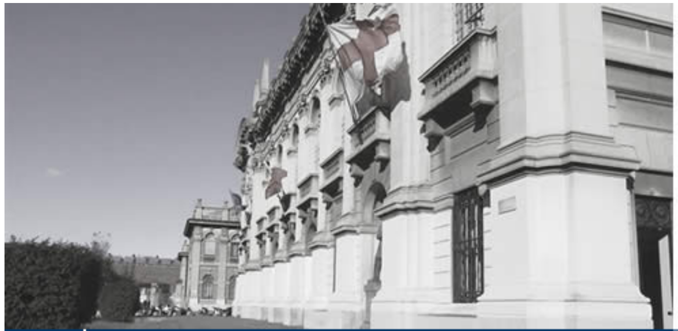


POLITECNICO DI MILANO

Computing Infrastructures

Performance modeling

Prof. Danilo Ardagna

Credits: Jane Hilston, Moreno Marzolla, Raffaela Mirandola, Marco Gribaudo, John Zahorian, Ed Lazowska

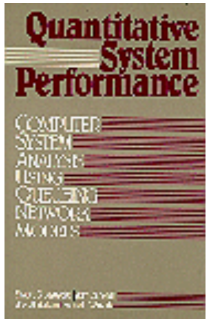
The topics of the course

A. **HW Infrastructures**:
- **System-level**: Computing Infrastructures and Data Center Architectures, Rack/Structure;
- **Node-level**: Server (computation, HW accelerators), Storage (Type, technology), Networking (architecture and technology)
- **Building-level**: Cooling systems, power supply, failure recovery

B. **SW Infrastructures**:
- **Virtualization**: Process/System VM, Virtualization Mechanisms (Hypervisor, Para/Full virtualization)
- **Computing Architectures**: Cloud Computing (types, characteristics), X-as-a service, Edge/Fog Computing
- **Machine and deep learning-as-a-service**

C. **Methods**:
- **Reliability and availability of datacenters** (definition, fundamental laws, RBDs)
- **Disk performance** (Type, Performance, RAID)
- **Scalability and performance of datacenters** (definitions, fundamental laws, queuing network theory)

Reference book



Quantitative System Performance
Computer System Analysis Using Queueing Network Models

Edward D. Lazowska, John Zahorjan,
G. Scott Graham, Kenneth C. Sevcik

Available on-line: http://homes.cs.washington.edu/~lazowska/qsp/

By the end of the course a handout will be made available on WeBeep

Big Picture

Performance

Average response time
Throughput

Dependability

MTTDL

Data center

Processing

Virtualization

Storage

RAID

Definition: Performance

- **Computer performance:**
  - The total **effectiveness** of a computer system, including throughput, individual response time and availability
  - Can be characterized by the amount of useful work accomplished by a computer system or computer network compared to the time and resources used

System quality: a central issue

- Common practice: system mostly validated versus “functional” requirements rather than versus quality ones
- Different (and often not available) skills required for quality verification
- Short time to market, i.e. quickly available products and infrastructures “seem” to be more attractive nowadays!
- Little information related to quality is usually available early in the system lifecycle but its understanding is of **great importance from the cost and performance point of view**
  - During design and system sizing
  - But also during system evolution
    - E.g. changes in workloads or number of users

Why performance matter

- In 2006, Amazon discovered that every additional 100ms of latency in page load time resulted in a 1% decrease in sales
  - For context, a 1% revenue loss in 2006 equated to $107 million, whereas today, it would be about $3.8 billion

- Around the same period, Google found that an additional 0.5 seconds in search page generation time led to a 20% drop in traffic

- Nowadays, a broker could lose up to $4 million in revenue per millisecond if their trading platform is 5 milliseconds slower than competitors

Head Count

- Every 5 years Australians update their census.

https://apo.org.au/sites/default/files/resource-files/2016/11/apo-nid70705-1232016.pdf

Credits: Prof. G. Moltò, UPV

Trusting Your Partners

- The ABS* through a public tender awarded IBM for $9.6M a contract to implement a digital census solution by 2016.
- ABS wisely allocated a "Load Test" appropriation ($469K of which $325K was spent on software licenses).

CN ID:	CN2641301
Agency:	Australian Bureau of Statistics
Publish Date:	27-Oct-2014
Category:	Software maintenance and support
Contract Period:	1-Oct-2014 to 31-Oct-2016
Contract Value (AUD):	$9,606,725.00
Description:	Design, development and implementation of eCensus Solution 2016
Procurement Method:	Limited tender
Confidentiality - Contract:	No
Confidentiality - Outputs:	No
Consultancy:	No
Agency Reference ID:	ABS2014.105

Supplier Details

Name:	IBM Australia Ltd
Postal Address:	8 Brisbane Ave
Town/City:	Barton
Postcode:	2600
State/Territory:	ACT
Country:	AUSTRALIA
ABN:	79 000 024 733

https://www.tenders.gov.au/Cn/Show/1D46611D-EA19-ED83-2C73-D65E88772130

* Australian Bureau of Statistics

Credits: Prof. G. Moltò, UPV

A story in three acts

Malcolm Turnbull @TurnbullMalcolm

We filled in the @ABSCensus tonight online - v easy to do. And so important for planning better Govt services & investment for the future

327 11:17 AM - Aug 9, 2016

1,475 people are talking about this

https://twitter.com/TurnbullMalcolm/status/762940763801989121

Australian Bureau of Statistics @ABSStats

The ABS & Census websites are currently experiencing an outage. We're working to restore the service. We will keep you updated. Thank you.

1,079 12:38 PM - Aug 9, 2016

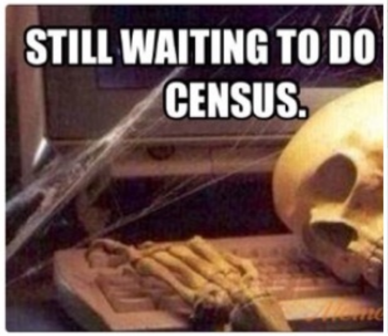
1,956 people are talking about this

https://twitter.com/ABSStats/status/762961251764805633

Narelle #FreePress @narelleford

@b_spectabilis @TurnbullMalcolm @ABSCens

20 2:11 PM - Aug 9, 2016



See Narelle #FreePress's other Tweets

https://twitter.com/narelleford/status/762984702915465216

Colby Swandale @oceanicpanda

Breaking news. We have an image of #census2016 datac from moments ago. #censusfail

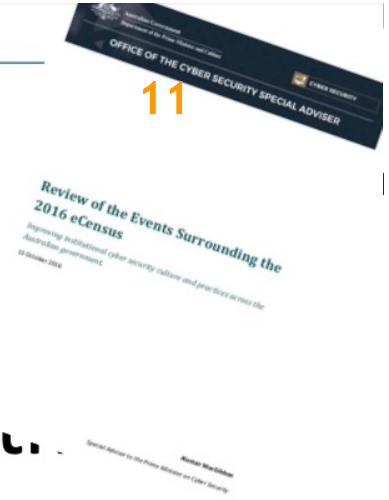
565 12:15 PM - Aug 9, 2016

255 people are talking about this

https://twitter.com/oceanicpanda/status/762955516096094208

Given that millions of Australians can play Pokemon Go at once and it doesn't crash is a good reason to outsource the census to Nintendo
— Tim Beshara (@Tim_Beshara) August 9, 2016

Credits: Prof. G. Moltò, UPV



Oficial vs No Oficial

- The official conclusion (13/10/2016) of the Office of Cybersecurity was:
  - *[…] although the site withstood an initial DDoS attack and was coping with over 7,000 census forms a minute, a second and third attack took it down*
- Critical: It is believed that the system was developed on IBM WebSphere and ran on IBM Softlayer (on-premises Cloud) instead of a public Cloud.

Credits: Prof. G. Moltò, UPV

An Unexpected Turn of Events

- A couple of students, with no previous AWS experience, developed a serverless system in one weekend supporting 4 times the load used to test the IBM system for ~~$500~~ $30

TECH

How two Uni Students built a better Census site in just 54 hours for $500

By TREVOR LONG

Posted on August 16, 2016

https://eftm.com/2016/08/how-two-uni-students-built-a-better-census-site-in-just-54-hours-for-500-30752

Credits: Prof. G. Moltò, UPV

How can we evaluate system quality?

- Use of intuition and trend extrapolation
    - Unfortunately, those who possess these qualities in sufficient quantity are rare
- Pro: rapid and flexible
- Con: accuracy

- Experimental evaluation of alternatives
    - Experimentation is always valuable, often required, and sometimes the approach of choice
    - It is also expensive - often prohibitively so
    - A further drawback: an experiment is likely to yield accurate knowledge of system behavior under one set of assumptions, but not any insight that would allow generalization
- Pro: excellent accuracy
- Con: laborious and inflexible

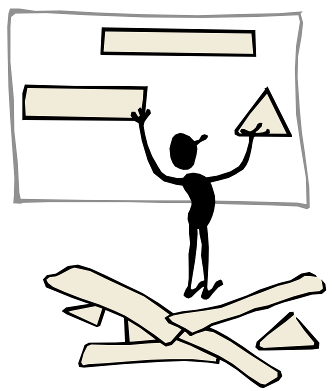
Solution: Model-Based Approach

Systems are complex so…

Abstraction of the systems: Models

"an attempt to distill, from the details of the system, exactly those aspects that are essentials to the system behavior"….
(E. Lazoswka)

