TUM – Courses
IN2072
Analysis of System Performance

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http://www.net.in.tum.de

Course organization

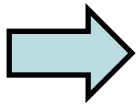
- Lecturer
  - Dr. Alexander Klein, klein@net.in.tum.de
    Office hours: Monday 10-11 / after arrangement, Room 03.05.61
  - Prof. Dr. Georg Carle, carle@net.in.tum.de
- Course
  - Lectures: 12 x 90/120 minutes, Wednesday 14–16 (c.t.), Room: 03.07.023
- ECTS:
  - 3 credits
- Exam:
  - Oral exam (approx. 15-20 minutes) at the end of the semester
- Course Material
  - http://www.net.in.tum.de/de/lehre/ss12/vorlesungen/vorlesung-analyse-von-systemperfomanz/
  - Login:
    Username: simtech-ss2011 Password: randomaccess

Course organization

- Exercises – (optional):
  - Exercises are rated (+/0/-)
  - Up to three students can submit their exercise together
  - If exercises are part of the lecture, they are also part of the oral exam

  - Exercises should be submitted via Email klein@net.in.tum.de
  - Subject: ASP–SS2012 – Exercise X – Lastname1 – Lastname2 – Lastname3
  - Figures and Descriptions should be submitted as PDF
  - Program code should be submitted as archive (zip/rar)

- Goal:
  - Get familiar with statistical issues (statistical significance)
  - Learn how to evaluate different systems (simulation/measurements)
  - Learn how to analyze and model distributed systems

