Case Study I: A Database Service

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- Most of the figures in this set of slides come from the book "Performance by Design: computer capacity planning by example," by Menascé, Almeida, and Dowdy, Prentice Hall, 2004. It is strictly forbidden to copy, post on a Web site, or distribute electronically, in part or entirely, any of the slides in this file.

DB Server Log Sample

	(msec) CPU	(count) Disk 1	(count) Disk 2	TR ID
1	116.824	9	9	18
2	64.383	7	9	37
3	35.403	7	9	58
4	104.409	8	12	77
5	119.793	9	8	19
6	47.956	5	7	1

OS Performance Measurements

Resource	Utilization (%)
CPU	45
Disk 1	75
Disk 2	65

Basic Statistics for the DB Service Workload

	CPU Time (msec)	No. I/Os Disk 1	No. I/Os Disk 2
Mean	238.2	51.38	44.85
Standard Deviation	165.9	27.0	26.4
Sample Variance	27510.4	728.7	698.1
Coeff. of Variation	0.696	0.525	0.677
Minimum	23.6	5	7
First Quartile (Q1)	104.4	33	26
Median (Q2)	151.6	63	39
Third Quartile (Q3)	418.1	72	68
Maximum	507.5	85	92
Range	483.9	80	85
Largest	507.5	85	92
Smallest	23.60	5	7
Sum	47640.8	10275	8969

$$CV = \frac{\text{standard deviation}}{\text{mean}}.$$

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Quantiles (quartiles, percentiles) and midhinge

- Quartiles: split the data into quarters.
  - First quartile (Q1): value of Xi such that 25% of the observations are smaller than Xi.
  - meadian – Second quartile (Q2): value of Xi such that 50% of the observations are smaller than Xi.
  - Third quartile (Q3): value of Xi such that 75% of the observations are smaller than Xi.
- Percentiles: split the data into hundredths.
- Midhinge: $Midhinge = \frac{Q_3 + Q_1}{2}$

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Example of Quartiles

1.05
1.06
1.09
1.19
1.21
1.28
1.34
1.34
1.77
1.80
1.83
2.15
2.21
2.27
2.61
2.67
2.77
2.83
3.51
3.77
5.76
5.78
32.07
144.91

Q1	1.32
Q2	2.18
Q3	3.00
Midhinge	2.16

In Excel:
Q1=PERCENTILE(<array>,0.25)
Q2=PERCENTILE(<array>,0.5)
Q3=PERCENTILE(<array>,0.75)

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Example of Percentile

1.05
1.06
1.09
1.19
1.21
1.28
1.34
1.34
1.77
1.80
1.83
2.15
2.21
2.27
2.61
2.67
2.77
2.83
3.51
3.77
5.76
5.78
32.07
144.91

80-percentile	3.613002

In Excel:
p-th percentile=PERCENTILE(<array>,p)
(0=p=1)

The 50th percentile is called the median.

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Range, Interquartile Range, Variance, and Standard Deviation

- Range: $X_{\max} - X_{\min}$
- Interquartile Range: $Q_3 - Q_1$
  - not affected by extreme values.
- Variance:

$$s^2 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}$$

In Excel:
s^2=VAR(<array>)

- Standard Deviation:

In Excel:
s=STDEV(<array>)

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n-1}}$$

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Meanings of the Variance and Standard Deviation

- The larger the spread of the data around the mean, the larger the variance and standard deviation.
- If all observations are the same, the variance and standard deviation are zero.
- The variance and standard deviation cannot be negative.
- Variance is measured in the square of the units of the data.
- Standard deviation is measured in the same units as the data.

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Coefficient of Variation

- Coefficient of variation (COV) : $s / \overline{X}$
  - no units

1.05
1.06
1.09
1.19
1.21
1.28
1.34
1.34
1.77
1.80
1.83
2.15
2.21
2.27
2.61
2.67
2.77
2.83
3.51
3.77
5.76
5.78
32.07
144.91

