Toward Better Simulation of MPI Applications on Ethernet/TCP Networks

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Grid 5000 Spring School (PMBS workshop / SC'13)

Toward Exascale ?

Already insanely complex platforms and applications with Peta-scale systems. Do we have a chance to understand exascale systems ?

- European approach to Exascale: Mont-Blanc; low-power commodity hardware s.a. ARM+GPUs+Ethernet
- Need for application performance prediction and capacity planning

MPI simulation: what for ?

1. Helping application developers
    - Non-intrusive tracing and repeatable execution
    - Classical debugging tools (gdb, valgrind) can be used
    - Save computing resources (runs on your laptop if possible)
2. Helping application users
    - How much resources should I ask for? (scaling)
    - Configure MPI collective operations
    - Provide baseline
3. Capacity planning (can we save on components? what-if analysis)

Performance Evaluation Through Fine Grain Simulation

Packet-level models full simulation of the whole protocol stack so hopefully perfect, but

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- complex models $\leadsto$ hard to instantiate and unstable

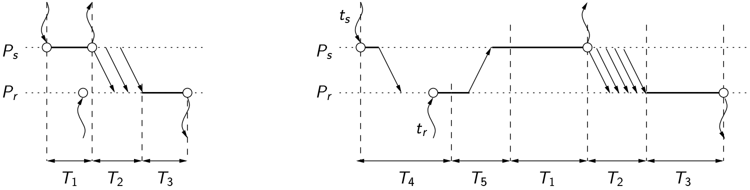
Flores Lucio, Paredes-Farrera, Jammeh, Fleury, Reed. *Opnet modeler and ns-2: Comparing the accuracy of network simulators for packet-level analysis using a network testbed.* WSEAS Transactions on Computers 2, no. 3 (2003)

- inherently slow (parallelism won't save you here!)
- sometimes wrongly implemented
- who can understand the macroscopic behavior of the application ?

When working at the application level, there is a need for something more high level that reflects the macroscopic characteristics of the machines

LogGPS in a Nutshell

The LogP model was initially designed for complexity analysis and algorithm design. Many variations available to account for protocol switch



Asynchronous mode ($k \leqslant \boxed{S}$) Rendez-vous mode ($k > S$)

The T_i's are basically continuous linear functions.

$$T_1 = o + kO_s \qquad T_2 = \begin{cases} L + kg & \text{if } k < \boxed{s} \\ L + sg + (k-s)G & \text{otherwise} \end{cases}$$

$$T_3 = o + kO_r \qquad T_4 = \max(L+o, t_r - t_s) + o \qquad T_5 = 2o + L$$

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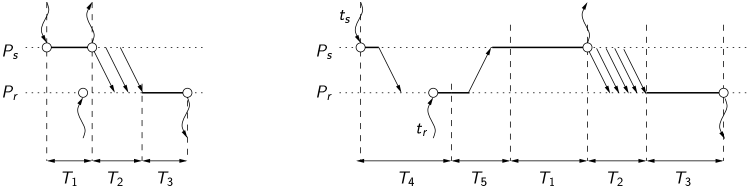

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Routine	Condition	Cost
`MPI_Send`	$k \leqslant S$	T_1
	$k > S$	$T_4 + T_5 + T_1$
`MPI_Recv`	$k \leqslant S$	$\max(T_1 + T_2 - (t_r - t_s), 0) + T_3$
	$k > S$	$\max(o + L - (t_r - t_s), 0) + o + T_5 + T_1 + T_2 + T_3$
`MPI_Isend`		o
`MPI_Irecv`		o

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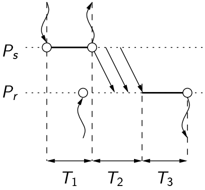

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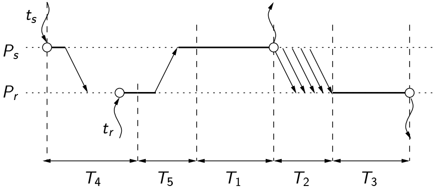


