CS672
Software Performance Engineering for Client/Server Systems

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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

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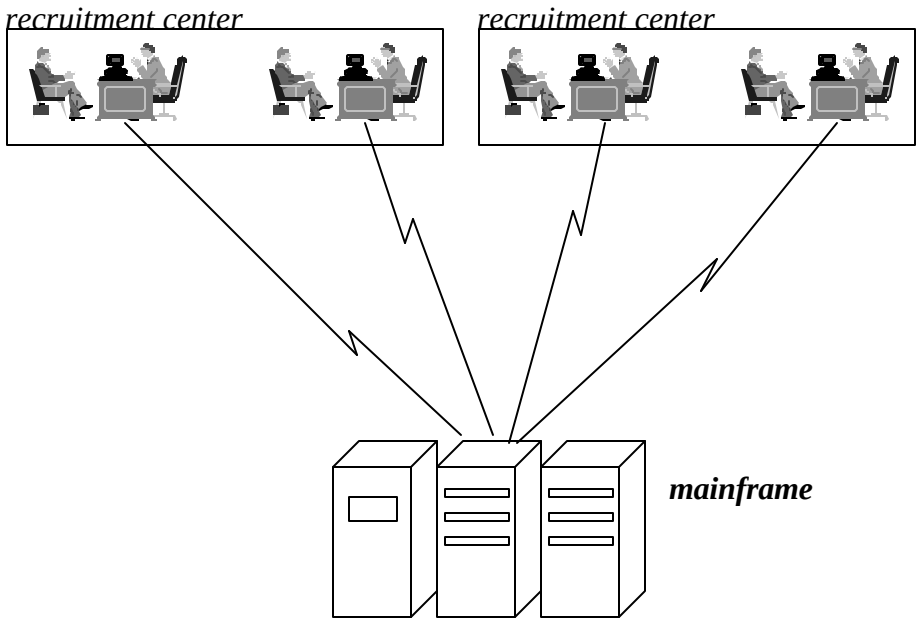
Motivating Example

- 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.

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.

