Discrete Event Simulation

Discrete Event Simulation

- Imitating the operation of a system over time.
- Typical objective- Support decisions related to the use of limited resources.

Discrete Event Simulation - Outline

- To understand how and why we simulate such systems we will cover:
  - Analysis options.
  - The mechanics of how a simulation is implemented on a computer.
    -
  - Modeling views/orientations.
  - The steps of a simulation study.
  - Analyzing input and output data.
  - Simulating randomness.

Analysis Options

- Utilize the simplest fastest methods that provide adequate decision support
  -

Analysis Options

- Resource allocation decisions – It may suffice to examine resource utilizations and WIP.

Example

- A workstation has two machines in parallel that can process jobs at a rate of 15 JPH. Jobs arrive over time at a rate of 25 JPH.

Analysis Options

- Unless a system has very high relative variability, utilizations < 90% will lead to "reasonable" queue sizes.
  - Demo

In-class Exercise

- Two types of jobs (A and B) arrive to a single machine for processing. The arrival rate of type A jobs is 5 per hour, and 2.5 per hour for type B jobs. Type A jobs have an average service time of 5 minutes, and type B jobs have an average service time of 11 minutes.
  - What is the utilization of the machine?

Analysis Options

- At the next level of detail queuing models may be applied.
  - More information than utilization calculations.
  - Difficult skill to apply.
  - Some G/G/m models were covered in IE 368.

Discrete Event Simulation - Basics

- Fundamental components/terminology.
- Simulation mechanics
  - Manual execution of a simulation.
- Performance measures.

Terminology

- We will simulate stochastic dynamic discrete-event systems.
  - Stochastic –
    -
  - Dynamic –
    -

Terminology

- Discrete event –
  - System state –
  - Examples

Terminology

- Entities – Objects that move through the simulated system.
  - Examples
    -
    - Entities can be combined and split.
- Attributes – Parameters, data specific to an entity.
  - Examples
    -
  - The same concept as objects (entities) and object data (attributes) in Object Oriented Programming

Terminology

- Global variables/parameters – System wide values accessible by all entities and resources.
  - Examples
    -
  - Resources – Items that are used by entities and found in limited amounts.
  - Queues – Spaces where entities wait for resources.