Often models are the only artifact to deal with!
e.g., design phase



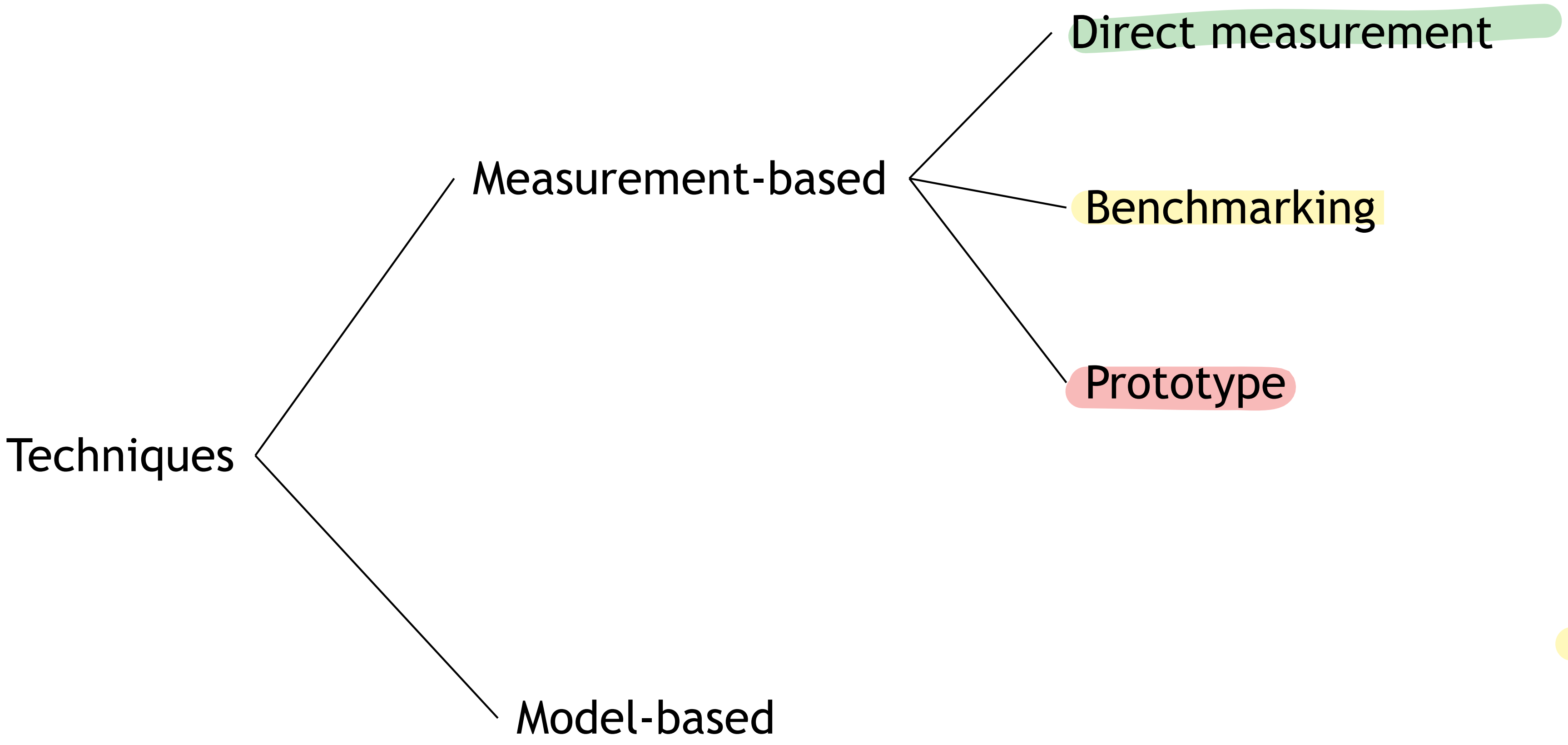
Models used to *drive* design decisions

- Which architecture ?
- How many resources to meet some performance/reliability goal?
-...

Quality Evaluation techniques

Techniques
- Measurement-based
- Model-based

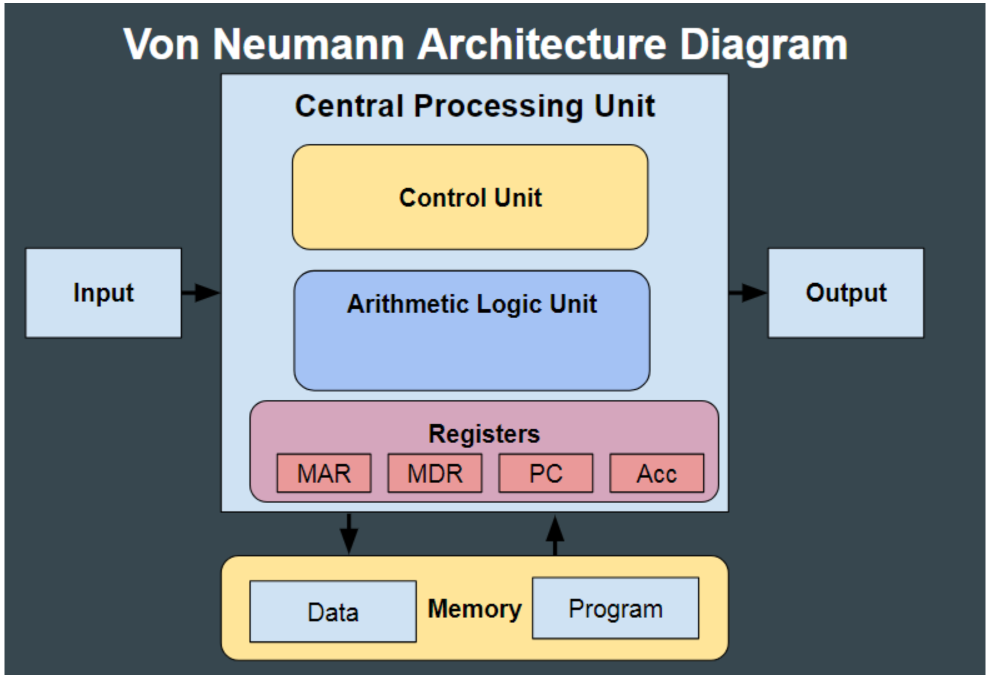
Quality Evaluation techniques

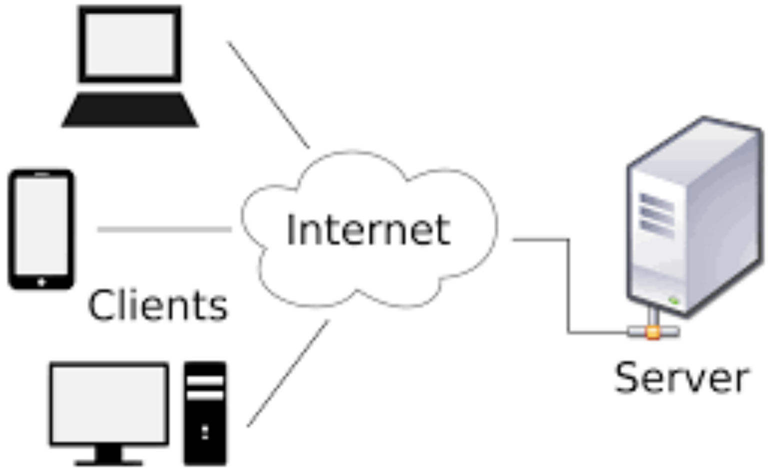


What is a model?

A representation of a system that is

- *simpler* than the actual system
- *captures the essential* characteristics
- *can be evaluated to make **predictions***





Model Definition

Existing system

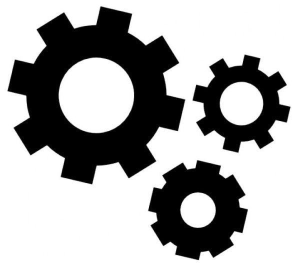
System Design

Parametrize the Model

Quality Model

Define the goal

Create the Model



Evaluate the Model

Performance indices

Quality Evaluation techniques

- Techniques
  - Measurement-based
    - Direct measurement
    - Benchmarking
    - Prototype
  - Model-based
    - Analytical and numerical
    - Simulation
    - Hybrid techniques

Model-based

- Analytical and Numerical techniques are based on the application of mathematical techniques, which usually exploit results coming from the **theory of probability and stochastic process**
  - They are the most efficient and the most precise, but are available only in very limited cases
- Simulation techniques are based on the reproduction of traces of the model
  - They are the most general, but might also be the less accurate, especially when considering cases in which rare events can occur
  - The solution time can also become really large when high accuracy is desired
- Hybrid techniques combine analytical/numerical methods with simulation

Reference Models of this course: Queueing Networks

Queueing theory is the theory behind what happens when you have a lot of jobs, scarce resources, and so long queue and delays.

Queueing network modelling is a particular approach to computer system modelling in which the computer system is represented as a *network of queues*

A network of queues is a collection of *service centers*, which represent system **resources**, and *customers*, which represent **users** or **transactions**

Queueing Networks

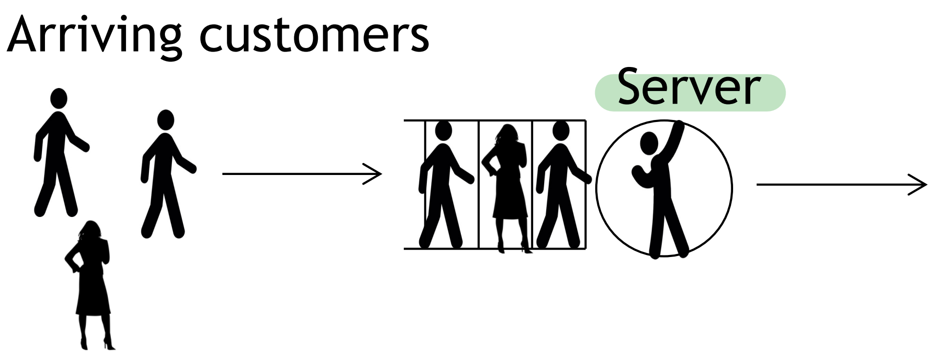
- Queueing theory applies whenever queues come up

- Queues in computer systems:
  - CPU uses a time-sharing scheduler
  - Disk serves a queue of requests waiting to read or write blocks
  - A router in a network serves a queue of packets waiting to be routed
  - Databases have lock queues, where transactions wait to acquire the lock on a record

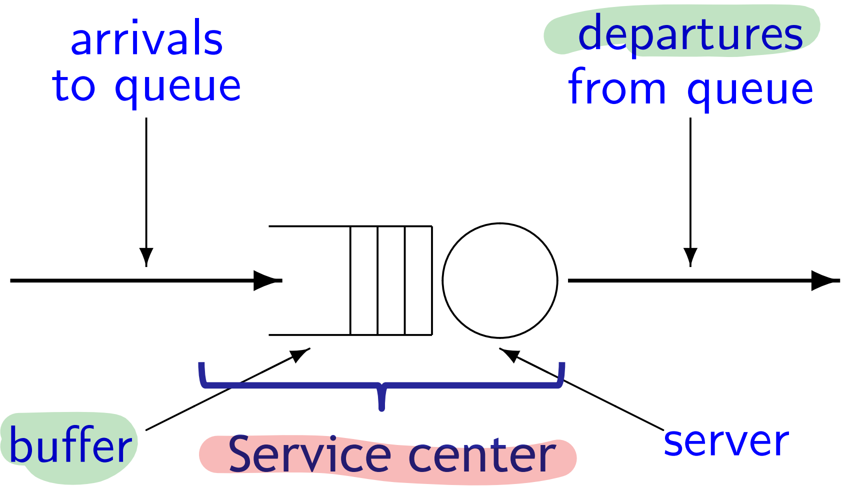
- Predicting performance e.g. for capacity planning purposes

- Queueing theory is built on an area of mathematics called stochastic modelling and analysis

Success of queueing network: low-level details of a system are largely irrelevant to its high-level performance characteristics



Single queue



- The basic scenario for a single queue is that customers, who belong to some population arrive at the service facility
- The service facility has one or more servers which can perform the service required by customers
- If a customer cannot gain access to a server it must join a queue, in a buffer, until a server is available
- When service is complete the customer departs, and the server selects the next customer from the buffer according to the service discipline (queueing policy)

Service center

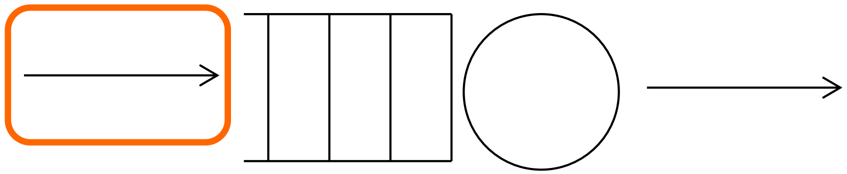
Different aspects characterize queuing models:

- Arrival
- Service
- Queue
- Population

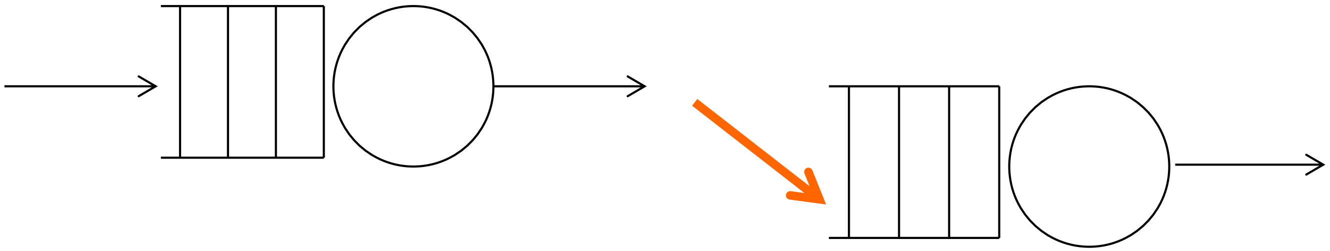
Arrival of customers

- Arrivals represent jobs entering the system: they specify how fast, how often and which types of jobs does the station service
- We are interested in the average arrival rate λ (req/s)

Arrival can come from an external source:



arrival can come from another queue:



or even from the same queue, through a loop-back arc

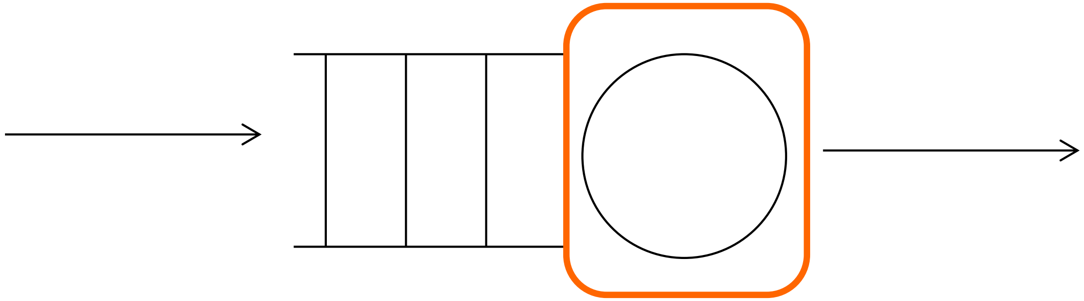
Service center

Different aspects characterize queuing models:

- Arrival
- Service
- Queue
- Population

Service & Service time

The service part represents the time a job spends being served



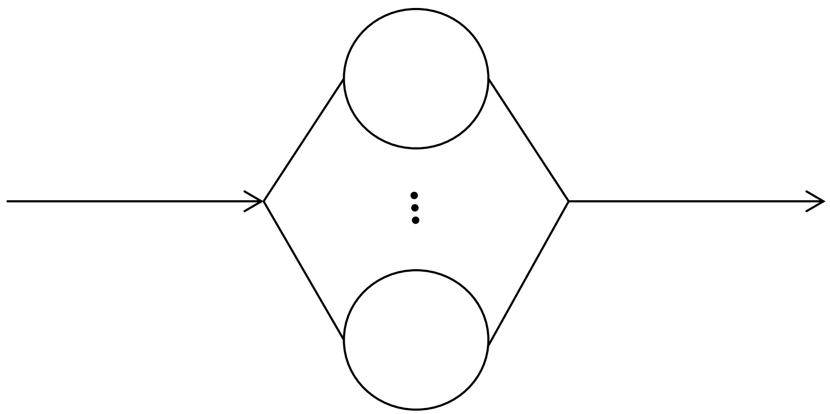
- The service time is the time which a server spends satisfying a customer
- As with the inter-arrival time, the important characteristics of this time will be its average duration (advanced: the distribution function)
- If the average duration of a service interaction between a server and a customer is $1/\mu$ then μ is the **maximum** service rate

Number of servers

Possible situations:

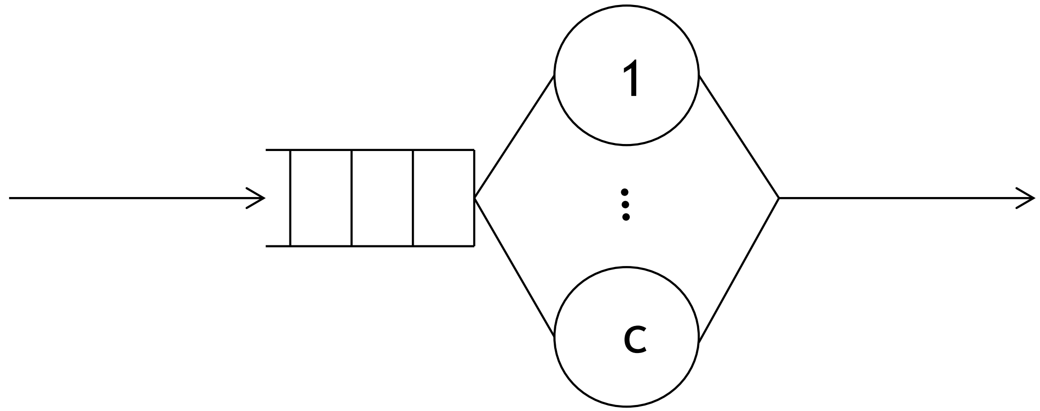
- a single server: the service facility only has the capability to serve one customer at a time; waiting customers will stay in the buffer until chosen for service; how the next customer is chosen will depend on the service discipline

- an infinite server: there are always at least as many servers as there are customers, so that each customer can have a dedicated server as soon as it arrives in the facility. There is no queueing, (and no buffer) in such facilities



Multiple servers

- Between these two extremes there are multiple server facilities
- These have a fixed number of c servers, each of which can service a customer at any time
- If the number of customers in the facility is less than or equal to c there will no queueing—each customer will have direct access to a server
- If there are more than c customers, the additional customers will have to wait in the buffer



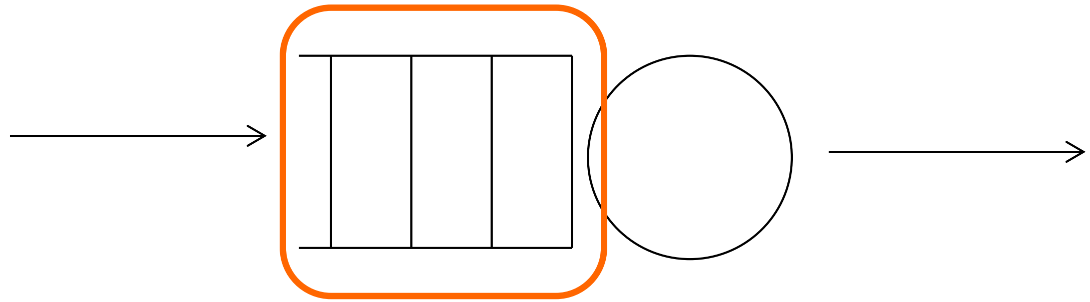
Service center

Different aspects characterize queuing models:

- Arrival
- Service
- Queue
- Population

Queue

If jobs exceed the capacity of parallel processing of the system, they are forced to wait *queueing* in a *buffer*



Buffer capacity

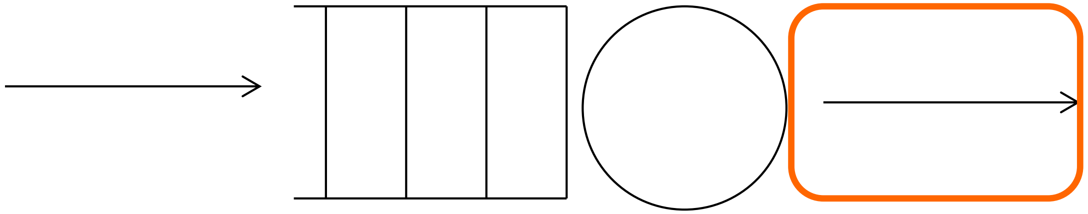
- Customers who cannot receive service immediately must wait in the buffer until a server becomes available

- If the buffer has finite capacity there are two alternatives for when the buffer becomes full:
  - the fact that the facility is full is passed back to the arrival process and arrivals are suspended until the facility has spare capacity, i.e., a customer leaves;
  - or, arrivals continue and arriving customers are lost (turned away) until the facility has spare capacity again

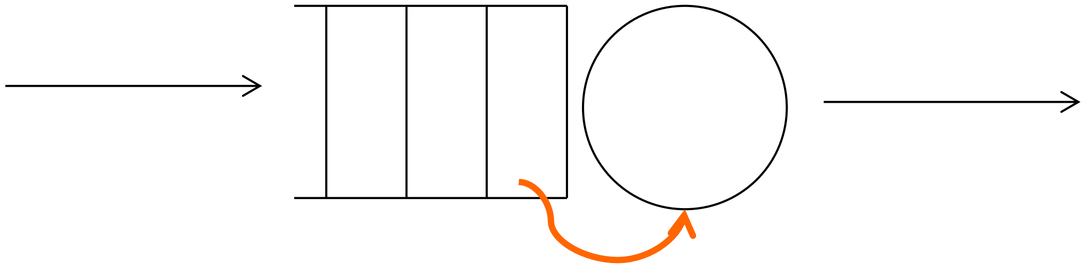
- If the buffer capacity is so large that it never affects the behaviour of the customers it is assumed to be infinite

Queue

When the (one of the) job(s) currently in service leaves the system, one of the job in the queue can enter the now free service center



Service discipline/queuing policy determines which of the job in the queue will be selected to start its service



Service discipline

- When more than one customer is waiting for service, we need a rule for selecting which of the waiting customers will be the next one to gain access to a server

- The commonly used service disciplines are
  - FCFS first-come-first-serve (or FIFO first-in-first-out)
  - LCFS last-come-first-serve (or LIFO last-in-first-out)
  - RSS random-selection-for-service
  - PRI priority, the assignment of different priorities to elements of a population is one way in which classes are formed

Service center

Different aspects characterize queuing models:

- Arrival
- Service
- Queue
- Population

Population

- The characteristic of the population which we are interested in is usually the size
- Clearly, if the size of the population is fixed, at some value N, no more than N customers will ever be requiring service at any time
- When the population is finite, the arrival rate of customers will be affected by the number who are already in the service facility (e.g., zero arrivals when all N are all already in the facility)
- When the size of the population is so large that there is no perceptible impact on the arrival process, we assume that the population is infinite

Population

- Ideally, members of the population are indistinguishable from each other
- When this is not the case, we divide the population into classes whose members all exhibit the same behaviour
- Different classes differ in one or more characteristics, for example, arrival rate, service time
- Identifying different classes is a workload characterisation task

