

CS672

Software Performance Engineering for Client/Server Systems

Daniel A. Menascé, Ph.D.
Department of Computer Science
George Mason University

menasce@cne.gmu.edu

<http://www.cs.gmu.edu/faculty/menasce.html>

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

3

© 1997 Daniel A. Menascé

Motivating Example

- Recruitment and Training System (RTS)
 - applicants go to recruitment centers spread all over the country.
 - a guiding counselor interviews the applicant and tries to match the applicant skills with the agency's desired skills.
 - accepted applicants are recruited and are assigned to one or more training classes where they will acquire the skills needed for the job.

4

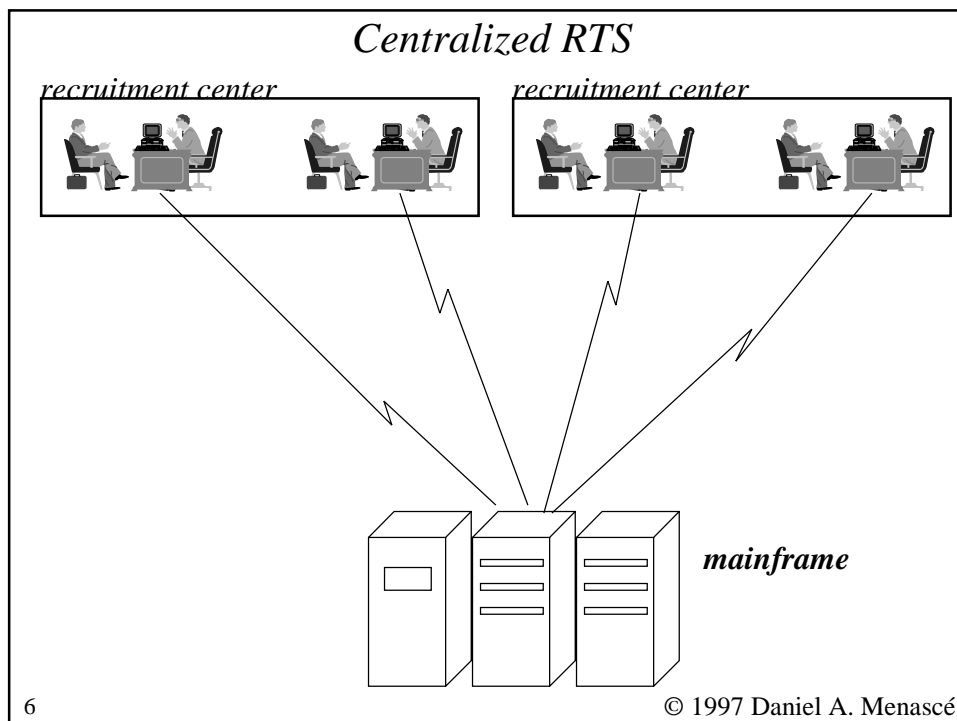
© 1997 Daniel A. Menascé

Motivating Example

- Current system:
 - centralized,
 - database and application on a mainframe,
 - line-oriented user interface,
 - expensive to maintain and upgrade (some programs are 20 years old),
 - does not scale well with the number of users.

