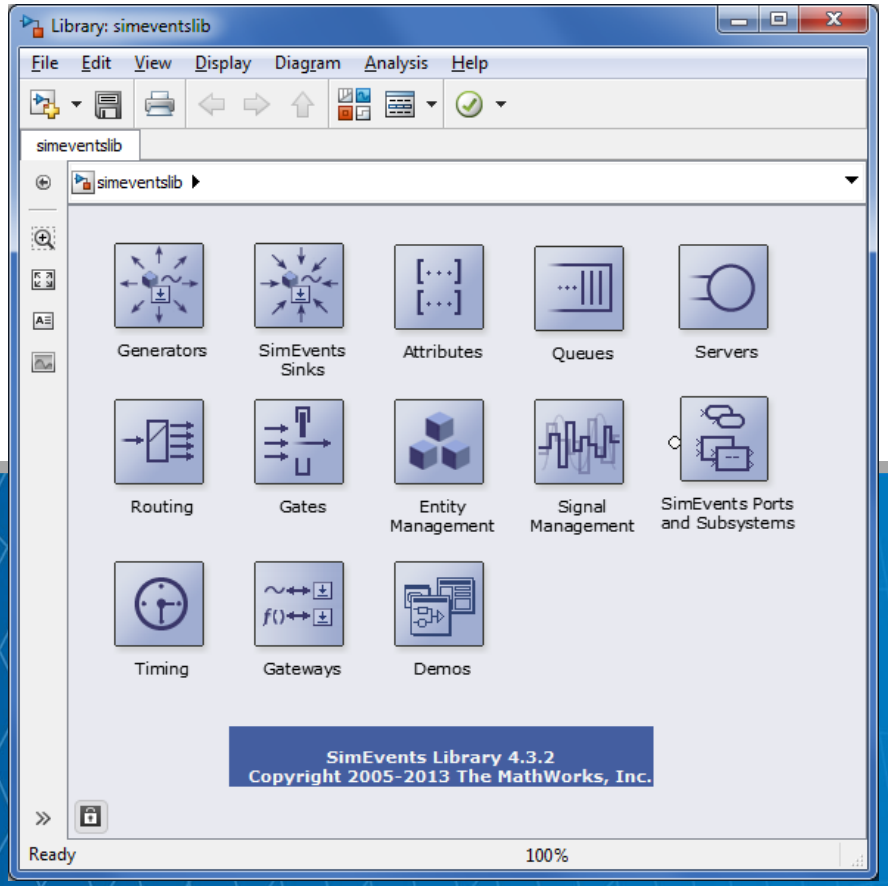
Modelling and Analysis of Discrete Event Simulations



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Agenda

- What is a Discrete Event System (DES)?
- DES Examples using SimEvents
  - Video streaming over a bandwidth limited channel
  - Batch production process
- SimEvents Tutorial
- Taking SimEvents Further
  - Custom routing example
  - Applying parameter sweeps
  - Incorporating optimisation
- Summary

What you will learn:

- SimEvents is useful to model non-deterministic, discrete event systems.
- SimEvents is useful for analysing, for example,
  - Resource contention
  - Congestion/bottlenecks/processing delays
  - System throughput
  - Scheduling and routing
- SimEvents can leverage the power of MATLAB and Simulink to extend simulation and analysis capabilities.

TriVector Verifies Time Latencies for Ares I Rocket

NASA's Ares I rocket.

Challenge

Analyze the time latency of health and status information aboard NASA's Ares I rocket

Solution

Use Simulink and SimEvents to model packet-level communications, run discrete-event simulations, and assess end-to-end latencies

Results

- Requirements validated one year sooner
- Timing specification problems uncovered
- Latency analysis results communicated visually

"Our SimEvents model for Ares I contains more than 45,000 blocks and tracks end-to-end delivery time for approximately 20,000 packets per second across multiple buses. This level of detail enabled us to validate requirements and identify issues with the timing requirements prior to hardware design."

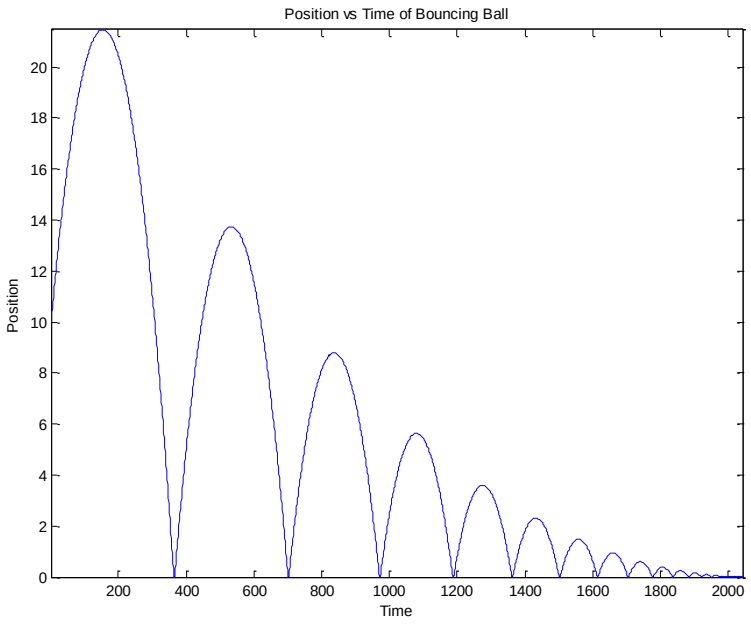
Kerry Alexander
TriVector Services

What is a Discrete Event System?

A system whose state changes based upon the occurrence of discrete events

Time Driven vs. Event Driven

Time Driven – Bouncing Ball



State of the system is dependent on time and physical parameters.

