Parallel Simulation of Peer-to-Peer Systems

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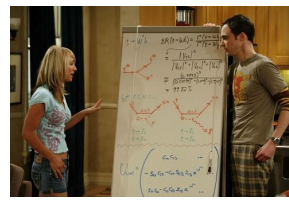
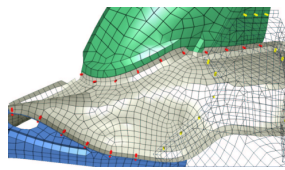
Context: Simulation of Peer-to-Peer Systems

Large Scale Distributed Systems exist already

- P2P, Grids, Clouds, Volunteer Computing, ...
- But these systems remain very hard to study (performance, correction)





Classical Scientific Pillars Apply

- Theoretical Approach: Mathematical study of algorithms
- Experimental Science: Study applications on scientific instrument
- Computational Science: Simulation of a system model

Performance Study $\rightsquigarrow$ Experimentation

- Theory still mandatory, but everything's NP-hard
- Experimental Facilities: Real applications on Real platform *(in vivo)*
  ☺ No bias; ☹ Difficult; no Experimental Control. Reproducibility?
- Simulation: Prototypes of applications on system's Models *(in silico)*
  ☹ Experimental bias? ☺ Simple. Perfect control/reproducibility;

Most studies in the literature are conducted through **simulation**

Context: Parallel Simulation of P2P Systems

Parallel Simulation: Three decades of literature

- All sort of simulations have been parallelized: continuous, discrete event
- For all sort of domains: physics, biology, economics, social science, engineering

Yet, Mainstream Simulators of P2P Systems are not Parallel

- Astonishing since scalability is their main goal
- How to leverage multi-core architecture ?

Objectives of this talk (and agenda)

- Contrast classical parallelisation schema and classical dist.apps simulation
- Propose a new parallelisation schema adapted to our settings
- Propose specific techniques to efficiently implement that schema
- Present some experimental results using the SimGrid framework

State of the Art on P2P simulators

No *de facto* simulator

- Huge amount of short lived simulators (not to say *one shot*)
- This jeopardizes research works that become obsolete when the tool disappears
- Many survey authors wish that a standard tool emerges eventually

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

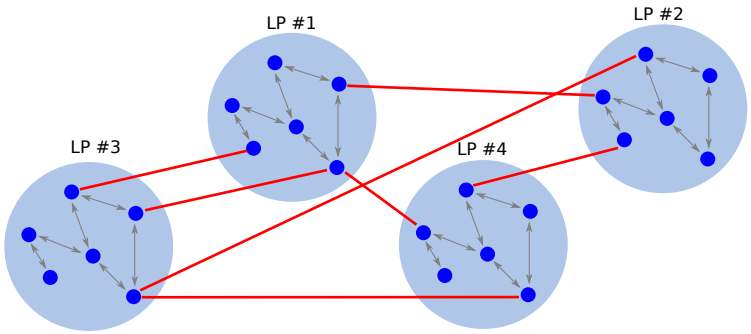
PlanetSim

- 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)



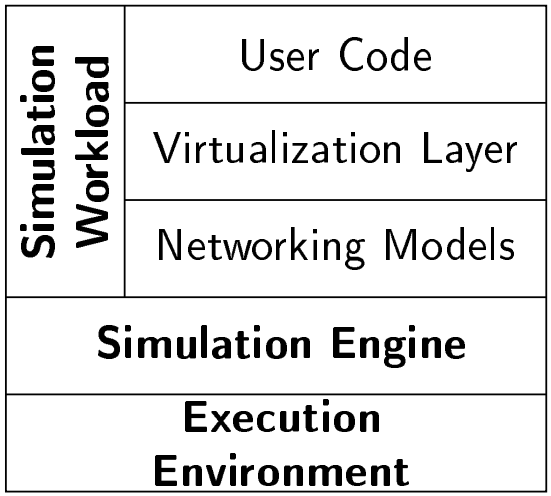
Experimental Results

- Uses Chord as a standard workload: e.g. 320,000 nodes $\rightsquigarrow$ 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*]



