MOSEL
MOdeling Specification and Evaluation Language

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Outline

- ❑ Motivation
- ❑ MOSEL
  - Structure of the MOSEL System
  - Constructs of MOSEL
  - Queueing Network Examples, Petri Net Example
- ❑ Production Line Examples
  - Fundamental Systems: Basic Model, Multiple Machines, Finite Buffer, Batch Processing, Unreliable Machines
  - Wafer Production System
- ❑ Other Real Life Examples
- ❑ **IGL I**ntermediate **G**raphic **L**anguage
- ❑ Related Work and Future Work

Motivation (1)

- **Performance and Reliability Evaluation is important for**
  - Design
  - Planning
  - Tuning
  - Comparison
  - Selection

  of
  - Manufacturing Systems
  - Computer Systems
  - Operating Systems
  - Communication Systems
  - Workflow Management Systems

Motivation (2)

- **Performance and Reliability Evaluation Methods**
  - Measurement:
    Expensive, only for already existing systems
  - Simulation:
    Very time consuming, but universal
  - Analytical Methods:
    Very fast, but restrictive
  - Numerical Methods:
    Faster than Simulation

Motivation (3)

- **Performance and Reliability Evaluation Models**
  - Queueing Network Models
  - Petri Net Models
  - Precedence Graph Models
  - Fault Trees
  - Markov Models
  - Modeling Languages

Motivation (4)

- **Tools for Performance and Reliability Evaluation**
  - Queueing Network Tools

    QNAP, RESQ, PEPSY, ...
  - Petri Net Tools

    SPNP, TIMENET, PETSI, GreatSPN, ...
  - Tools based on Modeling Languages

    MOSEL - Tool, SHARPE, QNAP, SPNP, ...

Motivation (5)

❑ **Problems**:

- Learning more than one modeling language is very time consuming
- Some systems are difficult to describe in a particular language
- Syntax of a modeling language is oriented to the specific characteristics of the particular tool ☞ tool oriented

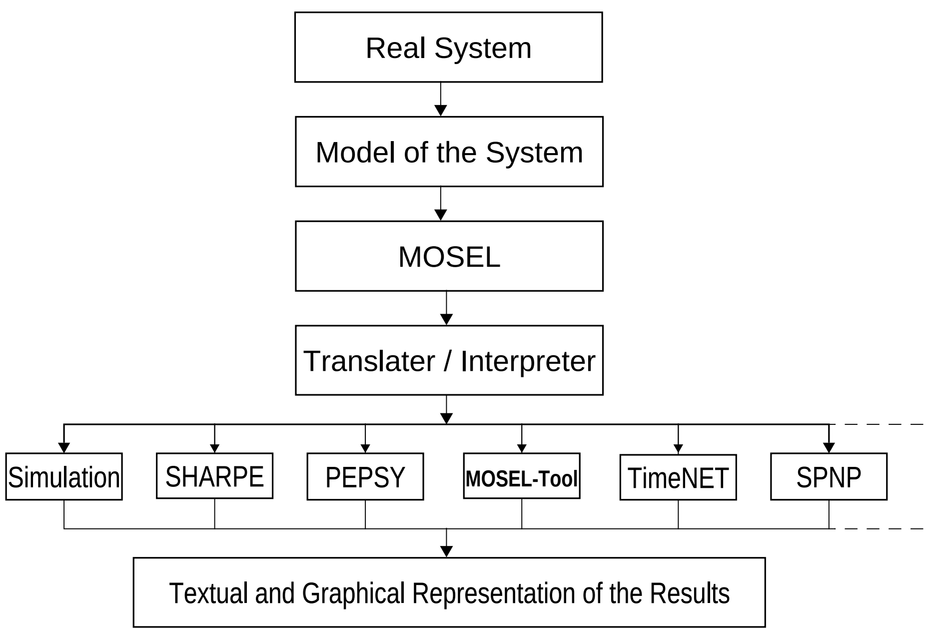
❑ **Solution**:

- Design a model description language that allows the user to describe the system directly without any knowledge of the underlying methods or tools
  ☞ system oriented
- Provide translators that transform this model description into the input languages/models needed by specific already existing tools.

  ☞ **MOSEL**: **MO**deling, **S**pecification and **E**valuation **L**anguage

MOSEL

Structure of the MOSEL System



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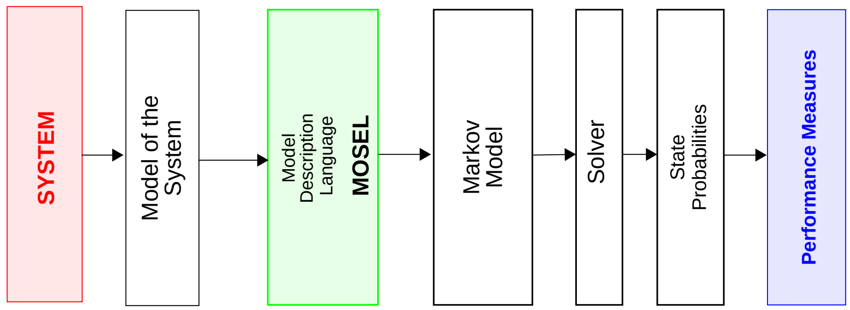
MOdeling **S**pecification and **E**valuation **L**anguage



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<u>**MO**</u>deling <u>**S**</u>pecification and <u>**E**</u>valuation <u>**L**</u>anguage

- ❑ **SPNP** - Stochastic Petri Net Package
  (Duke University)