S	29.50
Average	9.51
COV	3.10

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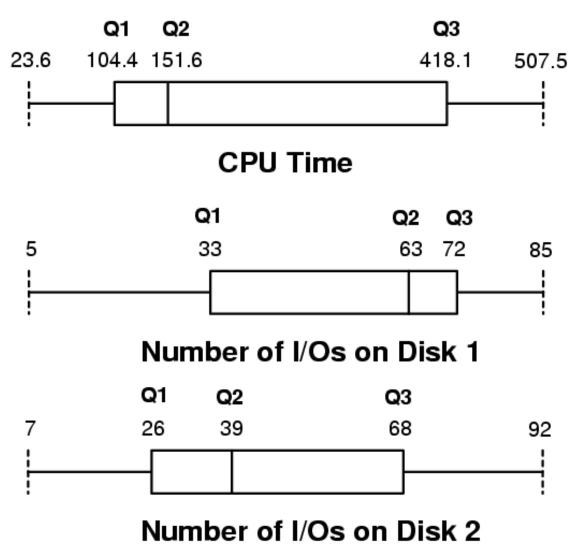
Box and Whisker Plots



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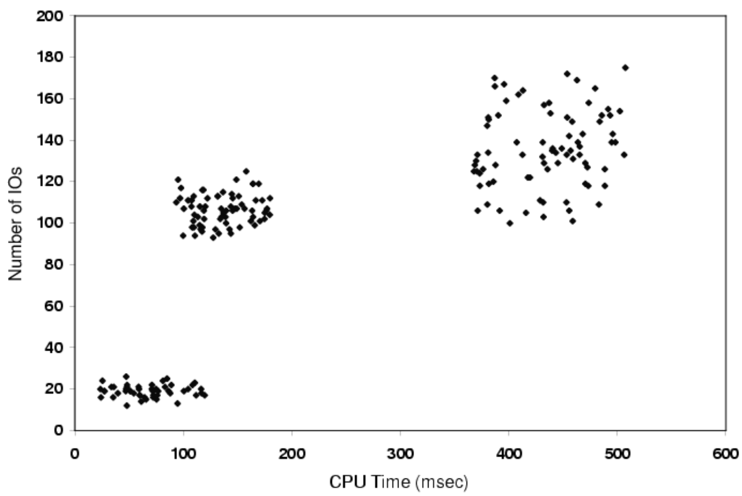
Total No. of I/Os vs CPU Time



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Result of Clustering Process

Cluster Number	CPU Time (msec)	I/Os disk 1	I/Os disk 2	Npoints
1	67.5	8.0	11.0	50
2	434.2	62.4	73.1	80
3	136.1	69.8	36.7	70

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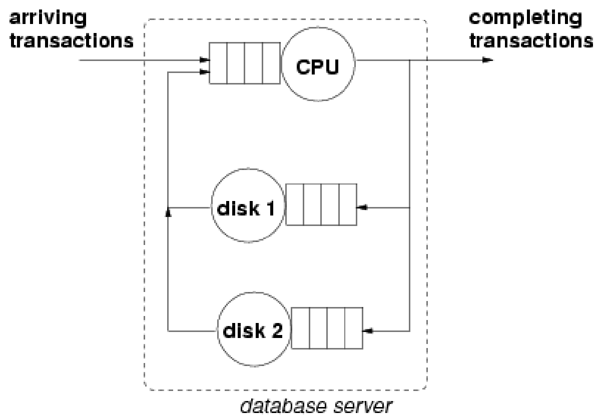
QN for the DB Server



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Building a Performance Model

- Need to apportion total resource utilizations to individual classes:

$$U_{i,r} = U_i \times f_{i,r}$$

The apportionment factor depends on the type of resource.

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CPU Apportionment Factor

$$f_{CPU,r} = \frac{\text{Total CPU Time for class r}}{\text{Total CPU Time for all classes}}$$

$$f_{CPU,1} = \frac{67.5 \times 50}{47640.8} = 0.071$$

$$f_{CPU,2} = \frac{434.2 \times 80}{47640.8} = 0.729$$

$$f_{CPU,3} = \frac{136.1 \times 70}{47640.8} = 0.200$$

Disk 1 Apportionment Factor

$$f_{disk-i,r} = \frac{\text{Total no. I/Os on disk i by class r}}{\text{Total no. I/Os on disk i for all classes}}$$

$$f_{disk-1,1} = \frac{8 \times 50}{10275} = 0.039$$

$$f_{disk-1,2} = \frac{62.4 \times 80}{10275} = 0.486$$

$$f_{disk-1,3} = \frac{69.8 \times 70}{10275} = 0.475$$

Disk 2 Apportionment Factor

$$f_{disk-i,r} = \frac{\text{Total no. I/Os on disk i by class r}}{\text{Total no. I/Os on disk i for all classes}}$$

$$f_{disk-2,1} = \frac{11 \times 50}{8969} = 0.061$$

$$f_{disk-2,2} = \frac{73.1 \times 80}{8969} = 0.652$$

$$f_{disk-2,3} = \frac{36.7 \times 70}{8969} = 0.287$$

Model Parameters

Log total time 150 sec Total Throughput 1.33

Apportionment Factors	Class 1	Class 2	Class 3	Total
CPU	0.071	0.729	0.2	1.00
Disk 1	0.039	0.486	0.475	1.00
Disk 2	0.061	0.652	0.287	1.00

