Fluid Simulation of Large Scale Networks: Issue and Tradeoffs

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Overview:

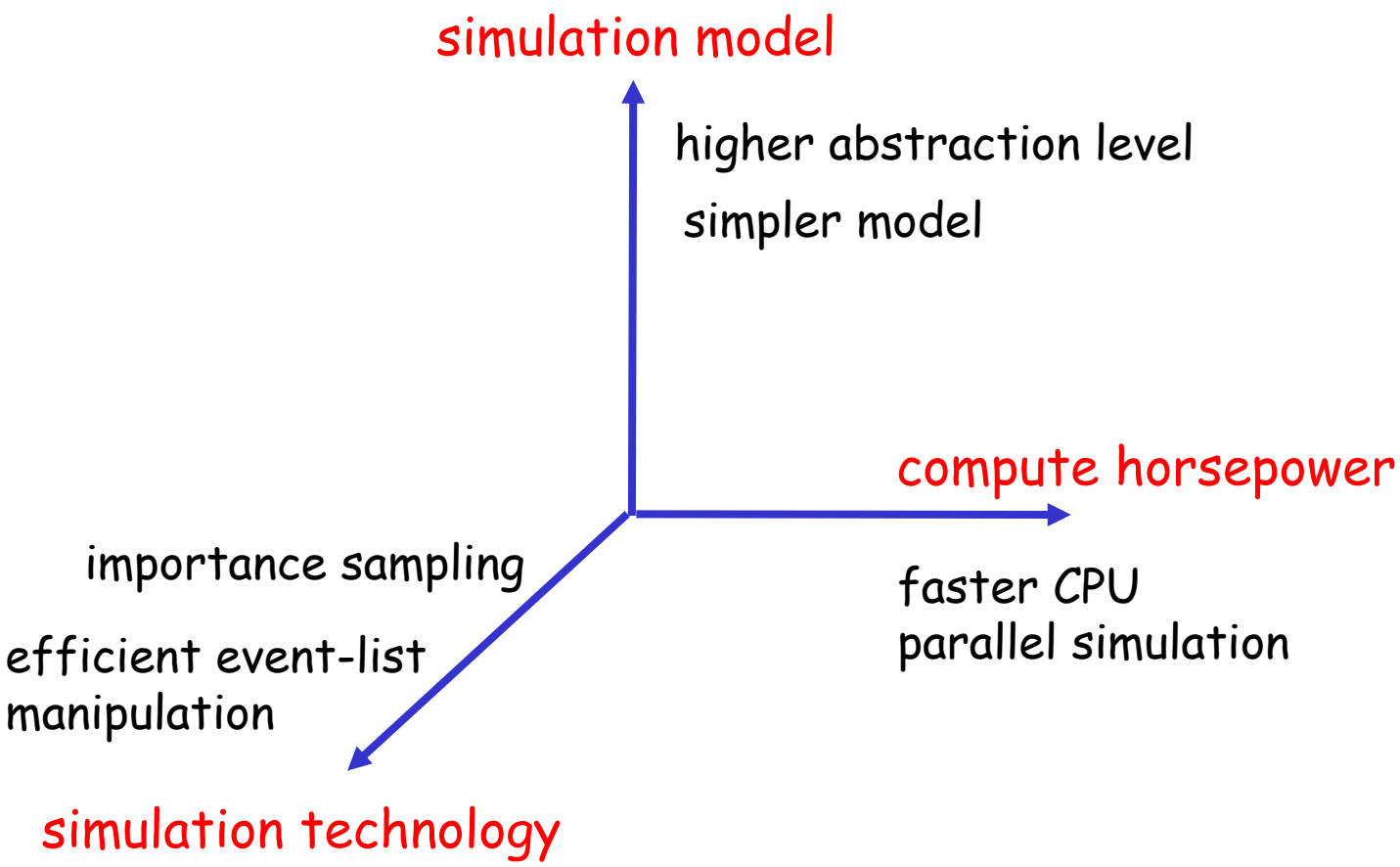
- *introduction*
- *understanding the computational workload of network simulation*
  - *packet versus fluid*
  - *effects of load, scheduling discipline, routing on network elements*
- *scenarios: event rate analysis*
- *decreasing a simulation's event rate*
- *summary, future work*

Motivatation:

- *workshop theme:* the internet as a large-scale, complex system
- *question:* how to simulate its behavior?
  - answer: **ns !**

Question: how to simulate large scale networks in a computationally tractable way?

Speeding up a simulation



Discrete-event network simulation

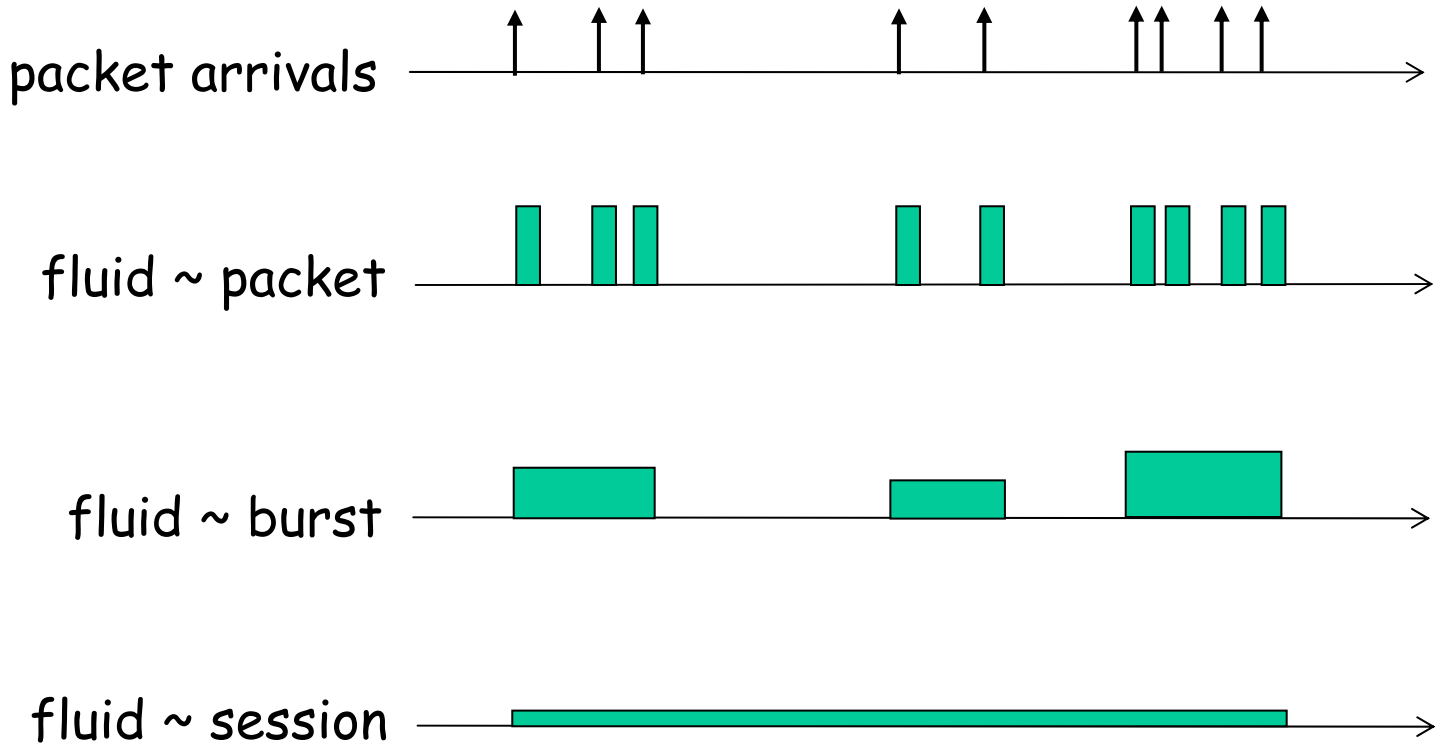
Packet-based simulation:

- network traffic flow: model packets in flow
- # sources, data rates increase, so too does simulation workload

Fluid-based simulation:

- network traffic flow: continuous fluid
  - rate changes at discrete points in time
  - rate constant between changes
- can modulate rate at different time scales
  - single modeling paradigm for many time scales
  - abstract out fine-grained details: *simulation efficiency*

Packets and fluids

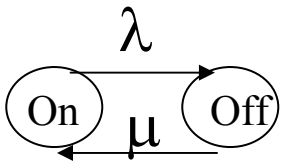


Intuitively: fluid simulation can be more "efficient"

efficiency of packet- versus fluid-based simulation?

