Web application performance

A Lecture for LinuxDays 2017

by
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HOME AT CLOUD

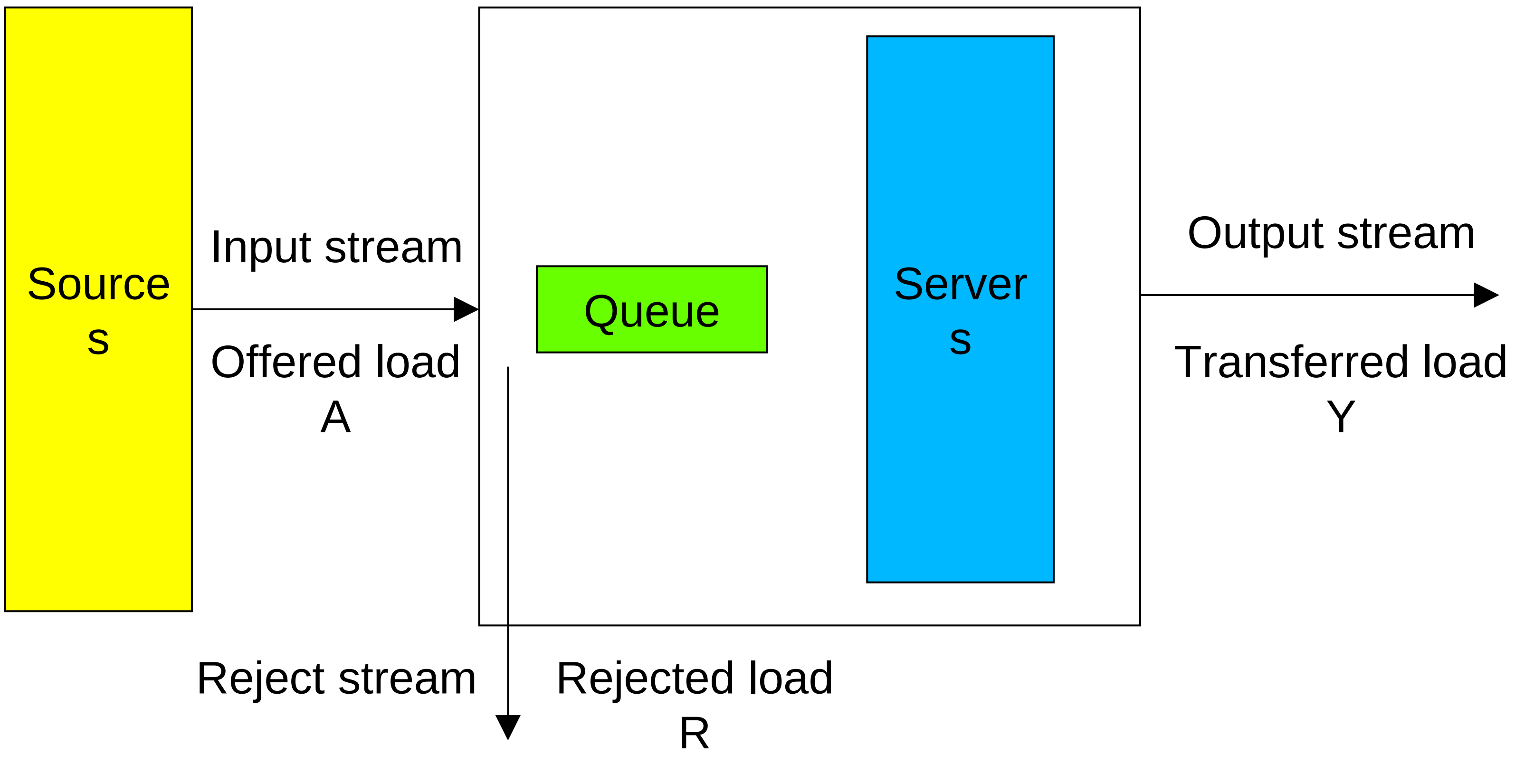
Capacity planning

- Marketing gives you: estimate of the number of customers and its trend
  - > You need to translate it to the technical view
    - How many clicks per second does a user produce?
    - How much is it in number of connections?
    - What is it written in?
    - How much power does it need?
    - How much power do the servers have?
    - Will there be room for usage spikes? And growth?
      - > How many servers do we need
      - (or) how much will the cloud cost

Theoretical approach

- Queueing theory (T. hromadné obsluhy)
  - Founded by Erlang, beginning of 20. century
  - Models problems in telecom, traffic, industry
  - Service system:
    - Request sources – s
    - Input process – intensity A, rate λ [1/s]
    - Queue – Q – if none -> system with loss
    - Service process – N servers, service demand D [s]
    - Output stream – intensity Y, rate μ [1/s]
    - Rejected stream – intensity R – if queue full
      - Intensity = rate * service demand; [erl = mostly minutes / hour]

Service system



Model properties

- Arrival and service: stochastic processes
- Conditions:
  - Stationary – stable in time, system is in a statistical equilibrium -> input and output intensities match
  - Ordinary – one request at a time, only interarrival time needs to be modeled
  - Independent – arrival and service processes are independent

Kendall's classification

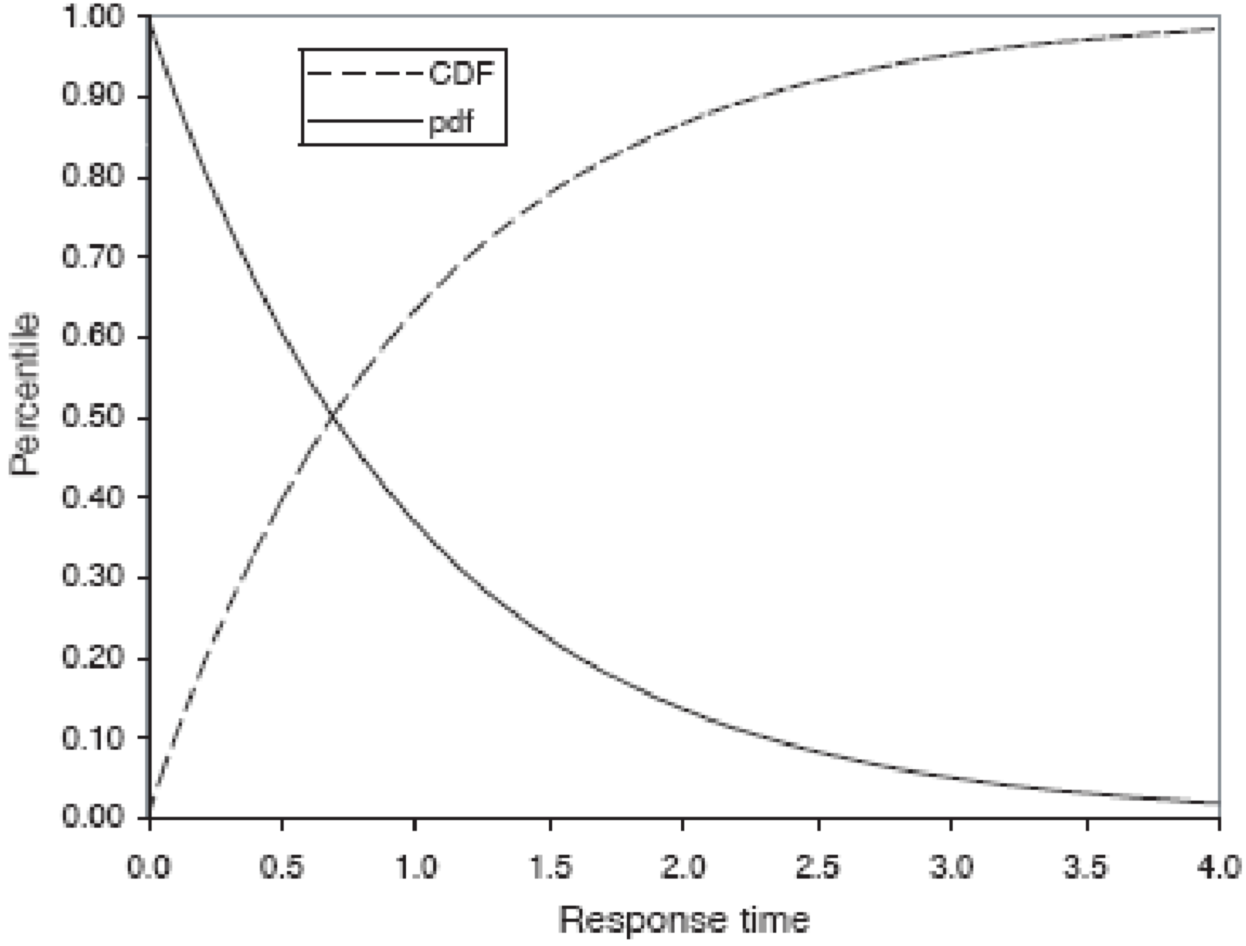
- Kendall introduced A/B/N(/M) notation
  - A: statistical distribution of arrival process
  - B: statistical distribution of service process
  - N: number of service lines
  - M: size of queue - not compulsory
- Where A and B may be:
  - M: Markovian, Poisson process, exp. Dist
  - D: Deterministic or Uniform
  - G: General
  - Ek: Erlang with parameter k

Poisson process

- Mostly M for Markovian is used.
- Assumes a Poisson process
  - Memoryless – arrival of one request is independent of others. Modelled by exp dist. of interarrival times.
    - Then the input rate [req/s] will have Poisson dist.
    - The load [busy time/hour] will have Erlang dist.
- If there the request are more grouped
  - i.e. the distribution has higher dispersion
  - In simulation, use Pareto or Weibull dist.
- Then with the same average arrival rate, the average waiting time will be higher.