Utilization Values	Class 1	Class 2	Class 3	Total
CPU	0.032	0.328	0.090	0.45
Disk 1	0.029	0.365	0.356	0.75
Disk 2	0.040	0.424	0.187	0.65

Class throughput 0.33 0.53 0.47

Service Demands	Class 1	Class 2	Class 3
CPU	0.096	0.615	0.193
Disk 1	0.088	0.683	0.763
Disk 2	0.119	0.795	0.400

Using the Model

Open Multiclass Queuing Networks - Residence Times

This wokbook comes with the books "Performance by Design," "Capacity Planning for Web Services" and "Scaling for E-Business"

by D. A. Menascé and V. A. F. Almeida, Prentice Hall, 2004, 2002 and 2000.

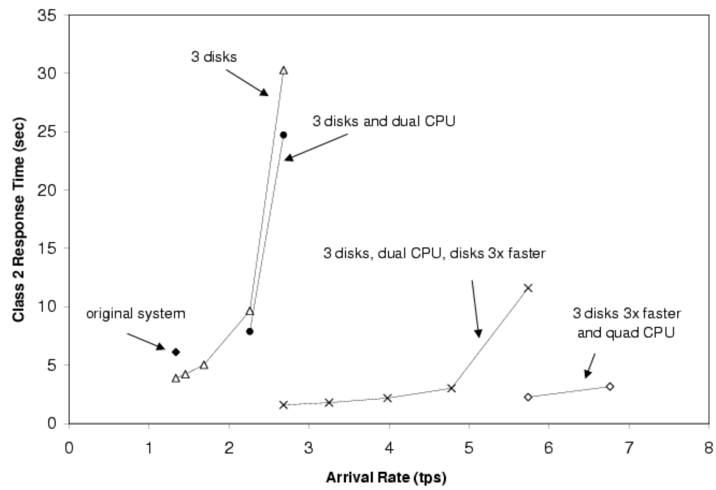
Queues ¯	**Classes** ® 1	2	3
CPU	0.17427	1.11835	0.35065
Disk 1	0.35100	2.73375	3.05357
Disk 2	0.33986	2.27036	1.14214
Response Time	0.86513	6.12246	4.54636

The ratio between the residence time and service demand at disk 1 is about 4.0 for all classes. This ratio is 0.8 and 1.9 for the CPU and disk 2. To improve performance, disk 1 needs to be upgraded.

Workload Intensity Variation

	Month	Arrival Rate (tps)
1	January	1.33
2	February	1.45
3	March	1.68
4	April	2.26
5	May	2.68
6	June	3.25
7	July	3.98
8	August	4.78
9	September	5.74
10	October	6.76

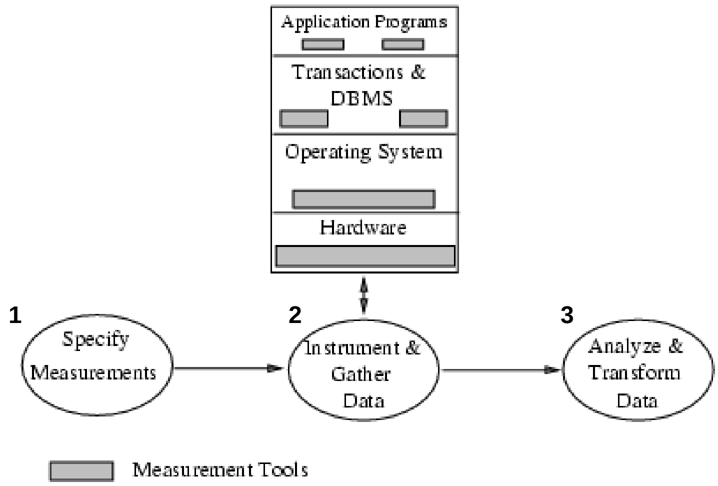
Class 2 Response Time for Various Scenarios



Monitoring Tools

- Hardware monitors
- Software monitors
  - Accounting systems
  - Program analyzers
- Hybrid Monitors
- Event-trace monitoring
- Sample monitoring