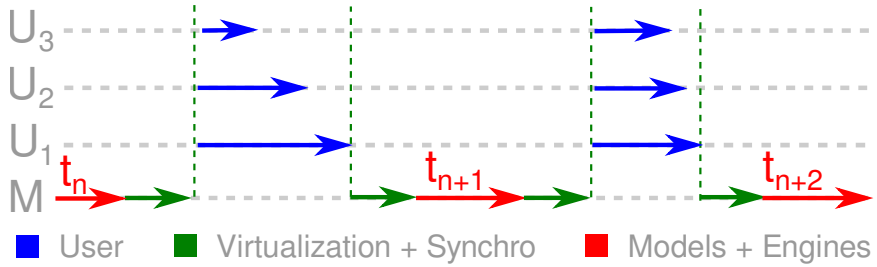
Layered View of
Dist. App. Simulators

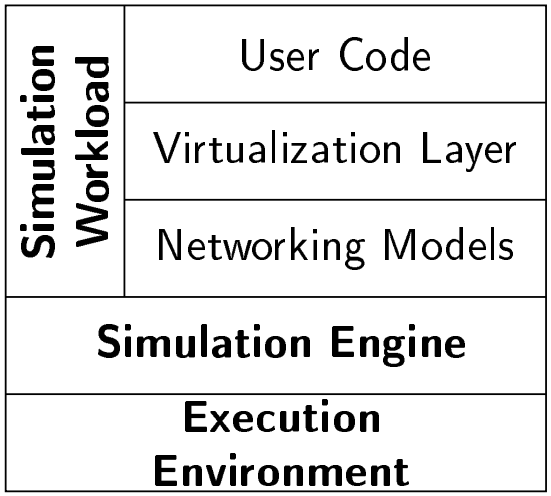
- The classical approach is to distribute the Simulation Engine entirely
- Hard issues: conservatives $\rightsquigarrow$ too few parallelism; optimistic $\rightsquigarrow$ roll back
- From our experience, most of the time is in so called "simulation workload"
  - User code executed as threads, that are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

Main Idea of this Work

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 $\leadsto$ simulation not reproducible...

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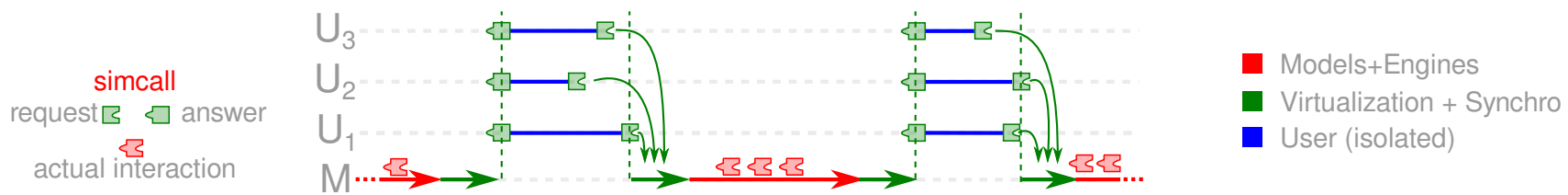
Solution: OS-inspired Separation Simulated Processes

- 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



1: $t \leftarrow 0$
2: $P_t \leftarrow P$
3: **while** $P_t \neq \emptyset$ **do**
4: parallel_schedule(P_t)
5: handle_simcalls()
6: $(t, events) \leftarrow$ models_solve()
7: $P_t \leftarrow$ proc_to_wake($events$)
8: **end while**