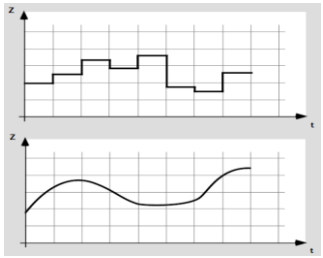


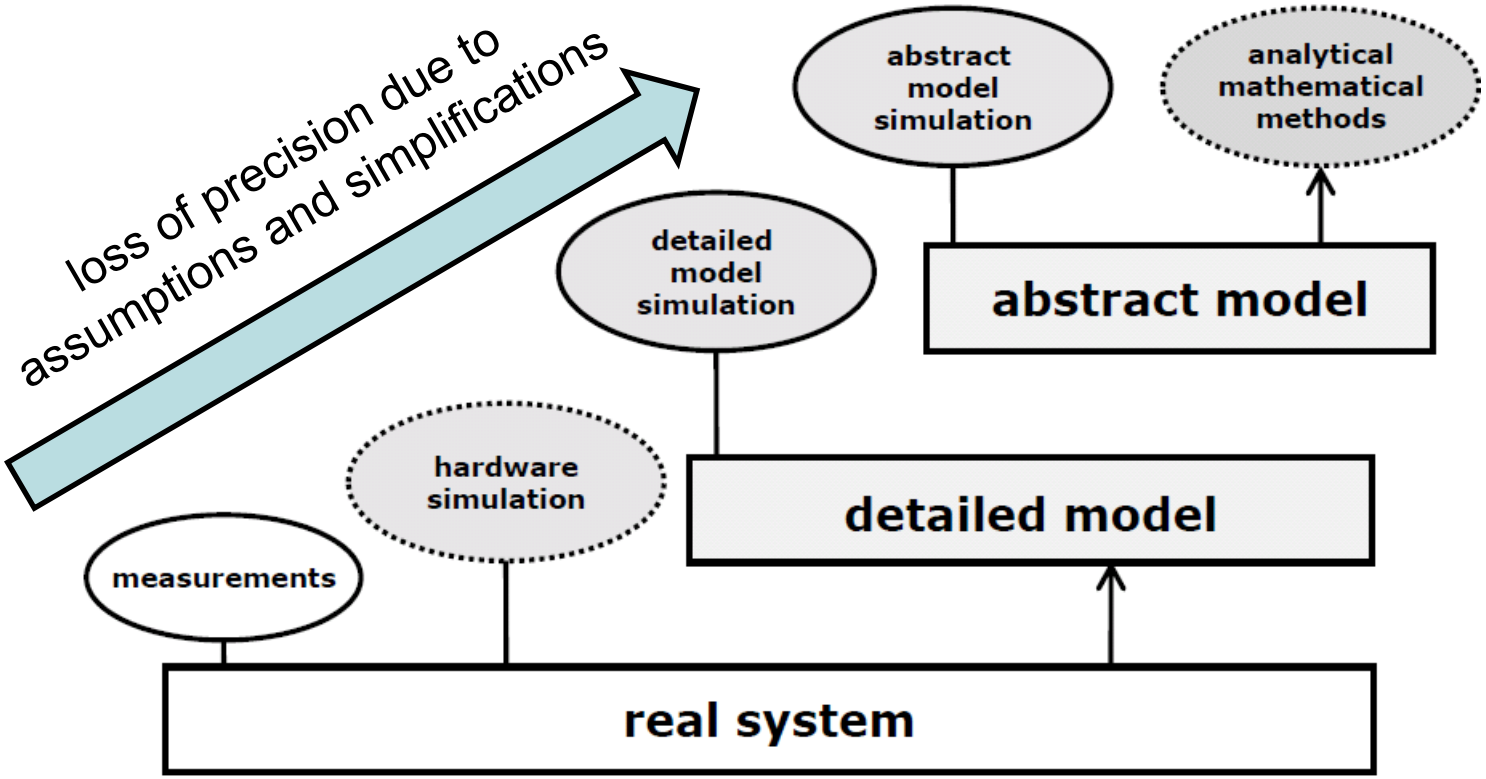
Prepare students for their BA/MA thesis

Course outline

1. Introduction to Modeling
   - ❑ Analysis vs. Simulation
   - ❑ Model Types
   - ❑ Queuing Network Models
   - ❑ Continuations and co-routines

