Erlang as a framework for parallel/distributed programming.

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2010

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- *Talk is cheap. Show me the code* put together a proof of concept
- it'll be nice to make a comparative benchmark (both on time and loc)

Erlang - Hystory

82-85 Experiments. The language must be high level, symbolic (Lisp , Prolog ...).

85-86 The language must contain primitives for concurrency and error recovery.

87-89 Erlang was developed.

89-97 Erlang grows both in users base and code base terms.

98 Erlang open sourced.

today Erlang, together with libraries and the real-time distributed database Mnesia, forms the Open Telecom Platform (OTP).

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Code is not first-class ⇒ modules should be.

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1  server_protocol(Msg)->
2    case Msg of
3      start -> start_service(),
4               send({start,ack});
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⇒ avoid it: production use.
define (`-def` and `-type`) and check (`dialyzer`) your types for serious projects.
`-type number :: float() | integer()`

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or remotely

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spawn(Node, Module, Function, ArgumentList) -> pid()
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Concurency follows the Actor model.

Erlang - Concurrent/Distributed example

```
1  rtt_server() ->
2  ...
3    Pids = map(fun(Node) ->
4                   spawn(Node,pmap,rtt_client,[self()])
5                end, Nodes),
6    Rtts = map(fun(Pid) ->
7                  Start = statistics(wall_clock),
8                  Pid ! Data,
9                  receive
10                   Rec when (Rec == Data) ->
11                             {_,Rtt} = statistics(
                                     wall_clock);
12                   _ -> io:format("ERROR")
13                 end,
14                 Rtt
15               end, Pids),
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```
1  rtt_client(Master) ->
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- Low level operators (erlang embedded)
- Code hotload

Erlang - Hot code load

As a consequece of higher order, it is possible to hot load code:

```
1  loop(F) ->
2            receive
3              {request, Pid, Data} ->
4                        Pid ! F(Data),
5                        loop(F);
6              {change_code, F1} ->
7                  loop(F1)
8            end
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```
1  Server ! {change_code, fun(I, J) ->
2                              do_something(...)
3                          end}
```

Parallel Map

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```
1  pmap(fun(X) -> X+1 end,[1,2,3]).
2  [2,3,4]
```

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Erlang:

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2  [2,3,4]
```

```
1  pmap(fun(Vect) ->
2           map(fun(X) ->
3               foreach(fun(_) ->
4                           math:erf(X)
5                       end,
6               seq(1,NCPU)),
7               X
8               end, Vect)
9       end, Data]),
10 ...Vect...
```

Pmap

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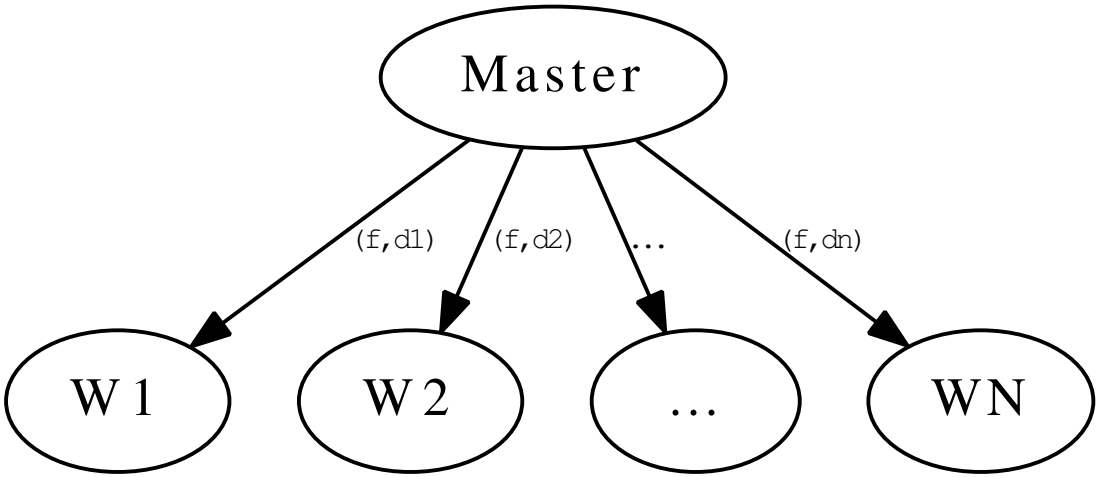
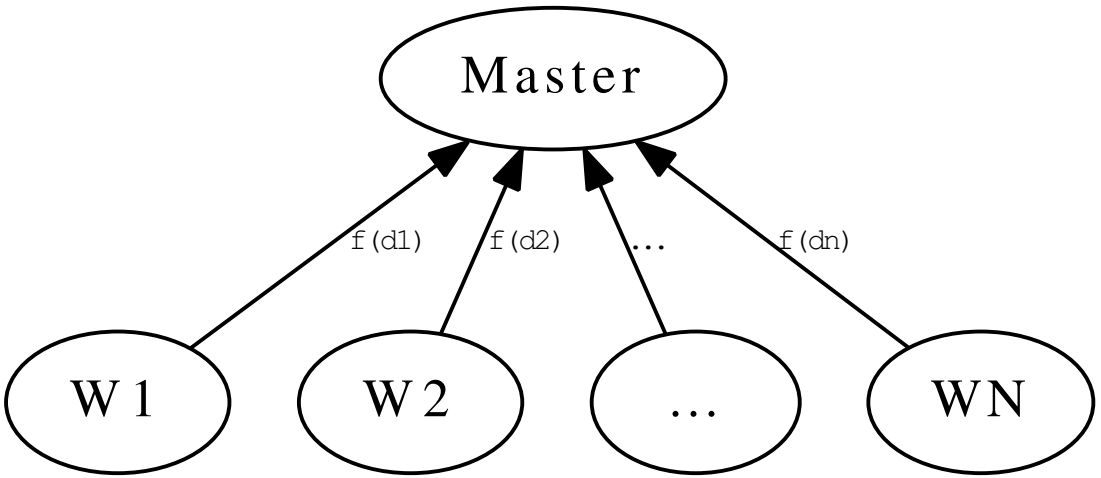


Pmap

Results are collected and sorted.



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1. Obtain n nodes.
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```
1  pmap(Function, Datas) ->
2      Nodes = get_nodes(length(Datas)),
3      Master = self(),
4      Indexed_data = zip(seq(1,length(Datas)),
5                                 Datas),
6      NDS = zip(Nodes,Indexed_data),
7  ...
```

Pmap

```
1  pmap(Function, Datas) ->
2  ...
3      lists:foreach(fun({Node,Data}) ->
4                            spawn(pmap,make_worker,
5                                  [Node, Function, Data,
                                       Master])
6                    end,NDS),
7      collect_results(length(Datas)).
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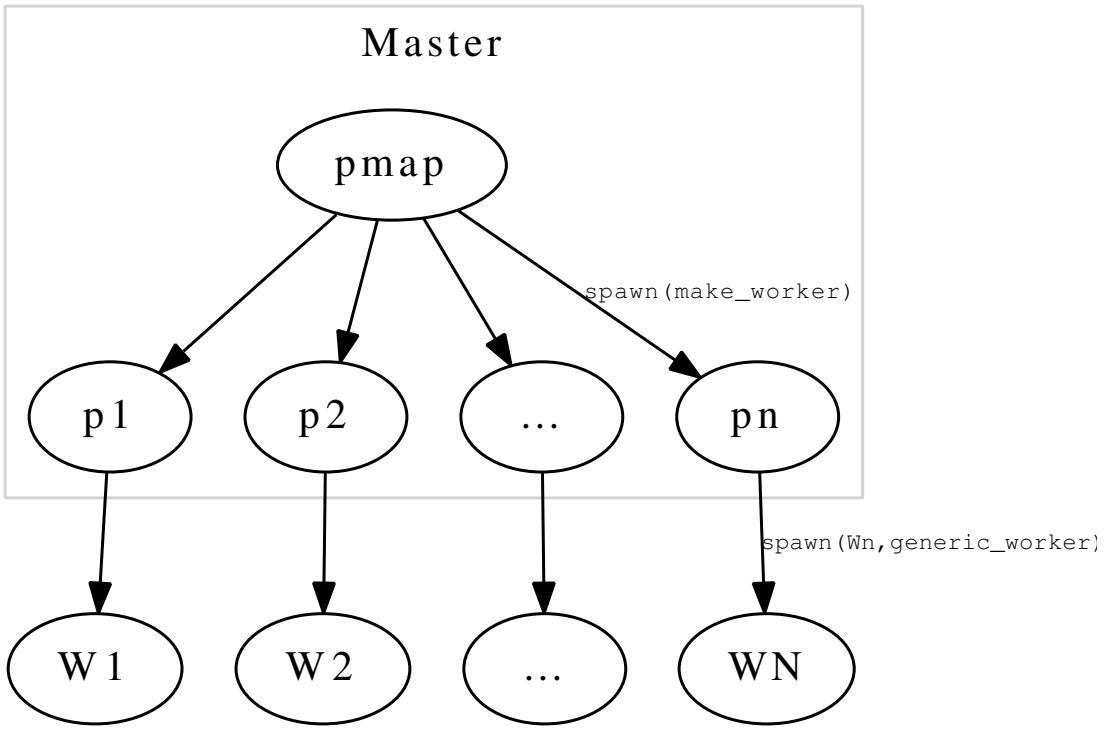

Pmap

Each process (*thread*), spawns on a different node.

```
1  make_worker(Node, Function, Data, Master) ->
2      spawn(Node, pmap, generic_worker,
3            [Function,Data,Master]).
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Function deployed on workers with its very complex wrapper...

```
1  generic_worker(Fun,{Idx,Data},Master) ->
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Testing/tracing infrastructure $\sim$ 150 loc

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2 run(data1,data2,...,datan).
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Erlang:

```
1  Pids = create([fun(X) -> X+1 end, fun(X) -> X*X end]),
2  Res = run([1,2,3,4,5], hd(Pids)).
3  [4,9,16,25,36]
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```
1  Pids = create(duplicate(Stage_Number,
2                          (fun(X) ->
3                            Matrix = duplicate2(50,2.0),
4                            multiply_matrix(duplicate(NCPU,
                                  Matrix)),
5                            X
6                           end)),
7  Res = run(duplicate(NData,duplicate2(DData,2.0)),
8            hd(Pids))
```

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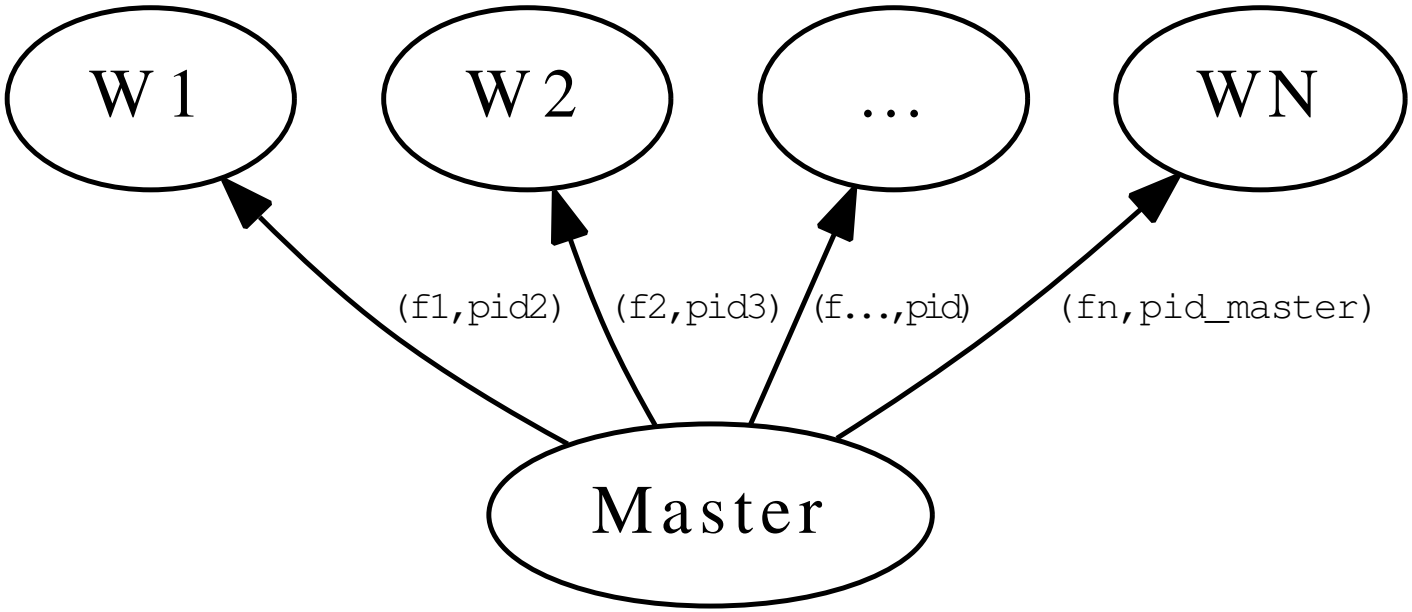
Ideally:



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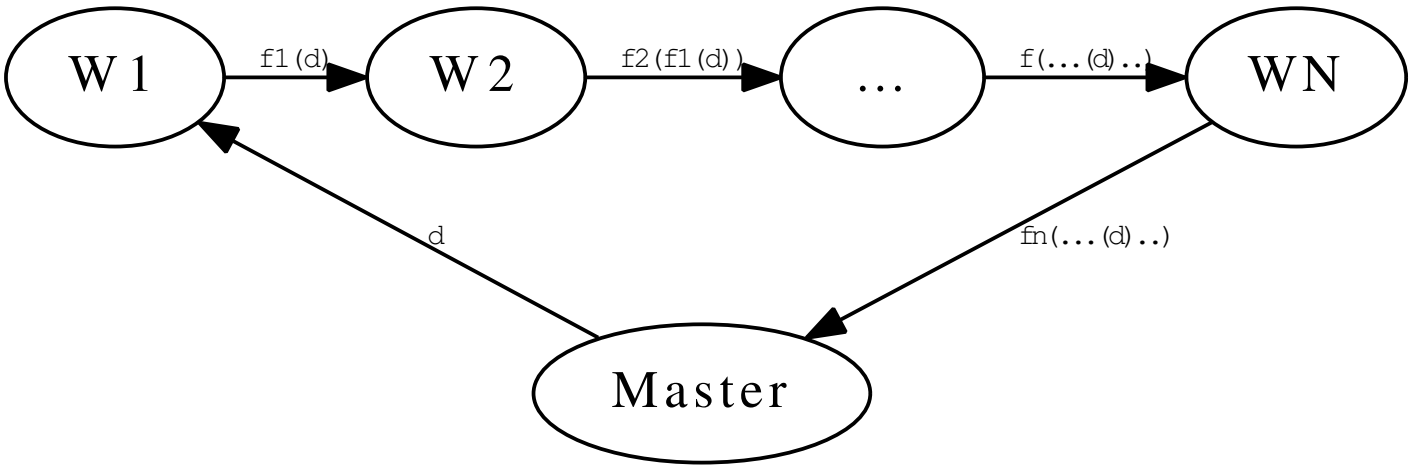

Pipeline

1. Master feeds EOF.

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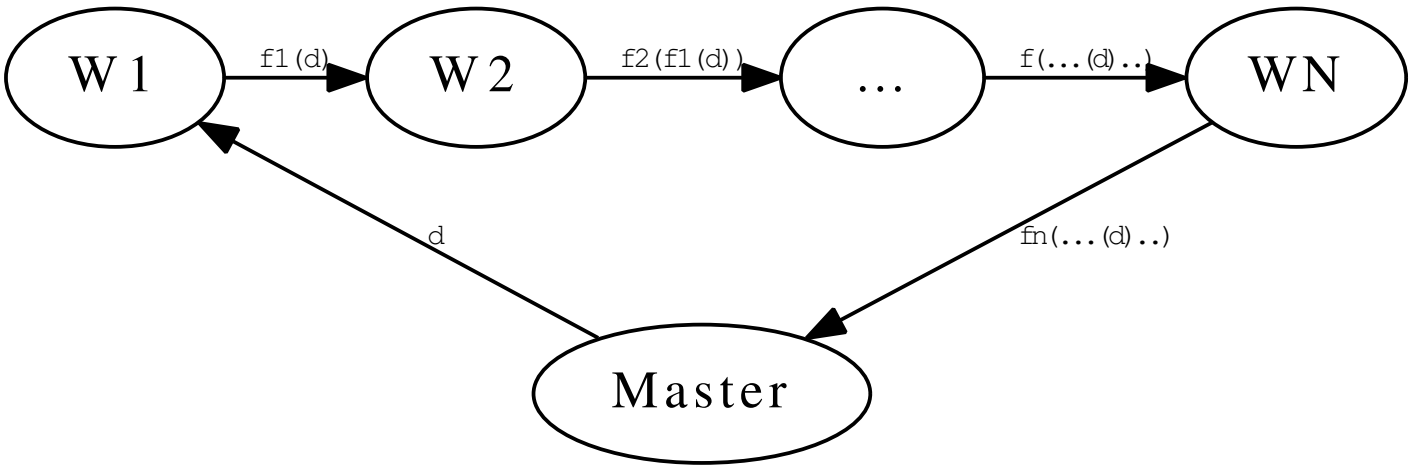
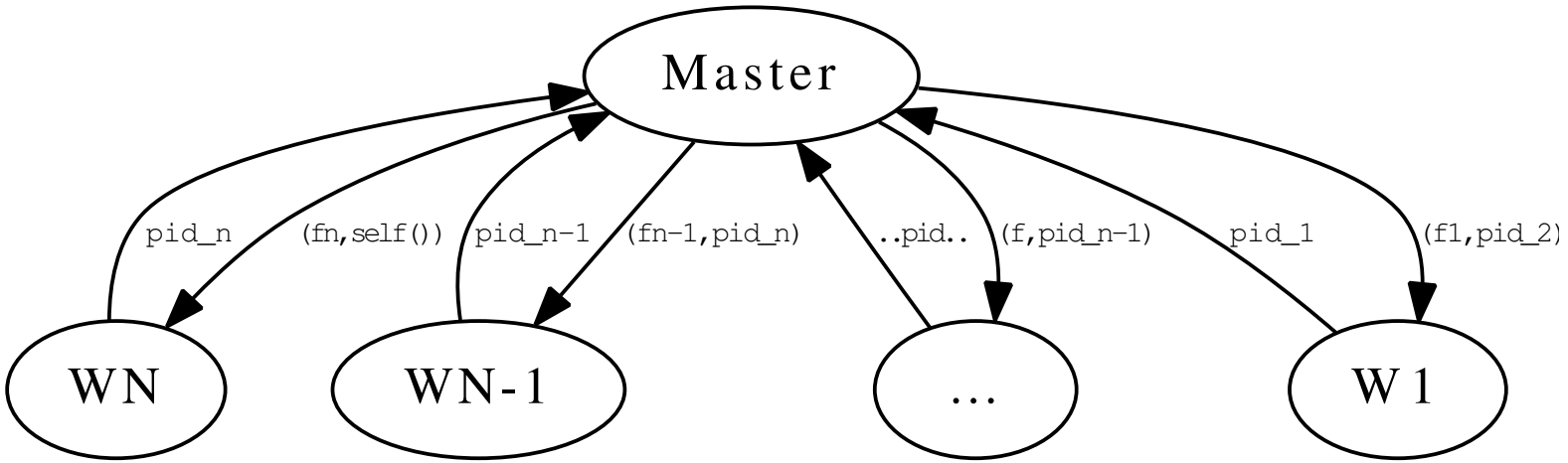


Pipeline

```
1  create(Functions) ->
2     Nodes = get_nodes(length(Functions)),
3     NFS = zip(Nodes, Functions),
4     Pids = foldr(fun(NF, Pids) ->
5                      Pid = make_worker(NF,hd(Pids)),
6                      [Pid] ++ Pids
7                  end, [self()], NFS),
8     Pids.
```



Pipeline

1. Wrapper function that is deployed on the stages.
2. Pattern matching on Data/EOF.
3. Tail-recursive call.
4. Timeout (soft real-time)

```
1  generic_worker(Fun,Pid)  ->
2      Timeout = 60000,%ms
3      receive
4          eof -> Pid ! eof;
5          X ->
6              Pid ! Fun(X),
7              generic_worker(Fun,Pid)
8      after
9          Timeout -> Pid ! eof
10     end.
```

Pipeline

```
1  feed(Data, Pid) ->
2      foreach(fun(Elem) ->
3                      Pid ! Elem,
4                      timer:sleep(10000),
5                end, Data),
6      Pid ! eof.
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2  collect(Acc) ->
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```
1  run(Data, Head) ->
2      feed(Data, Head),
3      collect().
```

pipeline implementation $\sim$ 70 loc

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Testing/tracing infrastructure $\sim$ 190 loc

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...
'fujim3.cli.di.unipi.it'
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Eshell V5.7.4  (abort with ^G)
(test@fujim1)1> net_adm:world(verbose).
Pinging test@fujim1 -> pong
Pinging test@fujim2 -> pong
Pinging test@fujim3 -> pong
[test@fujim1,test@fujim2,test@fujim3]
```

Machines Pool

The network of machines is managed by the erlang run-time.

```
# less .hosts.erlang
'fujim1'.
'fujim2'.
...
'fujim3.cli.di.unipi.it'

Eshell V5.7.4  (abort with ^G)
(test@fujim1)1> net_adm:world(verbose).
Pinging test@fujim1 -> pong
Pinging test@fujim2 -> pong
Pinging test@fujim3 -> pong
[test@fujim1,test@fujim2,test@fujim3]
```

The `get_nodes(number)` function returns a list of `number` active nodes, if less nodes are available the list is redundant so that consecutive functions are deployed on the same node (*pipeline*).

```
(test@fujim1)3> pipeline:get_nodes(5).
[test@fujim1,test@fujim2,test@fujim2,test@fujim3,test@fujim3]
```

Erlang library has a pool implementation.

Benchmarks

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$$g \sim \frac{C}{D}$$

Hypothesis:
Each node perform the exact same function, on data of the same size. D and C values are independent.

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The Inviso framework provided with Erlang was used to trace:

1. function calls, returns
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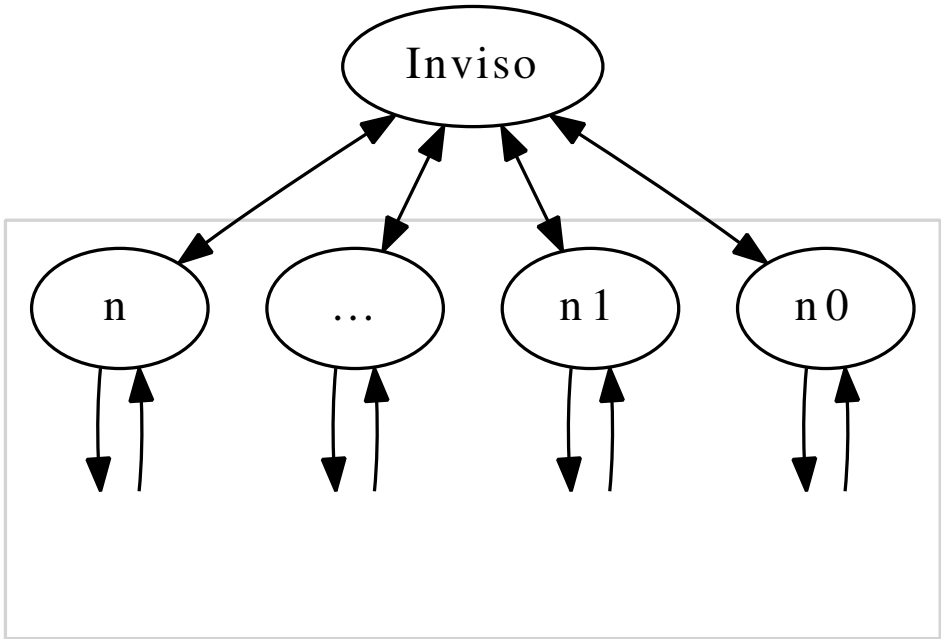

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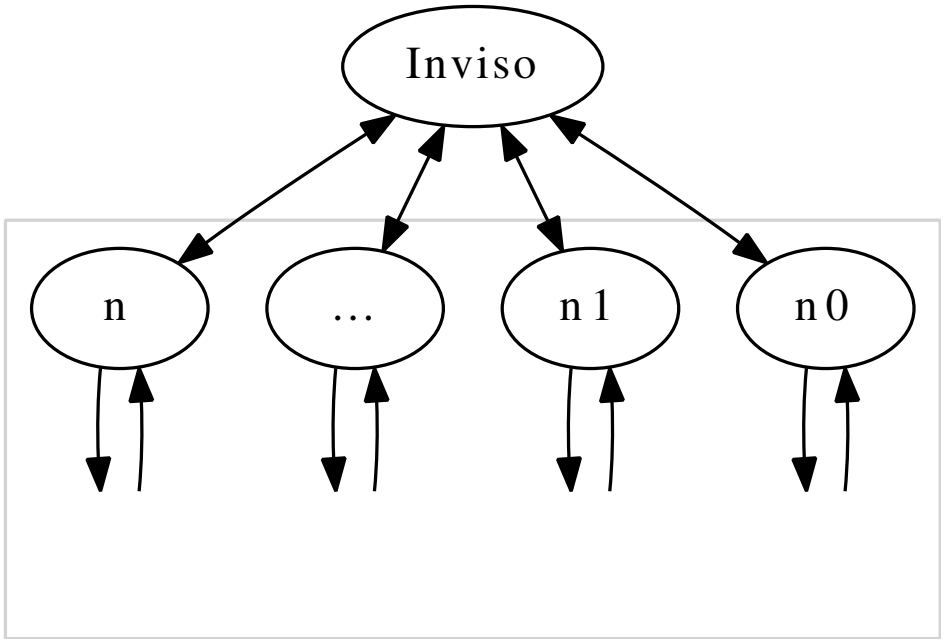

