COMP9334
Capacity Planning for Computer Systems and Networks

Week 9: Web services and fork-join queues

What you have studied so far …

- Performance analysis
  - Aim: Find mean response time, throughput etc.
- Techniques
  - Markov Chain
  - Single- or multi-server queues
    - Open model - M/M/1, M/G/1, G/G/1
    - Open model - M/M/m
  - A network of queues
    - Mean value analysis
  - Discrete event simulation

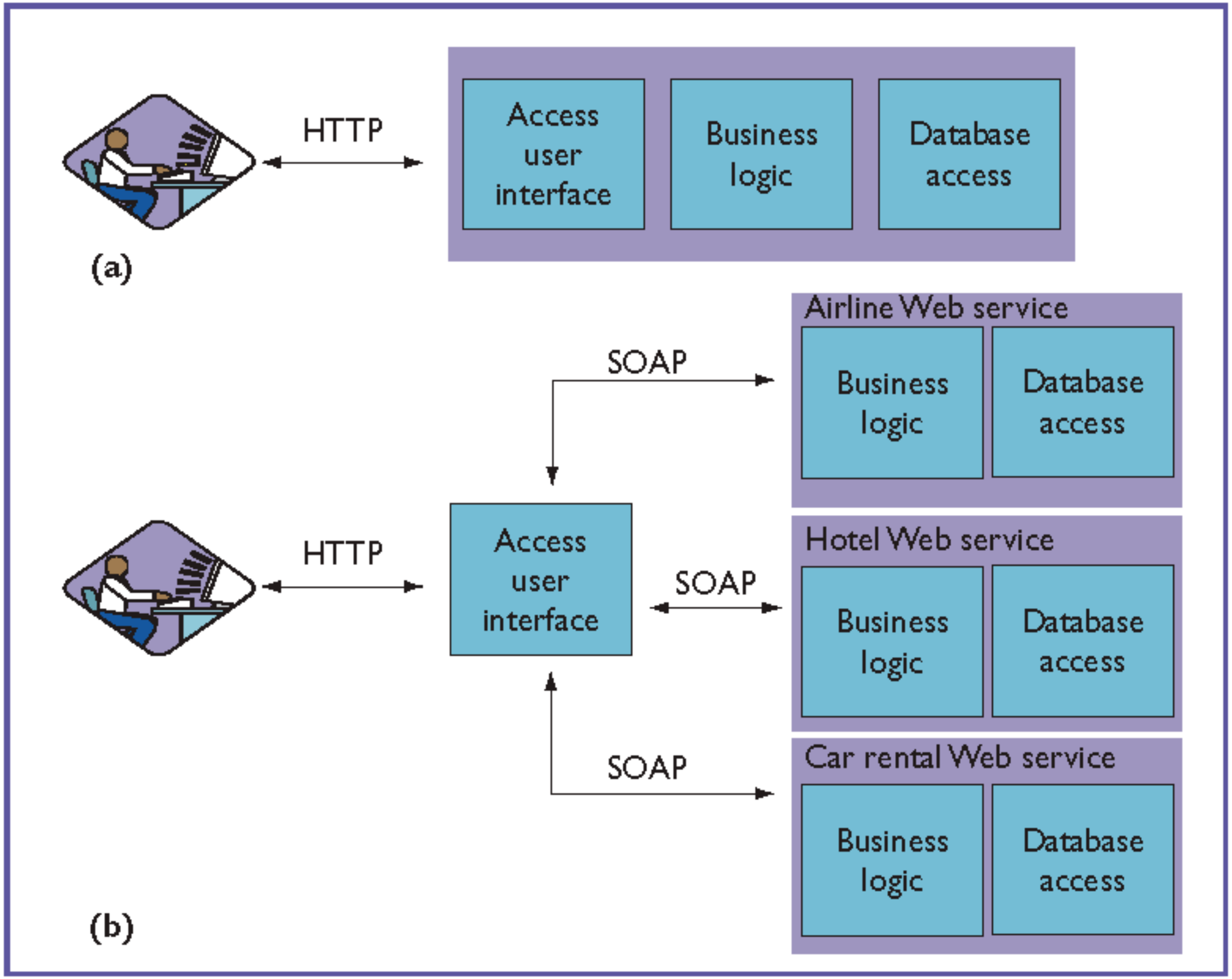
This lecture

- Web services
    - What is it?
    - Performance analysis
- Fork-join queue
    - Markov chain
    - MVA

Web access versus Web services

(a) Web access

(b) Composite web service for travel



Web service performance issues

- Metrics
  - Response time
  - Throughput
  - Availability
- Performance analysis method
  - Operational analysis
  - Markov chain

Web service flow graph

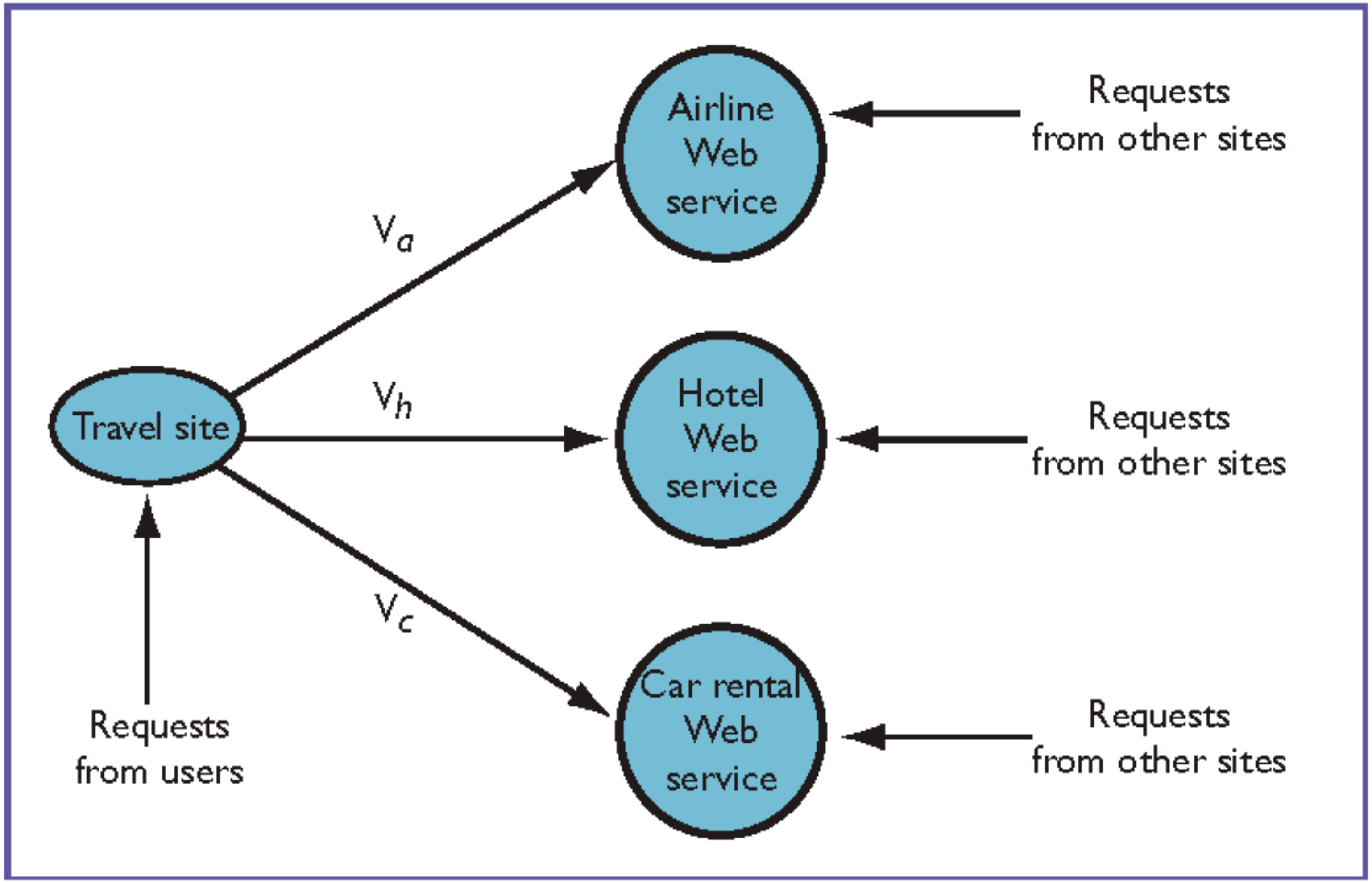
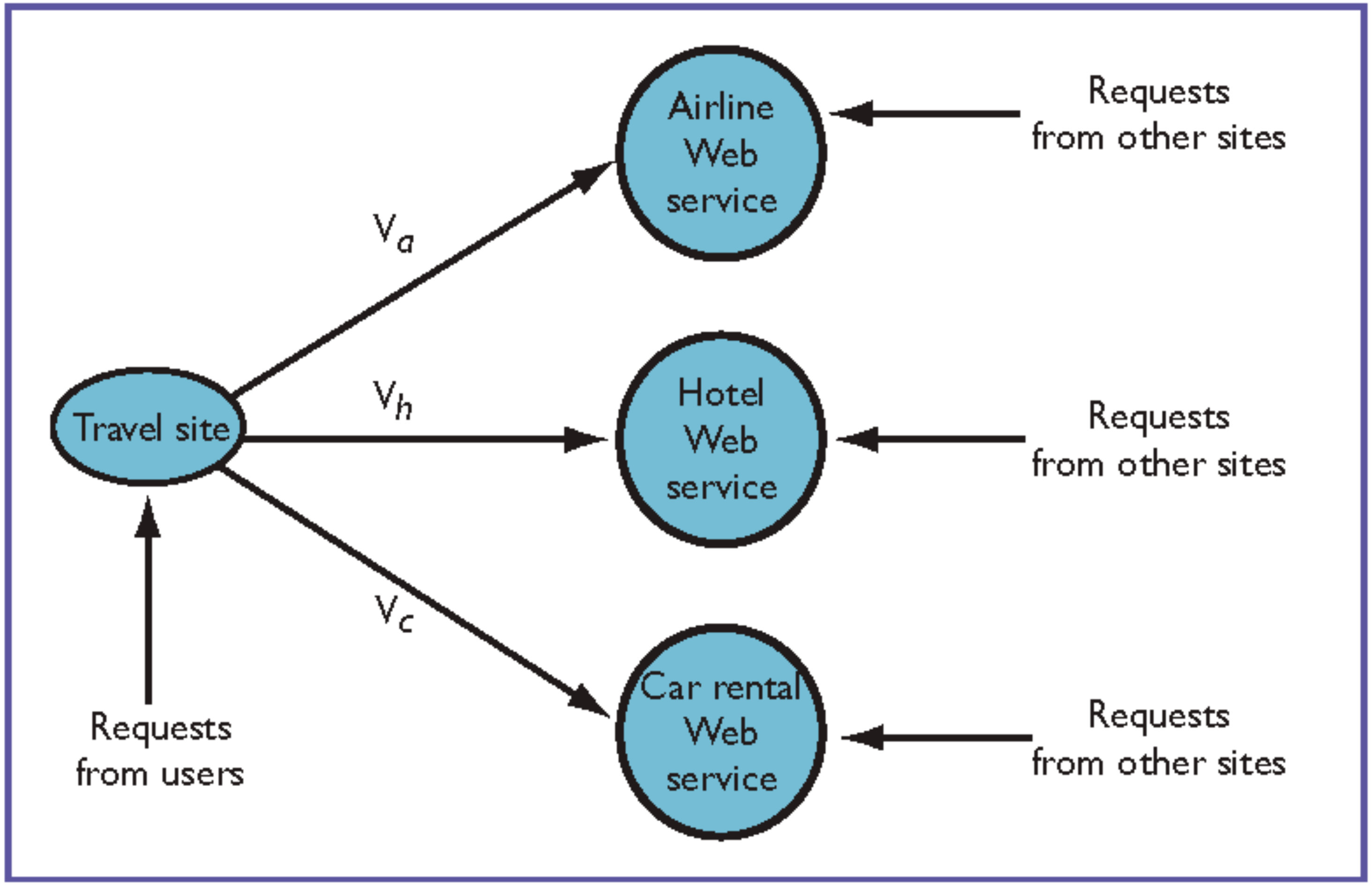