The Measurement Process



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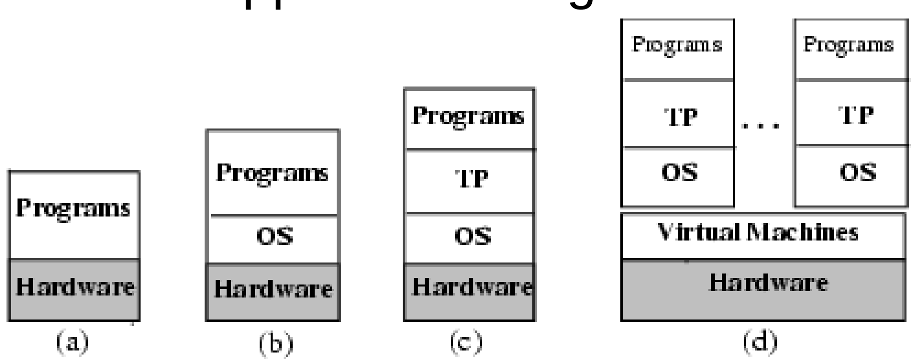
Execution Environments for Application Programs



The measurement of CPU utilization depends on the various software layers between the program and the bare machine.

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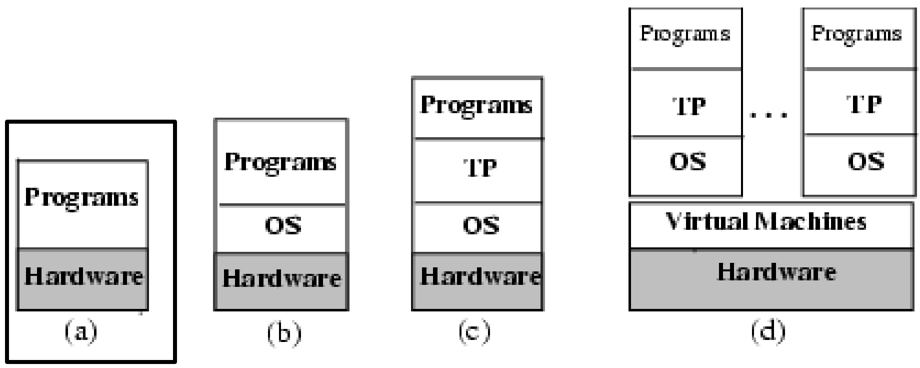
Execution Environments for Application Programs

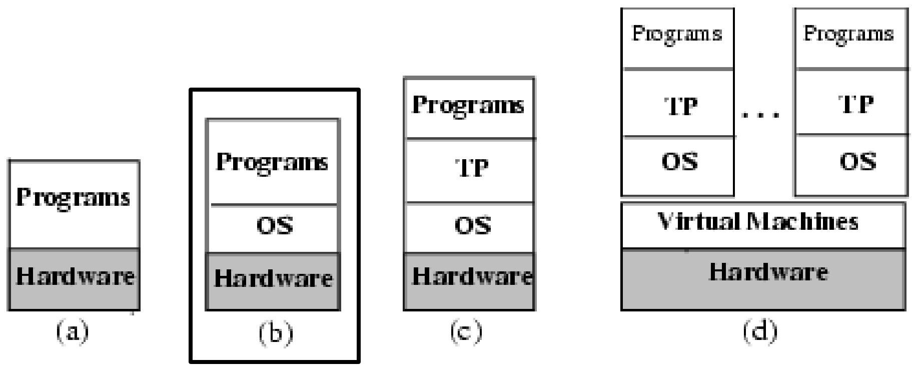


Bare Machine Example

- Consider an early computer with no OS that executes one program at a time. During 1,800 sec, a hardware monitor measures a utilization of 40% for the CPU and 100 batch jobs are recorded. The average CPU demand for each job is:

  0.4 x 1800 / 100 = 7.2 seconds

Execution Environments for Application Programs



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OS Example

- Consider a computer system running batch programs and interactive commands. The system is monitored for 1,800 sec and a software monitor measures the CPU utilization as 60%. The accounting log of the OS records CPU times for batch and for the 1,200 executed interactive commands separately. From this data, the class utilizations are batch = 40% and interactive = 12%.