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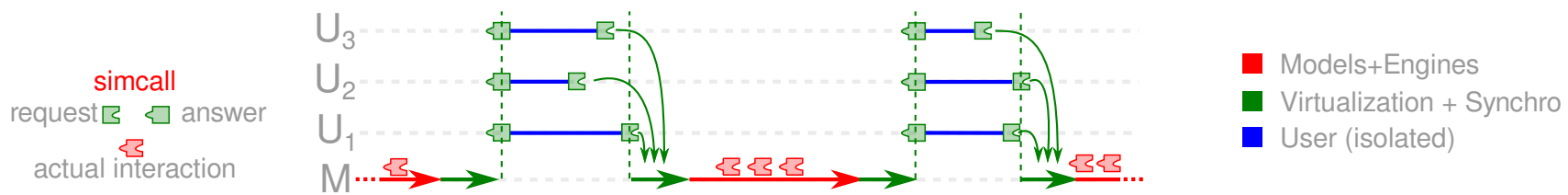


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2: P_t ← P
3: while P_t ≠ ∅ do
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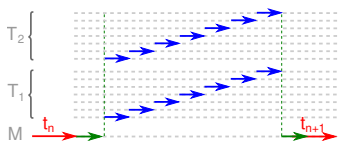
7:     P_t ← proc_to_wake(events)
8: end while
```

- Processes isolated from each others
  - Simcalls data locally stored
- Simcalls handled centrally once users blocked
  - Arbitrary fixed order for reproducibility

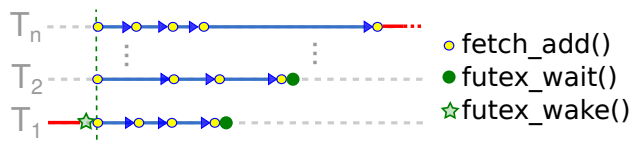
Efficient Parallel Simulation

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)