Figure 2. Web service flow graph. Arrows link the travel site to other Web services. The labels on the links indicate the average number of times a Web service is invoked per request to the travel site.

Va,Vh,Vc: Relative Visit Ratio

Every request to the travel site generates on average Va requests to the Airline web service etc.



$$X_{TA} = \text{Throughput of travel site}$$

$$X_a = \text{Throughput of airline Web service}$$

$$X_a \geq V_a \times X_{TA}$$

Similarly,

$$X_a \geq V_a \times X_{TA}$$

$$X_h \geq V_h \times X_{TA}$$

$$X_c \geq V_c \times X_{TA}$$

Xh = Throughput of hotel web service
Xc = Throughput of car rental web service

- Can you find an upper bound on the throughput of the travel site

$$X_{TA} \leq \min\{\frac{X_a}{V_a}, \frac{X_h}{V_h}, \frac{X_c}{V_c}\}$$

Example:

Xa = 20 requests/s
Xh = 15 requests/s
Xc = 10 requests/s
Va = 4, Vh = 2, Vc = 1

$$X_{TA} \leq \min\{\frac{20}{4}, \frac{15}{2}, \frac{10}{1}\} = 5 \text{ requests/s}$$

The airline web service is the bottleneck of the travel web site.

More complex web service graphs

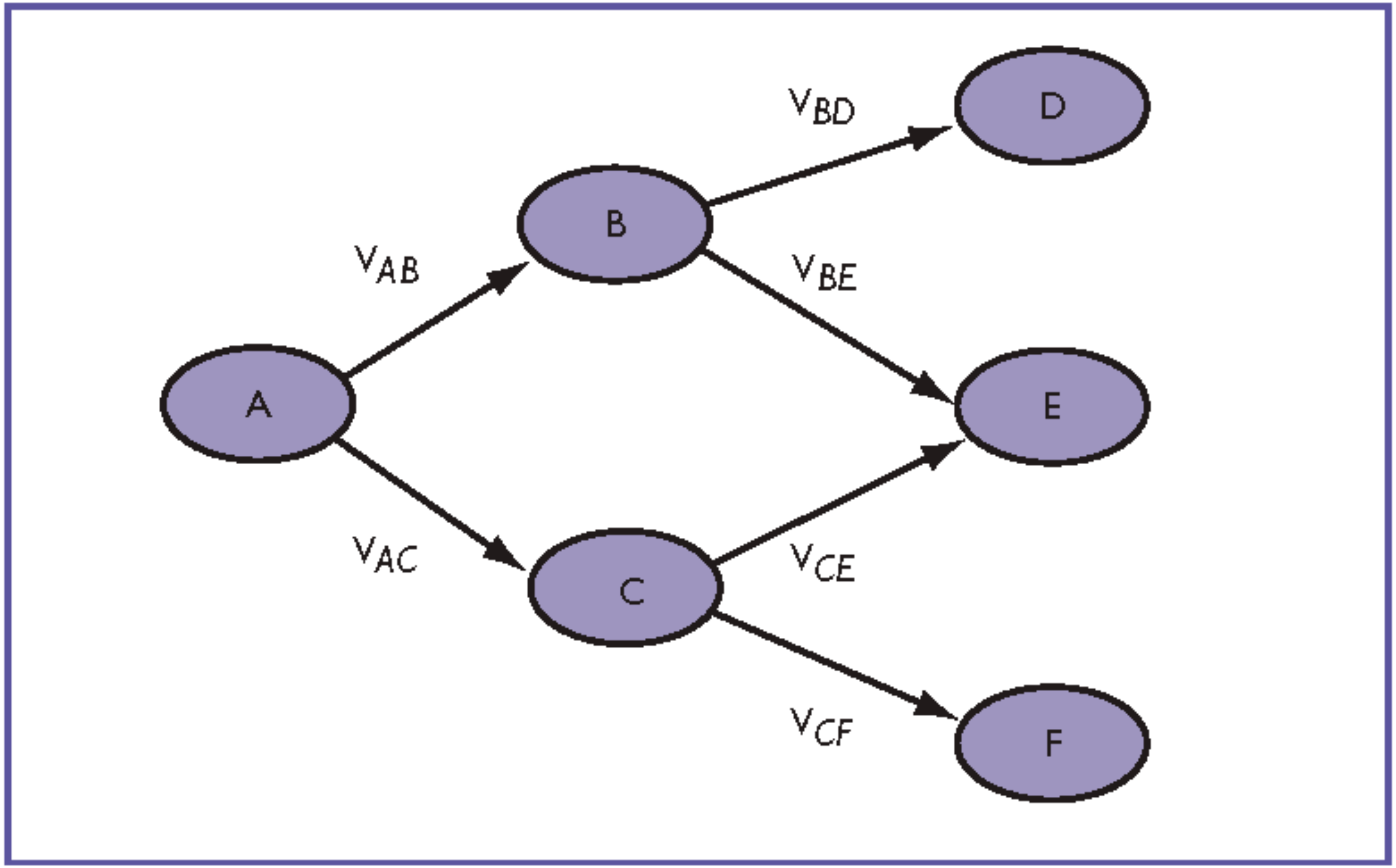


Figure 3. A more complex Web services flow graph. Web service A uses Web services B and C; B uses D and E; and C uses E and F.

What is the bound on throughput of web service A?

Bound on the throughput of web service A is:

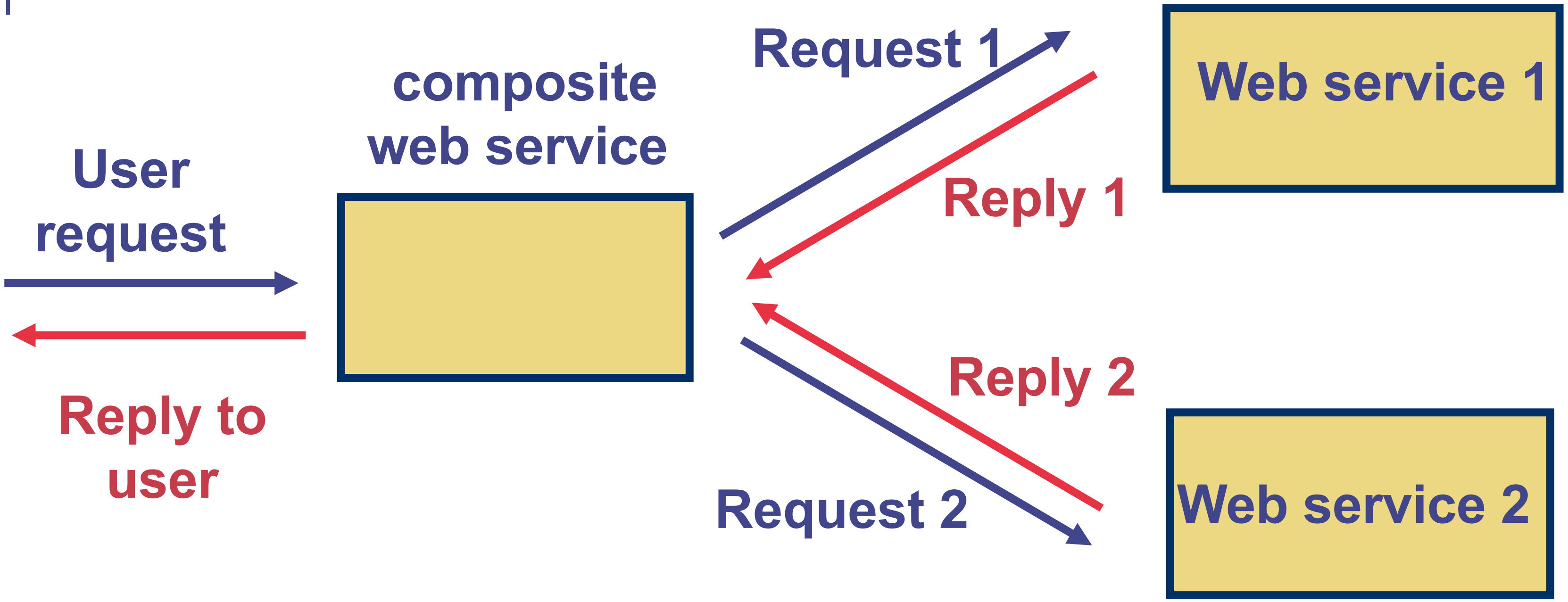
$$X_A \leq \min \left\{ \frac{X_B}{V_{AB}}, \frac{X_C}{V_{AC}}, \frac{X_D}{V_{AB}V_{BD}}, \frac{X_F}{V_{AC}V_{CF}}, \frac{X_E}{V_{AB}V_{BE} + V_{AC}V_{CE}} \right\}$$

