The queueing Package

Queueing Networks analysis with GNU Octave

Moreno Marzolla
marzolla@cs.unibo.it
http://www.moreno.marzolla.name/

Università di Bologna

december 4, 2012

Outline

What is queueing?

queueing is a software package for Queueing Network and Markov chain analysis.written in GNU Octave, an interpreted language for numerical computations

- queueing implements the most important numerical algorithms for QN analysis
  - Mean Value Analysis (MVA) for single and multiclass networks; convolution algorithm; performance bounds computation; ...
- queueing provides numerical algorithms for Markov chain analysis
  - Steady-state and transient state occupancy probabilities; mean time to absorption; mean residence times; time-averaged sojourn times; ...
- Free software (GPLv3+)

`http://www.moreno.marzolla.name/software/queueing/`

Installation

- Install from Octave-Forge

  ```
  octave> pkg install -local -forge queueing
  ```

  - If it doesn't work, get the tarball from `http://octave.sourceforge.net/queueing/` and install it

    ```
    octave> pkg install -local queueing-1.2.0.tar.gz
    ```

    - If it still doesn't work, get the tarball from the URL above

      ```
      tar xfz queueing-1.2.0.tar.gz
      octave -p queueing/inst/
      ```

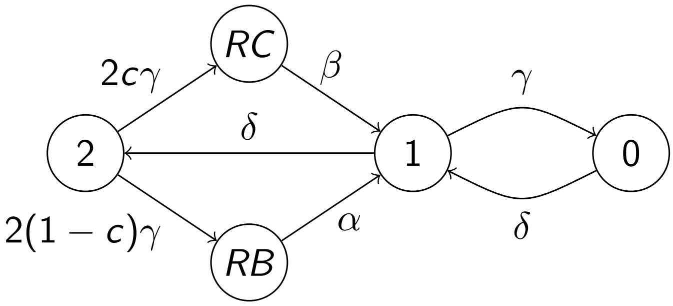
- Load the package at the Octave prompt

  ```
  octave> pkg load queueing
  ```

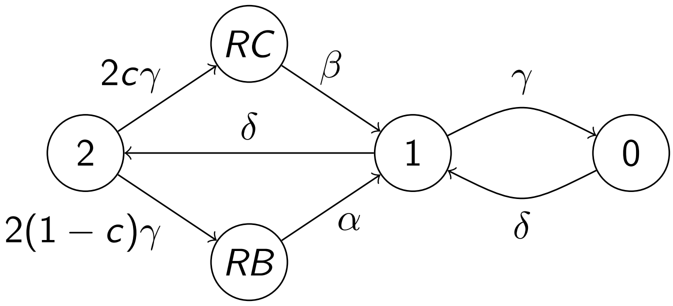
- Check if everything works

  ```
  octave> test qncsmva
  PASSES 9 out of 9 tests
  ```

Reliability Analysis of Multiprocessor Systems



There are $N = 2$ processors with individual Mean Time To Failure (MTTF) $1/\gamma$. States $n \in \{0, 1, 2\}$ denote that there are n working processors. If one processor fails, it can be recovered (state RC) with probability c; recovery takes time $1/\beta$. When the system can not be recovered, a reboot is required (state RB), which brings down the entire system for time $1/\alpha > 1/\beta$. The mean time to repair a failed processor is $1/\delta$.




```
a = 1/(10*60);     # 1/a = duration of reboot (10 min)
b = 1/30;          # 1/b = reconfiguration time (30 sec)
g = 1/(5000*3600); # 1/g = processor MTTF (5000 h)
d = 1/(4*3600);    # 1/d = processor MTTR (4 h)
c = 0.9;           # recovery probability
# state space enumeration {2, RC, RB, 1, 0}
Q = [ -2*g 2*c*g 2*(1-c)*g      0  0; \
         0    -b         0      b  0; \
         0     0        -a      a  0; \
         d     0         0 -(g+d)  g; \
         0     0         0      d -d ];
```

