جامعة المستقبل
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كلية العلـوم
قســـم الأنظمة الطبية الذكية

المحاضرة السابعة

المادة: Simulation and Modeling
المرحلة: الرابعة
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Discrete Event Simulation (DES)

What is Simulation?

- Process of imitating real systems to study behavior
  - Allows 'what-if' experiments without harming real systems
  - Useful when experiments are costly, dangerous, or slow

Why Discrete Event Simulation?

- Models systems where changes happen at discrete times (events)
  - Intuitive mapping to real-world processes (arrivals, services)
  - Requires less math than continuous models ideal for beginners

DES Components

- Entities (e.g., patients, customers)
  - Resources (servers: doctors, machines)
  - Events (arrival, service start, departure)
  - Queues and disciplines (FIFO typical)

Event List & Time Advance

- Maintain a list of future events sorted by time
  - Advance simulation time to the next event
  - Update system state and generate new events if needed

Discrete Event Simulation (DES) for Smarter Manufacturing

- DES provides the ability to model every step of the production flow, from individual machine actions to the overall factory layout. By leveraging this technology, manufacturers can:
- Identify bottlenecks: Locate problem areas in your production process before they cause delays.
- Test improvements: Virtually implement process changes to understand their impact on production speed, quality, and efficiency.
- Reduce downtime: Plan for maintenance and disruptions by modeling different what-if scenarios, ensuring minimal impact on production.
- Improve resource allocation: Optimize the use of materials, machines, and labor to achieve better outcomes with fewer resources.

Example System: Single-server Queue (M/M/1 style)

- Entities arrive according to a Poisson process (rate λ)
  - Service times are exponential with rate μ
  - Single server, FIFO queue

M/M/1 Queue — Key Formulas

- Utilization: $\rho = \frac{\lambda}{\mu}$
  - Average number in system: $L = \frac{\rho}{(1-\rho)}$ $(when\ \rho < 1)$
  - Average time in system: $W = \frac{1}{(\mu-\lambda)}$
  - Little's Law: $L = \lambda \times W$

Numeric Example:

- Let $\lambda = 0.8$ arrivals/min, $\mu = 1.0$ services/min
  - Compute: $\rho = 0.8 / 1.0 = 0.8$
  - $L = \frac{0.8}{(1-0.8)} = \frac{0.8}{0.2} = 4$)customers on average)
  - $W = \frac{1}{(1-0.8)} = \frac{1}{0.2} = 5\ minutes;\ check: L = \lambda W = 0.8 \times 5 = 4$

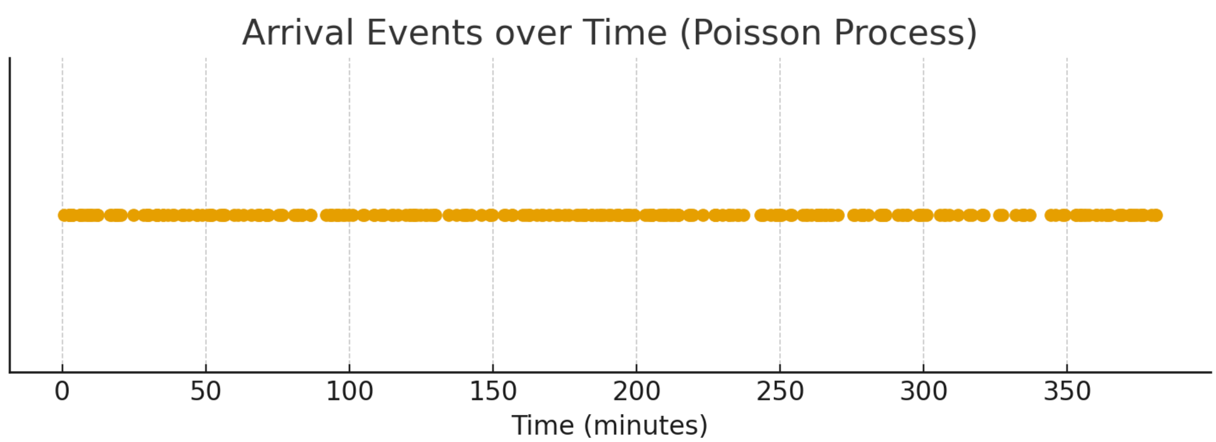
Assumptions & Limitations of M/M/1

- Arrivals Poisson, services exponential memoryless
  - Single server, infinite queue; assumptions may not hold in hospitals
  - DES can relax many assumptions by simulating exact rules