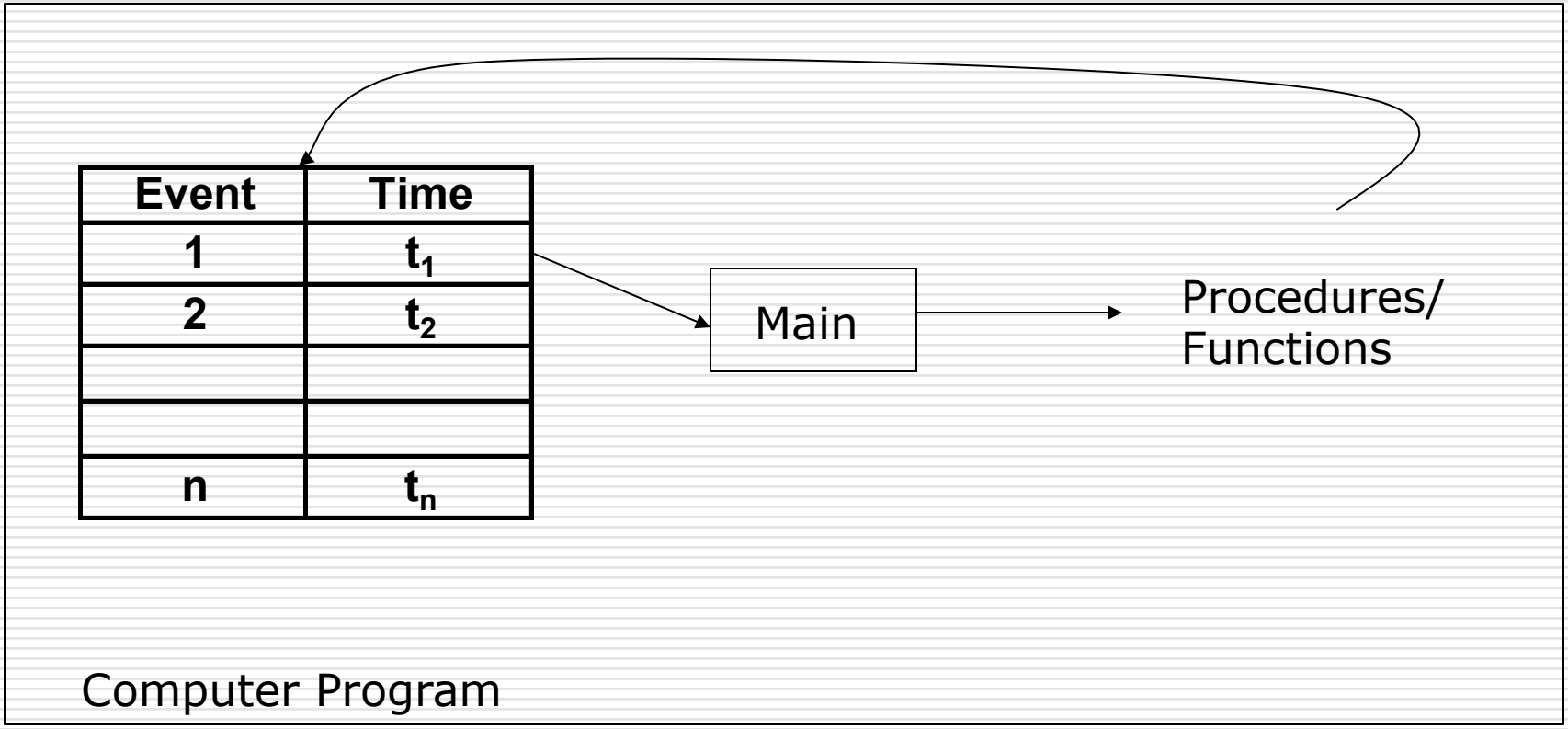
Terminology

- Events – Actions that cause the system state to change.
  - Examples
    -

Mechanics of Simulation

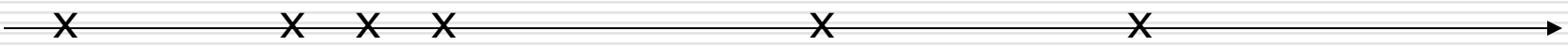
- Event calendar and the passage of simulated time.
  - Simulations maintain an event calendar that functions like the control center of the simulation.
  - The event calendar is a time sorted list of events and the times that they occur.
  - When the event at the top of the list occurs, simulated time is advanced and specific logic is initiated.
    - This logic changes the state, updates statistics, and schedules additional events.

Event Calendar



Simulation Clock

- Simulation time does not advance uniformly unless controlled.



- Arena demo

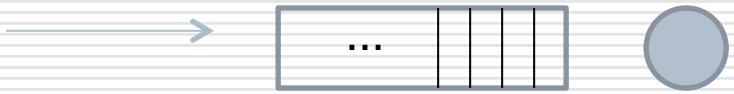
Manual Simulation

- We will execute a manual simulation on paper to understand the fundamentals of simulation mechanics.
- You will execute what the computer carries out in a simulation.

Example System

- A “single server queuing system with infinite queue capacity”.
- System description
  - Customers (jobs) arrive one at a time to be processed by a server who can serve a single customer at a time. If the server is idle when a customer arrives the customer immediately starts service, otherwise the customer waits in an infinite capacity queue and is served in first-in-first-out (FIFO) order.

Example System



Arrivals Queue Server

For some fixed simulated time:

- How many customers are processed?
- What's the average customer queue time?
- What's the average customer system time?
- What is the average number in queue?
- What is the server utilization?
- What are max observed values for
  - Queue time?
  - Time in system?
  - Number in queue?

Manual Simulation

- Will use pseudo code and a table to implement the simulation.
- See handout.

Manual Simulation Table

					Attributes		Statistical Accumulators										
Just Finished Event			Variables		Arrival Times												Event Calendar
Entity #	Time t	Event Type	Q(t)	B(t)	(In Queue)	In Sevice	P	N	∑WQ	WQ*	∑TS	TS*	∑WQ	∫Q	Q*	∫B	[Ent. #, Time, Type]

Notation

t = simulation time
t_{before} = prior event simulation time.
Q(t) = # in queue at time t
B(t) = 1 if the server is busy, and 0 if the server is idle
P = the number of customers/jobs processed after each event
N = the number of customers/jobs that have passed through the queue
$\sum WQ$ = the sum of the queue times observed for customers
WQ* = Max queue time observed
$\sum TS$ = the sum of the system times (queue + service) observed for customers
TS* = Max system time observed
$\int Q$ = the area under the Q(t) curve through time t
Q* = Max value for the number in queue observed
$\int B$ = the area under the B(t) curve through time t