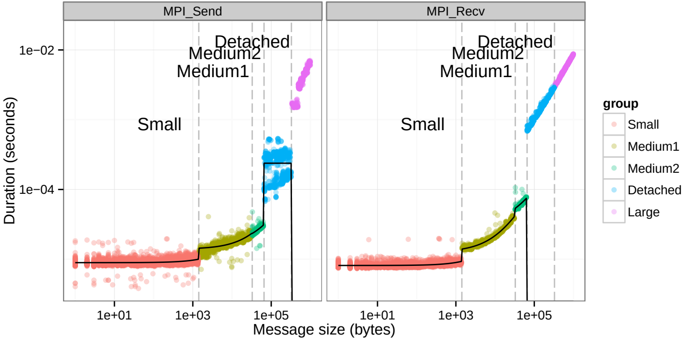
Rendez-vous mode ($k > S$)

The T_i's are basically continuous linear functions.

- May reflect the operation of specialized HPC networks from the early 1990s...
- Ignores potentially confounding factors present in modern-day systems (e.g., contention, topology, complex protocol stack, ...)
- Unless you have a well-tuned high-end machine, such model is unlikely to provide accurate estimations or useful baseline comparisons

MPI Point-to-Point Communication

Randomized measurements (OpenMPI/TCP/Eth1GB) since we are not interested in peak performances but in performance characterization



- There is a quite important variability
- There are at least 4 different modes
- It is piece-wise linear and discontinuous

SimGrid

- SimGrid is a 13 years old open-source project. Collaboration between France (INRIA, CNRS, Univ. Lyon, Nancy, Grenoble, ...), USA (UCSD, U. Hawaii), Great Britain (Cranfield), Austria (Vienna)...
- Initially focused on Grid settings, we argue that the same tool/techniques can be used for P2P, HPC and more recently cloud
- SimGrid relies on flow-level models that take topology into account.
  - Many naive flow-level models implemented in other simulators are *documented as wrong*
  - Some tools are *validated by general agreement*
  - Some tools present convincing graphs, which are *hardly reproducible*
  - Some tools are *optimistically validated*
  - We have tried hard to invalidate and improve our models for years

SMPI is the MPI flavor of SimGrid

Flow-level models

A communication is simulated as a single entity (like a flow in pipes):

$$T_{i,j}(S) = L_{i,j} + S/B_{i,j}, \text{ where } \begin{cases} S & \text{message size} \\ L_{i,j} & \text{latency between } i \text{ and } j \\ B_{i,j} & \text{bandwidth between } i \text{ and } j \end{cases}$$

Estimating $B_{i,j}$ requires to account for interactions with other flows

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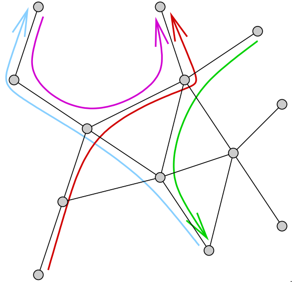
Assume steady-state and **share bandwidth** every time a new flow appears or disappears

Setting a set of flows $\mathcal{F}$ and a set of links $\mathcal{L}$

Constraints For all link j: $\sum_{\textbf{flow } i \textbf{ using link } j} \rho_i \leqslant C_j$



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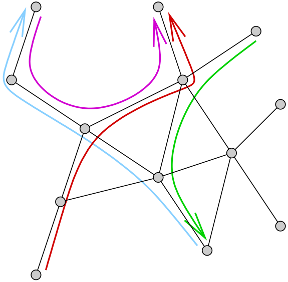

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Objective function Maximize $\min_i(\rho_i)$

