SURF 101

Getting Started with SimGrid Models

Da SimGrid Team

April 22, 2014

About this Presentation

Goals and Contents

- CPU and Network Models used in SimGrid (and elsewhere)
- Some realism considerations
- Choosing the models used in practice

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`

Outline

- Requirements
- CPU Model
- Network Models
  - Max-Min Fairness
  - TCP Key Features

Validity: Community Requirements

Networking Protocol design requires accurate packet-level simulations
$\leadsto$ overly detailed network; no CPU

P2P DHT geographic diversity, jitter, churn
$\leadsto$ no need for contention, only delay

P2P streaming network proximity, asymmetry, interference on the edge
$\leadsto$ ignore the core

Grid heterogeneity, complex topology, contention w. large transfers
$\leadsto$ no need to focus on packets

Volunteer Computing dynamic availability, heterogeneity
$\leadsto$ little need for networking

HPC complex communication workload, protocol peculiarities
$\leadsto$ build on regularity and homogeneity

Cloud mixture of previous requirements

Consequence: most simulators are $\underbrace{\text{ad hoc and domain-specific}}_{\text{read “dead within a year or so”}}$

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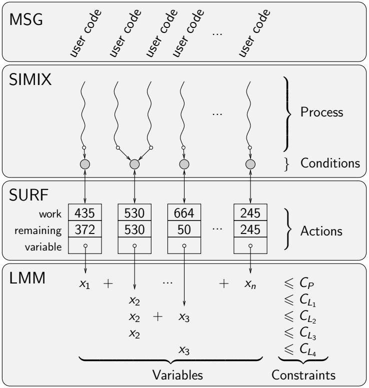
Interactions between the user code and the models

SimGrid Functional Organization

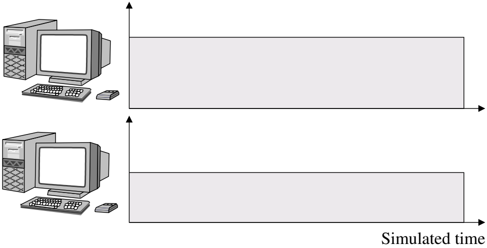
- MSG: User-friendly syntaxic sugar
- Simix: Processes, synchro (SimPosix)
- SURF: Resources usage interface
- Models: Action completion computation



The CPU model in a nutshell

Modeling computations in SimGrid

CPU = rate R in Mflop/s $\oplus$ Computation = amount A of Flops $\rightsquigarrow$ Time = A/R



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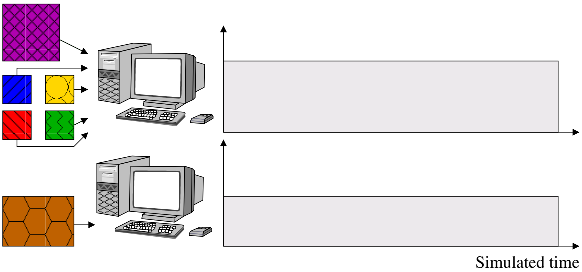
Simulation kernel main loop

1. Some actions get created (by application) and assigned to resources



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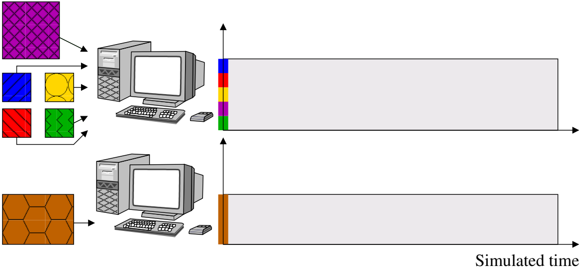

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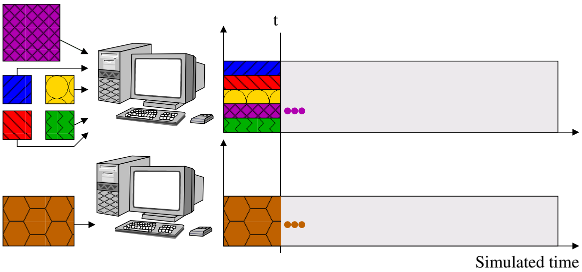

