Enhancing the performance of Grid Applications with Skeletons and Process Algebras

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A. Benoit, M. Cole, S. Gilmore, J. Hillston

School of informatics http://groups.inf.ed.ac.uk/enhance/

Introduction - Context of the work

- Parallel programs in a heterogeneous context
  - run on a widely distributed collection of computers
  - resource availability and performance unpredictable
  - scheduling/rescheduling issues
- High-level parallel programming
  - library of skeletons (parallel schemes)
  - many real applications can use these skeletons
  - modularity, configurability $\rightarrow$ easier for the user
  - Edinburgh Skeleton Library eSkel (MPI) [Cole02]

Introduction - Performance evaluation

- Use of a particular skeleton:
  information about implied scheduling dependencies
- Model with stochastic process algebra
  - include aspects of uncertainty
  - automated modelling process
  - dynamic monitoring of resource performance

$\rightarrow$ allow better scheduling decisions and adaptive rescheduling of applications

$\rightarrow$ *Enhance the performance of parallel programs*

Structure of the talk

- The Edinburgh Skeleton Library *eSkel*

  and comparison with the P3L concepts

  - Motivation and general concepts
  - Skeletons in eSkel
  - Using eSkel
- Performance models of skeletons
  - Pipeline model
  - AMoGeT (Automatic Model Generation Tool)
  - Some results
- Conclusions and Perspectives

eSkel - Brief history

- Concept of skeletons widely motivated
- eSkel
  - Murray Cole, 2002
  - Library of C functions, on top of MPI
  - Address issues raised by skeletal programming
- eSkel-2
  - Murray Cole and Anne Benoit, 2004
  - New interface and implementation
  - More concepts addressed for more flexibility

eSkel - Fundamental concepts

- Nesting Mode
  - define how we can nest several skeletons together
- Interaction Mode
  - define the interaction between different parts of skeletons, and between skeletons
- Data Mode
  - related to these other concepts, define how the data are handled

→ *How do we address such issues in eSkel?*
How are they addressed in P3L?

eSkel - Nesting Mode

- Can be either transient or persistent
- Transient nesting
  - an activity invokes another skeleton
  - the nested skeleton carries or creates its own data
- Persistent nesting
  - nested skeleton invoked once
  - gets the data from the outer level skeleton
- Linked to the data mode (detailed later)

eSkel - Nesting Mode: call tree

- Call tree built at the first interaction of each activity
- Structure of the persistently nested skeletons
  - search in the tree to find interaction partners
- Transiently nested skeletons
  - not in the main tree
  - created dynamically, limited life time
  - subtree built dynamically when invoked

eSkel - Nesting Mode in P3L

- P3L (Anacleto, SkIE)
  - all nesting of skeletons is persistent
  - Defined within the P3L layer
  - Clearly separated from the sequential code defining the activities
- P3L-based libraries (Lithium, SKElib)
  - Concept of transient nesting not explicitly addressed
  - Not forbidden but not supported
- ASSIST: not relevant

eSkel - Interaction Mode

- Can be either implicit or explicit
- Implicit
  - an activity has no control over its interactions
  - function taking input data and returning output data
- Explicit
  - interactions triggered in the activity code
  - direct calls to the generic functions `Take` and `Give`
- Additional devolved mode for nested skeletons: the outer level skeleton may use the interaction mode of the inner skeleton