Duration: 120 minutes



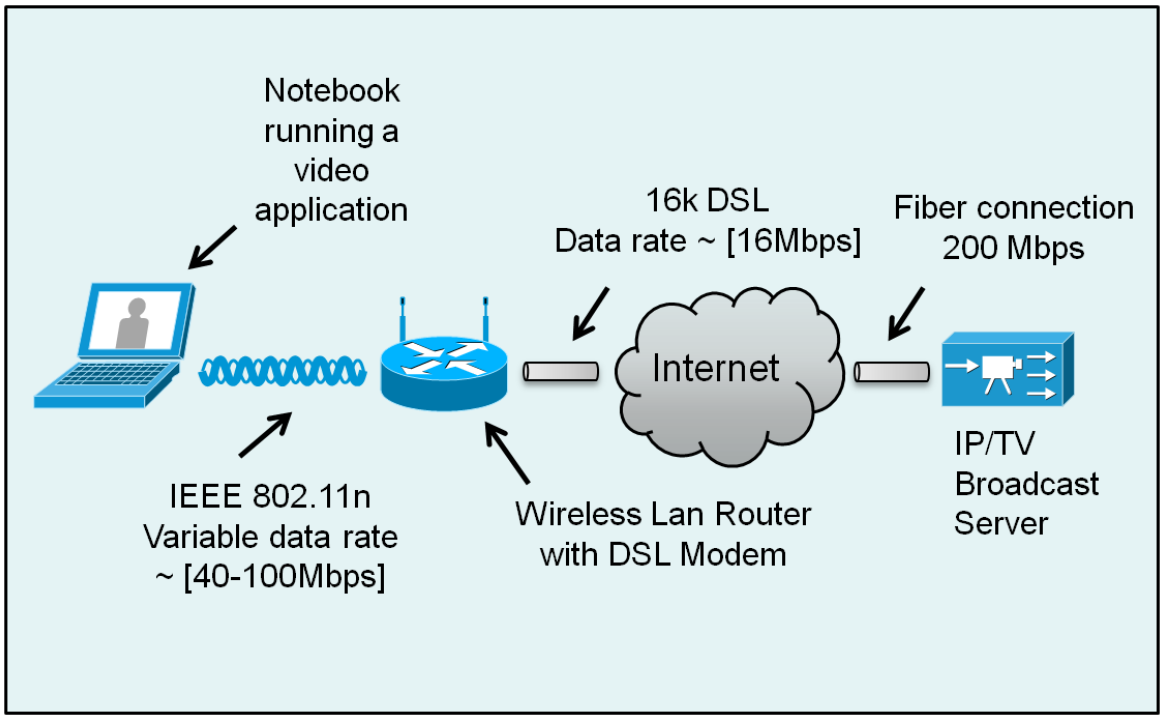


Course outline

1. Introduction to Modeling

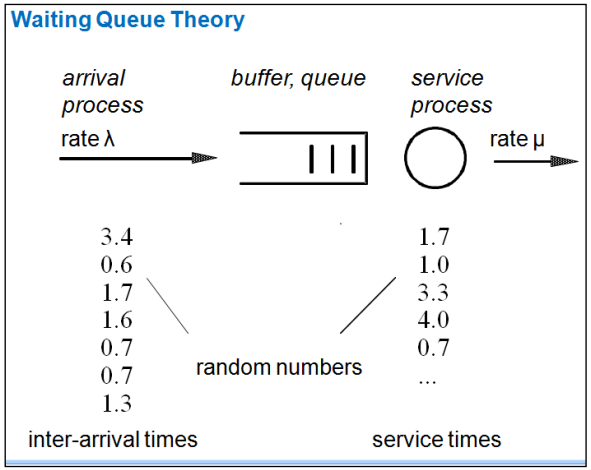
Duration: 90-120 minutes

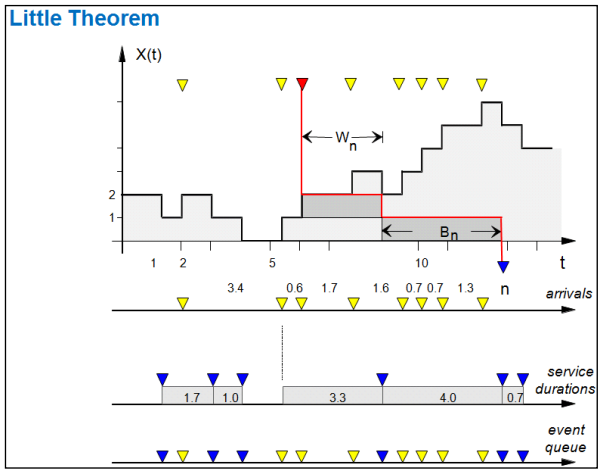
- ❑ Analysis vs. Simulation
- ❑ Model Types
- ❑ Queuing Network Models
- ❑ Continuations and co-routines



Course outline

2. Statistics fundamentals — Duration: 180 minutes
   - ❑ Introduction to Waiting Queues
   - ❑ Random Variable (RV), Discrete and Continuous RV
   - ❑ Probability Space, Frequency Probability
   - ❑ Distribution(discrete), Distribution Function(continuous)
   - ❑ Probability Density Function, Cumulative Density Function
   - ❑ Definitions: Expectation/Mean, Mode, Standard Deviation, Variance, Coefficient of Variation, p-percentile(quantile), Skewness, Scalability Issues, Covariance, Correlation, Autocorrelation Visualization of Correlation