- as a function of….
  - … numbers of flows
  - … topology, link speeds
  - … level of modeling granularity
  - … router scheduling discipline
- comparison with packet-based simulation
- important issue: accuracy (not today's topic)

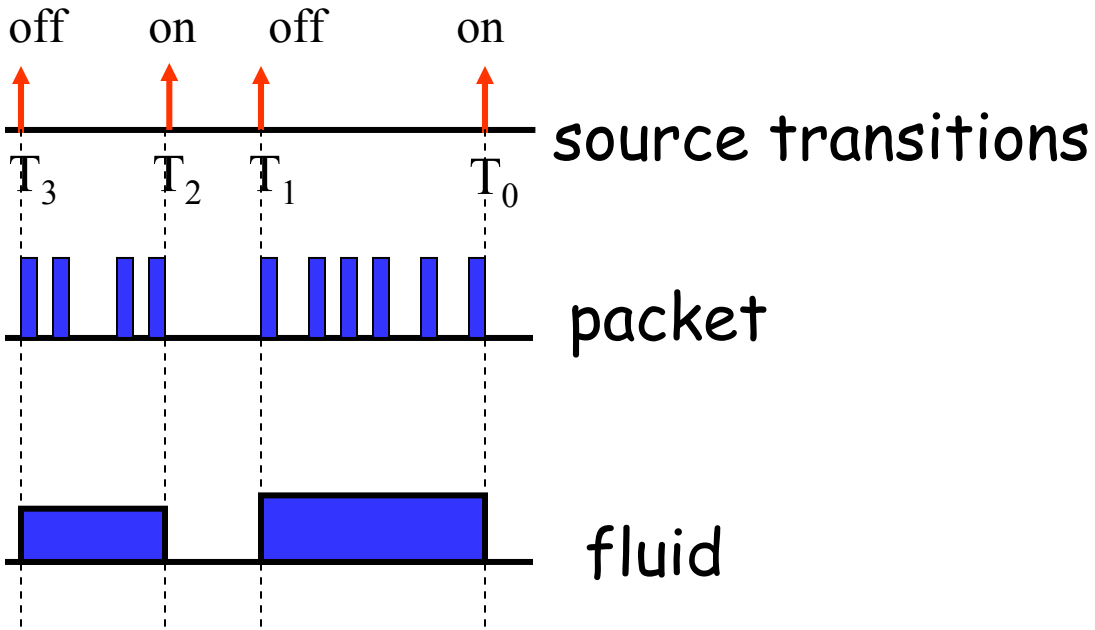
Traffic source model: open loop



Markov Process

packet rate: γ
avg. packet size: x

fluid rate: $\gamma\, x$



Key idea:

- represent burst of packets with fluid chunk
- less "work" to process one fluid chunk than many packets modeled by that chunk

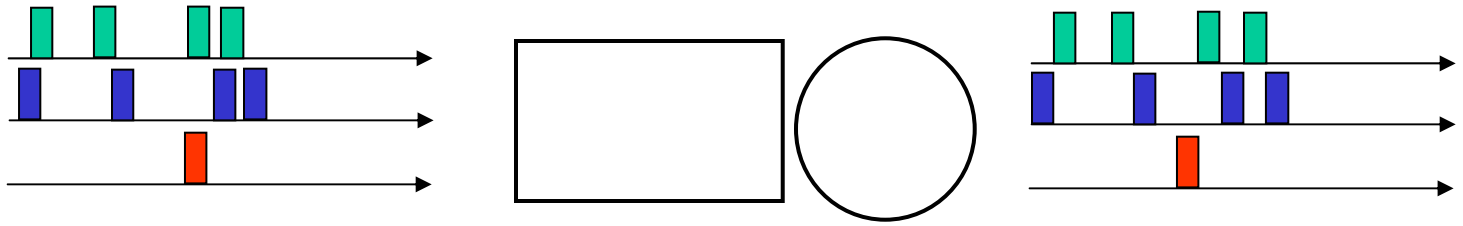
Measuring simulation "work"

event rate: number of event-list manipulations per unit time

- packet: arrivals/departures at queues
- simulation: rate changes at queues
- we'll see: analytic results for event rate correlate well with measured simulation run times

FIFO packet multiplexer event rate

simple: each arrival event generates one departure event



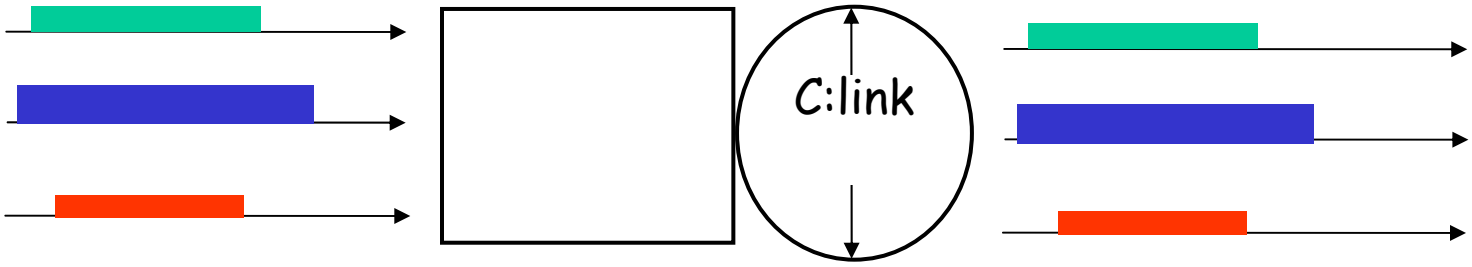
9 arrival events

output multiplexer

9 departure events

- rearranged in time
- arrivals to downstream router

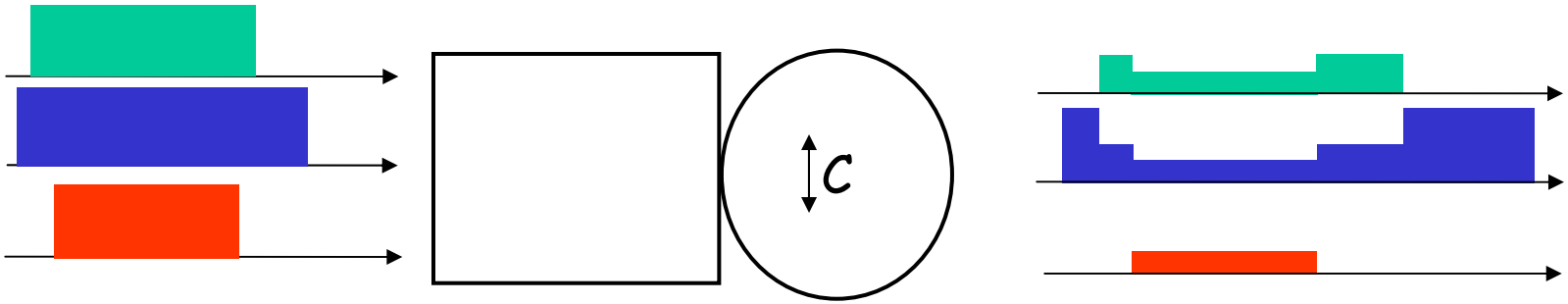
FIFO fluid multiplexer:



Case: $C > \Sigma$ input fluid rates

- no queueing
- fluids "pass though" multiplexer with no change in event rates

FIFO fluid multiplexer: more interesting!

