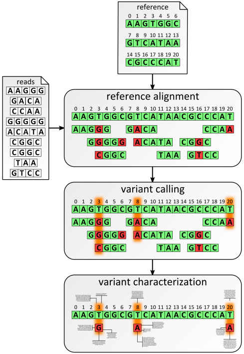

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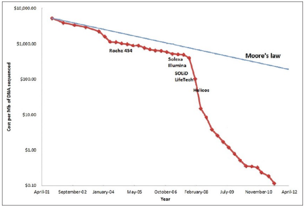

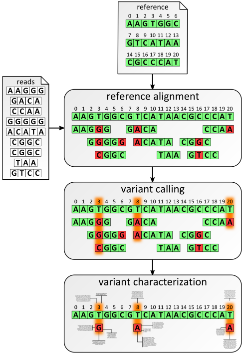

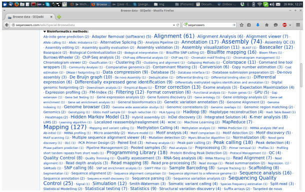

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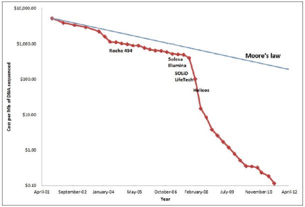

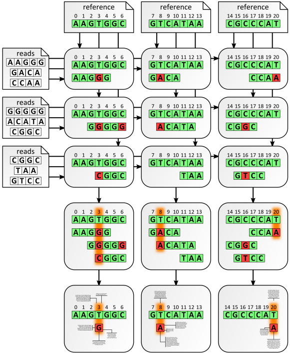

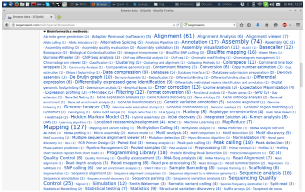

Desired Features in a Language

Is there a language that is . . .

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Desired Features in a Language

Is there a language that is . . .

- Like a workflow language

  So we can integrate all the tools

- Like MapReduce

  So we can derive parallelism and distribute the work

- Like a functional programming language

  So we can write arbitrary programs using lists and operations on lists

Cuneiform example

```
deftask gunzip( out( File ) : gz( File ) )in bash *{
  gzip -c -d $gz > $out
}*
```