Reliability Analysis of Multiprocessor Systems

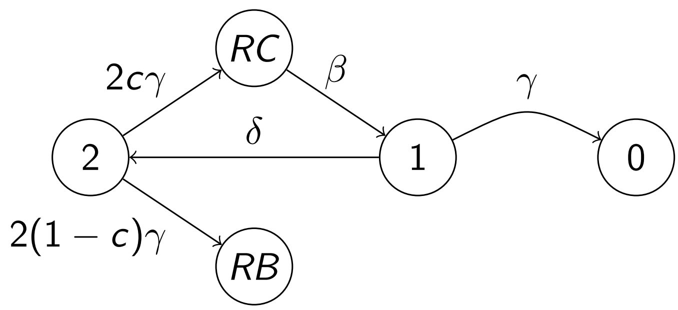
```
p = ctmc(Q)
=> 9.9839e-01   2.9952e-06   6.6559e-06
   1.5974e-03   1.2779e-06
# state space enumeration {2, RC, RB, 1, 0}
p(2)*60*24*365 # minutes/year spent in RC
=> 1.5743
p(3)*60*24*365 # minutes/year spent in RB
=> 3.4984
p(5)*60*24*365 # minutes/year spent in 0
=> 0.67169
```


Reliability Analysis of Multiprocessor Systems

Mean Time Between Failures (MTBF)

The MTBF is the mean duration of continuous operation. The system starts in state 2; state *RC* is considered operational.

If we make states 0 and *RB* absorbing by removing all their outgoing transitions, the MTBF is the mean time to absorption of the new chain.




```
# state space enumeration {2, RC, RB, 1, 0}
Q(3,:) = Q(5,:) = 0; # make states {0, RB} absorbing
p0 = [1 0 0 0 0];    # initial state occupancy prob.
MTBF = ctmcmtta(Q, p0)/60/60/24/365 # MTBF (years)
=> 2.8376
```

Example

Single Station Queueing Systems

Let us consider a $M/M/1$ system

- Arrival rate $\lambda = 0.3$ jobs/second
- Service rate $\mu = 0.4$ jobs/sec

We can compute the utilization U, response time R, average number of requests in the system Q and throughput X as follows:

```
lambda = 0.3;
mu = 0.4;
[U R Q X] = qsmm1(lambda, mu)
=> U =  0.75000
   R = 10.0000
   Q =  3.0000
   X =  0.30000
```