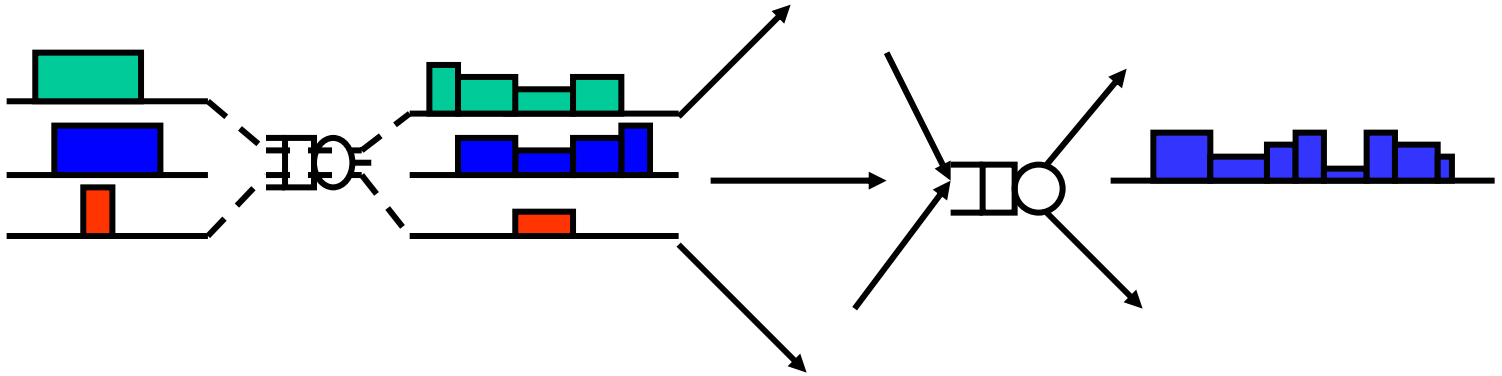


Case: $C < \Sigma$ input fluid rates

output multiplexer

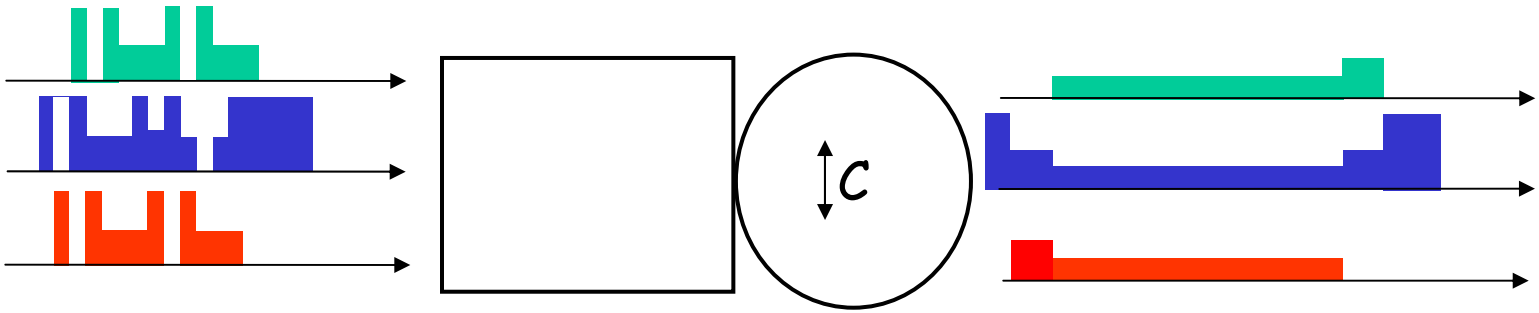
- output fluid rate affected by rate changes of other *input* flows!
- output event rate > input event rate: *ripple effect*

Ripple effect: bad news!



- ripples propagates to downstream routers
  - where they can be magnified
  - propagate further
- no ripple effect in packet simulation

WFQ fluid multiplexer: more interesting!



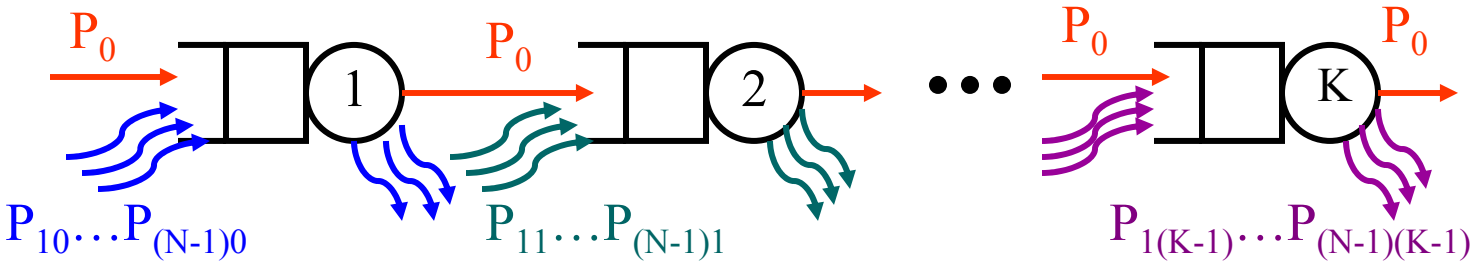
Case: $C < \Sigma$ input fluid rates

- WFQ provides isolation among flows
- queueing smooths out input rate variation within flow classes

Observations

- fluid event rates depend strongly on flow interactions, (service disciplines, link rates, propagation delays).
- Our efforts:
  - analytic characterization of fluid event rates in network setting: "calculus"
  - empirical investigation, comparison
  - techniques reducing fluid simulation event rates

