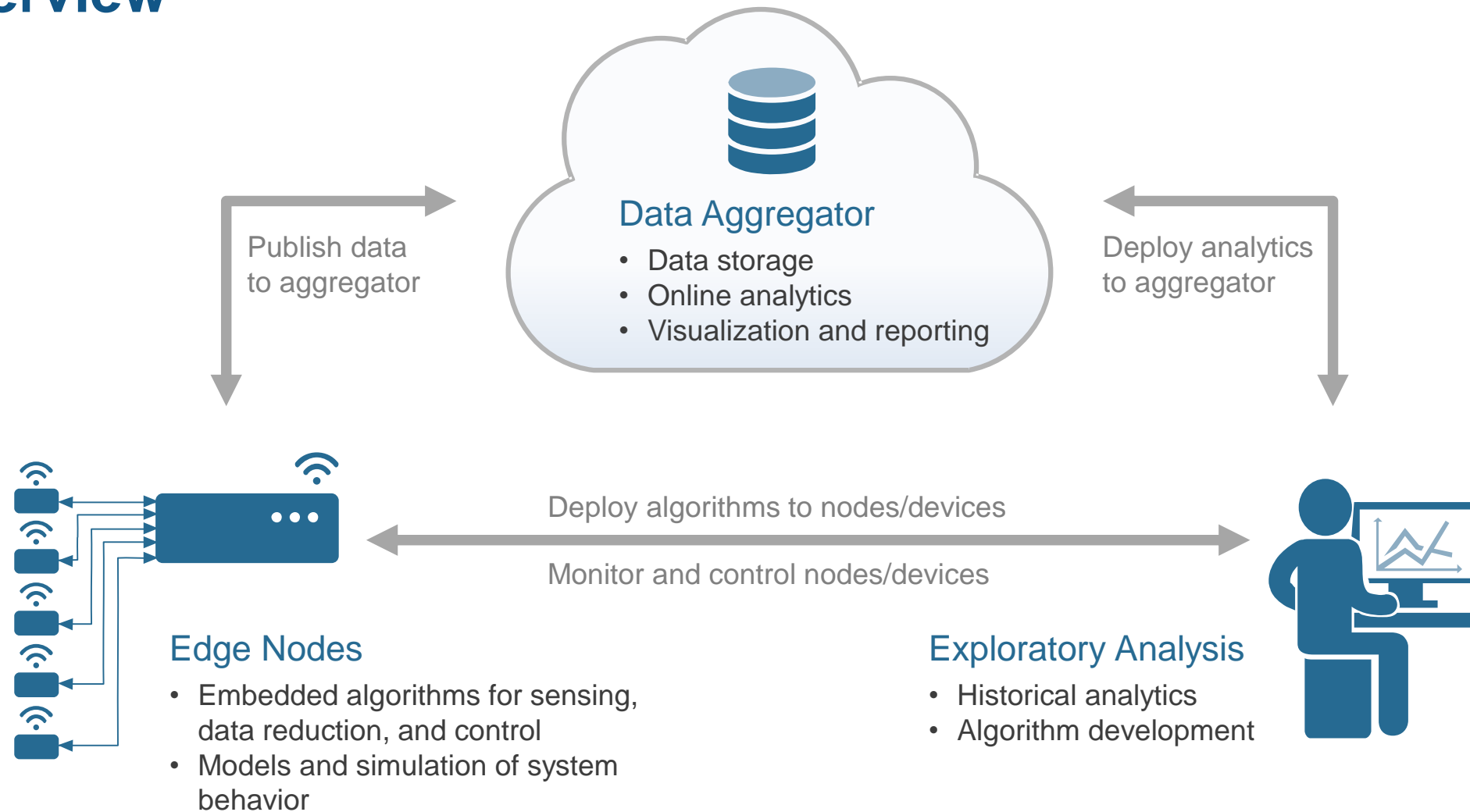


Data Analysis in the Internet of Things: IoT capabilities with MATLAB/Simulink

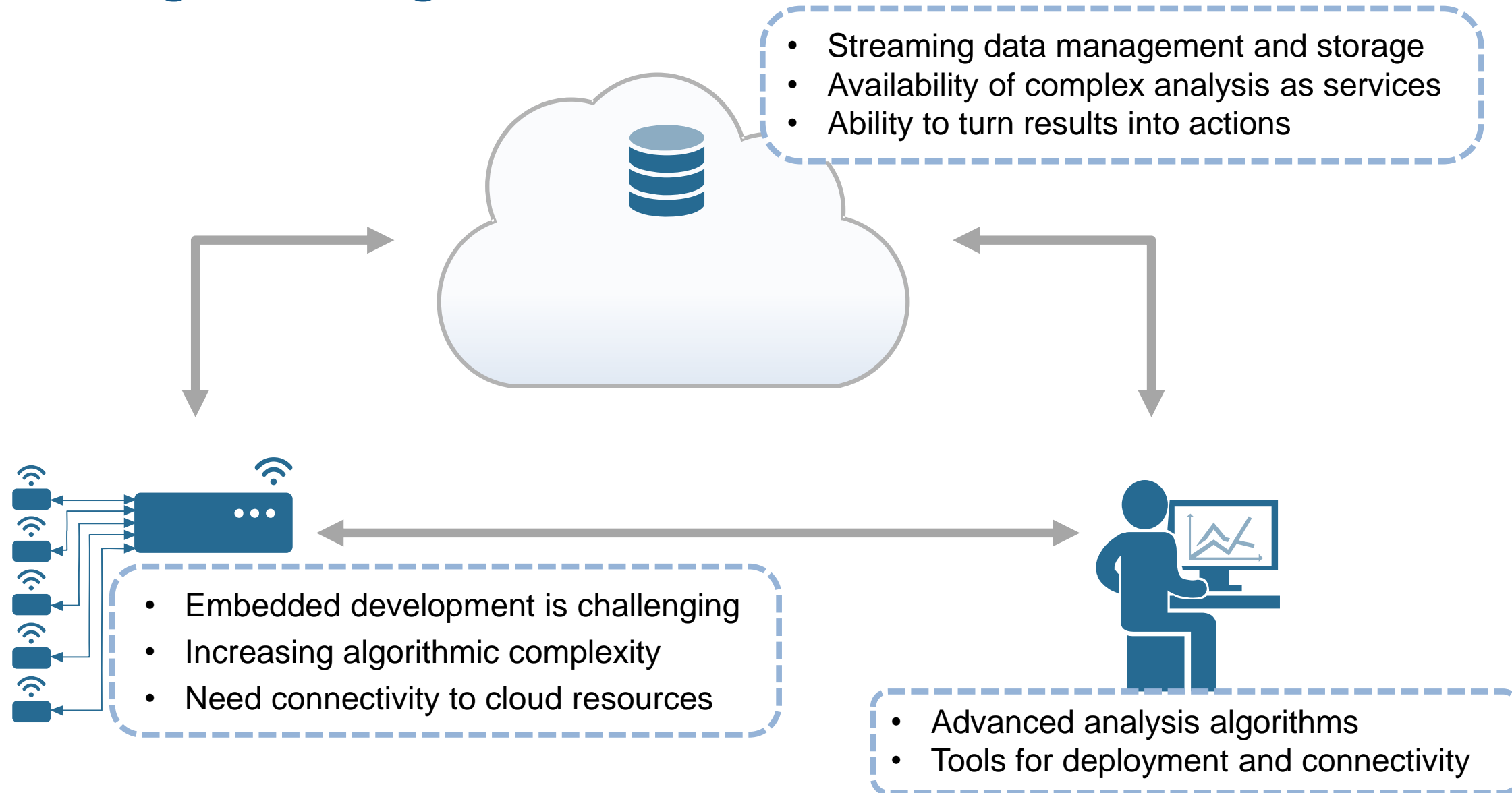
Dr.-Ing. Rainer Mümmeler
Application Engineering Team
The MathWorks GmbH

