End-to-End Traffic Control

Goal: Facilitate efficient usage of network resources and satisfy user requirement from edge of network.

$\longrightarrow$ view network as black box

Components:

- Reliability
- Congestion control
- QoS control

Reliability:

- ARQ and window control
- realization in TCP
- complications due to integration with congestion control

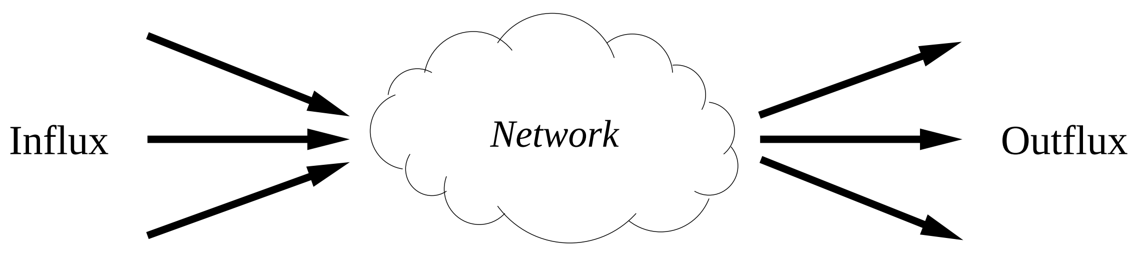
$\longrightarrow$ congestion control on top of window control

Congestion Control

Goal: Speedy and efficient transport of data to maximize throughput

$\longrightarrow$ reliable & unreliable

Throughput maximization:

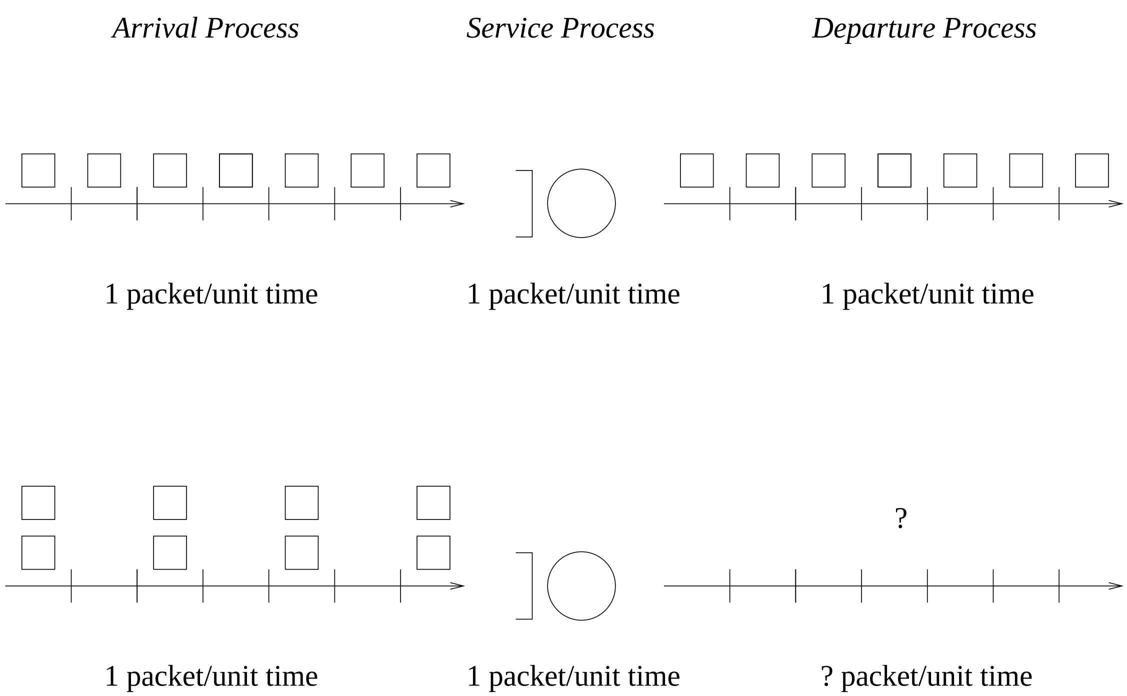


$\longrightarrow$ relationship between rate of influx/outflux

When the network is a single queue:

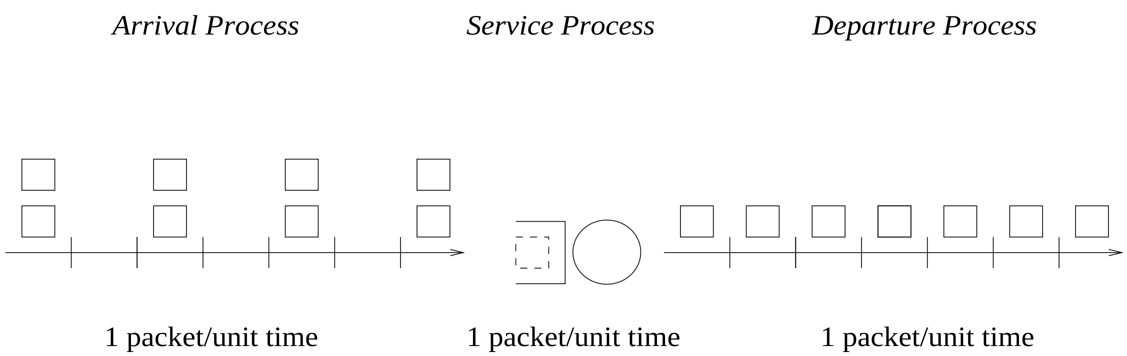
$\longrightarrow$ e.g., output link at single router

Zero buffer case:



Nonzero buffer case:

⟶ single packet capacity

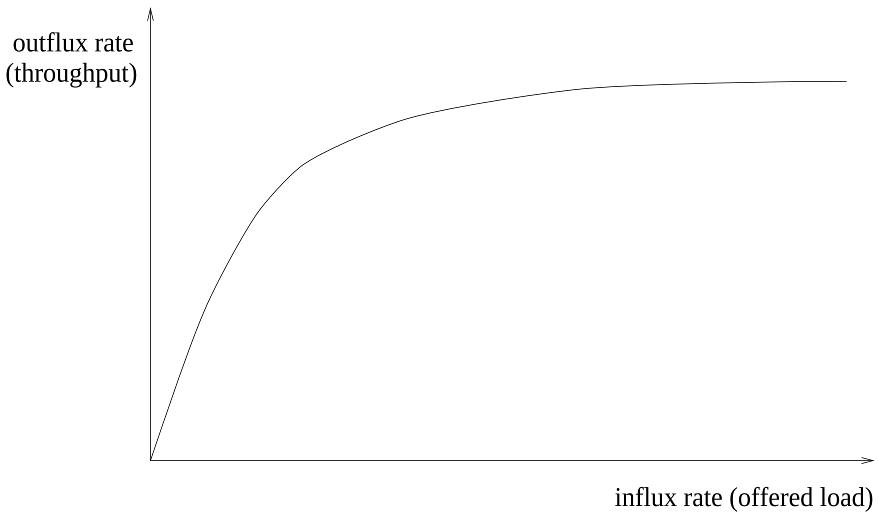


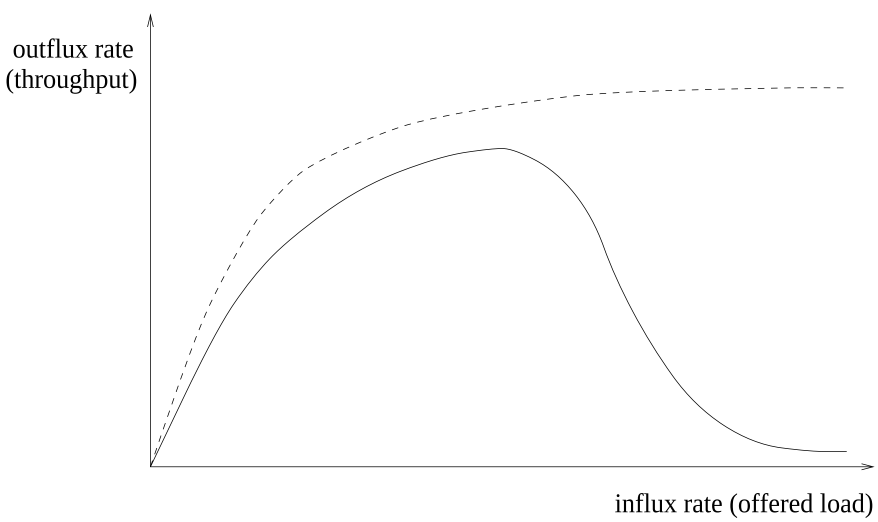
Components:

- buffer occupancy trace
- "remembering" (i.e., memory) helps

Influx rate/outflux rate relation:

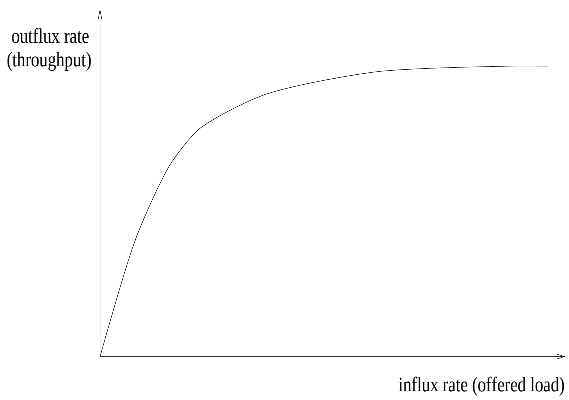
$\longrightarrow$ fixed link bandwidth or service rate

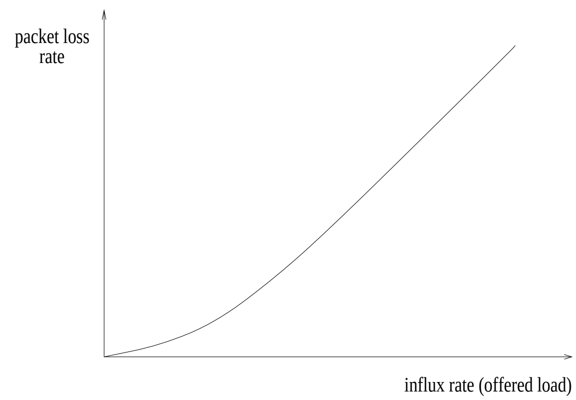




When is unimodal or "bell-shaped" curve possible?

$\longrightarrow$ penalize for packet loss





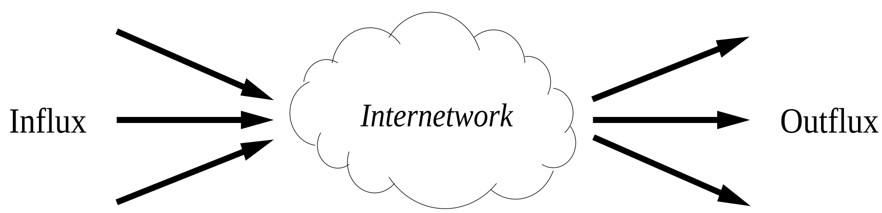
`Example`:

$$\textit{effective throughput} = \textit{throughput} \times (1 - c)^k$$

c: packet loss rate; $0 \leq c \leq 1$

k: penalty exponent; $k \geq 0$

When the network is a general internetwork:



Unimodal shape:

- reliable throughput
- what about "pure" outflux rate?