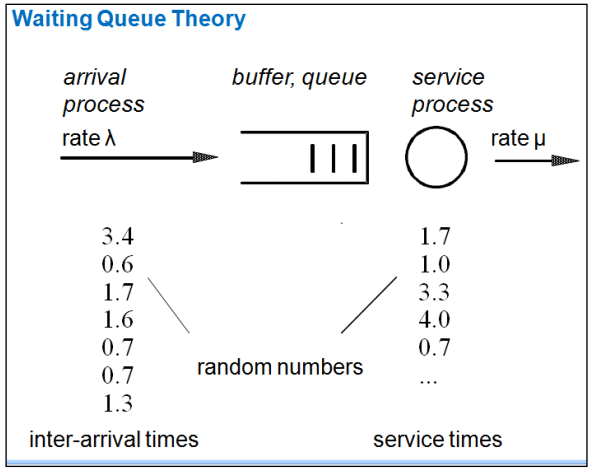


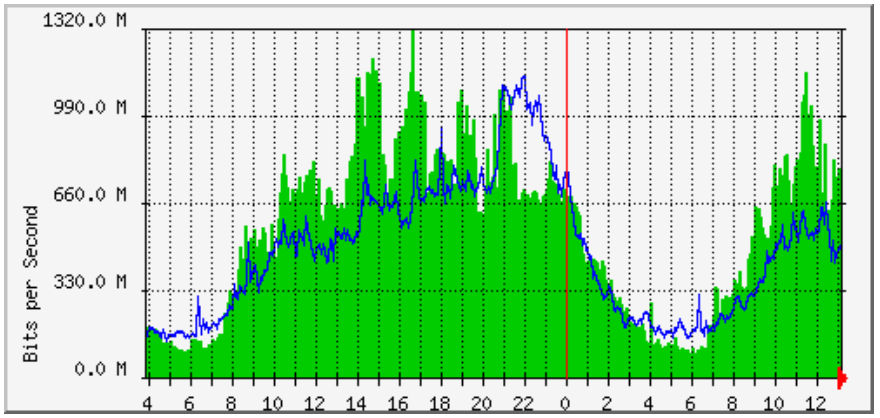


Course outline

2. Statistics fundamentals

Duration: 120/180 minutes





Throughput MWN – Router - Garching

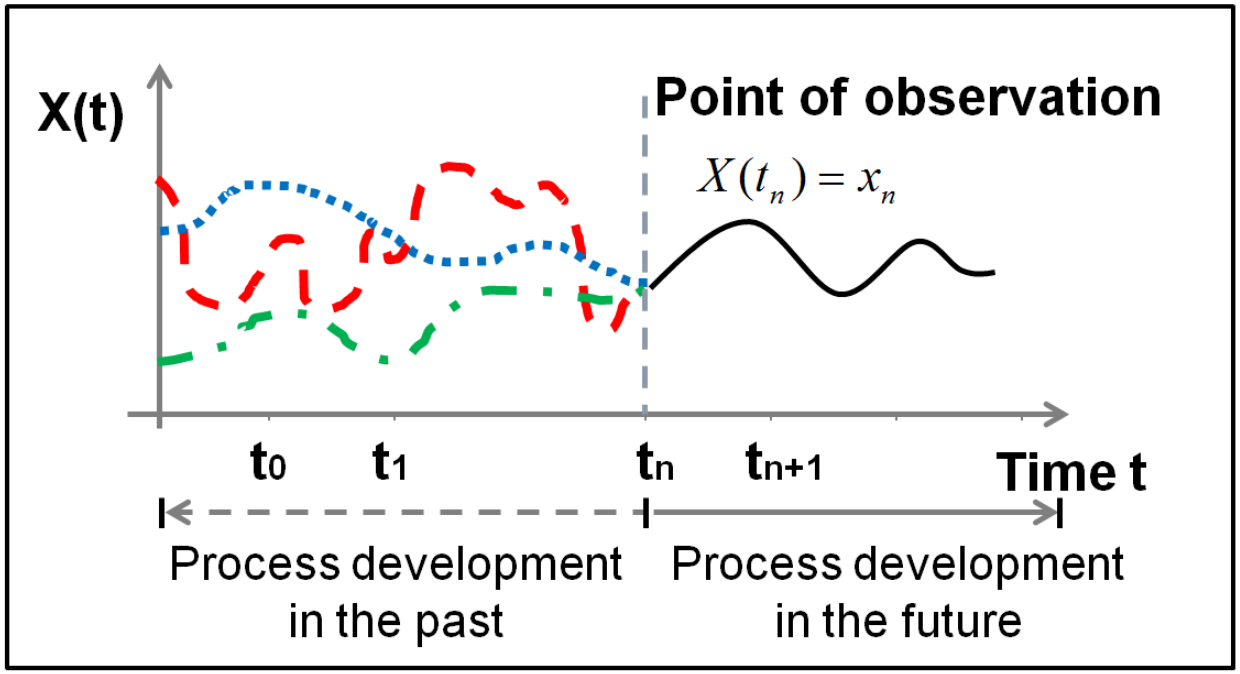
- Single high performance service process vs. multiple low performance service processes
- Impact for limited buffer size / storage capacity
- State / time dependent arrival process
- Performance parameters