Overview



MathWorks Provides Capabilities for All of these Steps

IoT – Design challenges



Use all types of data

MATLAB Data Support

**Business and
Transactional Data**

**Engineering,
Scientific, Test and
Field Data**

File I/O

- Text
- Spreadsheet
- XML
- CDF/HDF
- Image
- Audio
- Video
- Geospatial

Repositories

- Databases (SQL)
- NoSQL
- Hadoop

Real-Time Sources

- Sensors
- GPS
- Instrumentation
- Cameras
- Communication systems
- Machines:
 - embedded systems
 - fieldbus
- Financial datafeeds

Communication Protocols

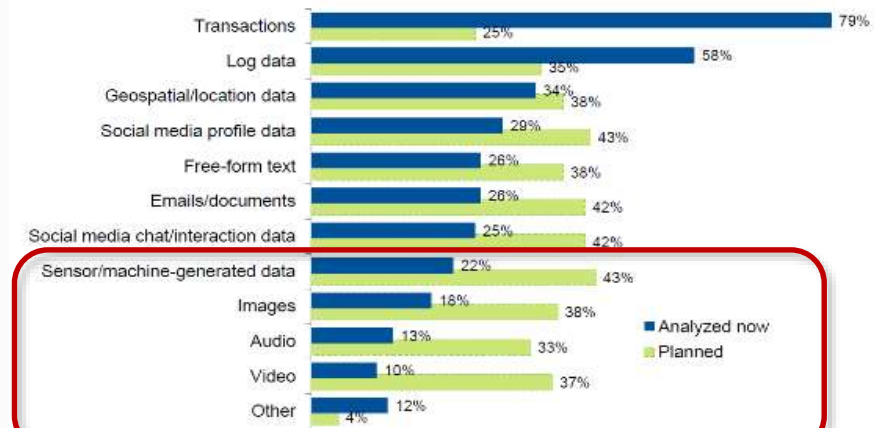
- CAN (Controller Area Network)
- DDS (Data Distribution Service)
- OPC (OLE for Process Control)
- XCP (eXplicit Control Protocol)

Types of Data

MATLAB handles numbers, text, time-series, categorical, and other “traditional” types

MATLAB *also* has deep capabilities to handle and process images, audio, RF signals, video, telemetry and other “new” sources

Traditional Data Sources Dominate, But Many New Sources Are Planned



Multiple responses allowed

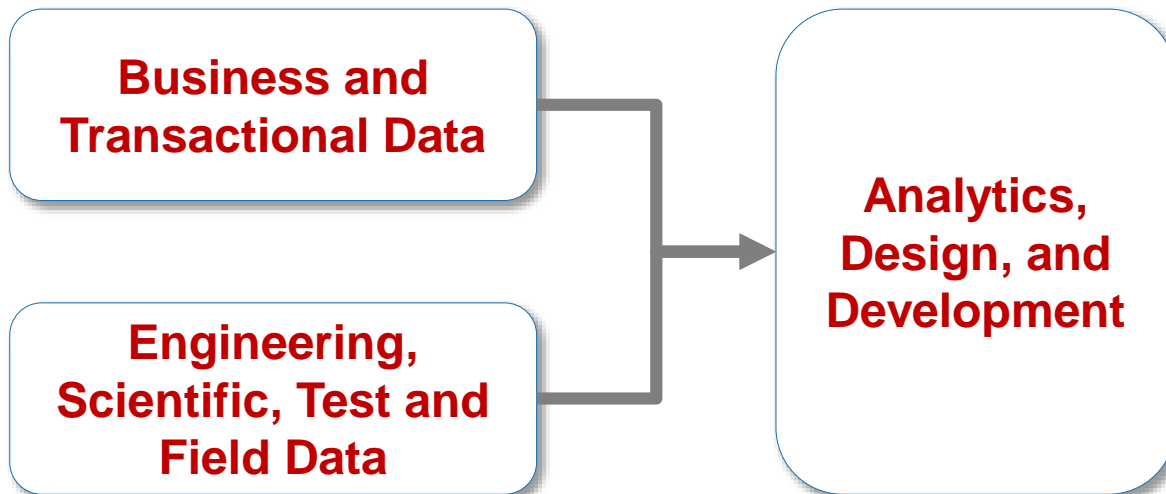
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24