Tandem queue example



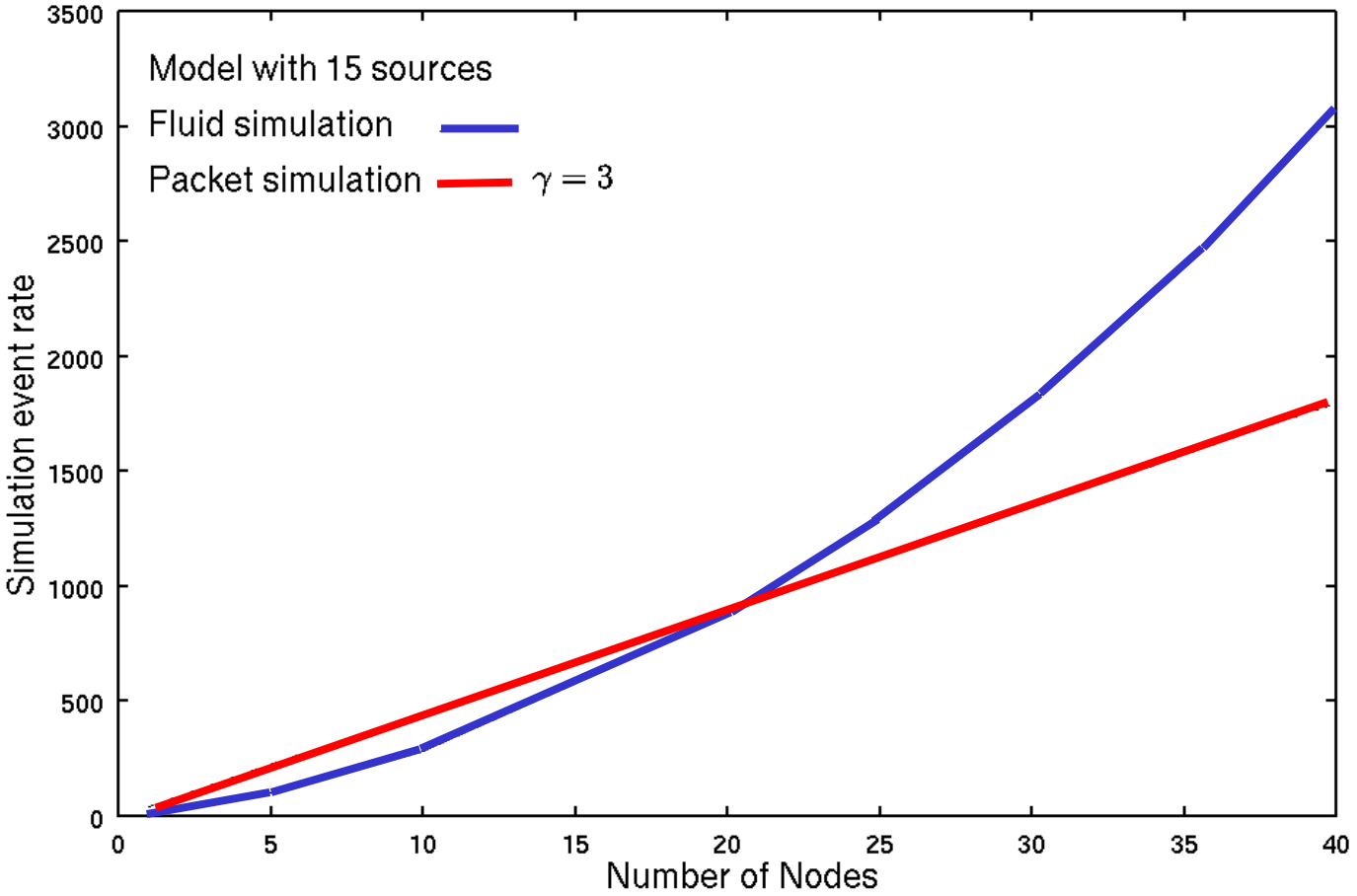
Assume $\lambda=\mu=1$, N = 10, γ = 3

Event rates as K (# queues) scales:

$$e^p = O(K) \qquad e^f = O(K^2)$$

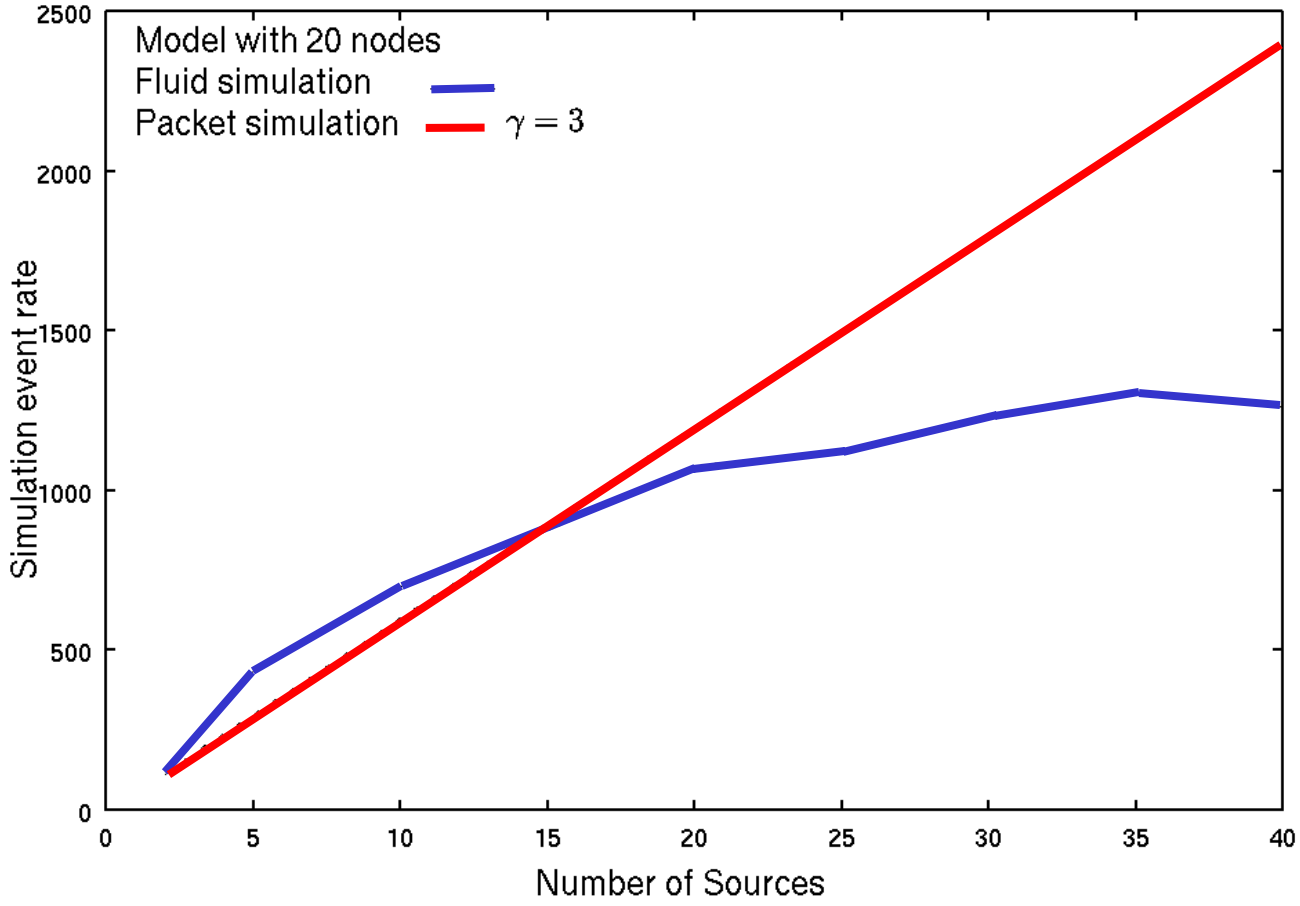
packet fluid

Tandem: scaling # nodes



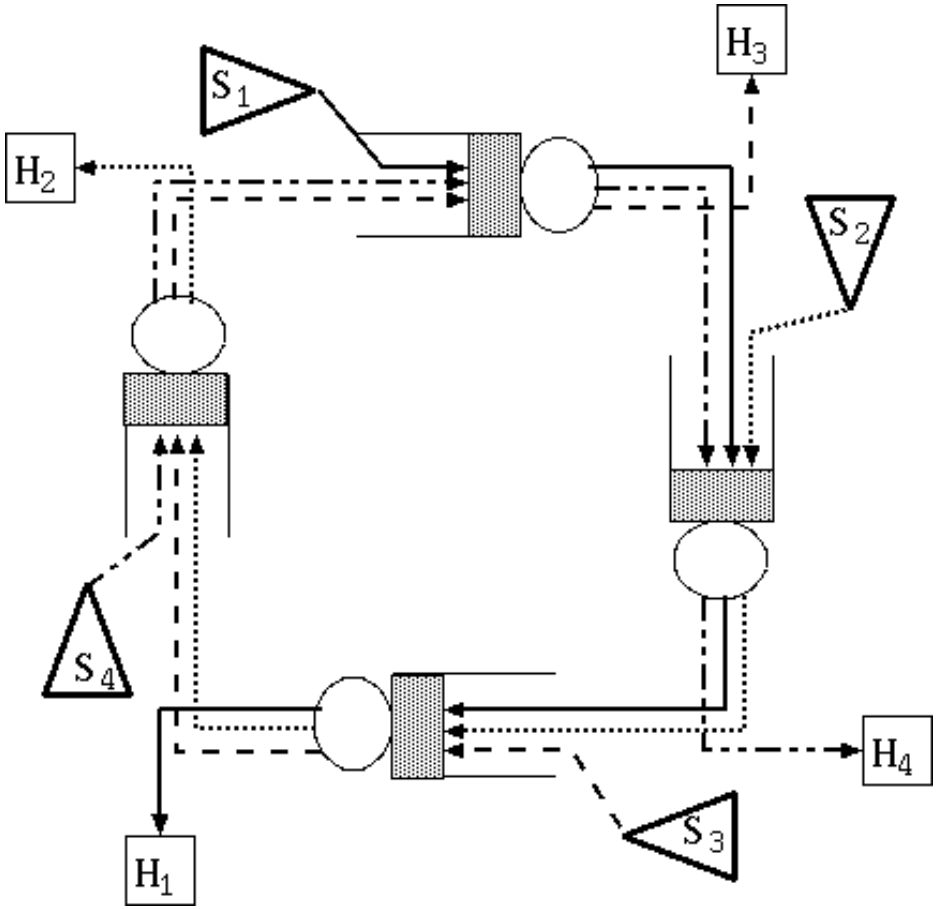
Tandem: scaling # sessions

$\lambda=\mu=1$, 20 = 10, γ = 3, ρ = 0.8

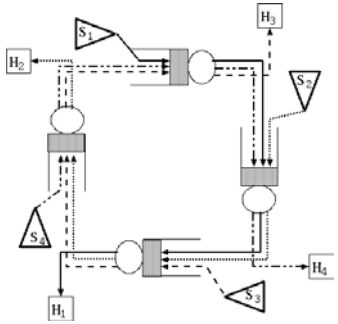


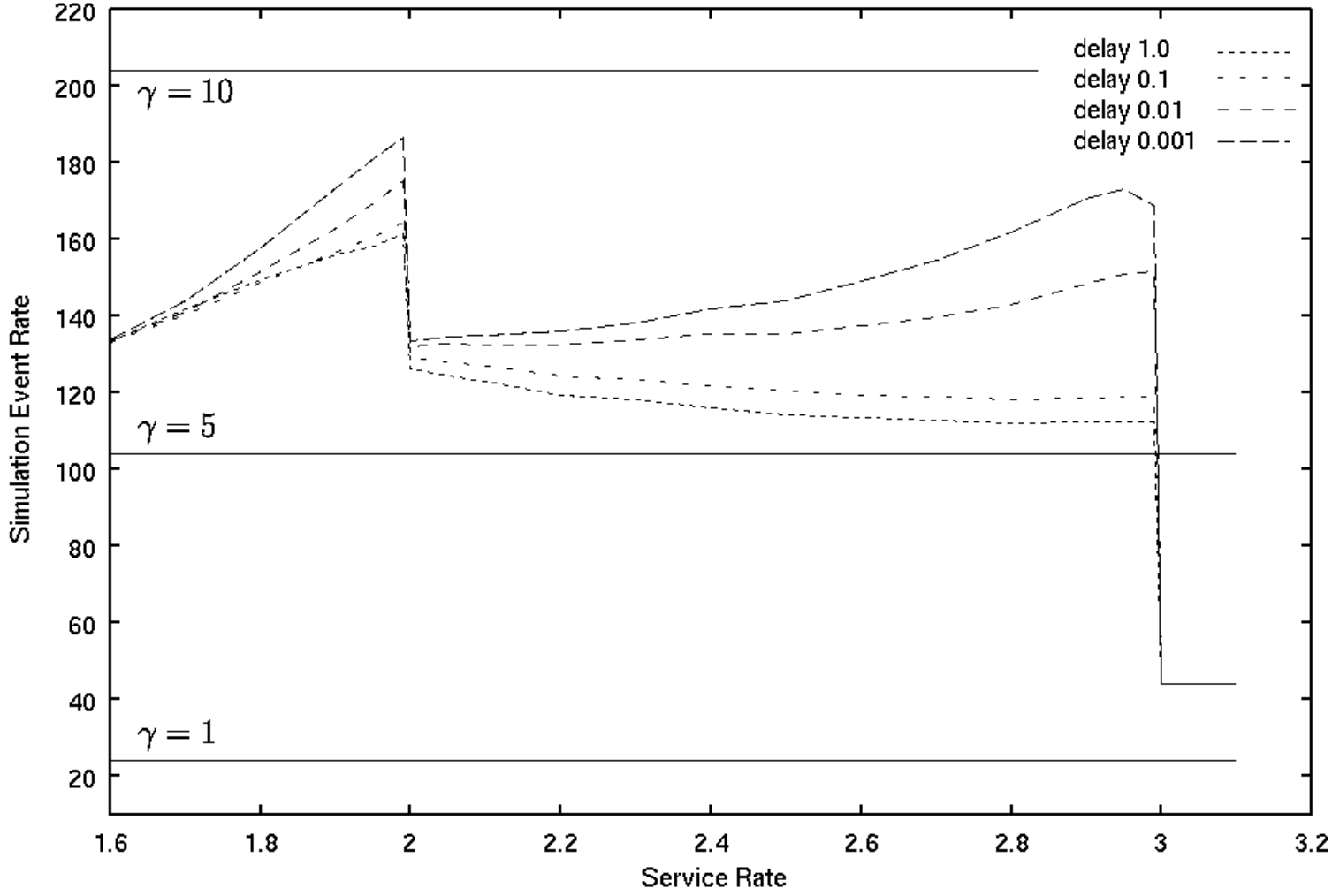
Feedback networks

- Feedback: ripple effect can feedback upon itself!
- Propagation delays between nodes limts feedback cycle