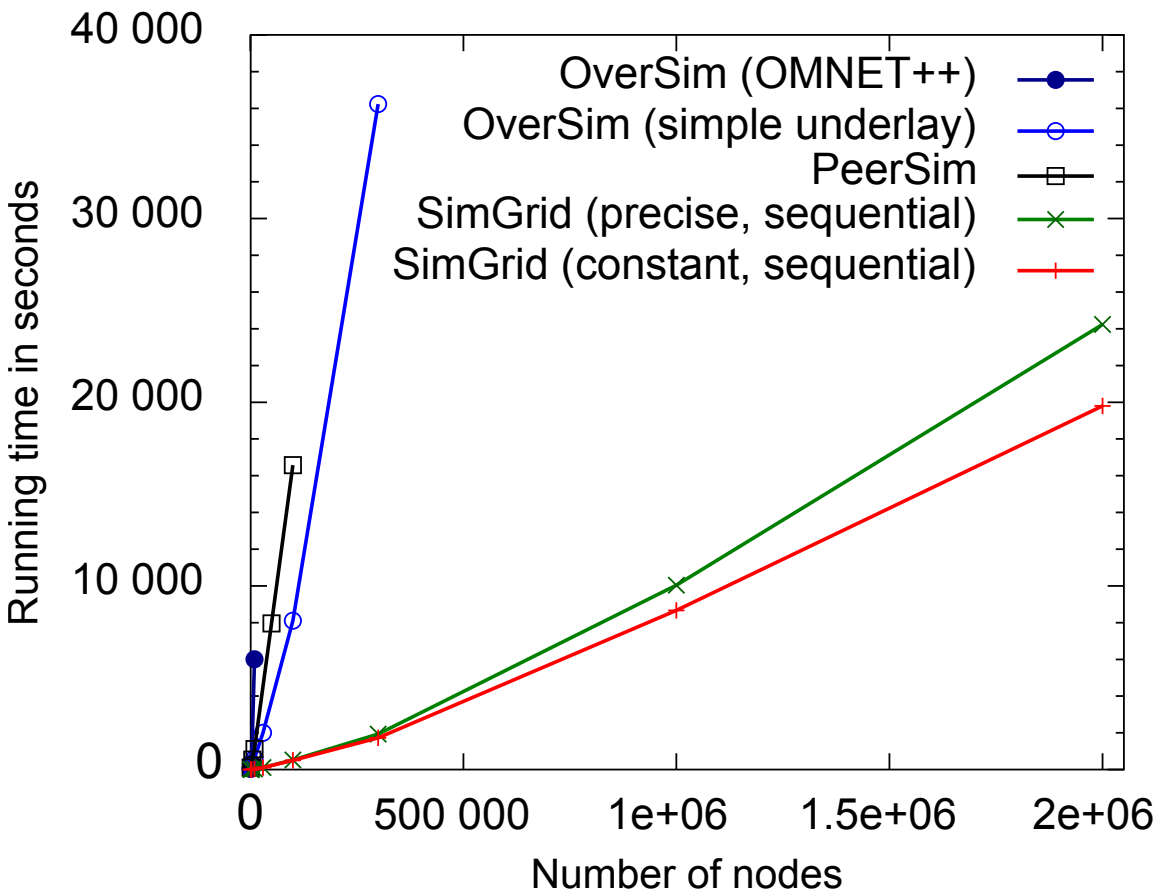
Measuring intrinsic synchronization costs

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

- 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

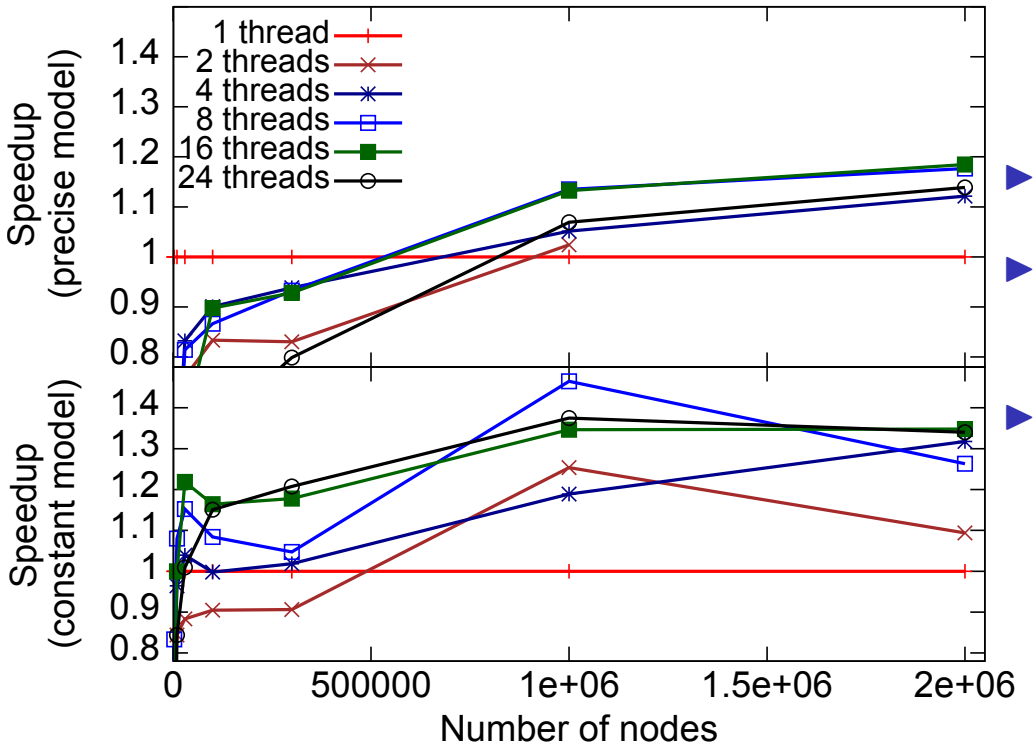
	Size	Time
Omnet++	10k	1h40
PeerSim	100k	4h36
OverSim	300k	10h
SG, precise	10k	130s
	300k	32mn
	2M	6h23
SG, simple	2M	5h30

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 and Future Work

Context DES of dist apps constitute a specific simulation workload
- Yet, scalability considered as main goal to P2P simulators (at least)

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