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OS Example (cont'd)

- The CPU demand for the interactive class is given by

$$D_{cpu,\text{interactive}} = \frac{U_{cpu}^{t} \times f_{cpu,\text{interactive}}}{X_{0,\text{interactive}}}$$

$$= \frac{0.6 \times [0.12/(0.12 + 0.40)]}{1200/1800} = 0.208 \text{sec}$$

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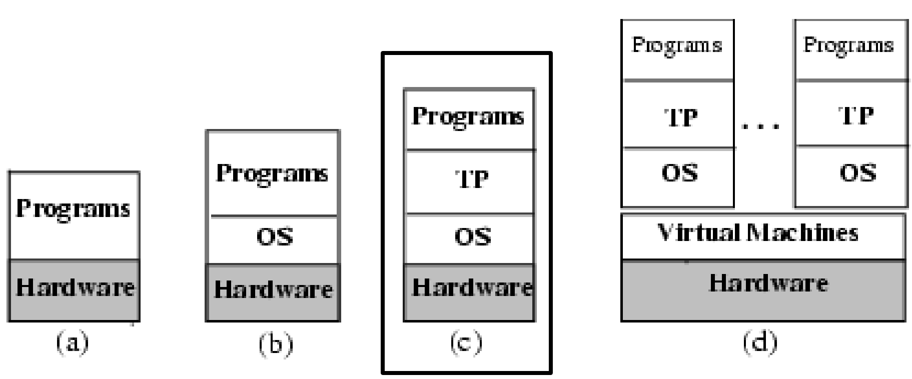
Execution Environments for Application Programs



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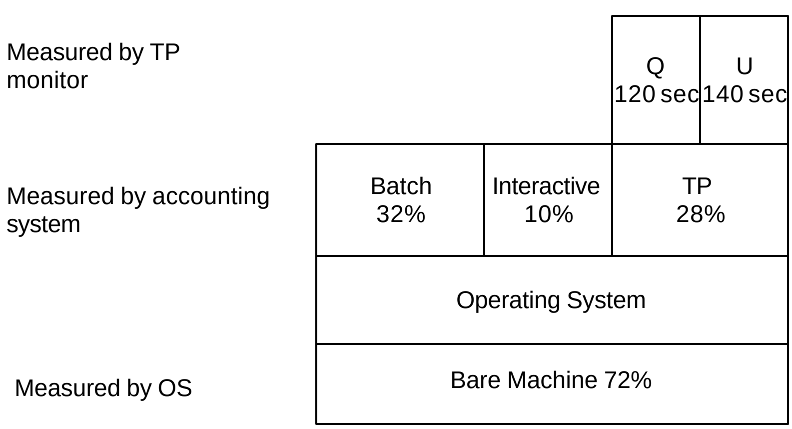
TP Example

- A mainframe processes 3 workload classes: batch (B), interactive (I), and transactions (T). Classes B and I run on top of the OS and class T runs on top of the TP monitor. There are two types of transactions: query (Q) and update (U). What is the service demand of update transactions.

TP Monitor Example



TP Example (cont'd)

- Measurements from the OS monitor during 1800 sec: CPU utilization is 72%.
- Measurements from the accounting facility:

$$U^{os}_{cpu,B} = 32\%$$

$$U^{os}_{cpu,I} = 10\%$$

$$U^{os}_{cpu,T} = 28\%$$

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TP Example (cont'd)

- Measurements from the program analyzer of the TP monitor:
  - 1200 query transactions, which consumed 120 sec of CPU.
  - 400 query transactions, which consumed 140 sec of CPU.

$$D_{cpu,U} = \frac{0.72 \times \frac{0.28}{0.32+0.10+0.28} \times \frac{140}{120+140}}{400/1800} = 0.698\text{sec}$$

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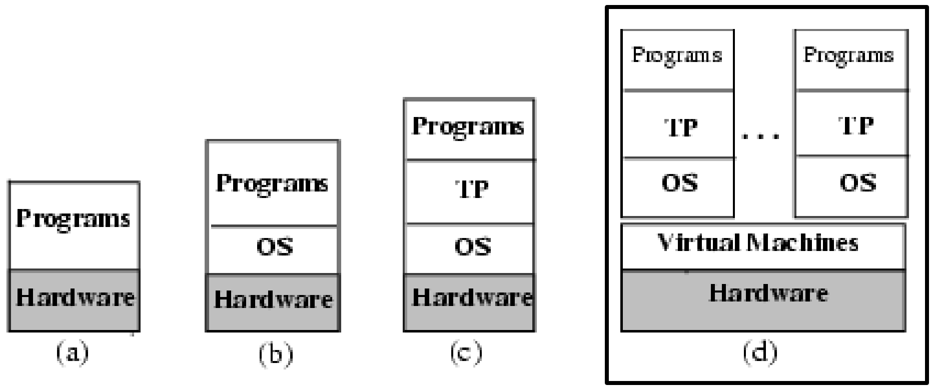
Execution Environments for Application Programs