- **Initial height of ball**
- **Initial velocity of ball**
- **Gravity**

Deterministic

→SIMULINK

Time Driven vs. Event Driven

Event Driven – Barber Shop

State of the system does not change unless an event occurs.

- **Customer arrives**
- **Customer queues**
- **Customer leaves**

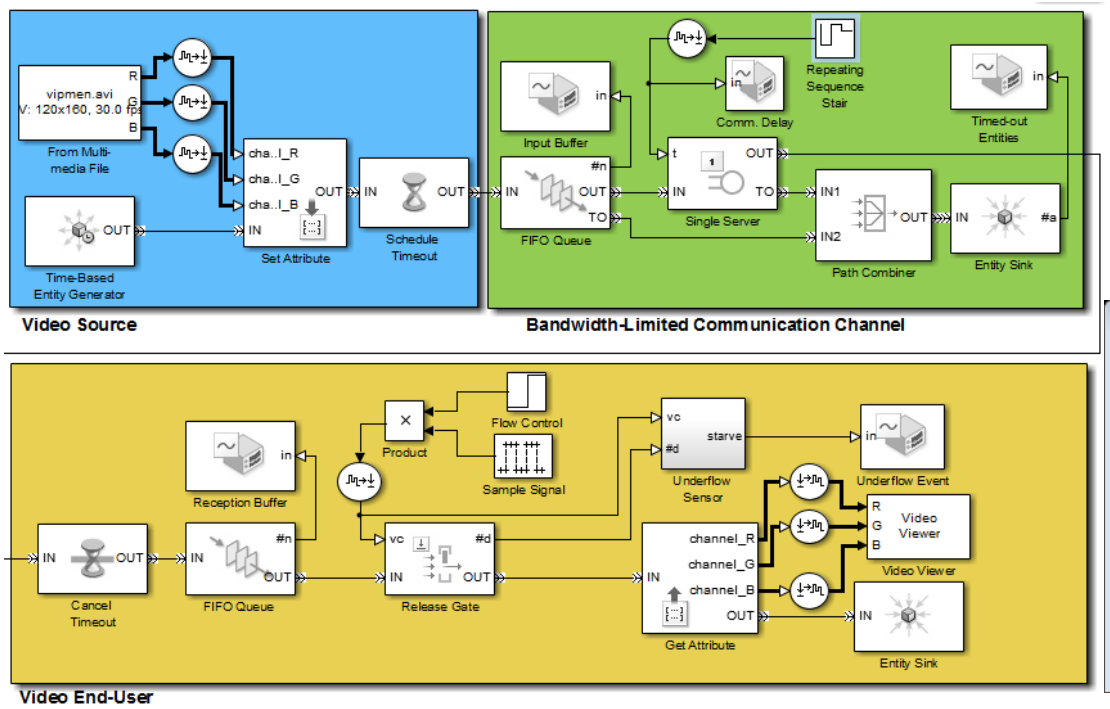
Non-Deterministic

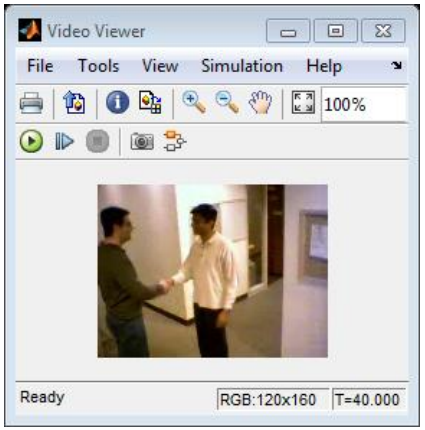
→SIMEVENTS

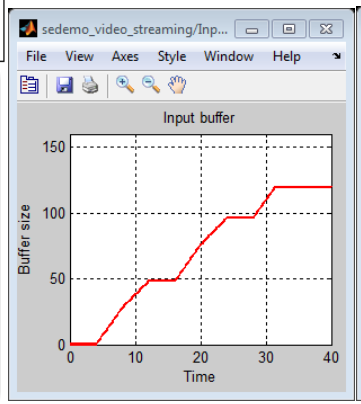
Example Applications of DES

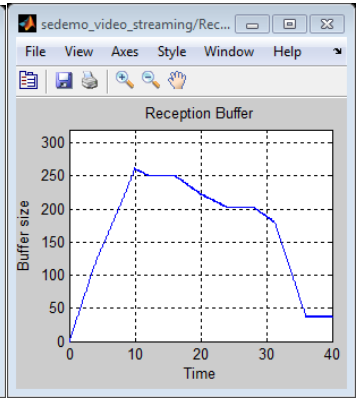
- Supply chain and logistics
- Mission planning
- Packet based communications
- Real-time operating system models
- Business and operational processes
- Manufacturing processes
- Service scheduling
- Etc.

