System Performance Evaluation

Internet of Things A.Y. 22-23
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System Performance Evaluation

System Performance Evaluation

- Allows to obtain the highest performance at the lowest cost.
- Allows performance comparison of a number of alternative designs/solutions to find the best one.
- Gives good insights on how well a system is performing and whether any improvements need to be made.
    - Useful at any stage of the system’s life cycle, i.e., design, manufacturing, use, upgrade, etc..

A systematic approach

- Most performance problems are unique.
- Evaluation techniques used for one problem generally cannot be used for a different problem.

- **Steps common to all performance evaluation projects:**

1. **State goals and define the system under evaluation**
   - Define the boundaries of the system.

A systematic approach

2. **List services and outcomes**
   - Each system provides a set of services
   - E.g., A computer network allows its users to send packets to specific destinations
   - A list of services and possible outcomes is useful in selecting the right metrics and workloads.

3. **Select metrics**
   - Select the criteria (metrics) to compare the performance
   - E.g., delay, accuracy, speed etc..

A systematic approach

4. **List of parameters that affect the performance**
   - System parameters (hardware and software)
   - Workload parameters (depend on users' requests)

5. **Select factors to study**
   - Some parameters will be varied during the simulation (factors) and will get different values (levels)

6. **Select evaluation technique**
   - Analytical modeling
   - Simulation
   - Real test-bed

A systematic approach

7. **Select Workload**
   - A list of service requests to the system
   - Analytical modeling: A probability of various requests
   - Simulation: Trace of requests measured on a real system
   - Test-bed: Scripts to be executed on the system.

8. **Design Experiments**
   - Decide on a sequence of experiments that offer maximum information with minimal effort
     - Varying number of factors and levels to determine their relative effect.

A systematic approach

9. **Analyze and Interpret Data**
   - The analysis produces results (not conclusions)
   - Each repetition of an experiment has a different outcome.

10. **Present results**
    - They should be presented in a manner that is easily understood, e.g., in a graph form
      - If it is needed, redefine system boundaries, included other factors and performance metrics…(several cycles).

Selecting an evaluation technique

Criterion	Analytical modeling	Simulation	Measurement
Stage	Any	Any	Post-prototype
Time required	Small	Medium	Varies
Tools	Analysts	Computer Languages	Instrumentation
Accuracy[a]	Low	Moderate	Varies
Trade-off evaluation	Easy	Moderate	Difficult
Cost	Small	Medium	High
Scalability	Low	Medium	High

a In all cases, results may be misleading or wrong.

Selecting an evaluation technique

- **Three rules of validation:**
  1. Do not trust the results of a simulation model until they have been validated by analytical modeling or measurements.
  2. Do not trust the results of an analytical model until they have been validated by a simulation model or measurements.
  3. Do not trust the results of a measurement until they have been validated by simulation or analytical modeling.

Selecting performance metrics

- For each performance study, a set of performance criteria must be chosen.
- Time to execute a task
  - Execution time, response time, latency
- Number of tasks per day, hour, sec, ns, etc.
  - Throughput, bandwidth.

Aircraft	DC to Paris	Speed (mph)	Passengers	Throughput (pmph)
Boeing 747	6.5 hours	610	470	286,700
Concorde	3 hours	1350	132	178,200

Selecting performance metrics

- Flight time of Concorde vs. Boeing 747?
  - Concorde: 1350 mph / 610 mph = 2.2 times faster
    = 6.5 hours / 3 hours

- **Concorde is 2.2 times («120%») faster in terms of flight time.**

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- Flight time of Concorde vs. Boeing 747:
  - Concorde: 1350 mph / 610 mph = 2.2 times faster
    = 6.5 hours / 3 hours
  - Concorde is 2.2 times (120%) faster in terms of flight time.

- Throughput = profit per passenger = speed per passenger (pmph)
  - Boeing 747 = 286,700 pmph
  - Concorde = 178,200 pmph
    - Boeing 747 produces 286,700 pmph / 178,200 pmph = 1.6 times (60%) more profit in terms of throughput.