Example

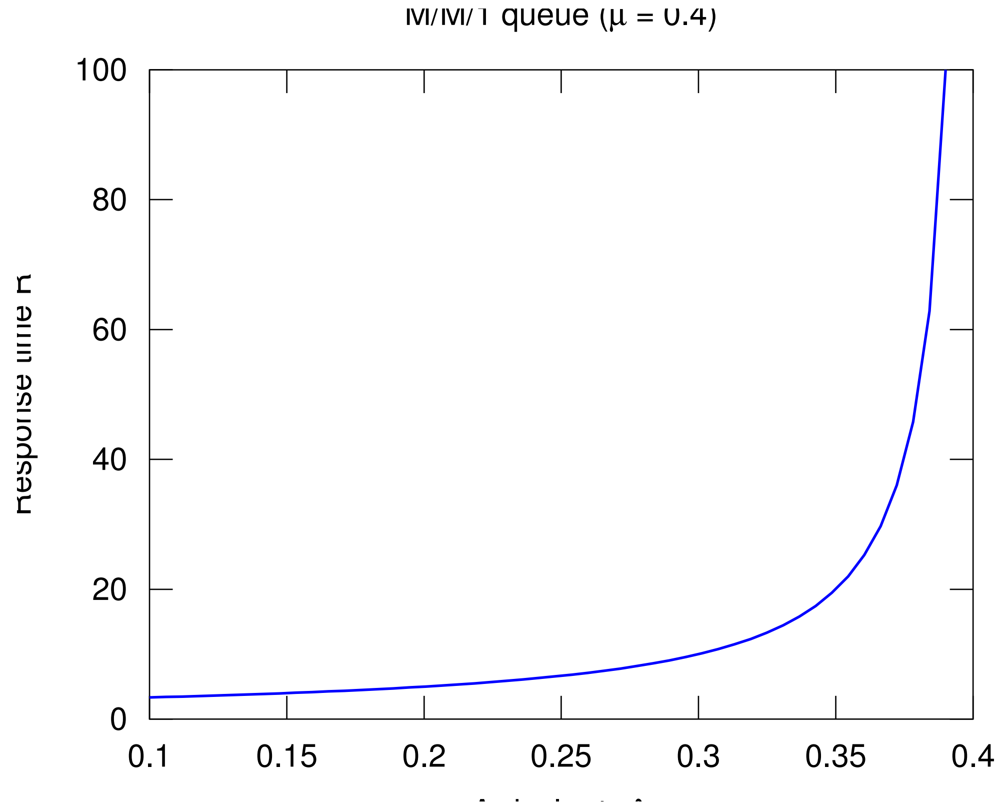
Single Station Queueing Systems

We can examine how the response time R grows as the arrival rate λ approaches the service rate $\mu = 0.4$

```
mu = 0.4;
lambda = linspace(0.1,0.39,50);
R = zeros(size(lambda));
for i=1:length(lambda)
  [nc R(i)]=qsmm1(lambda(i),mu);
endfor
plot(lambda,R);
```

Example

Single Station Queueing Systems



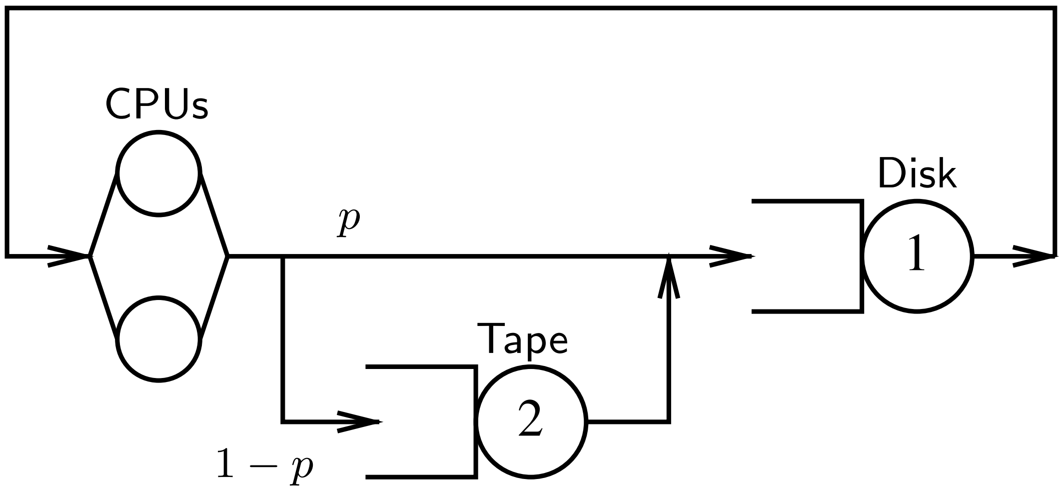
Compute Farm

Simple closed model of a scientific computing cluster

- N independent jobs process data stored in a tape library.
- A disk-based cache is used to limit the access of the (slow) tape library.
- A job reads the data it needs from disk; a cache miss happens with probability $1 - p$ and requires the data to be copied from tape to disk before the job is allowed to proceed.

Compute Farm

Closed QN Model



Compute Farm

Model Parameters

Mean CPU burst $Z = 1000s$, mean tape service time $S_2 = 200s$.

For the same amount of money we can buy:

- fast disks (costly, less disk space, lower cache hit ratio), or
- slow disks (cheap, more disk space, higher cache hit ratio).