Gartner

Extensive toolboxes and apps tuned for domain experts

MATLAB Advanced Analytics Algorithms



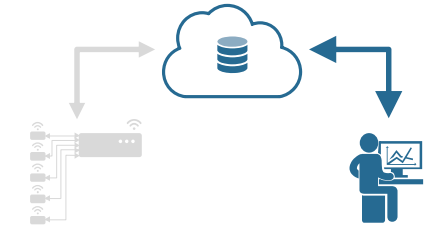
Analysis, Modeling, Design

- Data visualization
- Statistics
- Regression
- Machine learning (supervised and unsupervised)
- Neural networks
- Optimization (gradient-based and stochastic)
- Symbolic computing
- Image and video analysis
- Signal processing
- Financial modeling
- Geospatial computing

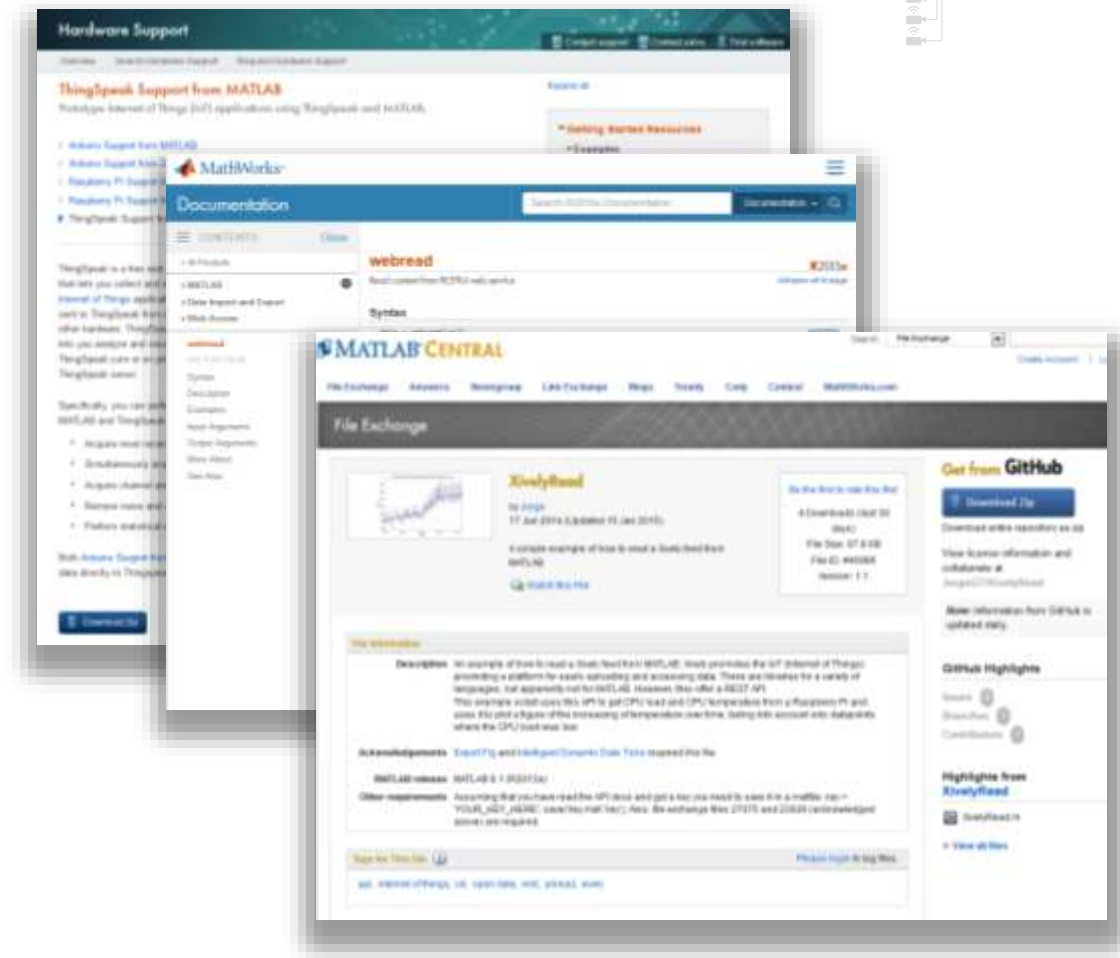
System Design

- Linear and nonlinear control methods
- Object recognition / Speech recognition
- System simulation and design
- Mechanical modeling
- RF and communication systems
- Fixed-point arithmetic
- Phased-array and radar analysis
- Communications system design
- Thousands of community-provided algorithms

Access to Aggregators and Services

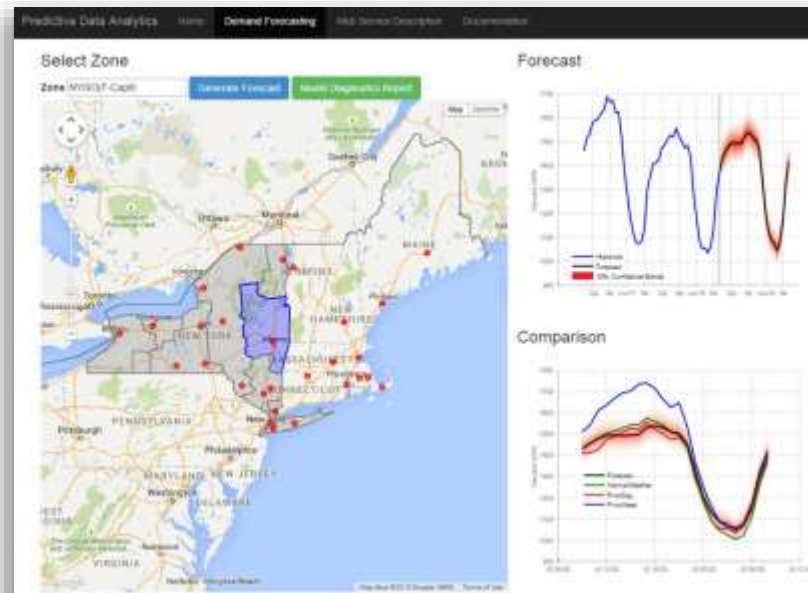
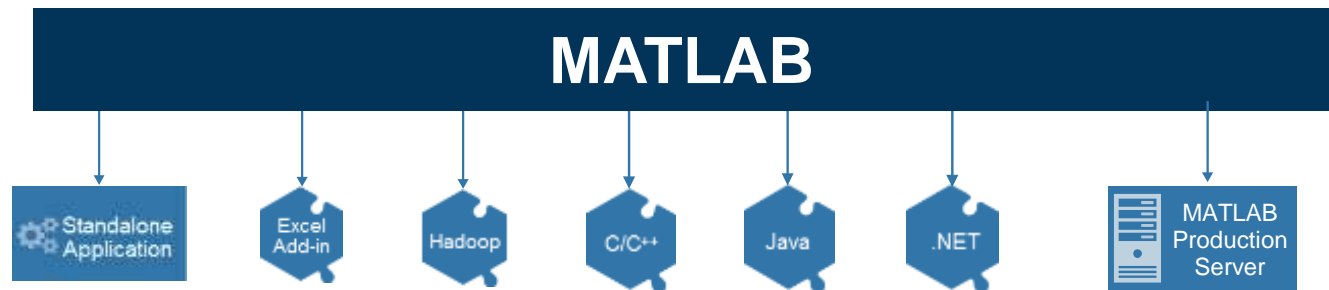
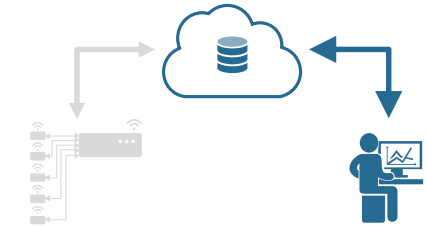