					Attributes		Statistical Accumulators										
Just Finished Event			Variables		Arrival Times												Event Calendar
Entity #	Time t	Event Type	Q(t)	B(t)	(In Queue)	In Sevice	P	N	∑WQ	WQ*	∑TS	TS*	∑WQ	∫Q	Q*	∫B	[Ent. #, Time, Type]

	Interarrival Times
First Arrival	0.0
1	1.73
2	1.35
3	0.71
4	14.28
5	0.7

Customer	Service Times
1	2.9
2	1.76
3	3.39
4	4.52
5	4.46
6	4.36

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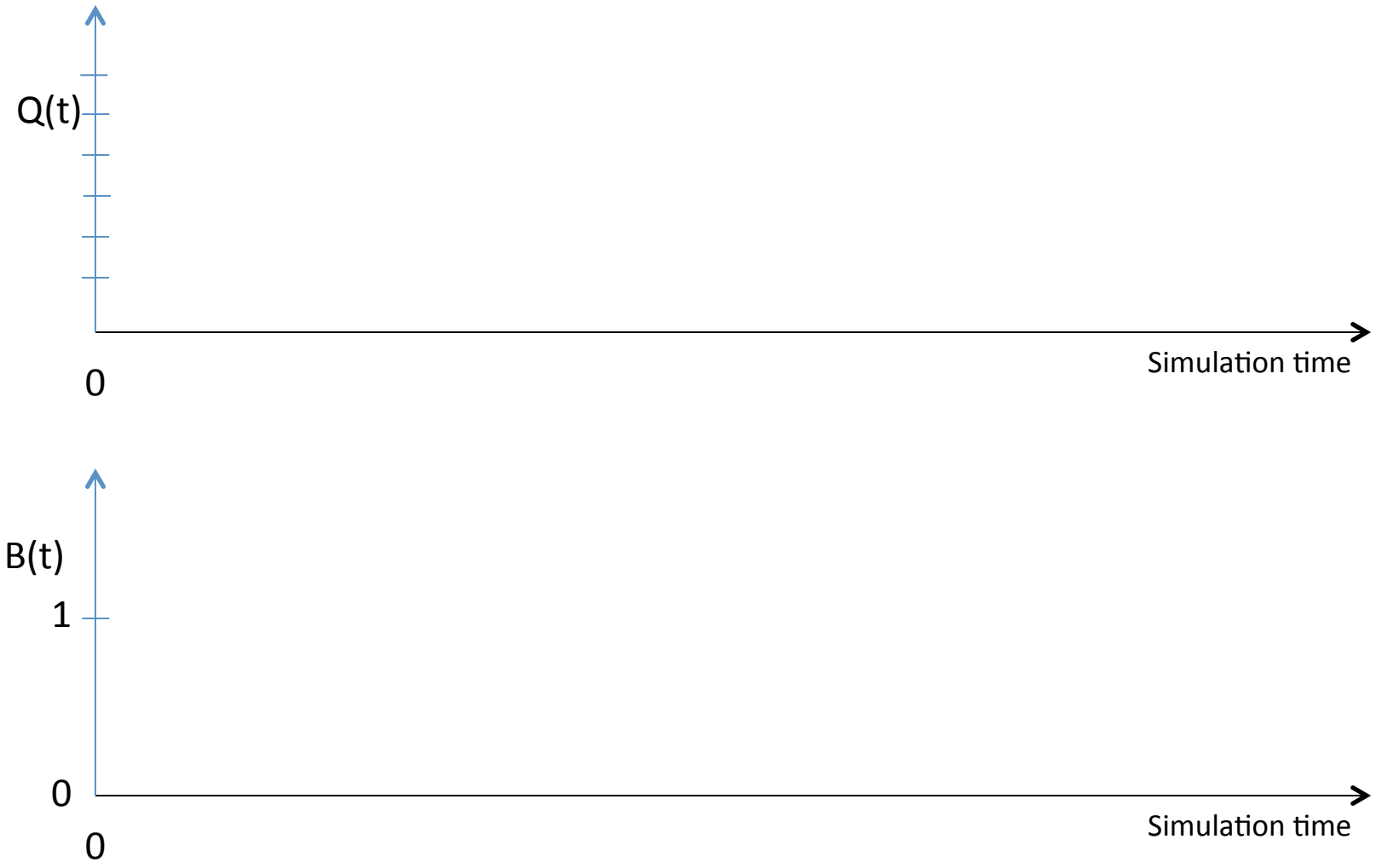