5

© 1997 Daniel A. Menascé

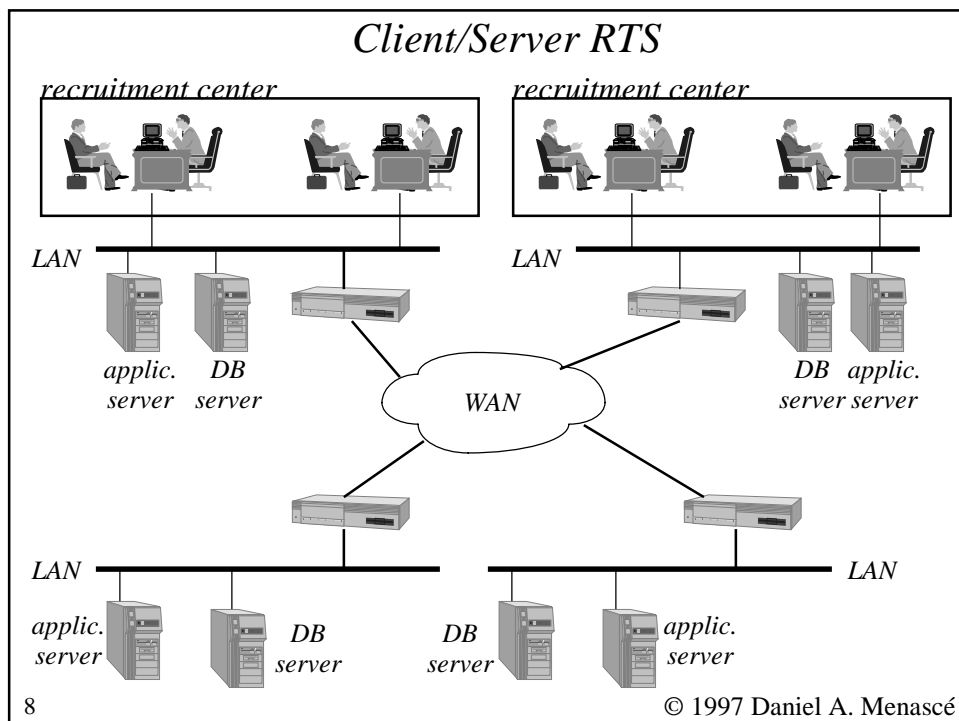


Motivating Example

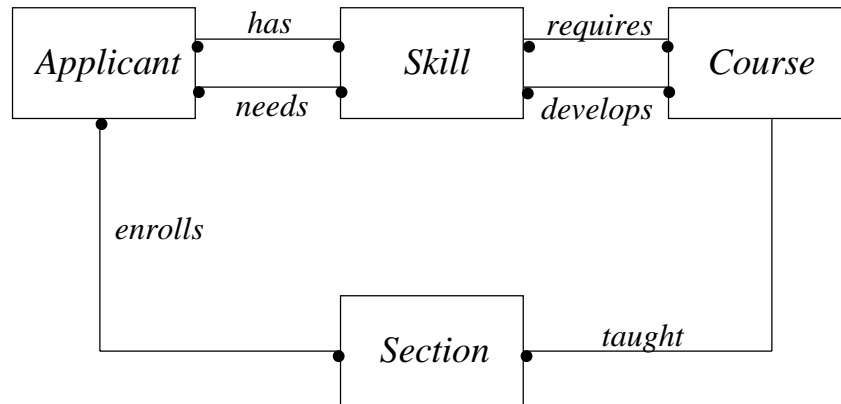
- The system will be migrated to a C/S environment with a GUI running at the clients.
- Application modules will be stored at different application servers and will be executed as needed.
- Several DB servers will store portions of the DB.

7

© 1997 Daniel A. Menascé



Motivating Example DB



9

© 1997 Daniel A. Menascé

Motivating Example DB Tables

Applicant

SSN	Name	StreetAddress	City	Zip	Phone	Education ...

Skill

SkillCode	SkillName	SkillDescription	SkillMinVal	SkillMaxVal

Course

CourseNum	CourseName	NumHours	Description

Section

CourseNum	SectionNum	StartDate	DayTime	Location	MaxCap

10

© 1997 Daniel A. Menascé

Motivating Example DB Tables

Enrollment

CourseNum	SectionNum	SSN

CourseDevelopsSkill

CourseNum	SkillCode

ApplicantHasSkill

SSN	SkillCode	SkillValue

CourseRequiresSkill

CourseNum	SkillCode

ApplicantNeedsSkill

SSN	SkillCode	SkillValue

11

© 1997 Daniel A. Menascé

Motivating Example SPE Questions

- How “thin” should the client software be?
 - How much work should be done at the client versus at the application server?
- How should the DB be distributed?
 - how many DB servers we need?
 - which tables should be stored in each DB server?
 - should tables be partitioned by rows and stored at different DB servers?
 - should tables be replicated and how?

12

© 1997 Daniel A. Menascé

Motivating Example SPE Questions

- What kind of hardware and OS platform should be used for the application servers?
- What kind of hardware and OS platform should be used for the DB servers?
- How many DB and application servers are needed and where should they be located?
- What type of networking technology and connectivity should be used?

13

© 1997 Daniel A. Menascé

Motivating Example SPE Questions

- What DBMS should be used to support the DB server?
- What indexes should be created on the various DB tables?

14

© 1997 Daniel A. Menascé

Motivating Example SPE General Questions

- *Will the new application meet the service level requirements?*
- *How many clients will be supported and at what cost?*

15

© 1997 Daniel A. Menascé

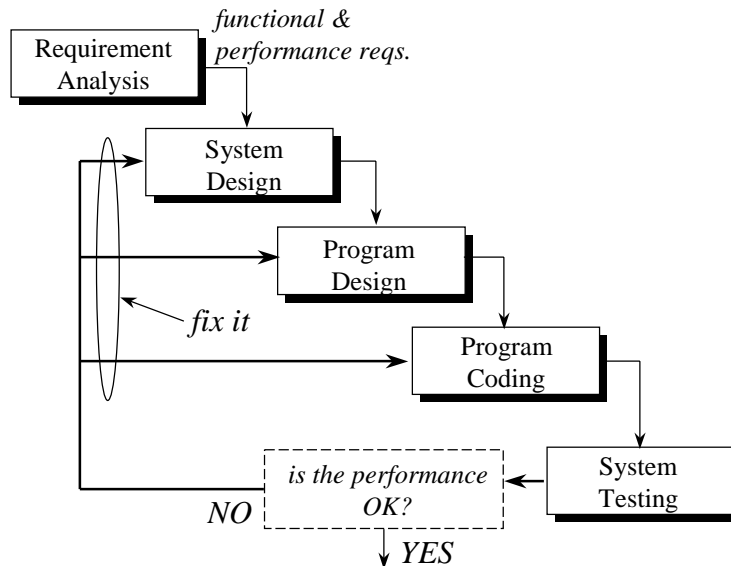
Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