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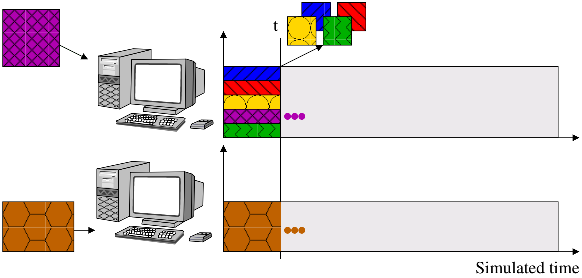

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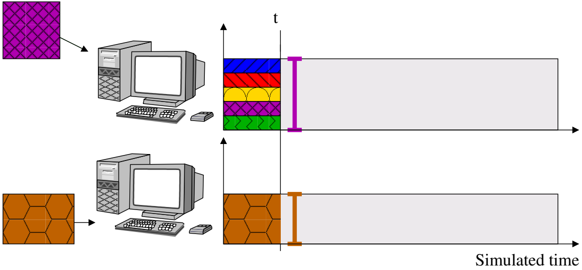

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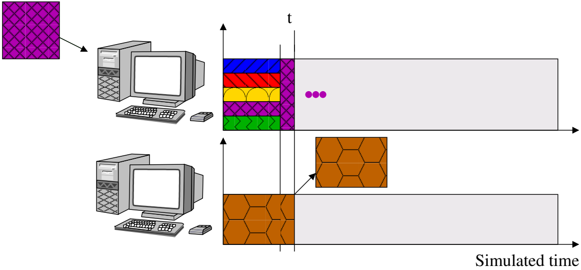

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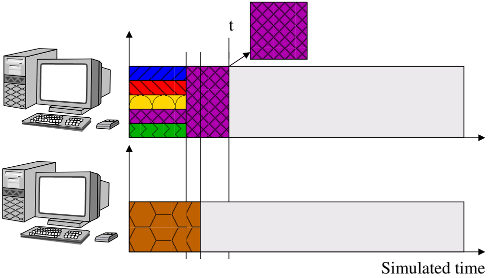


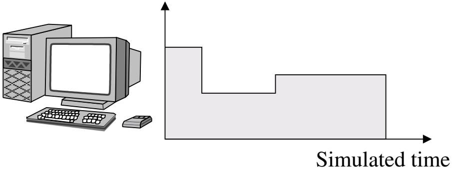
Adding Dynamic Availabilities to the Picture

Trace definition

- List of discrete events where the maximal availability changes
- $t_0 \rightarrow 100\%$, $t_1 \rightarrow 50\%$, $t_2 \rightarrow 80\%$, *etc.*

Adding traces doesn't change kernel main loop

- Availability changes: simulation events, just like action ends



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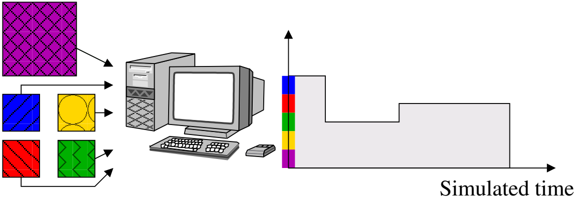

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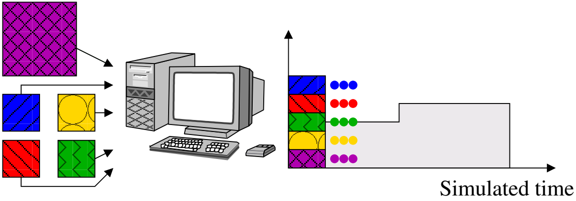

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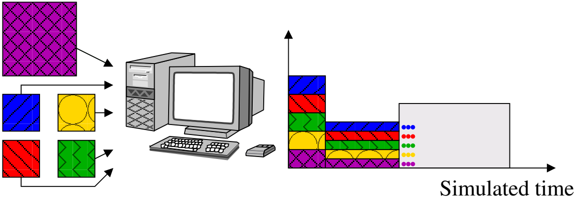

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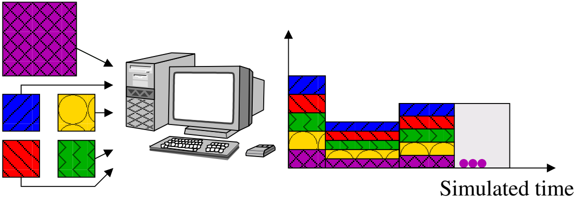