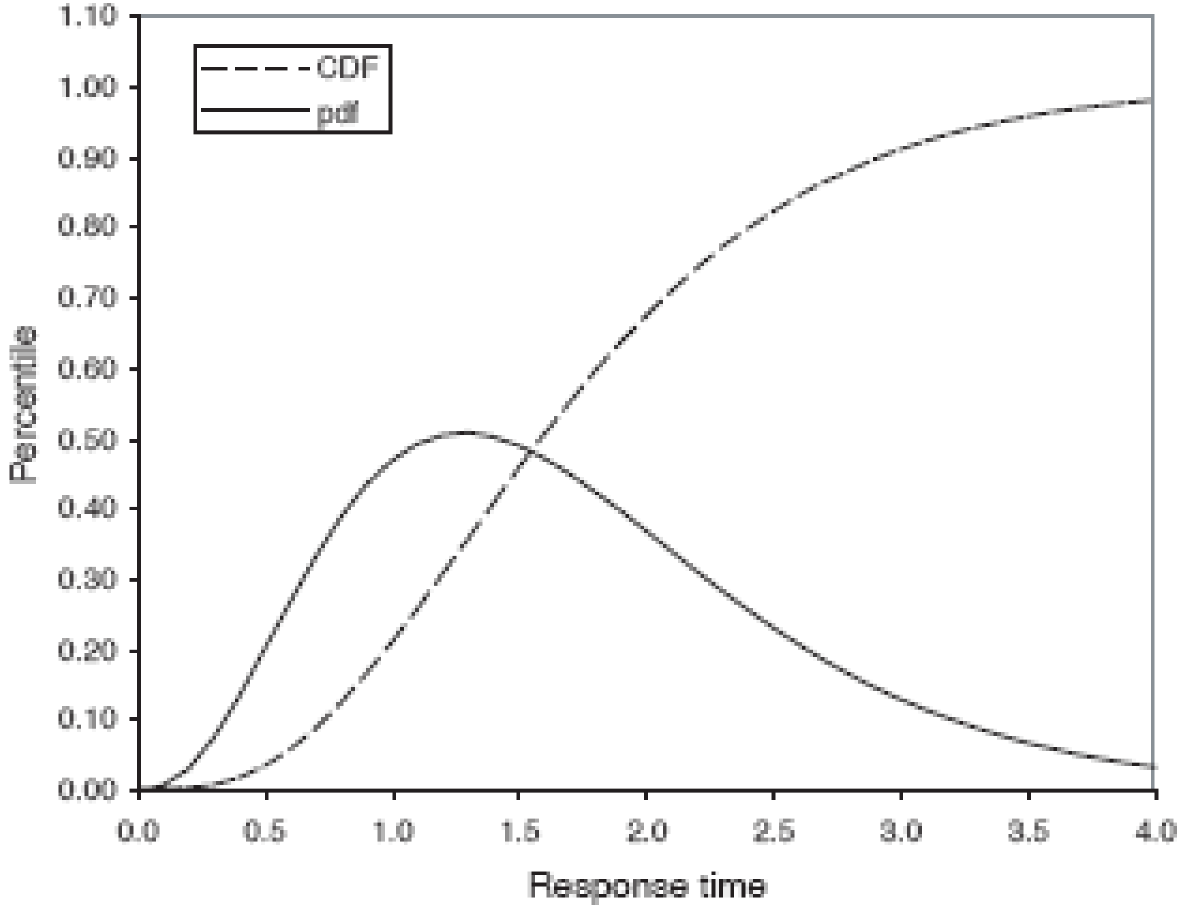
Exponential distribution

CDF: $f(t;\lambda) = \lambda e^{-\lambda t}$ PDF: $F(t;\lambda) = 1 - e^{-\lambda t}$



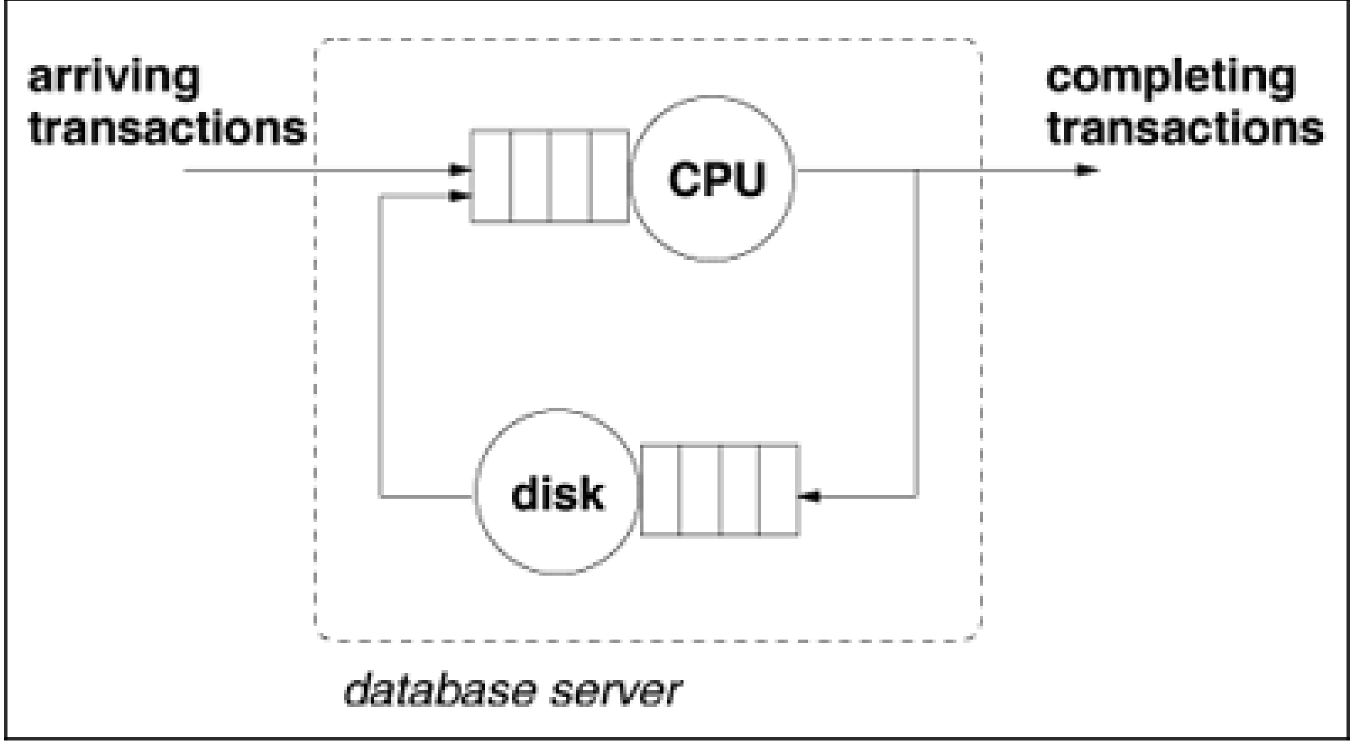
Poisson distribution

$$f(n,t) = \mathrm{e}^{-\lambda t}\frac{(\lambda t)^n}{n!},\ n = 1, 2, \ldots \qquad F(n,t) = \sum_{k=0}^{n} f(k,t)$$



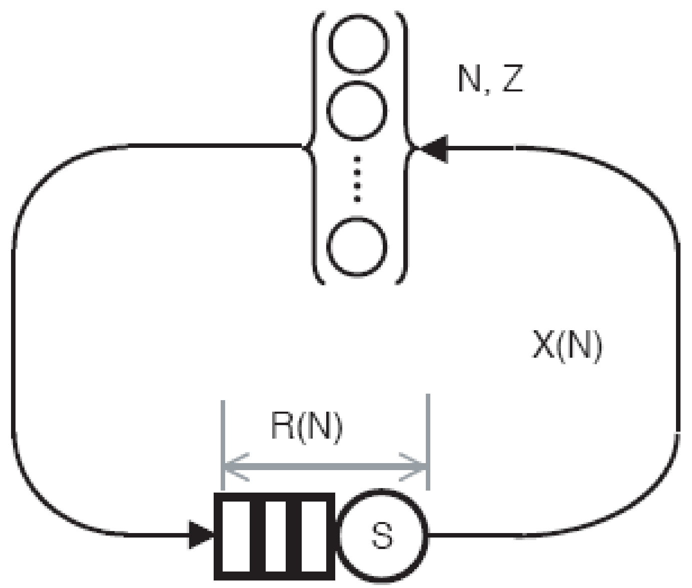
System types

- Open system
  - Number of customers not known
  - Characterized by arrival rate