Flow-level Models Facts

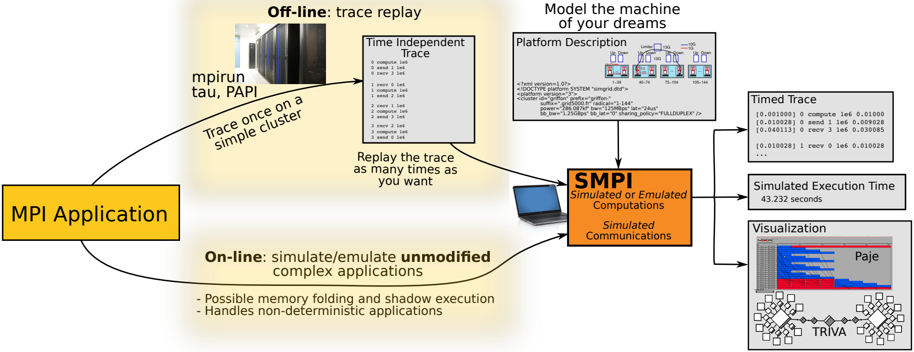
Many different sharing methods can be used and have been evaluated in the context of SimGrid

- **Pros**:
  - rather flexible (add linear limiters whenever you need one)
  - account for network topology
  - account for many non-trivial phenomena (e.g., RTT-unfairness of TCP and even reverse-traffic interferences to some extent)
- **Cons**:
  - ignores protocol oscillations, TCP slow start
  - ignores all transient phases
  - does not model well very unstable situations
  - does not model computation/communication overlap

Most people assume they cannot scale so they're ruled out in this context

Yet, when correctly implemented and optimized, it's better than commonly found implementations of delay-based models

SMPI – Offline vs. Online Simulation



Offline simulation

1. Obtain a time independent trace
2. Replay it on top of SimGrid as often as desired
3. Analyze with the comfort of a simulator

Fast, but requires extrapolation and limited to non-adaptive codes

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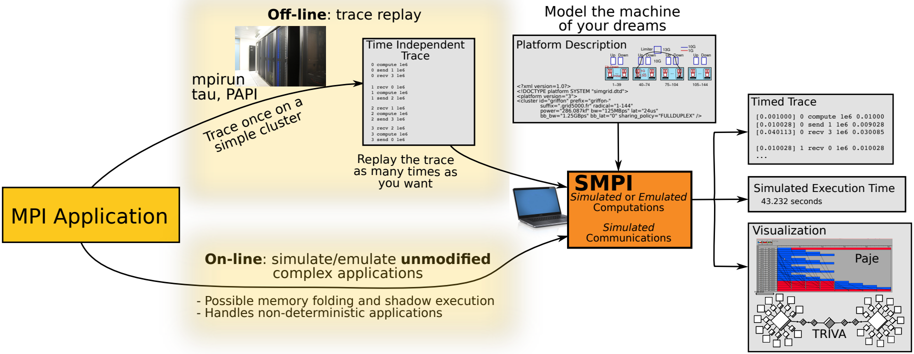


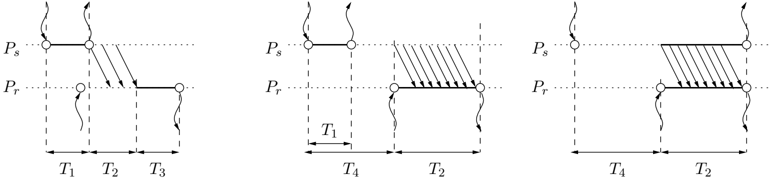
Online simulation

- Directly run the code on top of SimGrid
- Possible memory sharing between simulated processes (reduces memory footprint) and kernel sampling (reduces simulation time)
- Complies with most of the MPICH3 testsuite, compatible with many C F77 and F90 codes (NAS, LinPACK, Sweep3D, BigDFT, SpecFEM3D)