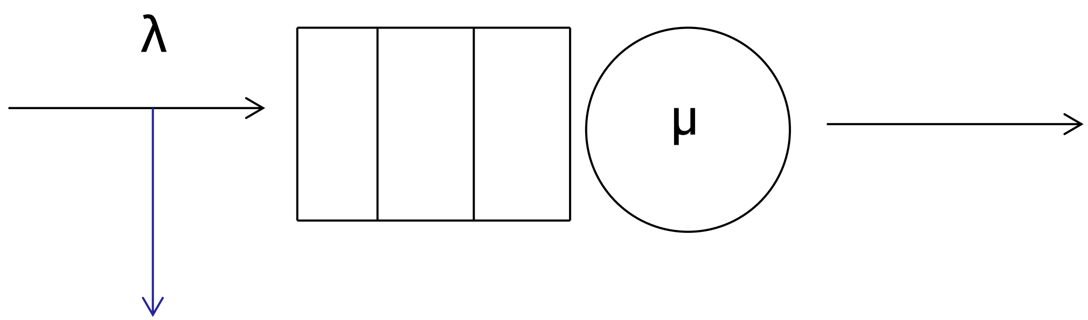
Example

- Consider a wireless access gateway:
- Measurements have shown that packets arrive at a mean rate of 125 packets per second, and are buffered
- The gateway takes 2 milliseconds on average to transmit a packet
- The buffer currently has 13 places, including the place occupied by the packet being transmitted and packets that arrive when the buffer is full are lost
- **Goal of the modelling and analysis:**
  - We wish to find out the buffer capacity which is sufficient to ensure that less than one packet per million gets lost

Example

A single queue center with:

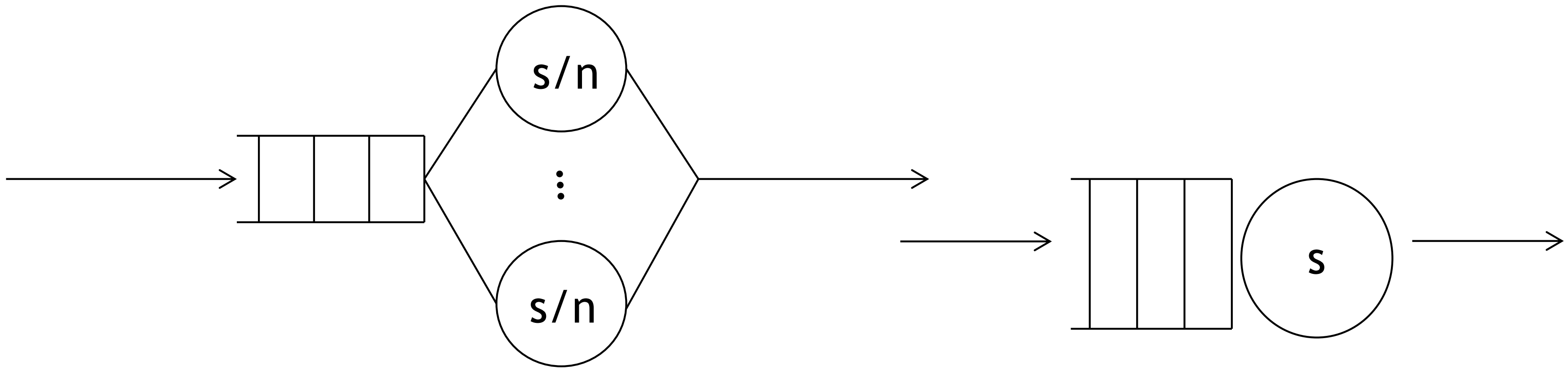
- Finite queue capacity=13
- FCFS service discipline
- Arrival rate λ = 125 req/s
- Service rate μ = 1/(2ms) = 500 req/s



Example

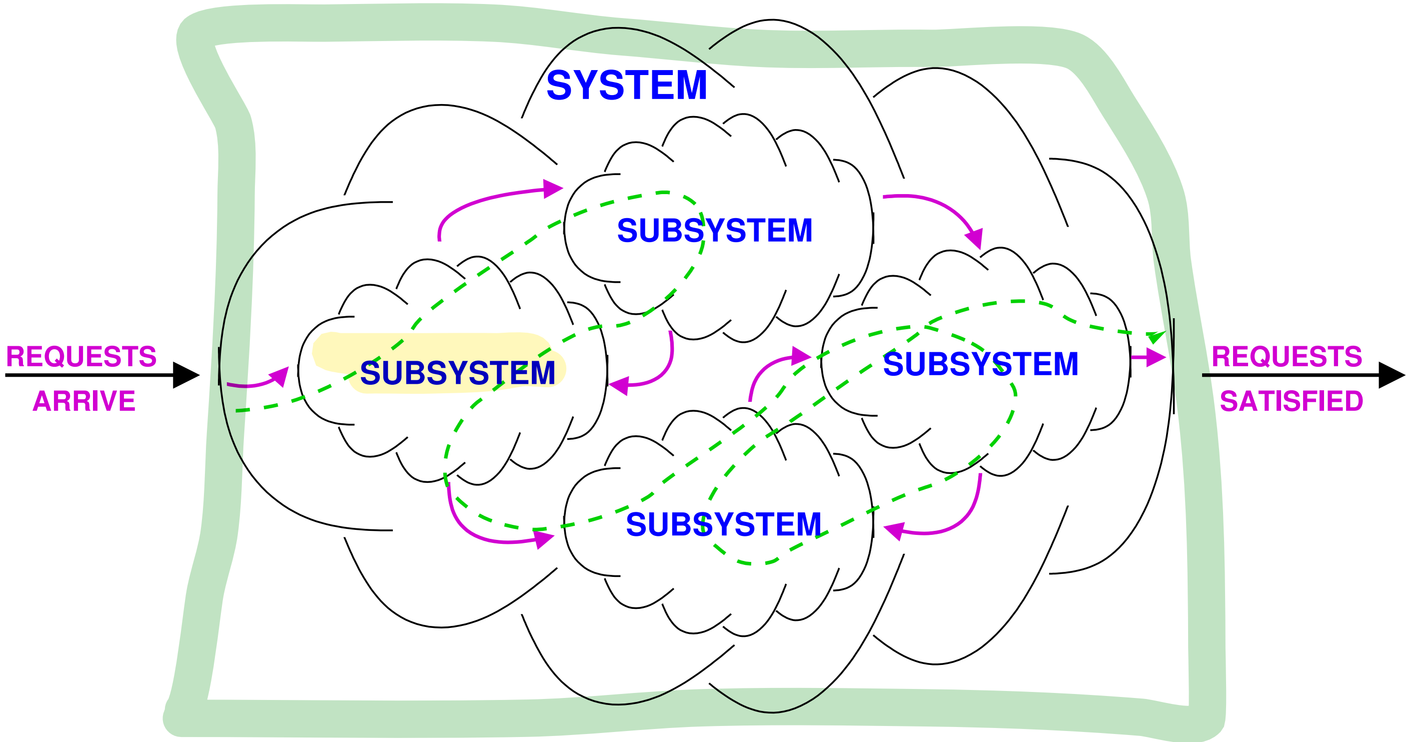
- You are given a choice between one fast CPU of speed s (maximum service rate μ) or n slow CPU each of speed s/n (maximum service rate μ/n). Your goal is to minimize mean response time

- Question: Which is the better choice? (Assume FCFS)
  - Arrival rate? Job type?
  - Pre-emption?

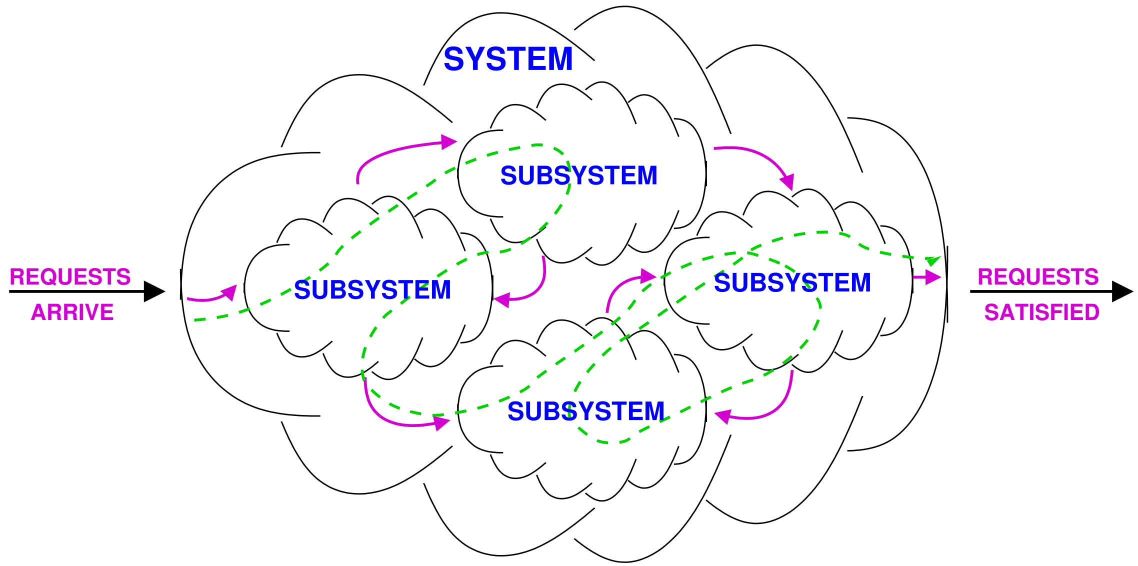


Queueing Networks

For many systems we can adopt a view of the system as a collection of resources and devices with customers or jobs circulating between them



Queueing Networks



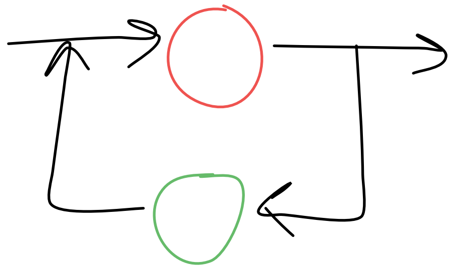
- We can associate a service center with each resource in the system and then route customers among the service centres

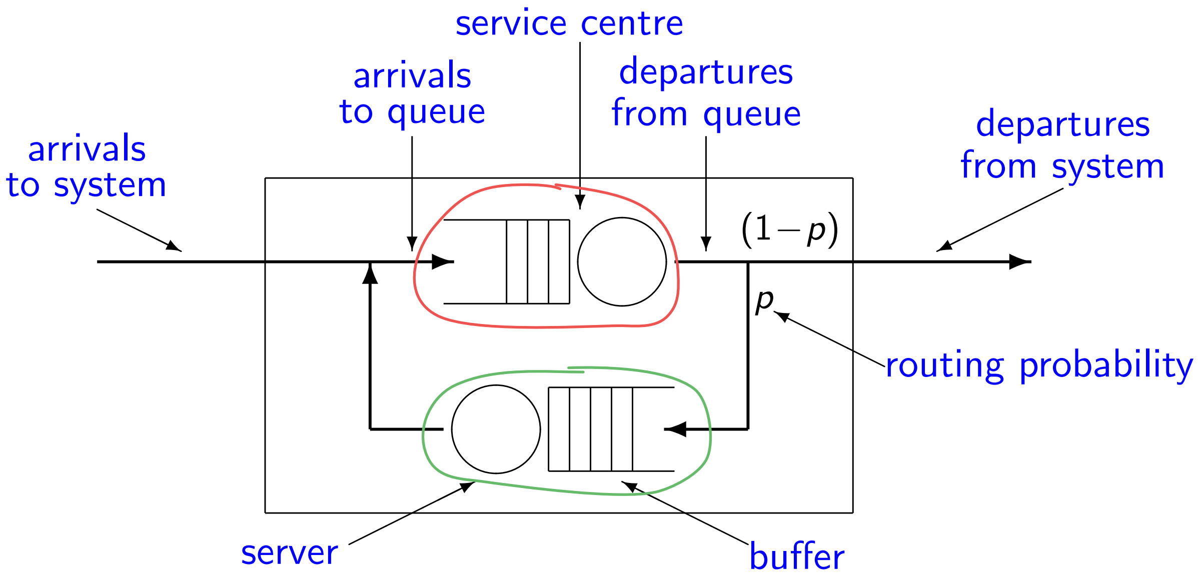
- After service at one service centre a customer may progress to other service centres, following some previously defined pattern of behaviour, corresponding to the customer’s requirement