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```
deftask gunzip( out( File ) : gz( File ) )in bash *{
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gunzip(
  gz: 'myarchive1.gz'
);
```

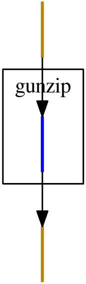

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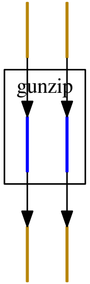

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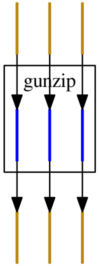
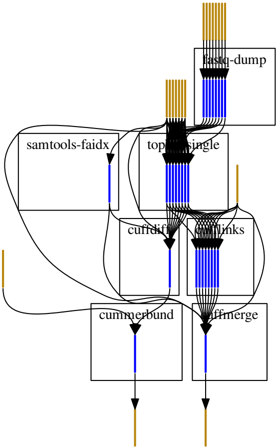


Workflow Implementations Available

Available example workflows:

- Variant calling
  `https://www.github.com/joergen7/variant-call`



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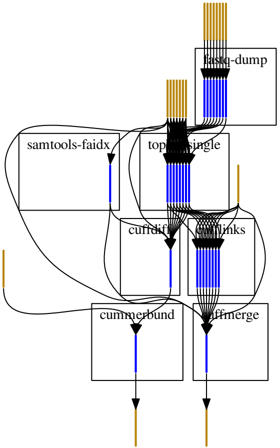

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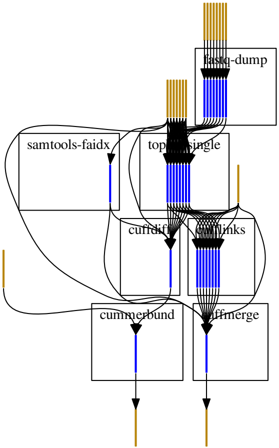

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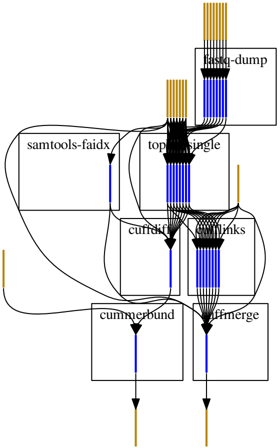
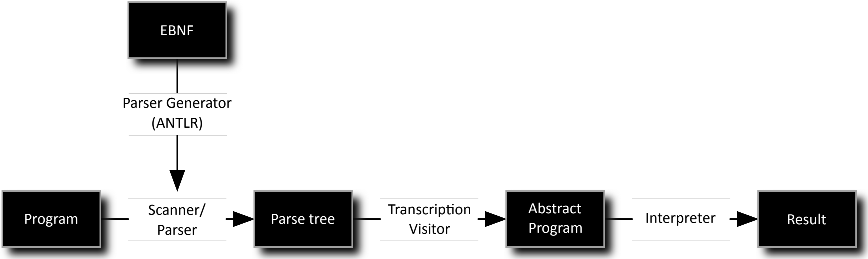
- etc (ChIP-Seq, miRNA detection, consensus prediction, ...)



Cuneiform Operational Semantics

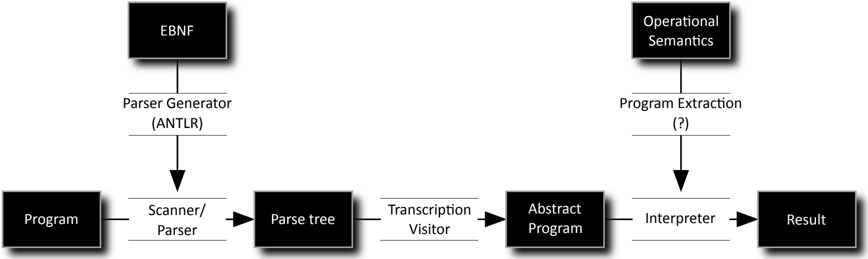
Program Interpretation in Cuneiform

Current design in Java implementation:



Program Interpretation in Cuneiform

Designated design but never implemented:



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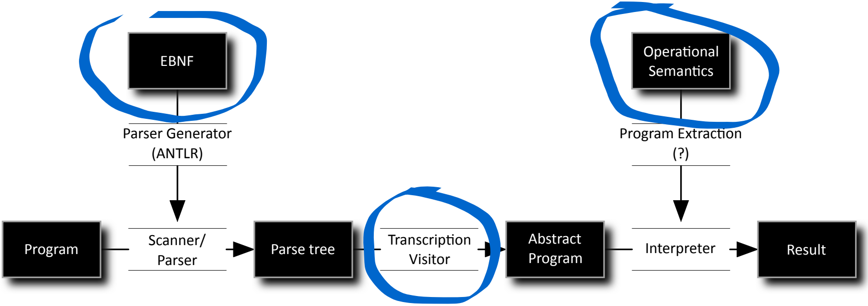
Designated design in Erlang:



The eval Function

$$\textbf{fun}\ \mathit{eval}(\mathit{Expr}, \rho, \mathit{GetFuture}, \mathit{Global}, \mathit{Fin}) \rightarrow \mathit{Result}\ \textbf{when}$$

$$\begin{array}{lcl}
\mathit{Expr} & :: & \mathit{expr} \\
\rho & :: & \mathit{string} => \mathit{expr} \\
\mathit{GetFuture} & :: & \mathit{fun} \\
\mathit{Global} & :: & \mathit{string} => \mathit{lam} \\
\mathit{Fin} & :: & \mathit{id} => \mathit{expr} \\
\mathit{Result} & :: & \mathit{expr}
\end{array}$$

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Expr The expression to be evaluated

The eval Function

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Fin Results of foreign task applications

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Expr The expression to be evaluated

ρ Current scope

GetFuture A function returning a future for a foreign task application

Global Task definitions

Fin Results of foreign task applications

Result The result of evaluation (may contain futures)

Computational Semantics

$$
\begin{array}{l}
\mathit{eval}(\mathit{Expr}, \rho, \mathit{GetFuture}, \mathit{Global}, \mathit{Fin}) \rightarrow \\
\quad \mathit{Next} = \mathit{step}(\mathit{Expr}, \rho, \mathit{GetFuture}, \mathit{Global}, \mathit{Fin}) \\