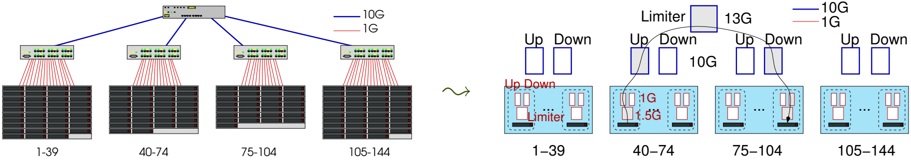
SMPI – Hybrid Model

SMPI combines accurate description of the platform, with both fluid and LogP family models:

- LogP: measure on real nodes to accurately model pt2pt performance (discontinuities) and communication modes (asynchronous, detached, synchronous)



- Fluid model: account for contention and network topology



Collective Communications

Classical approaches:

- use simple analytical formulas
- benchmark everything and inject corresponding timing
- trace communication pattern and replay

Real MPI implementations have several implementations for each collective and select the right one at runtime

- 2300 lines of code for the AllReduce in OpenMPI!!!

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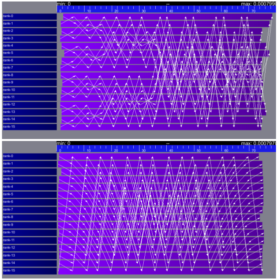
SMPI now uses



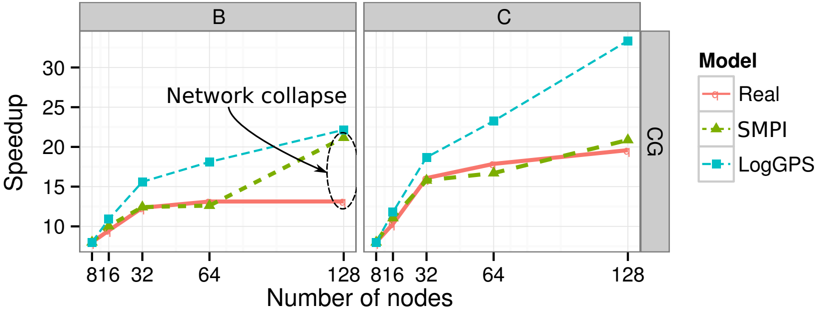
- more than 100 collective algorithms from three existing implementations (MPICH, OpenMPI, STAR-MPI) can be selected
- the same selection logic as MPICH or OpenMPI to accurately simulate their behavior

Such accurate modeling is actually critical to obtain decent predictions

Validation: Non-trivial Application Scaling (1)

Experiments run with several NAS parallel benchmarks to (in)validate the model for TCP platform

- Non trivial scaling
- Very good accuracy (especially compared to LogP)



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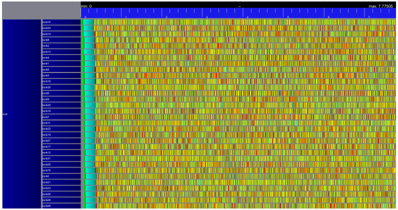

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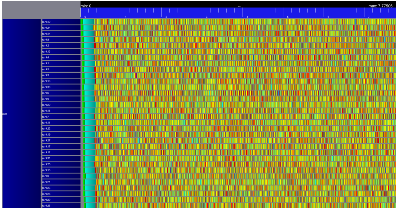

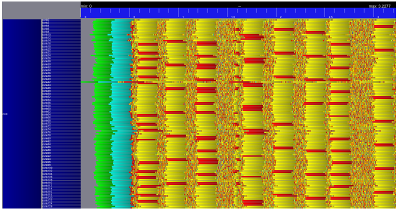

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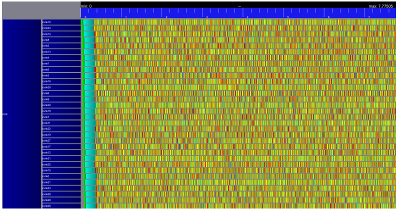

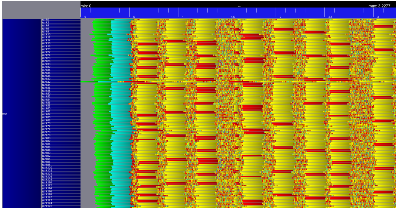

Massive switch packet drops lead to 200ms timeouts in TCP!