16

© 1997 Daniel A. Menascé

Traditional Software Development Life Cycle



17

© 1997 Daniel A. Menascé

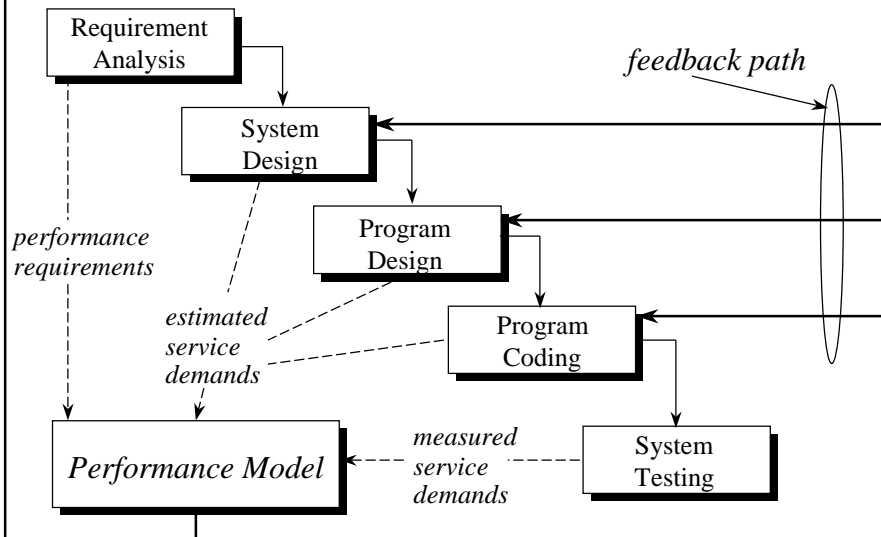
Traditional Software Development Life Cycle

- Common approach:
consider Functional Requirements only during development and check Performance Requirements at the end.
fix the system if performance is not good!
- Problem:
it is very costly and time consuming to fix the problem after the system is ready!
fixing the problem may imply in major software rewrites.

18

© 1997 Daniel A. Menascé

Integrating Software Performance Engineering Into the Software Development Life Cycle

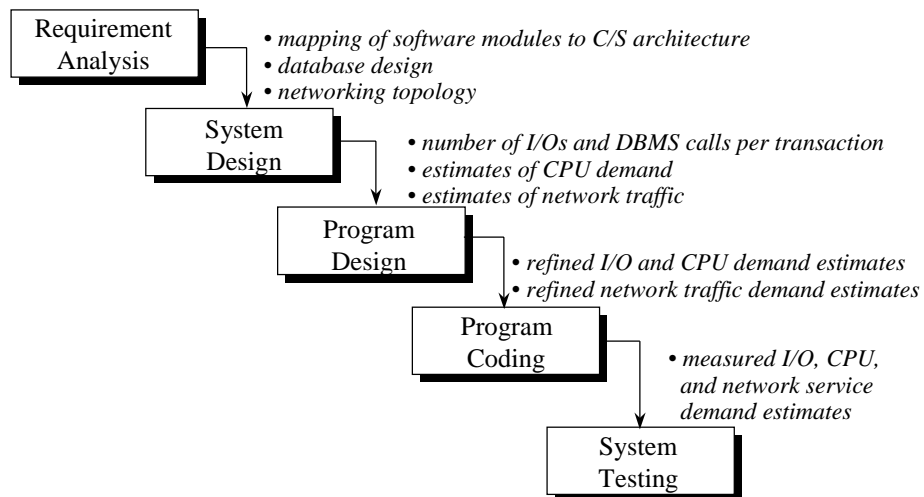


19

© 1997 Daniel A. Menascé

The Software Development Life Cycle and Inputs to SPE

- service levels (response times, throughputs, etc)
- hardware/software base (client and software platforms, networking technologies, DBMSs)



20

© 1997 Daniel A. Menascé

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

21

© 1997 Daniel A. Menascé

Main Steps in SPE for C/S Systems

Understand the Environment:

- determine the critical transactions using the 80/20 rule: 20% of transactions that are likely to use 80% of the resources.
- determine the cost and technology constraints
(e.g., what client and server H/S platforms should be used, what networking technologies are to be used)
- determine the service levels for the critical transactions.
- determine the base C/S architecture.
- is there a mainframe version of the application?

22

© 1997 Daniel A. Menascé

Main Steps in SPE for C/S Systems

Characterize the Workload:

- for each critical transaction, find:
 - estimated workload intensity (if there is a mainframe based system, get these from there).
 - estimated service demands for:
 - client and server processors
 - client and server disks
 - LAN segments
 - WANs
 - routers

23

© 1997 Daniel A. Menascé

Main Steps in SPE for C/S Systems

Build a Performance Model:

- build a performance (typically a queuing network model) that corresponds to the complete system.

Solve the Performance Model:

- obtain response times and throughputs per transaction
- obtain a break down of response time per device
- determine bottlenecks.