eSkel - Interaction Mode in P3L

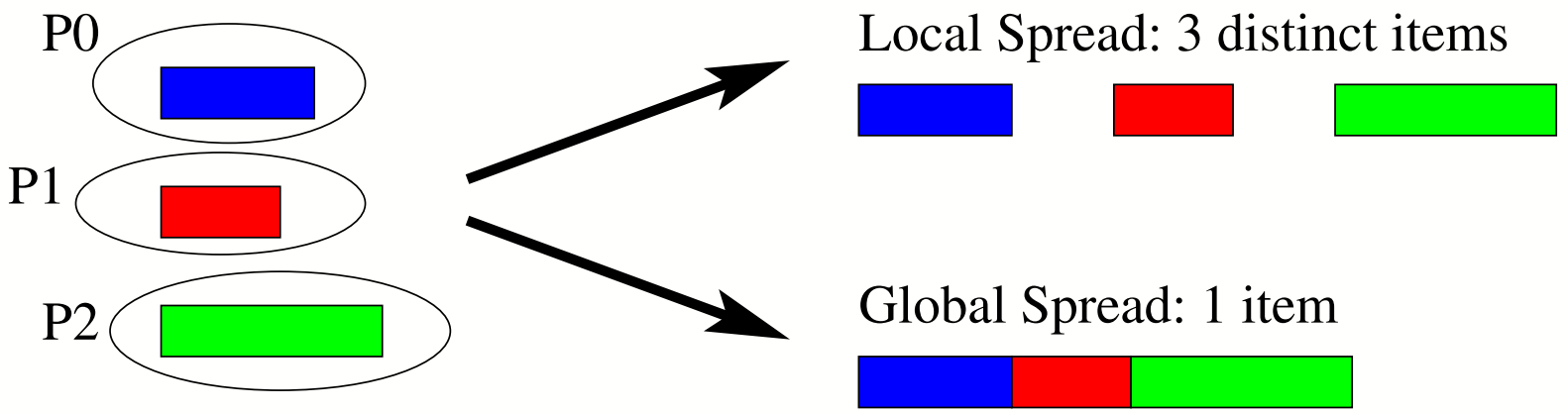
- P3L and related libraries
  - Interaction via streams of data
  - Implicitly defined by the skeleton
- ASSIST
  - more flexibility
  - implicit or explicit interaction is possible

eSkel - Data Mode

- Related to the previous concepts
- Buffer mode / Stream mode
  - BUF: data in a buffer *(transient nesting)*
  - STRM: the data flow into the skeleton from the activities of some enclosing skeleton call *(persistent nesting)*
- *eSkel Data Model* **eDM**
  - semantics of the interactions
  - unit of transfer: *eDM molecule*

eSkel - *eSkel Data Model*

- *eDM molecule*: collection of *eDM atoms*
- Type: defined using standard MPI datatypes
- eDM atom: local versus global spread



eSkel - Skeletons: brief description

- Pipeline & Farm: classical skeletons, defined in a very generic way
- Deal: similar to farm, except that the tasks are distributed in a cyclic order
- HaloSwap: 1-D array of single process activities, repeatedly (1) exchanging data with immediate neighbours, (2) processing data locally, (3) deciding collectively whether to proceed with another iteration
- Butterfly: class of divide & conquer algorithms

eSkel - Skeletons: task/data parallel

- Skeletons are commonly classified as
  - task parallel: dynamic communication processes to distribute the work – *pipeline, farm*
  - data parallel: works on a distributed data structure – *map, fold*
  - control skeletons: sequential modules and iteration of skeletons – *seq, loop*
- eSkel: only requires task parallel skeletons
  - data parallel skeletons: use of the *eDM*
  - control expressed directly through the C/MPI code

eSkel - Skeletons: interface

- eSkel:
  - not meant to be easy
  - based on MPI, the user must be familiar with it
  - structuring parallel MPI code
- P3L:
  - much easier to use, simple structure
  - less flexibility, structuring sequential code
  - data/task parallel and control skeletons
  - 3-stage pipeline: (create data, process, collect output)

eSkel - Interface: Pipeline

```
void Pipeline (int ns, Amode_t amode[], eSkel_molecule_t *
(*stages[])(eSkel_molecule_t *), int col, Dmode_t dmode, spread_t
spr[], MPI_Datatype ty[], void *in, int inlen, int inmul, void
*out, int outlen, int *outmul, int outbuffsz, MPI_Comm comm);
```