System types

- Closed system
  - Fixed number of customers
  - Alternating between two states
    - Thinking, Requesting service



Operational Analysis

- Analyzing (part of) a queuing system as a "black box", with one input for jobs and one output for jobs
- The internal structure of the system (queuing network) is unknown
  - The distribution of inter-arrival times is unknown
  - The service times distribution is unknown
- Can be used to derive simple relationships, mostly between mean values of the system’s parameters (not distributions of e.g. que.lengths)

Utilization

- $U = b / T$
  - Utilization is the fraction of busy time to total
    - Dimensionless [s/s]
- $\lambda = X = a / T = d / T$
  - Arrival rate=throughput is the number of arriving=departing jobs per time [1/s]
- $s = b / d$
  - Service time is busy time per job [s]
- $U = \lambda s = Xs$
- also $s = 1 / \mu \rightarrow U = \lambda / \mu$
  - If $\lambda > \mu$ – utilization/intensity > 1, system unstable

U – utilization
X – throughput
S – service time
λ – arrival rate
V – visit rate
D – service demand /min time
N – requests in system
R – response time
M – thinking clients
Z – think time

Utilization Law:

$$U_i = X_i \times S_i = \lambda_i \times S_i \qquad (3.2.12)$$

Forced Flow Law:

$$X_i = V_i \times X_0 \qquad (3.2.13)$$

Service Demand Law:

$$D_i = V_i \times S_i = U_i / X_0 \qquad (3.2.14)$$

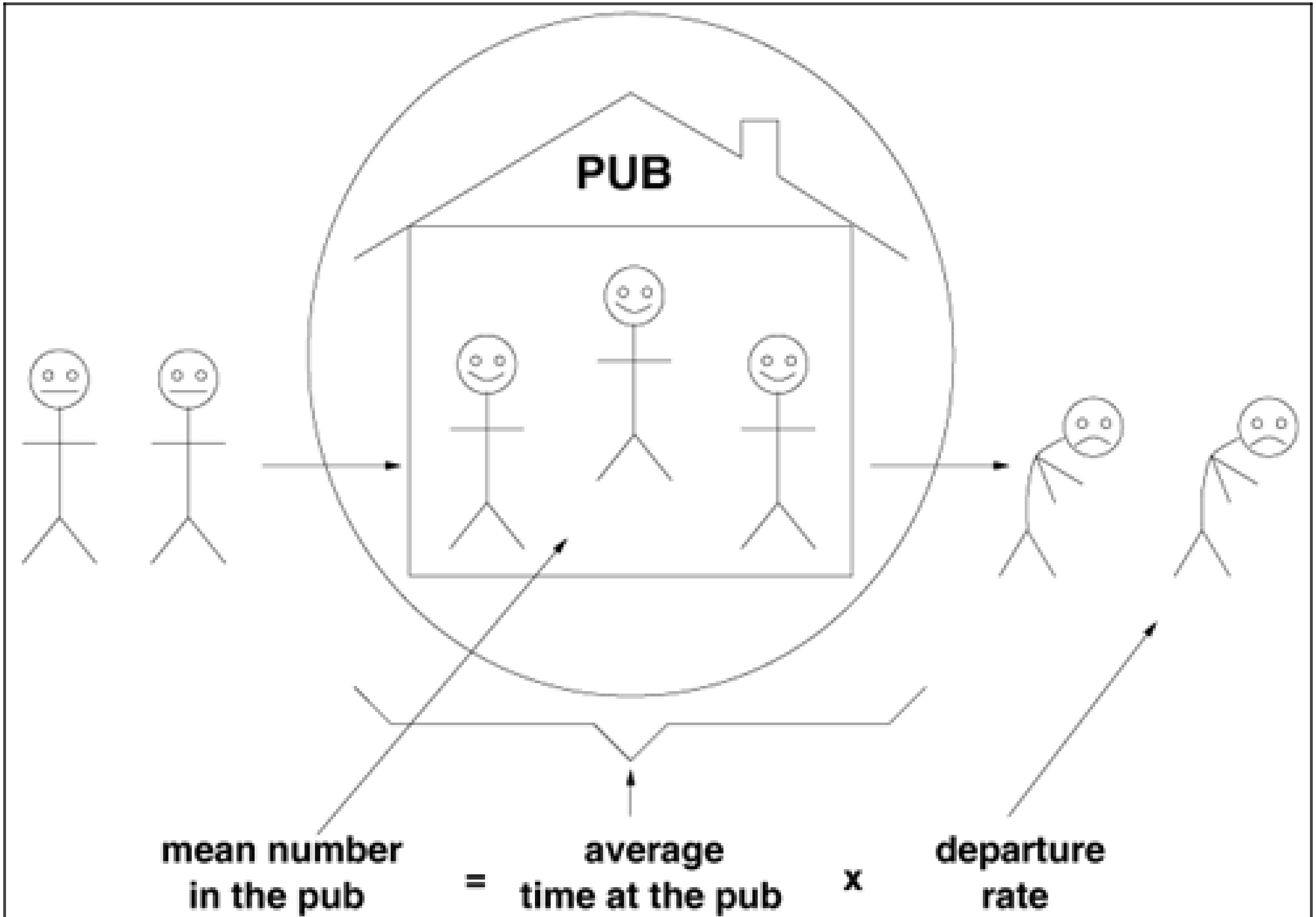
Little's Law:

$$N = X \times R \qquad (3.2.15)$$

Interactive Response Time Law

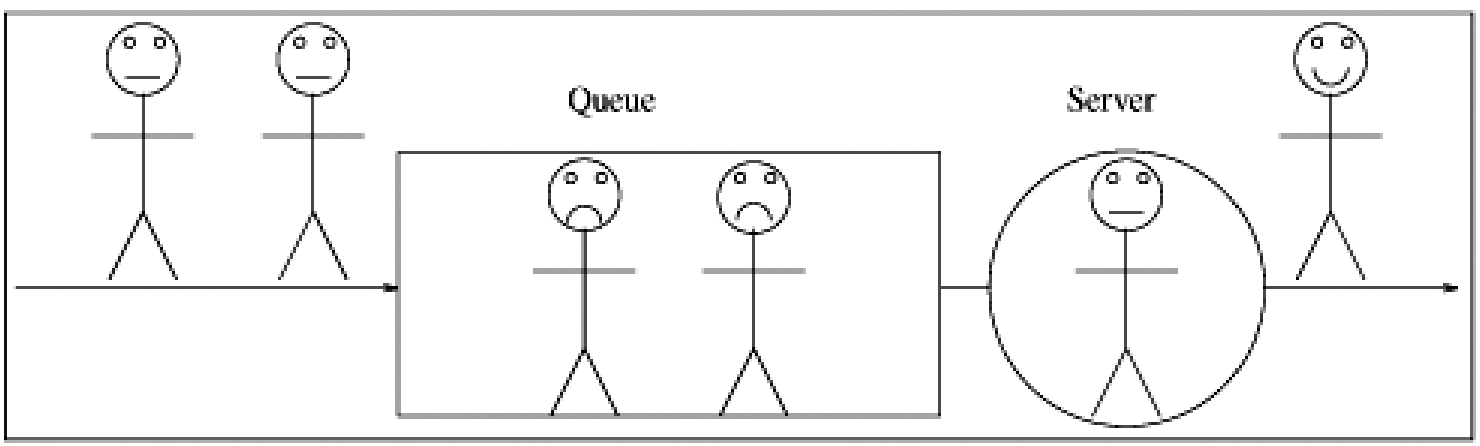
$$R = \frac{M}{X_0} - Z \qquad (3.2.16)$$