Example: Video Streaming



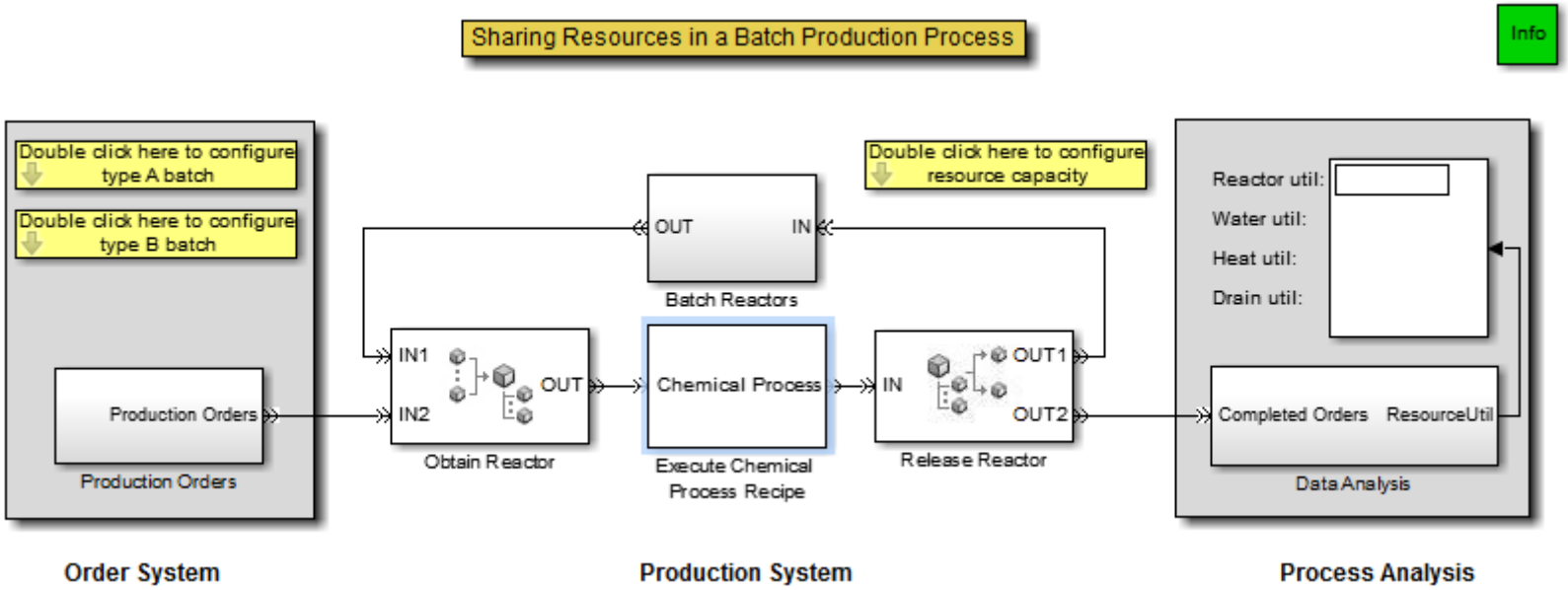






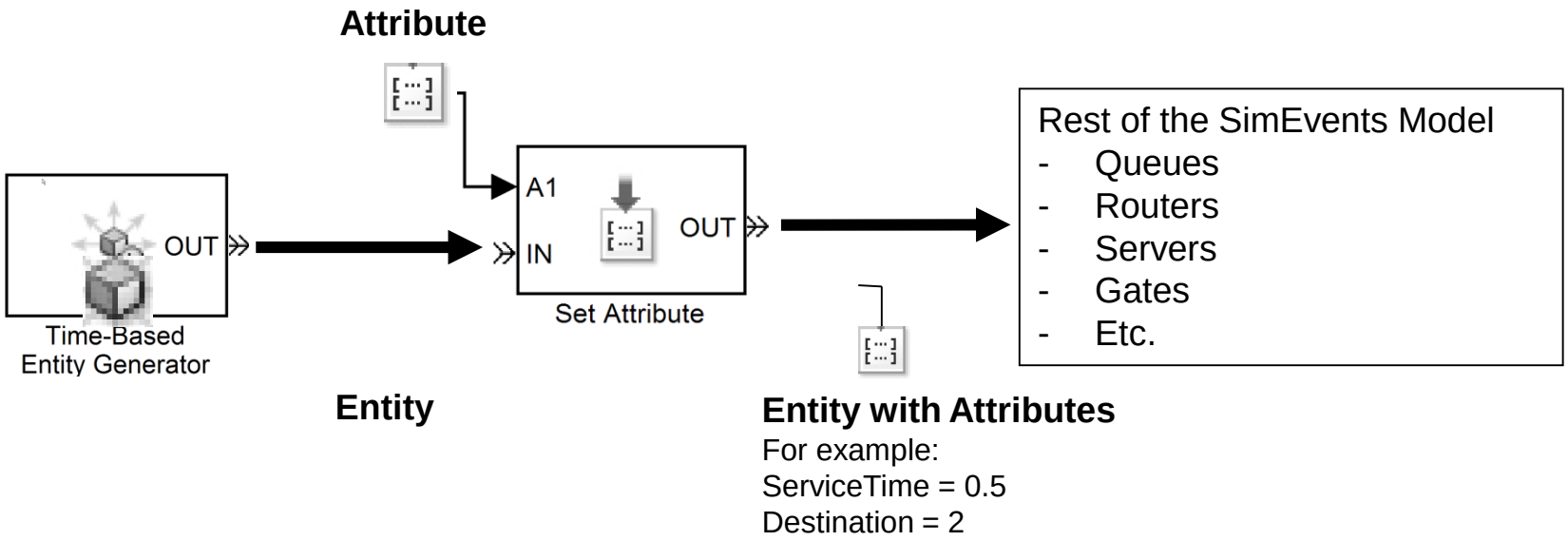
- Simulates a bandwidth limited communications channel
- Analysis of simulation results gives insight into how the channel affects received video quality.

Example: Batch Production Process



- Simulates the use of shared resources in a batch production process
- Analysis of simulation results gives insight into how we can alter the resource profile to improve the performance of the system.