Course outline

3. Random Process

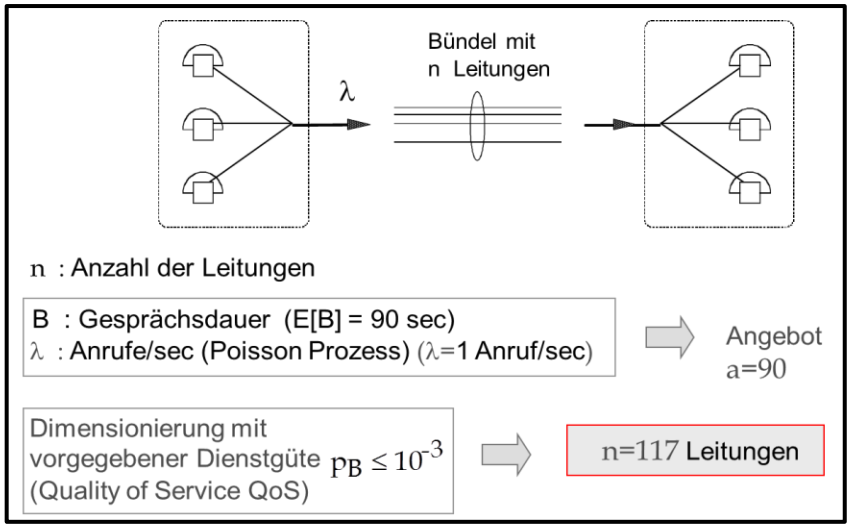
Duration: 140/240 minutes

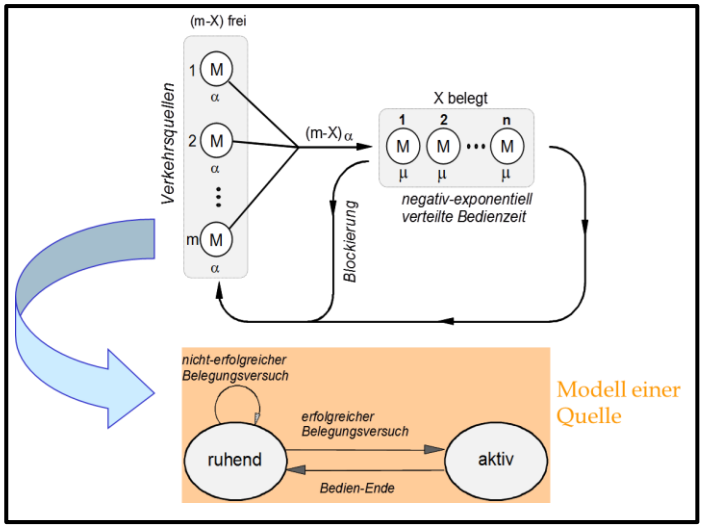
- Point process
- Renewal process
- Markov process
- Recurrence time
  - Continuous and time-discrete



Course outline

4. Continuous-Time Markov Chains (CTMCs) Duration: 240-360 minutes
   - ❑ Analysis of CTMCs
   - ❑ Birth-Death Processes
   - ❑ Loss Systems
     (M/M/n-0, M/GI/n-0, Loss System with a Finite Number of Sources)
   - ❑ Waiting Systems
     (M/M/n-∞, M/GI/1- ∞, M/D/1- ∞, n·D/D/1- ∞, …)