Little's Law


PUB
mean number
in the pub
=
average
time at the pub
x
departure
rate

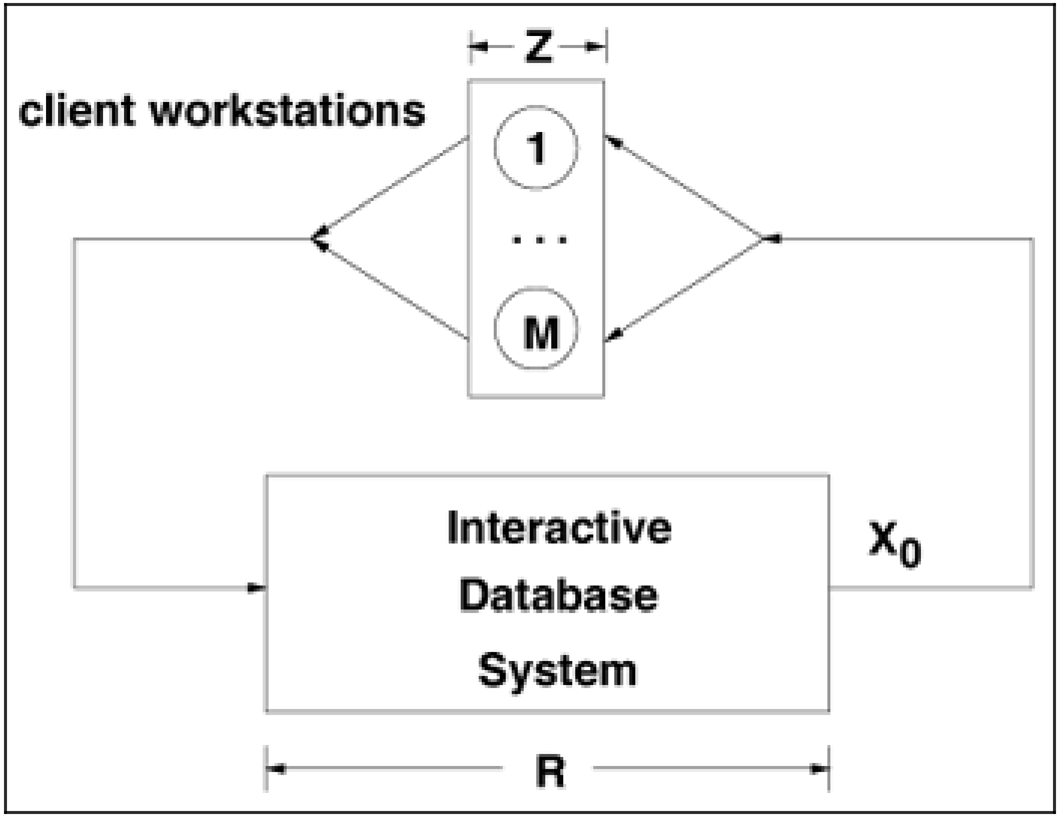
Little's Law

- Works with averages -> any steady-state
- On server only -> utilization law
- On server+queue -> computes queue length



$$\text{average number of customers in a box} = \text{departure rate from the box} \times \text{average time spent in the box.}$$

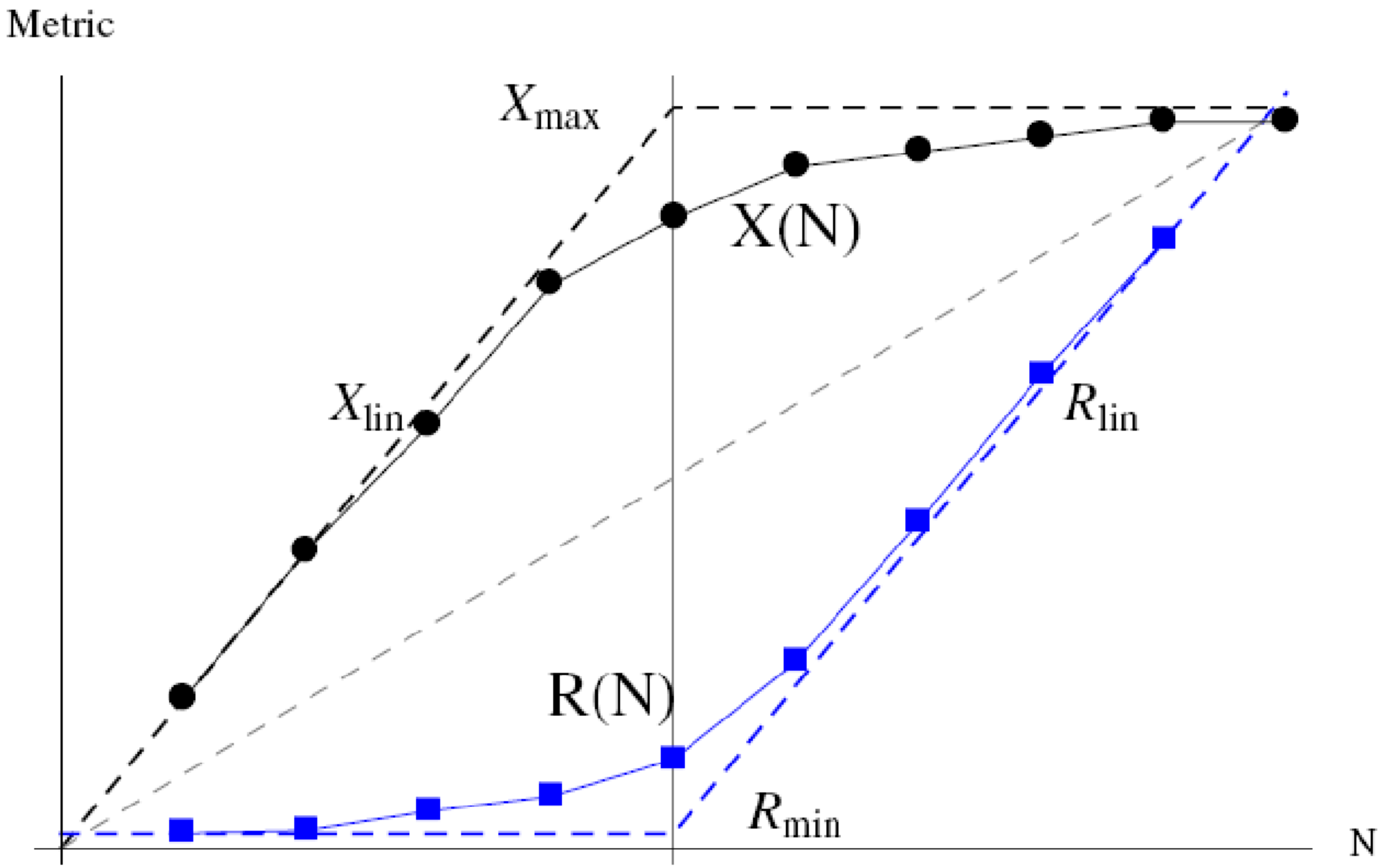
Interactive Response Time Law



$$R = \frac{M}{X_0} - Z.$$

Latency vs. throughput

(Z=0)



Asymptotics

- In previous graph, vertical line – optimum
- To the left – light load – underutilized
  - Throughput scales linearly by number of users, limited by sum of demands
  - Latency constant

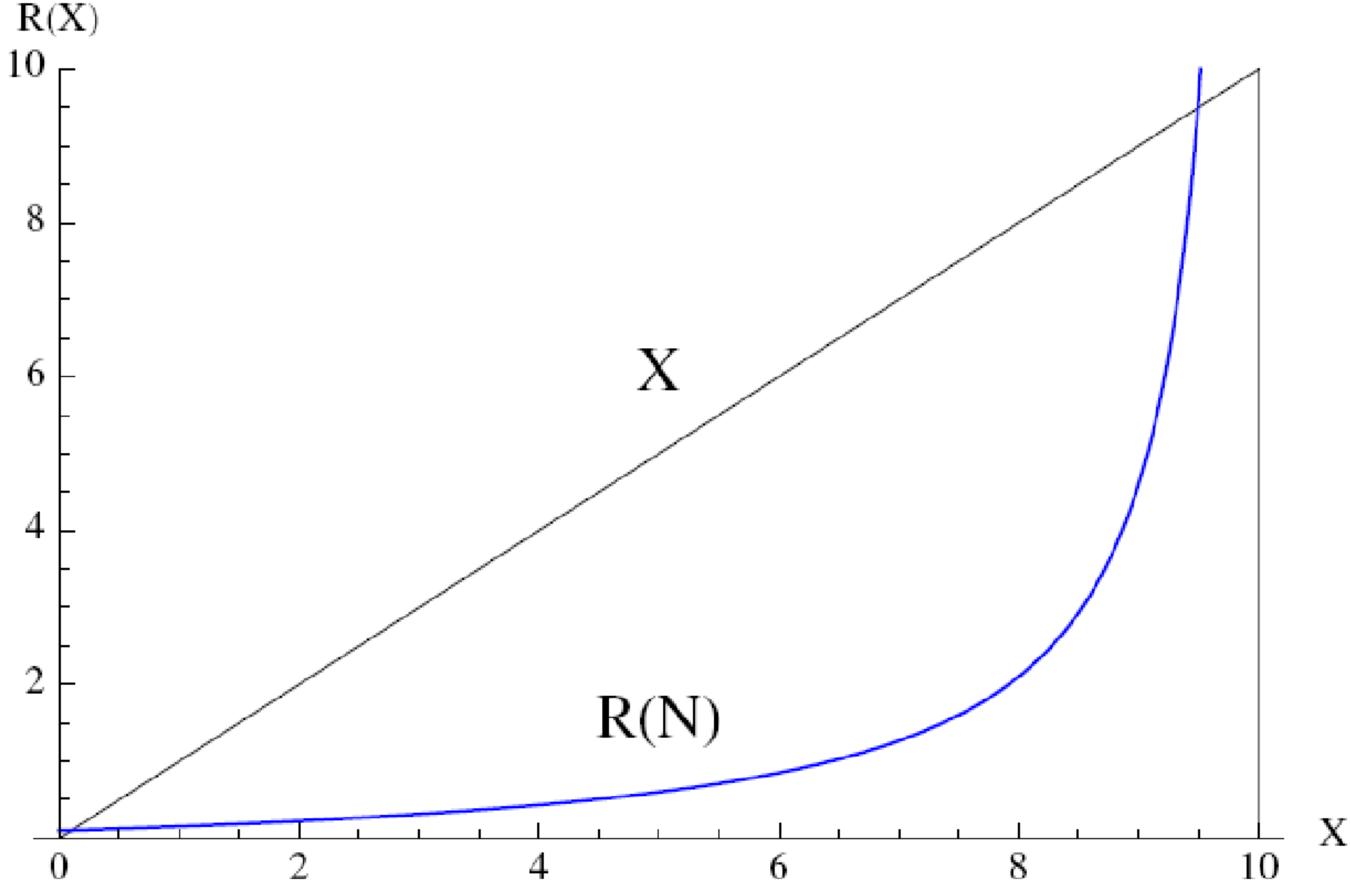
$$X_0 \leq \frac{N}{\sum_{i=1}^{K} D_i}.$$