SimEvents: Basic Model of Computation



- Entities
  - Abstraction of something in the simulation (e.g. data packet, people, vehicles)
  - Move through queues, servers, gates, and switches

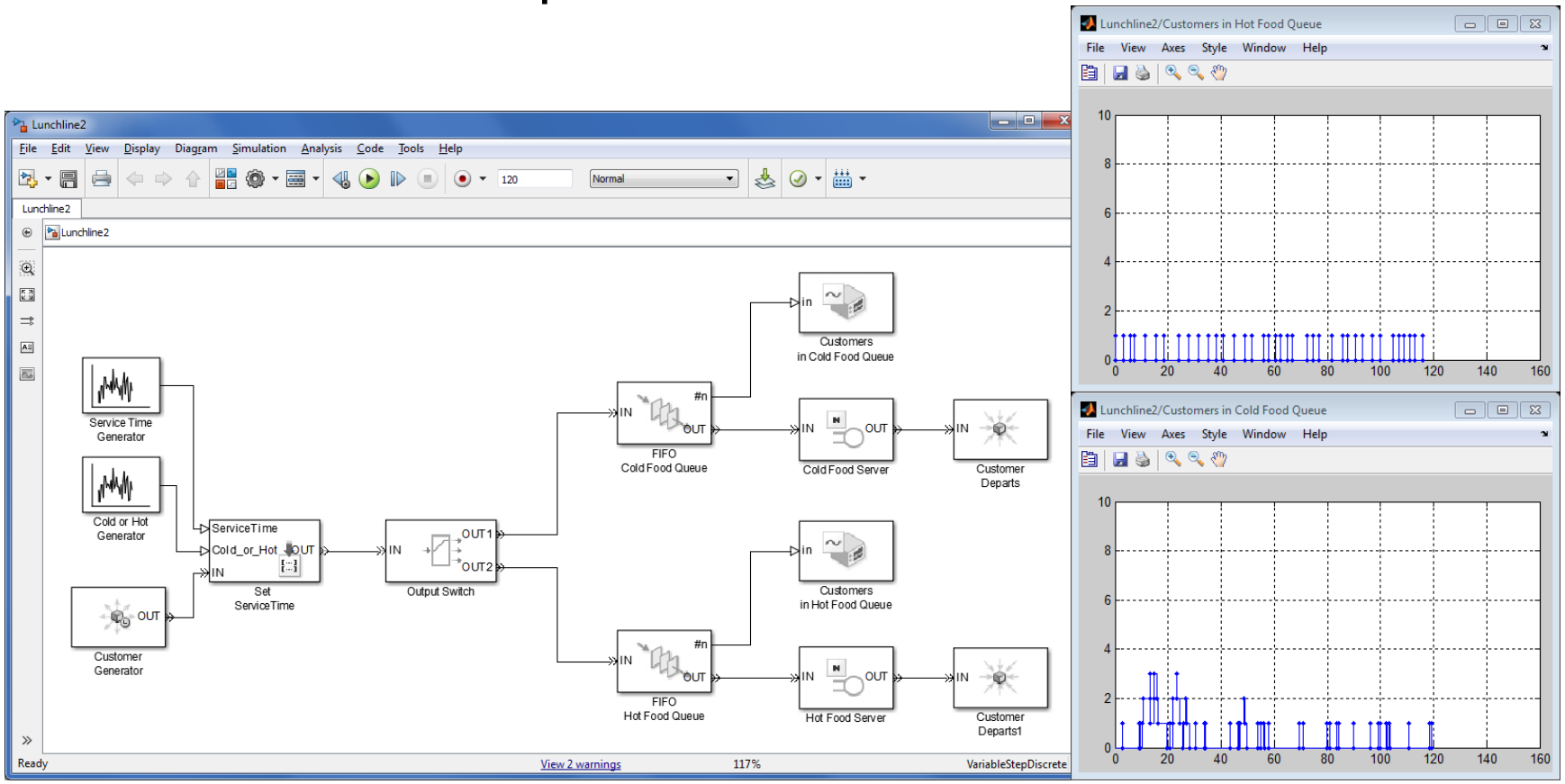
- Attributes
  - Numerical data carried by entities (i.e. Video frame, Length, Dest. Address,)
  - Attach unlimited number of Name-Value pairs to entities

Other Examples of Systems Using SimEvents

Application	Entities Represent	Modeling
Processor	Instructions Interrupts Processes	Processing Times Processor Utilisation Throughput Latency
Communication Channel	Data Frames Data Packets Components of a protocol	Channel Loading Channel Congestion Data Loss Latency
Business and Operational Processes	Physical information Messages People	Latency Resource Contention Probable Outcomes
Supply Chain and Logistics	Equipment Vehicles Products	Average wait times Throughput and congestion Effects of failure

SimEvents Tutorial

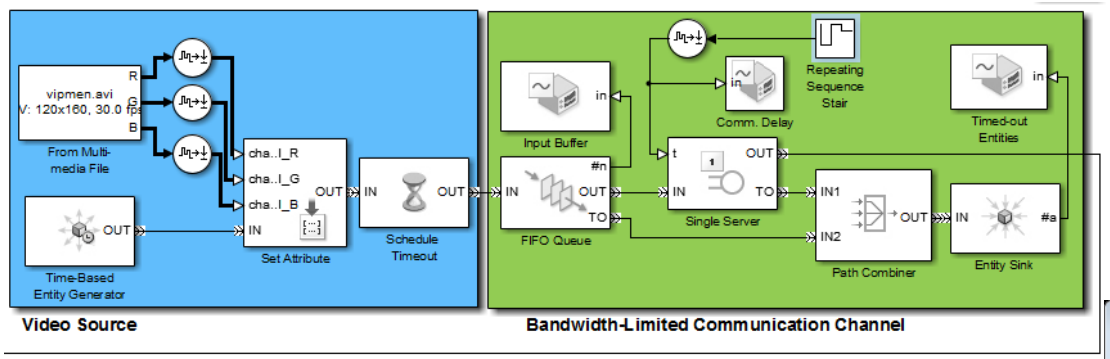
- Event driven, non-deterministic simulation
- Customers in a queue