- Aggregators
 - ThingSpeak
 - Google Cloud
 - AWS
 - homegrown
- Web services
- Protocols (e.g., Xively)



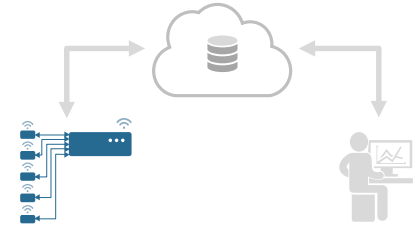
Operationalizing Analytics in Production Environments

- Dashboards and webpages
- Hadoop servers
- Databases
- Custom environments (e.g., Google Earth)

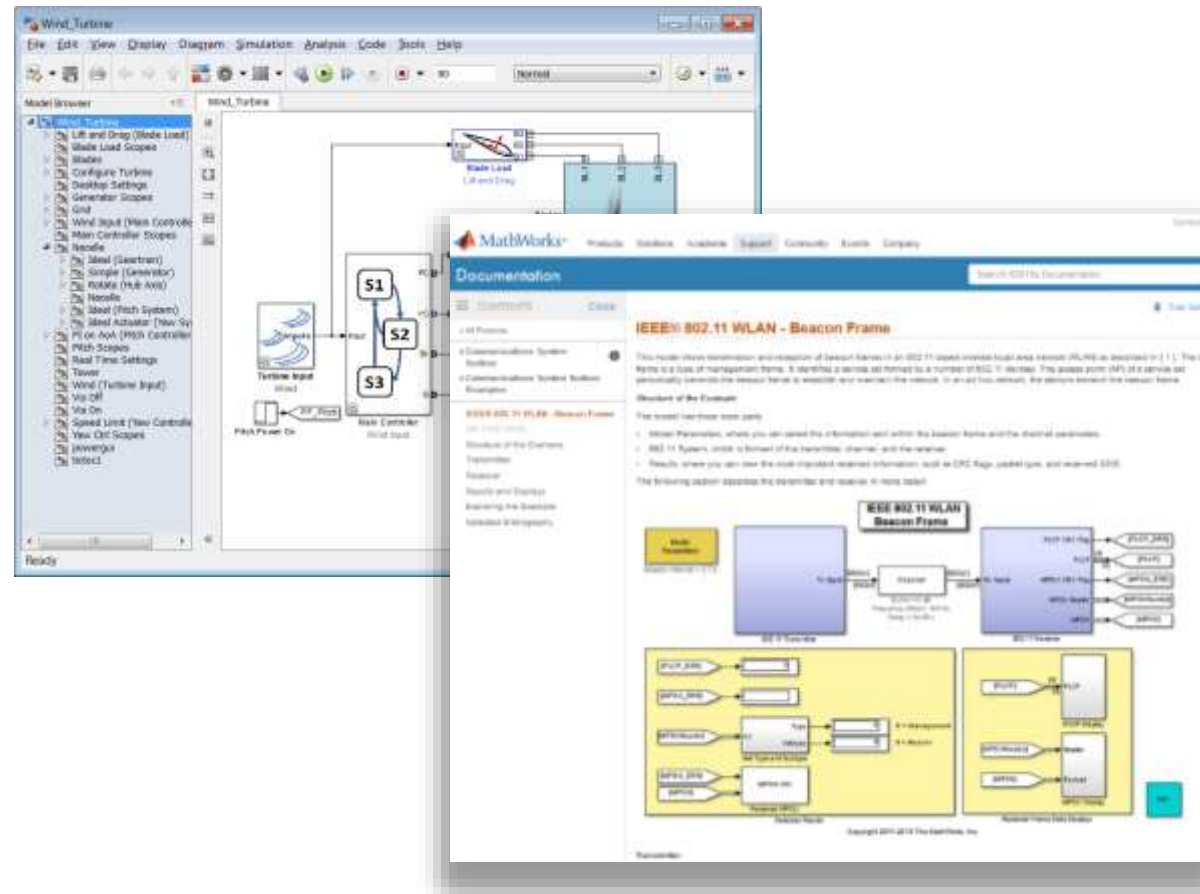


Modeling and Simulating the Edge Behavior

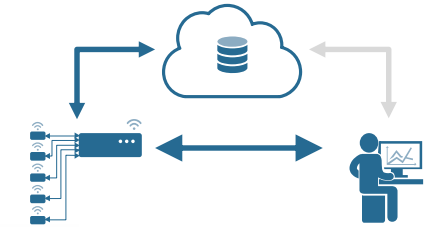
from simple devices to complex systems



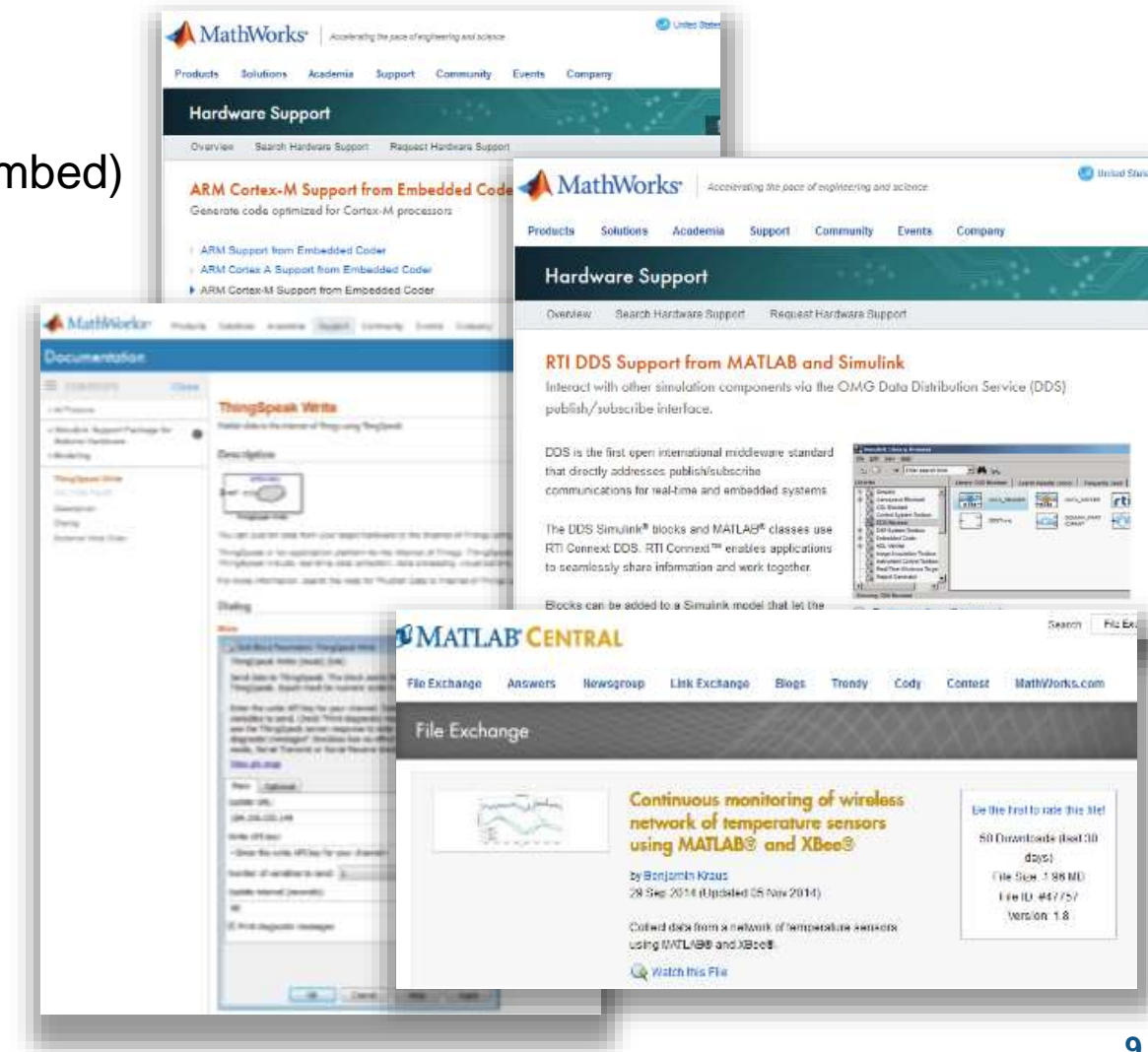
- **Physical components**
 - Electronic
 - Mechanical
 - Hydraulic, etc.