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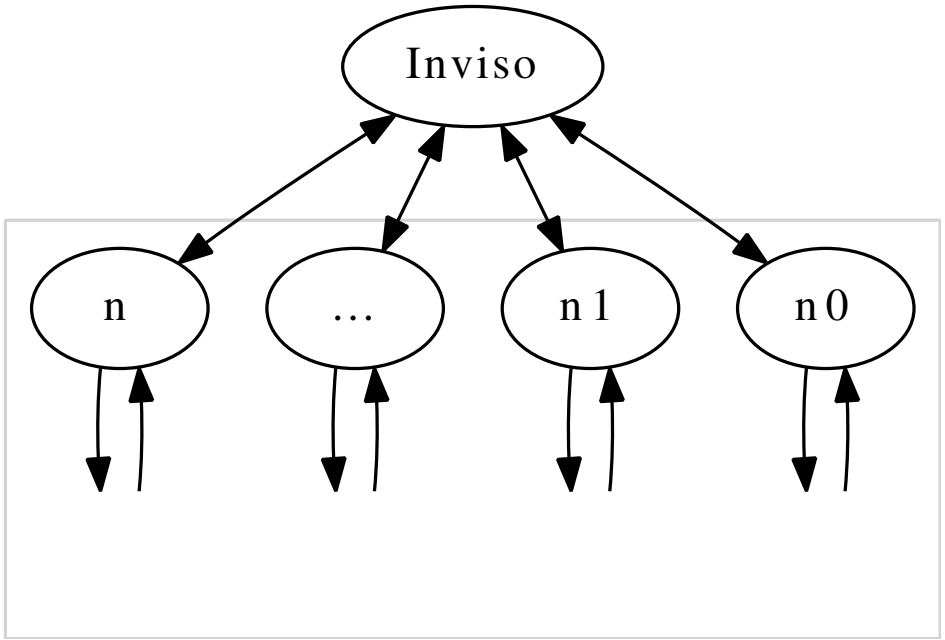

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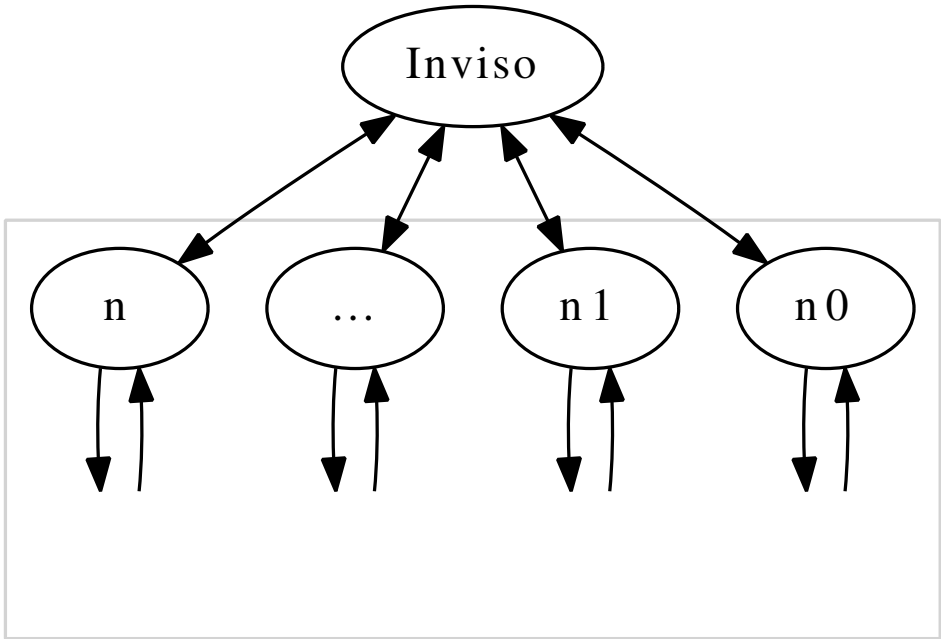

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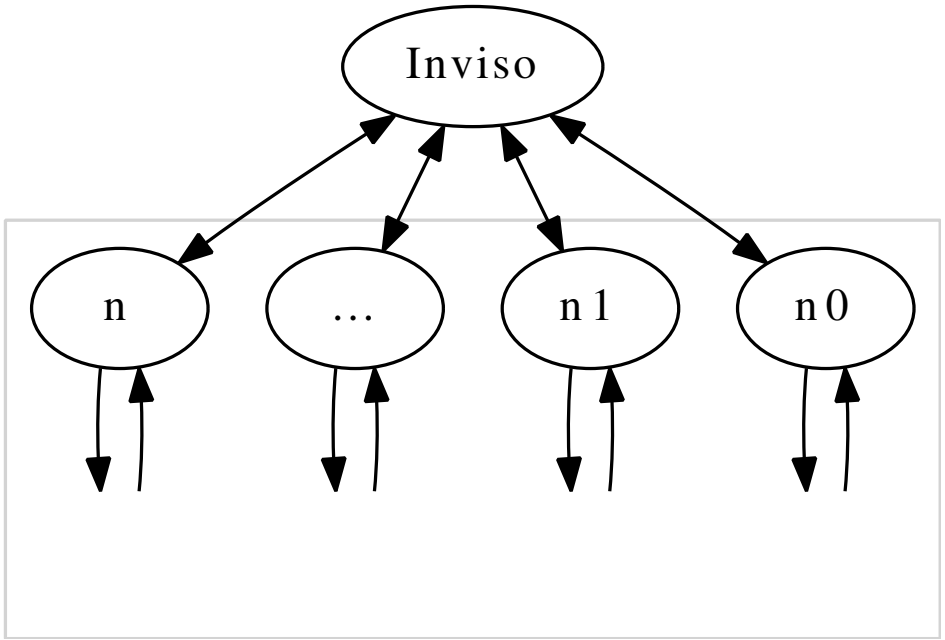

Data, once analyzed, contained precise measure (nanoseconds) of Cpu times and Communication times of every node.
Inviso proved to be very powerfull, very difficult to use, and eventually very buggy :P

Benchmarks - Inviso

Tell Inviso which node to trace and *how*:

```
1  trace() ->
2    inviso:start(),
3    inviso:add_nodes(Nodes,mytag,[]),
4    TracedList = lists:map(fun(Elem) ->
5         {Elem,[{trace,{relayer,node()}}]} end, OtherNodes)
               ,
6    inviso:init_tracing( TracedList ++ [
7                           {node(),
8                            [{trace,{fun filter/2,[]}}]}
9                            ]),
```

Benchmarks - Inviso

Alternatives

- Log all trace events to file:

```
1 inviso:init_tracing([{client_node(),
2                       [{trace,{file,"client_log"}}]},
3                      {server_node(),
4                       [{trace,{file,"server_log"}}]}])
                            .
```

  they can be later collected and merged.

Benchmarks - Inviso

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3                      {server_node(),
4                       [{trace,{file,"server_log"}}]}])
                              .
```

  they can be later collected and merged.

- Display all trace events in the shell of the node where they occur:

```
1 inviso:init_tracing([{client_node(),
2                       [{trace,collector}]},
3                      {server_node(),
4                       [{trace,collector}]}]).
```

Benchmarks - Inviso

Tell Inviso what needs to be traced:

```
1   inviso:tpl(OtherNodes,pipeline,funcfunc,'_',
2                              [{'_',[],[{return_trace}]}]),
3   inviso:tf(OtherNodes,all,[send,'receive']),
4   inviso:tf(all,[call,timestamp]).
```

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```

alternatives:

- send
- receive
- procs
- call
- return_to
- running : Trace scheduling of processes.
- exiting
- garbage_collection
- timestamp
- cpu_timestamp

Benchmarks - Inviso - filter()

Define a function to treat received data:
Function calls:

```
1  filter(X,CList) ->
2   case X of
3     {trace_ts,Pid,call,{M,F,_A},{MgS,S,McS}} ->
4         Call = {{M,F,Pid},(McS+(S*1000000)+
5                            (MgS*1000000000000))},
6         CList ++ [Call];
7     {trace_ts,Pid,return_from,{M,F,_A},_R,{MgS,S,McS}} ->
8         FTime = (McS+(S*1000000)+
9                            (MgS*1000000000000)),
10        case lists:keysearch({M,F,Pid},1,CList) of
11            {value,{_,STime}} ->
12                ETime = FTime - STime,
13                log({node,Pid,ETime});
14             _ -> ok
15        end,
16        lists:keydelete({M,F,Pid},1,CList);
17 ...
```

Benchmarks - Inviso - filter()

Define a function to treat received data:
Messages:

```
1   {trace_ts,Pid,send,Msg,Dest,{MgS,S,McS}} ->
2       Time = McS+(S*1000000)+(MgS*1000000000000),
3       case Msg of
4           eof -> ok;
5           [[F|_]|_] when is_number(F) ->
6               log({send,Pid,Time});
7           _ -> ok
8       end,
9       CList;
10  ...
```

Benchmarks - Inviso - raw log

Raw log generateb by Inviso:

```
{rec,  "<9434.102.0>", 126857427179982 9}.
{rec,  "<9434.102.0>", 126857427380368 3}.
{rec,  "<9434.102.0>", 126857427580762 7}.
{node, "<9434.102.0>", 19354161}.
{send, "<9434.102.0>", 126857428714750 8}.
{rec,  "<9471.101.0>", 126857428457275 1}.
{node, "<9471.101.0>", 18370486}.
{send, "<9471.101.0>", 126857430294508 3}.
{rec,  "<9472.99.0>",  126857430318489 0}.
{node, "<9434.102.0>", 19671653}.
{send, "<9434.102.0>", 126857430686706 6}.
{rec,  "<9471.101.0>", 126857430429147 4}.
...
```

Benchmarks - Inviso - analyze()

Pass the log through analyze() to extract needed info:

```
1  analyze(Pids,File) when is_list(Pids)->
2      {ok, Log} = file:consult("log.txt"),
3      SendList2 = lists:filter(fun({Type,Pid,Time}) ->
4                               case Type of
5                                   send -> true;
6                                   _ -> false
7                               end
8                       end,Log),
9      {L11,L12,L13} = lists:unzip3(SendList2),
10     SendList= lists:keysort(1,lists:zip(L12,L13)),
11     ...
12     RecList= lists:keysort(1,lists:zip(L22,L23)),
13     ...
14     NodeList= lists:keysort(1,lists:zip(L32,L33)),
15     CPUTimes = ...
16     {ok, FileDescriptor} = file:open(File, [append]),
17     io:format(FileDescriptor, "#service time: ~p~n",
18                               [max(CPUTimes)/1000000]),
19     ...
20     file:close(FileDescriptor).
```

Benchmarks - Inviso - log

Refined log for pmap:

```
{dimData, "nData", nCPU}.
{1500000, "2", 160}.
{node, "<3961.15734.0>", 50637248}.
{node, "<3970.10574.0>", 50419248}.
{total, "time", nmachines}.
{total, "54107364", 2}.
```

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{dimData, "nData", nCPU}.
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{total, "time", nmachines}.
{total, "54107364", 2}.
```

Refined log for pipeline:

```
#nStages nCPU nData nData
#3 10 50 5
#PIDS: ["<3960.85.0>","<3962.85.0>","<3961.85.0>"]
#service time: 1.915271
1    1.915271    1.892735    1.899414    1.884896    1.848452
2    1.856185    1.842149    1.839809    1.853133    1.85122
3    1.866492    1.848686    1.830319    1.850508    1.842933
```

no network data ;(

Erlang Overhead

Al test were performed with lists of floats on 32bit single-core machines (fujim).
List of N floats $= N * (1 + 4words) * 4bytes = N * 20bytes$.
Erlang introduces an overhead of 20% for data structures.
Overhead due to byte code transfer should be negligible for our applications.

Average Roud Trip Time tested on 10 machines:

Data	Dim	Est Dim	RTT(sec)	MBs
matrix	2000	76 MB	7.876	19
matrix	1000	19 MB	1.895	21
matrix	300	1757 KB	0.184	18
matrix	200	781 KB	0.083	18
matrix	150	439 KB	0.046	18
matrix	100	195 KB	0.020	19
matrix	50	48 KB	0.008	11
lists	1500000	28 MB	3.056	18

Communication Speed $\approx$ 20 MB/sec $\Rightarrow$ 160Mb/s
Very impressive on a 100 Mb/s network :)

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Pmap Benchmark

Parallel map was tested with simple lists of floats for finer grained results.