- ❑ Generation and Solution of the Markov Chain
  - Input: Description of the System in CSPL
    - Generated automatically from the MOSEL Description of the System by a Translater
  - Output: State Probabilities
  - Solution Methods
    - Power (Iterative)
    - Gauss Seidel (Iterative)
    - SOR (Iterative)
    - Uniformization (Transient Solution)

MOSEL

MOdeling Specification and Evaluation Language

- **MOSEL - Tool** (University of Erlangen)
- Generation and Solution of the Markov Chain
  - Input: Description of the System in CSPL
    - Generated automatically from the MOSEL Description of the System by a Translater
  - Output: State Probabilities
  - Solution Methods
    - Power, SOR
    - Gauss Seidel
    - Multi Level
    - Uniformization
    - (Simulation)

MOSEL

MOdeling Specification and Evaluation Language

- **Structure of a MOSEL file (1)**
  - **Parameter declaration part** (optional)
    - Variables
    - Constants
  - **System state definition part (Vector description part)**
    - Components of the state vector
    - Range of the state space
    - Start vector (optional)
    - Specification of the prohibited states (optional)

MOSEL

MOdeling **S**pecification and **E**valuation **L**anguage

❑ Structure of a MOSEL file (2)

- **Transition definition part (Rules part)**
  - Specification of the transitions between the states
    - Condition part
    - Action part (rate, probability)
- **Results part**
  - Specification of the performance measures
- **Picture part**
  - Specification of the values to be plotted

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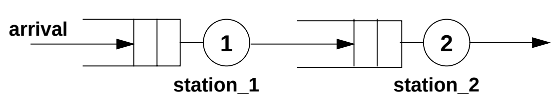
Queueing Network Examples

❑ Open Tandem Network (1)



- **Description in MOSEL**

/* Definition of the state vector */

NODE station_1 **[**K**]** **=** 0**;**
NODE station_2 **[**K**]** **=** 0**;**
NODE num **[**K**]** **=** 0**;**

/* Definition of the arrival of jobs */

FROME **TO** station_1**,** num **W** arrival**;**

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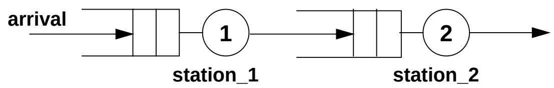
Queueing Network Examples

❑ **Open Tandem Network (2)**



/* Definition of the behavior of the stations */

FROM station_1 **TO** station_2 **W** ServiceRate_1**;**
FROM station_2**,** num **TOE** **W** ServiceRate_2**;**

/* Definition of the performance measures */

RESULT>> k_1 **=** **MEAN** station_1**;**

RESULT>> WIP **=** **MEAN** num**;**

RESULT>> system_time **=** WIP **/** arrival**;**

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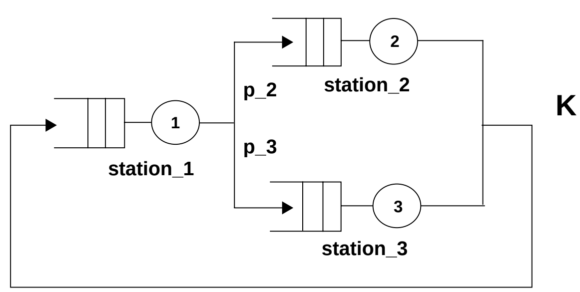
Queueing Network Examples

❑ **Closed Queueing Network (1)**



Description in MOSEL

/* Definition of the state vector */

NODE station_1 **[**K**]** **=** K;
NODE station_2 **[**K**]** **=** 0;
NODE station_3 **[**K**]** **=** 0;

NOT station_1 + station_2 + station_3 **!=** K;

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Queueing Network Examples

- **Closed Queueing Network** (2)

```
/* Definition of the behavior of the stations */

FROM station_1 W ServiceRate_1
     { TO station_2 P p_2;
          TO station_3 P p_3;}
FROM station_2 TO station_1 W ServiceRate_2;
FROM station_3 TO station_1 W ServiceRate_3;

/* Definition of the performance measures */

     RESULT>> utilization_1 = UTIL station_1;
     RESULT>> throughput_1 = utilization_1 * ServiceRate_1;
```


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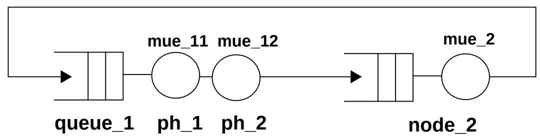
Queueing Network Examples

- **Short MOSEL Version**

```
/* Definition of the state vector */

        NODE station_1 [K]          = K;
<2,3>   NODE station_# [K]          = 0;

        NOT station_1 + station_2 + station_3 != K;

/* Definition of the behavior of the stations */

        FROM station_1 W ServiceRate_1
             { TO station_2 P p_2;
               TO station_3 P p_3;}
<2,3>   FROM station_# TO station_1 W ServiceRate_#;

/* Definition of the performance measures */

<1,2,3>RESULT>> utilization_# = UTIL station_#;
<1,2,3>RESULT>> throughput_# = utilization_# * ServiceRate_#;
```

MOSEL
Queueing Network Examples

❑ Nonproductform Queueing Network (1)



/* Definition of the state vector */

NODE queue_1 **[K]** **=** 0;

NODE phase_1 **[**1**]** **=** 0;

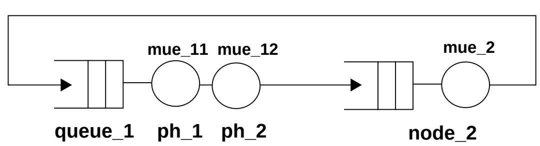
NODE phase_2 **[**1**]** **=** 0;

NODE node_2 **[**K**]** **=** 0;

NOT queue_1 **+** phase_1 **+** phase_2 **+** node_2 **!=** K;