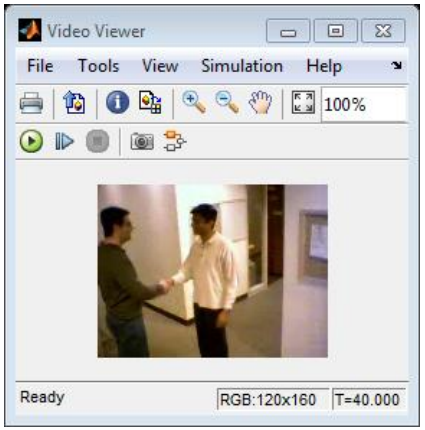


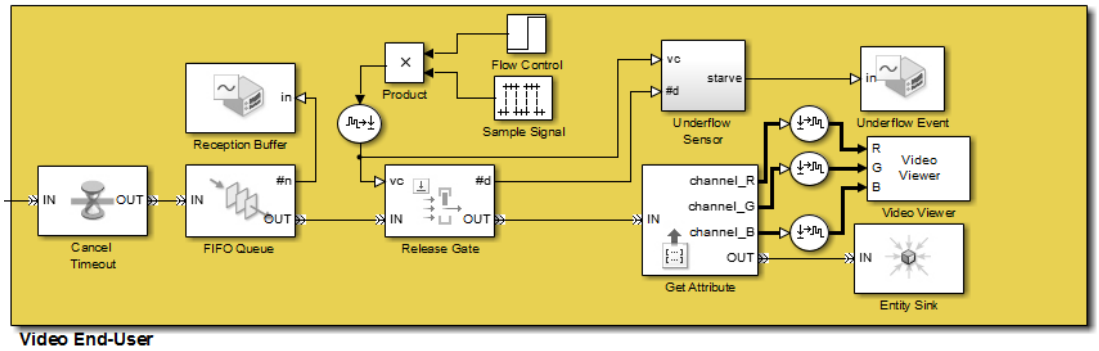
SimEvents Tutorial Summary

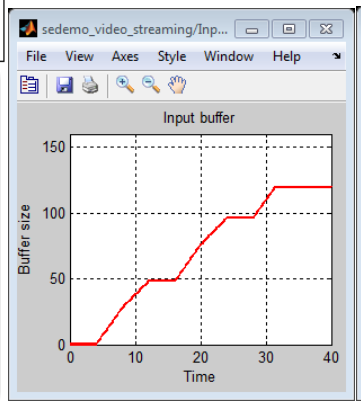
- SimEvents adds an event calendar to Simulink
- Library of commonly used DES blocks
- Drag and drop blocks to construct models
- Entities with custom data attributes
- Deterministic or non-deterministic simulations
- Blocks internally collect statistics about events
- Visualise data using scopes

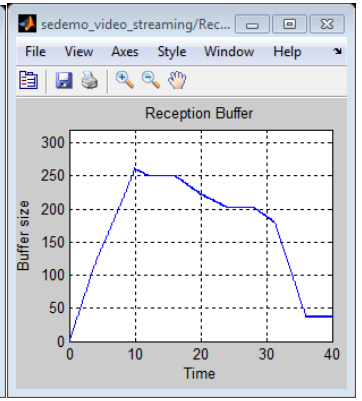
Video Streaming: Revisited











- Simulates a bandwidth limited communications channel
- Analysis of simulation results gives insight into how the channel affects received video quality.

Taking SimEvents Further

- SimEvents is fully integrated with MATLAB and Simulink.

- We can leverage the power of MATLAB and Simulink for more powerful modelling and simulation capabilities, e.g.
  - Combine Simulink and SimEvents blocks for hybrid time and discrete event driven simulations
  - Drive simulations from MATLAB scripts to perform parameter sweeps and/or sensitivity analysis
  - Access to Toolboxes, e.g.
    - Optimisation and statistical analysis
    - Parallel Computing