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1. a list of D floats is splitted into N sublists.
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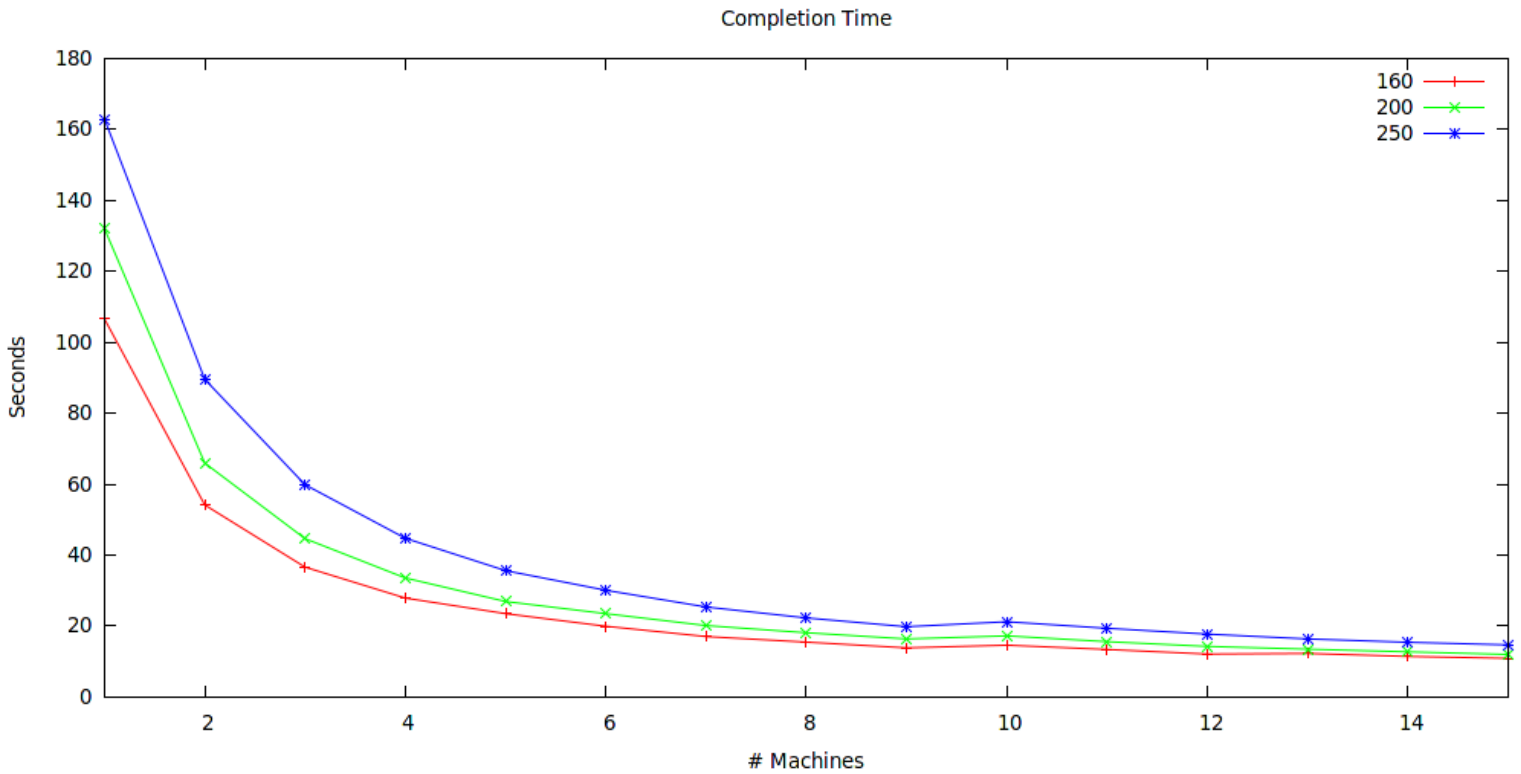
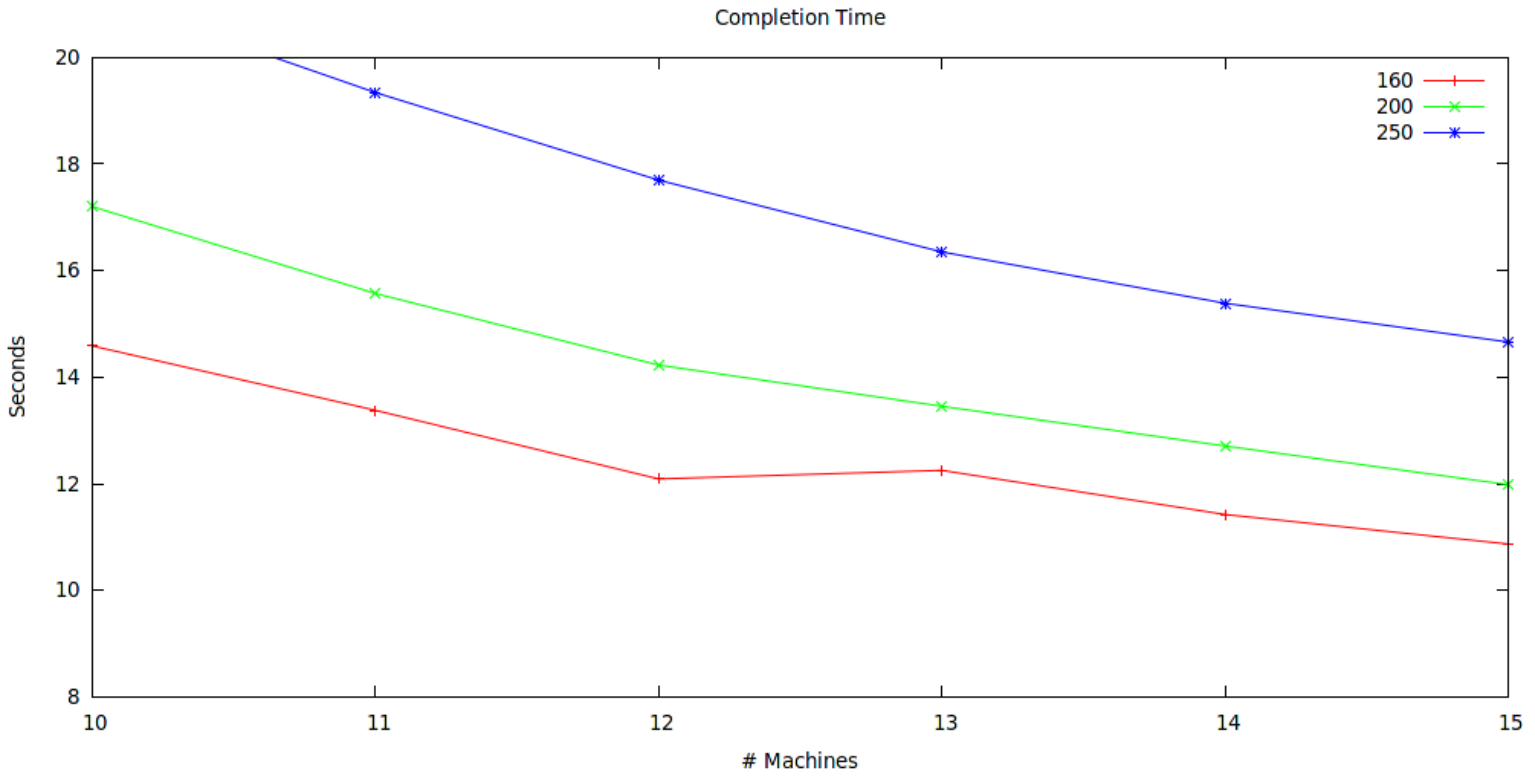
```
1  test(DimData, NData, NCPU) ->
2  ...
3    Data = [list od DimData is splitted to NData]
4    pmap(fun(Vect) ->
5              map(fun(X) ->
6                      foreach(fun(_) ->
7                                   math:erf(X)
8                              end,
9                              seq(1,NCPU)),
10                     X
11                 end, Vect)
12         end, Data),
13 ...
```

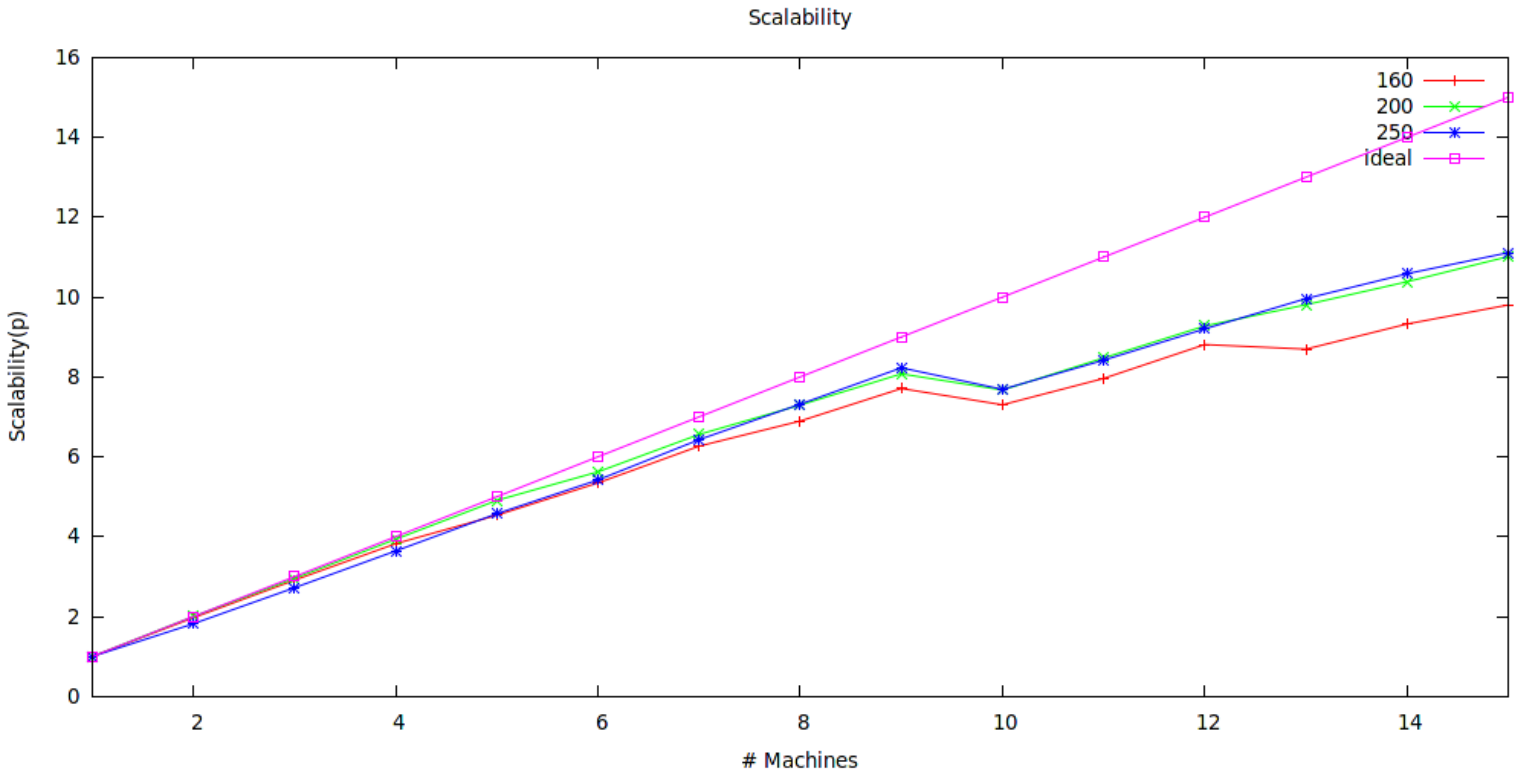
Pmap


Completion Time
Seconds
Machines
160
200
250
0
20
40
60
80
100
120
140
160
180
2
4
6
8
10
12
14

Pmap


Completion Time
Seconds
Machines
160
200
250
20
18
16
14
12
10
8
10
11
12
13
14
15