\quad \textbf{case } \mathit{Next} \textbf{ of} \\
\qquad \begin{array}{lcl}
\mathit{Expr} & \rightarrow & \mathit{Expr} \\
\_ & \rightarrow & \mathit{eval}(\mathit{Next}, \rho, \mathit{GetFuture}, \mathit{Global}, \mathit{Fin})
\end{array} \\
\quad \textbf{end}
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- single step is computed

Computational Semantics

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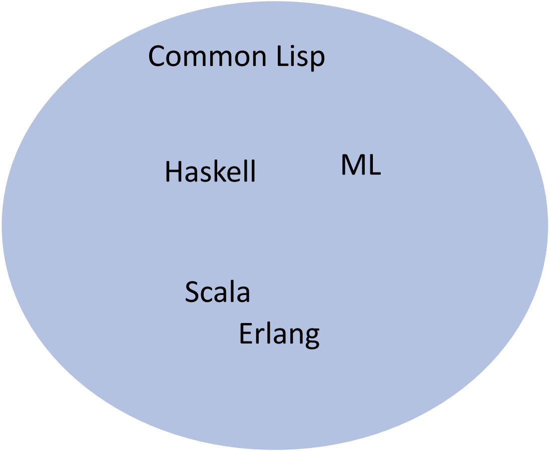
$$

- single step is computed
- If the step has no effect evaluation terminates
- Otherwise eval is called recursively

Languages Suitable for Operational Semantics

Choosing a language

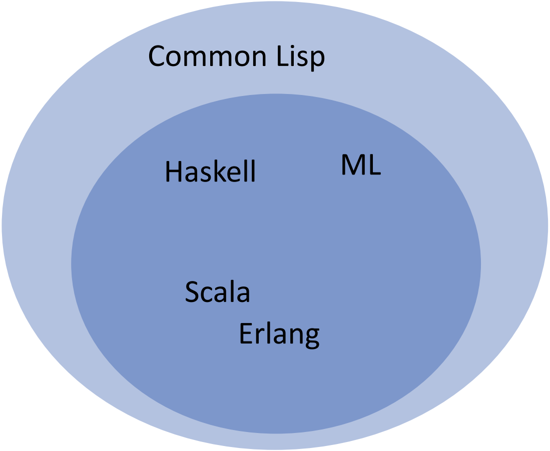
- Functional Language



Formalisms Suitable for Operational Semantics

Choosing a language

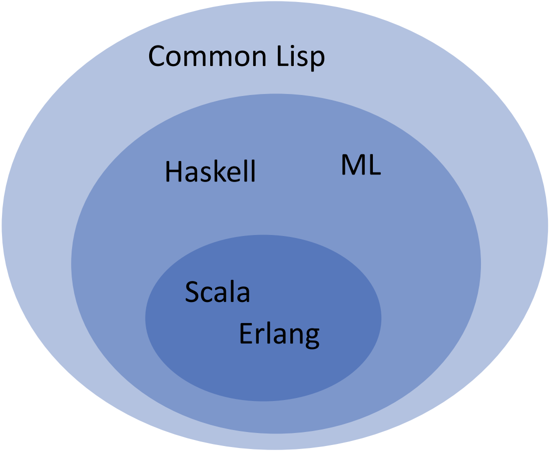
- Functional Language
- With Pattern Matching



Formalisms Suitable for Operational Semantics

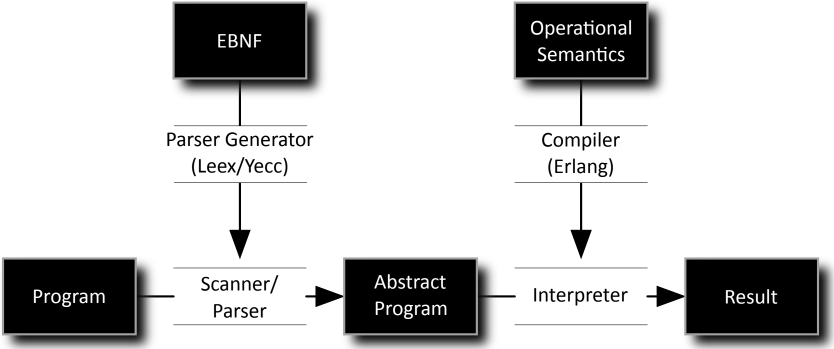
Choosing a language

- Functional Language
- With Pattern Matching
- Concurrency Orientation



Program Interpretation in Cuneiform

New design:



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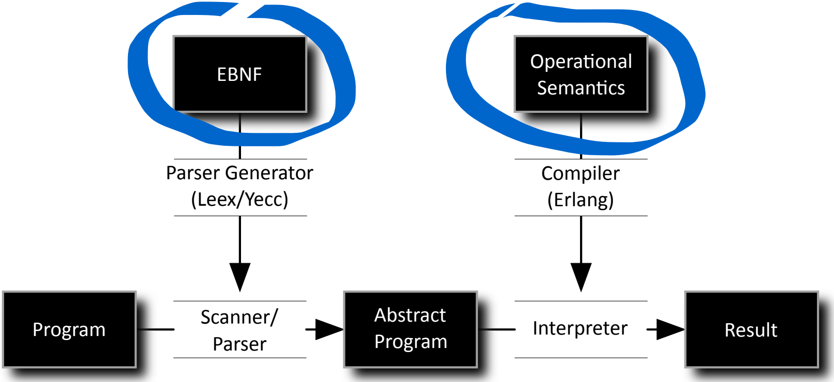
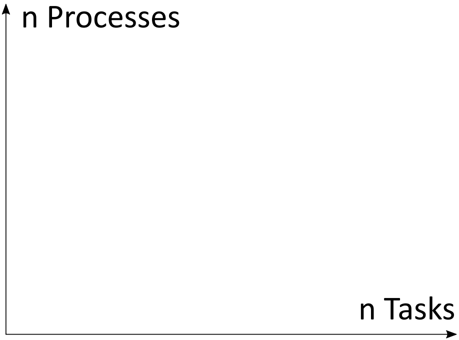