VM Example

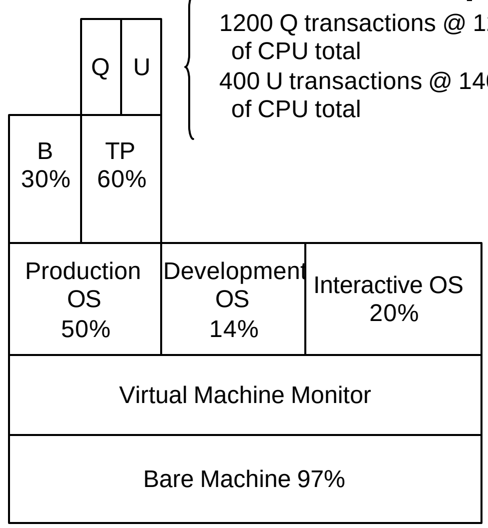
1200 Q transactions @ 120 sec of CPU total
400 U transactions @ 140 sec of CPU total

Measured by TP monitor

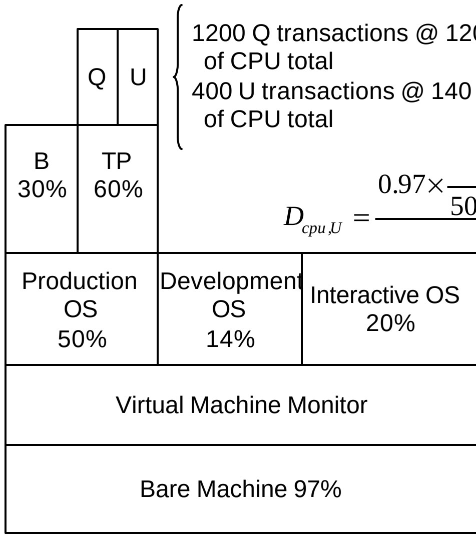
Measured by production OS monitor

Measured by VMM software monitor

Measured by system monitor



VM Example (cont'd)



1200 Q transactions @ 120 sec of CPU total
400 U transactions @ 140 sec of CPU total

$$D_{cpu,U} = \frac{0.97 \times \frac{50}{50+14+20} \times \frac{60}{30+60} \times \frac{140}{120+140}}{400/1800} = 0.933\,\text{sec}$$

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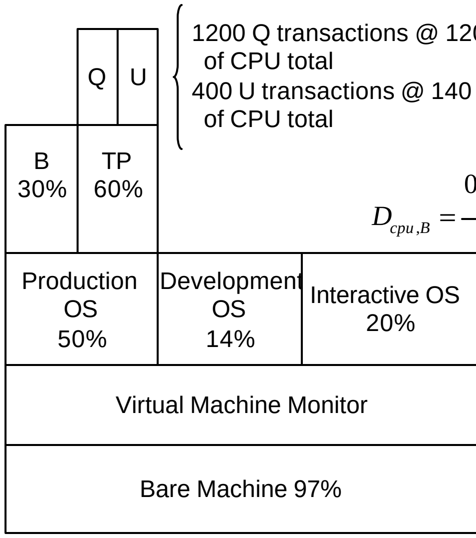
VM Example (cont'd)



1200 Q transactions @ 120 sec of CPU total
400 U transactions @ 140 sec of CPU total

$$D_{cpu,B} = \frac{0.97 \times \frac{50}{50+14+20} \times \frac{30}{30+60}}{80/1800} = 4.33\,\text{sec}$$

assuming that 80 batch jobs complete during the period.

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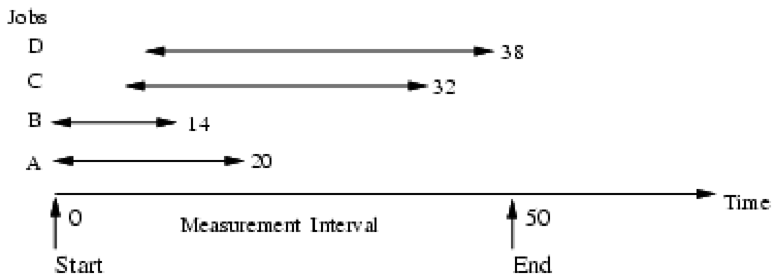
Computing the average concurrency level



$$\overline{N} = \frac{20 + 14 + 32 + 38}{50} = 2.08$$

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