Selecting performance metrics

- Global metrics: Reflect the systemwide utility
  - Resource utilization, reliability, availability.
- Individual metrics: Reflect the utility of each single user
  - Response time, throughput.
- There are cases when the decision that optimizes individual metrics is different from the one that optimizes the system metric.

Selecting performance metrics

- E.g.: Total vs. per node throughput
  - Keep the system throughput constant while increasing the number of packets from one source may lead to increasing its throughput, but it may also decrease someone's else throughput.

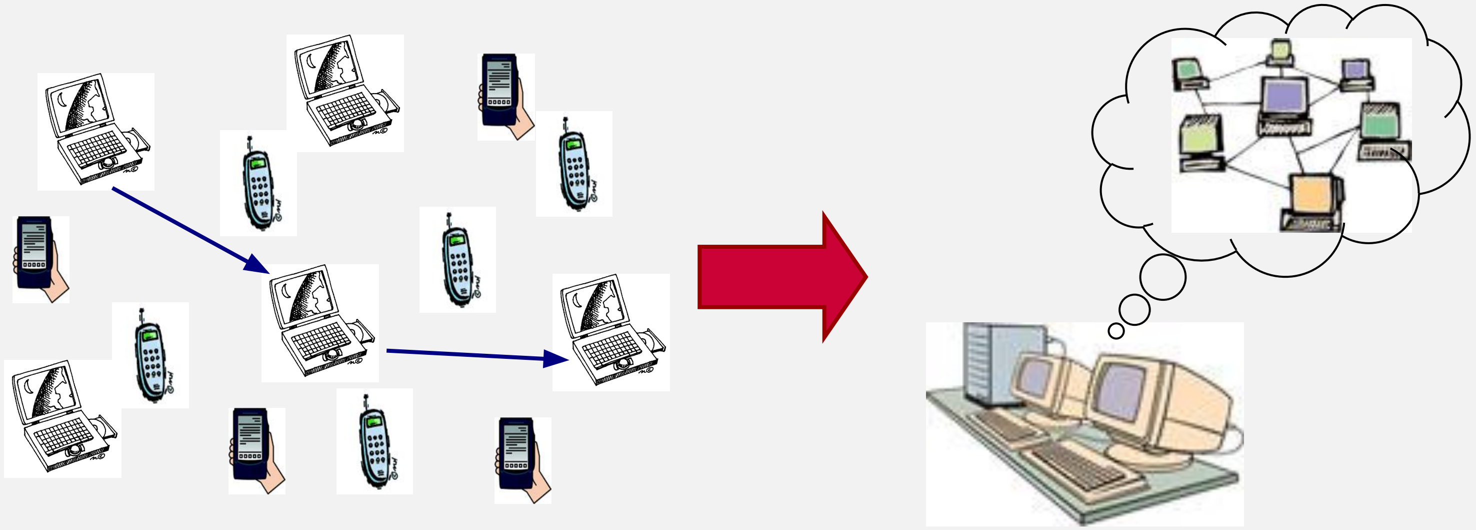
  - Using only the system throughput or the individual throughput may lead to unfair situations.

Selecting performance metrics

1. Low variability: Reduce the number of repetitions required to obtain a given level of statistical confidence.
2. Non-redundancy: Similar metrics should be avoided.
3. Completeness: All possible outcomes should be reflected in the set of performance metrics.

Introduction to Simulation

Introduction to Simulation



- **What is a network simulator?**
  - A software for modeling network applications and protocols (wired and wireless).
    - **What is it used for?**
      - Reproducing a system that evolves like the real system according to certain aspects, based on a model.

Introduction to Simulation

Simulation: When to use it

- Study and experimentation of the internal interactions of a complex system.

- System performance evaluation before the prototype.

- Verify analytical solutions.