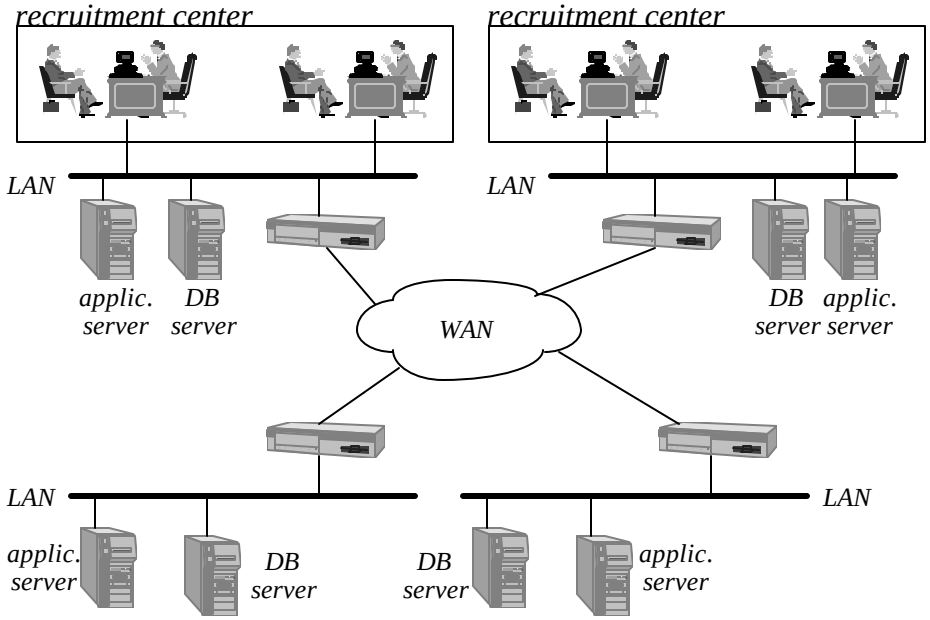
Centralized RTS



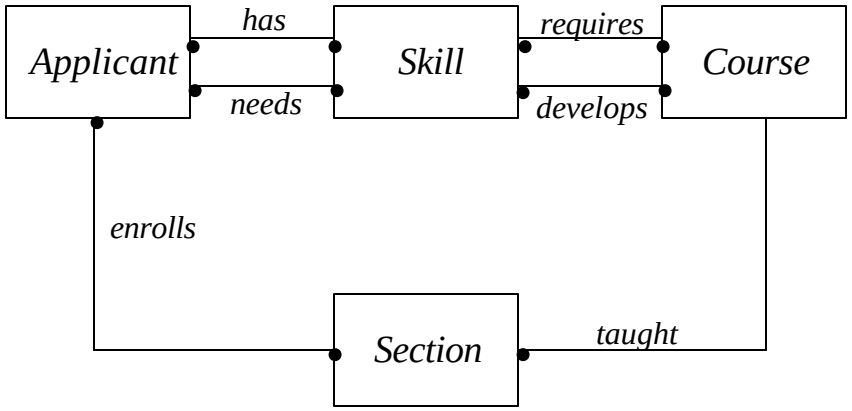
Motivating Example

- 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.

Client/Server RTS



Motivating Example DB



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

Motivating Example DB Tables

Enrollment

CourseNum	SectionNum	SSN

CourseDevelopsSkill

CourseNum	SkillCode

ApplicantHasSkill

SSN	SkillCode	SkillValue

CourseRequiresSkill

CourseNum	SkillCode

ApplicantNeedsSkill

SSN	SkillCode	SkillValue

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?

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?

Motivating Example
SPE Questions

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

Motivating Example
SPE General Questions

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

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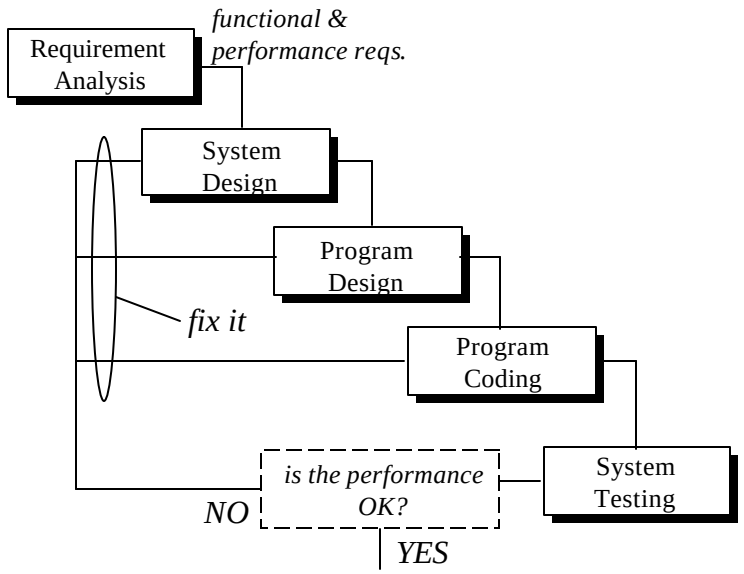
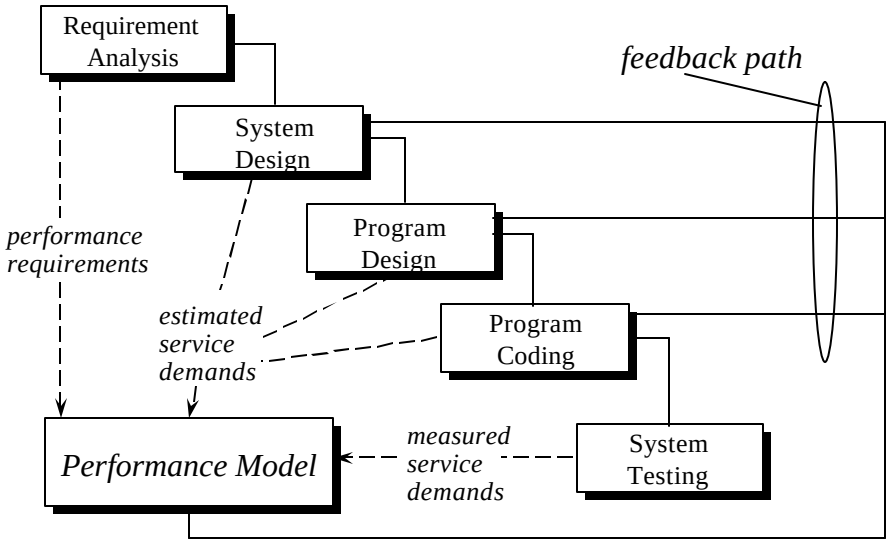
Traditional Software Development Life Cycle



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.