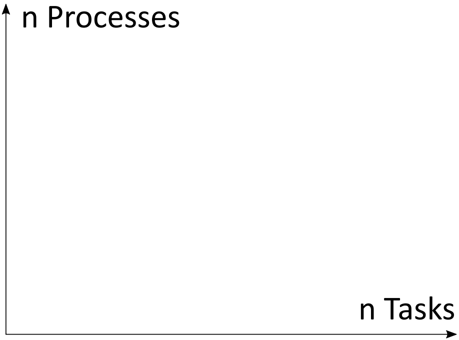
Fault Tolerance

Two types of complexity



Distributed applications can be complex in two independent ways:

Two types of complexity

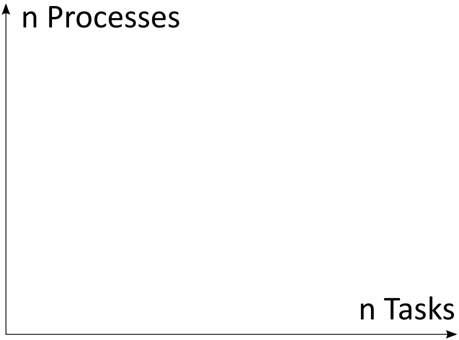


Distributed applications can be complex in two independent ways:

- in the number of processes involved to compute one task

  the more system components the more likely one component fails

Two types of complexity



Distributed applications can be complex in two independent ways:

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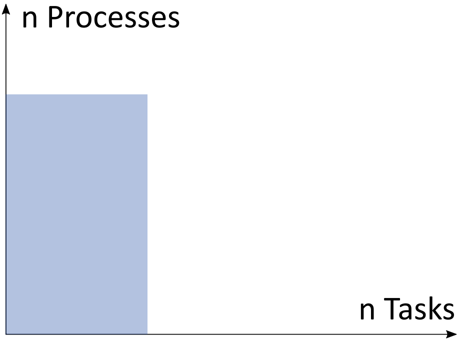

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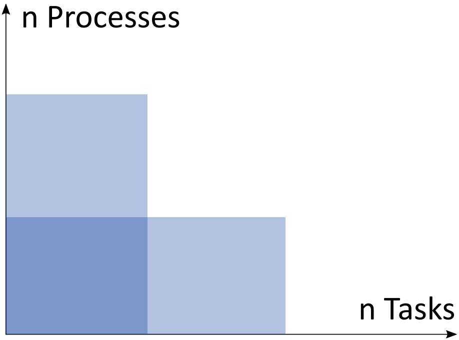

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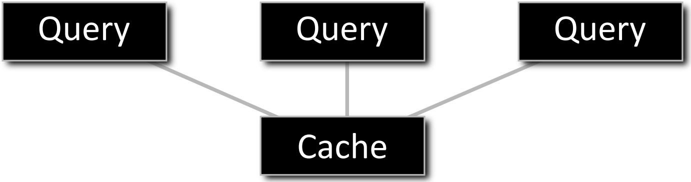

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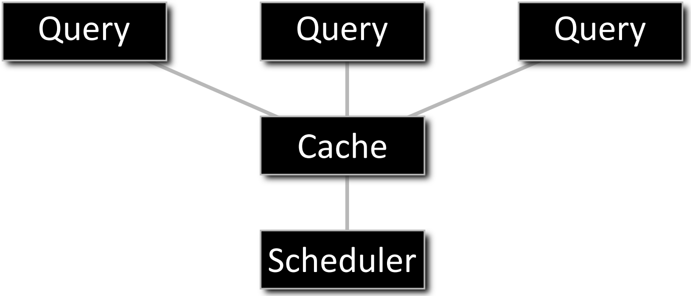

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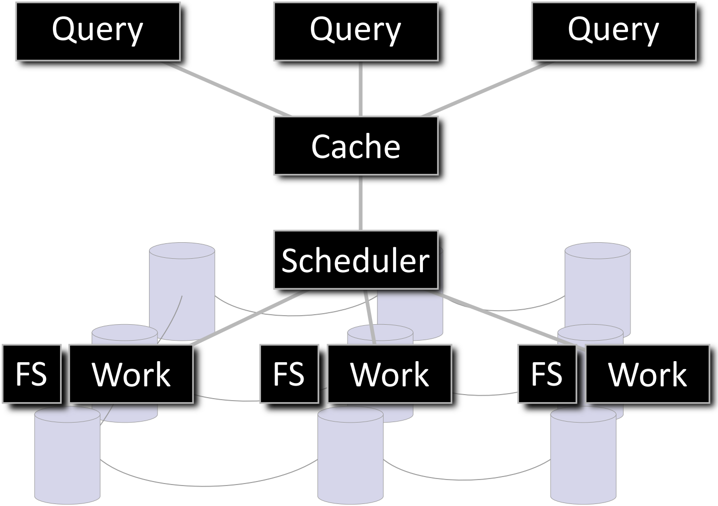

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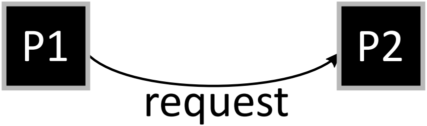
  so plain restarting of components is not enough
- Restarting of workflow helps only if workflows are small and system has few components

Generic process behaviour

Golden path:

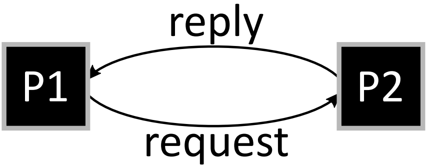