24

© 1997 Daniel A. Menascé

Main Steps in SPE for C/S Systems

Performance Assessment:

- compare estimated performance metrics with service levels.
- if performance is poor, verify where transactions spend most of their time and give feedback to system designers to cause changes in:
 - software architecture
 - work distribution between clients and servers
 - database allocation to servers
 - allocation of servers to networks
 - other

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

Clisspe: a Client Server Software Performance Engineering System

27

© 1997 Daniel A. Menascé

Clisspe: a Client Server Software Performance Engineering language

- Declaration Section
- Mapping Section
- Transaction Section

28

© 1997 Daniel A. Menascé

Clisspe Declaration Section

- clients and client types
- servers and server types
- disks and disk types
- database management systems
- database tables
- networks and network types
- transactions
- remote procedure calls
- numeric constants

29

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System

model rts

declaration ! declaration section for RTS example

dbms Oracle page_size= 2048;

! client types and client declarations

client_type Pentium120 specint92= 133 specfp92= 99

IO_benchmark (a= 0.001, b= 0.5);

client gc_DC type= Pentium120 number= 100

disk dsk01 seek= 0.01 latency= 0.00833 xfer_rate= 10;

client gc_LA type= Pentium120 number= 50

disk dsk01 seek= 0.01 latency= 0.00833 xfer_rate= 10;

client gc_WA type= Pentium120 number= 80

disk dsk01 seek= 0.01 latency= 0.00833 xfer_rate= 10;

30

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
! server types
server_type IBM_RS/6000_M43P133 ! DB server type
    specint_92= 176.4 specfp_92= 156.5
    IO_benchmark (a= 0.00005, b= 0.06) ;

server_type IBM_RS/6000_M43P120 ! application server type
    specint_92= 157.9 specfp_92= 139.2
    IO_benchmark (a= 0.00005, b= 0.06) ;
```

31

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
! application servers
server appl_DC type= IBM_RS/6000_M43P120
    num_CPUs= 1
    disk dsk01 seek= 0.015 latency= 0.00833 xfer_rate= 10;

server appl_LA type= IBM_RS/6000_M43P120
    num_CPUs= 1
    disk dsk01 seek= 0.015 latency= 0.00833 xfer_rate= 10;

server appl_WA type= IBM_RS/6000_M43P120
    num_CPUs= 1
    disk dsk01 seek= 0.015 latency= 0.00833 xfer_rate= 10;
```

32

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
! database servers
disk_type ServerDisk seek= 0.015 latency= 0.00833 xfer_rate= 10;

server DBserver_DC type= IBM_RS/6000_M43P133
  dbms= Oracle DB_BuffSize= 8192 num_CPUs= 2
  disk dsk01 type= ServerDisk disk dsk02 type= ServerDisk
  disk dsk03 type= ServerDisk;

server DBserver_LA type= IBM_RS/6000_M43P133
  dbms= Oracle DB_BuffSize= 8192 num_CPUs= 2
  disk dsk01 type= ServerDisk disk dsk02 type= ServerDisk disk
  dsk03 type= ServerDisk;

server DBserver_WA type= IBM_RS/6000_M43P133
  dbms= Oracle DB_BuffSize= 8192 num_CPUs= 2
  disk dsk01 type= ServerDisk disk dsk02 type= ServerDisk
  disk dsk03 type= ServerDisk;
```

33

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
! declaration of DB tables
table applicant num_rows= 1000000 row_size= 120 dbms= Oracle
  columns= (ssn, name, city/200, zip/99999, education/10)
  index= (key= (city) key_size= 20 btree)
  index= (key= (zip) key_size= 5 btree clustered);

table skill num_rows= 200 row_size= 100 dbms= Oracle
  columns= (SkillCode, SkillName, MinVal/4, MaxVal/4);

table course num_rows= 1000 row_size= 60 dbms= Oracle
  columns= (coursenum, cname, hours/3)
  index= (key= (coursenum) key_size= 4 btree clustered);

table section num_rows= 10000 row_size= 70 dbms= Oracle
  columns= (coursenum, SectionNum/10, StartDate/24, daytime/4,
  location/30, maxcap/4)
  index= (key= (location) key_size=20 btree clustered);
```

34

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
table enrollment num_rows= 400000 row_size= 20 dbms=oracle  
columns = (coursenum/1000, SectionNum/10, ssn)  
index= (key= (coursenum, SectionNum) btree clustered);  
  
table ApplicantHasSkill num_rows= 5000000 row_size= 16 dbms= Oracle  
columns= (ssn/1000000, SkillCode/200, SkillValue/4)  
index= (key= (ssn) key_size= 9 btree clustered);
```

Example of Clisspe Declaration Section for RTS System (continued)

```
table ApplicantNeedsSkill num_rows= 5000000 row_size= 16  
dbms= Oracle  
columns= (ssn/1000000, SkillCode/200, SkillValue/4)  
index= (key= (ssn) key_size= 9 btree clustered);  
  
table CourseDevelopsSkill num_rows= 3000 row_size= 12  
dbms= Oracle  
columns= (coursenum/1000, SkillCode/200)  
index= (key= (coursenum) key_size= 4 btree clustered);
```

Example of Clisspe Declaration Section for RTS System (continued)

```
! network declarations
network_type RecruitmentLan bandwidth= 10 type= Ethernet;
network_type CenterLan    bandwidth= 100 type= Fast_Ethernet;
network_type Enterprise   bandwidth= 45 type= WAN;

network LA_LAN    type= RecruitmentLan;
network NY_LAN    type= RecruitmentLan;
network WA_LAN    type= RecruitmentLan;
network Center_Lan type= CenterLan;
network EnterpriseNet type= Enterprise;
```

37

© 1997 Daniel A. Menascé

Example of Clisspe Declaration Section for RTS System (continued)