MOSEL
Queueing Network Examples

❑ Nonproductform Queueing Network (2)



/* Behavior of node_1 */

FROM queue_1 **TO** phase_1 **IF** **(**phase_1 **+** phase_2 **==** 0**)**;

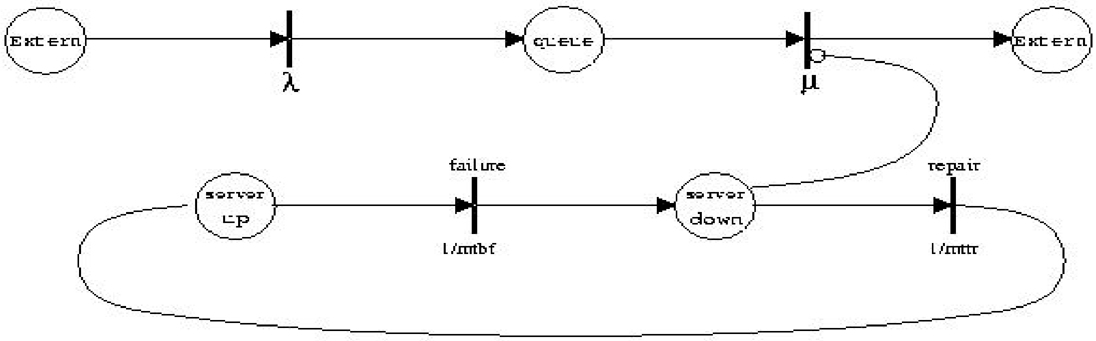
FROM phase_1 **TO** phase_2 **W** mue_11;

FROM phase_2 **TO** node_2 **W** mue_12;

/* Behavior of node_2 */

FROM node_2 **TO** queue_1 **W** mue_2;

Petri Net Example



Petri Net Example (1)

MOSEL Specification

/*---------------------------------- **Different values** (loops) -------*/

#**define** K 10
#**define** mtbf 10000
#**define** mttr 10
#**define** lambda 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 0.8, 1
#**define** mue 0.5, 0.8, 1, 1.5, 1.8, 2, 3

/*-- **Node definitions** -------*/

enum down_up { down, up };
NODE queue[K] = 0 ;
NODE server[down_up] = up;

/*--------------------------- **Arrival and service of the jobs** -------*/

FROME TO queue **W** lambda;
IF server == up **FROM** queue **TOE W** mue ;

Petri Net Example (2)

MOSEL Specification

```
/*------------------------------ Repair/Failure of the server -------*/

FROM server[up]    TO server[down]  W 1/mtbf;
FROM server[down]  TO server[up]    W 1/mttr;

/*-------------------------------------------------- Results -------*/

RESULT>>  IF (queue == 0) server_idle   += PROB          ;
RESULT>>  IF (queue == K) server_reject += PROB          ;
RESULT>>              rate_reject = lambda *server_reject;
RESULT>>              mean_qlength   = MEAN queue        ;
RESULT>>              thruput = util_server*mue     ;
RESULT>>              util_server = UTIL queue         ;

/*------------------------------------------------- Pictures -------*/

PICTURE "Mean queue length" -BACKGROUND gray90
   XSCALE lambda       -MIDDLE -HIGHVALUE 1.4 -LABELNR 7
   CURVE  mean_qlength -DIFF THICK, POINT
```


Petri Net Example (3)

Results

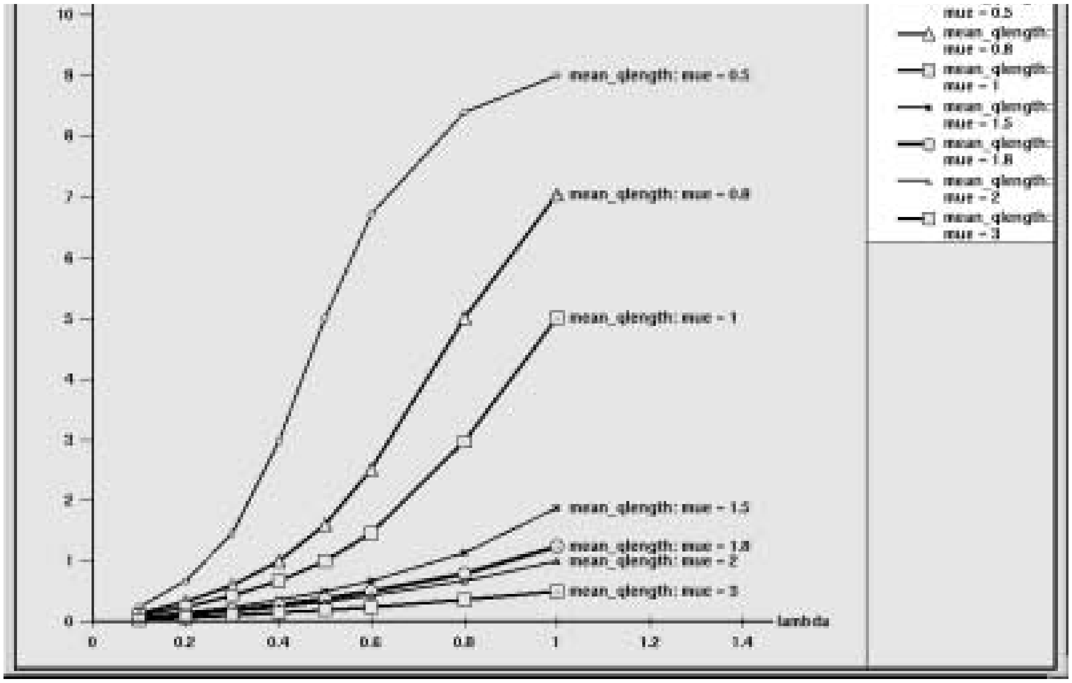
Call of the MOSEL-TOOL:

mosel -cs petri.msl --> petri.res --> petri.igl
igl petri.igl --> pictures

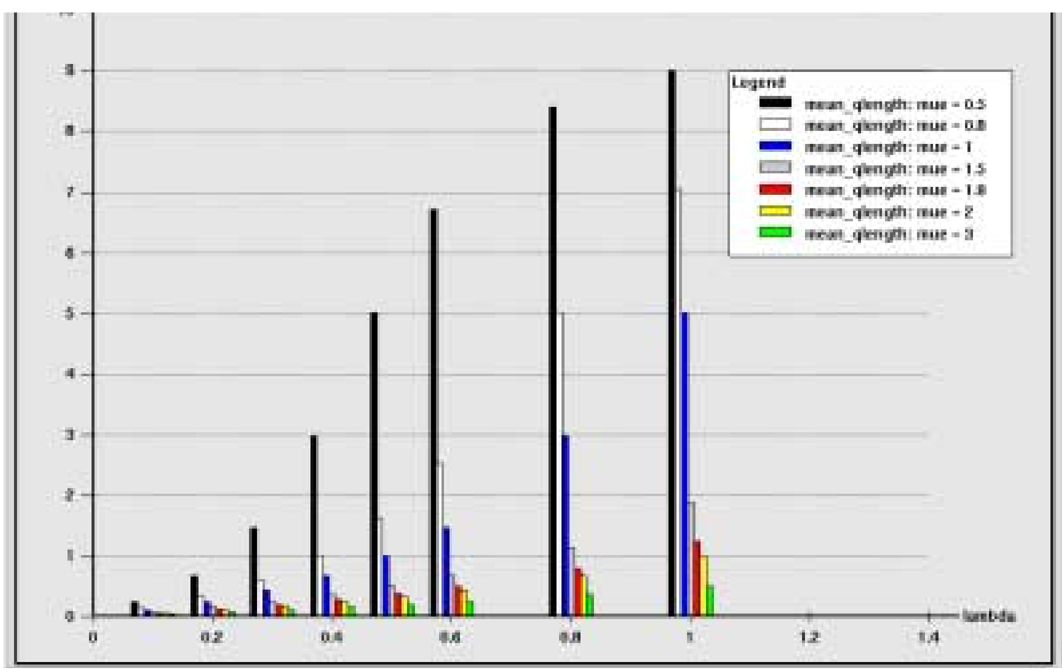
Results:

```
.......... lambda = 0.1, mue = 0.5 ..........
   server_idle = 0.665874058769
   server_reject = 1.82017918692e-06
   rate_reject = 1.82017918692e-07
   mean_qlength = 0.251555031241
   thruput = 0.10029957828
   util_server = 0.20059915656
.......... lambda = 0.1, mue = 0.8 ..........
   server_idle = 0.874438162634
   server_reject = 1.33052923469e-06
   rate_reject =  .....
   .
   .
   .
.......... lambda = 1, mue = 2 ..........
   server_idle = 0.499527144294
   server_reject = 0.000962398971526
   rate_reject = 0.000962398971526
   mean_qlength = 1.00283434233
   thruput = 1.00094571141
   util_server = 0.500472855706
.......... lambda = 1, mue = 3 ..........
   server_idle = 0.665874058769
   server_reject = 1.82017918692e-06
   rate_reject =  .....
```

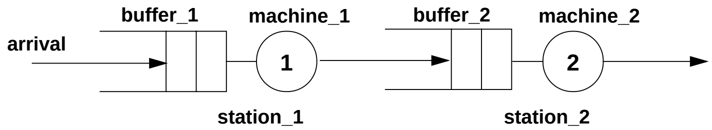
Petri Net Example (4)



PETRI NET EXAMPLE (5)



Production Line Examples
Basic Model (1)



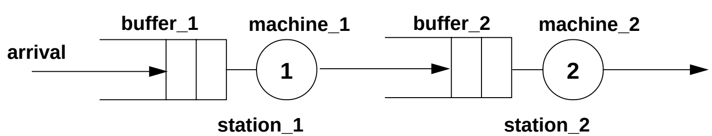
/* Declaration part*/

enum machine_state {idle, busy};

/* Vector Description part*/

NODE buffer_1 **[**K**]** = 0;
NODE machine_1 **[**1**]** = 0;
NODE station_2 **[**K**]** = 0;
NODE num **[**K**]** = 0;

Production Line Examples
Basic Model (2)



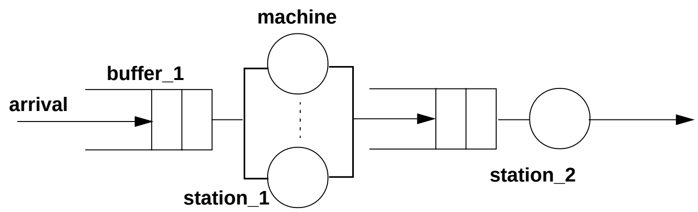
/* Rules part */

FROME TO buffer_1, num **W** arrival;
FROM buffer_1 **TO** machine_1;
FROM machine_1 **TO** station_2 **W** ServiceRate_1;
FROM station_2, num **TOE** **W** ServiceRate_2;