- To the right – heavy load – overutilized
  - Throughput constant, limited by bottleneck resource
  - Latency scales linearly

$$X_0 \leq \frac{1}{\max\ \{D_i\}}.$$

$$R = \frac{N}{X_0} \geq \frac{N}{\min\left[\frac{1}{\max\ \{D_i\}}, \frac{N}{\sum_{i=1}^{K} D_i}\right]} = \max\left[N \times \max\ \{D_i\}, \sum_{i=1}^{K} D_i\right].$$

Open system latency/throughput



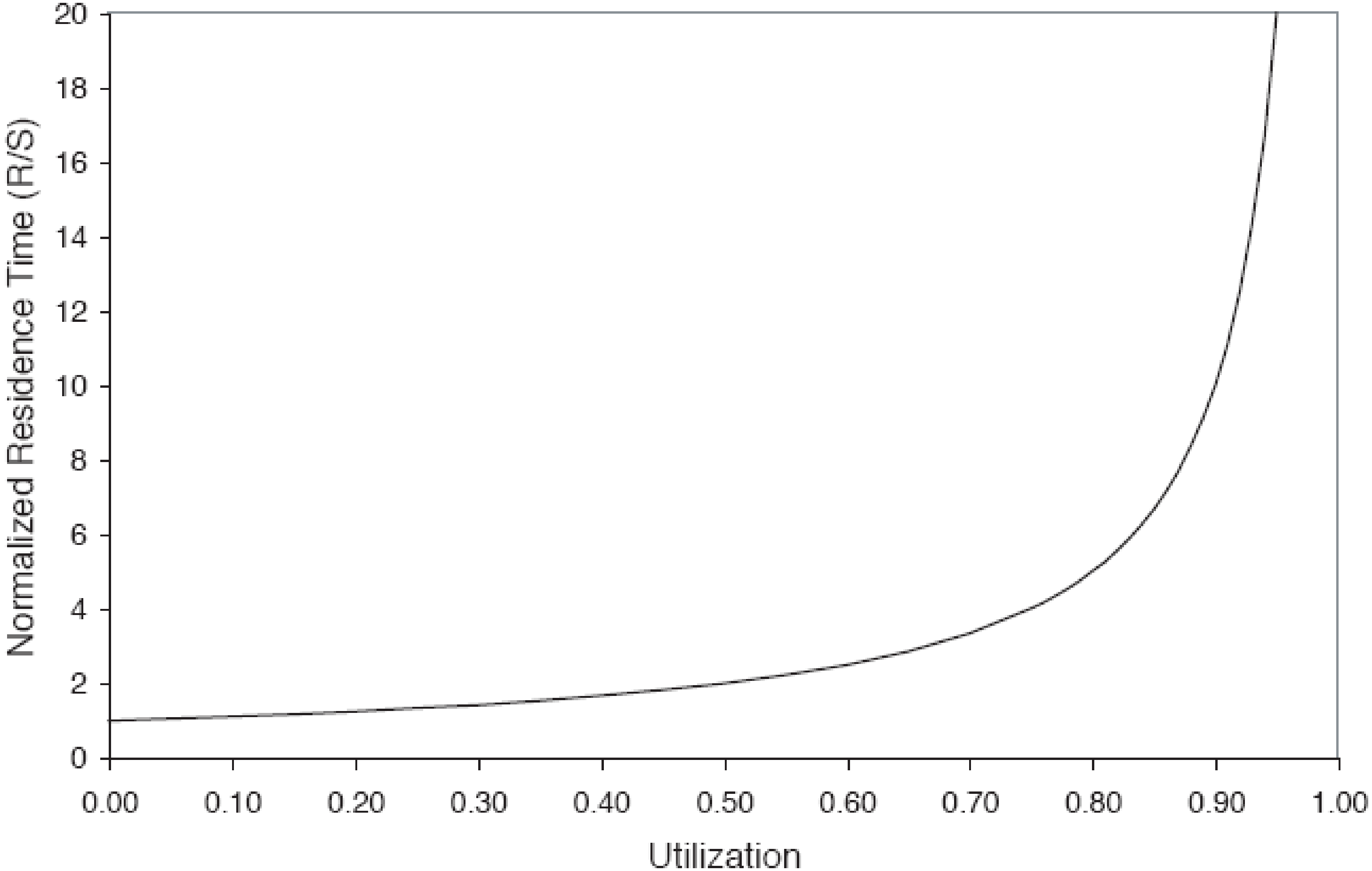
M/M/1

- No longer operational analysis (G/G/*)
  - We need the memoryless property of exp.dist.
  - PASTA: Poisson Arrivals See Time Averages
    - Distribution of the residual time until the next arrival is also exponentially distributed with the same parameter l as the time between consecutive arrivals.
    - Distribution of the residual service time is the same as that of the service time.
- R = QS + S – avg. response time is avg. service time of jobs in the queue + the job being served
  - Arriving job sees Q jobs ahead, no matter how much of the service time remains for the job(s) being served