Integrating Software Performance Engineering Into the Software Development Life Cycle



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)*

Requirement Analysis
- *mapping of software modules to C/S architecture*
- *database design*
- *networking topology*

System Design
- *number of I/Os and DBMS calls per transaction*
- *estimates of CPU demand*
- *estimates of network traffic*

Program Design
- *refined I/O and CPU demand estimates*
- *refined network traffic demand estimates*

Program Coding
- *measured I/O, CPU, and network service demand estimates*

System Testing

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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?

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

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.

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

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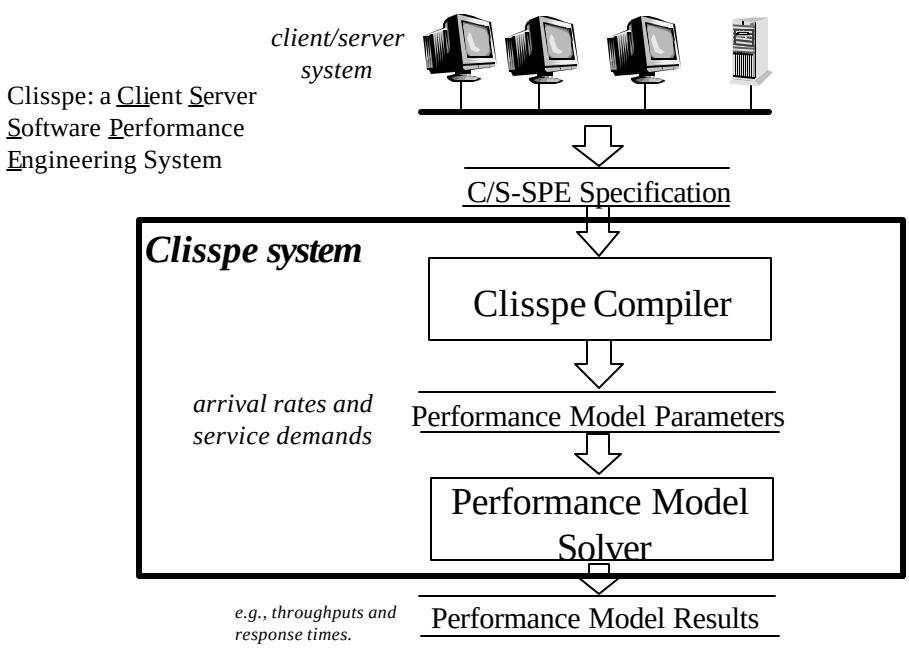


Clisspe: a Client Server Software Performance Engineering language

- Declaration Section
- Mapping Section
- Transaction Section

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

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;
```

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) ;
```


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;
```

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;
```


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);
```

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;
```


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 ;
```

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;
```


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);
```

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);
```


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;
```

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;
```


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;
```

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;
```


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;
```

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;
```


Clisspe Transaction Section Statements

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

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
```


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;
```

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;
```


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;
```

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;
```


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.

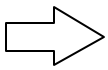
$S_{i,r}$: set of statements that generate demands at device i for class r.

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

p_s : probability that statement s is executed.

Service Demand Generation

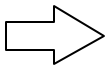
```
if 0.3 then
        s1;
        s2;
else    s3;
end_if
```



$$p_{s1} = 0.3$$
$$p_{s2} = 0.3$$
$$p_{s3} = 0.7$$

Service Demand Generation

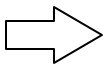
```
switch
   case 0.1:  s1;
   case 0.3:  s2;
              s3;
   case 0.6: s4;
end_switch;
```



$$p_{s1} = 0.1$$
$$p_{s2} = 0.3$$
$$p_{s3} = 0.3$$
$$p_{s4} = 0.6$$

Service Demand Generation

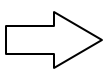
```
loop  3.5
   s1;
   s2;
   s3;
end_loop;
```



$$n_{s1} = 3.5$$
$$n_{s2} = 3.5$$
$$n_{s3} = 3.5$$

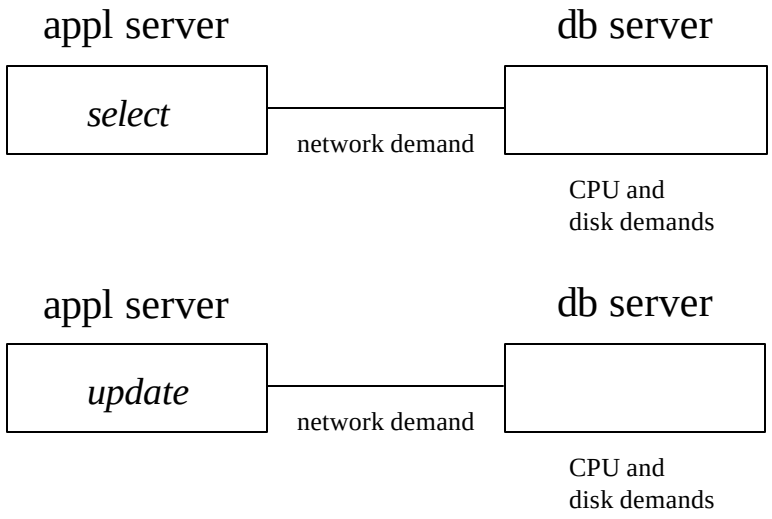
Service Demand Generation