Response time analysis

- The bottleneck analysis only gives an upper bound on the throughput
- Can we find the response time?
  - Markov chain
  - Approximate MVA

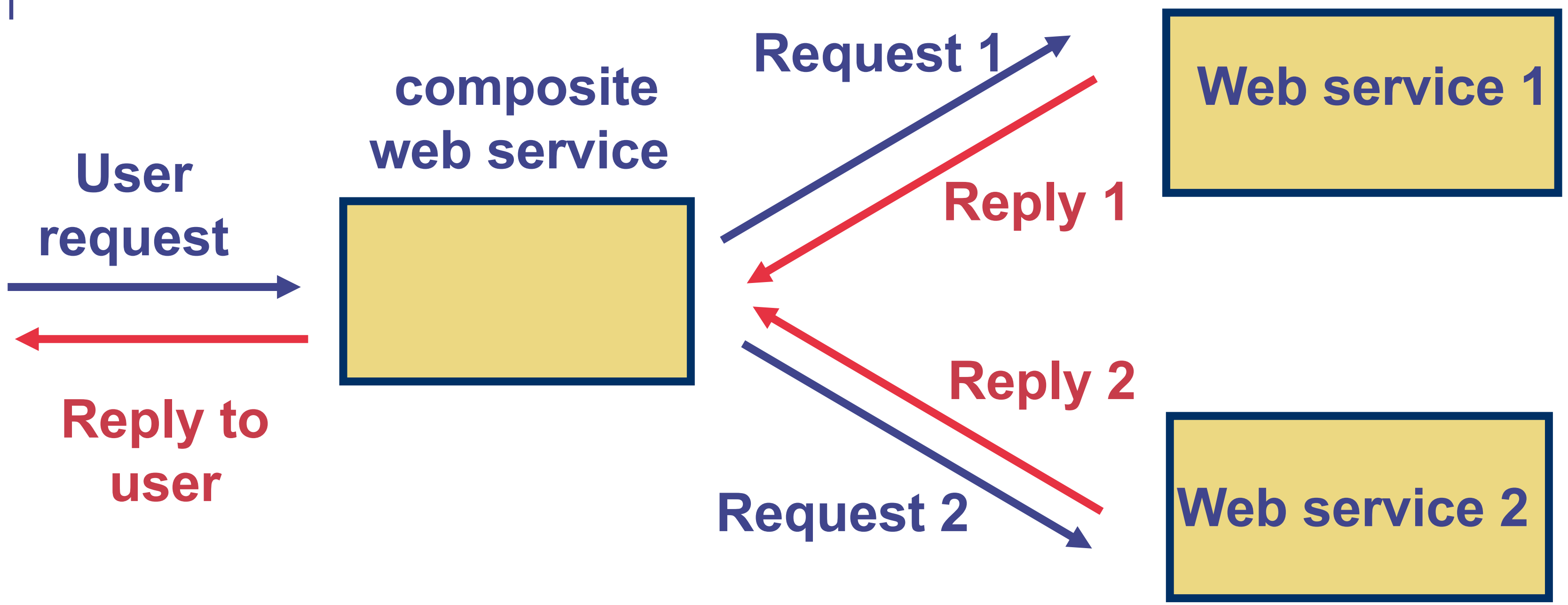
- We begin with a motivating example

A simple web service scenario (1)



- A composite web service uses two web services
- Sequence of events
  1. Composite web service receives a user request
  2. Composite web service sends Request 1 and Request 2
  3. The web services reply *independently*
     - *That is, Reply 1 and Reply 2 may arrive at different times*
  4. After the composite web service receives *both* replies, it responds to the user

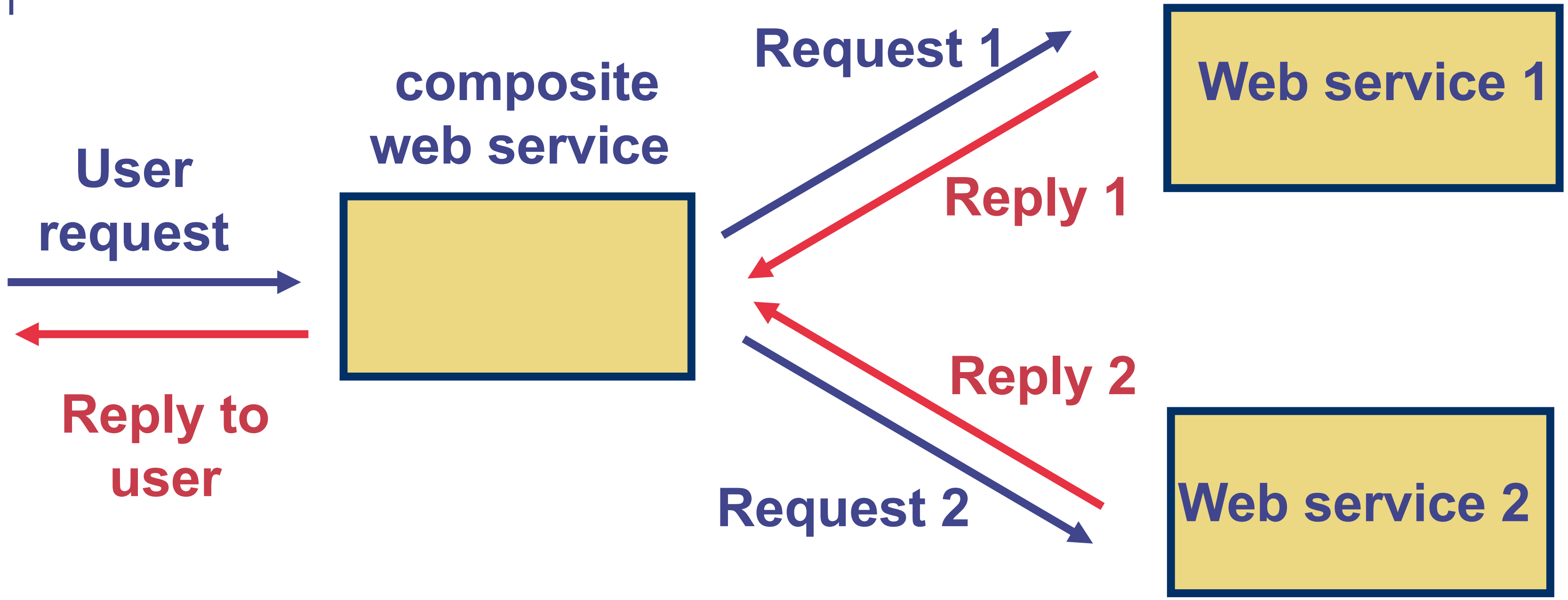
A simple web service scenario (2)



- Recall the definition of response time
- Response time of Web Service 1

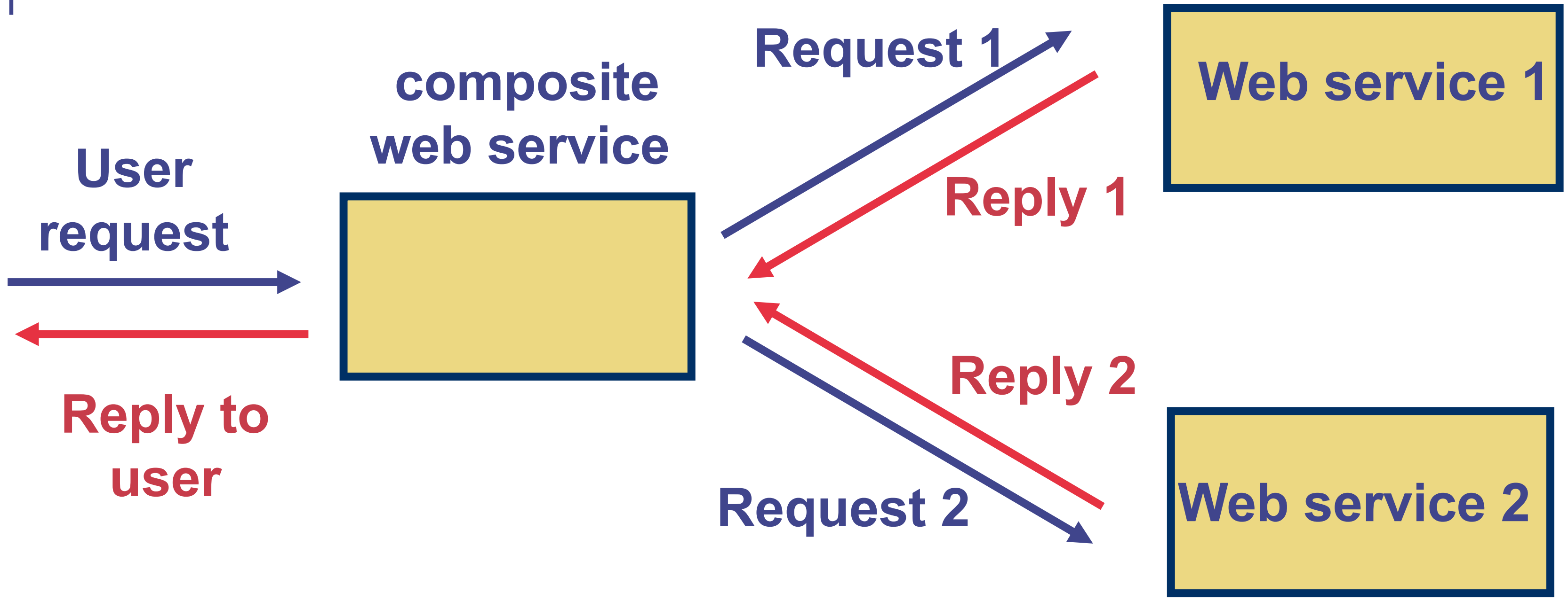
  = Time at which composite web service receives Reply 1 *minus*
  Time at which composite web service sends Request 1
- Similarly, definition for Web Service 2

A simple web service scenario (3)



- Assuming that:
  - Web service 1 has a response time distribution of
    - 0.2s with probability 0.5
    - 0.3s with probability 0.5
  - Web service 2 has a response time distribution of
    - 0.2s with probability 0.5
    - 0.3s with probability 0.5
- What is the average time that the composite web service has to wait until both replies are return?