DES Pseudocode

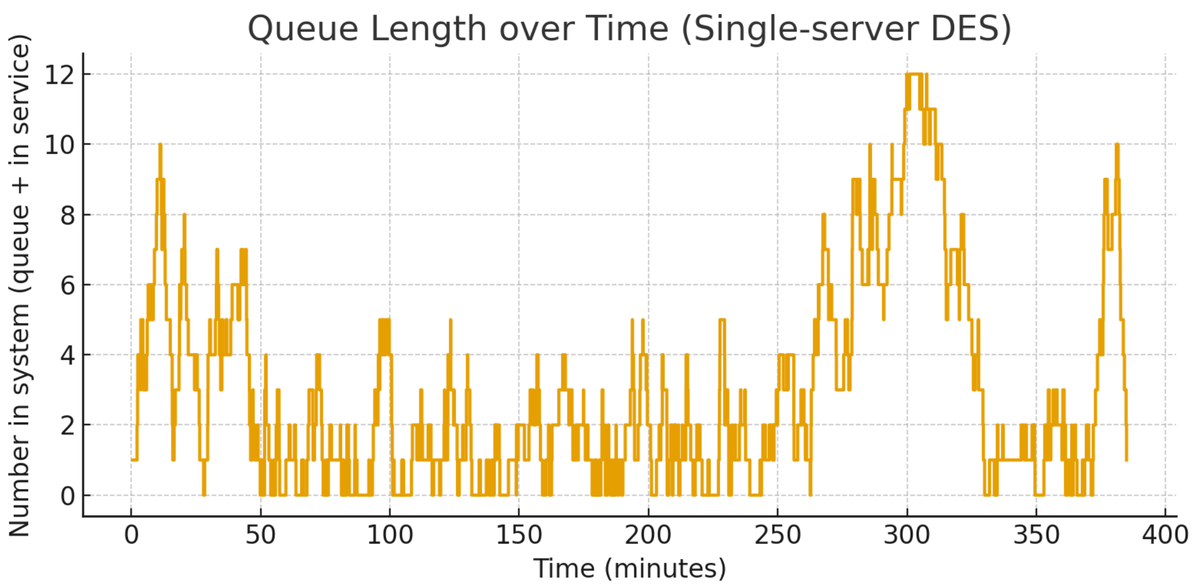
- Initialize event list with first arrival
  - While events exist and not finished:
  - Pop next event, advance clock to event time
  - If arrival: schedule service or enqueue
  - If departure: free server and start next (if any)
  - Record metrics (wait times, utilization, throughput)

Arrival Events over Time



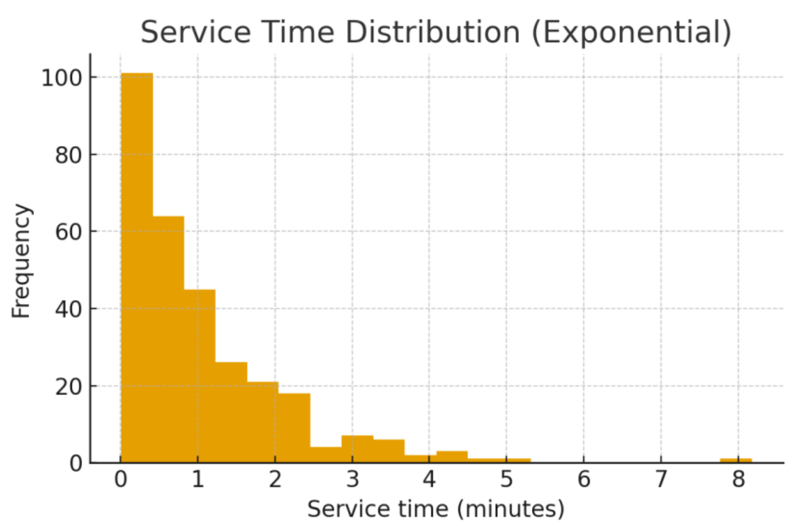
Each dot is an arrival. Interarrival times are exponential → Poisson arrivals.

Queue Length over Time



Step-plot shows how many entities are in the system (queue + in service) at each event time.

Service Time Distribution



Exponential service times (many short services and few long ones).

Performance Metrics to Measure

- Average waiting time in queue (W_q)
  - Average time in system (W)
  - Average number in queue (L_q) and system (L)
  - Server utilization (ρ) and throughput

Validation & Verification

- Compare to analytical results when available (e.g., M/M/1)
  - Check Little's Law: $L \approx \lambda \times W$
  - Run multiple replications to estimate variance and confidence intervals

Medical Application — ER Triage (DES use)

- Model patient arrivals and triage categories (critical, urgent, non-urgent)
  - Assign priorities and resources (doctors, beds)
  - Measure waiting times by severity and identify bottlenecks
  - ER →Emergency Room

Medical Application — OR Scheduling & ICU

- Simulate OR schedules, cleaning times, and emergency insertions
  - Model ICU bed occupancy and patient flow from ER → ICU → Ward
  - Evaluate staffing needs and resource allocation
  - OR →Operating Room
  - ICU →Intensive Care Unit