- general information about pipeline (ns, ...)
- specify the several modes: interaction mode (amode); data mode (dmode), spread (spr) and type (ty)
- information relative to the input buffer
- information relative to the output buffer

eSkel - Interface: Deal

```
void Deal (int nw, Amode_t amode, eSkel_molecule_t *worker
(eSkel_molecule_t *), int col, Dmode_t dmode, void *in, int inlen,
int inmul, spread_t inspr, MPI_Datatype inty, void *out, int
outlen, int *outmul, spread_t outspr, MPI_Datatype outty, int
outbuffsz, MPI_Comm comm);
```

- general information about deal (nw, ...)
- specify the several modes: interaction mode (amode) and data mode (dmode)
- information relative to the input buffer
- information relative to the output buffer

eSkel - Use of the library

- C/MPI program calling skeletons functions
- Great care should be taken for the parameters
- Definition of nested skeletons, workers, ... through standard C/MPI functions
- Only Pipeline and Deal implemented so far in eSkel version 2.0

→ *Demonstration of the use of eSkel*

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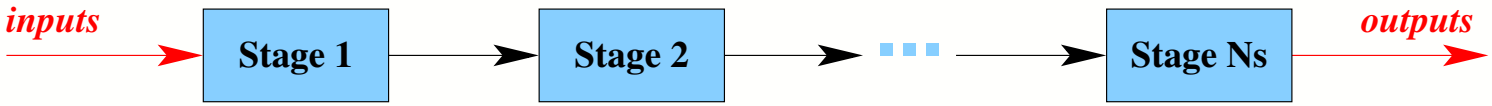
Pipeline - Principle of the skeleton



- N_s *stages* process a sequence of *inputs* to produce a sequence of *outputs*
- All input passes through each stage in the same order
- The internal activity of a stage may be parallel, but this is transparent to our model
- Model: mapping of the application onto the computing resources: the network and the processors

Pipeline - Application model

- Application model: independent of the resources
- 1 PEPA component per stage of the pipeline $(i = 1..N_s)$

  $Stage_i \stackrel{def}{=} (move_i, \top).(process_i, \top).(move_{i+1}, \top).Stage_i$
- Sequential component: gets data ($move_i$), processes it ($process_i$), moves the data to the next stage ($move_{i+1}$)
- Unspecified rates ($\top$): determined by the resources
- Pipeline application = cooperation of the stages

  $Pipeline \stackrel{def}{=} Stage_1 \underset{\{move_2\}}{\bowtie} Stage_2 \underset{\{move_3\}}{\bowtie} \ldots \underset{\{move_{N_s}\}}{\bowtie} Stage_{N_s}$
- Boundary: $move_1$: arrival of an input in the application

  $move_{N_s+1}$: transfer of the final output out of the Pipeline

Pipeline - Network model

- Network model: information about the efficiency of the link connection between pairs of processors
- Assign rates λ_i to the $move_i$ activities ($i = 1..N_s + 1$)

$$Network \stackrel{def}{=} (move_1, \lambda_1).Network + \ldots$$
$$+(move_{N_s+1}, \lambda_{N_s+1}).Network$$

- λ_i represents the connection between the processor j_{i-1} hosting stage $i-1$ and the processor j_i hosting stage i
- Boundary cases:
  - j_0 is the processor providing inputs to the Pipeline
  - j_{N_s+1} is where we want the outputs to be delivered

Pipeline - Processors model

- Processors model: Application mapped on a set of N_p processors
- Rate μ_i of the $process_i$ activities ($i = 1..N_s$): load of the processor, and other performance information
- One stage per processor ($N_p = N_s \ ; \ i = 1..N_s$):

$$Proc_i \stackrel{def}{=} (process_i, \mu_i).Proc_i$$

- Several stages per processor:

$$Proc_1 \stackrel{def}{=} (process_1, \mu_1).Proc_1 + (process_2, \mu_2).Proc_1$$