- **Communication protocols**
 - LTE
 - 802.11
 - DDS
 - Personal area networks
- **Algorithms**
 - Feedback control
 - Computer vision
 - Signal and image processing, etc.



Implementing Algorithms at the Nodes



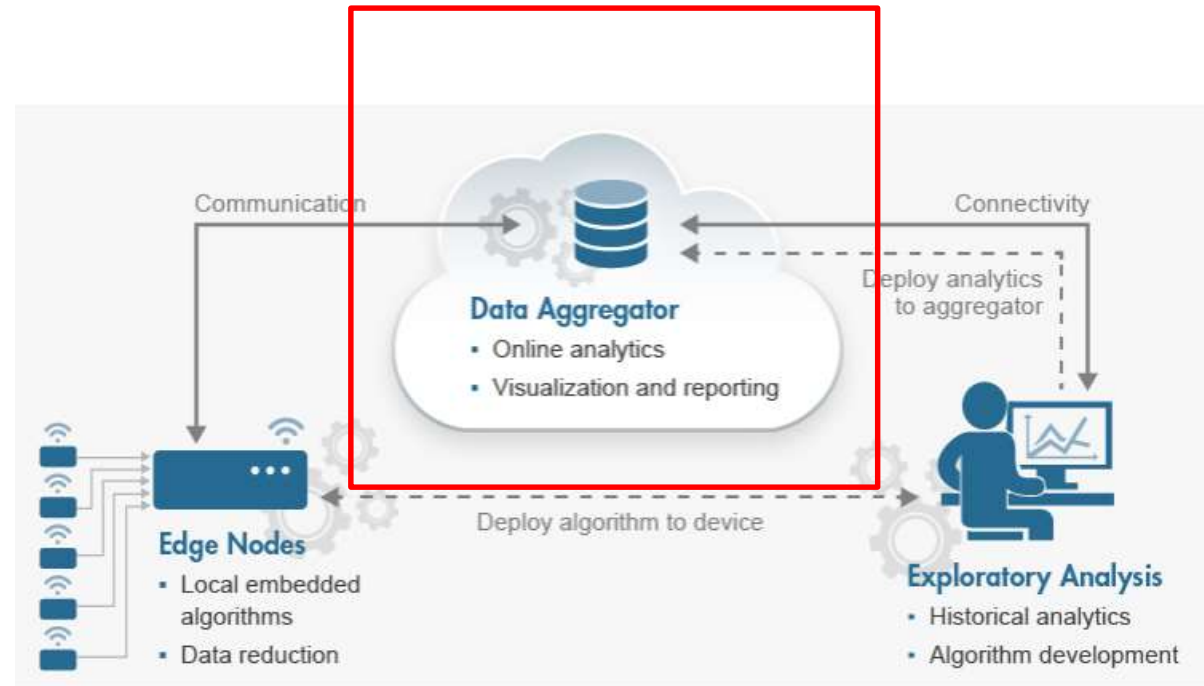
- **Automatic Code Generation**
 - Embedded processors and FPGAs
 - Popular IoT devices (e.g., Arduino, Cortex M, ARM mbed)
- **Communication**
 - M2M (e.g., DDS)
 - Device to aggregator (e.g., ThingSpeak)
 - Device to analyst (e.g., XBee®)
- **Verification/Validation and Process Support**
 - Model- and Code proving
 - Lifecycle management tools