- Common approach in research:
    - Design of new protocols
    - Comparison of protocols
    - Traffic analysis

Simulation: Why to use it

- Only one workstation is enough to run simulations.
- Allows the study of a wide range of scenarios in a relatively short time.
- Allows realization of complex and expensive networks to be implemented in a real test-bed.
- Easy to test/check the impact of changes in a simulated solution.

Simulation: Pros & Cons

- **Pros**
  - System verification before the production of a prototype
  - Easy debugging of the simulated protocol
  - Possibility to analyze the system's scalability
  - Identification of system vulnerabilities
  - Flexibility on studying the behavior of the system.

- **Cons**
  - The design/implementation of a model and its validation require the understanding of the simulation tool.
  - It is not always possible to capture the various aspects of the simulated system.

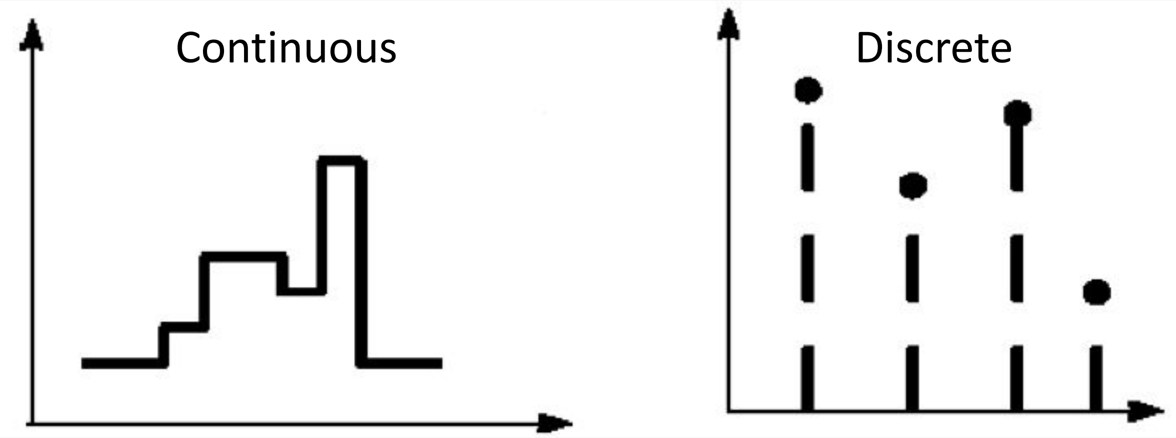
Simulation: Terminology

- **State variables:**
  - The variables whose values define the state of the system
  - Network simulation: number of nodes, packet queue, mac and routing protocols used etc..

- **Event:**
  - A change in the system state.
    - Network simulation: packet transmission, packet reception etc..