A simple web service scenario (4)



- What if the service time distribution is:
  - Web service 1 has a response time distribution of
    - 0.2s with probability 0.5
    - 0.3s with probability 0.5
  - Web service 2 has a response time distribution of
    - 0.2s with probability 0.5
    - 0.5s with probability 0.5
- What is the average time that the composite web service has to wait until both replies are return?

Analysis scenario

- Lesson learnt: Slow web services can become the bottleneck for composite web service

- We consider Composite Web Services (illustration next slide)
  - With parallel invocation of N services
  - Web services 1 through N-1 have a mean service time of S (exponentially distributed)
  - Web service N has a mean service time of g x S (exponentially distributed)
  - The next service step can only be completed after all these N steps have been completed.

Servers 1 to N-1 : mean response time = S
Server N: mean response time = g x S

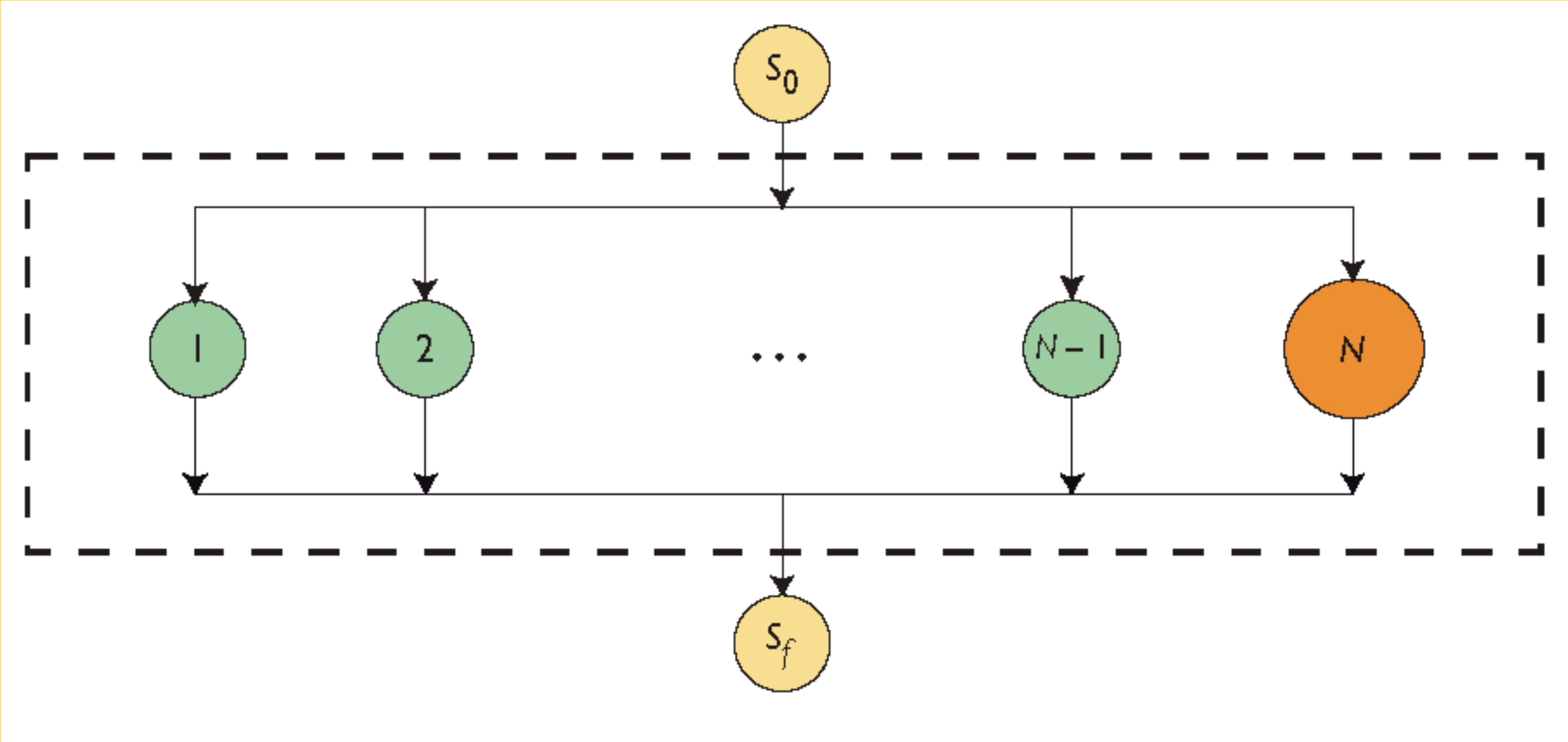


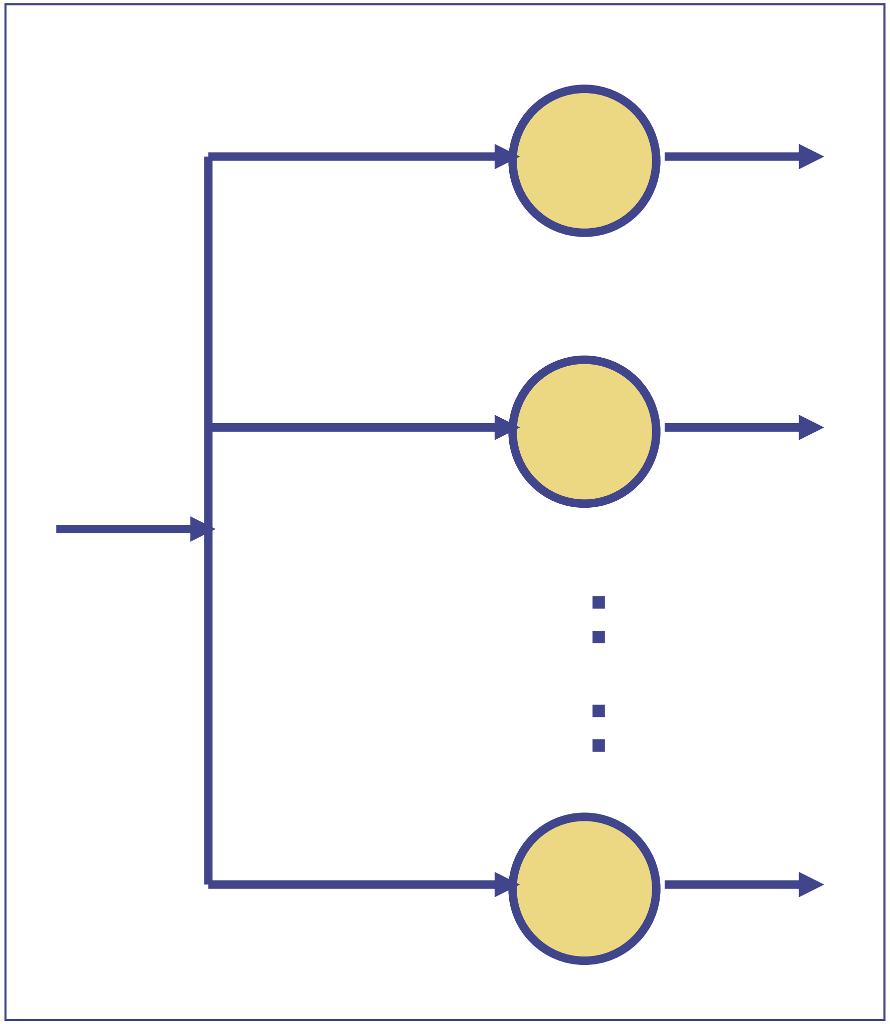
Figure 1. A composite Web service. After an initialization step S_0, N Web services are invoked in parallel. Service N takes longer than the others, and the final step S_f can only be carried out after all N services have completed.