ThingSpeak, MATLAB and the Internet of Things (IoT): Collecting and Analyzing IoT Data

What is ThingSpeak?

- Free online data aggregation platform
 - Typically used to collect data from sensors (“Things”)
 - Provides instant visualization of the data
 - Popular for people experimenting in IoT
 - Has more than 60,000 users
- Can be used to analyze data
 - New MATLAB integration allows users to run scheduled MATLAB code on data coming into ThingSpeak
- Can be used to act on data
 - E.g. Tweet a message when the temperature in your backyard reaches 32 degrees



ThingSpeak: Collecting Data using Channels

The screenshot shows the ThingSpeak 'New Channel' form and a 'Help' section. The form has a blue header with the ThingSpeak logo and navigation links: Channels, Apps, Blog, Support, Account, and Sign Out. The 'New Channel' section includes a 'Name' field, a 'Description' field, and a list of 8 'Fields'. Field 1 is labeled 'Field Label 1' and is checked. Fields 2 through 8 are empty and unchecked. The 'Help' section is titled 'ThingSpeak Channel' and explains that channels store data and can be used with ThingSpeak apps. Below this is a 'Channel Settings' section with a list of settings: Channel Name, Description, Fields, Metadata, Tags, and Latitude.

New Channel

Name

Description

Field 1 ☒

Field 2 ☐

Field 3 ☐

Field 4 ☐

Field 5 ☐

Field 6 ☐

Field 7 ☐

Field 8 ☐

Help

ThingSpeak Channel

Channels store all the data that a ThingSpeak application collects. Each channel includes eight fields that can hold any type of data, plus three fields for location data and one for status data. Once you collect data in a channel, you can use ThingSpeak apps to analyze and visualize it.

Channel Settings

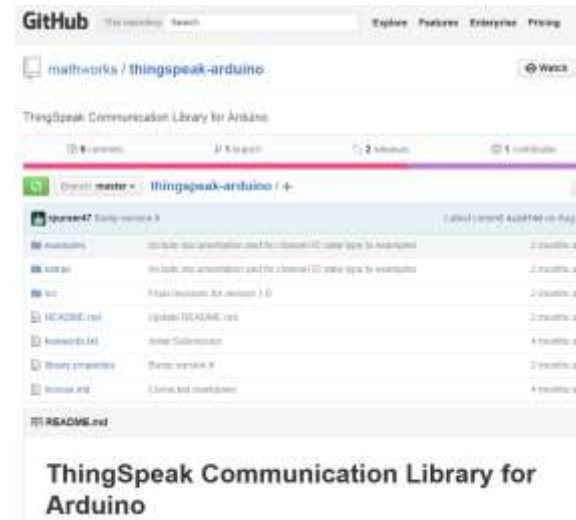
- **Channel Name:** Enter a unique name for the ThingSpeak channel.
- **Description:** Enter a description of the ThingSpeak channel.
- **Fields:** Check the box to enable the field, and enter a field name. Each ThingSpeak channel can have up to 8 fields.
- **Metadata:** Enter information about channel data, including JSON, XML, or CSV data.
- **Tags:** Enter keywords that identify the channel. Separate tags with commas.
- **Latitude:** Specify the position of the sensor or thing that collects data in decimal degrees. For example, the latitude of the city of London is 51.5072.

- For any new data, first login and create a channel in ThingSpeak
- Channels have read and write API keys and can be public or private
- A channel is made up of 8 fields and can store 8 streams of data (Temp, Humidity, etc.)
- Channels can be updated at a maximum rate of once every 15 seconds

[ThingSpeak Weather Channel](#)

Getting data into ThingSpeak

- Rest API
- Native Libraries
 - Particle
 - Arduino
- Simulink Support Packages
 - Raspberry Pi
 - Arduino
 - BeagleBone Black



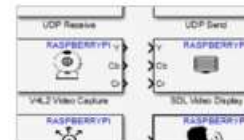
Arduino Support from Simulink

Create and run Simulink models on Arduino boards

Vendors: [Arduino](#)

Tags: [C/C++ Code Generation](#), [MathWorks Supported](#), [Project-Based Learning](#), [Run on Target Hardware](#), [Support Package](#)