Integration with MATLAB and Simulink

Examples

1. MATLAB Function block from Simulink Library
   - Incorporate MATLAB code within model

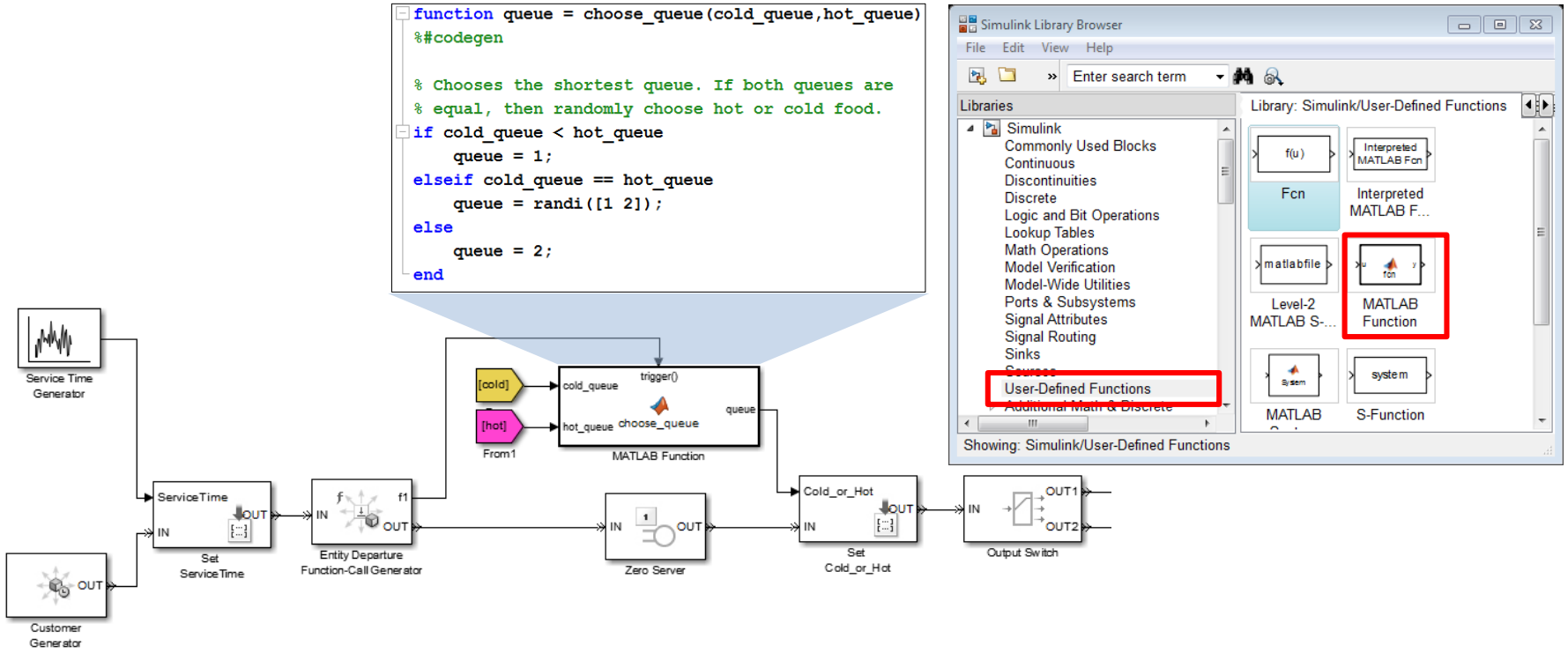
2. MATLAB Scripting
   - Drive a model using MATLAB to manage input parameters

3. Leverage Optimisation Toolbox
   - Incorporate optimisation into the simulation

Integration with MATLAB and Simulink
MATLAB Function Block

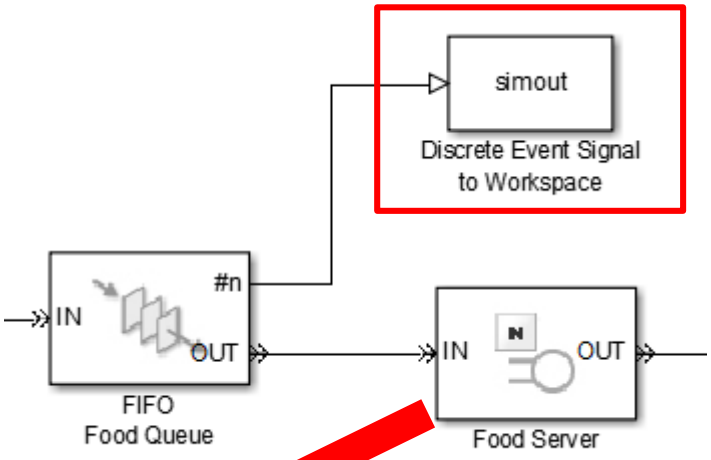
- Use MATLAB code to control the routing of customers based on the current state of the food queues
- Customers will join the shortest queue

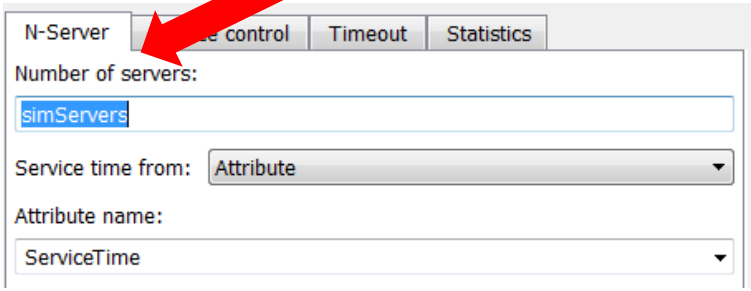
```
function queue = choose_queue(cold_queue,hot_queue)
%#codegen

% Chooses the shortest queue. If both queues are
% equal, then randomly choose hot or cold food.
if cold_queue < hot_queue
    queue = 1;
elseif cold_queue == hot_queue
    queue = randi([1 2]);
else
    queue = 2;
end
```



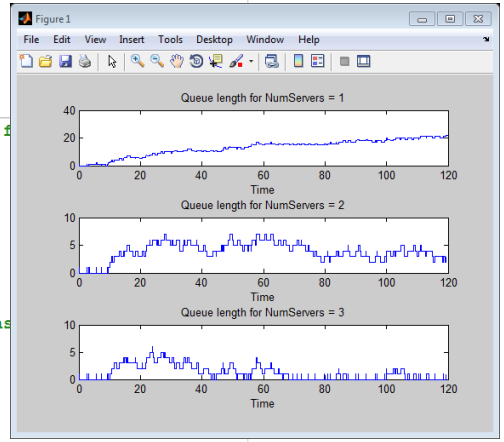
Integration with MATLAB and Simulink
MATLAB Scripting

- Drive the simulation with a MATLAB script
- Read from and write to EXCEL sheets






```
%% Import data and initialise variables
importSimData;                % Automatically generated using Import Tool
mdl = 'Lunchline1_param.slx';
resultsFilename = 'SimResults.xlsx';
figure(1);
plotnum = 1;
numSims = length(NumServers);
%% Run simulations, plot results, and write to XLS f

for i = 1:numSims
    % Define simulation data
    simMean = Mean_ServiceTime(i);
    simSTD = STD_ServiceTime(i);
    simServers = NumServers(i);

    % Run simulation.  Data is saved to workspace as
    sim(mdl);

    % Plot Queue
    subplot(numSims,1,plotnum);
    stairs(simout.time,simout.signals.values);
    title(['Queue length for NumServers = ' num2str(simServers)]);
    xlabel('Time')

    % Increment plot number
    plotnum = plotnum+1;

    % Write Results to EXCEL spreadsheet
    sheetname = ['NumServers ' num2str(simServers)];
    xlswrite(resultsFilename,[simout.time simout.signals.values],sheetname,'A1')
    xlswrite(resultsFilename,{'Mean:',simMean},sheetname,'D1')
    xlswrite(resultsFilename,{'StdDev:',simSTD},sheetname,'D2')

end
```