Queueing Networks

A queueing network can be represented as a graph where nodes represent the service centers *k* and arcs the possible transitions of users from one service center to another

Nodes and arcs together define the network topology





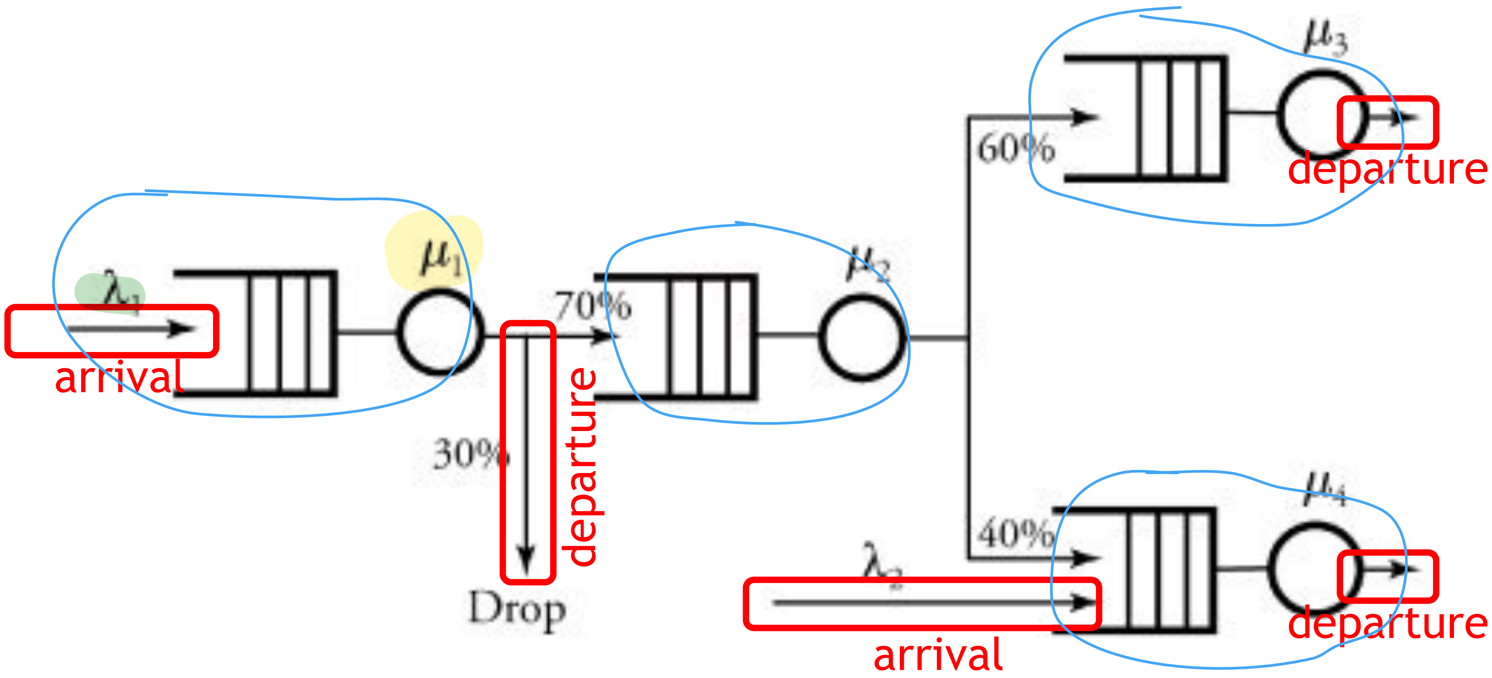
Queueing Networks

A network may be:

- Open: customers may arrive from, or depart to, some external environment
- Closed: a fixed population of customers remain within the system
- Mixed: there are classes of customers within the system exhibiting open and closed patterns of behaviour respectively

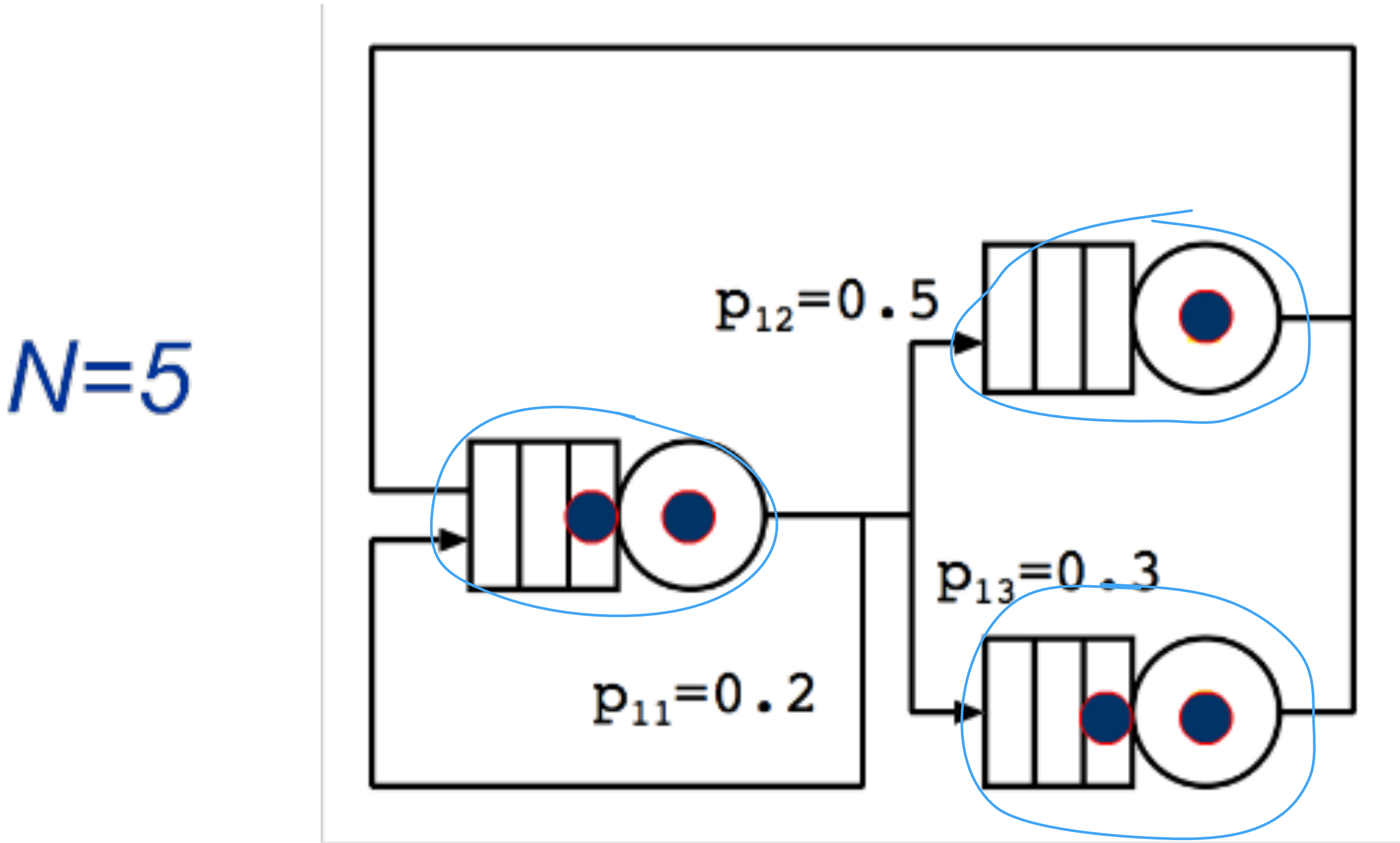
Queuing networks

Open Models are characterized by *arrivals* and *departures* from the system

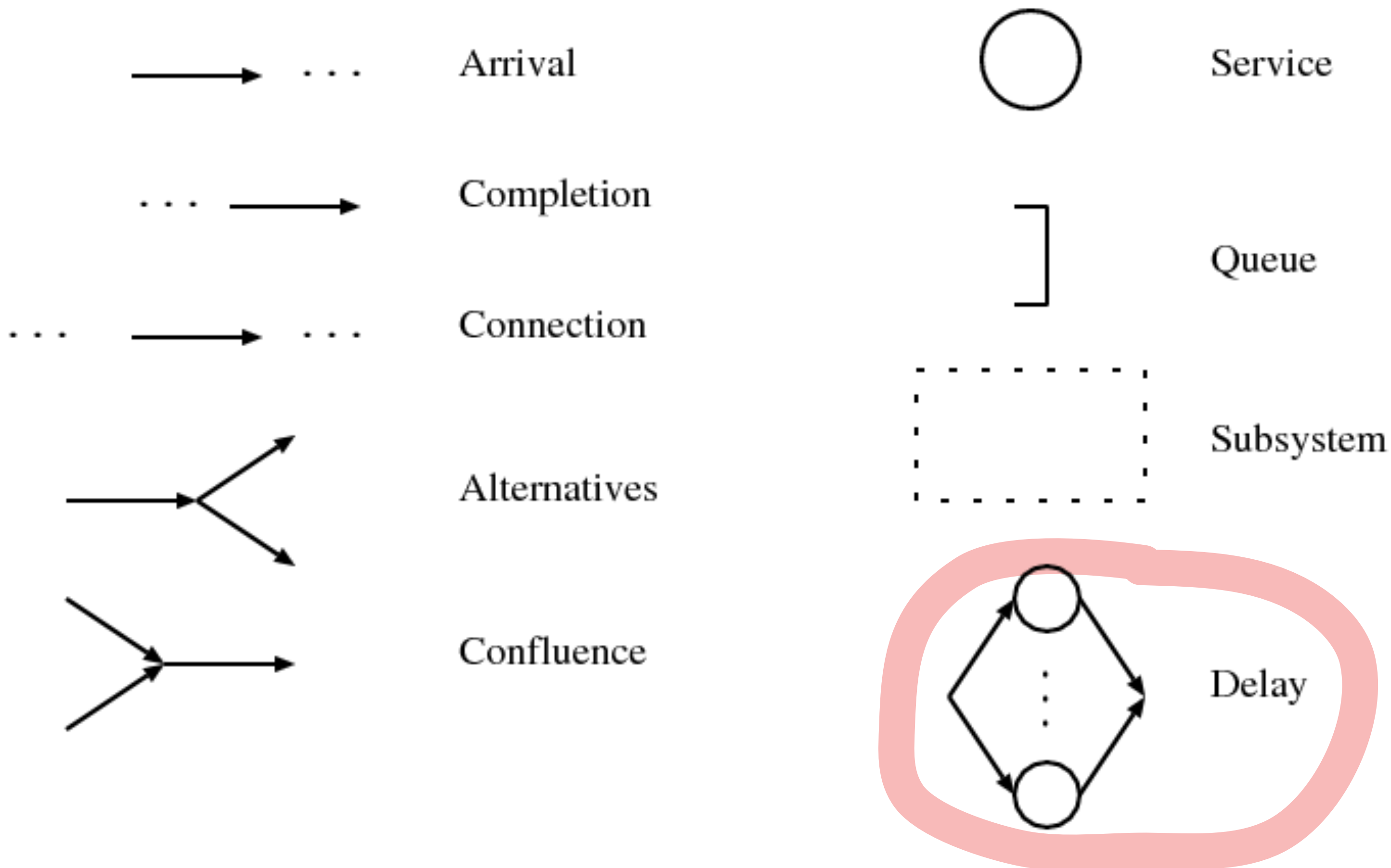


Queuing networks

In closed models we have a parameter *N* that accounts for the fixed population of jobs that continuously circulate inside the system