Fork-join system

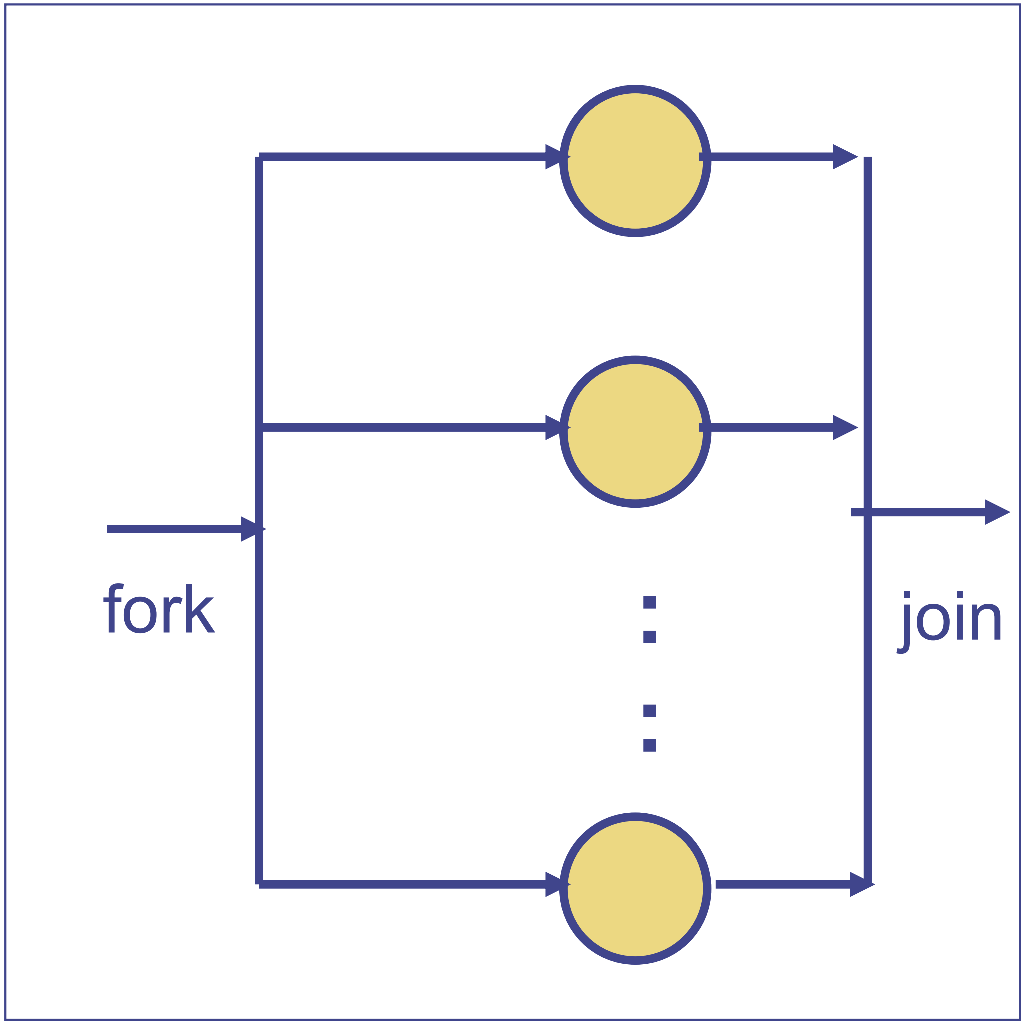
- The type of system described earlier is known as fork-join system
  - Fork is referring to the parallel invocation
  - All services must complete at the joining point before the next service can start

You’ ve seem parallel processing before:

M/M/c queue

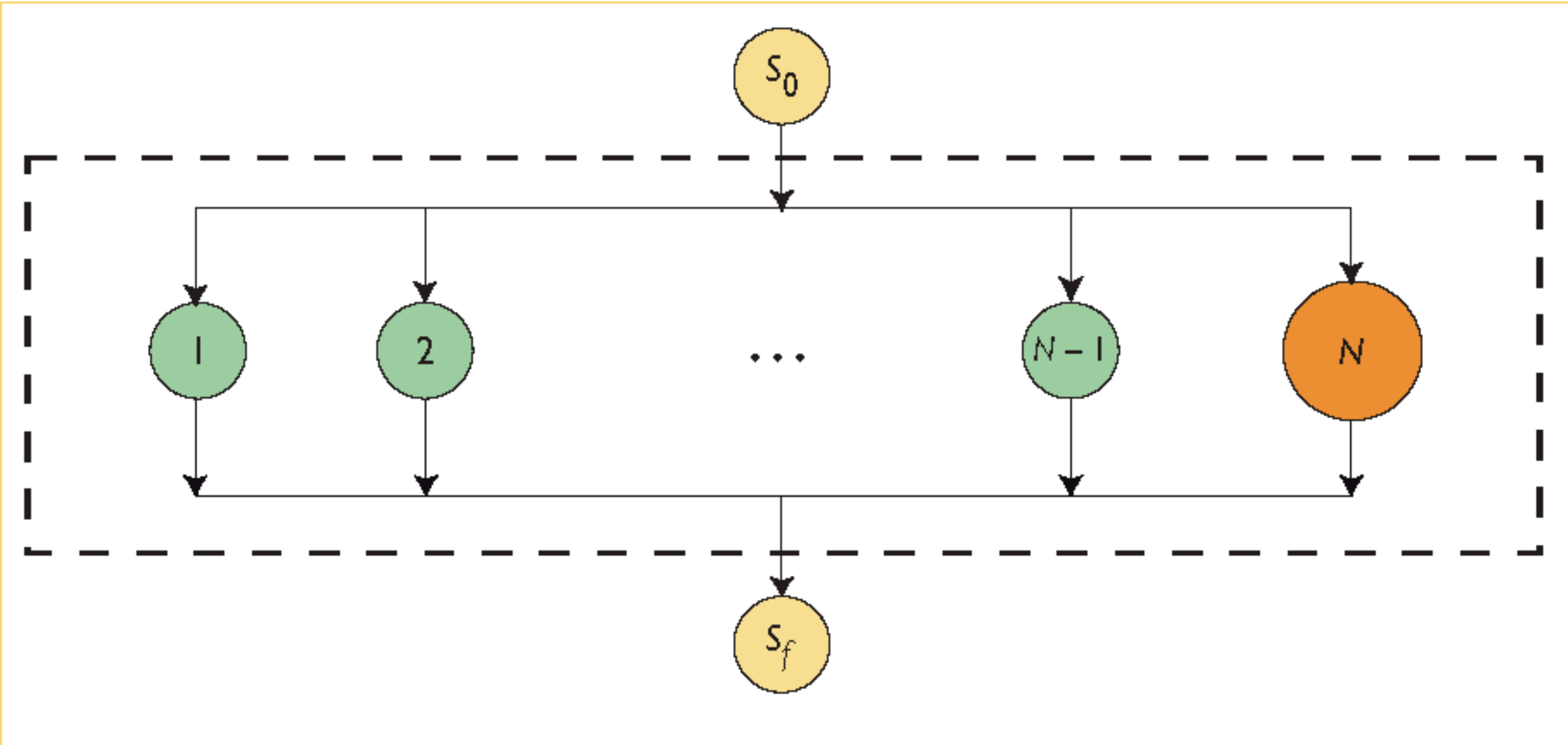


Fork-join queue



What is the difference between these two queueing networks?

Servers 1 to N-1 : mean response time = S
Server N: mean response time = g x S



- We want to understand how g affects the response time of the composite web services

$$T(g) = \text{Response time of this system}$$

What is T(1)?

- In this case, all constituent web services have the same response time distribution
- If all mean response times are exponentially distributed with mean S

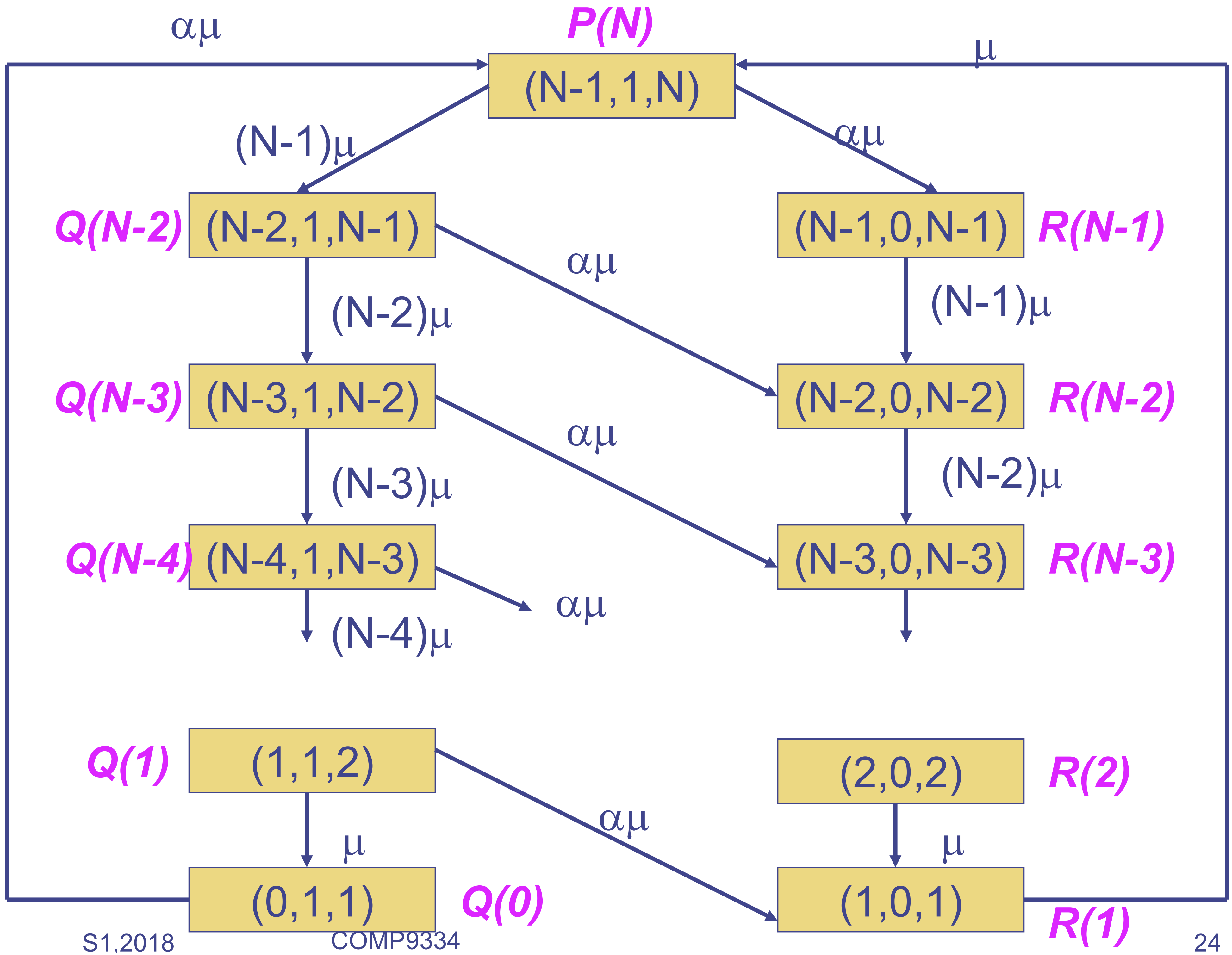
$$T(1) = \underbrace{(1 + \frac{1}{2} + \frac{1}{3} + ... + \frac{1}{N})}_{=H_N} S$$

$$H_N = \text{ } N\text{-th harmonic number}$$

(We will prove this later.)

