SimGrid Kernel 101

Introducing the SimGrid Kernel

Da SimGrid Team

May 27, 2014

About this Presentation

Goals and Contents

- Present Simix, the simulation kernel of SimGrid
- Show some gore details about where our performance comes from
- This is NOT for newcommers but for hardcore SimGrid users (or curious folks)

The SimGrid 101 serie

- This is part of a serie of presentations introducing various aspects of SimGrid
- SimGrid 101. Introduction to the SimGrid Scientific Project
- SimGrid User 101. Practical introduction to SimGrid and MSG
- SimGrid User::Platform 101. Defining platforms and experiments in SimGrid
- SimGrid User::SimDag 101. Practical introduction to the use of SimDag
- SimGrid User::Visualization 101. Visualization of SimGrid simulation results
- SimGrid User::SMPI 101. Simulation MPI applications in practice
- SimGrid User::Model-checking 101. Formal Verification of SimGrid programs
- SimGrid Internal::Models. The Platform Models underlying SimGrid
- SimGrid Internal::Kernel. Under the Hood of SimGrid
- Get them from `http://simgrid.gforge.inria.fr/documentation.html`

SimGrid Internals in a Nutshell

Example of user code to execute

Alice

```
Send "toto" to Bob
Listen from Bob
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Bob

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Listen from Alice
Send "blah" to Alice
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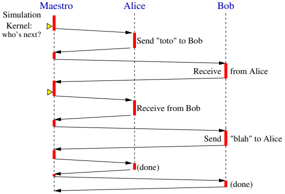

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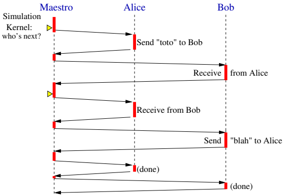
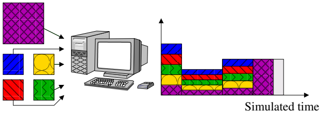


SimGrid internal Main Loop

1. Run every ready user process in row
   - Each wants to consume resources
   - Assign actions on resources
2. Compute share for actions
3. Get earliest finishing action
4. Unlock user code waiting on this action



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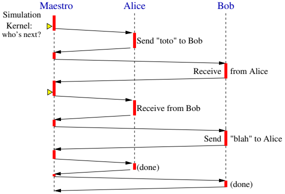

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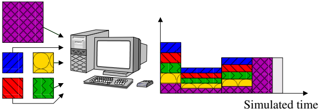
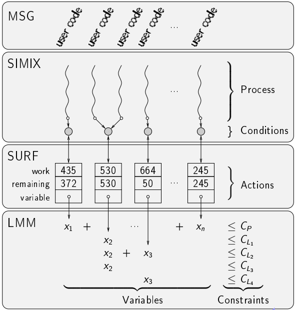


SimGrid Functional Organization

- MSG: User-friendly syntaxic sugar
- Simix: Processes, synchro (SimPosix)
- SURF: Resources usage interface
- Models: Action completion computation



Introduction Example

function P1

//Compute...
Send()
...
end function

function P2

//Compute...
Recv()
...
end function

$time \leftarrow 0$
$P_{time} \leftarrow \{P_1, P_2\}$
while $P_{time} \neq \emptyset$ **do**
schedule(P_{time})
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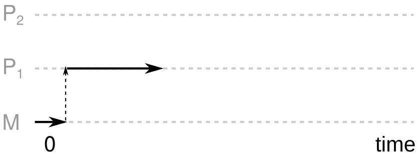

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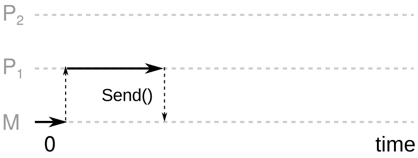

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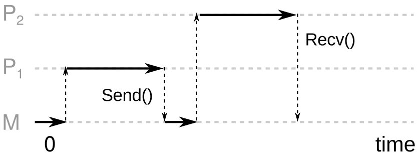

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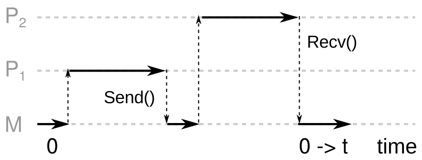

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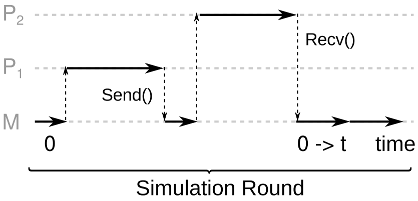


Simix as an OS (Operating Simulator)

Requirements

- User code to run in a thread-like thing, we control the scheduling
- We want portability

$\leadsto$ generic mechanisms; several implementations

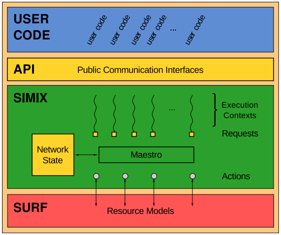
- We want to run the processes in parallel; we want model-checking

$\leadsto$ Isolate processes from each others

- We want it as efficient as possible $\leadsto$ That's what an OS does!

Chosen Design

- Processes are perfectly isolated from environment
  simcalls: only way of interacting with others/platform
  The maestro runs that code "in kernel mode"
- Processes virtualized with context factories
  Threads (pthread/win); ucontexts; Raw assembly
  Java contexts, Java continuations, Ruby contexts



How efficiently can we simulate P2P Protocols

P2P is a nightmare for the simulator

- People want huge fine grained systems (many events in large platforms)