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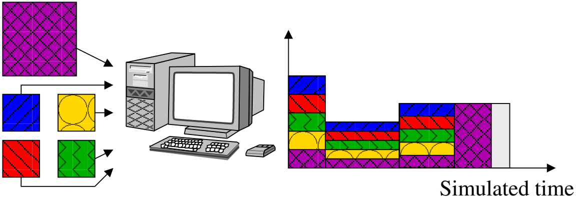
- Availability changes: simulation events, just like action ends
- Efficient implementation thanks to trace integration



SimGrid also accept state changes (on/off)

Pros and Cons

Pros

- Simple and accounts for speed heterogeneity
- Trace integration $\leadsto$ very efficient implementation
- Simple multi-core extension where each process receives $min(R, pR/N)$

Cons

- Too simple:
  - does not account neither for affinity/memory nor compiler/OS peculiarities
    $\leadsto$ rate is bound to a specific kernel
  - (a priori) bad modeling of inter-core communications
  - does not account for cache sharing between cores
    $\leadsto$ neither trashing nor symbiosis
- The failure mechanism has been here for 8 years but people barely use it
- No GPU model in SimGrid yet

Outline

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 $\leadsto$ hard to instantiate
- inherently **slow**
- beware of simplistic packet-level simulation

Along the same lines: Weaver and MsKee, *Are Cycle Accurate Simulations a Waste of Time?*, Proc. of the Workshop on Duplicating, Deconstruction and Debunking, 2008

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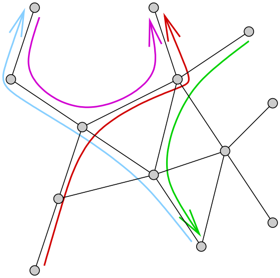
Assume steady-state and **share bandwidth** every time a new flow appears or disappears



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

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

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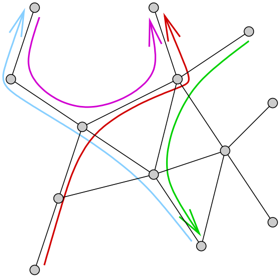

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Objective function

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

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Max-Min Fairness

Objective function: maximize $\min_{f \in \mathcal{F}}(\varrho_f)$

- Equilibrium reached if increasing any ϱ_f decreases a ϱ'_f (with $\varrho_f > \varrho'_f$)
- Very reasonable goal: gives fair share to anyone
- Optionally, one can add prorities w_i for each flow i
  $\rightsquigarrow$ maximizing $\min_{f \in \mathcal{F}}(w_f \varrho_f)$

Bottleneck links

- For each flow f, one of the links is the limiting one l
  (with more on that link l, the flow f would get more overall)
- The objective function gives that l is saturated, and f gets the biggest share

$$\forall f \in \mathcal{F}, \exists l \in f, \quad \sum_{f' \ni l} \varrho_{f'} = C_l \quad \text{and} \quad \varrho_f = \max\{\varrho_{f'}, f' \ni l\}$$

L. Massoulié and J. Roberts, *Bandwidth sharing: objectives and algorithms*, IEEE/ACM Trans. Netw., vol. 10, no. 3, pp. 320-328, 2002.

Implementation of Max-Min Fairness

Bucket-filling algorithm

- Set the bandwidth of all flows to 0
- Increase the bandwidth of every flow by ε. And again, and again, and again.
- When one link is saturated, all flows using it are limited ($\leadsto$ removed from set)
- Loop until all flows have found a limiting link

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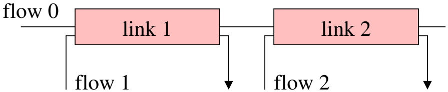
Efficient Algorithm

1. Search for **the** bottleneck link l so that: $\dfrac{C_l}{n_l} = min\left\{\dfrac{C_k}{n_k},\ k \in \mathcal{L}\right\}$
2. $\forall f \in l,\ \ \varrho_f = \frac{C_l}{n_l}$;
   Update all n_l and C_l to remove these flows
3. Loop until all ϱ_f are fixed