Installer Enabled



Raspberry Pi Support from Simulink

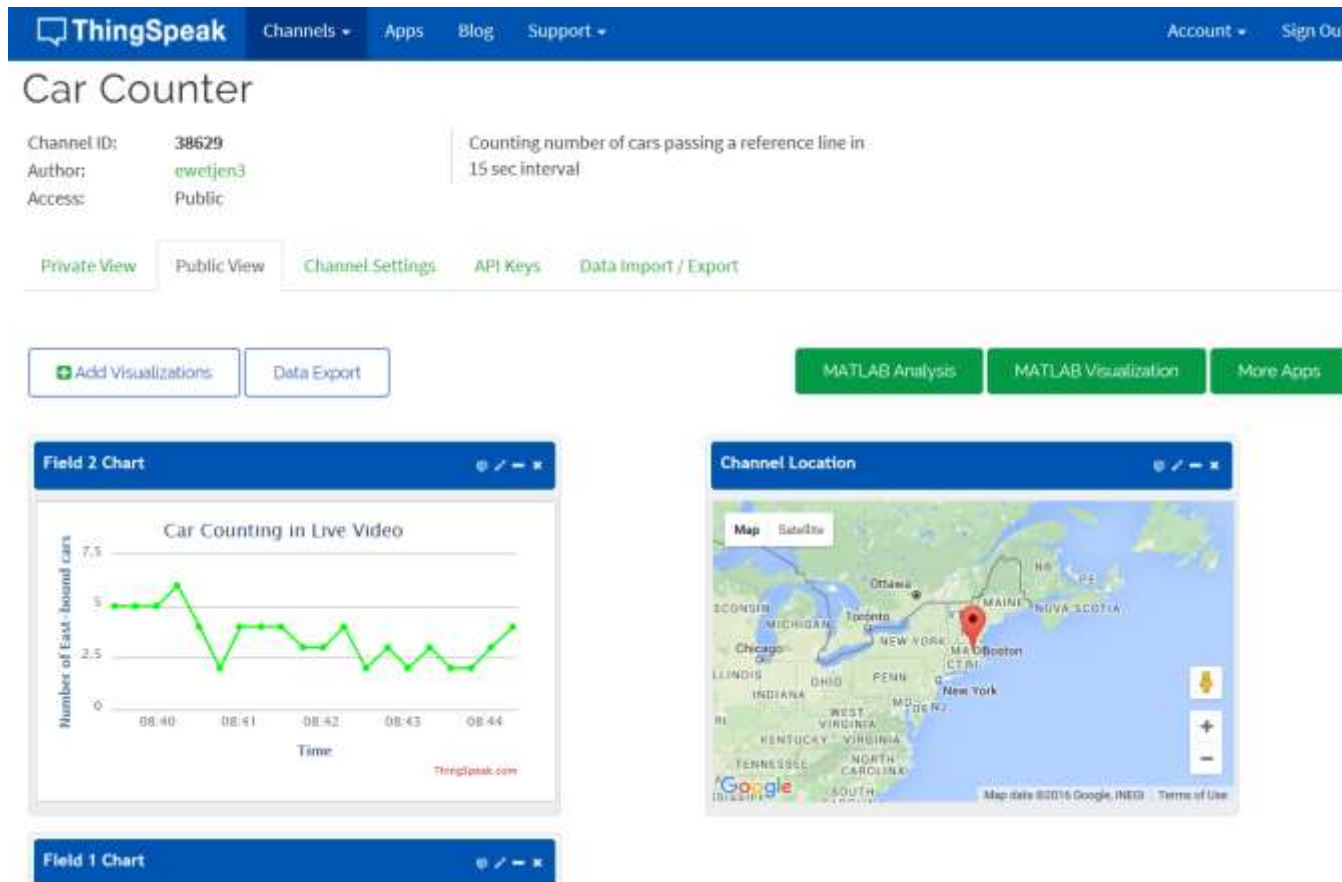
Credit-card sized, low-cost, single-board computer with audio and video input/output, designed for teaching.

Vendors: [Raspberry Pi](#)

Tags: [C/C++ Code Generation](#), [MathWorks Supported](#), [Project-Based Learning](#), [Run on Target Hardware](#), [Support Package](#)

Installer Enabled

ThingSpeak: Visualizing the Data



- Each field in each channel is provided with a default visualization which updates automatically based on the data coming in
- The default visualization contains iFrame code which can be used to embed the visualization in other applications
- Channel Location is also shown on Google Map

[ThingSpeak Car Counter Channel](#)

ThingSpeak: Custom Analysis with MATLAB Analysis App

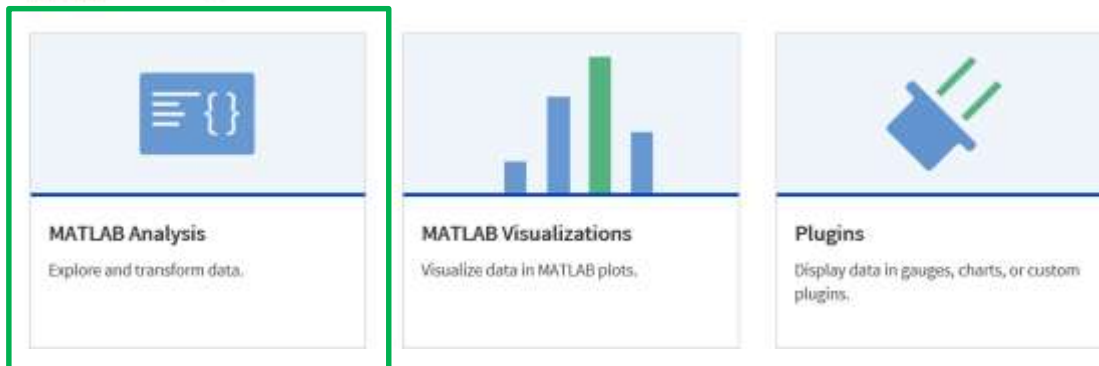
- ThingSpeak is integrated with MATLAB in the Cloud
- Use the Apps Tab to use MATLAB inside ThingSpeak



Apps

ThingSpeak channels store data. Upload data from the web or send data from devices to a ThingSpeak channel. Use these apps to transform and visualize data or trigger an action. See [Tutorial: ThingSpeak and MATLAB](#) to create a channel. [Learn more](#) about MATLAB inside ThingSpeak."