```
transaction apply rate= 0.001;
transaction check_skills rate= 0.002;
transaction enroll rate= 0.0001;

! rpc declarations
rpc RPCtoApplServer
    local_time= 0.0015 benchmark= 30 (specint92)
    remote_time= 0.0030 benchmark= 40 (specint92)
    nbytes= 2048;

end_declaration ;
```

38

© 1997 Daniel A. Menascé

Clisspe Mapping Section

- clients to networks
- servers to networks
- DB tables to servers
- transactions to clients
- network paths definitions
- transactions to network paths

Example of Clisspe Mapping Section for RTS System

mapping

! mapping of servers to networks

server appl_DC is_in network DC_LAN;

server appl_LA is_in network LA_LAN;

server appl_SE is_in network SE_LAN;

server DBServer is_in network CenterLan;

Example of Clisspe Mapping Section for
RTS System (continued)

! mapping of clients to networks
client gc_DC is_in network DC_LAN;
client gc_LA is_in network LA_LAN;
client gc_SE is_in network SE_LAN;

41

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for
RTS System (continued)

! mapping of tables to servers
table applicant is_in server DBServer
(dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);
table skill is_in server DBServer
(dsk01: 1.0);
table course is_in server DBServer
(dsk02: 1.0);
table section is_in server DBServer
(dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);

42

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

```
table enrollment is_in server DBServer  
  (dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);  
table ApplicantHasSkill is_in server DBServer  
  (dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);  
table ApplicantNeedsSkill is_in server DBServer  
  (dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);  
table CourseDevelopsSkill is_in server DBServer  
  (dsk01: 0.3, dsk02: 0.3, dsk03: 0.4);
```

43

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

```
! mapping of transactions  
transaction applyDC submitted_by  
  client gc_DC percent_rate= 0.2;  
transaction applyLA submitted_by  
  client gc_LA percent_rate= 0.35;  
transaction applySE submitted_by  
  client gc_SE percent_rate= 0.45;
```

44

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

*transaction check_skillsDC submitted_by
client gc_DC percent_rate= 0.2;
transaction check_skillsLA submitted_by
client gc_LA percent_rate= 0.35;
transaction check_skillsSE submitted_by
client gc_SE percent_rate= 0.45;*

Example of Clisspe Mapping Section for RTS System (continued)

*transaction enrollDC submitted_by
client gc_DC percent_rate= 0.2;
transaction enrollLA submitted_by
client gc_LA percent_rate= 0.35;
transaction enrollSE submitted_by
client gc_SE percent_rate= 0.45;*

Example of Clisspe Mapping Section for RTS System (continued)

! network paths to application servers
net_path applDC from client gc_DC
to server appl_DC via networks DC_LAN;
net_path applLA from client gc_LA
to server appl_LA via networks LA_LAN;
net_path applSE from client gc_SE
to server appl_SE via networks SE_LAN;

47

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

! network paths from application to DB servers
net_path dbaccessDC from client gc_DC
to server appl_DC to server DBServer
via networks DC_LAN, EnterpriseNet, CenterLan;
net_path dbaccessLA from client gc_LA
to server appl_LA to server DBServer
via networks LA_LAN, EnterpriseNet, CenterLan;
net_path dbaccessSE from client gc_SE
to server appl_SE to server DBServer
via networks SE_LAN, EnterpriseNet, CenterLan;

48

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

! mapping of transactions to network paths
transaction applyDC uses net_path applDC routing_frequency= 1.0;
transaction applyLA uses net_path applLA routing_frequency= 1.0;
transaction applySE uses net_path applSE routing_frequency= 1.0;
transaction applyDC uses net_path dbaccessDC routing_frequency= 1.0;
transaction applyLA uses net_path dbaccessLA routing_frequency= 1.0;
transaction applySE uses net_path dbaccessSE routing_frequency= 1.0;

49

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

transaction check_skillsDC uses net_path applDC
routing_frequency= 1.0;
transaction check_skillsLA uses net_path applLA
routing_frequency= 1.0;
transaction check_skillsSE uses net_path applSE
routing_frequency= 1.0;
transaction check_skillsDC uses net_path dbaccessDC
routing_frequency= 1.0;
transaction check_skillsLA uses net_path dbaccessLA
routing_frequency= 1.0;
transaction check_skillsSE uses net_path dbaccessSE
routing_frequency= 1.0;

50

© 1997 Daniel A. Menascé

Example of Clisspe Mapping Section for RTS System (continued)

```
transaction enrollDC uses net_path applDC  
    routing_frequency= 1.0;  
transaction enrollLA uses net_path applLA  
    routing_frequency= 1.0;  
transaction enrollSE uses net_path applSE  
    routing_frequency= 1.0;  
transaction enrollDC uses net_path dbaccessDC  
    routing_frequency= 1.0;  
transaction enrollLA uses net_path dbaccessLA  
    routing_frequency= 1.0;  
transaction enrollSE uses net_path dbaccessSE  
    routing_frequency= 1.0;  
end_mapping;
```

51

© 1997 Daniel A. Menascé

Clisspe Transaction Section Statements

- DB query (select)
- DB update
- rpc
- compute
- if then else
- switch
- loop

52

© 1997 Daniel A. Menascé

Example of Clisspe Transaction Section for RTS System (continued)