Max-Min Fairness on Homogeneous Linear Network



$$C_1 = C \qquad n_1 = 2$$
$$C_2 = C \qquad n_2 = 2$$

$$\varrho_0 =$$
$$\varrho_1 =$$
$$\varrho_2 =$$

- All links have the same capacity C
- Each of them is limiting. Let's choose link 1

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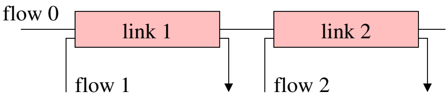

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$\Rightarrow$ $\varrho_0 = C/2$ and $\varrho_1 = C/2$

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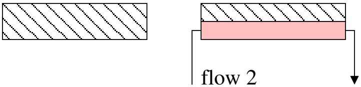

$C_1 = 0 \qquad n_1 = 0$
$C_2 = C/2 \qquad n_2 = 1$

$\varrho_0 = C/2$
$\varrho_1 = C/2$
$\varrho_2 =$

- All links have the same capacity C
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$\Rightarrow$ $\varrho_0 = C/2$ and $\varrho_1 = C/2$

- Remove flows 0 and 1; Update links' capacity

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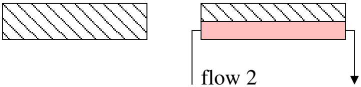

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- Link 2 sets $\varrho_1 = C/2$

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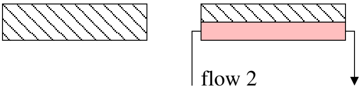

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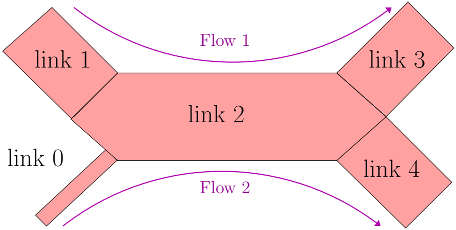
We're done computing the bandwidth allocated to each flow

Max-Min Fairness on Backbone



$$
\begin{array}{ll}
C_0 = 1 & n_0 = 1 \\
C_1 = 1000 & n_1 = 1 \\
C_2 = 1000 & n_2 = 2 \\
C_3 = 1000 & n_3 = 1 \\
C_4 = 1000 & n_4 = 1
\end{array}
$$

$\varrho_1 =$

$\varrho_2 =$

- The limiting link is link 0 $\left(\text{since } \frac{1}{1} = min\left(\frac{1}{1}, \frac{1000}{1}, \frac{1000}{2}, \frac{1000}{1}, \frac{1000}{1}\right)\right)$

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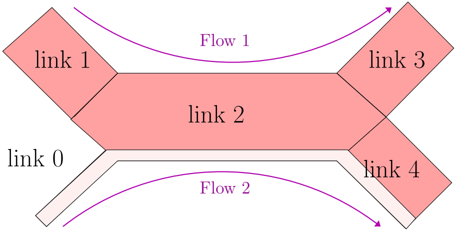

$C_0 = 0$ $\quad n_0 = 0$
$C_1 = 1000$ $\quad n_1 = 1$
$C_2 = 999$ $\quad n_2 = 1$
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$\varrho_1 =$
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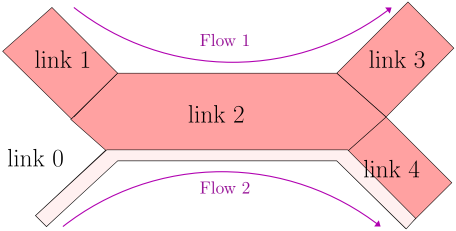

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- The limiting link is link 2

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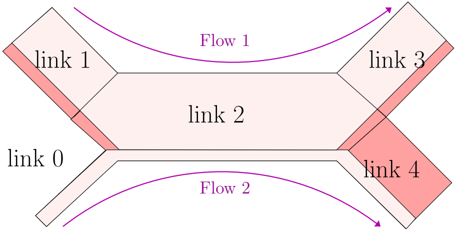

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$C_2 = 0$ $n_2 = 0$
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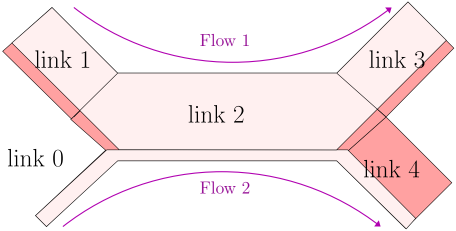