- As a result, no standard too. Many short lived ones (even *one shoot* ones)
- If we manage be efficient on this workload, others will be easy

PeerSim

- Simple enough to get adapted, but no network in model (abstracted)
- Query-cycle mode (application as automata): 10^6 nodes; DES: 10^3
- Query-cycle: user-unfriendly way to express dist. apps; DES: sequential

OverSim

- Scalable: 10^5 nodes using simplistic network models
- Realistic: can leverage the omNET++ packet-level simulator
- Simplistic models are sequential, parallel omNET++ seemingly never used

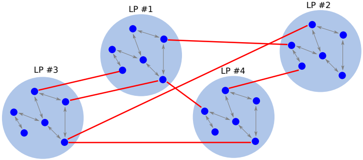
PlanetSim

- Parallel execution, but query-cycle mode only (embarrassingly parallel)

Parallel P2P simulators: the dPeerSim attempt

dPeerSim

- Parallel implementation of PeerSim/DES (not by PeerSim main authors)
- Classical parallelization: spreads the load over several Logical Processes (LP)



Experimental Results

- Uses Chord as a standard workload: e.g. 320,000 nodes $\leadsto$ 320,000 requests
- The result are impressive at first glance
  - 4h10 using two Logical Processes: only 1h06 using 16 LPs
  - Speedup of 4 using 8 times more resources, that really not bad
- But this is to be compared to sequential results
  - The same simulation takes 47 seconds in the original sequential PeerSim
  - (and 5 seconds using the precise network models of SimGrid in sequential)

Parallel Simulation vs. Dist. Apps Simulators

Simulation Workload	▶ Granularity, Communication Pattern ▶ Events population, probability & delay ▶ #simulation objects, #processors
Simulation Engine	▶ Parallel protocol, if any: – Conservative (lookahead, ...) – Optimistic (state save & restore, ...) ▶ Event list mgnt, Timing model...
Execution Environment	▶ OS, Programming Language (C, Java...), Networking Interface (MPI, ...) ▶ Hardware aspects (CPU, mem., net)

Classical Parallel Simulation Schema
[Balakrishnan *et al*]

<table>
<tr><td rowspan="3">Simulation Workload</td><td>User Code</td></tr>
<tr><td>Virtualization Layer</td></tr>
<tr><td>Networking Models</td></tr>
<tr><td colspan="2">Simulation Engine</td></tr>
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</table>

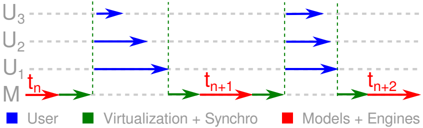
Layered View of
Dist. App. Simulators

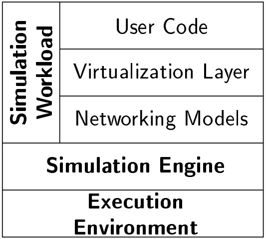
- The classical approach is to distribute the Simulation Engine entirely
- Hard issues: conservatives $\leadsto$ too few parallelism; optimistic $\leadsto$ roll back
- From our experience, most of the time is in so called "simulation workload"
  - User code executed as threads, that are scheduled according to simulation
  - The user code itself can reveal resource hungry: numerous / large processes

Main Idea here

Split at Virtualization, not Simulation Engine

- Virtualization contains threads (user's stack)
- Engine & Models remains sequential





Understanding the trade-off

- Sequential time: $\sum_{SR} (engine + model + virtu + user)$
- Classical schema: $\sum_{SR} \left(\max_{i \in LP} (engine_i + model_i + virtu_i + user_i) + proto \right)$
- Proposed schema: $\sum_{SR} \left(engine + model + \max_{i \in WT} (virtu_i + user_i) + sync \right)$
- Synchronization protocol expensive wrt the engine's load to be distributed

Enabling Parallel Simulation of Dist.Apps

Challenge: Allow User-Code to run Concurrently

- DES simulator full of shared data structures: how to avoid race conditions?
- Fine-locking would be difficult and inefficient; wouldn't avoid app-level races
  - *A*: *recv*, *B*: *send*, *C*: *send*; Which *send* matches the recv from *A* in simulation?
  - Depends on execution order in host system $\rightsquigarrow$ simulation not reproducible...

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Solution: OS-inspired Separation Simulated Processes

- Mediate any interaction of processes with their environment, as in real OSes
  e.g. don't create a new process directly, but issue a *simcall* to request creation