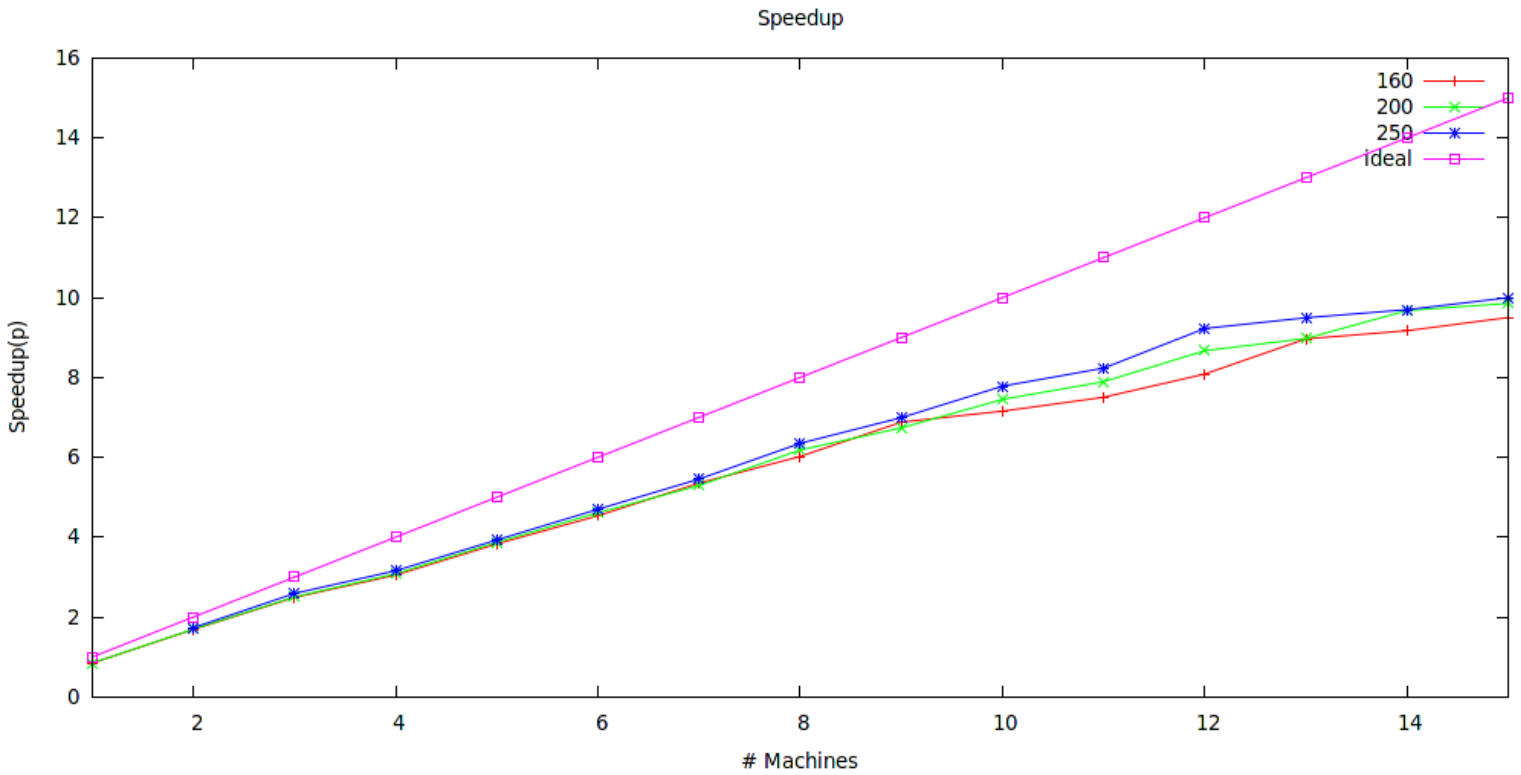
Pmap


Scalability
Scalability(p)
# Machines
160
200
250
ideal
0
2
4
6
8
10
12
14
16

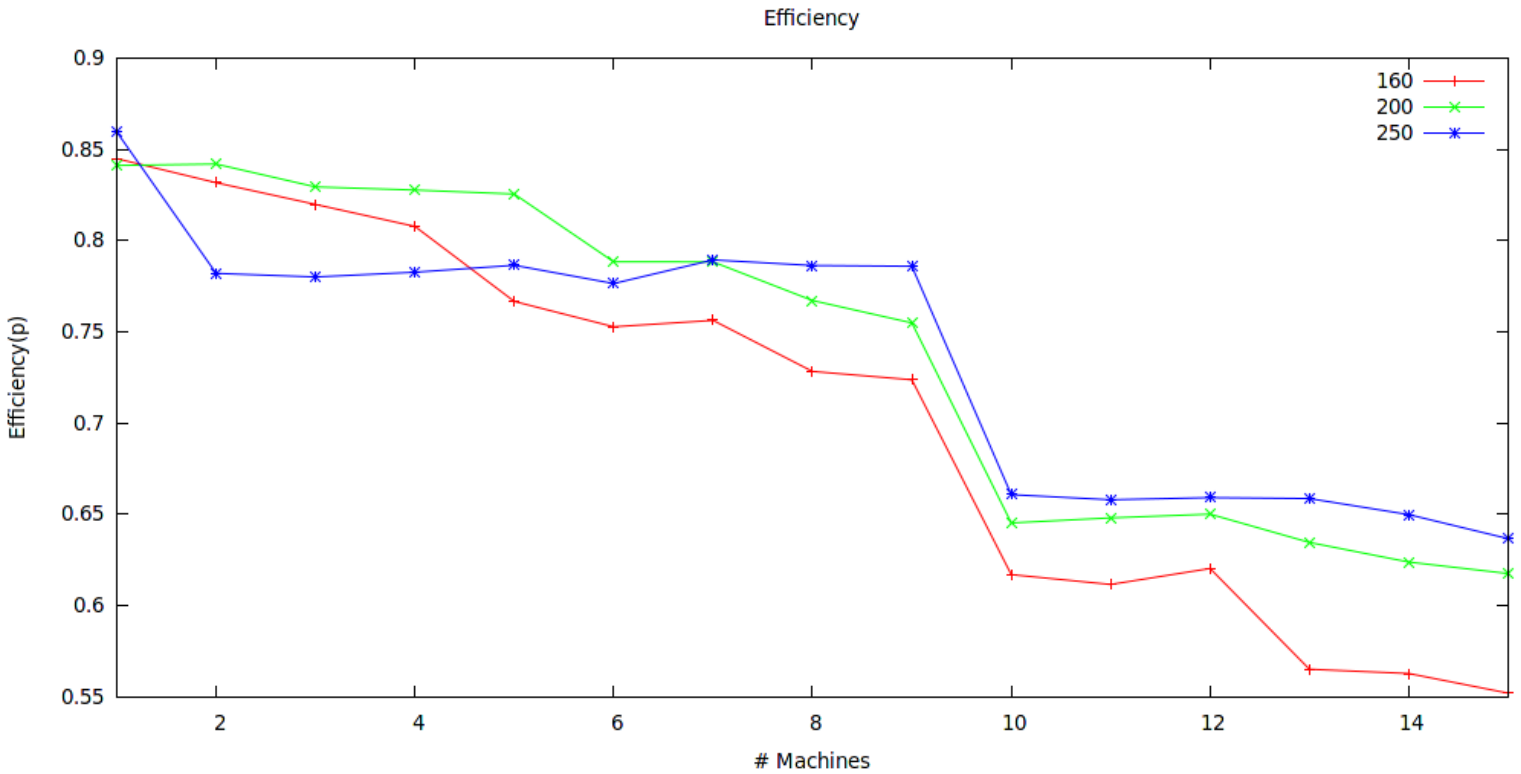
Pmap best sequential

```
1  seque(DimData, NCPU) ->
2     Data = duplicate(DimData,2.0),
3     {Time,Res} =
4         tc(lists,map,
5              [fun(X) ->
6                    foreach(fun(_) ->
7                                  erf(X)
8                            end,
9                            seq(1,NCPU)),
10                   X
11             end, Data]),
12    Time.
```

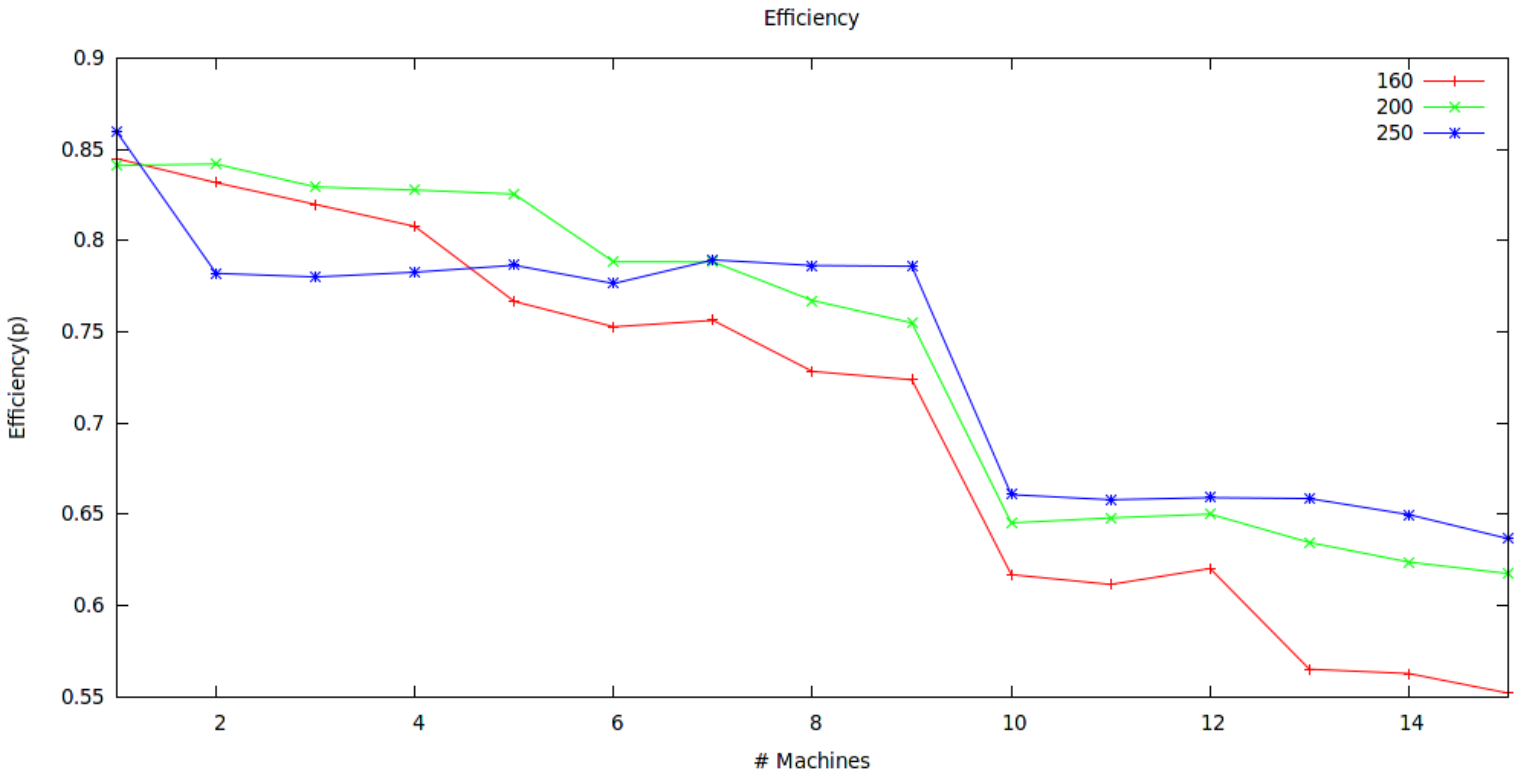
Pmap



Pmap

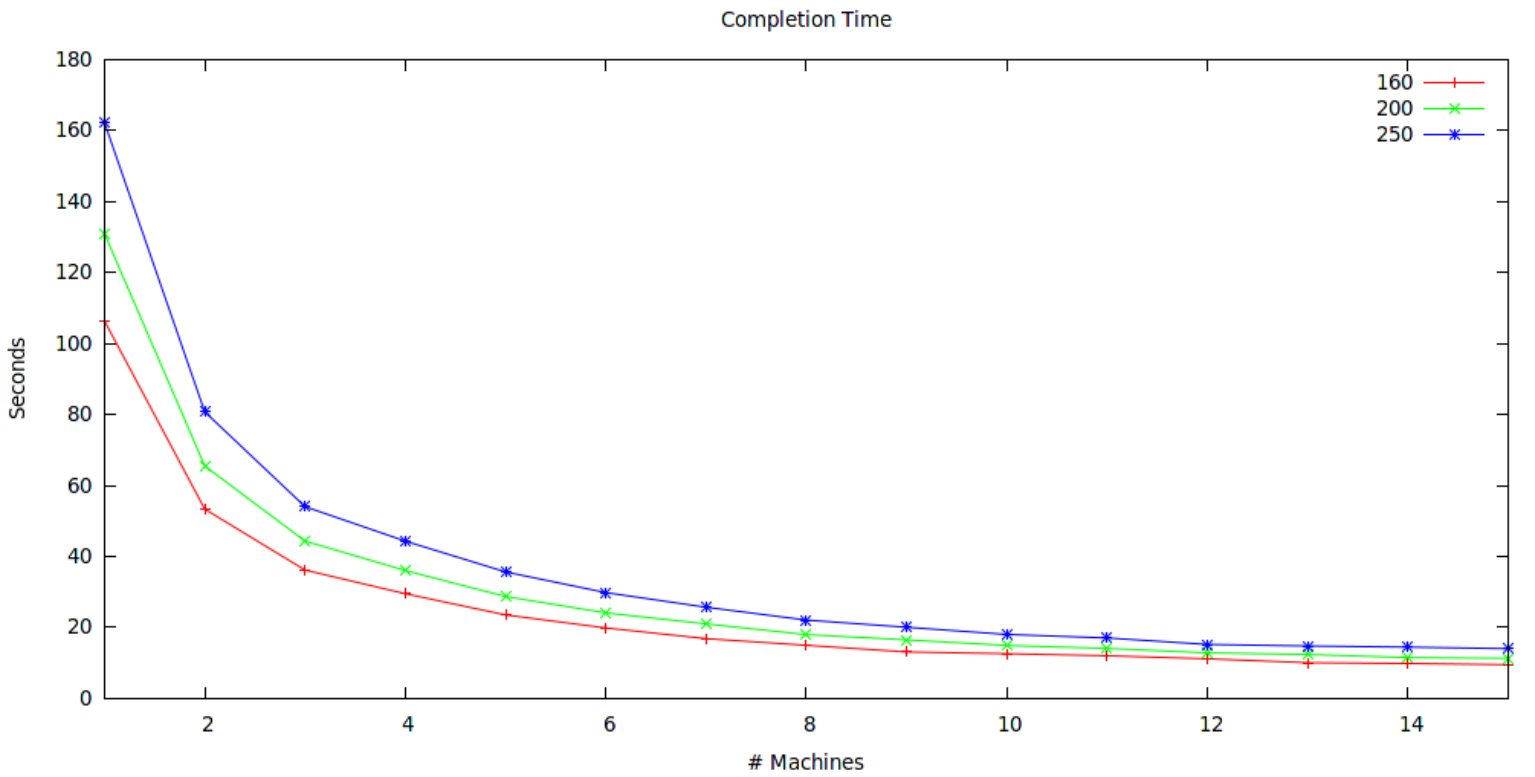

Efficiency
Efficiency(p)
# Machines
160
200
250
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
2
4
6
8
10
12
14