- Set of processors: parallel composition

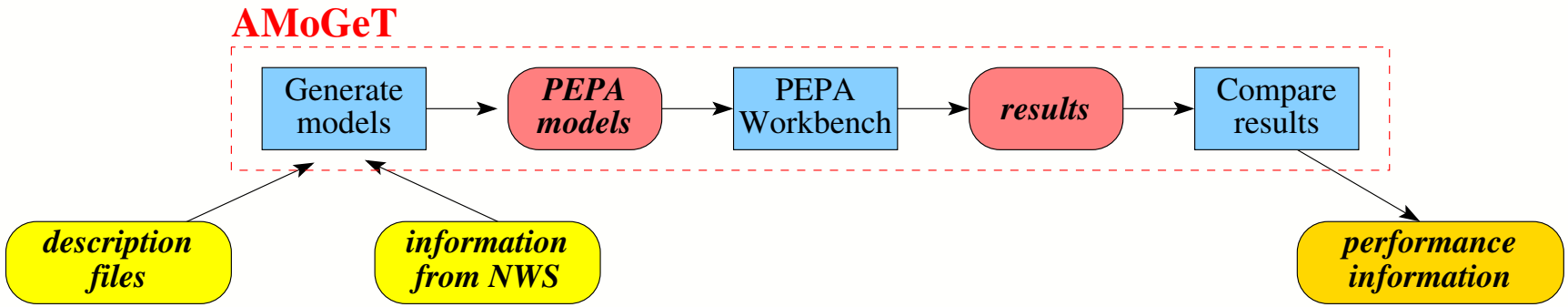
$$Processors \stackrel{def}{=} Proc_1 || Proc_2 || ... || Proc_{N_p}$$

Pipeline - Overall model

- The overall model is the mapping of the stages onto the processors and the network by using the cooperation combinator
- $L_p = \{process_1, ..., process_{N_s}\}$ synchronize $Pipeline$ and $Processors$
- $L_m = \{move_1, \ldots, move_{N_s+1}\}$ synchronize $Pipeline$ and $Network$

$$Mapping \stackrel{def}{=} Network \underset{L_m}{\bowtie} Pipeline \underset{L_p}{\bowtie} Processors$$

AMoGeT - Overview



- AMoGeT: Automatic Model Generation Tool
- Generic analysis component
- Ultimate role: integrated component of a run-time scheduler and re-scheduler

AMoGeT - Description files (1)

- Specify the names of the processors
  - file `hosts.txt`: list of IP addresses
  - rank i in the list $\rightarrow$ processor i
  - processor 1 is the *reference processor*

```
wellogy.inf.ed.ac.uk
bw240n01.inf.ed.ac.uk
bw240n02.inf.ed.ac.uk
france.imag.fr
```

AMoGeT - Description files (2)

- Describe the modelled application *mymodel*
  - file `mymodel.des`
  - stages of the Pipeline: number of stages N_s and time tr_s (sec) required to compute one output for each stage $s = 1..N_s$ on the reference processor

    `nbstage=`N_s`; tr1=10; tr2=2; ...`
  - mappings of stages to processors: location of the input data, the processor where each stage is processed, and where the output data must be left.

    `mappings=[1,(1,2,3),1],[1,(1,1,1),1];`

AMoGeT - Using the Network Weather Service

- The Network Weather Service (NWS) [Wolski99]
  - Dynamic forecast of the performance of network and computational resources
  - Just a few scripts to run on the monitored nodes
  - Information we use:
    - av_i fraction of CPU available to a newly-started process on the processor i
    - $la_{i,j}$ - latency (in ms) of a communication from processor i to processor j
- cpu_i - frequency of the processor i in MHz (`/proc/cpuinfo`)

AMoGeT - Generating the models

- One Pipeline model per mapping
- Problem: computing the rates
  - Stage s ($s = 1..N_s$) hosted on processor j (and a total of nb_j stages hosted on this processor):

$$\mu_s = \frac{av_j}{nb_j} \times \frac{cpu_j}{cpu_1} \times \frac{1}{tr_s}$$

  - Rate λ_s ($s = 1..N_s + 1$): connection link between the processor j_{s-1} hosting stage $s-1$ and the processor j_s hosting stage s: $\lambda_s = 10^3 / la_{j_{s-1},j_s}$