```
t ← 0
P_t ← P
while P_t ≠ ∅ do
    parallel_schedule(P_t)
    handle_simcalls()
    (t, events) ← models_solve()
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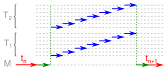
- Processes isolated from each others
  - Simcalls data locally stored
- Simcalls handled centrally once users blocked
  - Arbitrary fixed order for reproducibility

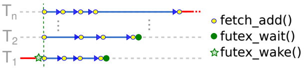
Efficient Parallel Simulation

Leveraging Multicores

- P2P involve millions of user processes, but dozens of cores at best
- Having millions of System threads is difficult (when possible)
- Co-routines (Unix ucontexts, Windows fibers): highly efficient but not parallel
- N:M model used: millions of coroutines executed on few threads



Logical View



Ideal Algorithm

Reducing Synchronization Costs

- Inter-thread synchronization achieved through system calls (of real OS)
- Costs of syscalls are critical to performance $\rightsquigarrow$ save all possible syscalls
- Assembly reimplementation of ucontext: no syscall on context switch
- Synchronize only at scheduling round boundaries using futexes
- Dynamic load distribution: hardware fetch-and-add next process' index

Microbenchmarking Synchronization Costs

Rq: P2P and Chord are ultra fine grain: this is thus a worst case scenario

Comparing our user context containers

- pthreads hit a scalability limit by 32,000 processes (amount of semaphores)
- System contexts and ASM contexts have no hard limit (beside available RAM)

- pthreads are about 10 times slower than our own ASM contexts
- ASM contexts are about 20% faster than system ones
  (only difference: avoid any syscalls on user context switches)