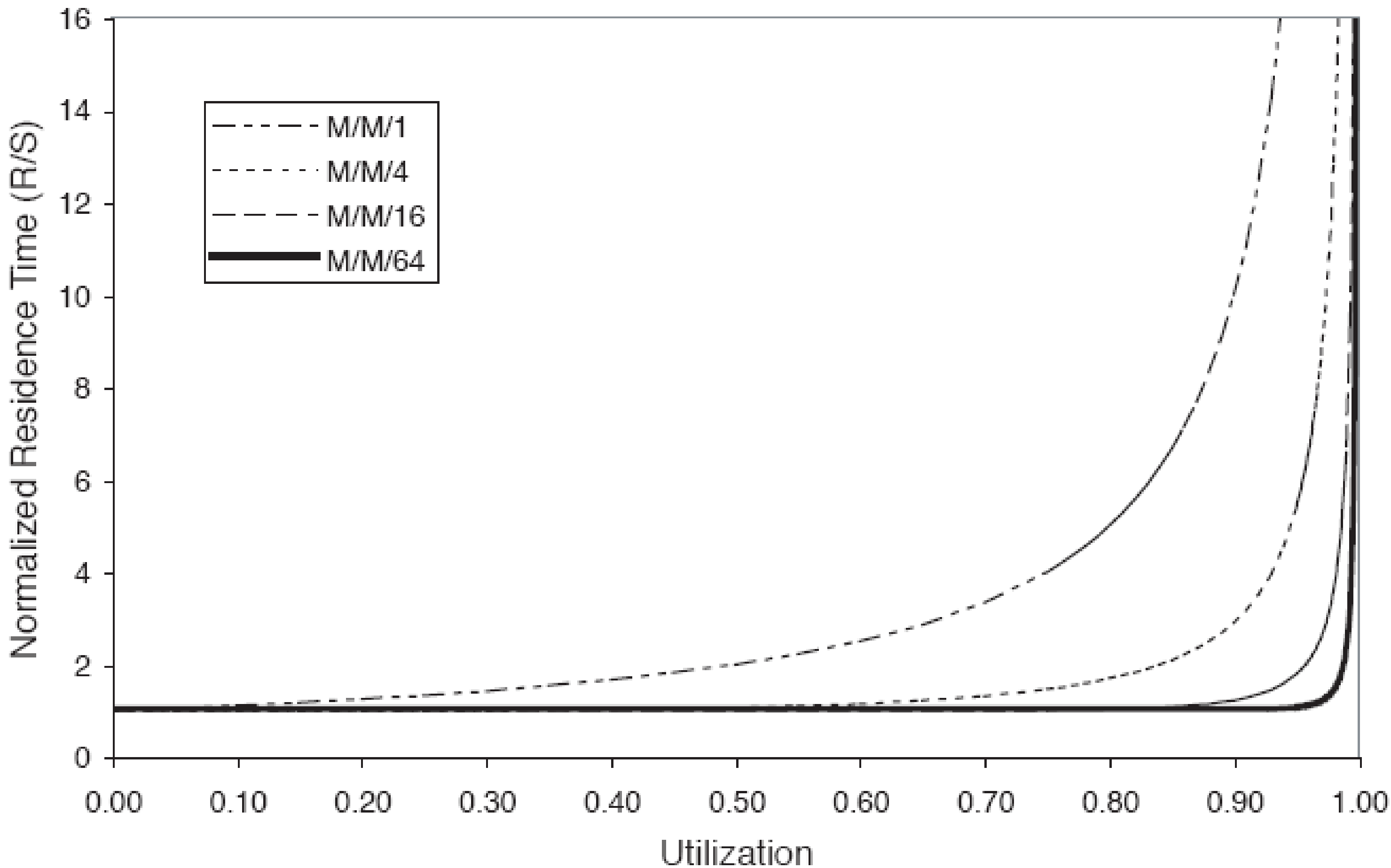
M/M/1

- Using Little’s law on Q
  - $R = (\lambda R)S + S$
  - $> R = S / (1 - \lambda S)$
    - Using Little’s law on λS
      - $> R = S / (1 - U)$
      - Residence time depends on utilization.
- Stretch factor: (on basic service demand)
  - $F = R / S = 1 / (1 - S) = Q / mU$
    - Where Q is Unix load average, m number of CPUs, U percent CPU busy