How about T(g) for g>1?

- We use Markov chain.
- States (i,j,k)
  - i (i = 0,…,N-1) is the number of web services still running in fast Web services
  - j (j = 0,1) is the number of web services running on the slow Web service
  - k (k = 1,2,..,N) is the number of web services yet to complete


P(N)
αμ
μ
(N-1,1,N)
(N-1)μ
αμ
Q(N-2)
(N-2,1,N-1)
(N-1,0,N-1)
R(N-1)
αμ
(N-2)μ
(N-1)μ
Q(N-3)
(N-3,1,N-2)
(N-2,0,N-2)
R(N-2)
αμ
(N-3)μ
(N-2)μ
Q(N-4)
(N-4,1,N-3)
(N-3,0,N-3)
R(N-3)
αμ
(N-4)μ
Q(1)
(1,1,2)
(2,0,2)
R(2)
αμ
μ
μ
(0,1,1)
Q(0)
(1,0,1)
R(1)

$$T(g) = \frac{S}{\left(N - 1 + \frac{1}{g}\right) P(N)}$$

where

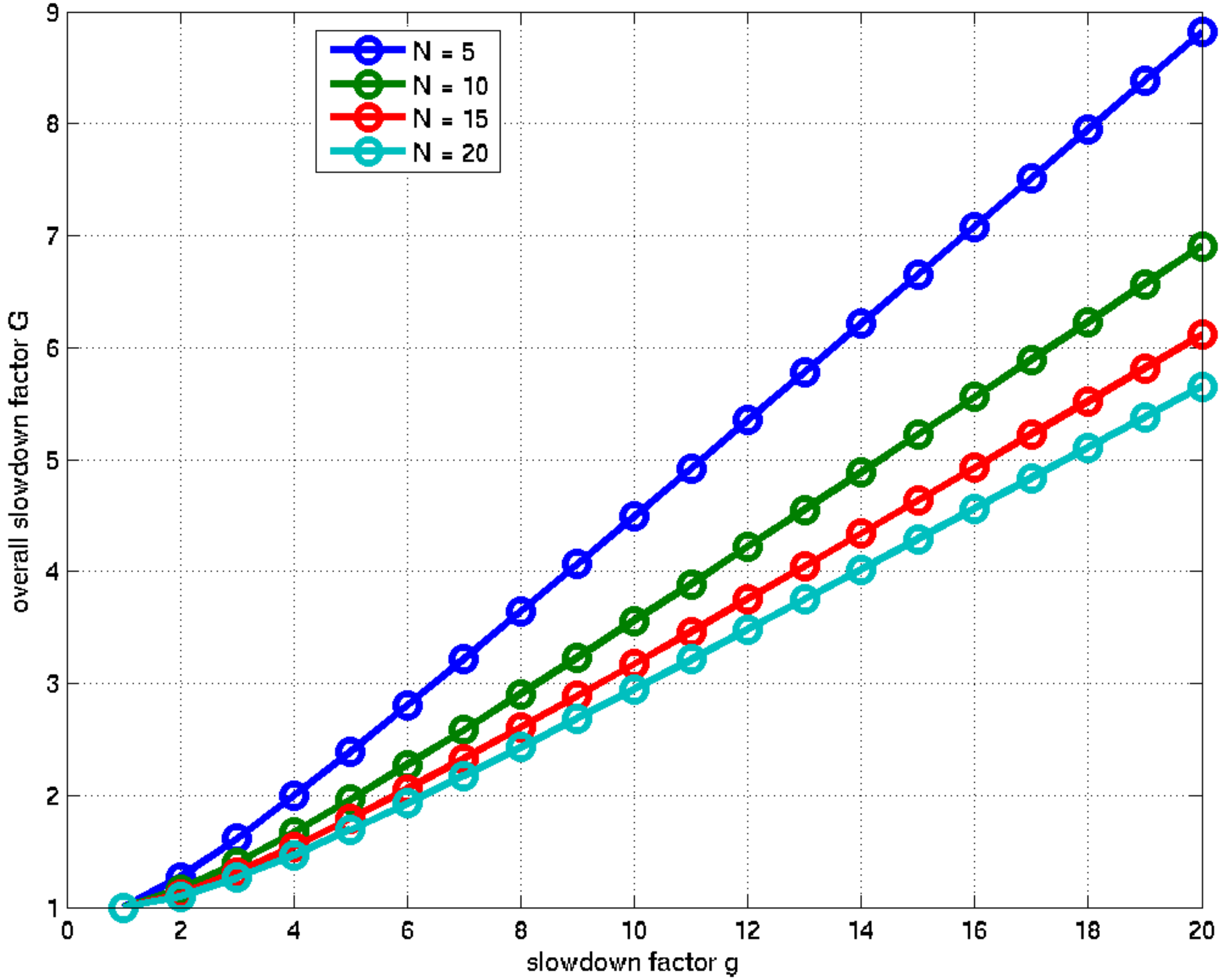
$$P(N) = \left[1 + \sum_{i=1}^{N-2} F(i) + gF(1) + V\right]^{-1},$$

$$V = \frac{1}{g} \sum_{j=1}^{N-1} \frac{1}{j} \sum_{i=j}^{N-1} F(i),$$

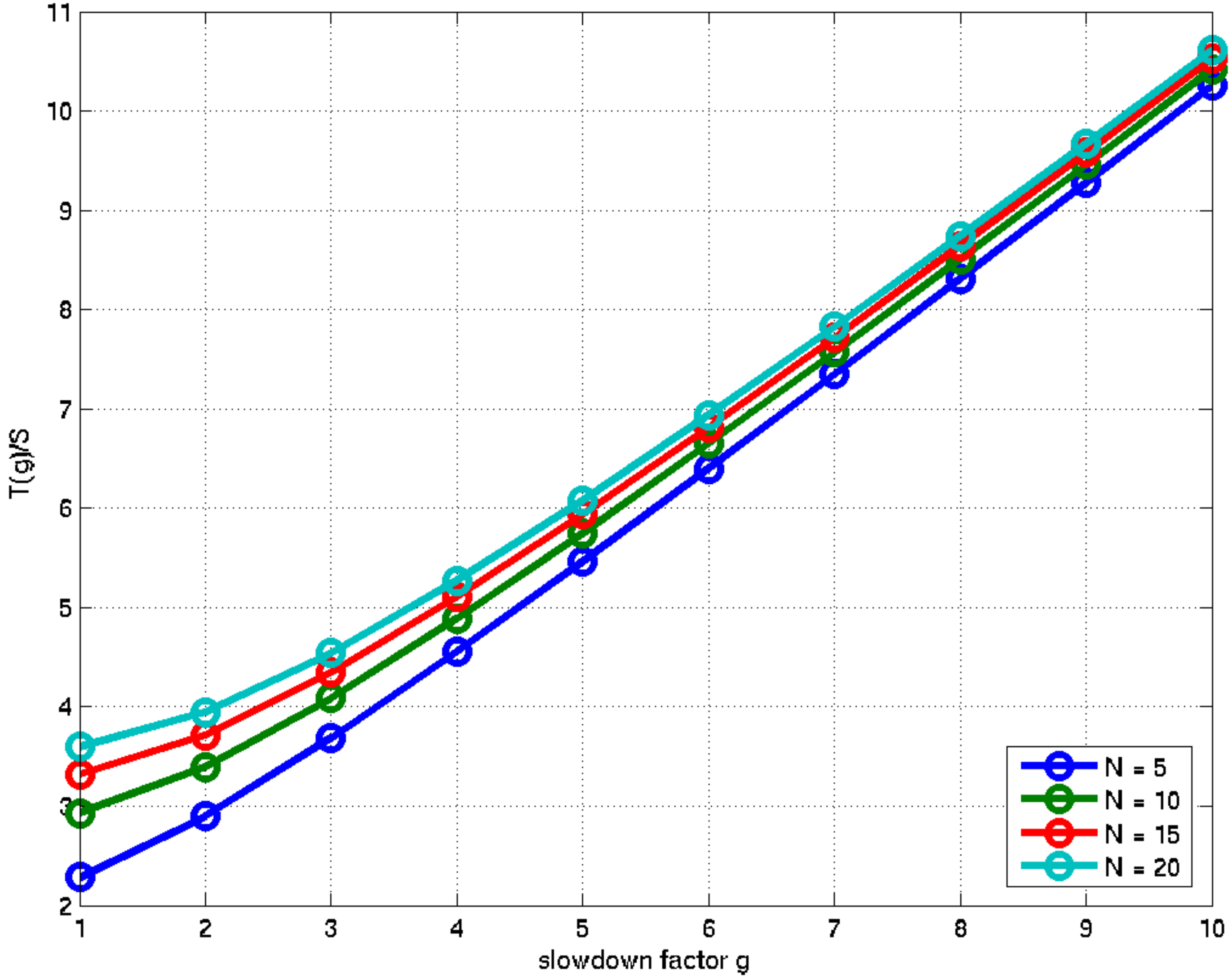
$$F(i) = \prod_{j=1}^{N-i-1} \frac{N-j}{N-j-1+\frac{1}{g}}.$$