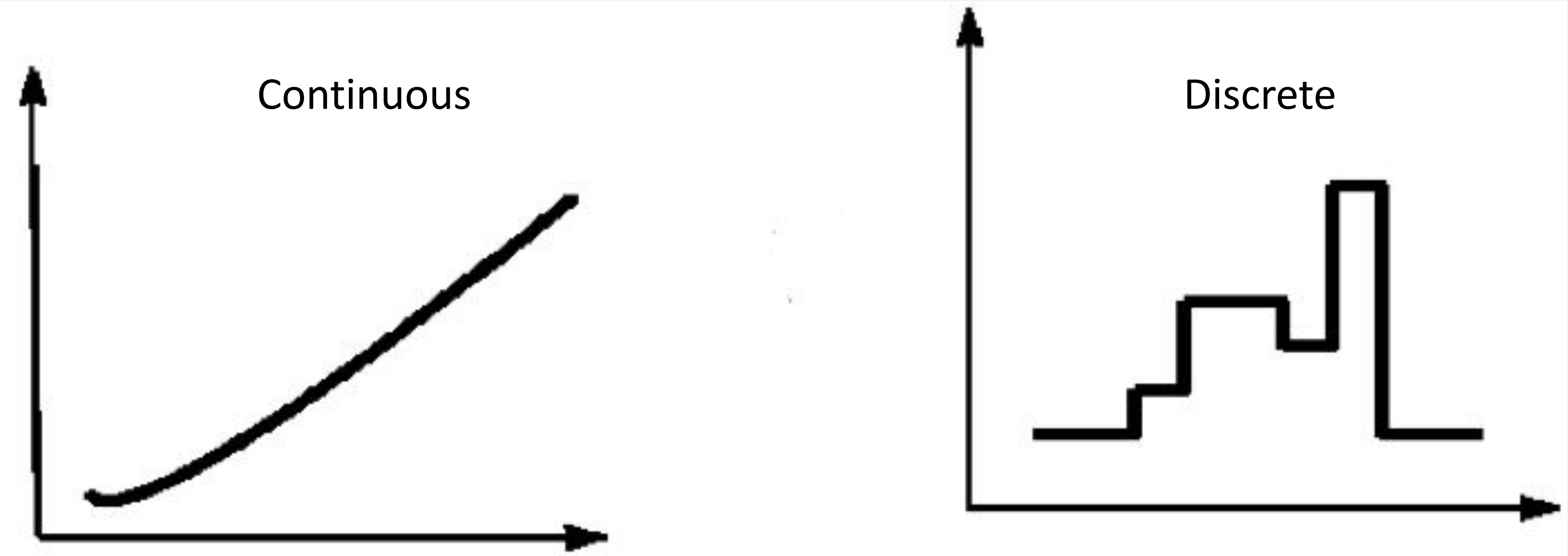
Simulation: Terminology

- **Continuous-Time and Discrete-Time models:**
  - *Continuous time model:* A model in which the system state is defined at all times.
    - Network simulation: number of nodes, communication among nodes is defined at any time.
  - *Discrete-Time model:* The system state is defined only at particular instants in time.
    - Classes: weekly



Simulation: Terminology

- **Continuous-State and Discrete-State models:**
  - *Continuous:* State variables are continuous.
  - *Discrete:* State variables are discrete.
    - Network simulation: number of nodes, packet queue length.



Simulation: Terminology

- Continuous-state models = Continuous-event models
- Discrete-state models = Discrete-event models

- **Continuity of time does not imply continuity of state and vice-versa!**

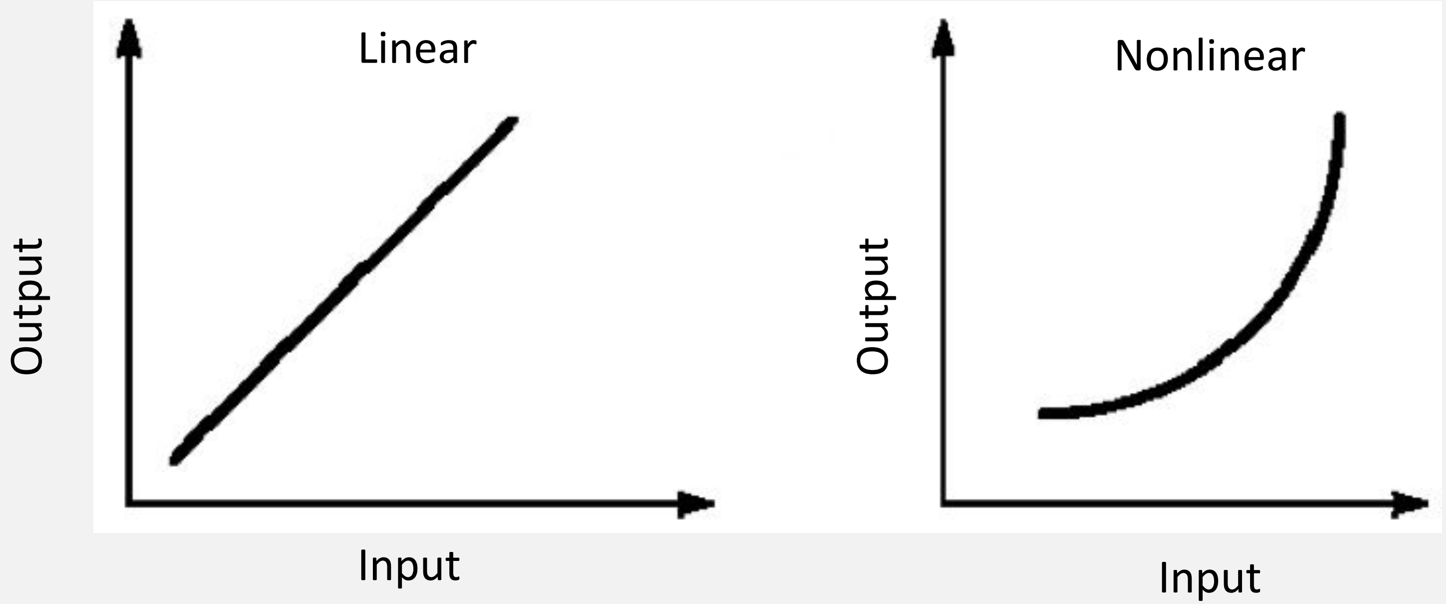
- Four possible combinations:
  1. Continuous state/continuous time
  2. Discrete state/discrete time
  3. Continuous state/discrete time
  4. Discrete state/continuous time