```
! transaction apply
transaction applyDC running_on client
  rpc RPCtoApplServer to_server appl_DC;
end_transaction;

transaction applyDC running_on server appl_DC
  ! check if applicant exists
  select from applicant where ssn;
  ! in ten percent of the cases the applicant is already in the DB
  if 0.9
  then ! add applicant to database
    update applicant num_rows= 1;
  end_if;
end_transaction; ! applyDC
```

53

© 1997 Daniel A. Menascé

Example of Clisspe Transaction Section for RTS System (continued)

```
! transaction check_skills
transaction check_skillsDC running_on client
  ! check if applicant exists
  rpc RPCtoApplServer to_server appl_DC;
  ! if applicant exists check applicant skills
  if 0.9
  then rpc RPCtoApplServer to_server appl_DC;
  end_if;
end_transaction;
```

54

© 1997 Daniel A. Menascé

Example of Clisspe Transaction Section for RTS System (continued)

```
transaction check_skillsDC running_on server appl_DC
  ! check if applicant exists
  select from applicant where ssn;
  ! if applicant exists check applicant skills
  if 0.9
  then ! find all courses the applicant qualifies for
    select from ApplicantHasSkill where ssn
      from CourseRequiresSkill where CourseNum
        joined_by ApplicantHasSkill.SkillCode =
          CourseRequiresSkill.SkillCode;
  end_if;
end_transaction;
```

55

© 1997 Daniel A. Menascé

Example of Clisspe Transaction Section for RTS System (continued)

```
transaction enrollDC running_on client
  ! for all courses to be enrolled
  loop #avg_courses_enrolled
    ! check seat availability for all sections
    loop #sections_checked
      rpc RPCtoApplServer to_server appl_DC;
    end_loop;
    ! enroll applicant in section
    rpc RPCtoApplServer to_server appl_DC;
  end_loop;
end_transaction;
```

56

© 1997 Daniel A. Menascé

Example of Clisspe Transaction Section for RTS System (continued)

```

transaction enrollDC running_on server appl_DC
! for all courses to be enrolled
loop #avg_courses_enrolled
  ! check seat availability for all sections
  loop #sections_checked
    select from enrollment where coursenum;
  end_loop;
  ! enroll applicant in section
  update enrollment num_rows = 1;
end_loop;
end_transaction;

```

57

© 1997 Daniel A. Menascé

Service Demand Generation

$$D_{i,r} = \sum_{s \in S_{i,r}} n_s \times p_s \times D_{i,r}^s$$

where,

$D_{i,r}^s$: average service demand at device i for class r due to statement s .

$S_{i,r}$: set of statements that generate demands at device i for class r .

n_s : average number of time that statement s is executed.

p_s : probability that statement s is executed.

58

© 1997 Daniel A. Menascé

Service Demand Generation

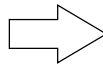
if 0.3 then

s1;

s2;

else s3;

end_if



$$p_{s1} = 0.3$$

$$p_{s2} = 0.3$$

$$p_{s3} = 0.7$$

59

© 1997 Daniel A. Menascé

Service Demand Generation

switch

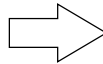
case 0.1: s1;

case 0.3: s2;

s3;

case 0.6: s4;

end_switch;



$$p_{s1} = 0.1$$

$$p_{s2} = 0.3$$

$$p_{s3} = 0.3$$

$$p_{s4} = 0.6$$

60

© 1997 Daniel A. Menascé

Service Demand Generation

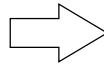
```
loop 3.5
```

```
  s1;
```

```
  s2;
```

```
  s3;
```

```
end_loop;
```



$$n_{s1} = 3.5$$

$$n_{s2} = 3.5$$

$$n_{s3} = 3.5$$

61

© 1997 Daniel A. Menascé

Service Demand Generation