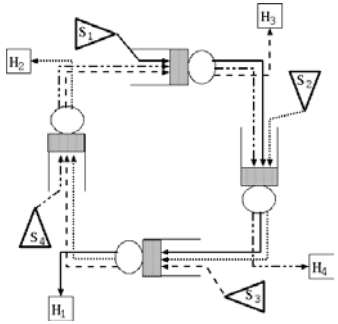


Feedback networks

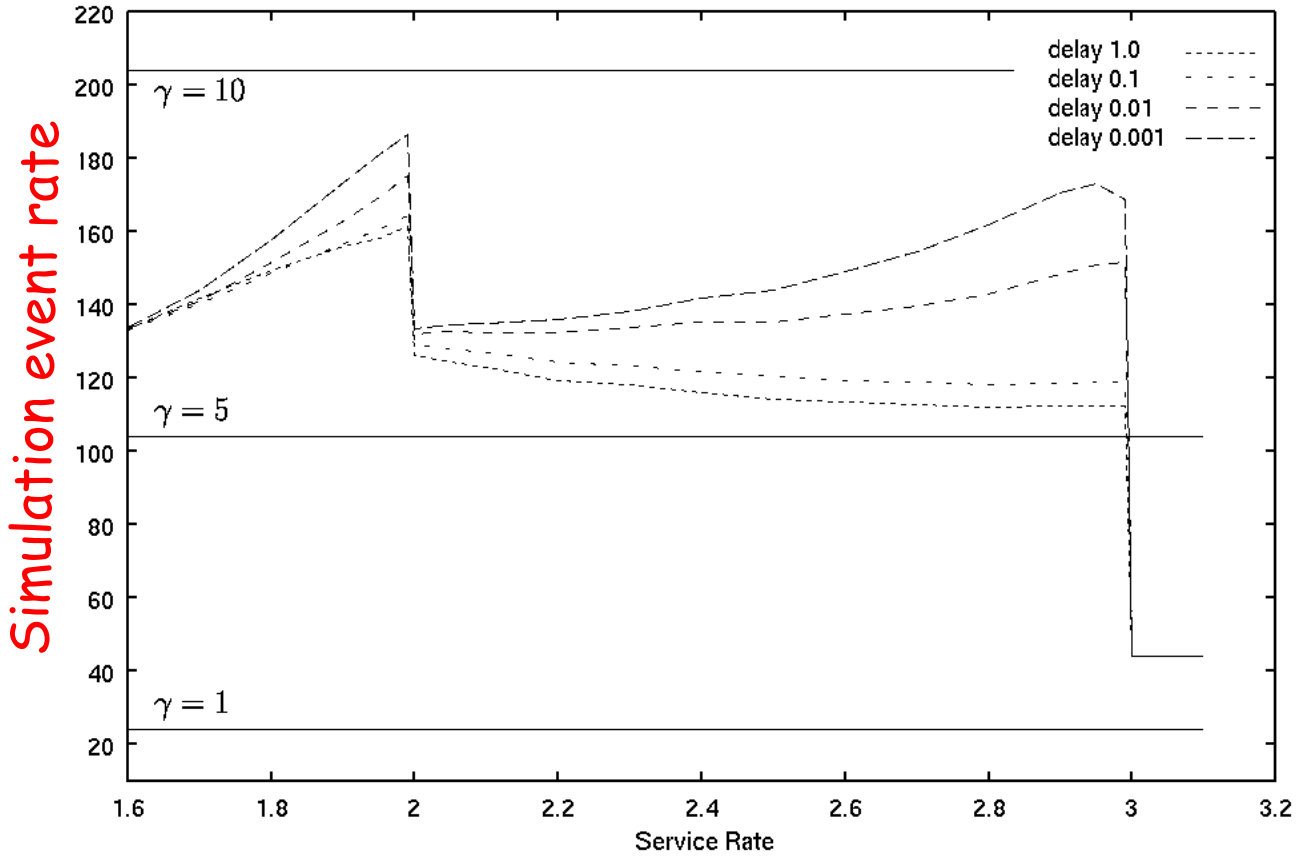




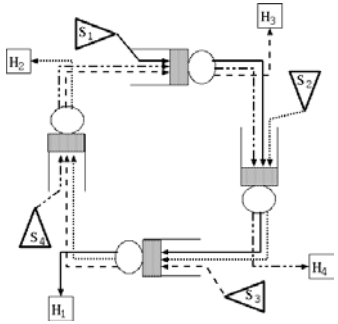
Event rate as measure of effort



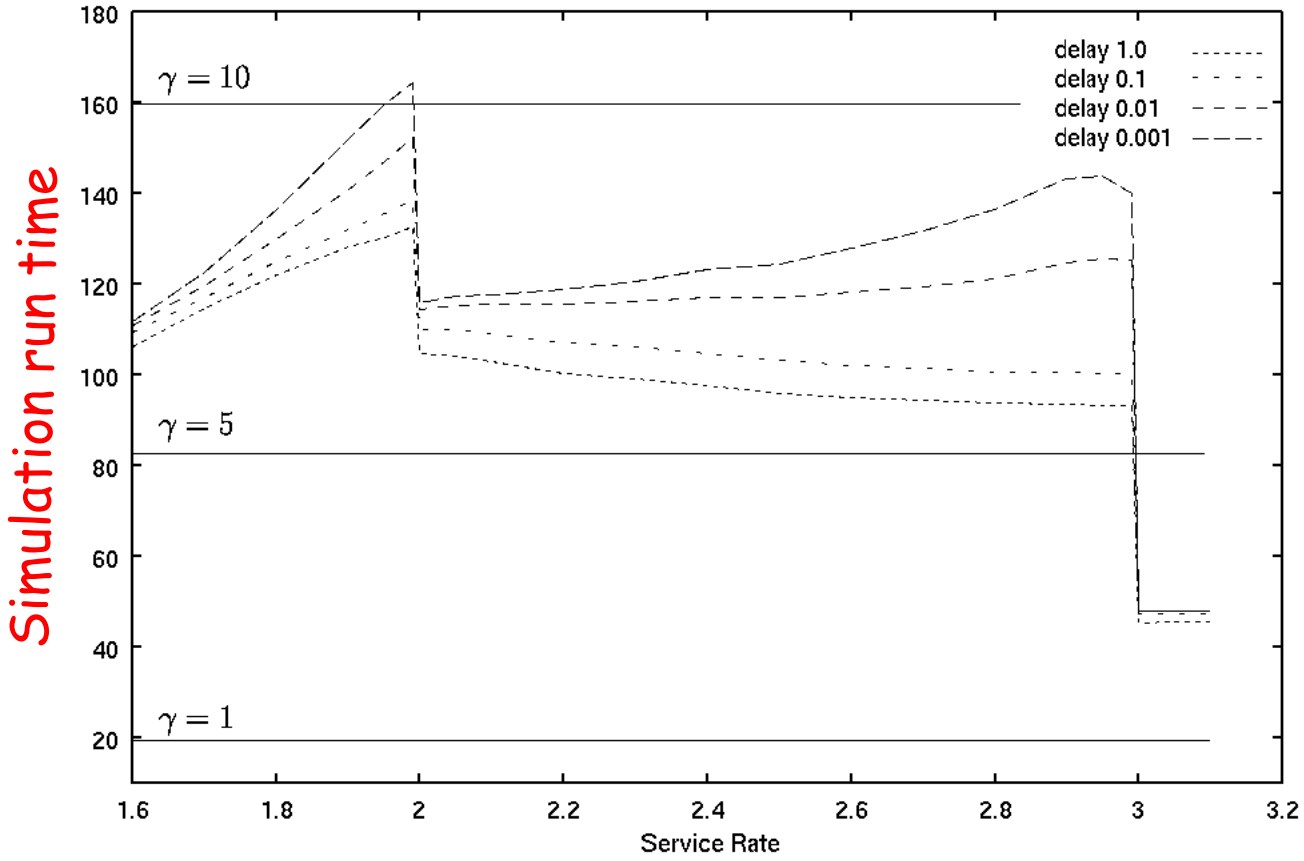
Measure of computational effort:
event rate