Integration with MATLAB and Simulink
Optimisation

- Revisit the Batch Production Process model
- Drive the simulation with a MATLAB script
- Wrap an optimisation problem around the simulation
  - Find the optimal number of resources based on a cost function

```
% Execute genetic algorithm solver
[finalResult,fval,exitflag] = ga(@productionCost,4,[],[],[],[],...
    lb,ub,[],IntCon,opts);

% Cost function that assign different values to the decision variables in
% the model
    function obj = productionCost(vecX)
        cost = [100 200 200 200]*vecX';
        assignin('base','x',vecX);
        [~,~,z] = sim('batchProcess_optim');
        backlog = z(end);
        obj = backlog*10000+cost;
    end
```

Lockheed Martin Builds Discrete-Event Models to Predict F-35 Fleet Performance

F-35s ready for flight.

Challenge

Predict F-35 fleet performance to minimize life-cycle costs and maximize mission readiness

Solution

Build a discrete-event model of the fleet with Simulink and SimEvents, use MATLAB Distributed Computing Server to accelerate thousands of simulations, and interpolate the results with Neural Network Toolbox

Results

- Simulation setup time reduced from months to hours
- Development effort lessened
- Simulation time cut by months

"By building a model with Simulink and SimEvents and running discrete-event simulations on a computer cluster, we rapidly identified many opportunities to maximize F-35 fleet performance while minimizing development and execution efforts."

Justin Beales
Lockheed Martin

Summary

- Simulation is a valuable tool for understanding the dynamics of a system
- SimEvents adds Discrete Event Simulation (DES) capabilities to Simulink. It is used to model the movement of some physical “entity” through a process.
- SimEvents is useful for analysing, for example,
  - Resource contention
  - Congestion/bottlenecks/processing delays
  - Throughput
  - Scheduling and routing

Summary

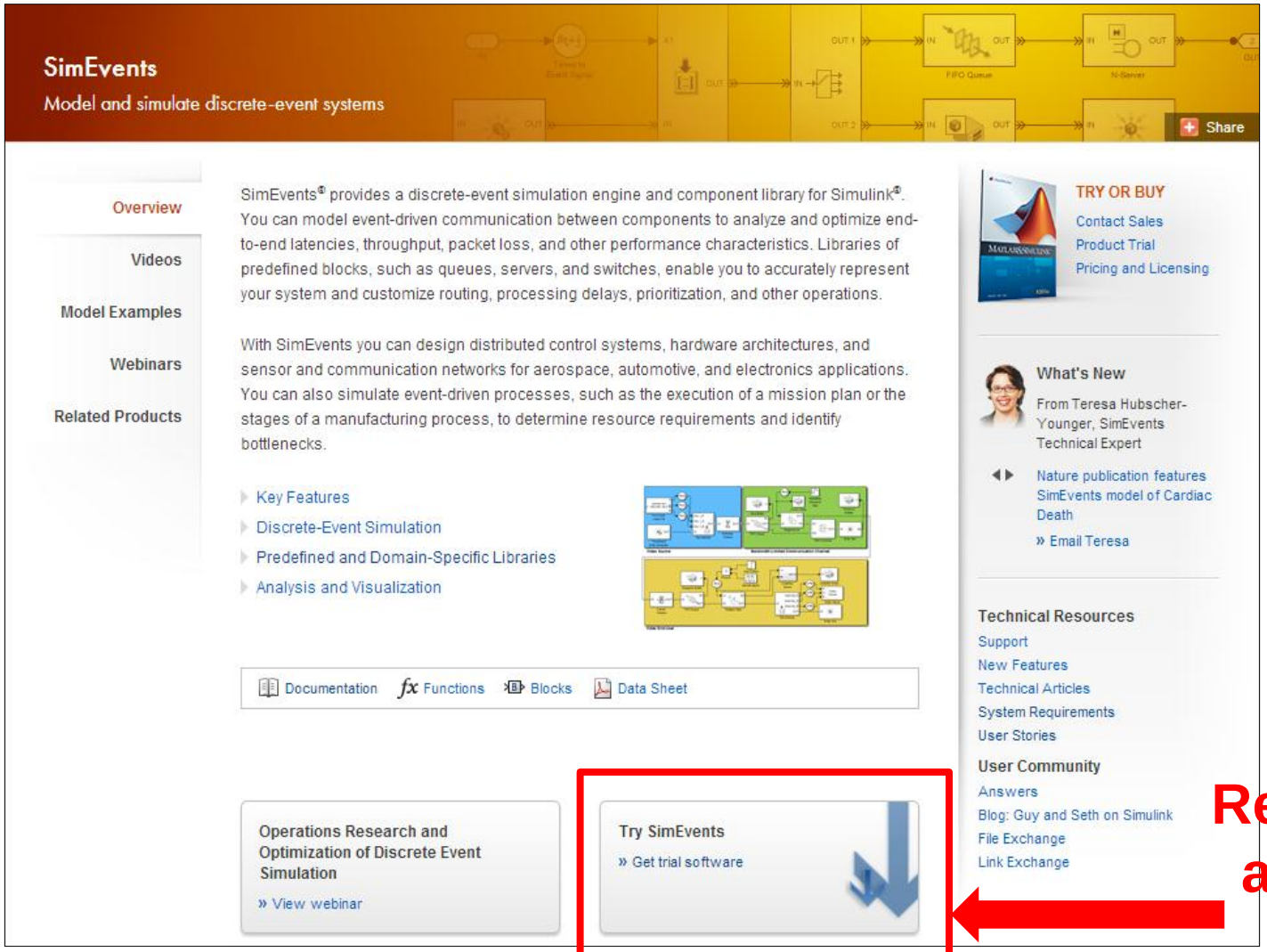
- Example Applications
  - Supply chain and logistics
  - Mission planning
  - Packet based communications
  - Real-time operating system models
  - Business and operational processes
  - Manufacturing processes
  - Service scheduling
  - Etc.