Pmap

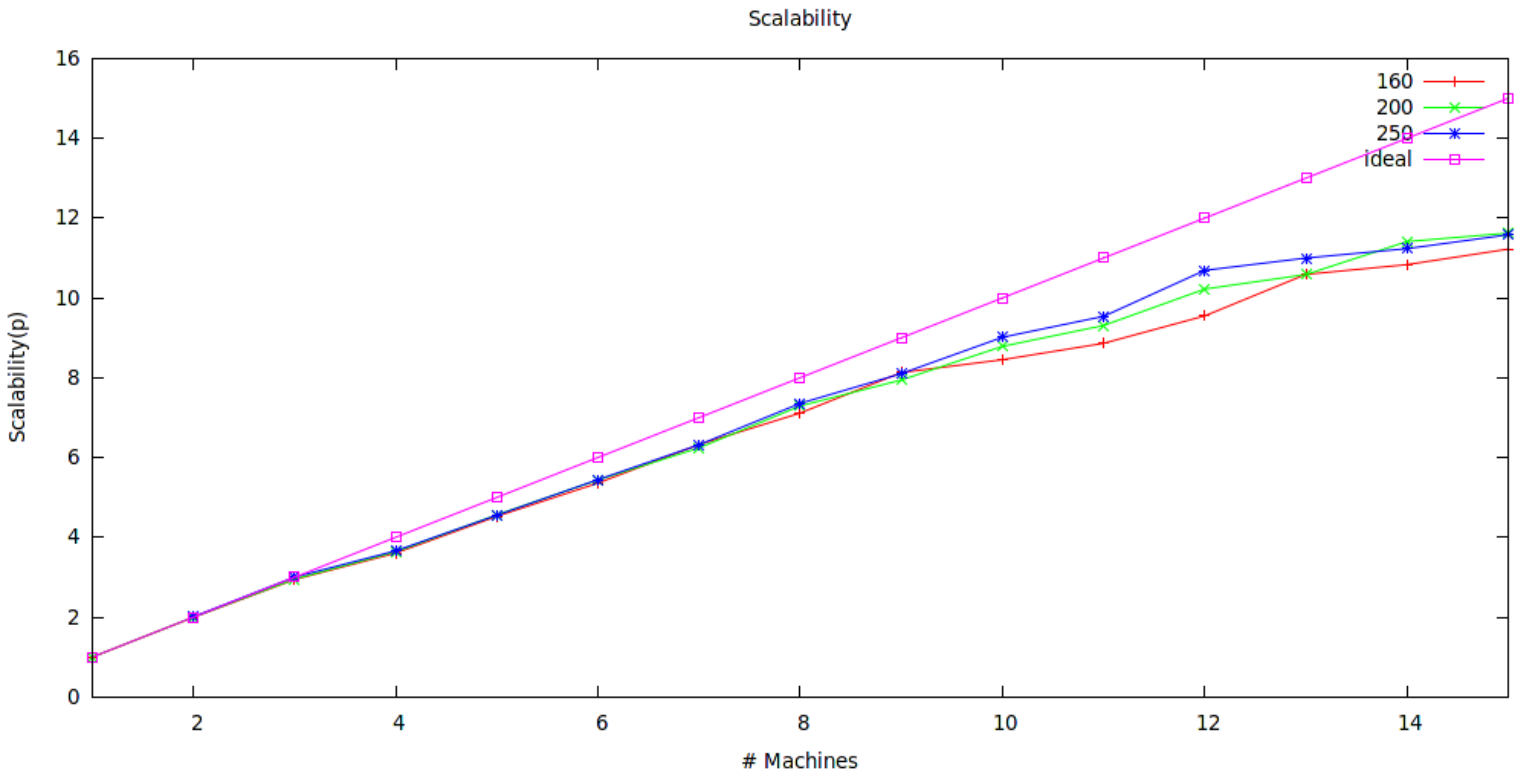


Notice the fall on 10 machines...

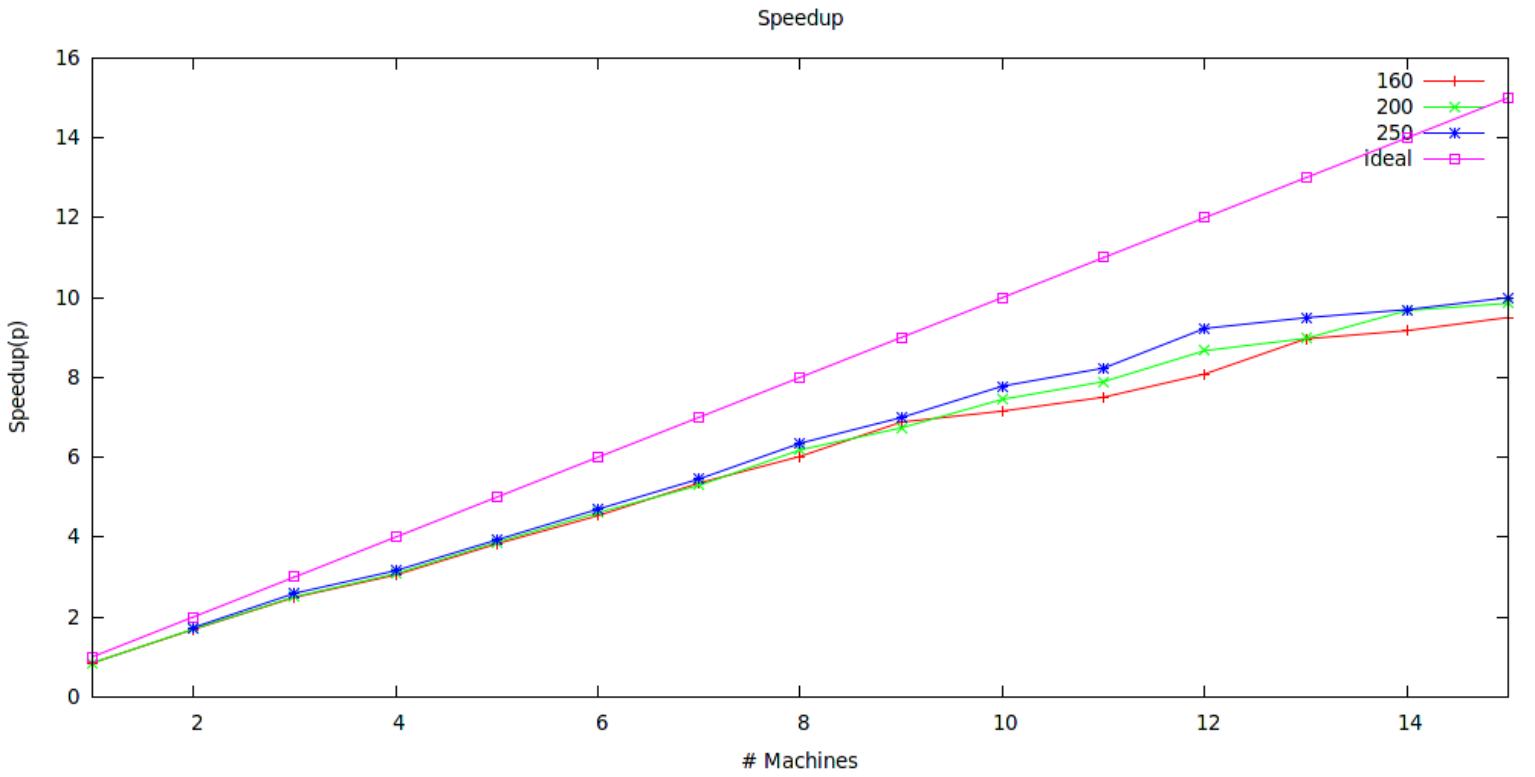
Pmap


Completion Time
Seconds
Machines
160
200
250
0
20
40
60
80
100
120
140
160
180
2
4
6
8
10
12
14

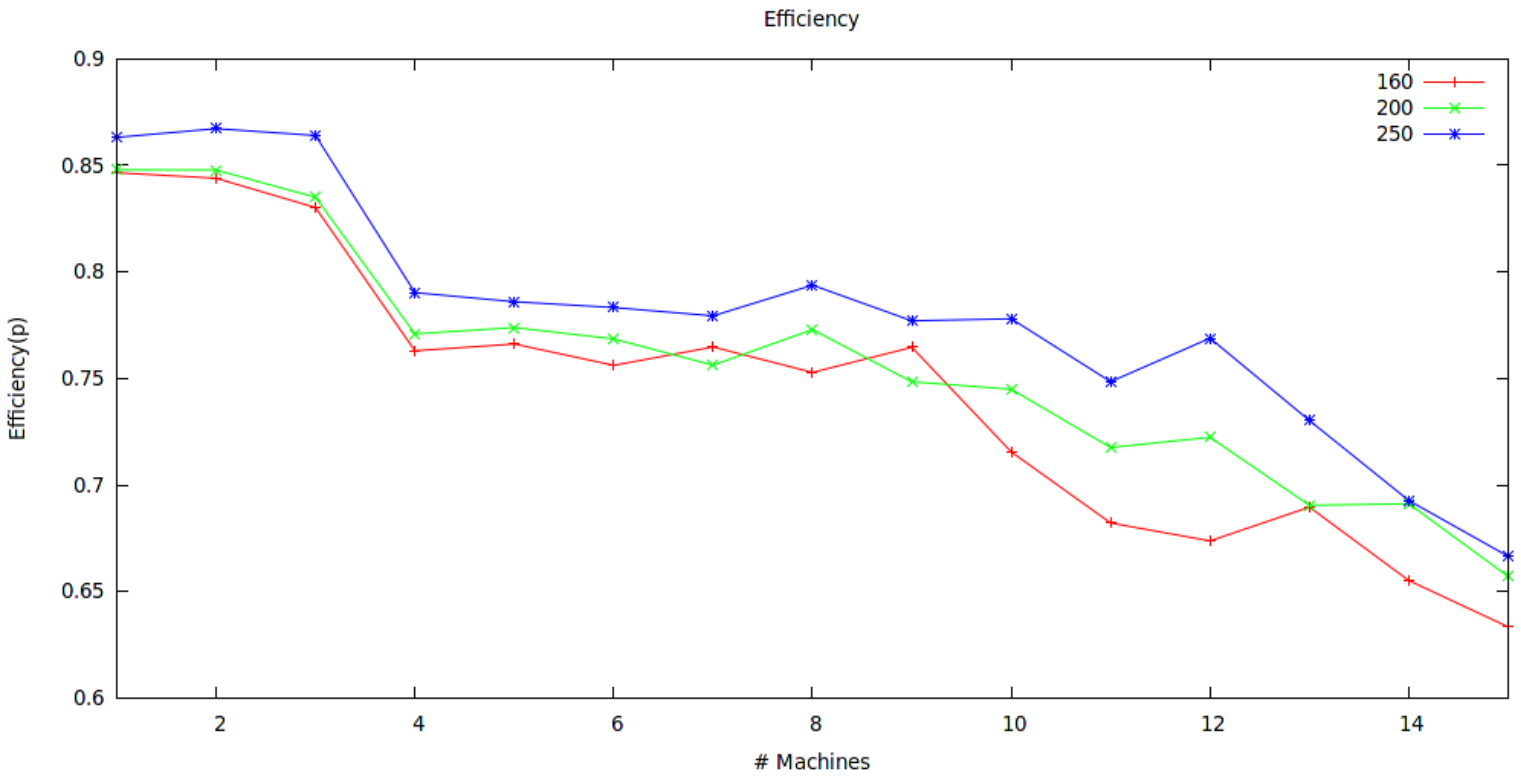
Pmap


Scalability
Scalability(p)
# Machines
160
200
250
Ideal
0
2
4
6
8
10
12
14
16

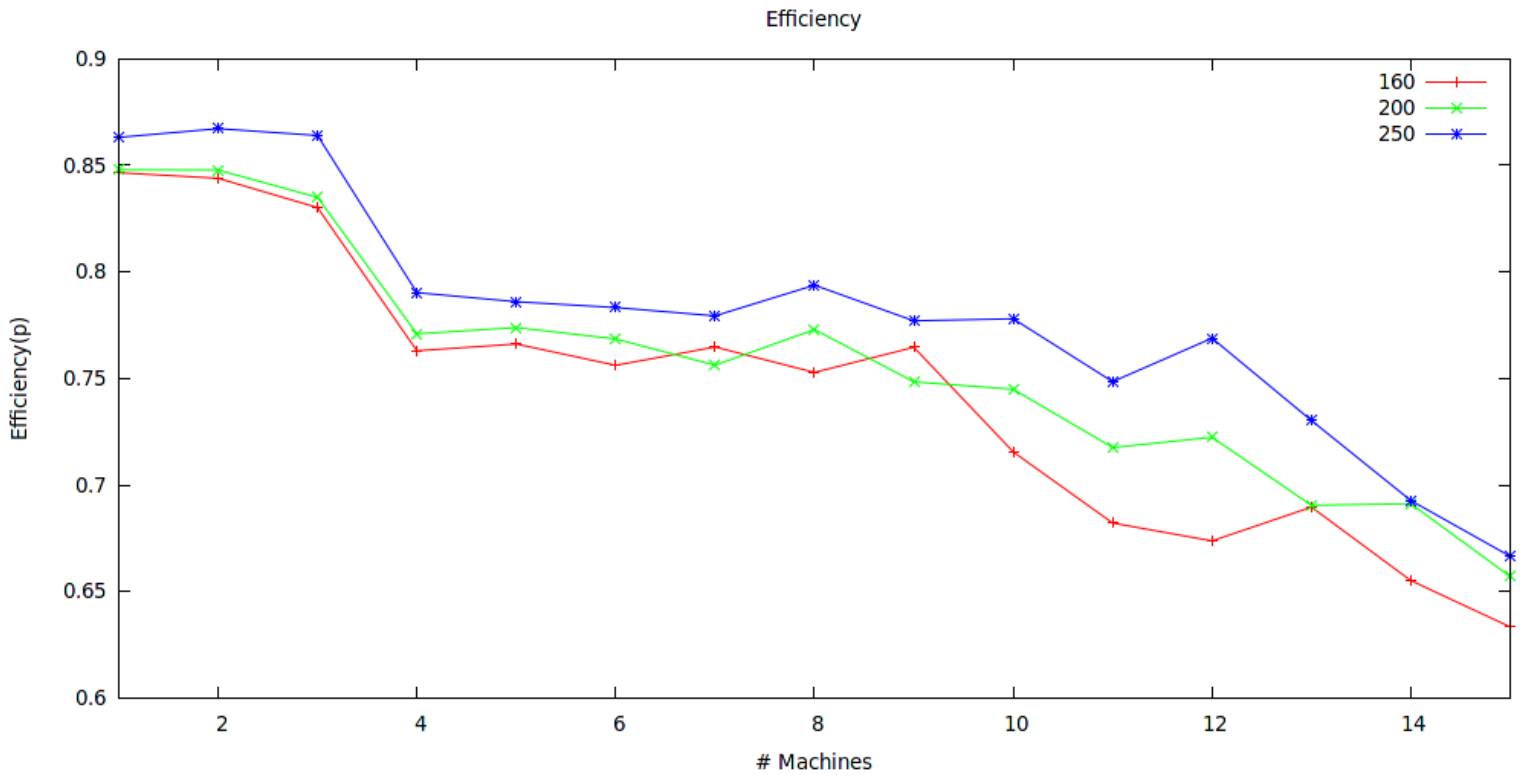
Pmap


Speedup
Speedup(p)
# Machines
160
200
250
Ideal
0
2
4
6
8
10
12
14
16

Pmap


Efficiency
Efficiency(p)
# Machines
160
200
250
0.9
0.85
0.8
0.75
0.7
0.65
0.6
2
4
6
8
10
12
14