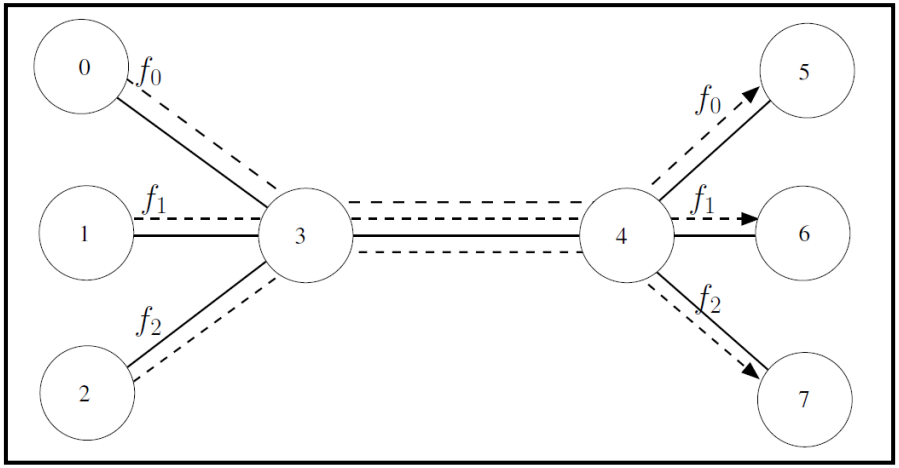


Course outline

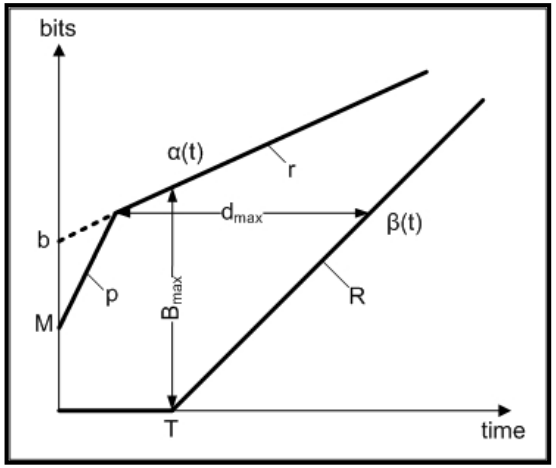
5. Network Calculus

Duration: 120 minutes

- Networks Worst-case analysis:
  - Packet Based, Tandem Networks, Feed Forward, Non Feed Forward
- Deterministic Network Calculus
  - Token Bucket / Leaky Bucket, Min-plus Algebra, Arrival and Service Curves, Latency and Backlog Bounds, Tightening Bounds
- (Optional) Stochastic Network Calculus



Tandem Network



Example Calculation

Course outline

(Optional) Evaluation of simulation results: Duration: 150 minutes

- Consistent Estimator, Unbiased Estimator, Variance of an Estimator, Bessel's Correction, Efficient Calculation
- Confidence Interval
  - Chebyshev
  - Central Limit Theorem
  - t-Distribution
- Evaluation and comparison of Simulation Results Replicate-Delete Method, Batch Means Method, Stationarity

Confidence interval according to the central limit theorem

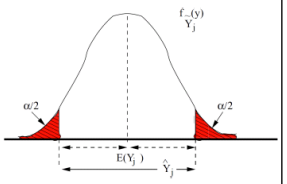
- Idea: The central limit theorem is still valid if σ^2 is replaced by $\tilde{S}^2$. Thus, it is possible to calculate the critical values out of the normal distribution.
- Recapitulate the "flipping of a coin example" with $\tilde{Y}$ representing the distribution of the estimator and Y being the distribution of the estimand. Then we can calculate the confidence interval as follows:

$$P[|Z| \geq \varepsilon] = P\left[\left|\frac{\tilde{Y} - E(Y)}{\tilde{S}/\sqrt{n}}\right| \geq \varepsilon\right] = \alpha$$

$$P[|\tilde{Y} - E(Y)| \geq \varepsilon \cdot \tilde{S}/\sqrt{n}] = \alpha$$

$$\tilde{Y} \pm z_\alpha \cdot \tilde{S}/\sqrt{n}$$

z_α is the $\alpha/2$ percentile of $N(0,1)$



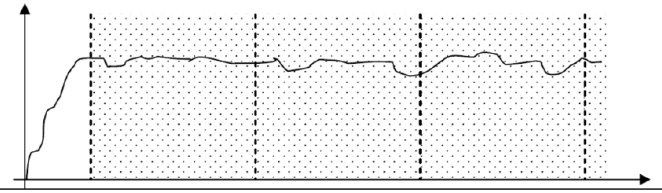
Picture taken from Buchholz

Batch-Means Method (LK 9.5.3)

- Estimate the duration of the transient phase
- Perform a long simulation run
- Remove the transient phase
- Divide the gathered results in n intervals of equal length (Batches) which hold m samples