Graphical notation



- Graphical notation is not unique, but it usually corresponds to a graph where edges denotes the flow of customers in the network

Queueing networks

Different aspects characterize queuing models:

- Arrival
- Service
- Queue
- Population
- Routing

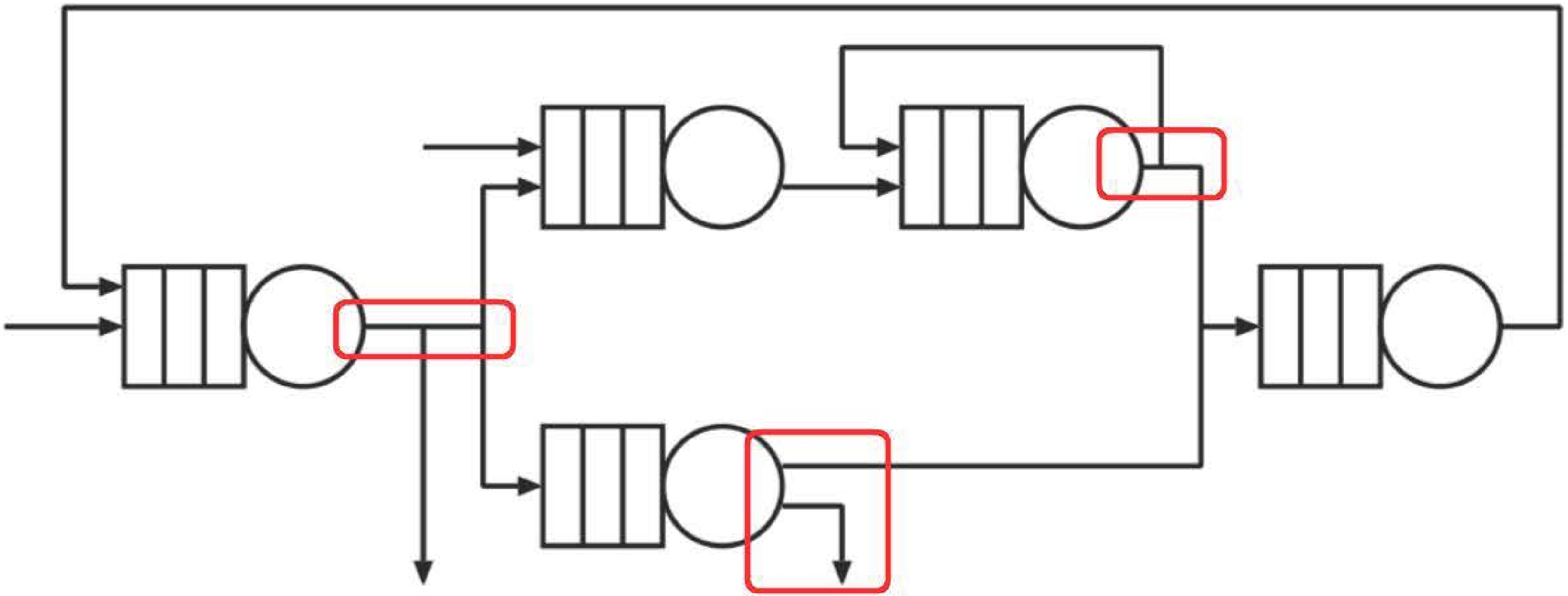
Routing

- Whenever a job, after finishing service at a station has several possible alternative routes, an appropriate selection policy must be defined

- The policy that describes how the next destination is selected is called routing

- Routing specification is required only in all the points where jobs exiting a station can have more than one destination

Routing

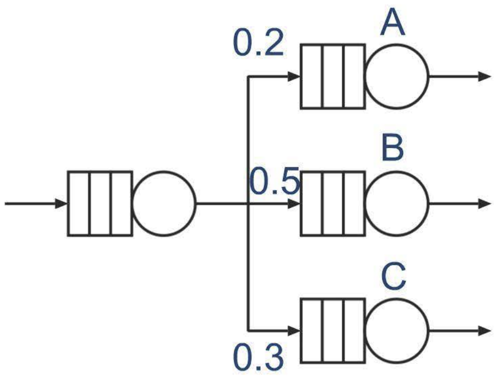


Routing

The main routing algorithms that we will consider are:

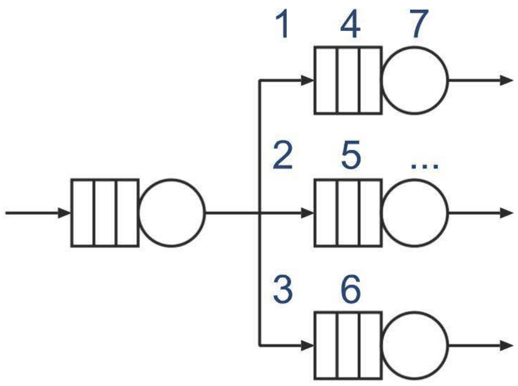
Probabilistic

- each path has assigned a probability of being chosen by the job that left the considered station



Round robin

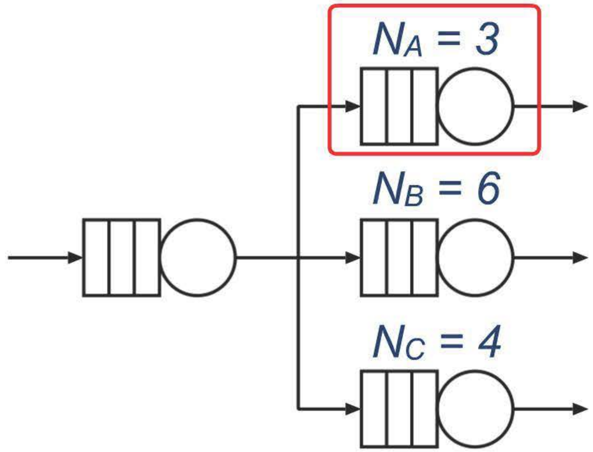
- the destination chosen by the job rotates among all the possible exits



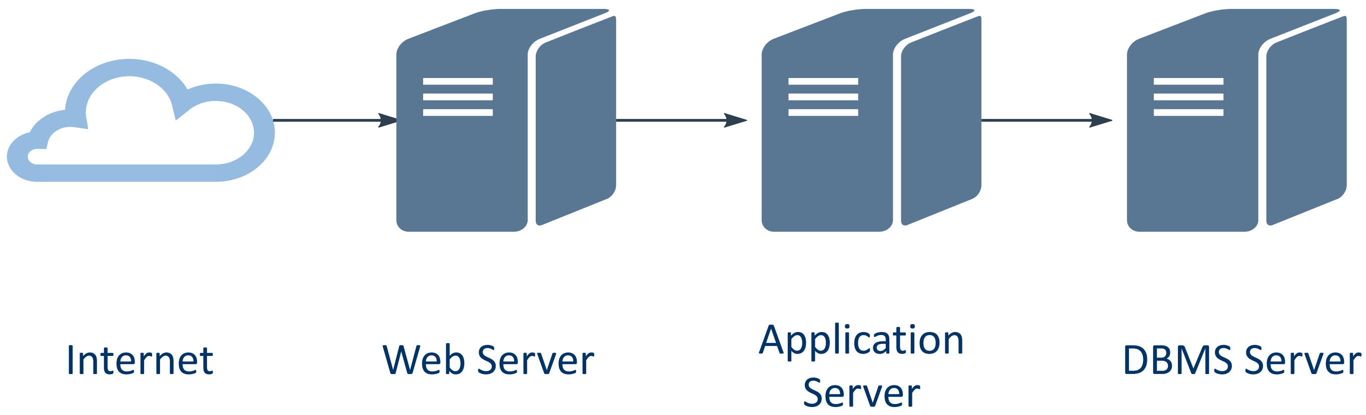
Routing

Join the shortest queue

- jobs can query the queue length of the possible destinations, and chose to move to the one with the smallest number of jobs waiting to be served



Open Networks: Examples



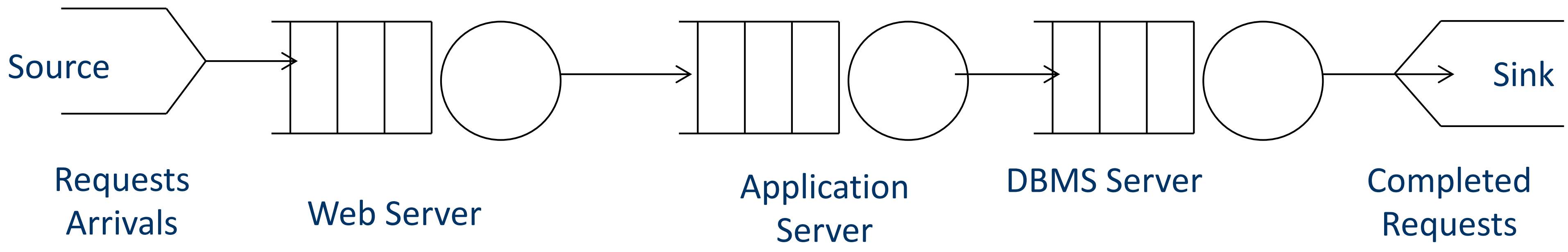
A client server system, dealing with external arrivals, which is architected with three tiers: the first one includes one web server, the second tier includes one application server and the third one includes a database server