Case A: Slow disks

- Disk service time $S_1 = 1s$
- Cache hit ratio $p = 0.9$

Case B: Fast disks

- Disk service time $S_1 = 0.9s$
- Cache hit ratio $p = 0.8$

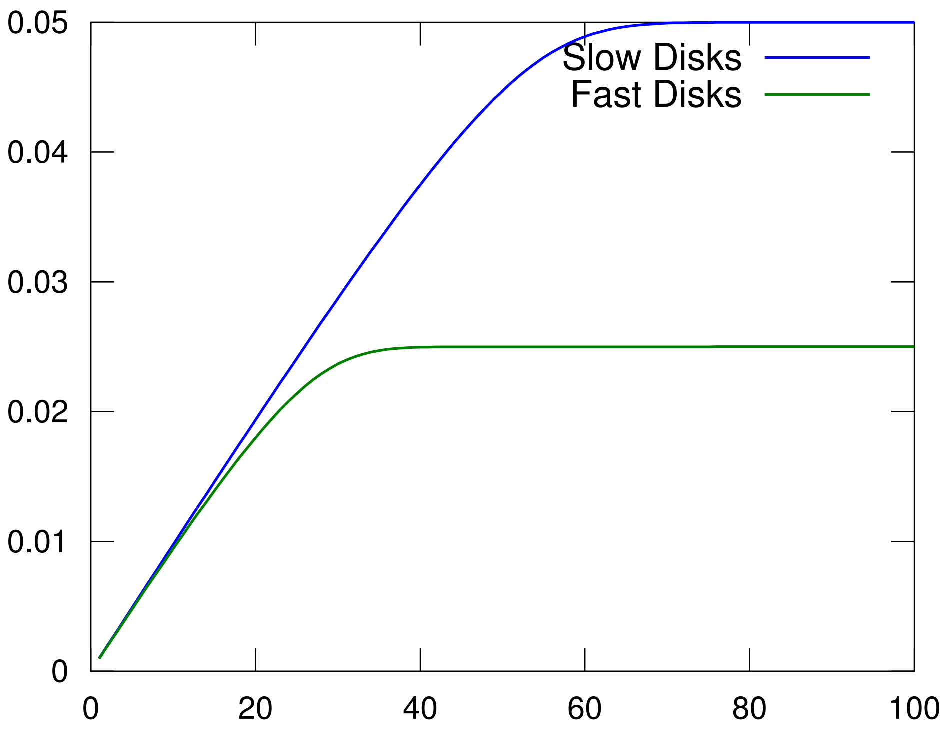
Compute Farm

Octave code

```
#### Case A: slow disks ####
SA = [1   200]; pA = .9; PA = [pA 1-pA; 1 0 ];
VA = qnvisits(PA);
#### Case B: fast disks ####
SB = [0.9 200]; pB = .8; PB = [pB 1-pB; 1 0 ];
VB = qnvisits(PB);
#### Compute performance ####
Z = 1000;    # CPU burst length
NN = 1:100;  # number of concurrent jobs
XA = XB = zeros(size(NN));
for n=NN
  [U R Q X] = qncsmva(n, SA, qnvisits(PA), 1, Z);
  XA(n) = X(1)/VA(1);
  [U R Q X] = qncsmva(n, SB, qnvisits(PB), 1, Z);
  XB(n) = X(1)/VB(1);
endfor
```