Note: When g = 1, $T(g) = H_N\ S$

$G = \frac{T(g)}{T(1)}$ = Overall slowdown factor

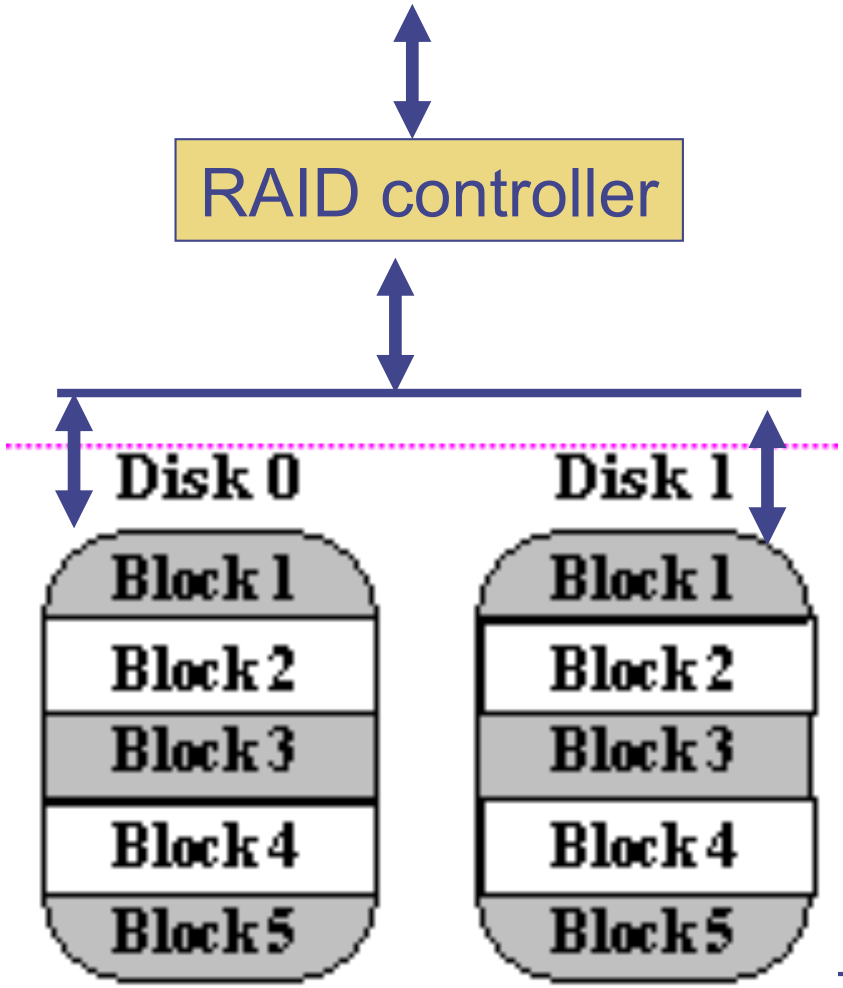


How T(g)/S varies with g?



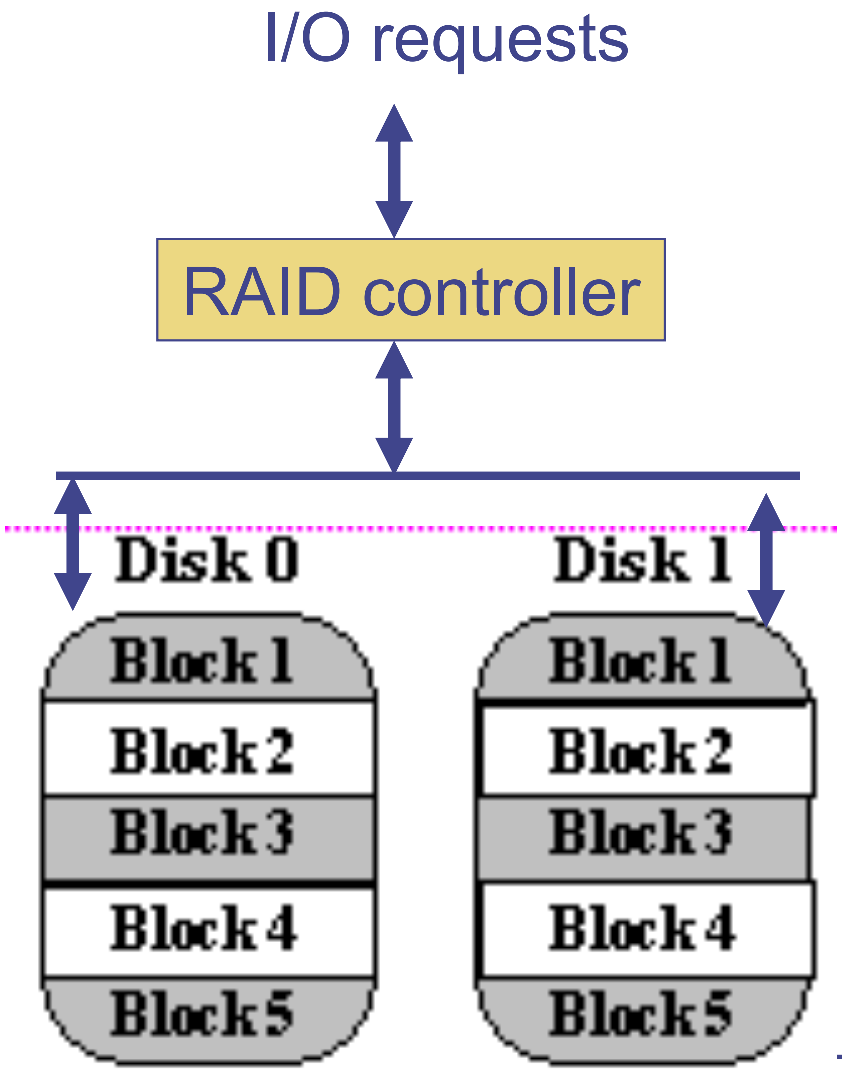
Other examples of fork-join QNs

- Disk array, e.g. RAID (Redundant Array of Independent Disks)



Example of RAID1
Mirrored disks

Fork-join in disk array



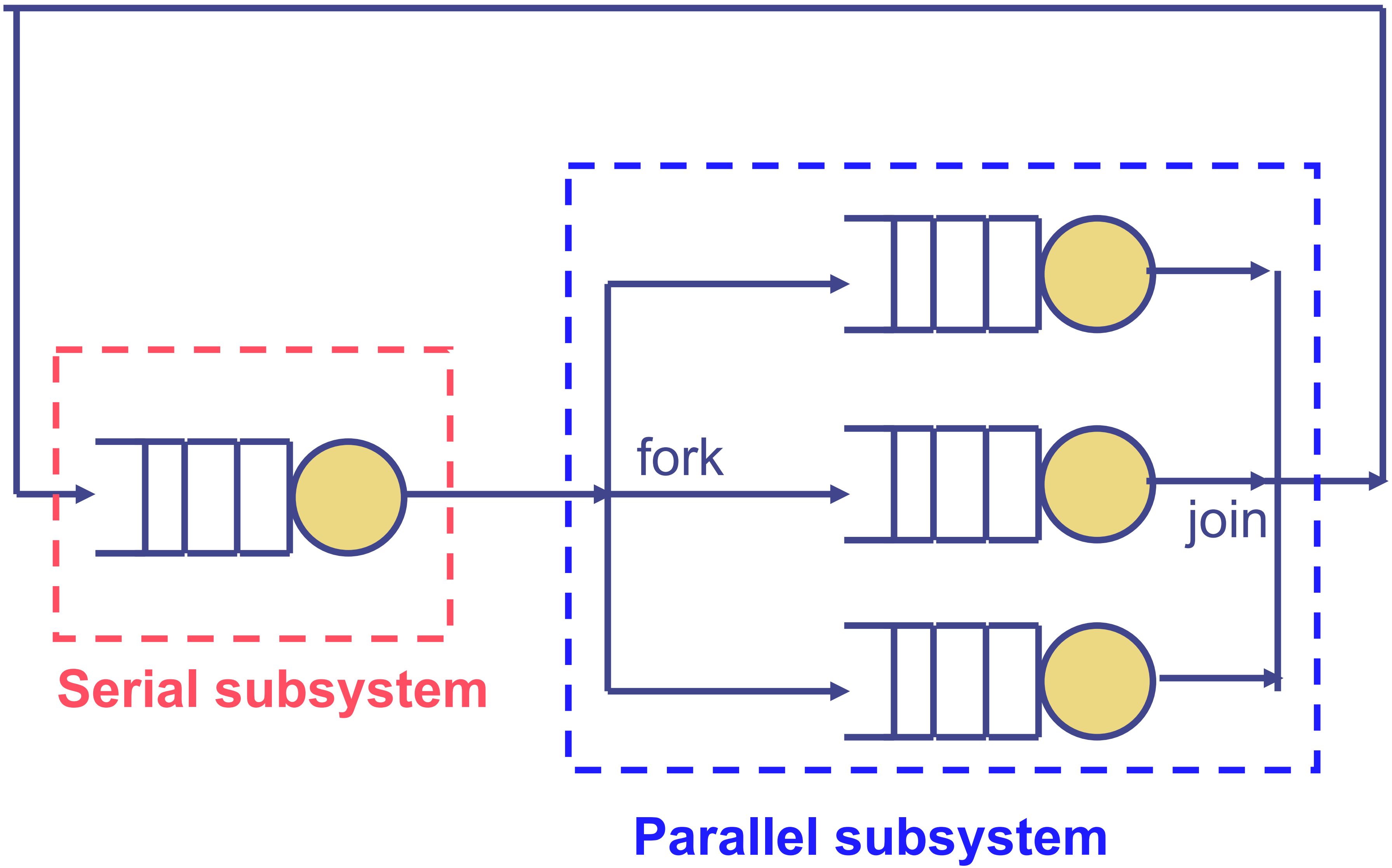
Example 1
Read a file in parallel
1st half of the file from Disk 0
2nd half of the file from Disk 1
Need to wait for both halves of the file before the next operation

Example 2
Write to disk.
Need to write to both disks (for consistency)
Need to wait for both disks to complete