Event rate as measure of effort

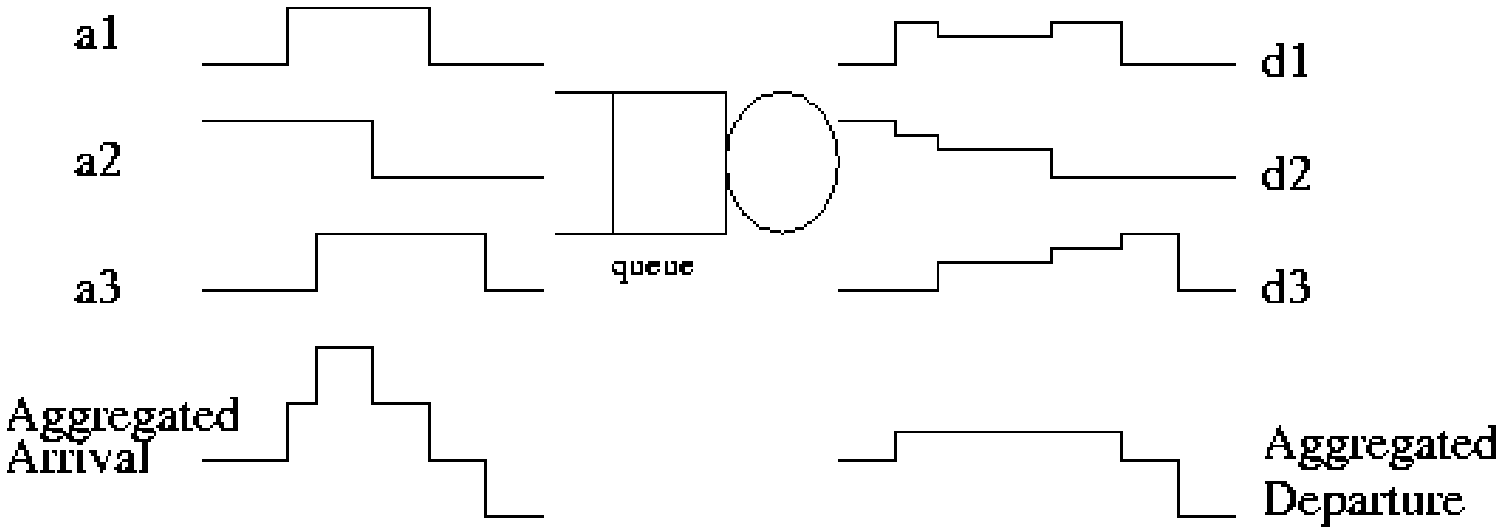


Measure of computational effort: simulation run time

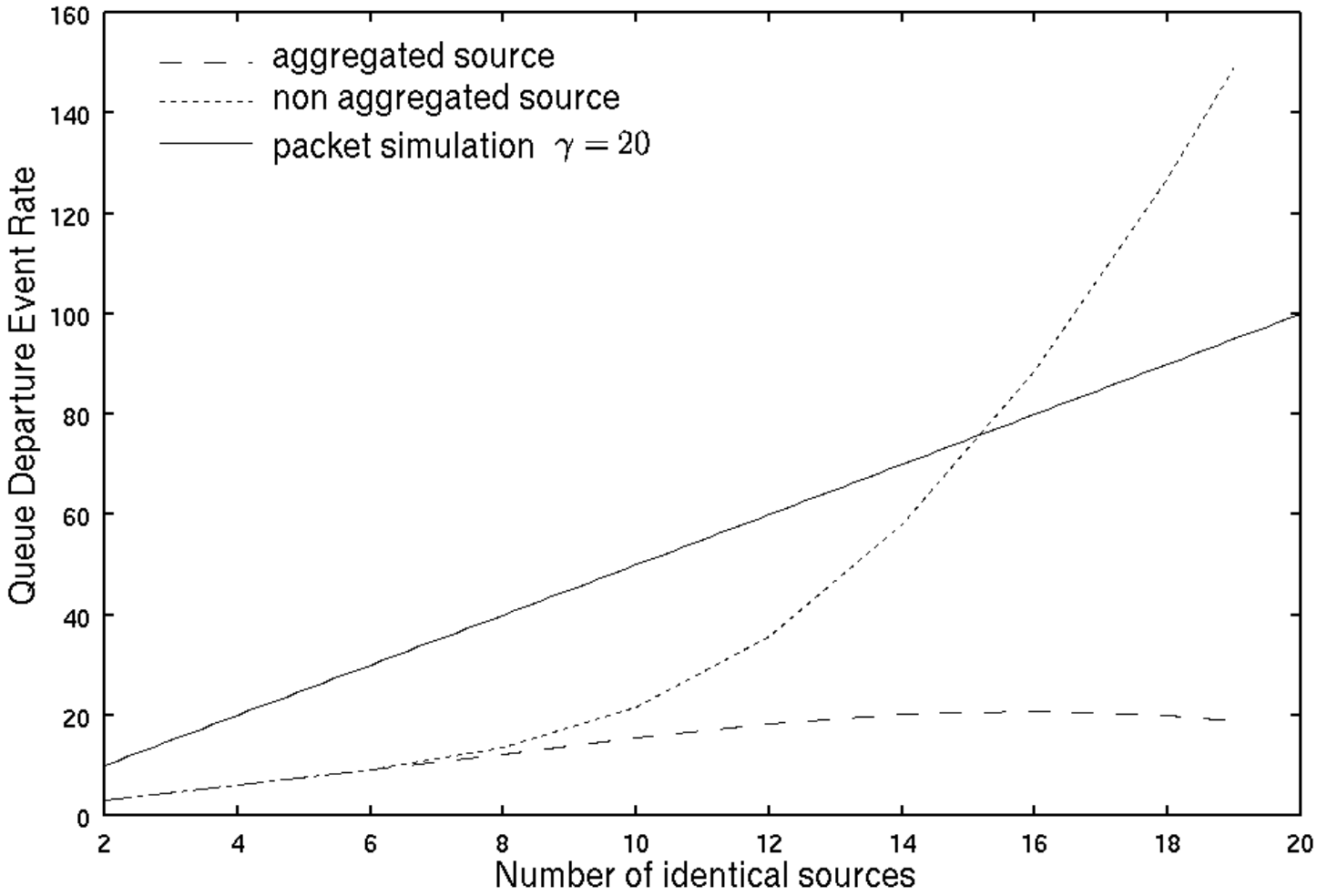


Speeding up a fluid simulation

aggregation: aggregate fluid flows when individual dynamics not of concern



Aggregation: single queue example



Time-Stepped Fluid Simulation

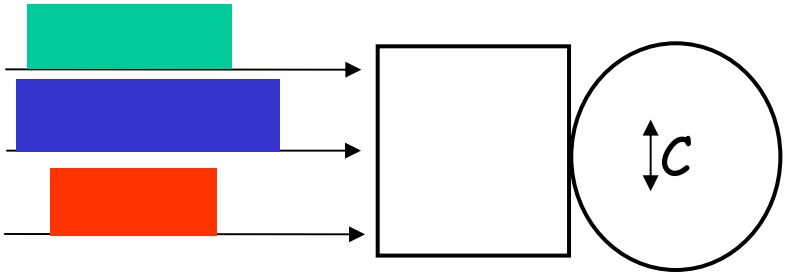
So far:

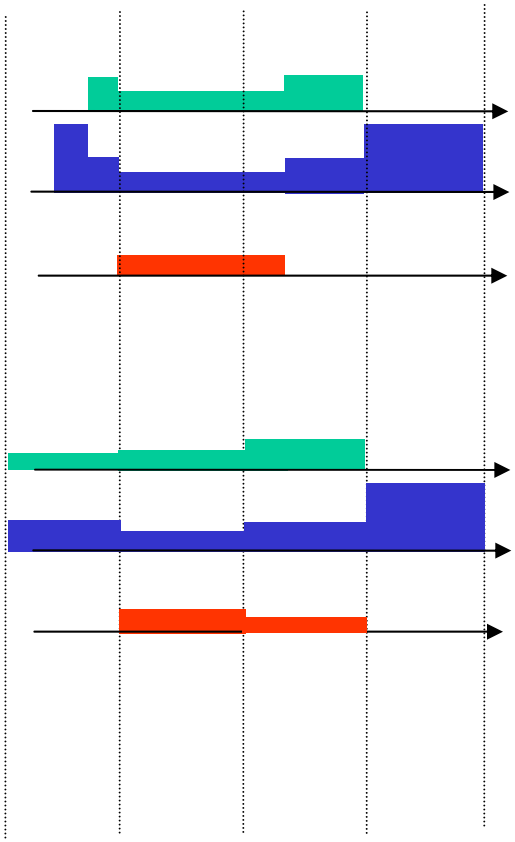
- sources approximated by fluids
- *exact* simulation of fluid dynamics within network

Idea:

- smooth out fluid variations at queue outputs
  - over what time scale?
  - time-stepped fluid simulation