```
loop  3.5
   if  0.3
   then s1;
          loop 2
            s2;
          end_loop;
   else  s3;
   end_if;
end_loop;
```

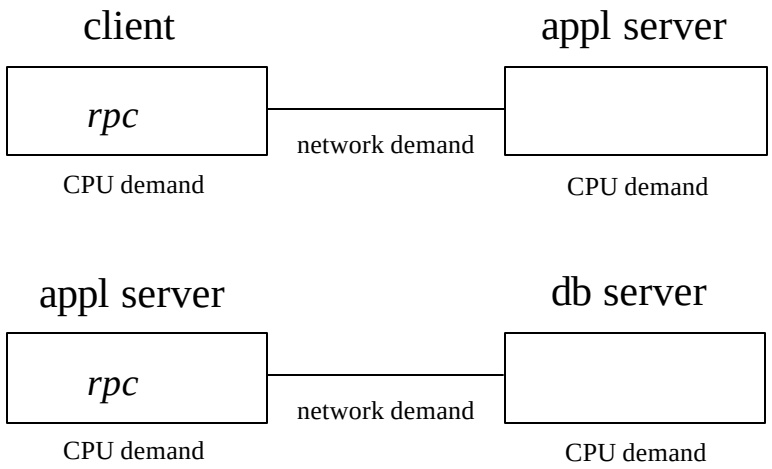


	n_s	p_s
s_1	3.5	0.3
s_2	7.0	0.3
s_3	3.5	0.7

Service Demand Generation

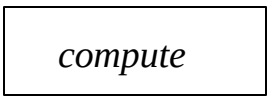


Service Demand Generation



Service Demand Generation

client or server

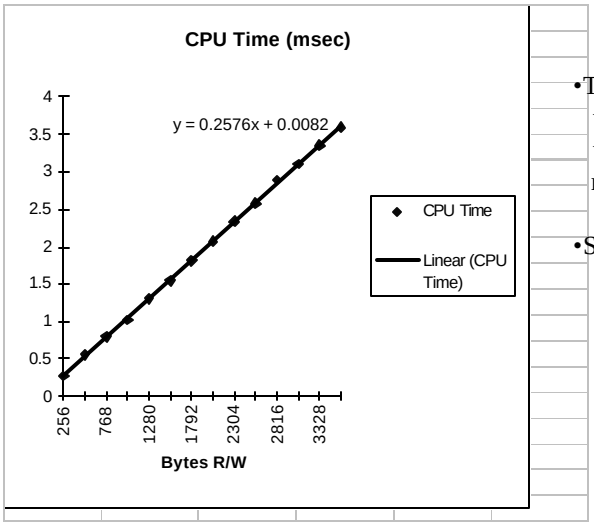


CPU demand

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

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

$y = a\,x + b$

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**) ;**

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;
       }
   }
}
```


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;
       }
   }
}
```

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

$$y = a\,x + b$$

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```
>>> 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
```

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```
>>> 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
```

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```
>>> 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    ...
```

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```
>>> Response Times

                        Transaction Name     Resp. Time    Throughput
                                                (sec)        (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
```

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```
>>> 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
```


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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.