Q(t)
0
Simulation time
B(t)
1
0
0
Simulation time

“Simulation Performance Measures”

- Simulation performance measures

  - Tally statistics –”Tally” is an Arena term.
    -

"Simulation Performance Measures"

- Simulation performance measures.
  - Counters – Incremented when specific events occur.
    - E.g., Completed jobs.
  - Time average measures – Arena calls these "Time persistent"
    -

"Simulation Performance Measures"

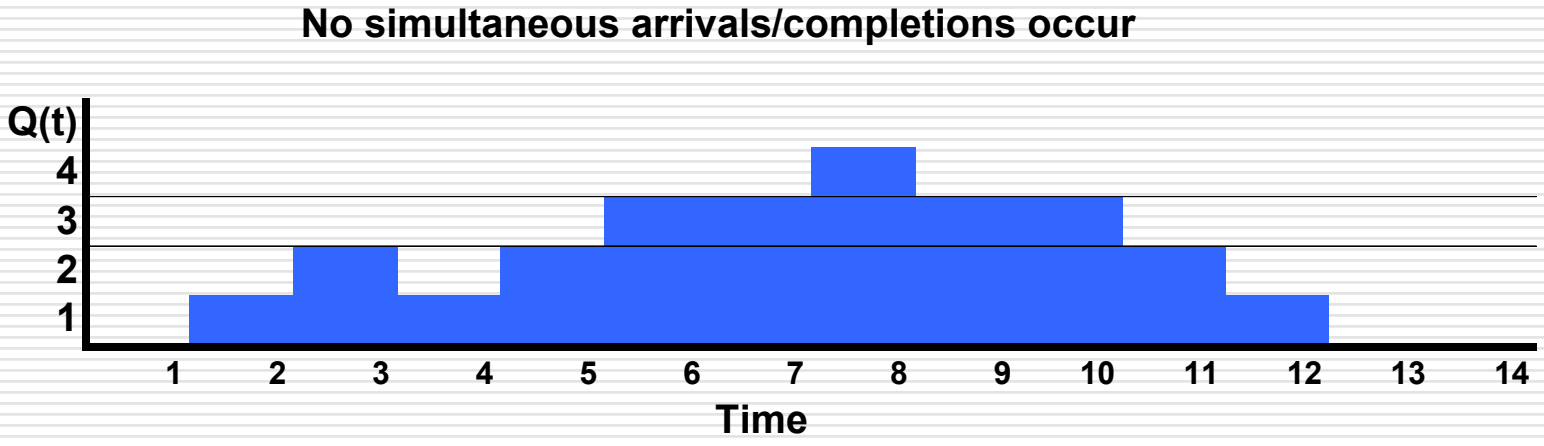
- Simulation performance measures.
  - Maximums and minimums – Changed when specific comparisons indicate.
    - E.g., Maximum jobs in queue.

“Simulation Performance Measures”

- The average time a part spends in the system.
  - Tally or Time average?
- Utilization of a machine.
  - Tally or Time average?

In-class Exercise

- Compute the average number in system, and average time in system through T = 14 (assume first-in-first-out).



In-class Exercise

Simulation Modeling Views

- The manual simulation looked at the system dynamics by examining the events that occur.
  - This is called event orientation.
- Event orientation
  -

Simulation Modeling Views

- Process orientation – The focus on defining the system dynamics is on entities and how they flow through the system.
- Manual simulation.
  - Arrive-> Queue -> Machine -> Depart
- Arena is process orientated simulation system.
- Process orientation tends to be easier when modeling large systems.
- Most simulations are implemented in an event driven manner (including Arena).

Initial Steps in a Simulation Study

- Define the objectives of the study.
  -
- Write a description of the system.
  -
- List assumptions if any.
- Write a report introduction.
- From the system description identify
  - Data collection needs
    -

Intermediate Steps

- Begin model development.
  -
- Fit distributions to data for use in the model.
  -
- Verify and validate the model.
- Experimentation and analysis.
  -

Final Steps

- Report writing.
- Presentations.
  - Animation if necessary
- Other points.
  - On going communication throughout the study.
  - Observation/face time.