```
loop 3.5
```

```
  if 0.3
```

```
  then s1;
```

```
    loop 2
```

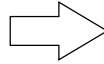
```
      s2;
```

```
    end_loop;
```

```
  else s3;
```

```
  end_if;
```

```
end_loop;
```

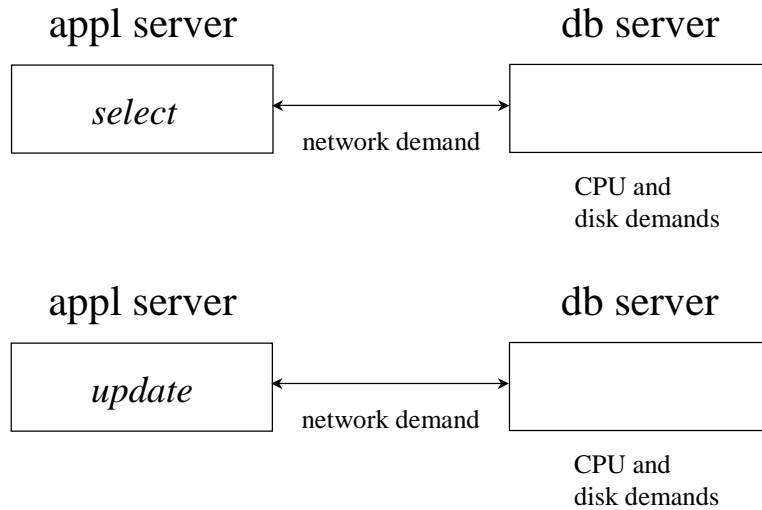


	n_s	p_s
s_1	3.5	0.3
s_2	7.0	0.3
s_3	3.5	0.7

62

© 1997 Daniel A. Menascé

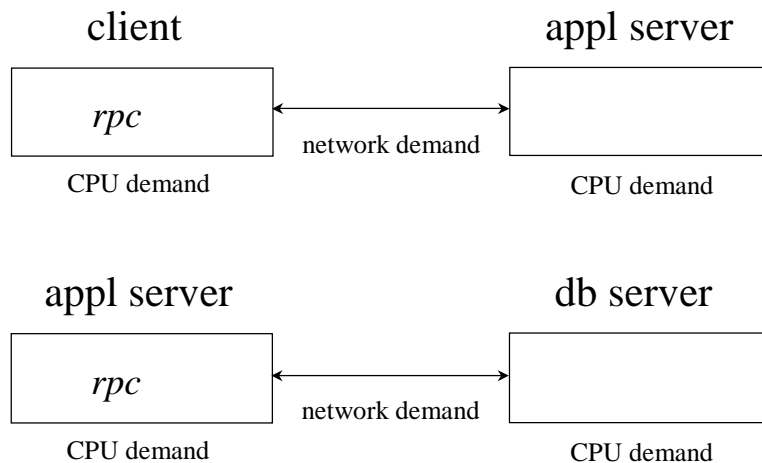
Service Demand Generation



63

© 1997 Daniel A. Menascé

Service Demand Generation



64

© 1997 Daniel A. Menascé

Service Demand Generation

client or server

compute

CPU demand

65

© 1997 Daniel A. Menascé

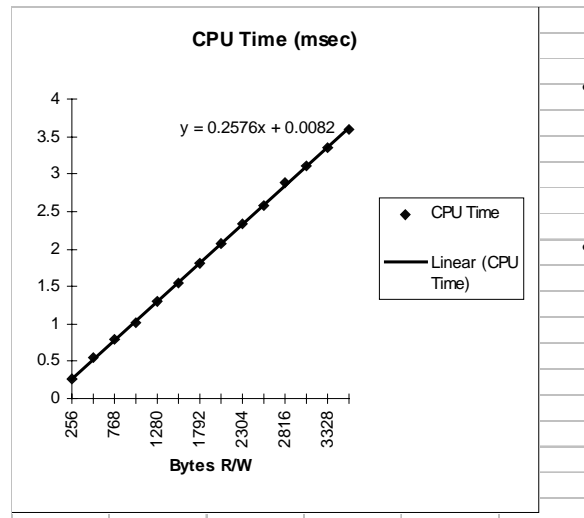
Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

66

© 1997 Daniel A. Menascé

Benchmarking and Data Collection



- The CPU time associated with I/O is linear with number of bytes read/written.

- Simple benchmark programs can be written to obtain the parameters of the line

$$y = a x + b$$

67

© 1997 Daniel A. Menascé

Benchmarking and Data Collection

The *server_type* command in Clisspe (see below) requires that the parameters *a* and *b* for the server be provided.

```
server_type SUNsparc20 specint92= 150 specfp92= 230
IO_benchmark (a= 0.2576, b= 0.0082, specint92= 100) ;
```

68

© 1997 Daniel A. Menascé

Benchmarking and Data Collection

1. Create a file called IO_bench with at least 800 blocks of 512 bytes each.
2. Write a program called IO_time with the following pseudo code:

```
#define Nblocks n    /* the value of this constant will change for each
                      execution of this program */
#define MAXBLOCKS 800 /* maximum number of blocks */
main ()
{
  int i, k, b;
  /* repeat experiment several times */
  for (k=1; k <= 50; ++k)
  { /* read n randomly selected blocks */
    for (i = 1; i <= n; ++i)
    { select an integer random number b between 1 and MAXBLOCKS;
      read block b from file IO_bench;
    }
  }
}
```

69

© 1997 Daniel A. Menascé

Benchmarking and Data Collection

3. Write a program called Loop_time with the pseudo code given below. This program is identical to program IO_time except that it does not have the read statement inside the loop