/* Results part */

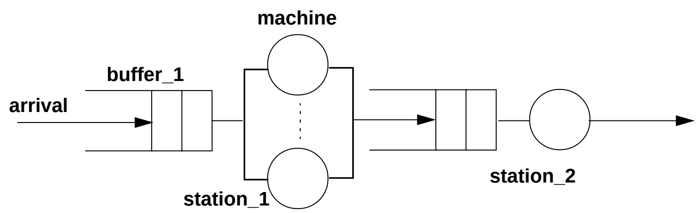
RESULT>> utilization_1 **= UTIL** machine_1**;**
RESULT>> utilization_2 **= UTIL** station_2**;**
RESULT>> WIP **= MEAN** num;
RESULT>> T **=** WIP **/** Arrival;

Production Line Examples
Multiple Machines (1)




```
#define m 4;

NODE buffer_1 [K];
NODE machine [m];
NODE station_2 [K];
NODE num [K];

FROME TO buffer_1, num W arrival;
```

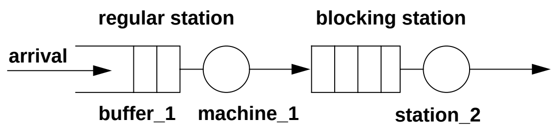

Production Line Examples
Multiple Machines (2)




```
        FROM buffer_1 TO machine;
<1..m> FROM machine TO station_2 W
                #*ServiceRate_1 IF machine == #;

        FROM station_2, num TOE W ServiceRate_2;

        /* Mean number of active machines in station_1 */
        RESULT>>      A = MEAN machine;

        /* Utilization of station_1 */
        RESULT>>      utilization_1 = A/m;
```

Production Line Examples

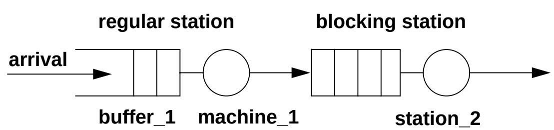
Finite Buffer (Blocking) (1)




```
/* Definition of the state vector */

NODE   station_1 [K]           = 0;
NODE   block [1]               = 0;
NODE   station_2 [Capacity]  = 0;
NODE   num [K];
```


Production Line Examples

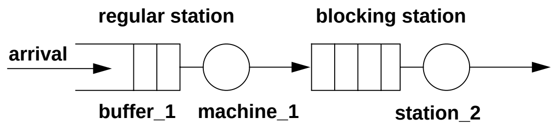
Finite Buffer (Blocking) (2)




```
/* Definition of the arrivals */
FROME  TO  station_1   W  arrival;

/* Definition of the behavior of station_1 */
FROM    station_1 TO  block  W   ServiceRate _1;
FROM    block   TO  station_2:

/* Definition of the behavior of station_2 */
FROM   station_2  TOE   W   ServiceRate_2;
```

Production Line Examples

Finite Buffer (Blocking) (3)



/* Definition of the Results */

RESULT>> utilization_2 **= UTIL** station_2;

RESULT>> throughput **=** utilization_2 ***** ServiceRate_2;

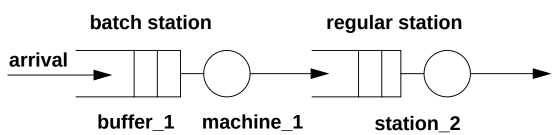
RESULT>> **IF** **(**block == 1**)** blockprob **+ = PROB**;

RESULT>> **IF** (station_1 > 0 **OR** block == 1) utilization_1 **+ = PROB**

RESULT>> WIP = **MEAN** num;

Production Line Examples

Batch Processing (1)



/* Declaration part*/

VAR **int** b; /* Batch size */**;**

/*Definition of the state vector */

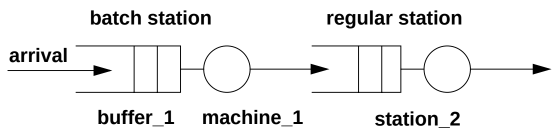
NODE buffer_1 **[**K**]**;

NODE machine_1 **[**b**]**;

NODE station_2 **[**K**]**;

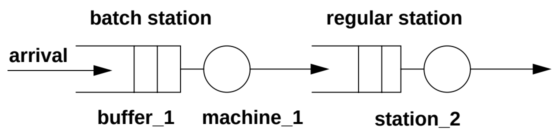
NODE num **[**K**]**;

Production Line Examples
Batch Processing (2)




```
/* Arrival of jobs */
FROME   TO   num, buffer_1   W   arrival;

/* station_1 */
FROM  buffer _1 (b)   TO   machine_1 (b)
                                   IF (buffer_1 >= b);
FROM   machine_1 (b) TO  station_2 (b)   W  ServiceRate_1;

/* station_2 */
FROM   station_2,  num   TOE   W  ServiceRate_2;
```

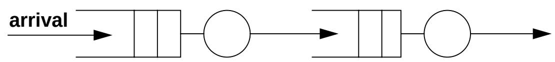

Production Line Examples
Batch Processing (3)



/* Performance measures */

RESULT>> utilization_2 = **UTIL** station_2;
RESULT>> throughput = utilization_2 * ServiceRate_2;
RESULT>> IF (machine_1 = 0) P_0 **+= PROB**;
RESULT>> utilization_1 = 1 - P_0;
RESULT>> WIP = **MEAN** num;
RESULT>> **DIST** num;

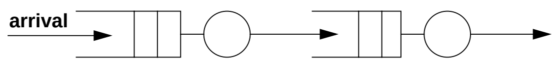
Production Line Examples
Unreliable Machines (1)



/* Declaration part */
enum state_a **{**up, down**}**;

/* Definition of the state vector */
NODE station_1 **[**K**]** **=** 0;
NODE station_2 **[**K**]** **=** 0;
NODE num **[**K**]** **=** 0;
NODE server **[**state**]** **=** up;

Production Line Examples
Unreliable Machines (2)