    (boundary cases: stage 0 = input and stage $N_s + 1$ = output)

AMoGeT - Solving the models and comparing the results

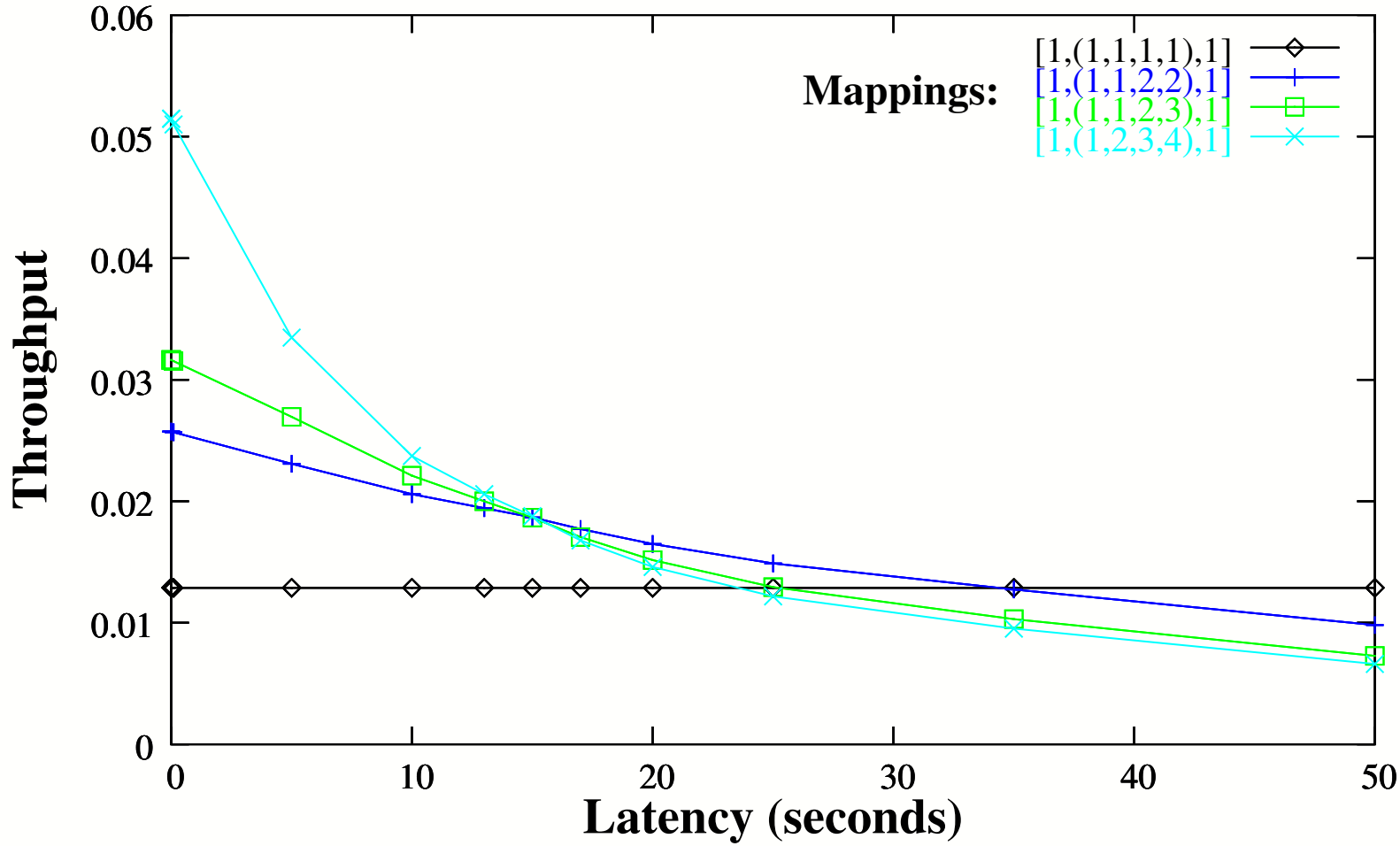
- Numerical results obtained with the PEPA Workbench [Gilmore94]
- Performance result: throughput of the $move_s$ activities = throughput of the application
- Result obtained via a simple command line, all the results saved in a single file
- Which mapping produces the best throughput?
- Use this mapping to run the application