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$\varrho_1 = 999$
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- This fixes $\varrho_2 = 1$. Update the links
- The limiting link is link 2
- This fixes $\varrho_1 = 999$
- Done. We know ϱ_1 and ϱ_2

Side note: OptorSim 2.1 on Backbone

OptorSim (developped @CERN for Data-Grid)

- One of the rare ad-hoc simulators not using simplistic packet-level routing

Unfortunately, "strange" resource sharing:

1. For each link, compute the share that each flow may get: $\frac{C_l}{n_l}$
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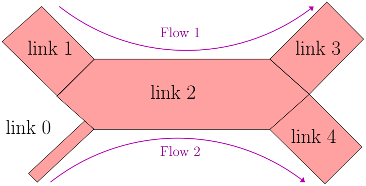

$$
\begin{array}{lll}
C_0 = 1 & n_1 = 1 & \text{share} = \\
C_1 = 1000 & n_1 = 1 & \text{share} = \\
C_2 = 1000 & n_2 = 2 & \text{share} = \\
C_3 = 1000 & n_3 = 1 & \text{share} = \\
C_4 = 1000 & n_4 = 1 & \text{share} =
\end{array}
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$\varrho_1 =$

$\varrho_2 =$

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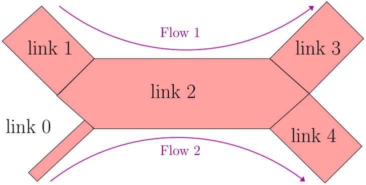

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$$\varrho_1 = min(1000, 500, 1000)$$
$$\varrho_2 = min(\ 1\ \ \ , 500, 1000)$$

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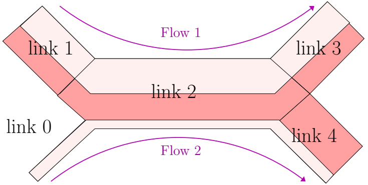

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\end{array}
$$

$\varrho_1 = min(1000, 500, 1000) = \mathbf{500}!!$

$\varrho_2 = min(\ 1\ \ , 500, 1000) = 1$

ϱ_1 limited by link 2, but 499 still unused on link 2

This "unwanted feature" is even listed in the README file...

Side note: GridSim and CloudSim

GridSim 5.2 on a single link

- Packet-level: latency paid for every packet, not only the first one
  $\rightsquigarrow$ actually wormhole of packets
- Flow sharing: buggy, only subsequent flows share the link
  The code intend seems to be on reevaluating the sharings, but it fails on tests

CloudSim

- Flow sharing, but no sharing between flows starting at t and $t + \varepsilon$
- Consequence:
  - 1 message of size S takes time t
  - 2 flows take time T and 2T.
    Not because it's FIFO but because bandwidth allocation is not reavaluated upon flow arrival and departure...

Proportional Fairness

Max-Min validity limits

- MaxMin gives a fair share to everyone
- Reasonable, but TCP does not do so
- Congestion mecanism: Additive Increase, Muplicative Decrease (AIMD)
- Complicates modeling, as shown in literature

Other sharing methods

- MaxMin gives more to long flows (resource-eager), TCP known to do opposite
- TCP Vegas achieves weighted proportionnal fairness and maximizes:

$$\sum_{f \in \mathcal{F}} L_f \log(\varrho_f) \qquad (L_f \text{ being the latency})$$

- TCP Reno maximizes $\displaystyle\sum_{f \in \mathcal{F}} \frac{\sqrt{3/2}}{L_f} \arctan\left(\frac{\sqrt{3/2}}{L_f} . \varrho_f\right)$

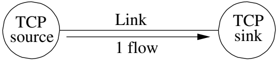
Kelly, *Charging and rate control for elastic traffic*, in European Transactions on Telecommunications, vol. 8, 1997, pp. 33-37.