Fork-join queueing networks

- Exact results are hard to come by
- Approximate solution methods are used

A Queueing network with a fork-join subsystem

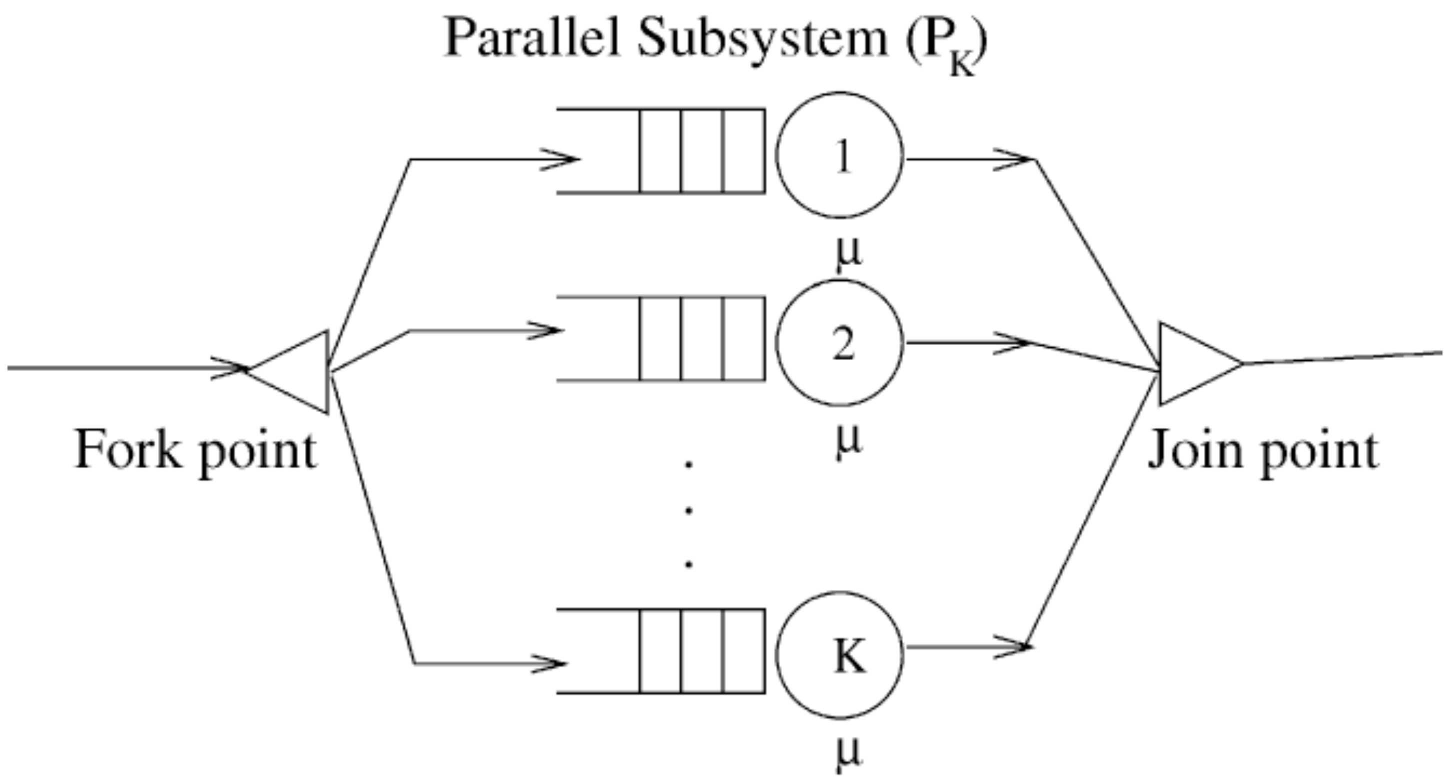


Approximate MVA for fork-join queueing networks

- For MVA with fork-join, the basic unit is a subsystem
  - A subsystem can be either a serial subsystem (= a device) or parallel one
    - A serial subsystem is a special case of parallel subsystem
  - C.f. The basic unit for MVA before is a device

Arrival Theorem for Parallel Subsystems (1)

- Consider a parallel subsystem with *k* parallel service centres
- The average time each job requires at each service centre is S (exponentially distributed)

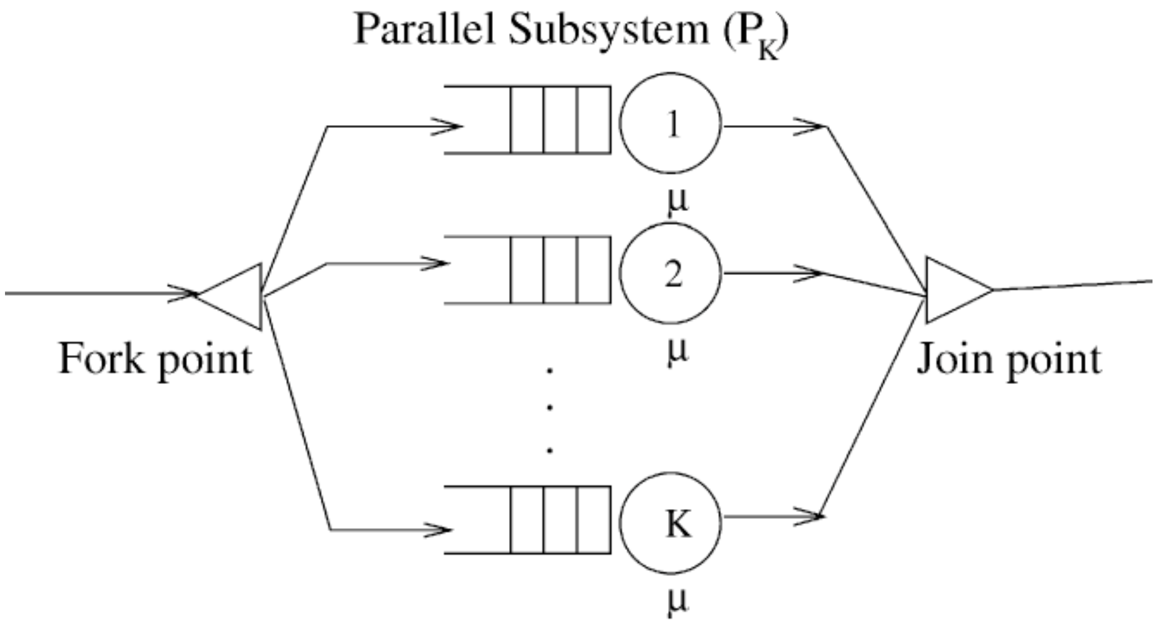


$\mu = 1/S$

Arrival Theorem for Parallel Subsystems (2)

When there are $n-1$ jobs in the whole QN, the average number of jobs in the subsystem is z. When there're n jobs in the system

One of the
n jobs (customers)



$$\text{Waiting time} = S \times z; \text{ Service time} = S \times H_k$$

$$\Rightarrow \text{Response time} = S \times (H_k + z)$$

Note that if $k = 1$, the subsystem is serial and is identical to a device in MVA analysis that we have seen before.

$$\begin{aligned}\text{Response time} &= S \times (H_1 + z) \\ &= S \times (1 + z) \\ &\quad (\text{Since } H_1 = 1)\end{aligned}$$

This is the same form of arrival theorem that we've seen before.

Notation:

$$I = \text{Number of subsystems in the QN}$$

$$S_i = \text{Avg. service time of a station in subsystem } i$$

$$k_i = \#\text{ parallel stations in subsystem } i$$

$$R_i(n) = \text{Response time at subsystem } i$$
$$\text{when there're } n \text{ jobs in the QN}$$

$$\bar{n}_i(n) = \text{Avg. }\#\text{ of jobs at subsystem } i$$
$$\text{when there're } n \text{ jobs in the QN}$$

$$V_i = \text{Visit ratio of subsystem } i$$

MVA for fork-join systems:

Mean # jobs in each subsystem $\bar{n}_i(n-1)$

(n-1) jobs in system

n jobs in system

$$R_i(n) = S_i \times (H_{k_i} + \bar{n}_i(n-1))$$

Mean response time of each subsystem $R_i(n)$

$$X_0(n) = \frac{n}{R_0(n)} = \frac{n}{\sum_{i=1}^{I} V_i R_i(n)}$$

Throughput of the system $X_0(n)$

$$\bar{n}_i(n) = V_i \times X_0(n) \times R_i(n)$$

Mean # jobs in each subsystem $\bar{n}_i(n)$

Example

- A system consists of a processor and 2 disk arrays
- Disk arrays operate under synchronous workload
  - Transactions are blocked until I/O are completed

	Service demand	# parallel systems
Processor	0.01	1
Disk array 1	0.02	2
Disk array 2	0.03	3

What is the system response time when there are 50 transactions? How many transactions can the system have if the system response time should not exceed 1s?

Exercise

- The MVA algorithm on p.37 assumes that you have both visit ratios V_i and mean service time S_i available
- You may recall that service demand $D_i = V_i * S_i$
- Now, let us assume that you are only given the service demands D_i. That is, you know only D_i but you do not know V_i and S_i. How can you modify the MVA algorithm on p.37 so that it can work with knowing service demands only?

References (1)

- Web services
  - D. Mensace et al. Static and Dynamic Processor Scheduling Disciplines in Heterogeneous Parallel Architectures," *Journal of Parallel and Distributed Computing,* Vol. 28 (1), July 1995, pp. 1-18.
  - D. Mensace, "QoS Issues in Web Services," *IEEE Internet Computing*, November/December 2002, Vol. 6, No. 6.
  - D. Mensace, "Response Time Analysis of Composite Web Services," *IEEE Internet Computing,* January/February 2004, Vol. 8, No. 1
  - D. Mensace, "Composing Web Services: A QoS View," D. Menasce, IEEE Internet Computing, Vol. 8., No. 6, Nov/Dec 2004.
  - These papers can be downloaded from the course website (use your CSE password)
    - We didn't cover the last paper but it's well worth a read.
- Derivation of Markov chain on pp. 23-25 is further explained in the file *forkjoin_mc.pdf*

References (2)

- Fork-join MVA
  - Menasce et al.,"Performance by desing". Section 15.6.
- Addition references outside the scope of this course
  - Tutorial on RAID http://www.slcentral.com/articles/01/1/raid/