$\longrightarrow$ monotonicity property

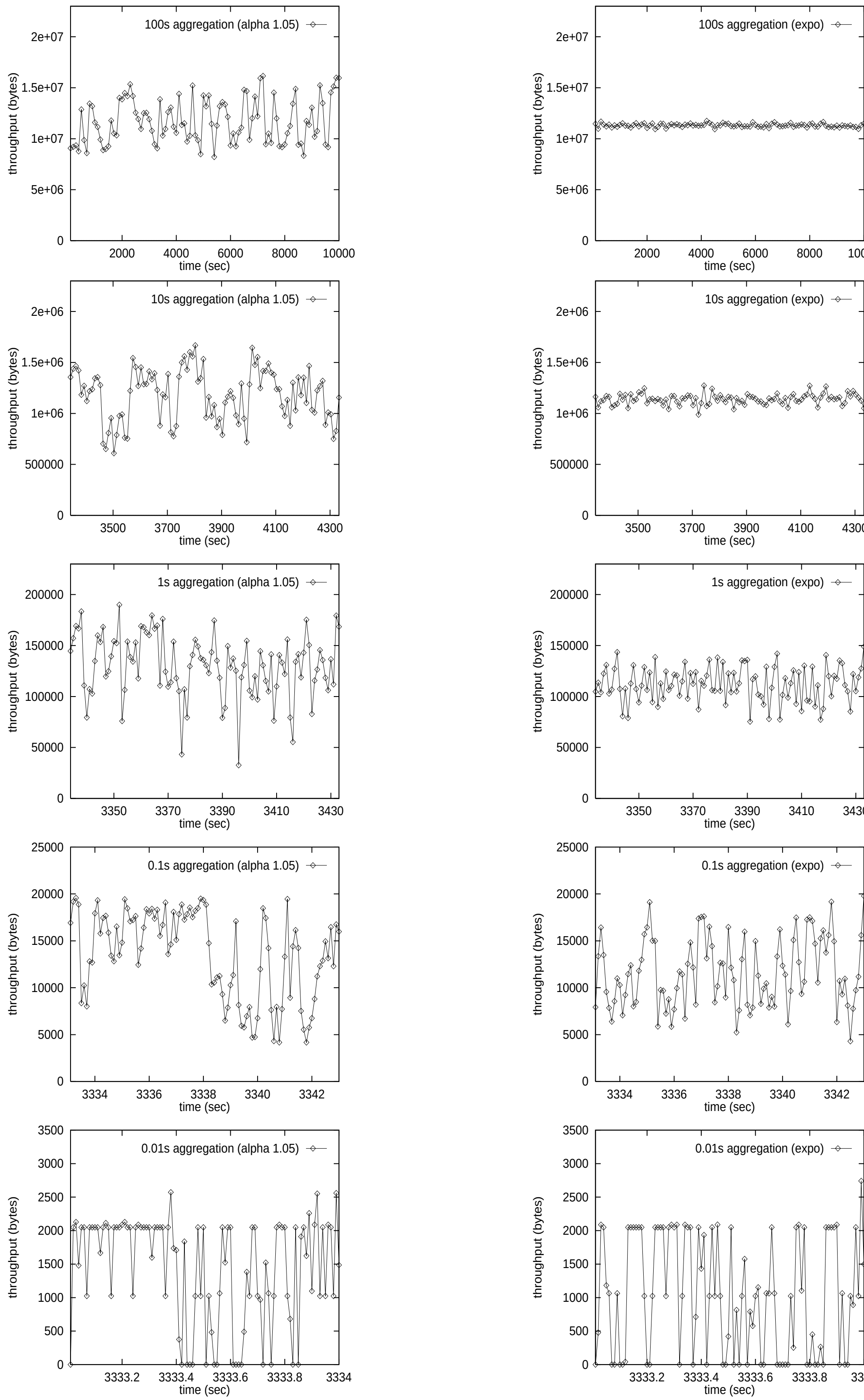
How does actual traffic look like?

$\longrightarrow$ depends

Two main cases

- telephone traffic
- data traffic (i.e., Internet)

$\longrightarrow$ Poisson vs. self-similar/fractal


100s aggregation (alpha 1.05)
100s aggregation (expo)
10s aggregation (alpha 1.05)
10s aggregation (expo)
1s aggregation (alpha 1.05)
1s aggregation (expo)
0.1s aggregation (alpha 1.05)
0.1s aggregation (expo)
0.01s aggregation (alpha 1.05)
0.01s aggregation (expo)
throughput (bytes)
time (sec)

Implications to traffic management:

1. Easier to manage Poisson traffic than fractal traffic

   $\longrightarrow$ closer to CBR

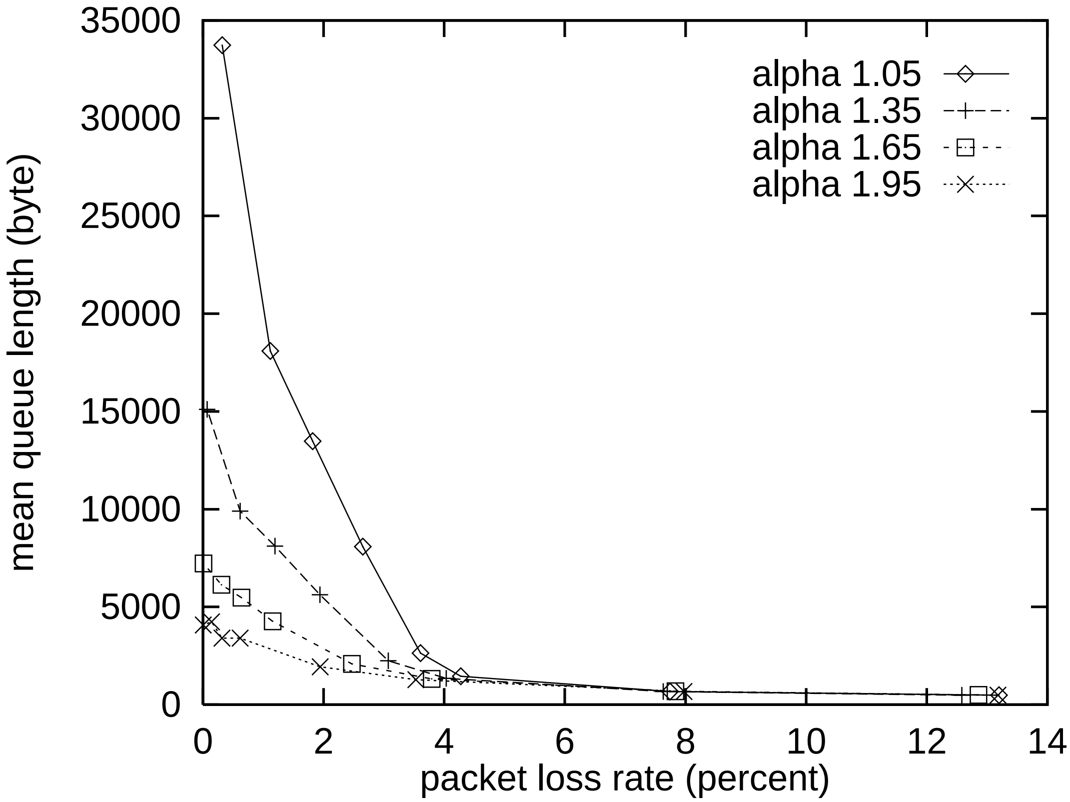
2. Pronounced trade-off between utilization and quality of service (QoS)

   a. utilization $\uparrow$ implies QoS $\downarrow$

   b. QoS $\uparrow$ implies utilization $\downarrow$

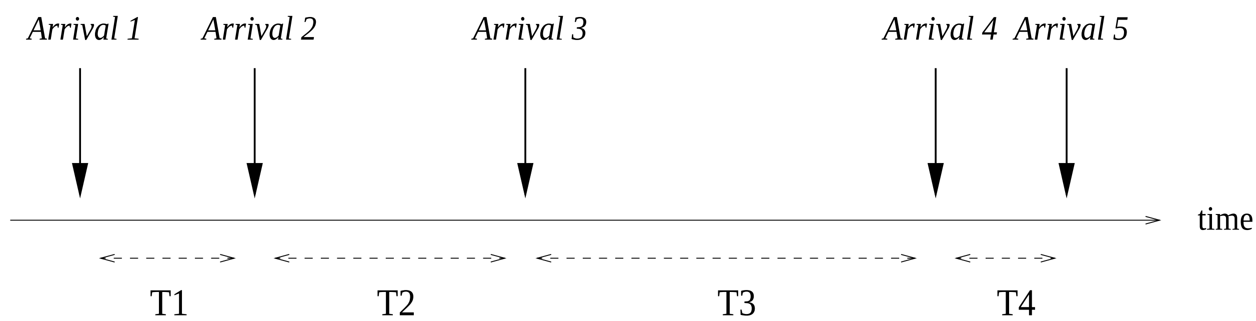
3. Sensitive trade-off between different QoS indicators

Packet loss vs. queueing delay trade-off:



- $\alpha \approx 1$ means more self-similar
- $\alpha \approx 2$ means less self-similar

Definition of Poisson Traffic:



Perform observation and record time interval between successive packet arrivals

$\longrightarrow$ interarrival time

- If T1 = T2 = $\cdots$ then CBR
- If not, then VBR

But, assuming VBR, what if T1, T2, ... are consistent with outcome of sampling from (negative) exponential distribution? I.e.,