Time-Stepped Fluid Simulation

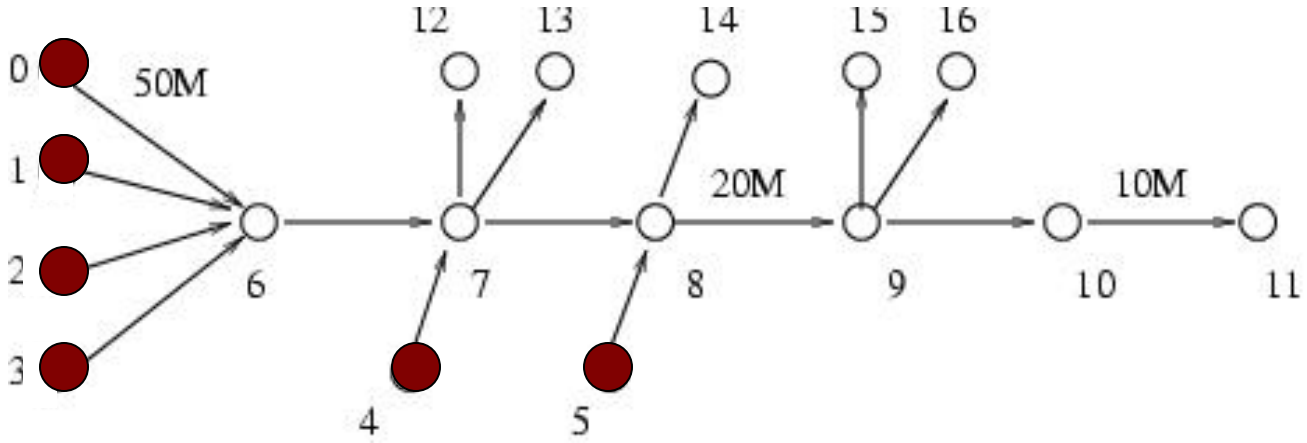




exact fluid simulation

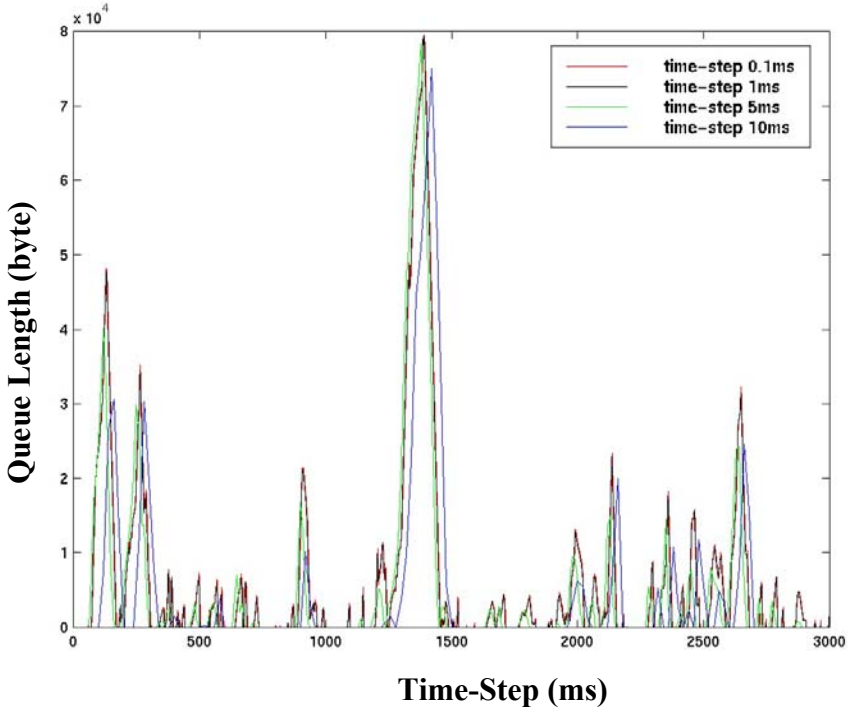
time-stepped fluid simulation

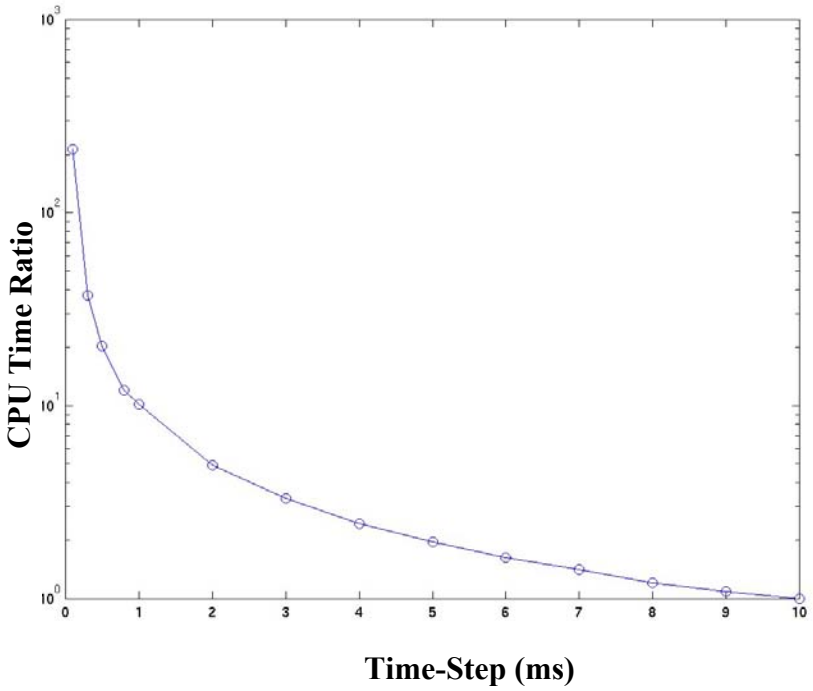
Simulation Experiment: Fluid Network



Time-step(ms)	0.1	1	5	10
AvgQ length(byte)	6787.0	6692.6	6454.1	6043.6
Thruput(byte/ms)	850.4	850.4	850.4	850.4

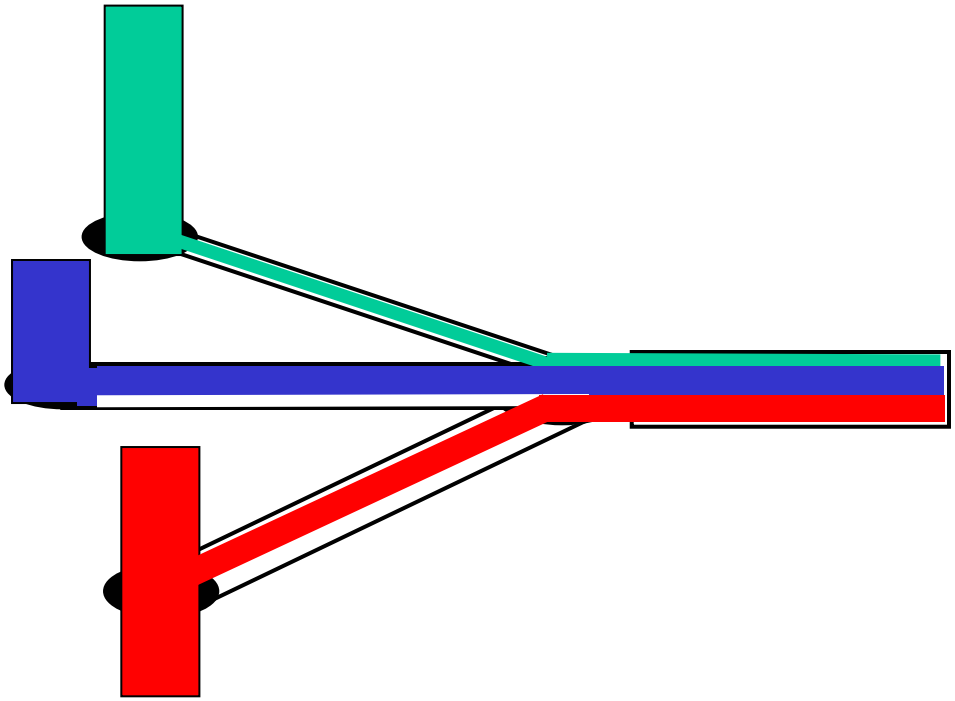
Fluid Network (2)





Big picture question:

- question: from packet- to session-level abstraction
- *flow rate:* determined by link capacity, sharing requirements
- *networks* of processor-sharing-like queues



Summary

- Packet versus fluid simulation: efficiency
  - propagation of rate change effects
- Current/future work:
  - study of WFQ
  - flow-level modeling
  - what's the right abstraction level?
    - efficiency versus accuracy

The end

Slides available at
http://gaia.cs.umass.edu/kurose/santa_fe_01.ppt

Papers available at
http://gaia.cs.umass.edu

- B. Liu, D. Figueiredo, Y. Guo, J. Kurose, D. Towsley, "A Study of Networks Simulation Efficiency: Fluid Simulation vs. Packet-level Simulation" to appear in Proceedings of IEEE Infocom 2001.
- Y. Guo, W. Gong, D. Towsley, "Time-stepped Hybrid Simulation (TSHS) for Large Scale Networks, "Proc. IEEE Infocom'00 (Tel-Aviv, Israel, March, 2000).

Observations

- gaps:
  - between theory and theory
  - between theory and practice
  - in vocabulary
- interesting questions have hard-to-define (but important!) measures, e.g.: evolvability, complexity, maintainability, robustness
  - "the Internet is evolvable"
  - "Internet soft-state control is robust"

…we need to be precise and we need help with definitions

Observations

- many interesting questions
  - at application-level
  - in the control plane
  - in the legal plane
  - in how the infrastructure grows and is measured and modeled