Scalable Multi-Purpose Network Representation for Large Scale Distributed System Simulation

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ANR 08 SEGI 022
ANR 11 INFRA 13

CCGrid 2012

Large Scale Distributed Systems

LSDS (clusters, P2P, grid, volunteer computing, clouds, . . .) are a pain

- analytic methods quickly become intractable and often fail to capture key characteristics of real systems
- experiments on the field are tedious, time-consuming, non-reproducible, sometimes even impossible

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- **scalability** (both in terms of speed and memory)
- **accuracy**/validity/realism (a very context-dependent notion)
- **genericity**

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Most works trade everything for scalability although...

Premature optimization is the root of all evil

– D.E.Knuth

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Volunteer Computing dynamic availability, heterogeneity

⇝ little need for networking

HPC complex communication workload, protocol peculiarities

⇝ build on regularity and homogeneity

Cloud mixture of previous requirements

Consequence: most simulators are ad hoc and domain-specific

read "dead within a year or so"

Network Communication Models

Packet-level simulation Networking community has standards, many popular open-source projects (NS, GTneTS, OmNet++,. . .)

- full simulation of the whole protocol stack
- complex models $\rightsquigarrow$ hard to instantiate
- inherently **slow**

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Delay-based models The simplest ones...

- communication time = constant delay, statistical distribution, LogP $\rightsquigarrow$($\Theta(1)$ footprint and $O(1)$ computation)
- coordinate based systems to account for geographic proximity $\rightsquigarrow$($\Theta(N)$ footprint and $O(1)$ computation)

Although very scalable, these models ignore network congestion and typically assume large bissection bandwidth

Network Communication Models (cont'd)

Flow-level models A communication (flow) is simulated as a single entity:

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

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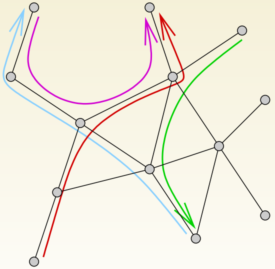
Assume steady-state and **share bandwidth** every time a new flow appears or disappears

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

Constraints For all link j: $\displaystyle\sum_{\text{if flow i uses link j}} \varrho_i \leqslant C_j$



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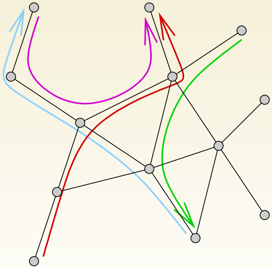
Objective function

- Max-Min $\max(\min(\varrho_i))$
- or other fancy objectives
  e.g., Reno $\sim \max(\sum \log(\varrho_i))$



Wrap up on flow-level models

Such **fluid models can account** for TCP key characteristics

- slow-start
- flow-control limitation
- RTT-unfairness
- cross traffic interference

They are a very reasonable approximation for most LSDC systems

Yet, many people think they are too complex to scale.

Let's prove them wrong! ⌣̈

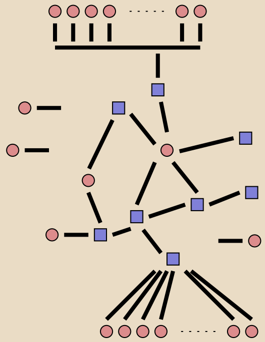
How to achieve scalability

Platform description

Main issues with topology

- description size, expressiveness
- memory footprint
- computation time

N nodes and E links



Representation	Input	Footprint	Parsing	Lookup

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Classical network representation

1. Flat representation
   5000 hosts doesn't fit in 4Gb!

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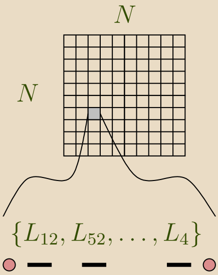

Representation	Input	Footprint	Parsing	Lookup
Flat	N^2	N^2	N^2	1

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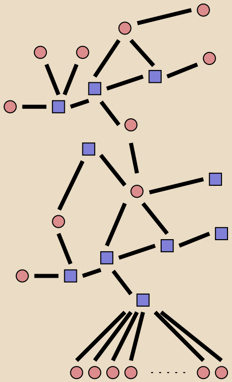

Representation	Input	Footprint	Parsing	Lookup
Dijsktra	$N+E$	$E+N\log N$	$N+E$	$E+N\log N$
Floyd	$N+E$	N^2	N^3	1

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2. Graph representation assuming shortest path routing
3. Special class of structures (star, cloud, ...)