```
#define Nblocks n    /* the value of this constant will change for each
                      execution of this program */
#define MAXBLOCKS 800 /* maximum number of blocks */
main ()
{
  int i, k, b;
  /* repeat experiment several times */
  for (k=1; k <= 50; ++k)
  { for (i = 1; i <= n; ++i)
    { select an integer random number b between 1 and MAXBLOCKS;
    }
  }
}
```

70

© 1997 Daniel A. Menascé

Benchmarking and Data Collection

4. Run program `IO_time` for $n = 1, 5, 10, 15$, and 20 . For each execution of the program obtain the CPU time (not the elapsed time) and divide it by 50 .
5. Run program `Loop_time` for $n = 1, 5, 10, 15$, and 20 . For each execution of the program obtain the CPU time (not the elapsed time) and divide it by 50 .
6. Build the following table where the value in the last column is equal to the value in column 2 minus the value in column 3.

N	CPU time for IO_time / 50	CPU time for Loop_time / 50	number of bytes (x)	CPU time for I/O in msec (y)
1			512	
5			2560	
10			5120	
15			7680	
20			10240	

Apply linear regression to the last two columns of the table above to obtain the relationship
 $y = a x + b$

71

© 1997 Daniel A. Menascé

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

72

© 1997 Daniel A. Menascé

>>> List of Devices of the Performance Model

Dev. No.	Name	#Servers	Type
1	CL:gc_DC	1	Client
2	CL:gc_LA	1	Client
3	CL:gc_SE	1	Client
4	SP:appl_DC	1	Server Processor
5	SD:04:dsk01	1	Server Disk
6	SP:appl_LA	1	Server Processor
7	SD:06:dsk01	1	Server Disk
8	SP:appl_SE	1	Server Processor
9	SD:08:dsk01	1	Server Disk
10	SP:DBServer	2	Server Processor
11	SD:10:dsk01	1	Server Disk
12	SD:10:dsk02	1	Server Disk
13	SD:10:dsk03	1	Server Disk
14	NT:DC_LAN	1	Network
15	NT:LA_LAN	1	Network
16	NT:SE_LAN	1	Network
17	NT:CenterLan	1	Network
18	NT:EnterpriseNet	1	Network

73

© 1997 Daniel A. Menascé

>>> List of Workloads of the Performance Model

Workload No.	Workload Name	Arr. Rate (tps)
1	applyDC:gc_DC	0.02000
2	applyLA:gc_LA	0.01750
3	applySE:gc_SE	0.03600
4	check_skillsDC:gc_DC	0.04000
5	check_skillsLA:gc_LA	0.03500
6	check_skillsSE:gc_SE	0.07200
7	enrollDC:gc_DC	0.00200
8	enrollLA:gc_LA	0.00175
9	enrollSE:gc_SE	0.00360

74

© 1997 Daniel A. Menascé

```
>>> Matrix of service demands (in sec):
```

	1	2	3	4	5	...
1	0.00034	0.00000	0.00000	0.00064	0.00000	...
2	0.00000	0.00034	0.00000	0.00000	0.00064	...
3	0.00000	0.00000	0.00034	0.00000	0.00000	...
4	0.00195	0.00000	0.00000	0.00386	0.00000	...
5	0.00000	0.00000	0.00000	0.00000	0.00000	...
6	0.00000	0.00195	0.00000	0.00000	0.00386	...
7	0.00000	0.00000	0.00000	0.00000	0.00000	...
8	0.00000	0.00000	0.00195	0.00000	0.00000	...
9	0.00000	0.00000	0.00000	0.00000	0.00000	...
10	0.00043	0.00043	0.00043	0.00097	0.00097	...
11	0.02547	0.02547	0.02547	0.04098	0.04098	...
12	0.02547	0.02547	0.02547	0.04098	0.04098	...
13	0.03397	0.03397	0.03397	0.05464	0.05464	...
14	0.00381	0.00000	0.00000	0.00677	0.00000	...
15	0.00000	0.00381	0.00000	0.00000	0.00677	...
16	0.00000	0.00000	0.00381	0.00000	0.00000	...
17	0.00017	0.00017	0.00017	0.00031	0.00031	...
18	0.00039	0.00039	0.00039	0.00068	0.00068	...

75

© 1997 Daniel A. Menascé

```
>>> Response Times
```

Transaction Name	Resp. Time (sec)	Throughput (tps)
applyDC:gc_DC	0.0929	0.02000
applyLA:gc_LA	0.0929	0.01750
applySE:gc_SE	0.0929	0.03600
check_skillsDC:gc_DC	0.1513	0.04000
check_skillsLA:gc_LA	0.1513	0.03500
check_skillsSE:gc_SE	0.1513	0.07200
enrollDC:gc_DC	0.9772	0.00200
enrollLA:gc_LA	0.9772	0.00175
enrollSE:gc_SE	0.9774	0.00360

76

© 1997 Daniel A. Menascé

>>> Bottleneck Analysis

Transaction Name	Bottleneck	% Contr.
applyDC:gc_DC	SD:10:dsk03	37.02
applyLA:gc_LA	SD:10:dsk03	37.02
applySE:gc_SE	SD:10:dsk03	37.02
check_skillsDC:gc_DC	SD:10:dsk03	36.57
check_skillsLA:gc_LA	SD:10:dsk03	36.57
check_skillsSE:gc_SE	SD:10:dsk03	36.57
enrollDC:gc_DC	SD:10:dsk03	27.30
enrollLA:gc_LA	SD:10:dsk03	27.30
enrollSE:gc_SE	SD:10:dsk03	27.30

Outline

- Motivating Example
- Basic Issues in SPE
- A Methodology for SPE in C/S
- *Clisspe*: A Language for SPE in C/S
- Benchmarking and Data Collection for SPE
- A Case Study
- Concluding Remarks

Concluding Remarks

- Software performance engineering for C/S systems requires a language to describe the clients, servers, networks, connectivity, DB tables, mappings, and transactions.
- The compiler for the language should generate a performance model that generates performance metrics for the C/S system.