Pmap



Much better :)

Pipeline Benchmark

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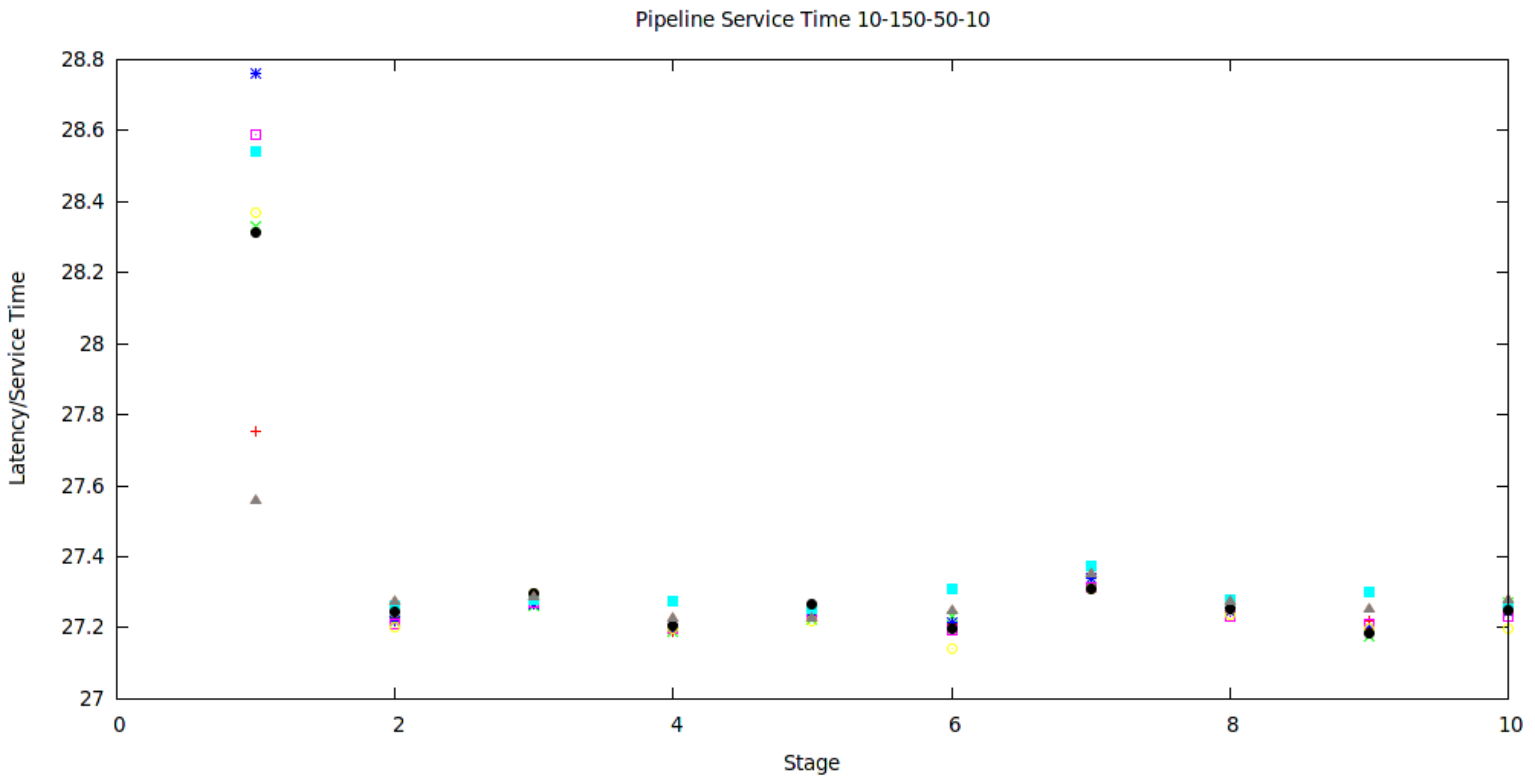
3. C power: `multiply_matrix(duplicate(C,duplicate2(D,X)))`

```
1  test(NStages,NCPU,DData,NData) ->
2  ...
3    Pids = create(duplicate(NStages,
4               fun(X) ->
5                 Matrix = duplicate2(50,2.0),
6                 multiply_matrix(duplicate(NCPU,Matrix)),
7                 X
8               end)),
9  ...
10   Res = run(duplicate(NData, duplicate2(DData,2.0)),
11              hd(Pids)),
12 ...
```

Pipeline

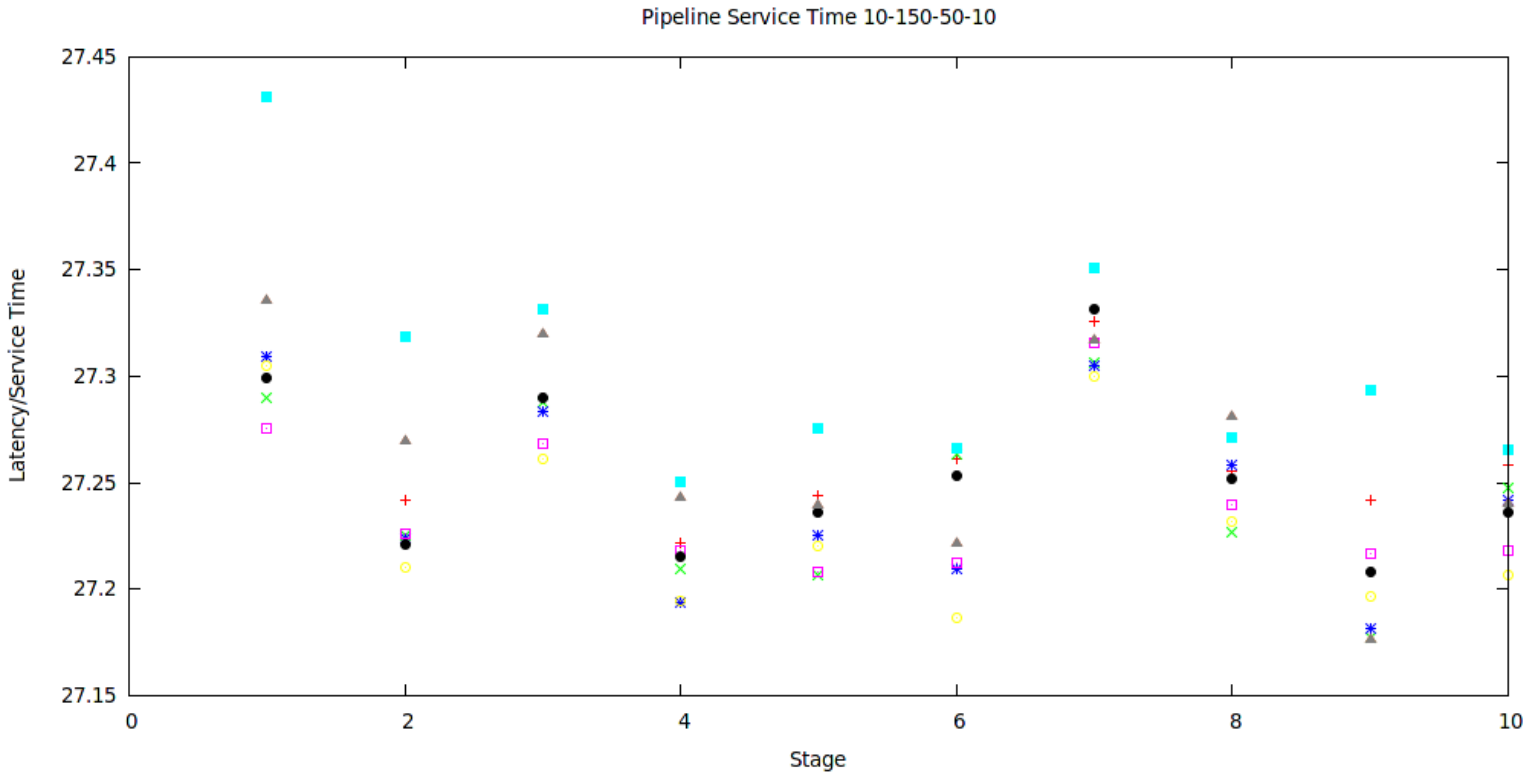
Feeding is too fast, in this case 2 sec.
Inter departure time $T_P \ll T_S$



Ts_α: 28.244
C=150 D=50

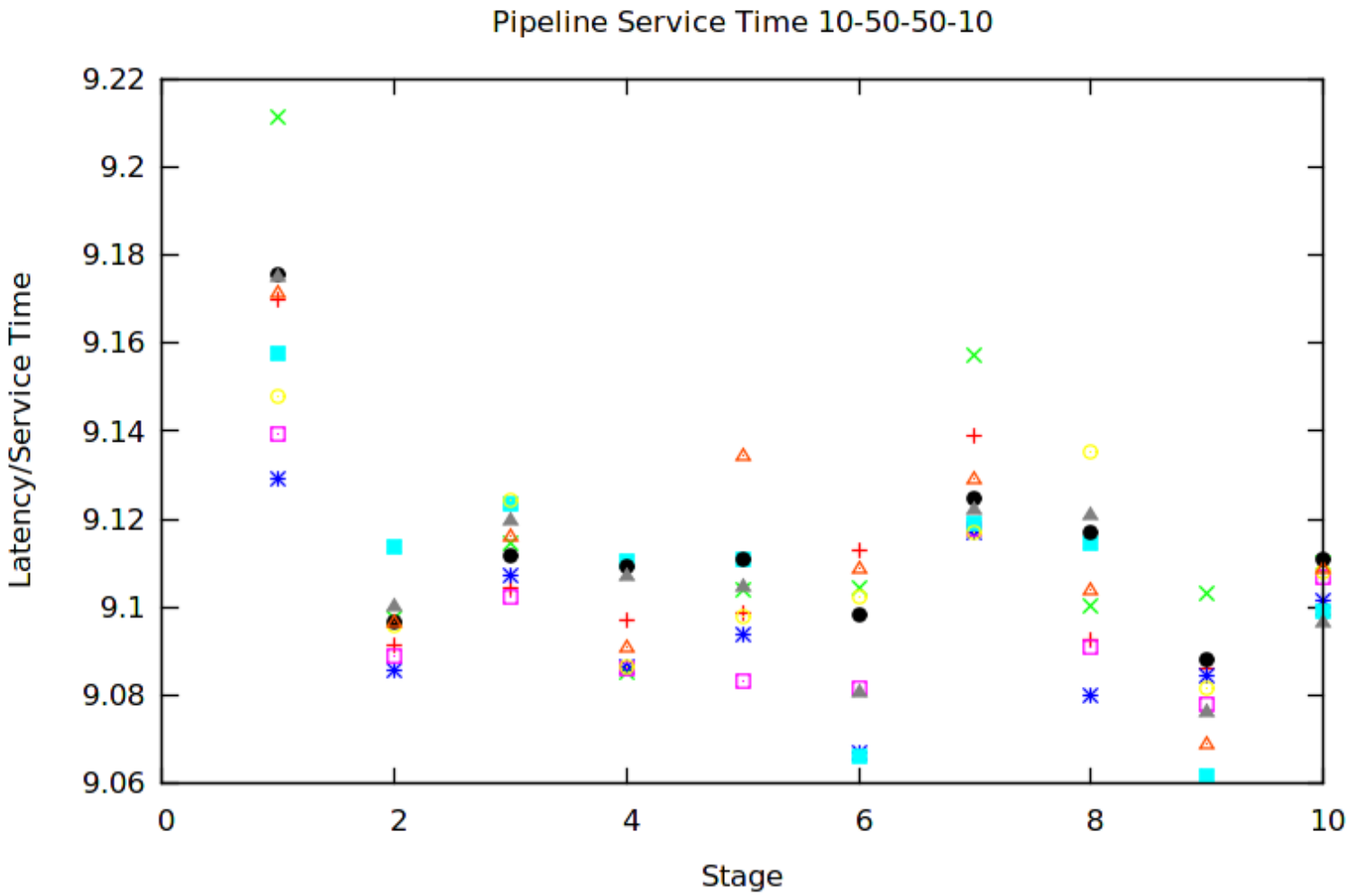
Pipeline Benchmark: head is the bottleneck

Feeding is close to average Service Time: 27 sec.