Outline

- Requirements
- CPU Model
- Network Models
  - Max-Min Fairness
  - TCP Key Features

Wanted Feature (1): Flow Control Limitation

Experimental settings



- Flow throughput as function of L and B
- Fixed size (S=100MB) and window (W=20KB)

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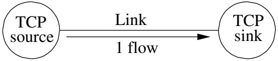

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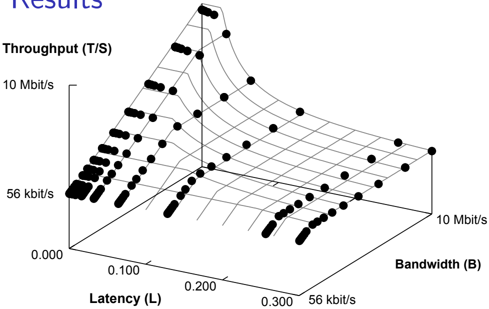

Legend

- Mesh: SimGrid results

$$\frac{S}{S/min(B, \frac{W}{2L}) + L}$$

- •: GTNetS results

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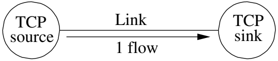

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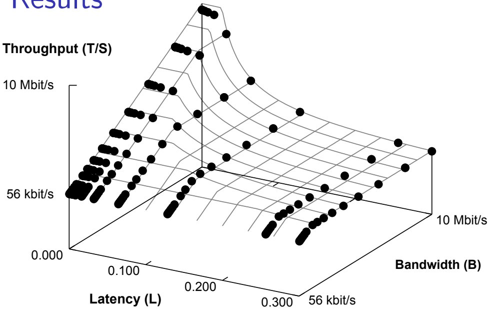

Legend

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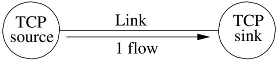
Conclusion

- SimGrid estimations close to packet-level simulators (when S=100MB)
  - When $B < \frac{W}{2L}$ (B=100KB/s, L=500ms), $|\varepsilon_{max}| \approx \overline{|\varepsilon|} \approx 1\%$
  - When $B > \frac{W}{2L}$ (B=100KB/s, L= 10ms), $|\varepsilon_{max}| \approx \overline{|\varepsilon|} \approx 2\%$

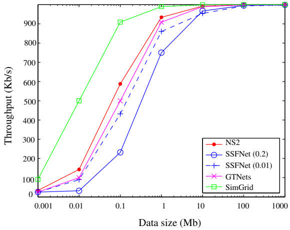
Wanted Feature (2): Slow Start

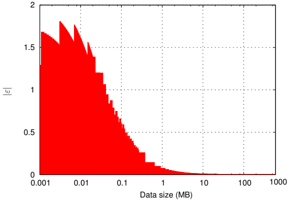
Experimental settings



- Compute achieved bandwidth as function of S
- Fixed L=10ms and B=100MB/s

Evaluation of the SimGrid fluid model





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- SSFNet `TCP_FAST_INTERVAL` bad default

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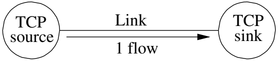

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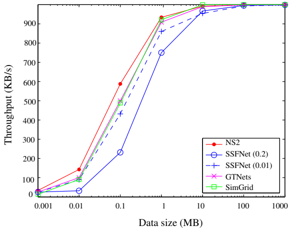

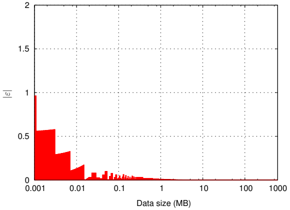

- Packet-level tools don't completely agree
- SSFNet `TCP_FAST_INTERVAL` bad default
- Statistical analysis of GTNetS slow-start
- New SimGrid model (LV08: MaxMin based)
  - Bandwidth decreased (97%)
  - Latency changed to $13.1 \times L$
  - Hence: $Time = \frac{S}{min\left(0.97 \times B, \frac{W}{2L}\right)} + 13.1 \times L$

- This dramatically improve validity range compared to using raw L and B

S	$\overline{\lvert\varepsilon\rvert}$	$\lvert\varepsilon_{max}\rvert$
$S < 100KB$	$\approx 12\%$	$\approx 162\%$
$S > 100KB$	$\approx 1\%$	$\approx 6\%$

Wanted Feature (3): RTT-unfairness

Hypothesis: **Bottleneck links are proportionally shared with respect to flow RTT**