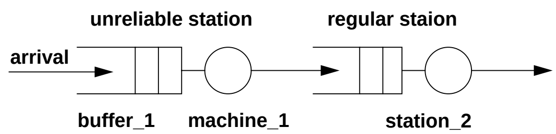
/* Arrival of jobs */

FROME **TO** num, station_1 **W** arrival;

/* Failure and repair */

FROM server **[**up**]** **TO** server **[**down**]** **W** 1/mtbf;
FROM server **[**down**]** **TO** server **[**up**]** **W** 1/mttr;

Production Line Examples
Unreliable Machines (3)

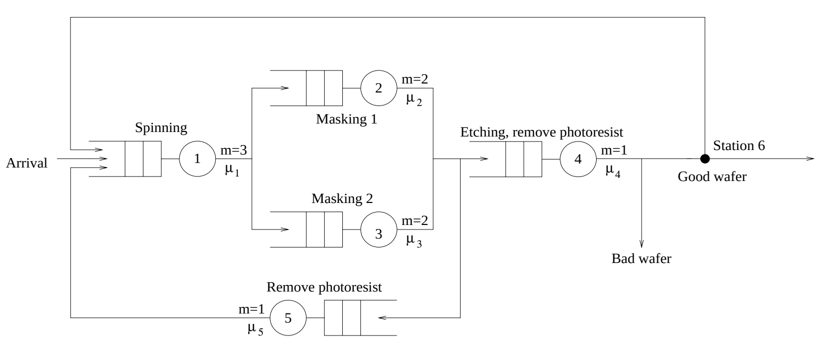


/* station_1 */
FROM station_1 **TO** station_2 **W** ServiceRate_1
IF (server **==** up**)**;

/* station_2 */
FROM station_2, num **TOE W** ServiceRate_2;

/* Performance Measures */
RESULT>> utilization_2 **= UTIL** station_2**;**
RESULT>> throughput_2 = utilization_2 * ServiceRate_2; ;
RESULT>> IF (server **==** up**)** upprob **+= PROB;**

Wafer Production System (1)



m1 = 3...10	p12 = 0.5	mue1 = 1
m2 = 2...4	p13 = 0.5	mue2 = 1
m3 = 2...4	p24 = 0.9	mue3 = 1
m4 = 2	p25 = 0.1	mue4 = 2
m5 = 1	p34 = 0.9	mue5 = 1
	p35 = 0.1	Arrival = 1
	p40 = 0.1	
	p46 = 0.9	
	p60 = 2/3	
	p61 = 1/3	

Model of the wafer production system

/* Nodes */
<1..5> NODE Buffer_# [K];
<1..5> NODE Active_# [m_#];
NODE Station_6 [K];
NODE num [K];

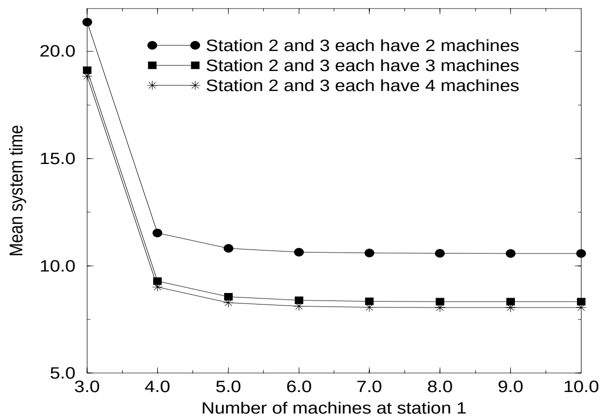
Wafer Production System (2)

```
                /* Rules */
                FROME   TO   Buffer_1, num  W  Arrival;
<1..5>          FROM Buffer_#   TO Active_#;
<1..m_1>  FROM Active_1 TO Buffer_2   W  #*mue_1  P  p12  IF Active_1 == #;;
<1..m_1>  FROM Active_1 TO Buffer_3   W  #*mue_1  P  p13  IF Active_1 == #;

<1..m_2>  FROM Active_2 TO Buffer_4   W  #*mue_2  P  p24  IF Active_2 == #;
<1..m_2>  FROM Active_2 TO Buffer_5   W  #*mue_2  P  p25  IF Active_2 == #;

<1..m_3>  FROM Active_3 TO Buffer_4   W  #*mue_3  P  p34  IF Active_3 == #;
<1..m_3>  FROM Active_3 TO Buffer_5   W  #*mue_3  P  p35  IF Active_3 == #;

<1..m_4>  FROM Active_4,    num  TOE    W  #*mue_4  P  p40  IF Active_4 == #;
<1..m_4>  FROM Active_4 TO   Station_6  W  #*mue_4  P  p46  IF Active_4 == #;

                FROM Active_5 TO Buffer_1 W  mue_5;

                FROM Station_6, num TOE    P  p60;
                FROM Station_6 TO Buffer_1  P  p61;
```

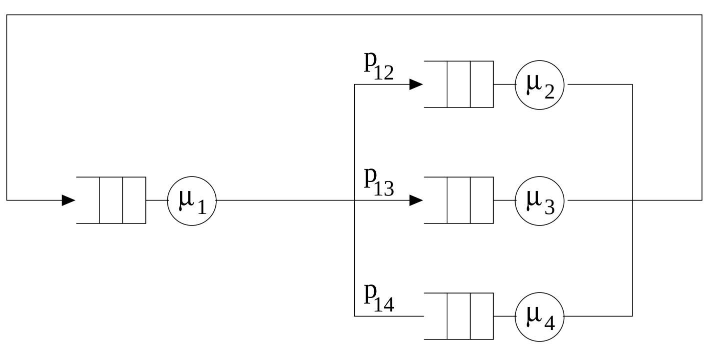

Wafer Production System (3)

```
/* Results */

/* Mean number of active machines */
<1..5>  RESULT>>       A_# = MEAN Active_#;

/* Utilization of the machines */
<1..5>  RESULT>>       utilization_# = A_#/m_#;

/* Mean buffer length */
<1..5>  RESULT>>       Q_# = MEAN Buffer_#;

/* Mean number of wafers (WIP) */
        RESULT>>       WIP = MEAN num;

/* Mean system time */
        RESULT>>       T = WIP / Arrival;
```