Numerical Results

- Example 1: 3 Pipeline stages, up to 3 processors
- 27 states, 51 transitions $\rightarrow$ less than 1 second to solve
- latency of the com 0.001 sec; all stages/processors are identical; time required to complete a stage t
- $\mu_i = 1/(t \times nb_j)$ (nb_j: nb stages on processor j)
- Mappings compared: all the mappings with the first stage on the first processor (mappings $[1, (1, *, *), *]$)
  - $t = 0.1$: optimal mappings (1,2,3) and (1,3,2) with a throughput of 5.64
  - $t = 0.2$: same optimal mappings (one stage on each processor), but throughput divided by 2 (2.82)

Numerical Results

- Example 2: 4 Pipeline stages, up to 4 processors, $t = 10$



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Conclusions - Part 1

- Why structured parallel programming matters? (*Murray Cole's invited talk to EuroPar 2004 in Pisa*)
- Presentation of the Edinburgh Skeleton Library *eSkel*
  - Concepts at the basis of the library
  - How do we address these concepts
- Comparison with the P3L language and concepts, designed in Pisa.

Perspectives - Part 1 (1)

- *eSkel*: ongoing development and implementation phase
  - Still several skeletons to implement
  - Interface could be made a bit easier and user-friendly
  - Necessity of a debugging mode to help the writing of application (checking the correctness of the definitions in the application code, the coherence between modes, ...)

→ *Demo for interested people*

Perspectives - Part 1 (2)

- Validation of these concepts
  - Develop a real application with *eSkel*
  - Promote the idea of skeletons
- Comparison with other approaches
  - P3L, ASSIST, ...
  - Kuchen's skeleton library
  - Parallel functional language Eden

→ *Motivation for my visit in Pisa*

Conclusions - Part 2

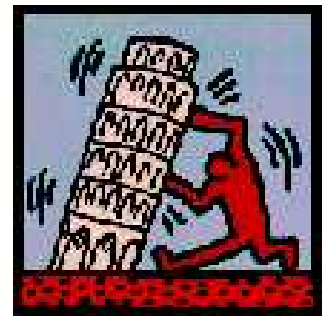
- Use of skeletons and performance models to improve the performance of high-level parallel programs
  - Pipeline and Deal skeleton
  - Tool AMoGeT which automates all the steps to obtain the result easily
  - Models: help us to choose the mapping to produce the best throughput of the application
  - Use of the Network Weather Service to obtain realistic models

Perspectives - Part 2

- Provide more detailed timing information on the tool to prove its usefulness - *Recent work*
- Extension to other skeletons
- Experiments with a realistic application on an heterogeneous computational Grid
- Integrate in a graphical tool to help the design of applications with *eSkel*

First case study → we have the potential to enhance the performance of high-level parallel programs with the use of skeletons and process algebras

Thank you for you attention!



Grazie per la vostra attenzione!

Any questions?

Related projects

- The Network Weather Service – [Wolski99]
  - benchmarking and monitoring techniques for the Grid
  - no skeletons and no performance models
- ICENI project – [Furmento02]
  - performance models to improve the scheduling decisions
  - no skeletons, models = graphs which approximate data
- Use of skeleton programs within grid nodes – [Alt02]
  - each server provides a function capturing the cost of its implementation of each skeleton
  - each skeleton runs only on one server
  - scheduling = select the most appropriate servers