Simulation: Terminology

- **Deterministic and Probabilistic models:**
  - *Deterministic:* The output (results) of a model can be predicted with certainty.
  - *Probabilistic:* For the same set on input parameters, each repetition gives a different output.
- **Static and Dynamic models:**
  - *Static:* Time is not a variable.
  - *Dynamic:* The system state changes with time.
- **Open and Closed models:**
  - *Open*: The input is external to the model and is independent of it.
  - *Closed:* No external input.

Simulation: Terminology

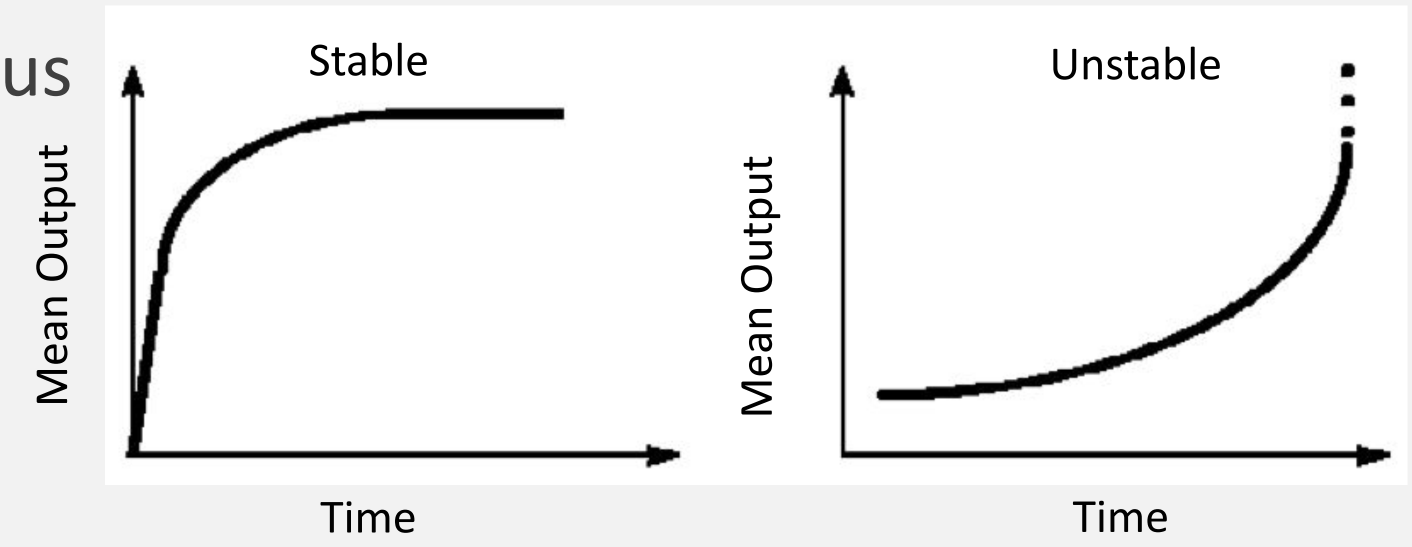
- **Linear and Nonlinear models:**
  - *Linear:* The output parameters are a linear function of the input parameter.
  - *Nonlinear:* Otherwise.