Summary

- Since SimEvents is built upon a MathWorks environment, you can leverage the power of MATLAB and Simulink to:
  - Combine Simulink and SimEvents blocks for hybrid time and discrete event driven simulations
  - Drive simulations from MATLAB scripts to perform parameter sweeps and/or sensitivity analysis
  - Access Toolbox functionality and capabilities, e.g.
    - Optimisation and statistical analysis
    - Parallel Computing

Further Information

http://www.mathworks.com.au/products/simevents/



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Training courses - Sydney

Course Name	Course Code	Start Date	End Date	City
MATLAB Fundamentals	MLBE	5-Aug-14	7-Aug-14	Sydney
Stateflow for Logic Driven System Modeling	SLSF	14-Aug-14	15-Aug-14	Sydney
Embedded Coder for Production Code Generation	SLEC	16-Sep-14	18-Sep-14	Sydney
MATLAB Fundamentals	MLBE	30-Sep-14	2-Oct-14	Sydney
MATLAB Programming Techniques	MLPR	14-Oct-14	15-Oct-14	Sydney
Physical Modeling of Multidomain Systems with Simscape	SLPM-S	16-Oct-14	16-Oct-14	Sydney
Statistical Methods in MATLAB	MLST	11-Nov-14	12-Nov-14	Sydney
Image Processing with MATLAB	MLIP	13-Nov-14	14-Nov-14	Sydney

Course Name	Course Code	Start Date	End Date	City
MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

Training courses - Adelaide

Course Name	Course Code	Start Date	End Date	City
Simulink for System and Algorithm Modeling	SLBE	21-Aug-14	22-Aug-14	Adelaide
Image Processing with MATLAB	MLIP	9-Sep-14	10-Sep-14	Adelaide
MATLAB Fundamentals	MLBE	4-Nov-14	6-Nov-14	Adelaide
Parallel Computing with MATLAB	MLPC	18-Nov-14	19-Nov-14	Adelaide

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MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

Training courses - Brisbane

Course Name	Course Code	Start Date	End Date	City
Simulink for System and Algorithm Modeling	SLBE	22-Oct-14	23-Oct-14	Brisbane
Optimization Techniques in MATLAB	MLOP	24-Oct-14	24-Oct-14	Brisbane
MATLAB Fundamentals	MLBE	11-Nov-14	13-Nov-14	Brisbane

Course Name	Course Code	Start Date	End Date	City
MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

MathWorks

Training courses - Melbourne

Course Name	Course Code	Start Date	End Date	City
MATLAB Fundamentals	MLBE	19-Aug-14	21-Aug-14	Melbourne
Building Interactive Applications in MATLAB	MLGU	22-Aug-14	22-Aug-14	Melbourne
Physical Modeling of Multidomain Systems with Simscape	SLMPM-S	22-Sep-14	22-Sep-14	Melbourne
MATLAB Programming Techniques	MLPR	23-Sep-14	24-Sep-14	Melbourne
Statistical Methods in MATLAB	MLST	25-Sep-14	26-Sep-14	Melbourne
MATLAB Fundamentals	MLBE	14-Oct-14	16-Oct-14	Melbourne
Optimization Techniques in MATLAB	MLOP	17-Oct-14	17-Oct-14	Melbourne
Parallel Computing with MATLAB	MLPC	28-Oct-14	29-Oct-14	Melbourne
Signal Processing with MATLAB	MLSG	30-Oct-14	31-Oct-14	Melbourne
Signal Processing with Simulink	SLBE-G	18-Nov-14	20-Nov-14	Melbourne

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MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

Training courses - Perth

Course Name	Course Code	Start Date	End Date	City
Statistical Methods in MATLAB	MLST	26-Aug-14	27-Aug-14	Perth
Simulink for System and Algorithm Modeling	SLBE	28-Aug-14	29-Aug-14	Perth
MATLAB Fundamentals	MLBE	23-Sep-14	25-Sep-14	Perth

Course Name	Course Code	Start Date	End Date	City
MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

Training courses - New Zealand

Course Name	Course Code	Start Date	End Date	City
Signal Processing with Simulink	SLBE-G	3-Sep-14	5-Sep-14	Christchurch
Statistical Methods in MATLAB	MLST	7-Oct-14	8-Oct-14	Wellington

Course Name	Course Code	Start Date	End Date	City
MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning

http://www.mathworks.com.au/services/training/

Training courses - OnLine

Course Name	Course Code	Start Date	End Date	City
MATLAB Programming Techniques	MLPR	12-Aug-14	13-Aug-14	e-learning
MATLAB Fundamentals	MLBE	2-Sep-14	4-Sep-14	e-learning
Simulink for System and Algorithm Modeling	SLBE	11-Sep-14	12-Sep-14	e-learning
MATLAB Fundamentals	MLBE	9-Dec-14	11-Dec-14	e-learning