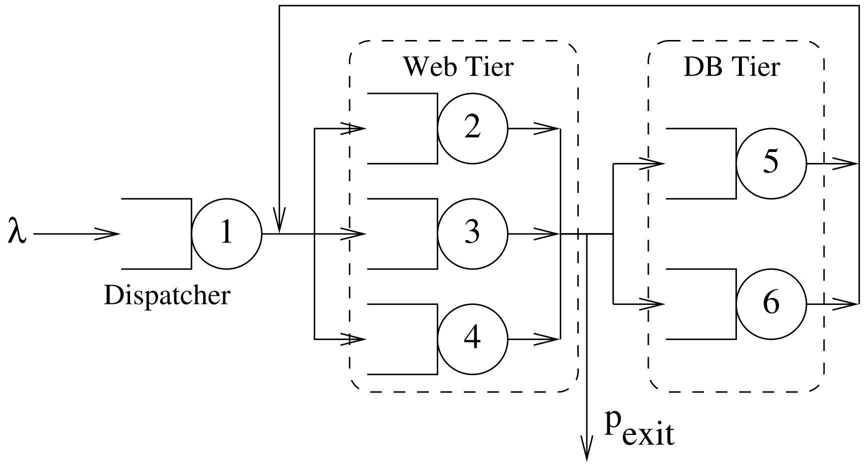

Compute Farm

Results



E-Commerce site

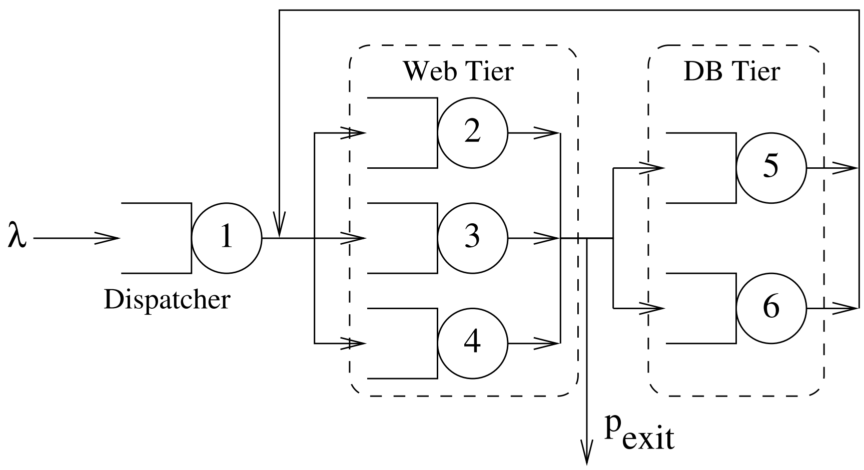
Open Queueing Network Model



- Dispatcher (center 1, service time $S_1 = 0.5$);
- Web Servers (centers 2–4, service time $S_2 = S_3 = S_4 = 0.8$);
- Database Servers (centers 5–6, service time $S_5 = S_6 = 1.8$);
- External Arrival at center 1 with rate $\lambda = 0.9 jobs/s$
- Uniform routing of requests, $p_{\mathrm{exit}} = 0.5$

E-Commerce site

Routing matrix



Routing Matrix

$$P = \begin{pmatrix} 0 & 1/3 & 1/3 & 1/3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/4 & 1/4 \\ 0 & 0 & 0 & 0 & 1/4 & 1/4 \\ 0 & 0 & 0 & 0 & 1/4 & 1/4 \\ 0 & 1/3 & 1/3 & 1/3 & 0 & 0 \\ 0 & 1/3 & 1/3 & 1/3 & 0 & 0 \end{pmatrix}$$

E-commerce example

Model Definition

```
ws = 2:4; db = 5:6; p_exit = 0.5;
K = 1 + length(ws) + length(db); ## n. of service centers
S = lambda = zeros(1,K);  P = zeros(K,K);
S(1) = 0.5;       ## Service time at the dispatcher
S(ws) = 0.8;      ## Service time at the Web Servers
S(db) = 1.8;      ## Service time at the DB servers
lambda(1) = 0.9; ## Arrival rate
P(1,ws) = 1/length(ws);
P(ws,db) = (1-p_exit)/length(db);
P(db,ws) = 1/length(ws);
V = qnvisits(P,lambda);
[U R Q X] = qnos(sum(lambda),S,V)
printf("System Throughput..... %f\n", X(1) / V(1));
printf("System Response Time.. %f\n", dot(R,V));
```


E-commerce example

Results

```
U =
   0.45000   0.48000   0.48000   0.48000   0.81000   0.81000

R =
   0.90909   1.53846   1.53846   1.53846   9.47368   9.47368

Q =
   0.81818   0.92308   0.92308   0.92308   4.26316   4.26316

X =
   0.90000   0.60000   0.60000   0.60000   0.45000   0.45000

System Throughput..... 0.900000
System Response Time.. 13.459698
```

Conclusions

Queueing networks are simple yet powerful tools for performance modeling and capacity planning. Useful insights can be obtained with very little effort.

Suggested reading:

Edward D. Lazowska, John Zahorjan, G. Scott Graham, and Kenneth C. Sevcik, *Quantitative System Performance: Computer System Analysis Using Queueing Network Models*, Prentice Hall, 1984. Online at:
`http://homes.cs.washington.edu/~lazowska/qsp/`

`http://www.moreno.marzolla.name/software/queueing/`