Computer system models: tempo continuo, stato discreto, probabilistico, dinamico e non lineare. Aperti o chiusi, stabili o instabili.

Simulation: Terminology

- **Stable and Unstable models:**
  - *Stable:* The dynamic behavior of the model settles down to a steady state.
  - *Unstable:* The behavior of the model is continuous changing.



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Simulation: Types

- **Model Carlo method:**
  - Static simulation without a time axis.
  - Model probabilistic phenomena that do not change characteristics with time.
- **Trace-driven:**
  - The simulation uses a trace as its input (a time-ordered record of events on a real system.)
- **Discrete-event:**
  - Discrete-state model of system.
    - Network simulation: number of packets in the queue.
    - Discrete- or continuous-time values.

Discrete-event Simulation

- **Components:**
  1. *Event scheduler*: It keeps a linked list of events waiting to happen.
  2. *Simulation clock*: Each simulation has a global variable representing simulated time.
     - The scheduler is responsible for advancing this time.
       - ***Unit time:*** Increments time by small increment and then checks to see if there are any events that can occur.
       - ***Event-driven:*** Increments the time automatically to the time of the next earliest occurring time.

Discrete-event Simulation

- **Components:**
  3. *Event routine:* Each event is simulated by its routine.
  4. *Input routines:* Get the model parameters.
  5. *Initialization routines:* Set the initial state of the system.
  6. *Trace routines:* Print out intermediate variables as the simulation proceeds; Useful on debugging.
  7. *Report generator:* Output routines executed at the end of the simulation; Calculate the final result.
  8. *Main program:* It brings all the routines together.

Common mistakes

1. **Inappropriate level of detail**
   - More details => Longer simulations => More bugs => More computations => More parameters ≠ Higher accuracy
2. **Inappropriate experimental design**
   - Too much generic => longer simulations and less accurate
3. **Unverified models**
   - Bugs in the code
4. **Invalid models**
   - Non realistic results

Common mistakes

5. **Improperly handled initial conditions**
    - Generally not representative of the system behavior in a steady state.
6. **Too short simulations**
7. **Poor random-number generators**
8. **Improper selection of seeds**
    - The seed for different random-number streams should be carefully chosen to maintain independence among the simulations.