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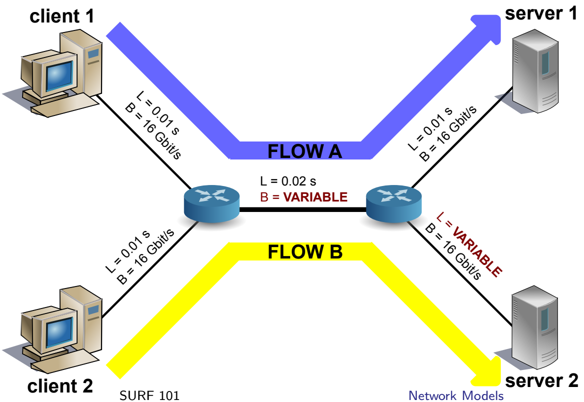
$$RTT_A.\varrho_A = RTT_B.\varrho_B \text{ where } RTT_i \approx \sum_{\text{flow i uses link j}} (L_j) \text{ (naive model)}$$

- Longer flows (higher latency) will receive slightly less bandwidth



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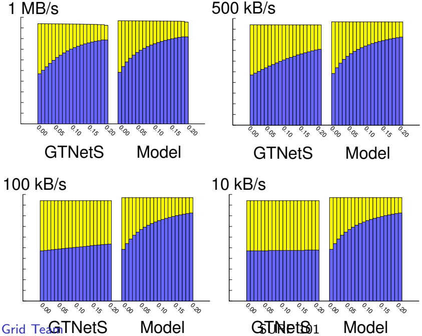

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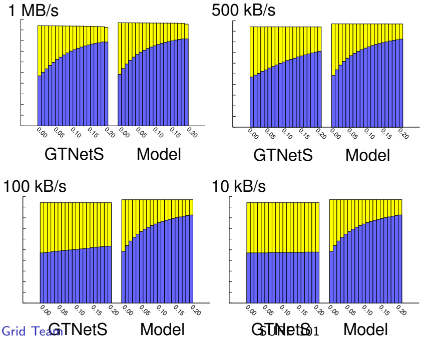

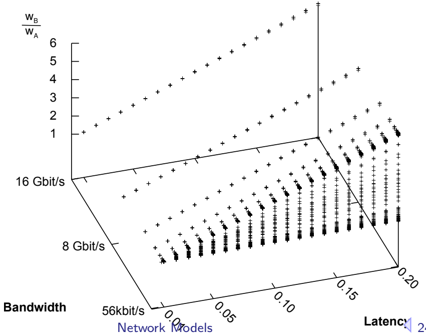

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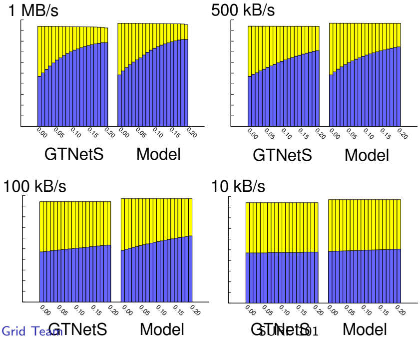
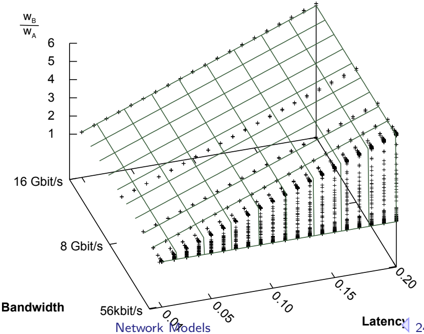
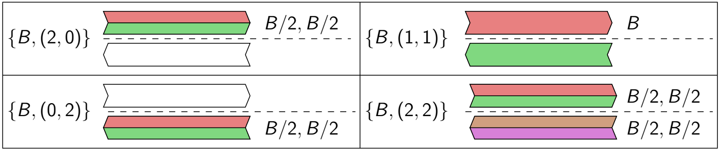
- Longer flows (higher latency) will receive slightly less bandwidth
- However, bandwidth also matters
- Simple fix: $RTT_i \approx \sum_{\text{flow i uses link j}} \left(\frac{M}{B_j} + L_j \right)$





Wanted Feature (4): Cross-Traffic Interference

Take two machines connected by a full-duplex ethernet link.