Assure that the mean of subsequent batches is uncorrelated (calculate the empirical autocorrelation)

Number of batches $n \geq 10$ Batch size $m \geq 10 \cdot x$



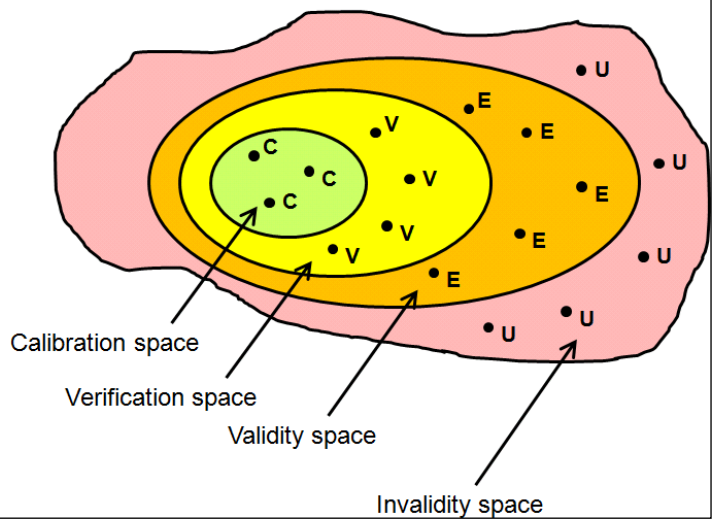
Course outline

(Optional) Evaluation of simulation results:

- Model Validation:
  - Calibration, Overfitting
  - Structural Change, Parameter Change
  - Comparison of Confidence Intervals:
    Welsh, Law & Kelton

Duration: 90 minutes

Calibration and Validation



Comparison of confidence intervals

Welch

- Estimators

$$\tilde{\mu}_R = \frac{1}{n}\cdot\sum_{i=1}^{n} V_{R_i} \qquad \tilde{S}_R^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(V_{R_i} - \tilde{\mu}_R\right)^2$$

$$\tilde{\mu}_S = \frac{1}{m}\cdot\sum_{i=1}^{m} V_{S_i} \qquad \tilde{S}_S^2 = \frac{1}{m-1}\sum_{i=1}^{m}\left(V_{S_i} - \tilde{\mu}_S\right)^2$$

- Difference of both samples are defined as follows:
  - $v_{RS\,i} = v_{Ri} - v_{Si}$
  - $v_{RS} = \{v_{RS_1}, v_{RS_2}, \ldots, v_{RS_n}\}$
  - $\tilde{\mu}_{RS} = \frac{1}{n}\cdot\sum_{i=1}^{n} V_{RS_i}$
  - $\tilde{S}_R^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(V_{R_i} - \tilde{\mu}_R\right)^2$

$$\hat{\mu}_{RS} \pm t_{n-1,1-\alpha/2}\cdot\tilde{S}_{RS}/\sqrt{n}$$

Both samples have to be statistically independent.

The samples must be of the same size. $m = n$

The variance of both samples must be equal. $Var(V_R) = Var(V_S)$

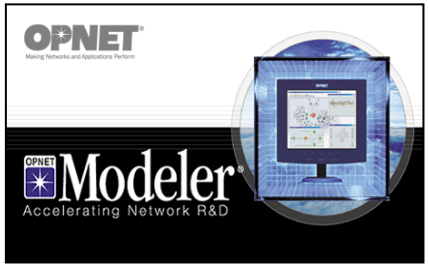
Course outline - Optional

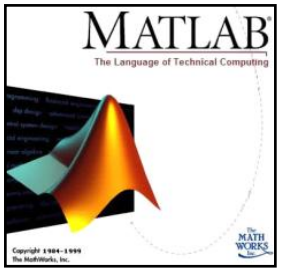
- Exercises: Processing Time: 120 minutes Duration: 60 minutes(each)
  - Exercise 1:
    - Evaluation of waiting queues
  - Exercise 2:
    - Evaluation of waiting queues
  - Exercise 3:
    - Matlab / Evaluation of samples