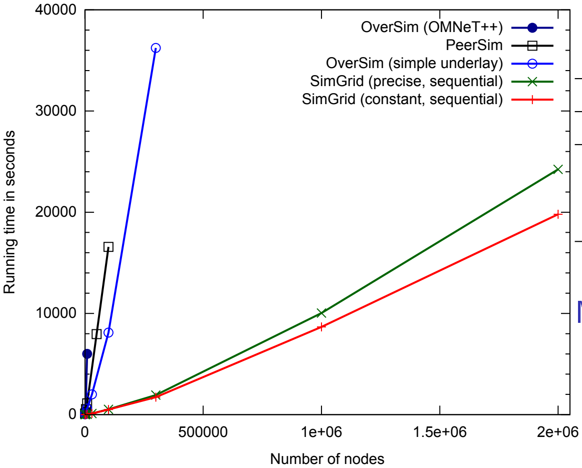
Measuring intrinsic synchronization costs

- Disabling parallelism at runtime: no noticeable performance change
- Enabling parallelism over 1 thread: 15% performance drop of

- Demonstrate the difficulty although the careful optimization

Sequential Performance in State of the Art

- Scenario: Initialize Chord, and simulate 1000 seconds of protocol
- Arbitrary Time Limit: 12 hours (kill simulation afterward)



Largest simulated scenario

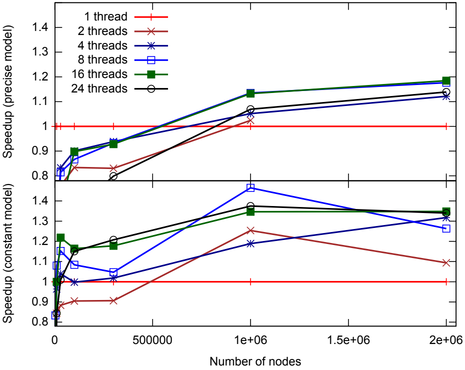
	Size	Time
Omnet++	10k	1h40
PeerSim	100k	4h36
OverSim	300k	10h
SG, precise	10k	130s
	300k	32mn
	2M	6h23
SG, simple	2M	5h30

Memory Usage

- 2M precise nodes: 32 GiB
- That is 18kiB per process (User stack: 12kiB)

Extra complexity to allow parallel execution don't impact sequential perf

Benefits of the Parallel Execution



- Speedup ($\frac{t_{seq}}{t_{par}}$): up to 45%
- More efficient with simple model:
  - Less work in engine + Amhdal law
- Speedup depends on thread amount
  - 8 threads (of 24 cores) often better
  - Synch costs remain hard to amortize
  - They depend on thread amount

Parallel Efficiency ($\frac{speedup}{\#cores}$) for 2M nodes

Model	4 threads	8 th.	16 th.	24 th.
Precise	0.28	0.15	0.07	0.05
Constant	0.33	0.16	0.08	0.06

- Baaaaad efficiency results
- Remember, P2P and Chord: Worst case scenarios

Yet, first time that Chord's parallel simulation is faster than best known sequential

Conclusions on Parallel Simulation

Problem Classical parallelisation is suboptimal (spatial decomposition)

- Optimistic's rollbacks difficult with complex network models
- Pessimistic look ahead limited because P2P app topology $\neq$ network one

$\Rightarrow$ dPeerSim: 2 LPs: 4h; 16 LPs: 1h, but 47 seconds sequential without LPs

Proposal Better to keep central engine and leverage virtualization threads

- Making this possible mandates an OS-inspired separation of processes
- Making this efficient for P2P mandates to reduce synchros to bare minimum

Evaluation Implemented in SimGrid (`http://simgrid.gforge.inria.fr`)

- Still orders of magnitude faster than PeerSim and OverSim in sequential
- Parallel execution (somehow) beneficial for (very) large amount of processes

Take home message

- Parallel P2P simulator mandates creative approaches and careful optimization

Future work

- Further technical improvements (automatic tuning thread amount; Java bindings)
- Attempt distribution (beyond memory limit and for HPC tasks)
- Leverage this tool to conduct nice studies