- P_1 sends request to P_2



Generic process behaviour

Golden path:

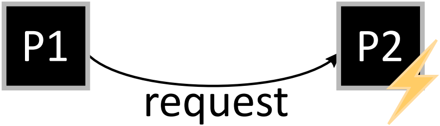
- P_1 sends request to P_2
- Asynchronously P_1 receives reply



Generic process behaviour

P_2 may fail:

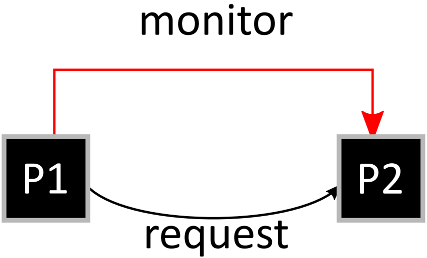
- P_1 sends request to P_2
- P_2 fails



Generic process behaviour

P_2 may fail:

- P_1 sends request to P_2
- P_1 creates monitor on P_2



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P_2 may fail:

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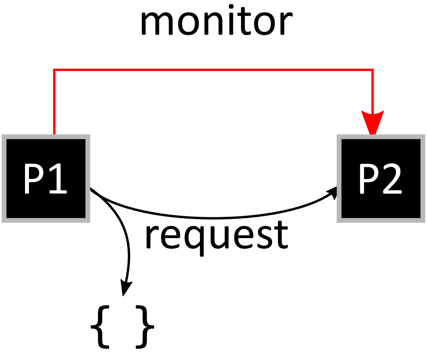

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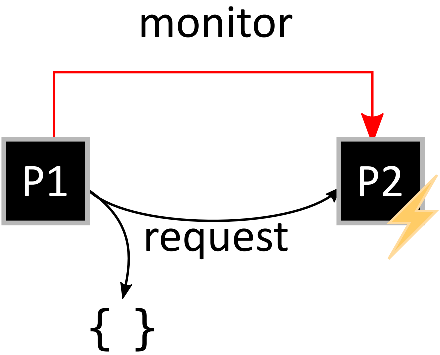

Generic process behaviour

P_2 may fail:

- P_1 sends request to P_2
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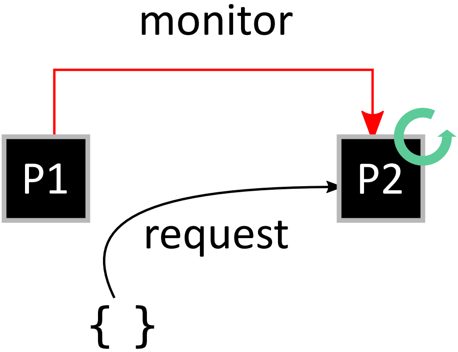
- P_2 fails
- P_2 supervisor restarts P_2

Generic process behaviour

P_2 may fail:

- P_1 sends request to P_2
- P_1 creates monitor on P_2
- P_1 memorizes request
- P_2 fails
- P_2 supervisor restarts P_2
- request is replayed to P_2
- monitor is recreated



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P_1 may fail:

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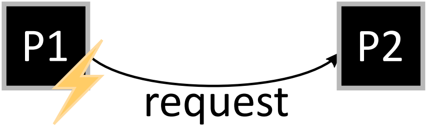

