MATLAB EXPO 2017
How to build an autonomous anything

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MathWorks
Well, hello Sunshine. What’s for breakfast?
Autonomous Technology
Autonomous

Acting independently
Autonomous Technology

Provides the ability of a system to act independent of direct human control under unrehearsed conditions
Capabilities of an Autonomous System

Sense
Capabilities of an Autonomous System
Capabilities of an Autonomous System

1. Sense
2. Perceive
3. Decide & Plan
Capabilities of an Autonomous System

Sense

Perceive

Decide & Plan

Act
Autonomous Technology – Balancing Responsibility

Degree of Autonomy

Responsibility

Human

Computer
Cost of rig: $1,000,000+
Repair cost: $100,000
Cost of valve: $200
Autonomous Service for Predictive Maintenance

Which sensor values should they use?

- Pressure
- Vibration
- Timing
- Temperature
- Other variables

Sense
Perceive
Decide & Plan
Act
Autonomous Service for Predictive Maintenance

Sense
Perceive
Decide & Plan
Act

Normal Operation
Monitor Closely
Maintenance Needed
Machine Learning or Deep Learning?

Machine Learning Approach

1. Normal
2. Monitor
3. Maintain

Deep Learning Approach

1. Normal
2. Monitor
3. Maintain

Sensor 1
Sensor 2
...
Sensor 25

Feature Extraction & Classification
R2017b Mega Release of Deep Learning Capabilities

Design Deep Learning & Vision Algorithm

Accelerate and Scale Training

High Performance Embedded Implementation

Deep learning design is easy in MATLAB

Apps for Ground Truth Labeling, Pixel Labeling

Pre-trained model importer Training Visualization

Parallel Computing Toolbox

- 7x faster than pyCaffe
- 2x faster than TensorFlow

GPU Coder

- 14x faster than pyCaffe
- 4x faster than TensorFlow
- 1.6x faster than C++ Caffe
What are the best predictors?

- Data-driven
What are the best predictors?

- Data-driven
- Model-driven
Autonomous Glucose Level Management
Autonomous Glucose Level Management
Bigfoot Biomedical

Sense

Perceive

Decide & Plan

Act

Target Glucose Level

+ -

Insulin Pump

Person

Continuous Glucose Monitor
Autonomous Glucose Level Management
Bigfoot Biomedical

Sense

Perceive

Decide & Plan

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Target Glucose Level

Insulin Pump

Mobile App

Continuous Glucose Monitor

Person
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Simulink, Stateflow, Polyspace

Target Glucose Level

Insulin Pump

Mobile App

Continuous Glucose Monitor

Person
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MathWorks
Autonomous Glucose Level Management
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- Target Glucose Level
- Mobile App
- Continuous Glucose Monitor
- Insulin Pump

Person

2017

2018
Virtual Clinic
Generating data through simulation
Virtual Clinic
Scaling computations to simulate 50 million patients a day
Where will you get your data?

- Simulation
- Public repositories
- In the lab
- In the field
- Internet of Things (IoT)
Working with **Big** Data Just Got Easier

Tall arrays in MATLAB

- **R2016b**
- **R2017a**

- **Machine Memory**
  - e.g. 4~8GB
  - e.g. 100GB~1TB

Tall Data

Stream large input signals from MAT-files

**R2017a**
Autonomous Trailer Filling

Sense

Perceive

Decide & Plan

Act
Autonomous Trailer Filling

Sense
Perceive
Decide & Plan
Act

Computer Vision Algorithms
Control Algorithms

3D Camera Image
3D Scene Simulator

Control outputs
Autonomous Trailer Filling

- **Sense**
- **Perceive**
- **Decide & Plan**
- **Act**

3D Cameras

Computer vision and controls algorithms

CAN

ECU

Actuators
Autonomous Trailer Filling

- **Sense**
- **Perceive**
- **Decide & Plan**
- **Act**

3D Cameras

Computer vision and controls algorithms

Vehicle Display Controller
- Driver Input
- Visualization

Vehicle Electronic Control Unit (ECU)

CAN

Actuators
Autonomous Trailer Filling

Sense

Perceive

Decide & Plan

Act

3D Cameras

Embedded Coder

Vehicle Display Controller

- Driver Input
- Visualization
- Computer Vision
- Controls

CAN

ECU

Actuators

Computer vision and controls algorithms
Autonomous Trailer Filling

- Sense
- Perceive
- Decide & Plan
- Act

- 3D Cameras
- Vehicle Display Controller
  - Driver Input
  - Visualization
  - Computer Vision
  - Controls
- CAN
- ECU
- Actuators

Act: Perception & Planning

Decide & Plan: Perception & Planning

Perceive: Perception & Planning

Sense: Perception & Planning

Monitoring: Perception & Planning
How will you put it into production?