Open system latency/utilization

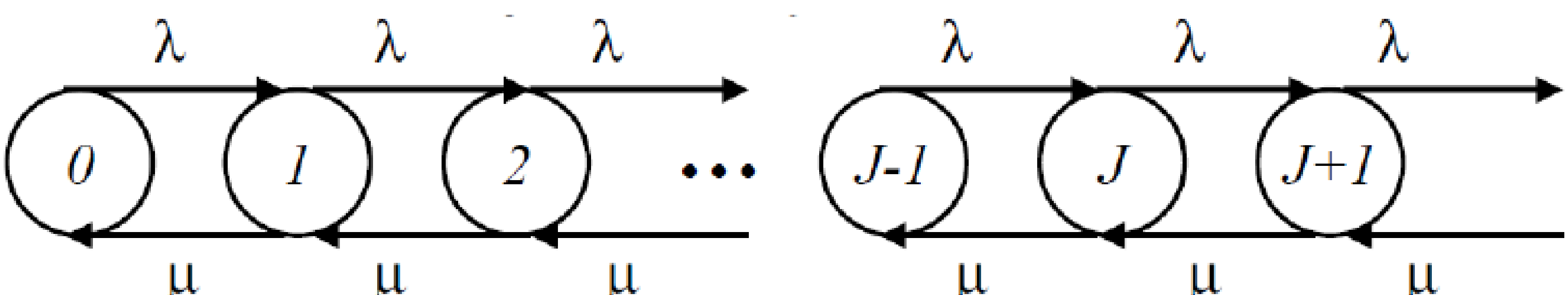


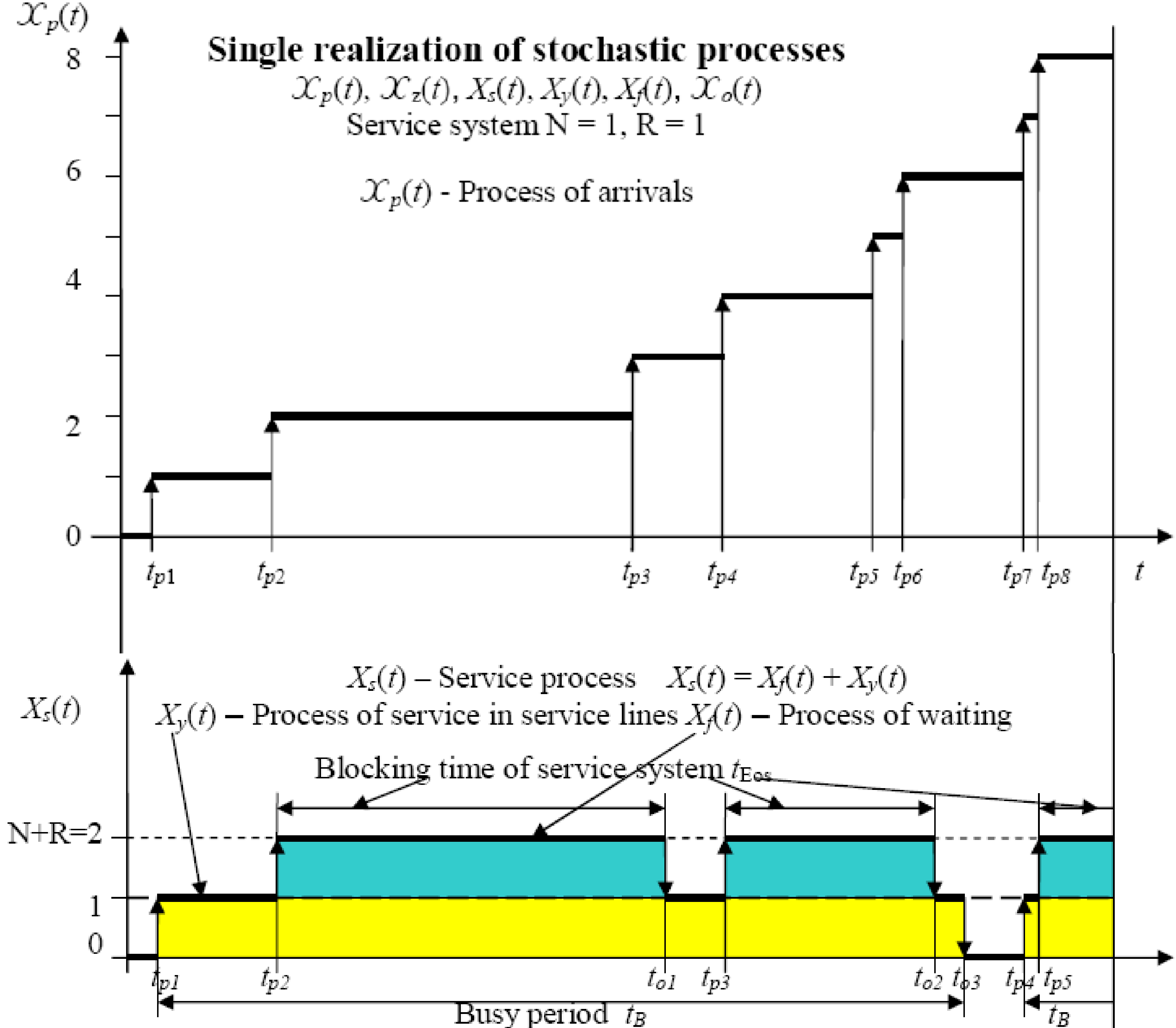
Multiserver latency/utilization



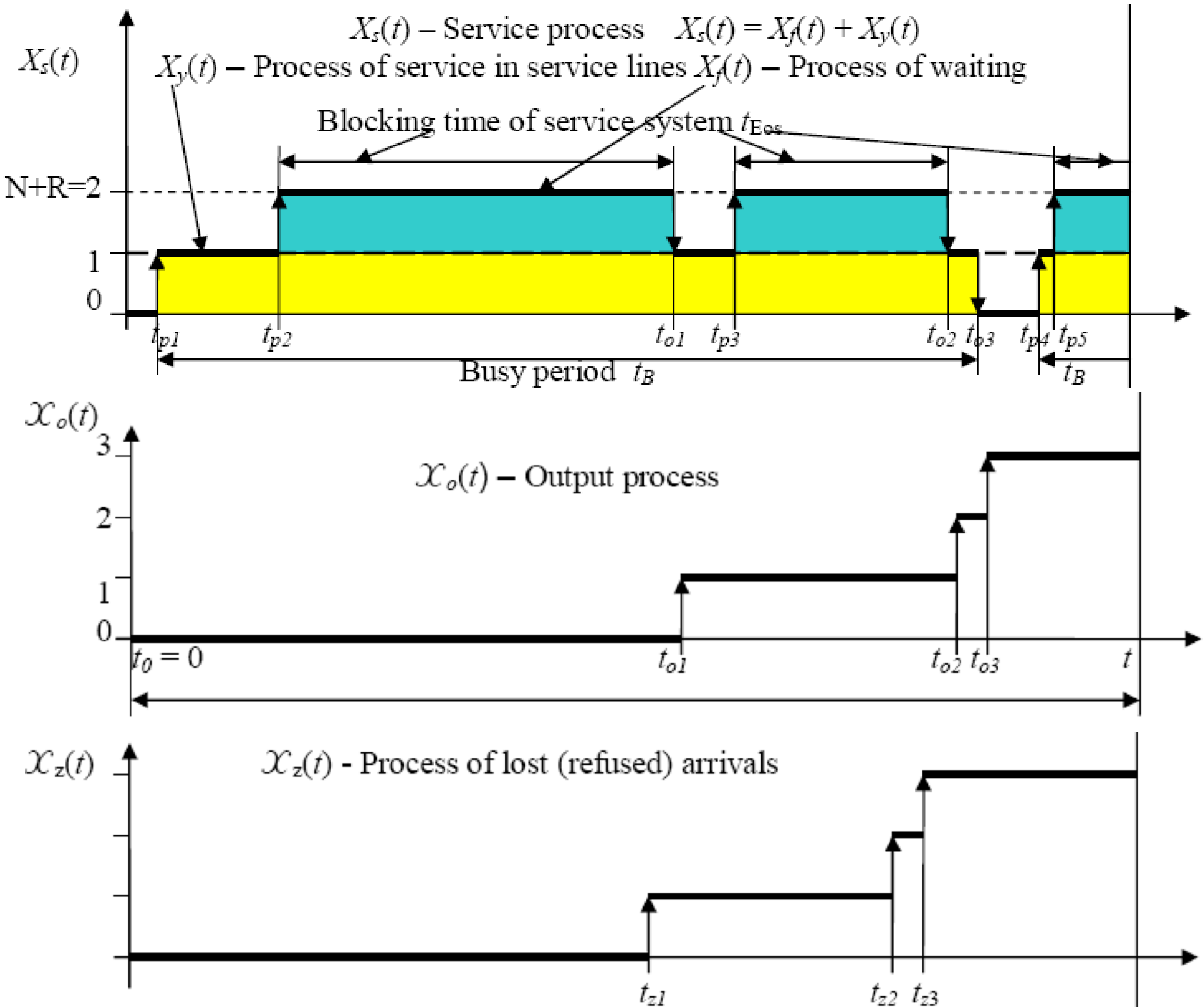
Markov chains

- Why does the queue behave like this?
  - Birth-death Markov process
    - States 0..J+1 (J - queue capacity)
      - Last state blocking
      - Arrival changes state to n+1, departure to n-1
  - Probability of n jobs in the system $p_n=(1-U)U^n$
  - Utilization $U = 1 – p_0$
  - Mean queue length $E[n] = \Sigma_n^J np_n = U / (1-U)$





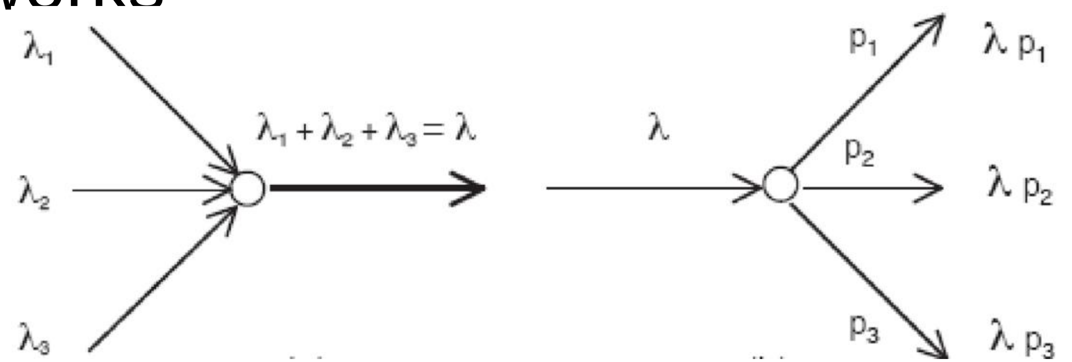
Single realization of stochastic processes
$\mathcal{X}_p(t)$, $\mathcal{X}_z(t)$, $X_s(t)$, $X_y(t)$, $X_f(t)$, $\mathcal{X}_o(t)$
Service system N = 1, R = 1
$\mathcal{X}_p(t)$ - Process of arrivals
$\mathcal{X}_p(t)$
8
6
4
2
0
t_{p1} t_{p2} t_{p3} t_{p4} t_{p5} t_{p6} t_{p7} t_{p8} t
$X_s(t)$ – Service process $X_s(t) = X_f(t) + X_y(t)$
$X_s(t)$
$X_y(t)$ – Process of service in service lines $X_f(t)$ – Process of waiting
Blocking time of service system t_{Eos}
N+R=2
1
0
t_{p1} t_{p2} t_{o1} t_{p3} t_{o2} t_{o3} t_{p4} t_{p5}
Busy period t_B
t_B



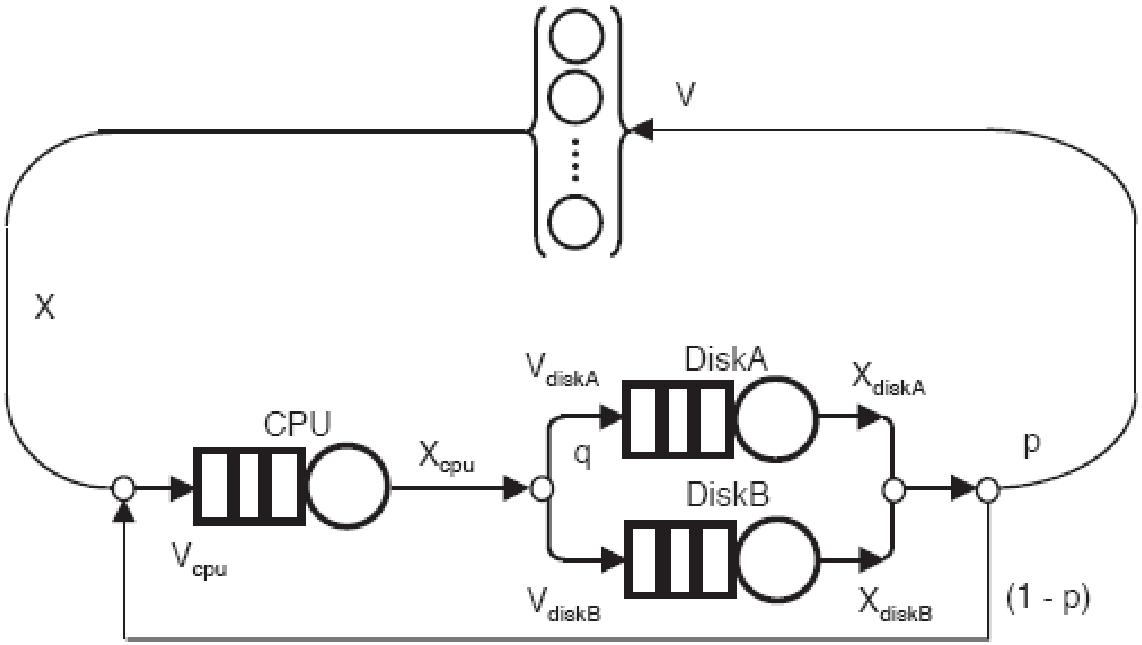
$X_s(t)$ – Service process $X_s(t) = X_f(t) + X_y(t)$
$X_s(t)$
$X_y(t)$ – Process of service in service lines $X_f(t)$ – Process of waiting
Blocking time of service system t_{Eos}
N+R=2
1
0
t_{p1}
t_{p2}
t_{o1}
t_{p3}
t_{o2}
t_{o3}
t_{p4}
t_{p5}
Busy period t_B
t_B
$\mathcal{X}_o(t)$
3
2
1
0
$\mathcal{X}_o(t)$ – Output process
$t_0 = 0$
t_{o1}
t_{o2}
t_{o3}
t
$\mathcal{X}_z(t)$
$\mathcal{X}_z(t)$ - Process of lost (refused) arrivals
t_{z1}
t_{z2}
t_{z3}

PASTA and splitting

- The memoryless property allows splitting and joining of request flows
  - Each flow is a series of totally random events
  - Splits defined by probabilities
    - Jackson's theorem translates to visit rates
  - Allows construction of product-form queueing networks