Wafer Production System (4)



IGL Intermediate **G**raphic **L**anguage (1)



IGL Intermediate Graphic Language (2)

```
/***====== Central-Server-model ==================*/

/**------------- Parameter declaration part----------------------------------------*/

#define     K     10
#define     mue1  3.5
#define     mue2  0.9
#define     mue3  2.3
#define     mue4  1.2
#define     p12   0.25
#define     p13   0.35
#define     p14   0.4

/**------------- System state definition part --------------------------------------------*/

      NODE N1[K] = K;
<2..4> NODE N#[K];

/**------------- Prohibited states ---------------------------------*/

NOT  N1 + N2 + N3 + N4 != K;
```


IGL Intermediate Graphic Language (3)

```
*-------------Transition definition part --------------------------------------------*/
FROM N1  WITH mue1 {
    <2..4> TO N#  P p1#;
}
<2,3,4> FROM N#  TO N1  WITH mue#;

/**------------- Result part--------------------------------------------*/

<1..4>  RESULT>>  IF (N#>0) rho# += PROB;  // utilization
<1..4>  RESULT   nquer# = MEAN N#;  // mean queue length
<1..4>  RESULT   DIST N#;  // distribution (probability of each possile queue length)
<1..4>  RESULT>>  lambda# = rho# * mue#;  // throughput
<1..4>  RESULT>>  tquer# = nquer# / lambda#;  // mean time a job is in a node

/**------------- Picture part-----------------------------*/

PICTURE  "Distribution for queue lengths"
          -FONTSIZE 16
  CURVE DIST  N1, N2, N3, N4

PICTURE  lambdas_and_rhos
          -FONT courier  -FONTSIZE 20
   LIST  lambda1, lambda2, lambda3, lambda4, rho1, rho2, rho3, rho4
   LEGEND -NOVISIBLE
```

IGL Intermediate Graphic Language (4)

```
=========================================================================
          Results provided by the tool   `CSPL'
=========================================================================
```

Constants:

K = 10
mue1 = 3.5
mue2 = 0.9
mue3 = 2.3
mue4 = 1.2
p12 = 0.25
p13 = 0.35
p14 = 0.4

- -

Results:

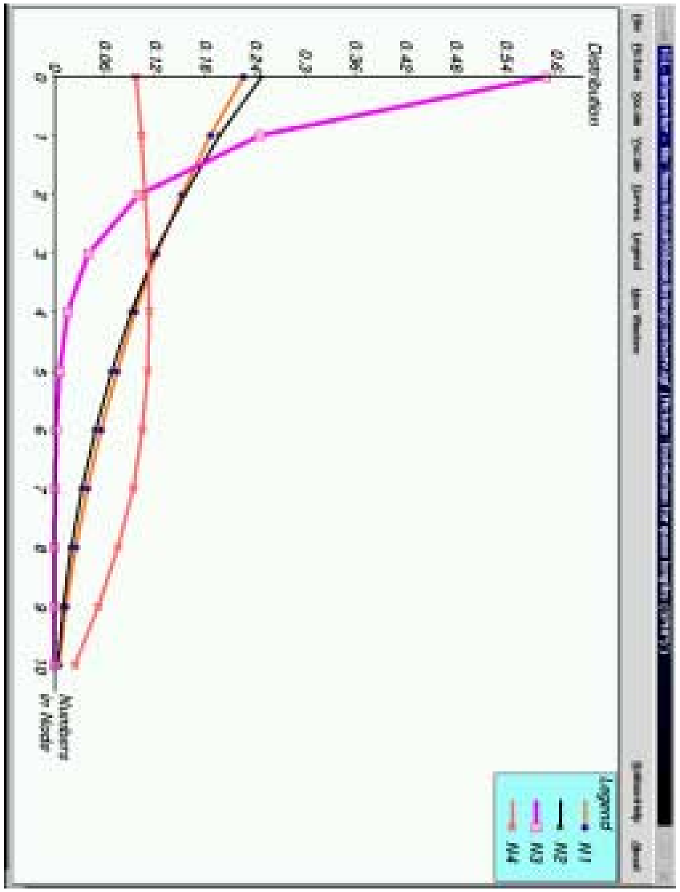
```
  __DIST N1 ___
        0: 0.226490510324
      ------------------
      10: 0.00523876082994
  __DIST N2 ___
        0: 0.247975421288
        ----------------
      10: 0.00395268685905
  __DIST N3 ___
        0: 0.588022114438
        ----------------
      10: 9.62301477005e-06
  __DIST N4 ___
        0: 0.0975734220455
        -----------------
      10: 0.0244732959731
```

rho1 = 0.773509489676
rho2 = 0.752024578712
rho3 = 0.411977885562
rho4 = 0.902426577954