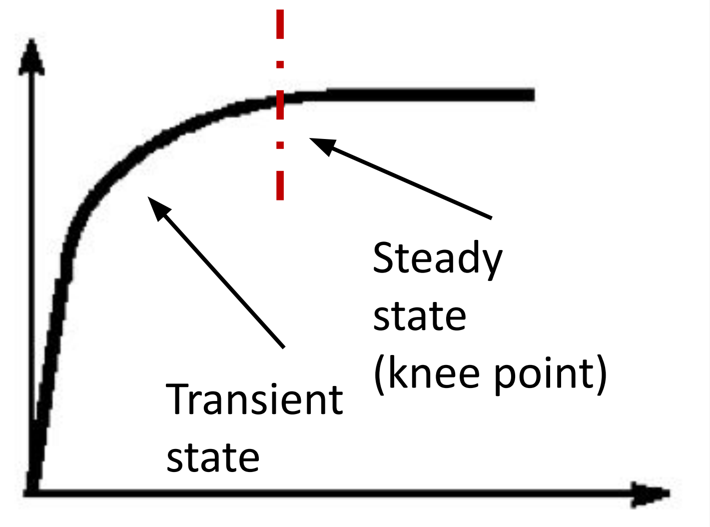
Model Verification and Validation

1. **Debugging:** Include additional checks and output in the program that will point out the bugs (if any).
    - E.g. 1: Check if the probabilities for certain events add up to 1.
    - E.g. 2: Packets received = pkts generated – pkts lost/dropped.
2. **Structured walk-through:** Explain the code to another person or a group. (It works even when the others do not understand the model!).
3. **Run simplified cases:** Easy to analyze them.
4. **Consistency test:** Check that the model produces similar results for input parameter values that have similar effects.
5. **Degeneracy test**: Check that the model works for extreme values of system configuration or workload parameters.

Simulation Results Analysis

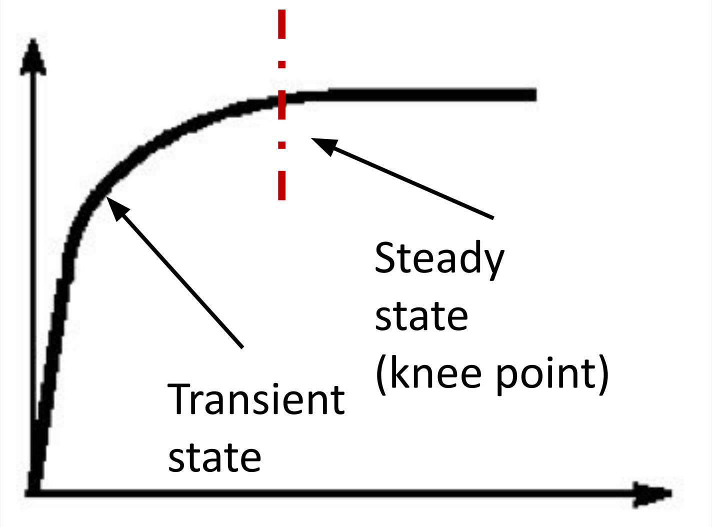
- In most simulations, only the **steady-state** performance is of interest!
- Results of the initial part of the simulation should not be included in the final computations.

- **Transient removal:** Identify the end of the transient state.
    - It is not possible to define exactly what constitutes the transient state and when the transient state ends.
        - All methods for transient removal are heuristic.



Simulation Results Analysis

- **Six methods for transient removal:**
  1. Long runs
  2. Proper initialization
  3. Truncation
  4. Initial data deletion
  5. Moving average of independent replications
  6. Batch means



Terminating Simulations

- Short simulations => low degree confidence
- Long simulations => waste of resources
- There are systems that never reach a steady-state performance.
  - These systems always operate under transient conditions.
  - Such simulations are called **terminating simulations**; they do not require transient removal.
  - E.g.: A system shuts down at 5pm every day.

- **To increase data confidence take the average over several independent repetitions.**

Simulators for IoT Systems

What is a Simulator?

- A tool/software that realistically imitates/models the behavior of IoT systems.

- Different types of simulators; Most commonly used:
  - Trace-Driven Simulators
  - Discrete-Event Simulators

Why do we use Simulators?

- The most common approach to develop and test new protocols/applications.
- Evaluate the performance of new solutions.
- Consider a large-scale IoT network:
  - Low cost
  - Easy(?) to implement
  - Practical

Simulators for IoT Systems

- Several simulators exist:
  - **ns-3/ns-2**
  - OMNeT
  - Castalia
  - GreenCastalia
  - SUNSET
  - COOJA
  - Avrora
  - …

Simulators for IoT Systems

Additional Resources

- R. Jain, "*The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling*“, Wiley-Interscience, New York, NY, April 1991. (Chapters 2, 3, 24)

Questions?