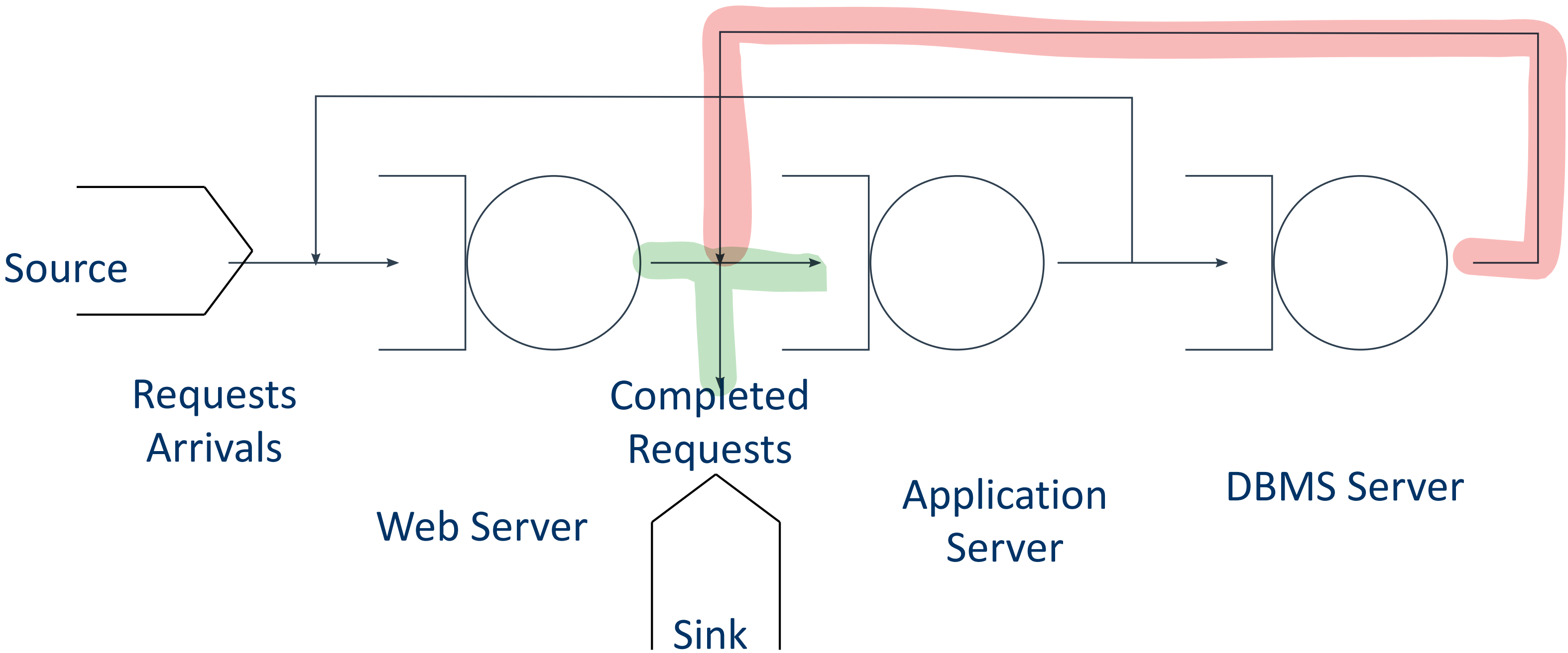
Provide a QN model of the system and evaluate the overall throughput considering that the network delay is negligible with respect to the other devices and two different cases:

1) The only thing we know is that each server should be visited by the application

2) In the second case we know that the application **after visiting the web server** requires some operations at **the application server** and then **can go back** to **the web server** and **leave** the system **or** can require service at the **DBMS** and then **go back** to the **application server**

Open Networks

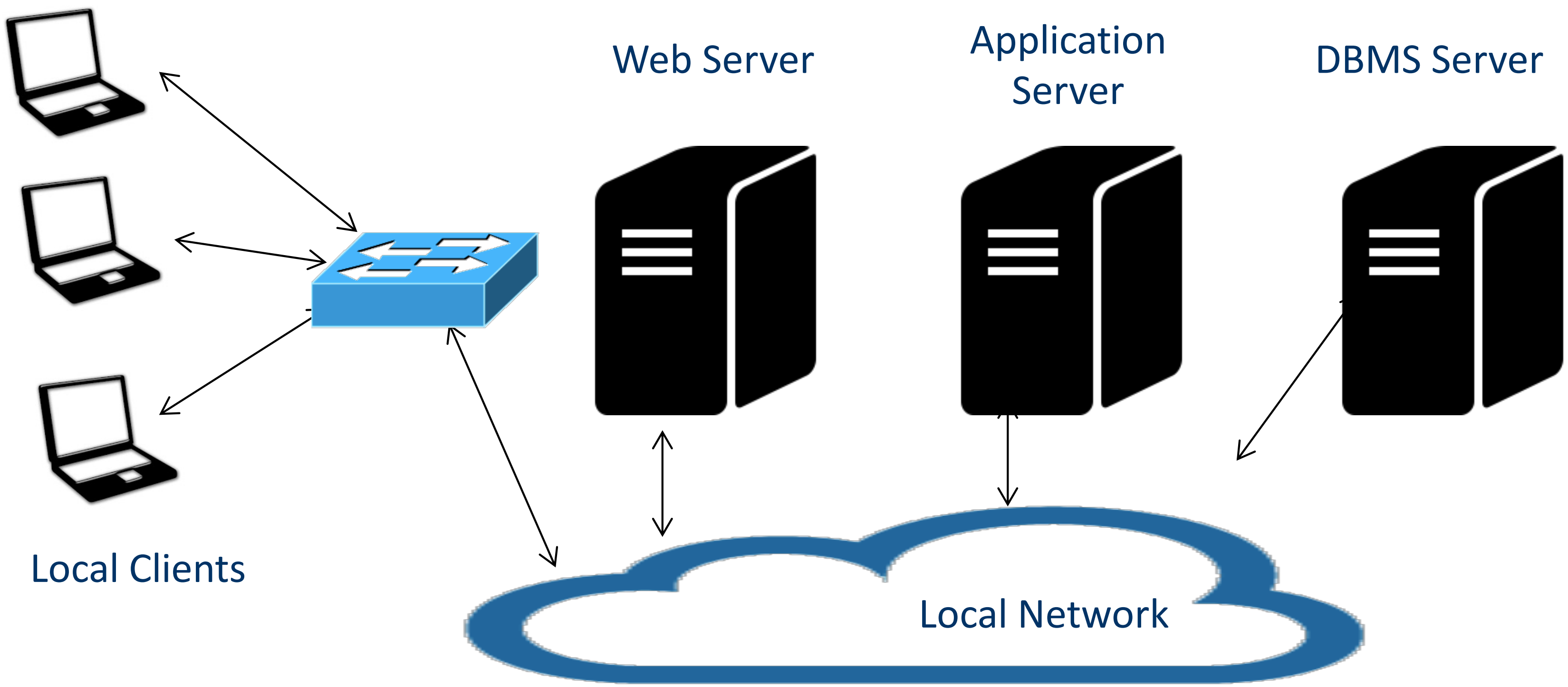




Scenario 1: Tandem networks

Tandem queuing networks are used for example to model production lines, where raw parts enter the systems, and after a set of stages, the final product is completed (and leaves)

Closed Networks: Examples

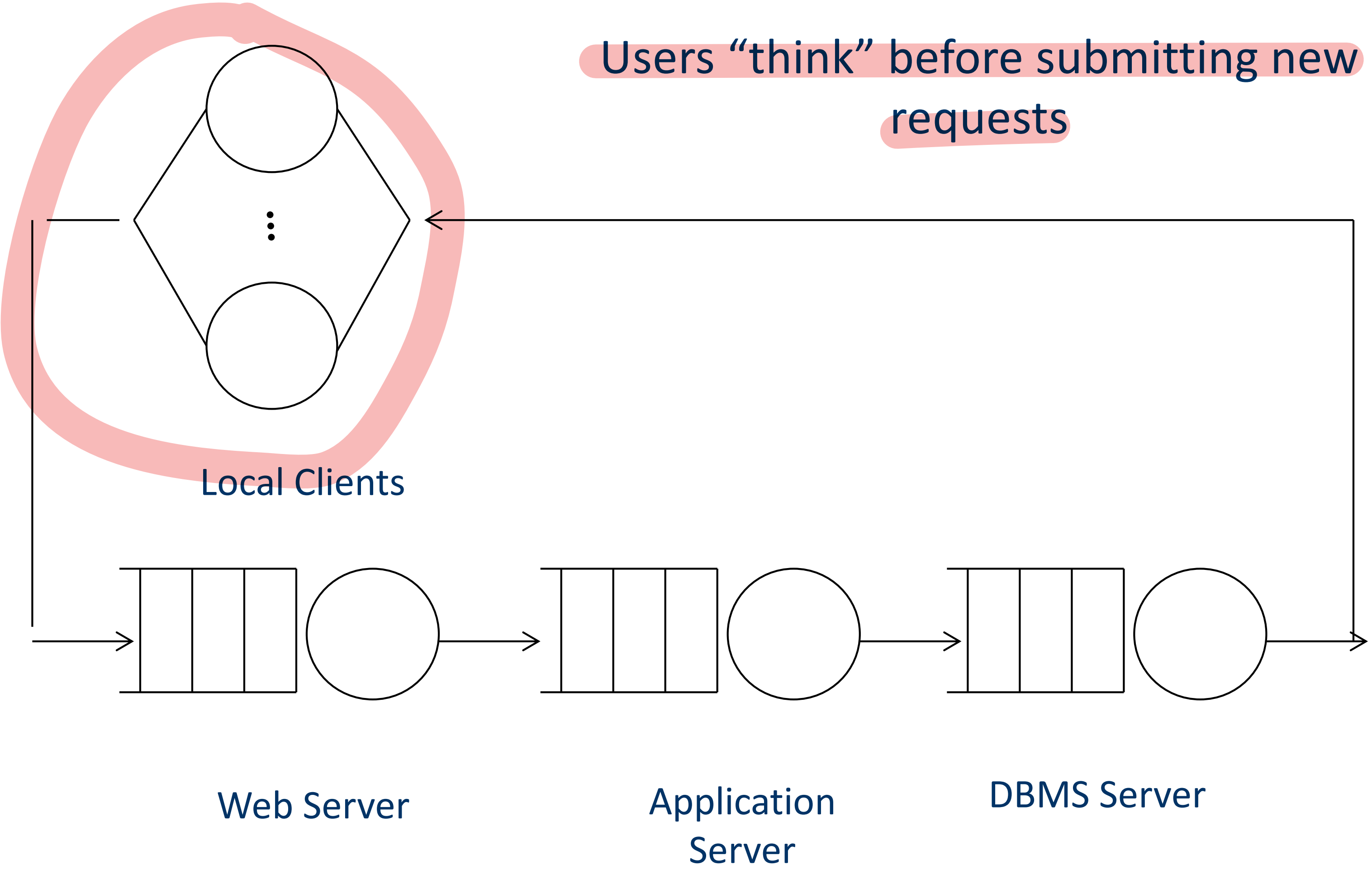


A client server system, **with a finite number of customers**, which is architected with three tiers: the first one includes one web server, the second tier includes one application server and the third one includes a database server.

Provide a QN model of the system and evaluate the system throughput considering that Network delay is negligible with respect to the other devices. Model the two different cases previously described.