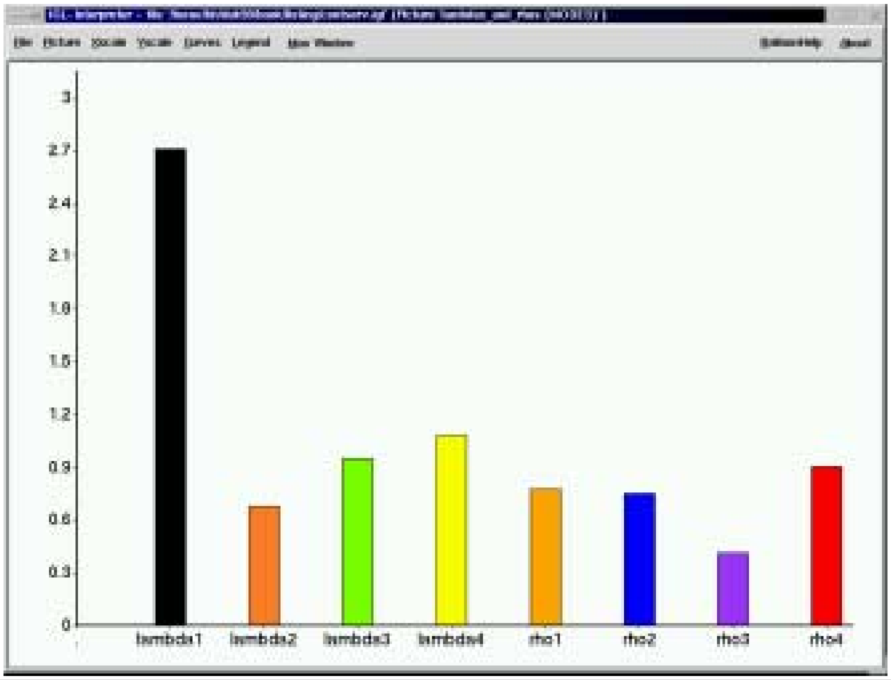
lambda1 = 2.70728321387
lambda2 = 0.676822120841
lambda3 = 0.947549136792
lambda4 = 1.08291189355

tquer1 = 0.965895587825
tquer2 = 3.56550339435
tquer3 = 0.720806197492
tquer4 = 3.96046645608

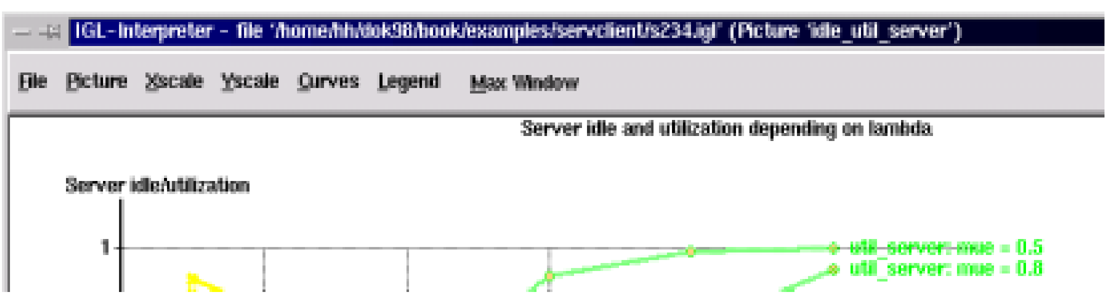
IGL Intermediate Graphic Language (5)

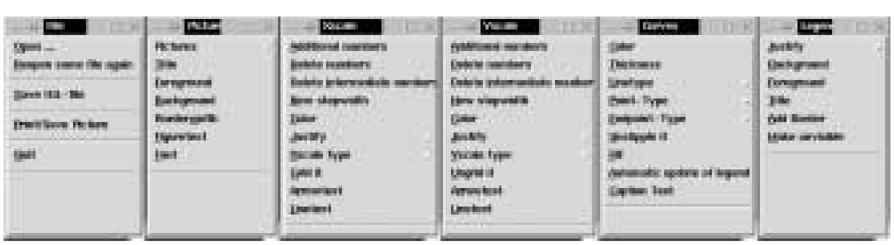


IGL Intermediate Graphic Language (6)



IGL Intermediate Graphic Language (7)





Real Life Examples

- MOSEL has been successfully used to model and to analyze systems from the following domains:
  - **Computer Systems:** UNIX Operating System, Polling Systems, Fork Join Systems, Terminal Systems, Multithreaded Architecture, Client Server, Multi Processor Systems
  - **Communication Systems:** Cellular Mobil Networks, ATM-Multiplexer, Internet Router, Retrial Systems
  - **Manufacturing Systems:** Batch Systems, Wafer Production Systems, ClusterTools for Single Wafer Processing

Remarks

- **Availability**: MOSEL is working on Solaris and Linux platforms.
  An earlier version had been compiled successfully under Windows NT.
  The IGL-interpreter is written in Tcl/Tk. MOSEL is implemented in C.
  The MOSEL-Tool (MOSEL, IGL) is freeware.
- **Documentation**: Practical Performance Modelling - *Application of the MOSEL Language;* by Begain, K.; Bolch, G.; Herold, H., Kluwer Academic Publishers, 2001, 409 pages.
  The book serves as a reference guide to MOSEL and IGL and contains a lot of real life examples
- **Current State:** MOSEL contains a translator to CSPL (suitable for SPNP v. 6.x, and a Petri Net based analysis module which was recently added to the MOSEL-Tool)
- http://www4.informatik.uni-erlangen.de/Projects/MOSEL/

Future Work and Related Work

- ❑ **Macros**
- ❑ **Parallel Solver**
- ❑ **Translator to other Tools**
- ❑ **Application to Special Systems**
  - Computer Systems
  - Operating Systems
  - Communication Systems (Ethernet (CSMA/CD, Tokenring), FDDI, ATM, Cellular Mobil Networks)
  - Fault Tolerant Systems
- ❑ **Simulation**
- ❑ **Non Phase Type Distribution**