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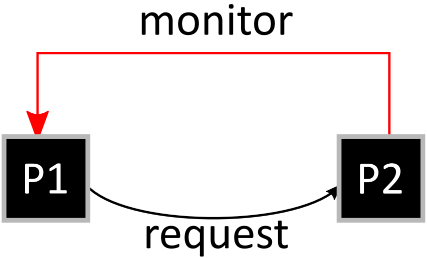

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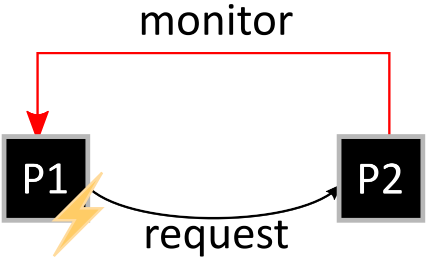
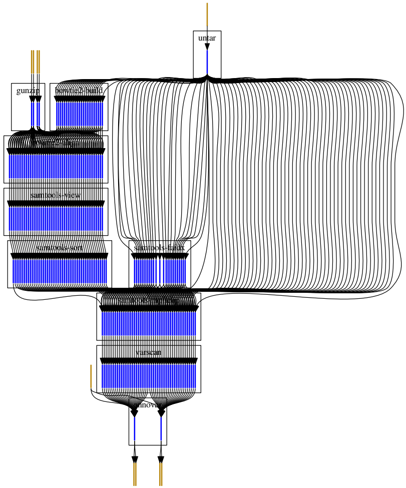


Generic process behaviour

P_1 may fail:

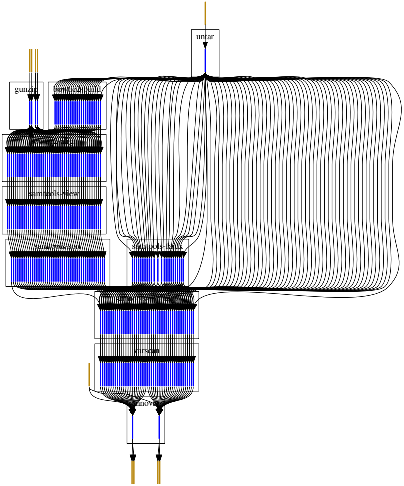
- P_1 sends request to P_2
- P_2 creates monitor on P_1
- P_1 fails
- request is canceled
- supervisor restarts P_1

- Cuneiform:



Conclusion

- Cuneiform:
  - Functional



Conclusion

- Cuneiform:
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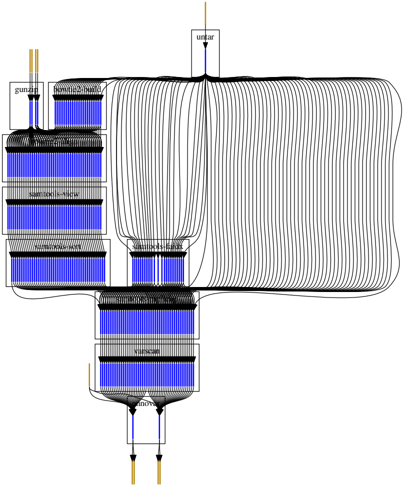
  - Integrate anything



Conclusion

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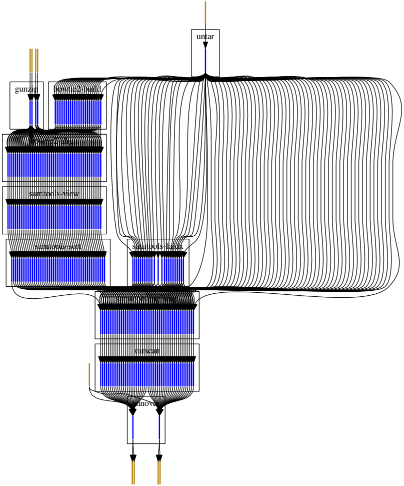
  - Parallelism



Conclusion

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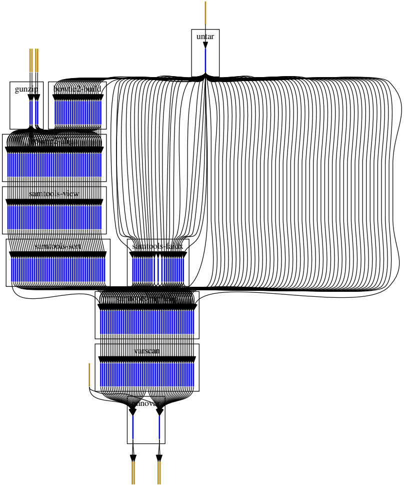
- Runs on Hadoop



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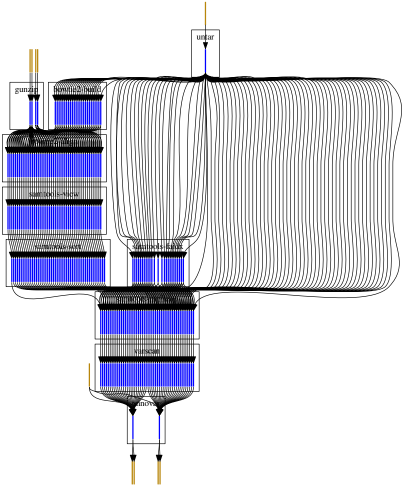

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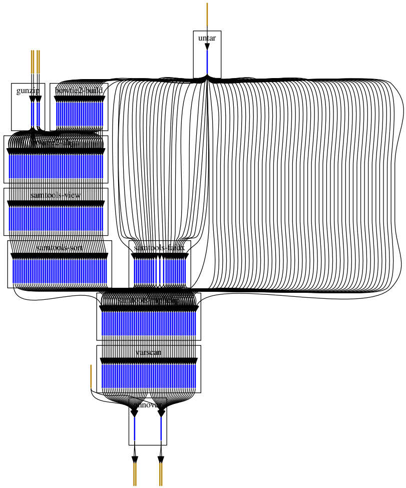

Conclusion

- Cuneiform:
  - Functional
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  - Parallelism
- Runs on Hadoop
- Implementation in Erlang:
  - Concise stateless semantics
  - Fine-grained fault tolerance