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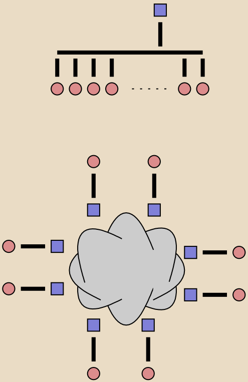
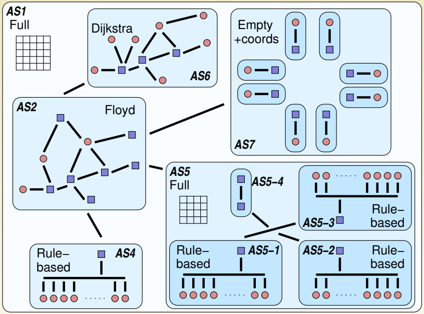


Representation	Input	Footprint	Parsing	Lookup
Star	1	N	N	1
Cloud	N	N	N	1

Our proposal

Every such representation has drawbacks and advantages
Let's build on the fact that *most* networks are *mostly* hierarchical

1. Hierarchical organization in AS
   - ⤳ cuts down complexity
   - ⤳ recursive routing
2. Efficient representation of classical structures
3. Allow bypass at any level



This approach has been integrated into
the open-source SimGrid simulation toolkit

Size of platform description file

Community	Scenario	Size
P2P	2,500 peers with Vivaldi coordinates	294KB
VC	5120 volunteers	435KB + 90MB
Grid	Grid5000: 10 sites, 40 clusters, 1500 nodes	22KB
HPC	1 cluster of 262144 nodes	5KB
HPC	Hierarchy of 4096 clusters of 64 nodes	27MB
Cloud	3 small data centers + Vivaldi	10KB

Evaluation

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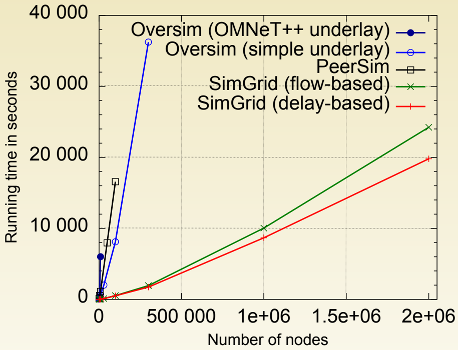
Grid Scenario a master distributes $500,000$ fixed size jobs to $2,000$ workers in a round-robin way

	GridSim	SimGrid
Network model	delay-based model	flow model
Topology	none	Grid5000
Time	1h	14s
Memory	4.4GB	165MB*

$\star$ 5.2Mb are used to represent the Grid 5000. Stack size not optimized (80KB/worker)

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



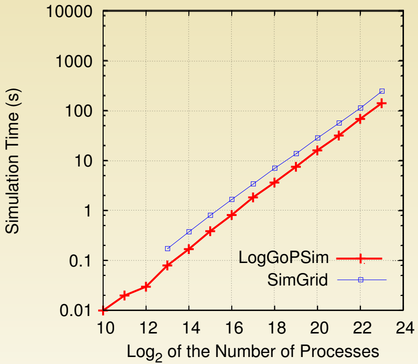
Largest simulated scenario

Simulator	size	time
OverSim (OMNeT++)	10k	1h40
OverSim (simple)	300k	10h
PeerSim	100k	4h36
SG (flow-based)	10k	130s
	300k	32mn
	2M*	6h23
SG (delay-based)	2M	5h30

$*$ 36GB = 18kB/ process (16kB for the stack)

- SimGrid is orders of magnitude more scalable than state-of-the-art P2P simulators
- Using the precise flow-based model incurs a limited ($\approx 20\%$) slow-down, while simulation accuracy is improved

HPC workload



Simulating a binomial broadcast:

- SimGrid is roughly 75% slower than LogGOPSim
- SimGrid is at least 20% more fat than LogGOPSim (15GB required for 2^{23} processors)

The genericity of SimGrid data structures comes at the cost of a slight overhead

This demonstrates that scalability does not necessarily comes at the price of realism (e.g., ignoring contention on the interconnect)

Conclusion

Take away message

- The widespread belief that "scalable simulations require to over-simplify the network models and avoid the use of threads" is erroneous
- SimGrid is open-source, mature, and does not trade accuracy and meaning for scalability $\rightsquigarrow$ use it instead of rewriting ad hoc simulators

http://simgrid.gforge.inria.fr

Future plan

1. Further reduce platform description size (hence parsing time) and memory footprint by exploiting stochastic regularity and improving programmable description approach
2. Consider the specifics of emerging computing systems such as clouds or exascale platforms:

http://infra-songs.gforge.inria.fr/