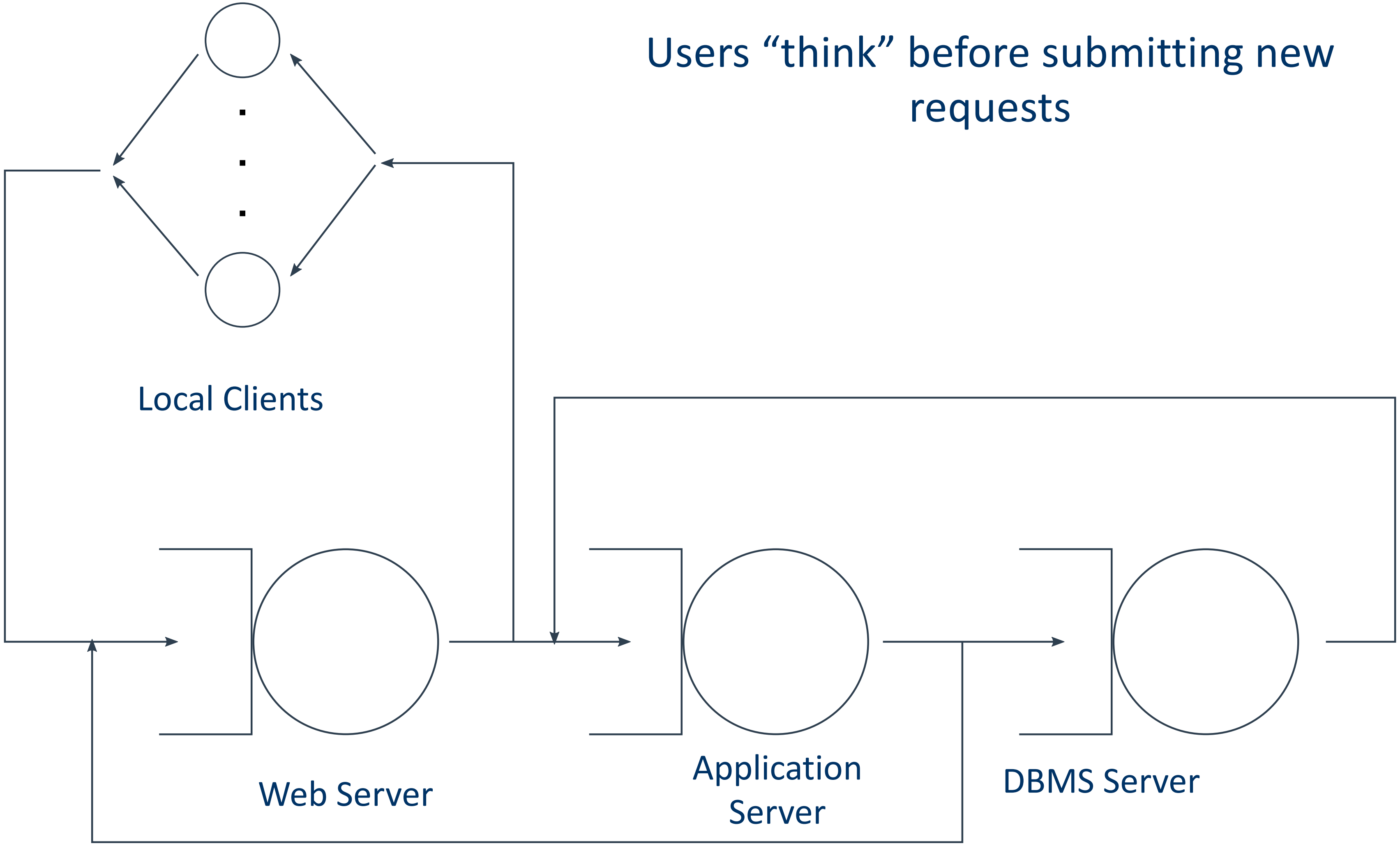
Closed Networks (first model)

Users “think” before submitting new requests

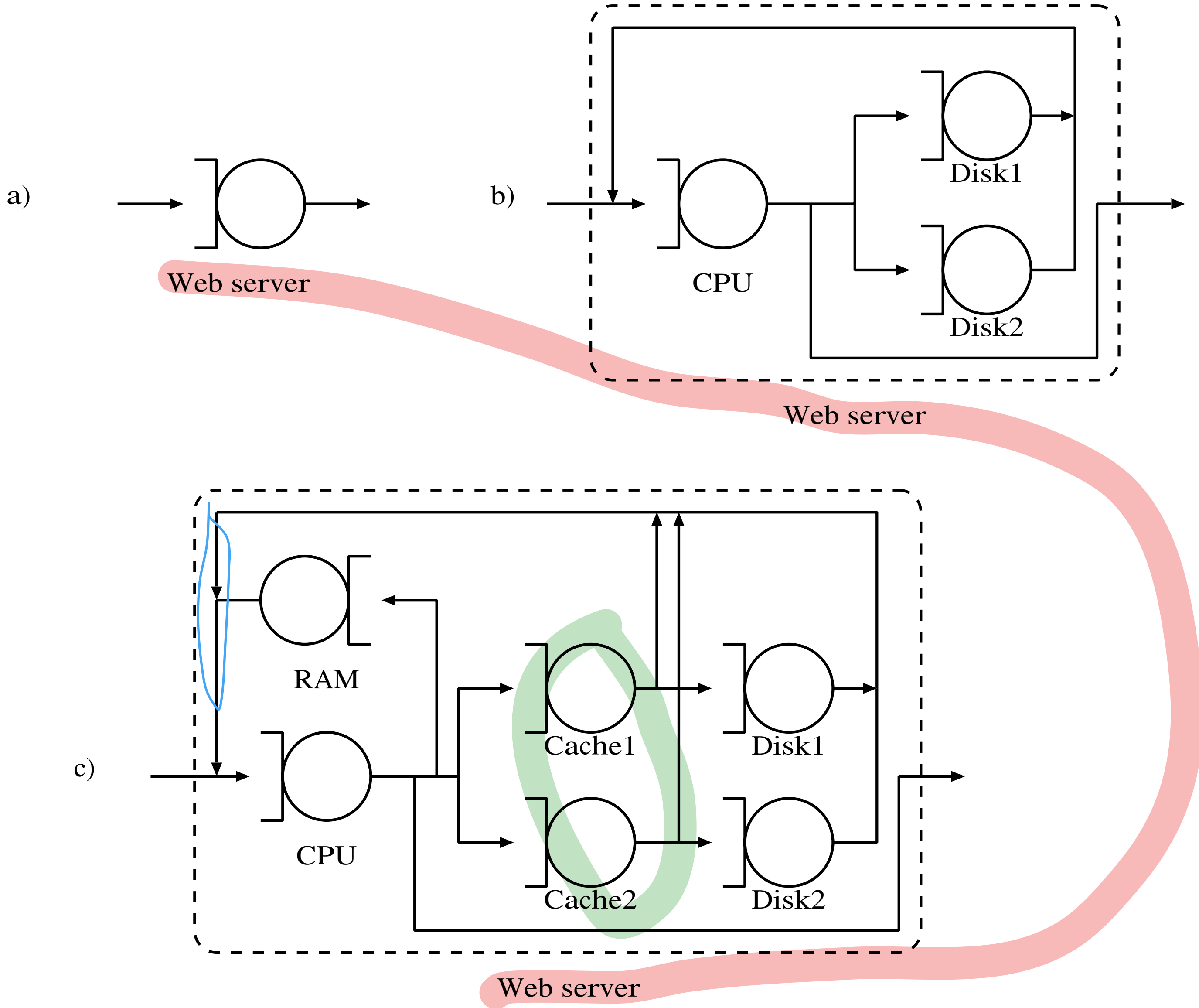


Closed Networks (second model)

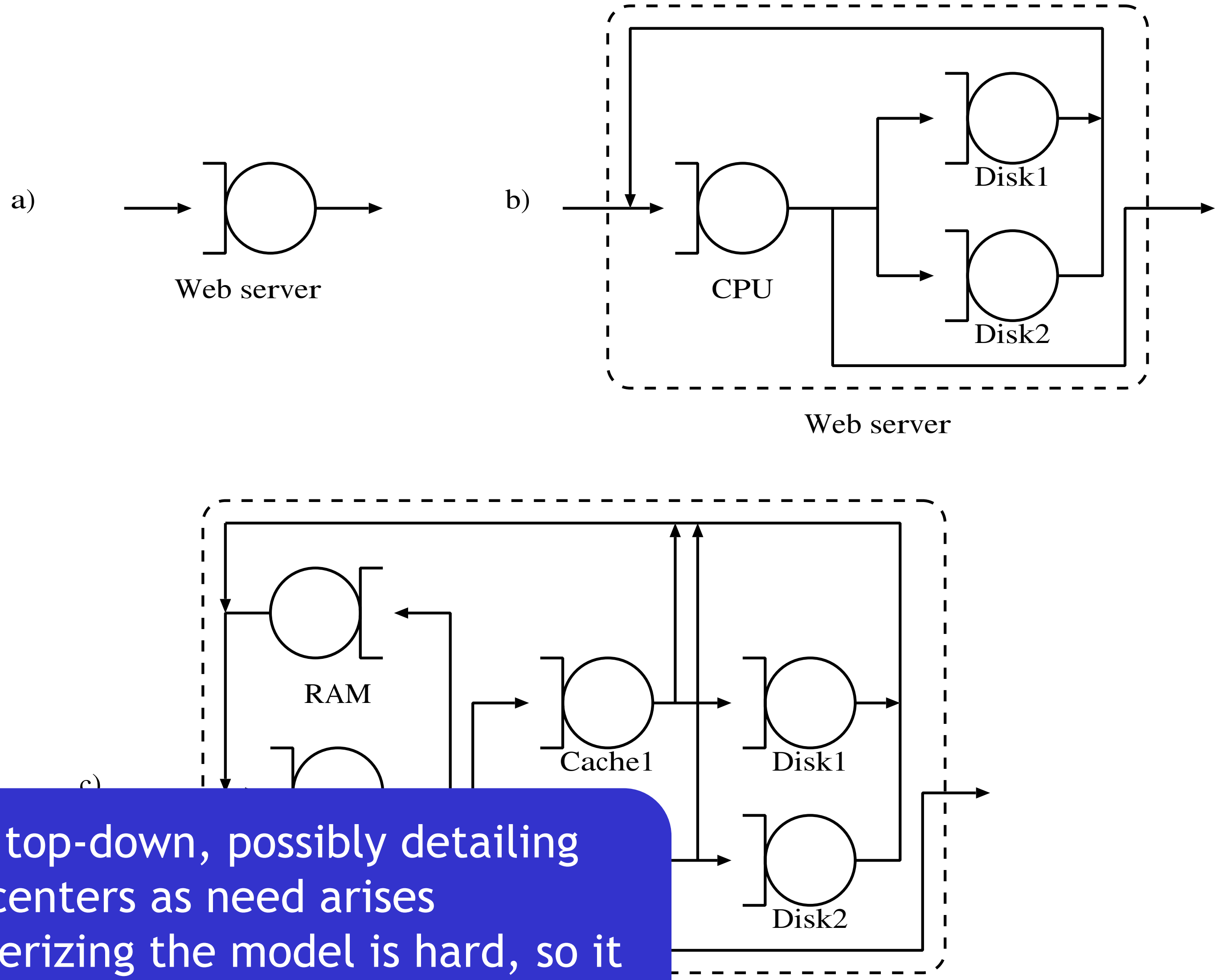
Users “think” before submitting new requests



Level of Detail



Level of Detail



- Proceed top-down, possibly detailing service centers as need arises
- Parameterizing the model is hard, so it is better to keep the complexity low