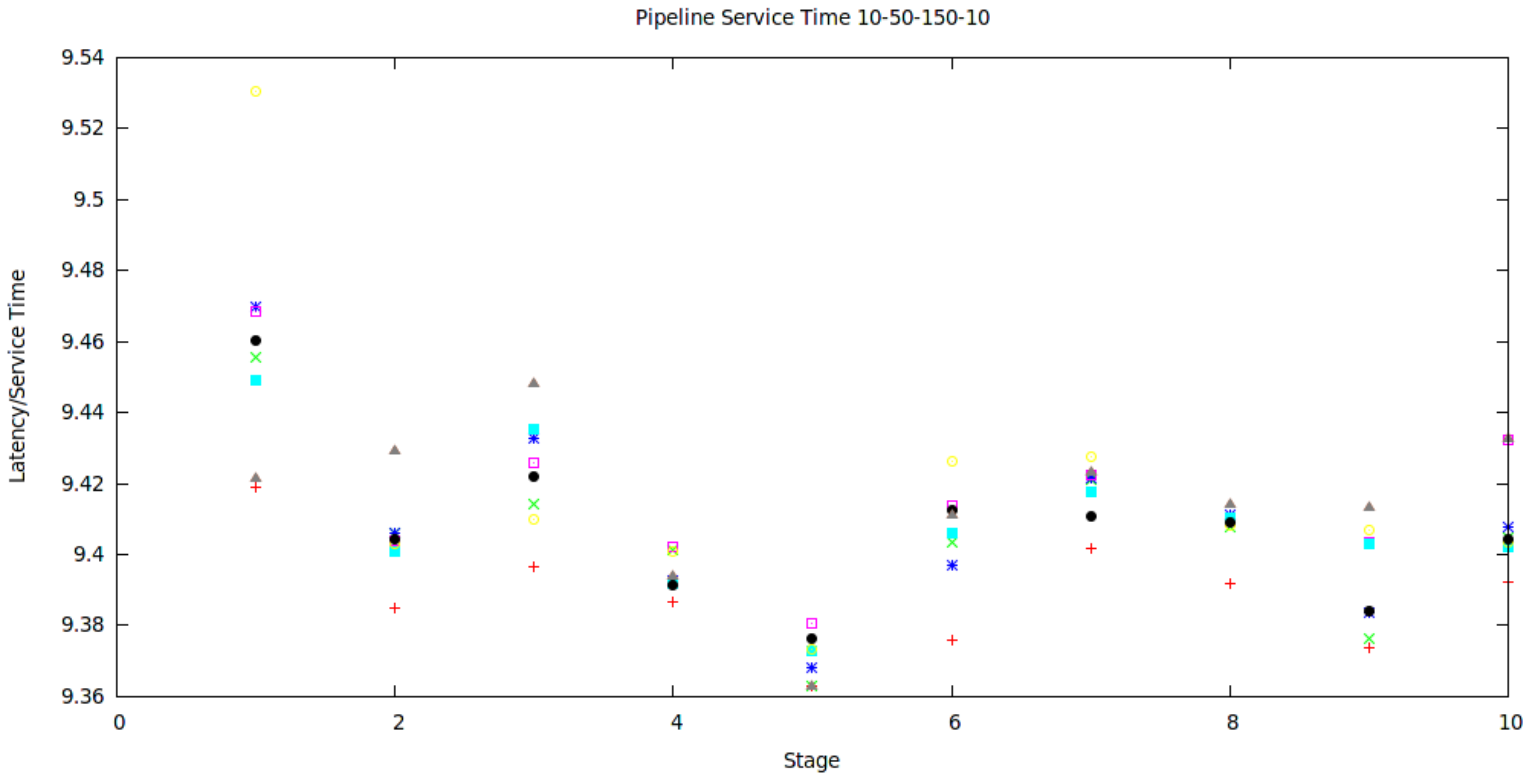
Ts_α: 27.374
C=150 D=50

Pipeline



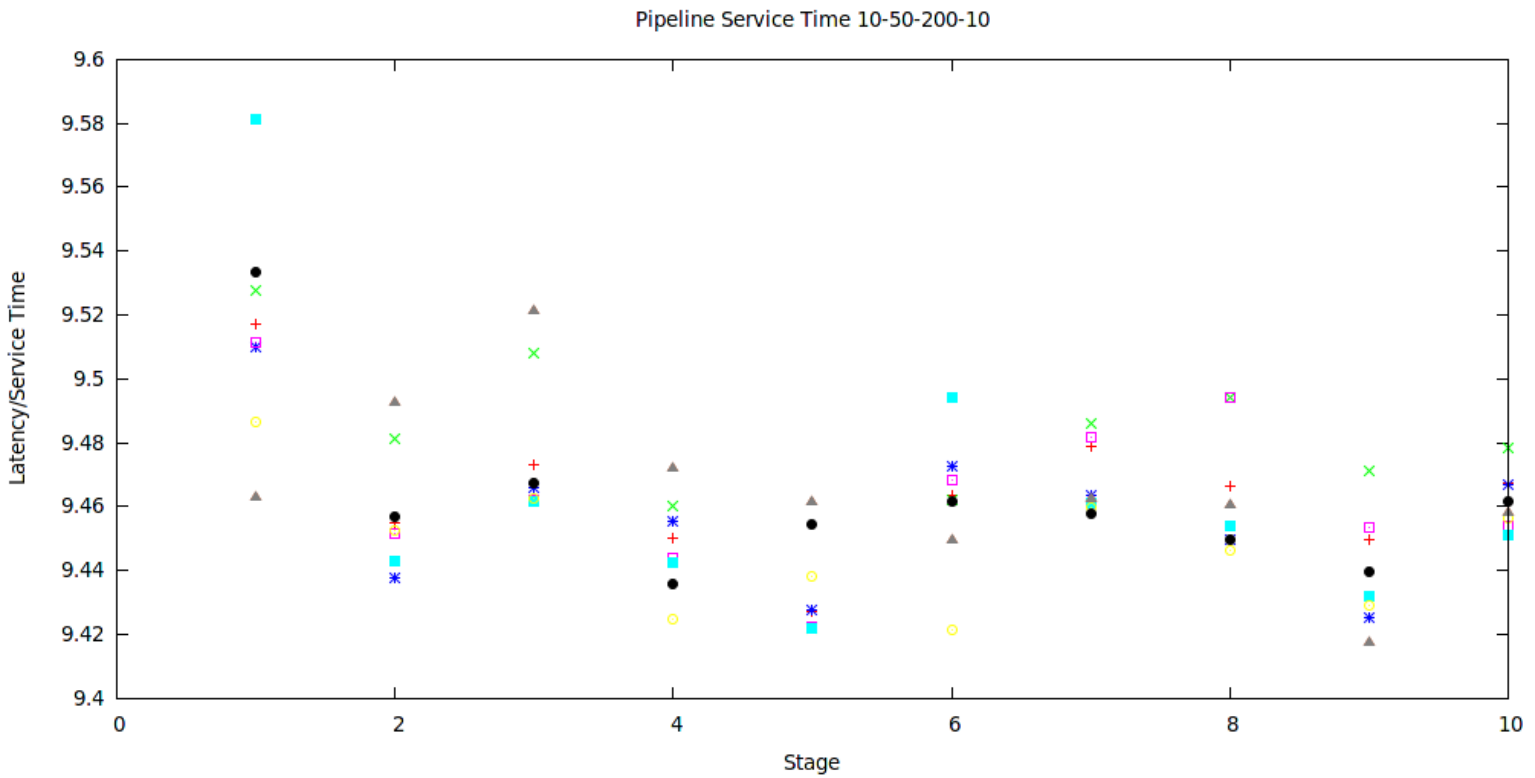
C=50 D=50

Pipeline - Ts_i



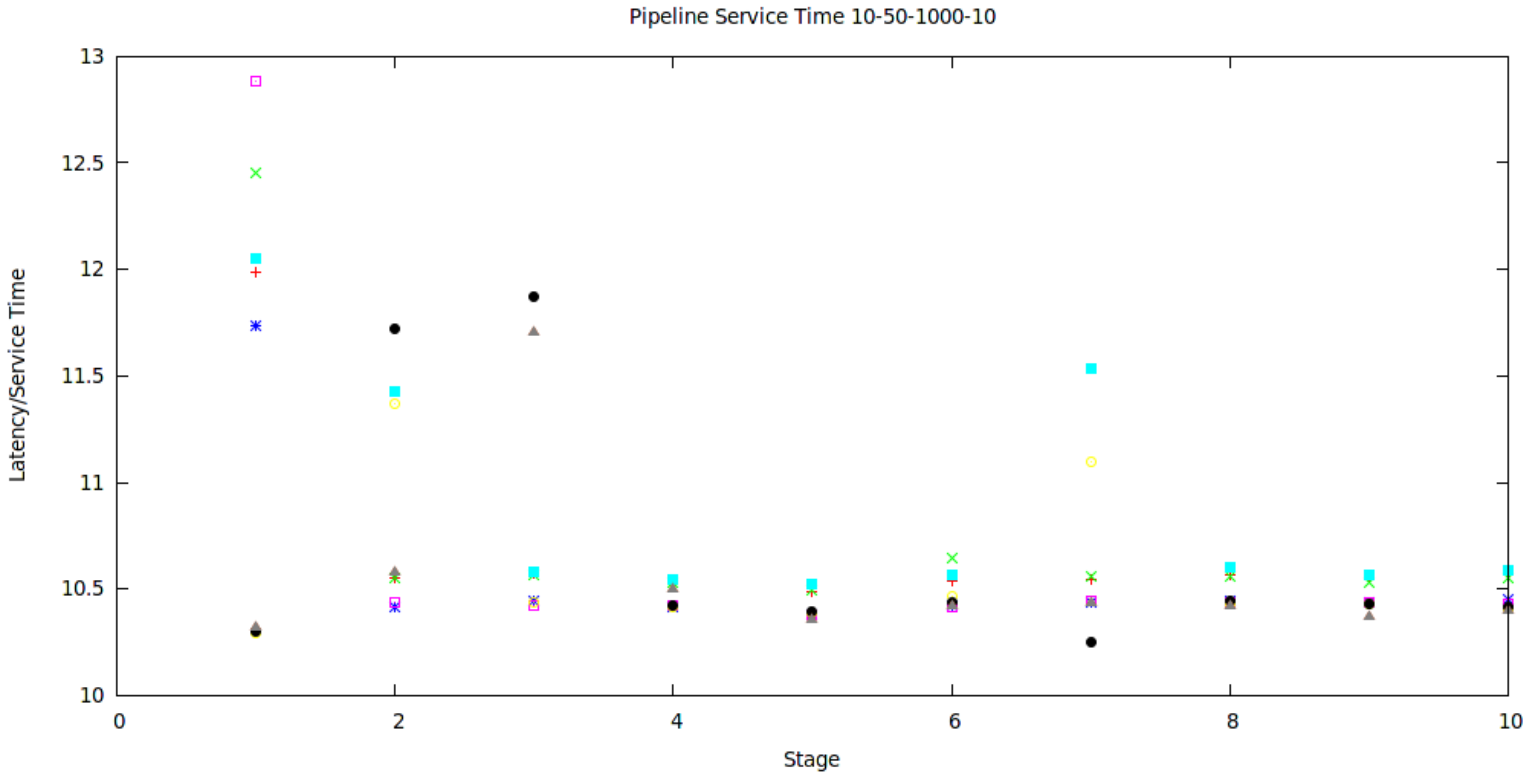
C=50 D=150

Pipeline - Ts_i



C=50 D=200

Pipeline - Ts_i



C=50 D=1000

Pipeline - Looking for the unbalanced case

$T_A = \text{average}(\text{InterArrivalTimes})$
$T_S = max\{Ts_i\}$

C	D	T_A	T_S	ρ
50	50	9.199	9.211453	1.00
50	150	9.629	9.530386	0.98
50	200	9.868	9.581177	0.97
50	300	10.069	9.799503	0.97
50	1000	19.452	12.882535	0.66

matrix of 1000 floats $\sim$ 19MB $\Rightarrow$ RTT: 1.895 sec.

Going further

- implement other skeletons:
  - farm as a general case for pmap
  - fold as a particular case for pipeline
- exploit higher order
  - compose skeletons: `pmap(fun(X) -> pmap(X) end, [[1..3000],[1..2000]])`
- do things the right way: erlang pool manager
- fault tolerance: handle exceptions
- learn from errors: autonomic first-stage pipeline
- make *ports* for dusty deck code

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- make *ports* for dusty deck code
- (lot further) make a manager with inviso/heartbeat...

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  - only short-coming is no shared memory support