Queueing networks



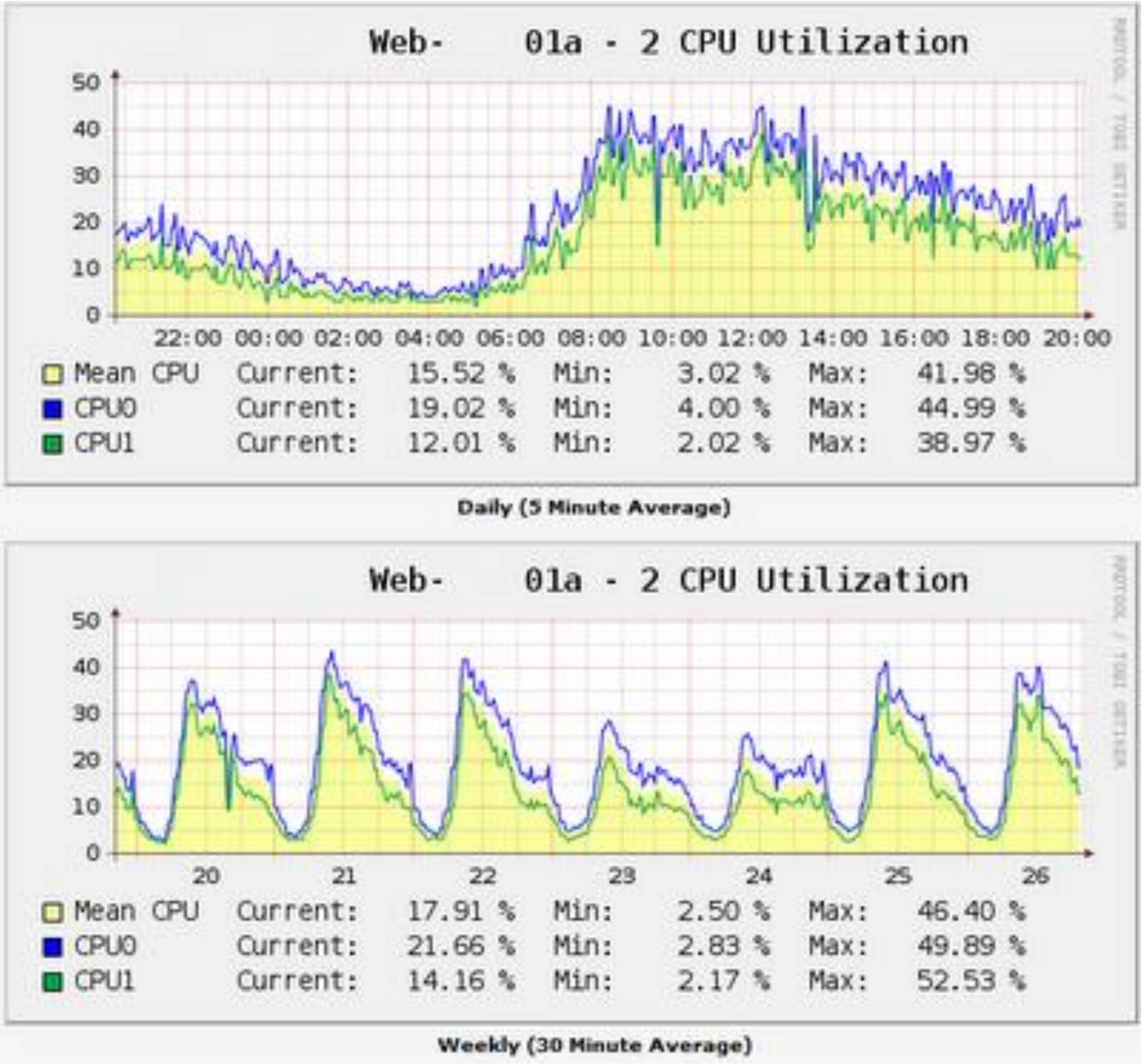
Mean Value Analysis

- Basis of QN solving tools
- $R_i(N) = S_i[1 + Q_i(N-1)]$
- Qi(n) – average number in queue I with N total jobs
- Nth job upon arrival sees the system with N-1 jobs
  - > Iterative algorithm
  - Starts with Qi(0)=0, n=1 until n=N

Practical possibilities

- Profiling from server logs
  - Also called Performance Monitoring
  - Shows server load in the past (CPU, RAM, network, number of processes, ..)
  - Shows its periodicity, can do trend predictions
  - Useful for existing applications to be migrated to the cloud
  - or as an estimate when done on a similar application

A CPU utilization graph



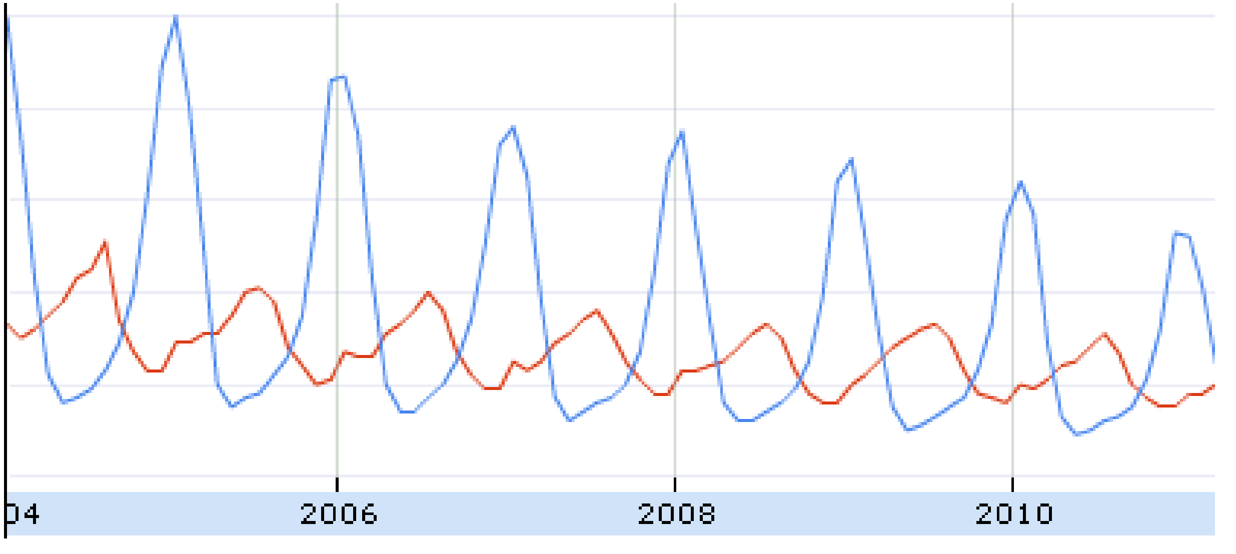
Web server statistics

- Apache has mod_status
  - Reports concurrency and throughput
  - Combined with CPU utilization
    - Allows to compute service demand, i.e. LATENCY
    - And to estimate maximum throughput
      - (service demand should be constant unless overloaded)

Tools

- Estimation of load profile from search engine statistics
  - Useful when marketing estimates the number of users and you need to know when they'll be accessing the site
  - It will give you the time profile, but not the actual amount of load
  - Available from search engine term statistics or some click counter providers

A graph from Google Insights



Load testing

- Good if you already have the application
  - Or a prototype, or something similar to test
- Will give you the answer to:
  - How much CPU/RAM does an app this complex written in this language need?
  - How many requests per second does it give on this particular server?
- Will give you the possibility to optimize the server
- You'll need to know the app's usage scenarios
  - To construct a good testing script/walk through the site
  - To be able to translate numbers of users to requests/s

Load testing tools

- httperf – made by HP, quite old
  - Simulates an open system
    - You give number of requests/s and a script
    - Returns number of failures and timeouts
      - When low enough, the system can sustain the offered load
      - Timeout needs to be set reasonably
        - » max 8s for whole page load is recommended
  - Used by ramping up load until failure
- siege
  - Simulates a closed system
    - You give number of users and think time (+ script)
    - Returns measured response times
      - If below threshold (see above), system can sustain the load

Load testing tools

- JMeter
  - closed system (I think)
  - Strong side: proxy to capture scenarios
  - Weak side: written in Java :-E
    - better than using scenarios is to test indiv. request types and construct a multiflow QN
- Tsung
  - my favorite
  - closed system, but can be convinced to do open
  - written in Erlang - very accurate
  - also has a proxy
  - automatic ramp-up scripts possible
  - integrated graphical reporting with GnuPlot

Queueing network tools

- JMT (Java Modelling Tools)
  - Can do several models, graphical, parametric or script input
  - Logfile extraction, Markov Chain simulation, and Asymptotics
  - Best for quick analyses, manual usage
- PDQ (Pretty Damn Quick)
  - Core is in C
  - Is a library with binding for several languages
  - Only script input
  - Best for integration in your programs

Conclusion – What to use

- Small company – Webhosting or VM rent
- Medium – Colocation + virtualization
- Medium with good conditions – Own servers + virtualization
- Large – private or hybrid IaaS
- Web App. Startup – PaaS and have an escape plan, or public IaaS
- Batch processing – public IaaS

Literature

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