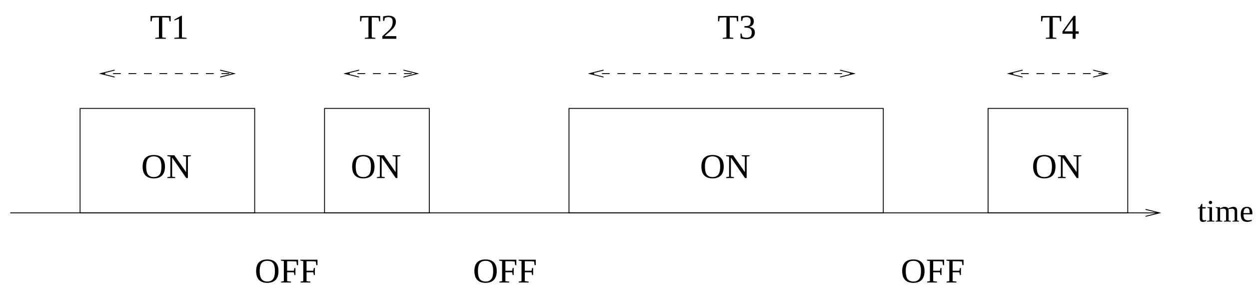
$$p(T) = \lambda e^{-\lambda T}$$

Then the total arrival process is called Poisson

$\longrightarrow$ counting process

$\longrightarrow$ total number of packets until time t

Definition of Self-similar Traffic:



"Packet train" notion of ON and OFF periods

$\longrightarrow$ ON/OFF model

Don't care about OFF periods

If ON periods T1, T2, . . . are consistent with outcome of sampling from a ***heavy-tailed*** distribution? I.e.,

$$p(T) = T^{-\lambda}$$

Then the total arrival process is called self-similar (a specific form)

$\longrightarrow$ most commonly used data traffic model

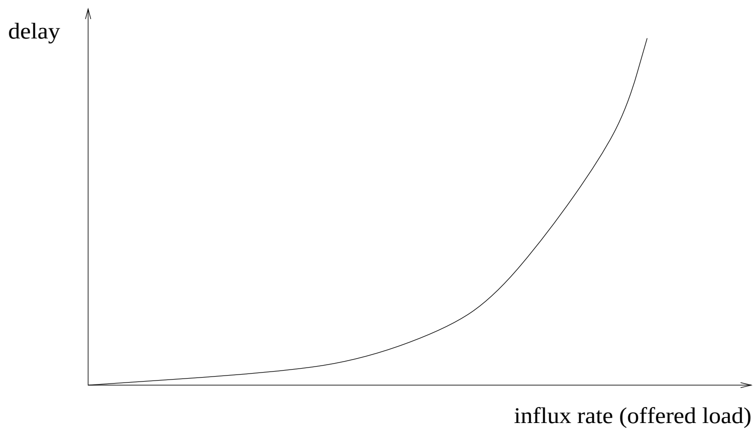
Why should ON periods be heavy-tailed?

$\longrightarrow$ physical modeling

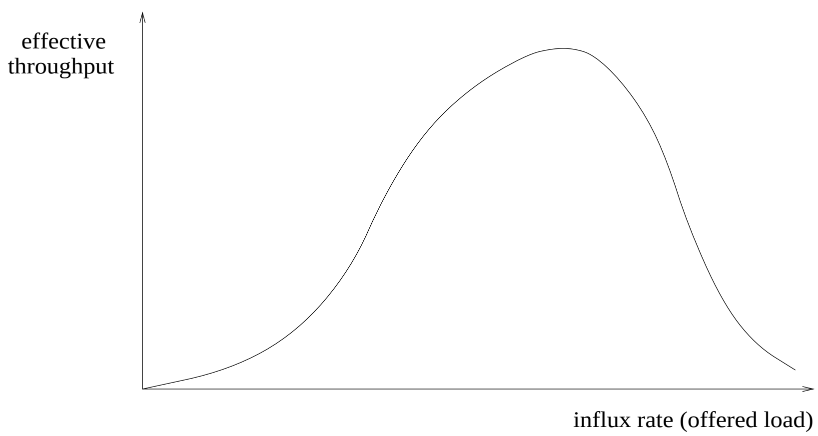
$\longrightarrow$ Web application: workload modeling

Definition of "congestion":

I. Delay perspective:



II. Throughput perspective:



What is "optimal" operating point?

- Delay:
  - may be user given
  - point where slope sharply increases
- Throughput:
  - may be user given
  - maximum point

A compromise:

$$\text{power} = \text{throughput}/\text{delay}$$

`Goal of congestion control`:

$\longrightarrow$ achieve optimal/target operating point

Means: adjustment of influx rate