Course outline - Optional

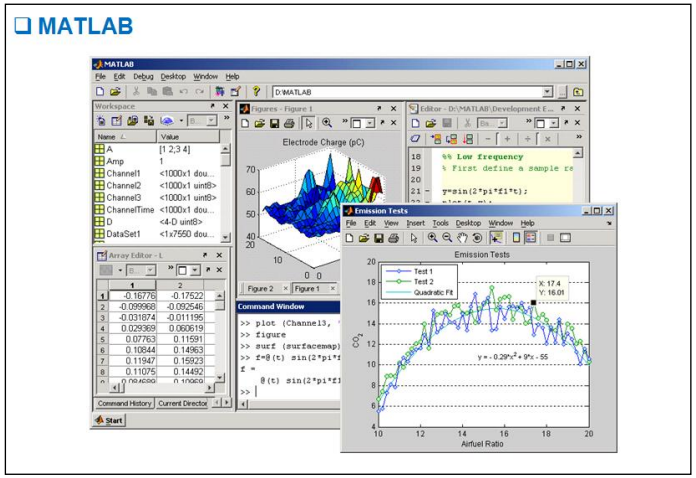
- Tutorial:

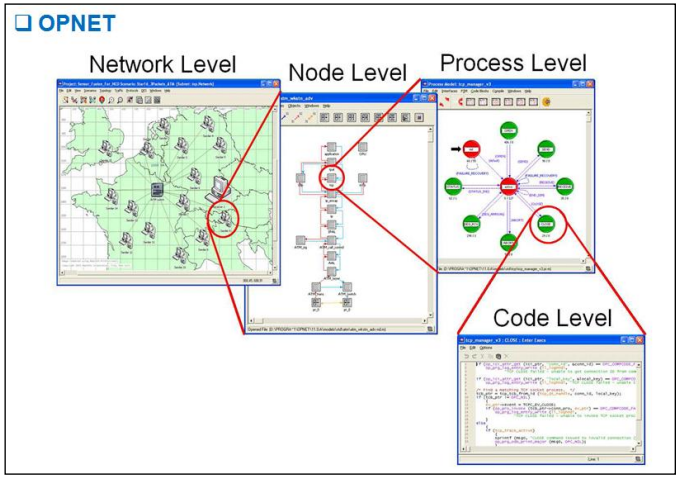
Duration: 180 minutes





  - Matlab / Octave / Gnuplot
    - Practical exercises
    - Evaluation of sample data
    - Visualization
  - OPNET Modeler
    - Discrete Event Simulator
    - Development of waiting queue model
    - Evaluation of results

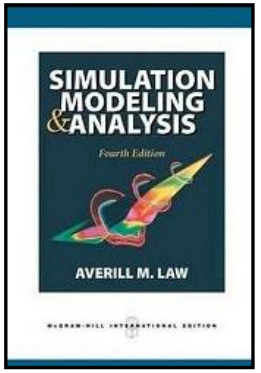




Material

- *Book:*

  Simulation Modeling and Analysis
  4th edition.
  Averill M. Law
  McGraw-Hill, 2007.

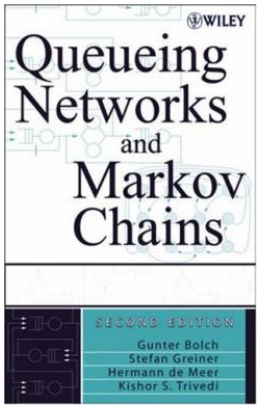


- *Book:*

  Queueing Networks and Markov Chains:

  Modeling and Performance Evaluation with Computer Science Applications
  G. Bolch, S. Greiner, H. de Meer, K. S. Trivedi

  Wiley, 1998/2006



- *Book:*

  Analytische Leistungsbewertung verteilter Systeme -

  Eine Einführung
  P. Tran-Gia

Material

- Lecture:
  - Performance Modeling of Computer Systems (2002)
    Prof. Gunter Bolch
    Informatik IV
    Universität Erlangen-Nürnberg

  - Modellgestützte Analyse und Optimierung
    Prof. Peter Buchholz
    Informatik IV
    Technische Universität Dortmund

  - Diskrete Simulation (IN2045)
    Dr. Alexander Klein
    Chair for Network Architectures and Services
    Technische Universität München