This is a software issue that needs to be fixed (not modeled) in reality

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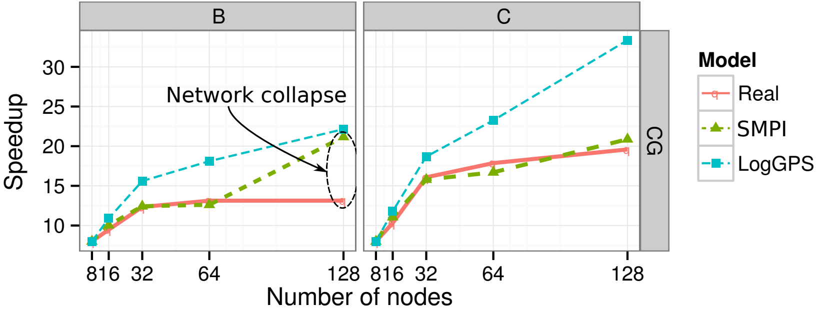

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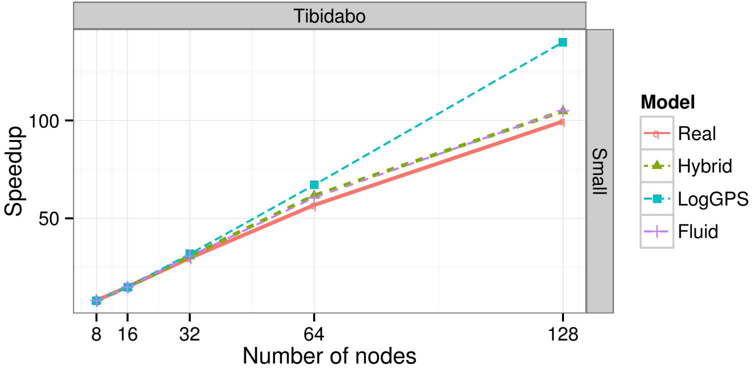
Validation: Non-trivial Application Scaling (2)

Experiments also run using real Physics code (BigDFT, SPECFEM3D) on Tibidabo (ARM cluster prototype)

- The set of collective operations may completely change depending on the instance, hence the need to use online simulation
- Very good accuracy (especially compared to LogP)



Conclusion

- We have now accurate baselines to compare with $\rightsquigarrow$ whenever there is a mismatch, we can question simulation as well as experimental setup:
  - TCP RTO issue
  - Inaccurate platform specifications
  - Flawed MPI optimization
- Hope it will be useful to
  - the Mont-Blanc project
  - you?...
  - the BigDFT developers
- Need to validate this approach on larger platforms, with other network types and topologies (e.g., Infiniband, torus)
- Communication through shared memory is ok, but modeling the interference between memory-bound kernels is really hard
- SMPI is open source/science: we put a lot of effort into making it usable

SIMGRID http://simgrid.gforge.inria.fr

Current Effort

Ongoing

- ☒ Seamless emulation (`mmap` approach works great)
- ☐ Modeling IB networks, torus/fat tree topologies
- ☐ Modeling energy (with A.C. Orgerie)
- ☒ Runtimes for hybrid (CPU+GPU) platforms (StarPU, with S. Thibault) on top of SimGrid
  - Works great for dense linear algebra so far (MAGMA/MORSE)
  - Ongoing effort for sparse linear algebra (QR-MUMPS with E. Agullo)
  - Large scale hybrid platforms (StarPU-MPI)
- ☐ Formal verification by exhaustive state space exploration

Future (really tricky)

- OpenMP/pthreads
- Computation/communication/memory access interferences
- IOs