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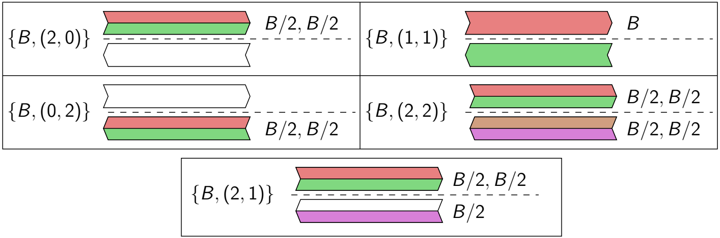

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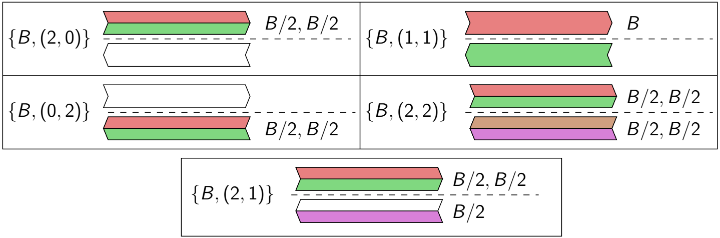

This is a well-known phenomenon when you are using ADSL

Burstiness at micro-scale severely impact macro-scale properties

Modeling such burstiness is ongoing research and resorts to complex differential algebraic equations

Tang et al., *Window Flow Control: Macroscopic Properties from Microscopic Factors*, in INFOCOM 2008

Wanted Features!

Key characteristics of TCP

- Flow-control limitation
- Slow start
- RTT-unfairness
- Cross Traffic Interference

That's messy. Have fluid models a chance ?

- Most previous models (delay, $\sum \log$, $\sum \arctan$, ...) are available in SimGrid
- When well-instantiated, max-min based model can account for all these well-known phenomenon
- The default SimGrid model is LV08: a pragmatic max-min based that is far from perfect but seems reasonnable according to our invalidation studies

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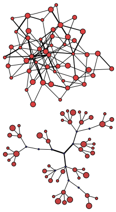

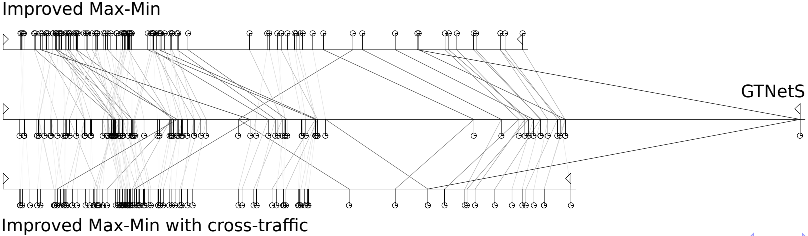

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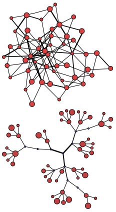

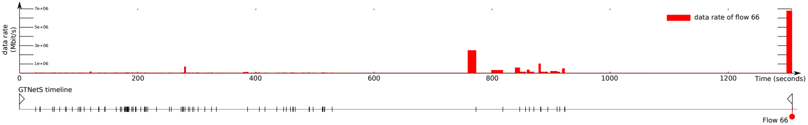

So, what is the model used in SimGrid?

"`network/model:`" command line argument

- `CM02` $\rightsquigarrow$ Old max-min fairness
- `Vegas` / `Reno` $\rightsquigarrow$ Vegas/Reno TCP fairness (Lagrange approach)
- By default since SimGrid v3.3: "smart" max-min LV08
- Example: `./my_simulator --cfg=network_model:Vegas`

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- Different implementations though (Lazy/TI/Full)

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- Compose with `workstation/model:compound` or use `ptask_L07` $\leadsto$ model specific to parallel tasks
- Plug your own model in SimGrid!!

Conclusion and Future Work

Conclusion

- SimGrid is among the few projects that made (in)validation studies
- One can choose and tweak existing models but you should stick with the default one...
- ...unless it does not fulfill your needs and you know of a less generic but more accurate one!

Future Work

- Network models for HPC networks
- Various storage models (in collaboration with the CERN)
- Improve the cpu model, add a notion of GPU, ...
- Use stochastic models with a careful management of randomness