- Embedded Systems
- IT Systems
- Cloud
- Desktop Apps
Investments in Model-Based Design

Efficient code generation

Floating-point HDL code generation

Floating-point Algorithm

HDL Coder

Native Floating Point

Target-Aware Mapping

Vendor-Independent ASIC/FPGA RTL

Altera / Xilinx
Soft IP

Altera
Hard IP

Clones

Clones replaced with library block
Investments in Model-Based Design

Code verification in support of CERT C standard

<table>
<thead>
<tr>
<th>CERT C</th>
<th>Description</th>
<th>Polyspace Code Prover</th>
</tr>
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<tbody>
<tr>
<td>ARR30-D</td>
<td>Do not form or use out-of-bounds pointers or array subscripts</td>
<td>Array access out of bounds</td>
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</tbody>
</table>

Detect and fix standards compliance issues at design time

- Usage of prohibited block
- Analog Input (Delayed)
- Transport Delay
- FiR x4 a Decimation
- FiR x4 b Decimation
- FiR x4 c Decimation
- Digitized Approxima

**Code snippet**

```c
if (output_v7 >= 0) {
    saved_values[output_v7] = s8_ret;
    return s8_ret;
}
return reset_temp;
```

**Table:**

- **CERT C:** ARR30-D
- **Description:** Do not form or use out-of-bounds pointers or array subscripts
- **Polyspace Code Prover:** Array access out of bounds
Connected Physical Assets in Operation

- **Smart assets**
  - Value in services, not just assets
  - SW in everything
  - Lots of sensors

- **Edge systems**
  - Pervasively connected
  - More computing and monitoring near the assets

- **Data transport protocols**
  - Transition to Web technology

- **OT Infrastructure**
  - Cloud & on-prem
  - Cloud: Big data
  - On-prem: IP, reliability, etc.

- **IT Systems**
  - Operational Technology
  - Optimization end-to-end
Automation through Digital Twins

Digital Twin: Composite of artifacts that characterize and predict behavior of a specific real asset.
“Digital Twin” isn’t a new concept…

Digital Twin concept has been used for a long time, especially when there is a small number of expensive assets and when reliability is critical (e.g., spacecraft, aircraft engines). The infrastructure has been one-off.
Re-imagining the Digital Twin

Digital Twin:
• models (dynamic, FEM, data-driven, etc.) and data
• for each asset (e.g., system, component, or system of systems)
• performance and conditions over the asset’s history.
• continuously updated as the asset is operated.
• always represents a faithful representation of the current state of the asset.
MATLAB and Simulink for Digital Twins: Key Capabilities

- Multi-domain system modeling
- Parameter estimation
- Control design and analysis
- Automatic code generation
- Variety and Volumes of Data
- Optimization
- Machine Learning and Deep Learning
- Enterprise system integration, with cluster/cloud execution
MATLAB and Simulink for Digital Twins throughout the lifecycle

- Wind farm planning
- Ensuring power grid reserves
- Cloud-based HVAC optimization
- Engine prognostics & health monitoring
- Future car infrastructure
- Automatic braking systems
- Asteroid rendezvous

Planning | Development | Operation | Maintenance
Capabilities of an Autonomous System

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- Decide & Plan
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How to build an autonomous anything

Focus on Perception
- Look for autonomy in creative places
- Do more than manually possible

Use the Best Predictors
- Data-driven
- Model-driven

Get the Right Data

Go to Production
# How to build an autonomous anything

## Focus on Perception
- Look for autonomy in creative places
- Do more than manually possible

## Use the Best Predictors
- Data-driven
- Model-driven

## Get the Right Data
- Reduce to actionable data
- Take advantage of Big Data
- Use simulation to supplement available data

## Go to Production
- Address the architecture
- Leverage Model-Based Design for embedded
- Automate integration with enterprise IT systems
What is *your* autonomous anything?