Analytics



Apps / MATLAB Analysis / Calculate Dew point 16

Name

Calculate Dew point

MATLAB Code

```
1 % Humidity and temperature are read from a ThingSpeak channel to calculate
2 % dew point. The dew point is then written to another ThingSpeak
3 % channel.
4
5 % Channel 12397 contains data from the MathWorks Weather Station, located
6 % in Natick, Massachusetts. The data is collected once every minute. Field
7 % 3 contains humidity data and field 4 contains temperature data.
8
9 % Channel ID to read data from
10 readChannelID = 12397;
11 % Humidity Field ID
12 HumidityFieldID = 3;
13 % Temperature Field ID
14 TemperatureFieldID = 4;
15
16 % To store the calculated dew point, write it to a channel other
17 % than the one used for reading data. To write to a channel, assign the
18 % write channel ID to the 'writeChannelID' variable, and the write API Key
```

Run and Save

Example: Calculate Dew Point on Live Data

ThingSpeak: Custom Analysis

The screenshot shows the ThingSpeak web interface. At the top is a blue navigation bar with the ThingSpeak logo, links for Channels, Apps, Blog, and Support, and buttons for Account and Sign Out. Below the navigation bar is a breadcrumb trail: Apps / MATLAB Analysis / New. The main content area is divided into two columns. The left column is titled 'New MATLAB Analysis' and contains a 'Templates' section with four radio button options: 'Custom (no starter code)' (which is selected), 'Get data from a private channel', 'Get data from a public channel', and 'Get data from a webpage'. Below this is an 'Examples' section with the text 'Sample code to analyze and transform data' and a list of six radio button options: 'Calculate Average Humidity', 'Calculate Dew point', 'Convert Celsius to Fahrenheit', 'Eliminate data outliers', 'Convert Fahrenheit to Celsius', and 'Calculate hourly max temperature'. The right column is titled 'Help' and contains two sections: 'MATLAB Analysis Templates' with a paragraph explaining that templates provide sample MATLAB code for analyzing data and writing it to a ThingSpeak channel, and 'MATLAB Analysis Examples' with a paragraph stating that to see MATLAB Analysis in action, users should select an example and click 'Create'. Below this, it says 'These examples read data from public ThingSpeak channels:' followed by a bulleted list of six examples: 'Calculate average humidity', 'Calculate dew point', 'Convert Celsius to Fahrenheit', 'Eliminate data outliers', 'Convert Fahrenheit to Celsius', and 'Calculate hourly max temperature'.

ThingSpeak Channels Apps Blog Support Account Sign Out

Apps / MATLAB Analysis / New

New MATLAB Analysis

Templates:

- ☒ Custom (no starter code)
- ☐ Get data from a private channel
- ☐ Get data from a public channel
- ☐ Get data from a webpage

Examples: Sample code to analyze and transform data

- ☐ Calculate Average Humidity
- ☐ Calculate Dew point
- ☐ Convert Celsius to Fahrenheit
- ☐ Eliminate data outliers
- ☐ Convert Fahrenheit to Celsius
- ☐ Calculate hourly max temperature

MATLAB Analysis Templates

Templates provide sample MATLAB code for analyzing data and writing it to a ThingSpeak channel. If you are new to MATLAB, you can learn interactively at [MATLAB Academy](#).

MATLAB Analysis Examples

To see MATLAB Analysis in action, select the example and click **Create**.

These examples read data from public ThingSpeak channels:

- **Calculate average humidity**, and write the data to a new channel.
- **Calculate dew point** from temperature and humidity data, and write data to a new channel.
- **Convert Celsius to Fahrenheit**, and write data to a new channel.
- **Eliminate data outliers** from temperature data, and write data to a new channel.
- **Convert Fahrenheit to Celsius**, and write data to a new channel.
- **Calculate hourly max temperature**, and write data with the timestamps to a new channel.
- **Remove missing values in data** of a weather channel and

- Create a new analysis
- Use code examples as a template
- Code examples use data sources that are already live in ThingSpeak


ThingSpeak: Custom Visualization with MATLAB Visualizations Apps




Apps

ThingSpeak channels store data. Upload data from the web or send data from devices to a ThingSpeak channel. Use these apps to transform and visualize data or trigger an action. See [Tutorial: ThingSpeak and MATLAB](#) to create a channel. [Learn more](#) about MATLAB inside ThingSpeak."


Analytics



MATLAB Analysis
Explore and transform data.



MATLAB Visualizations
Visualize data in MATLAB plots.



Plugins
Display data in gauges, charts, or custom plugins.



MATLAB code ran successfully.

Apps MATLAB Visualizations Traffic flow for past 48 hours Edit

Name:

Traffic flow for past 48 hours

MATLAB Code

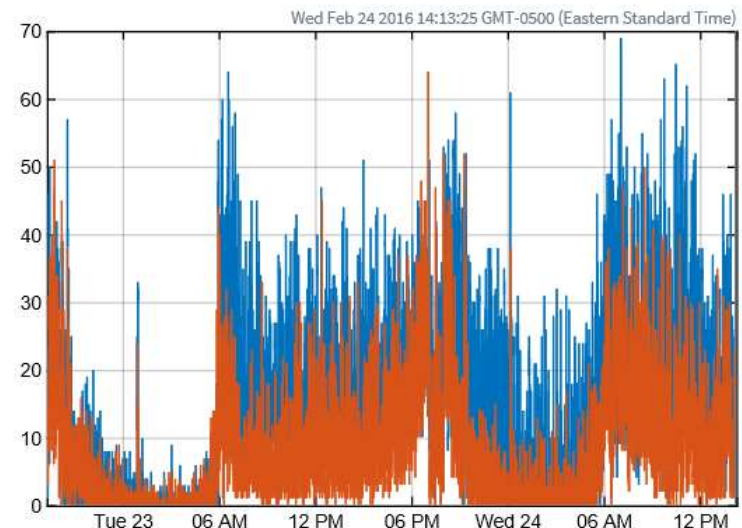
```
1 % Enter your MATLAB code below
2 stime=datetime(now);
3 stime=datetime(now-2);
4 endDate= datetime(stime,'ConvertFrom','datetime');
5 startDate= datetime(stime,'ConvertFrom','datetime');
6 % Create data vector
7 dataVector = startDate: endDate;
8 % Check to see that
9 % not append it
10 if (dataVector(end)
11     dataVector = [dataVector;
12     end
13 allTrafficData = [];
14 timespan = [];
15 % Load data in chunk
16 for dayCount = 1:100
17     dataRange = [dataVector;
18     end
```

☒ Make Public?

Run and Save

MATLAB Plot Output

Traffic Volume in 15 seconds for last 48 hours



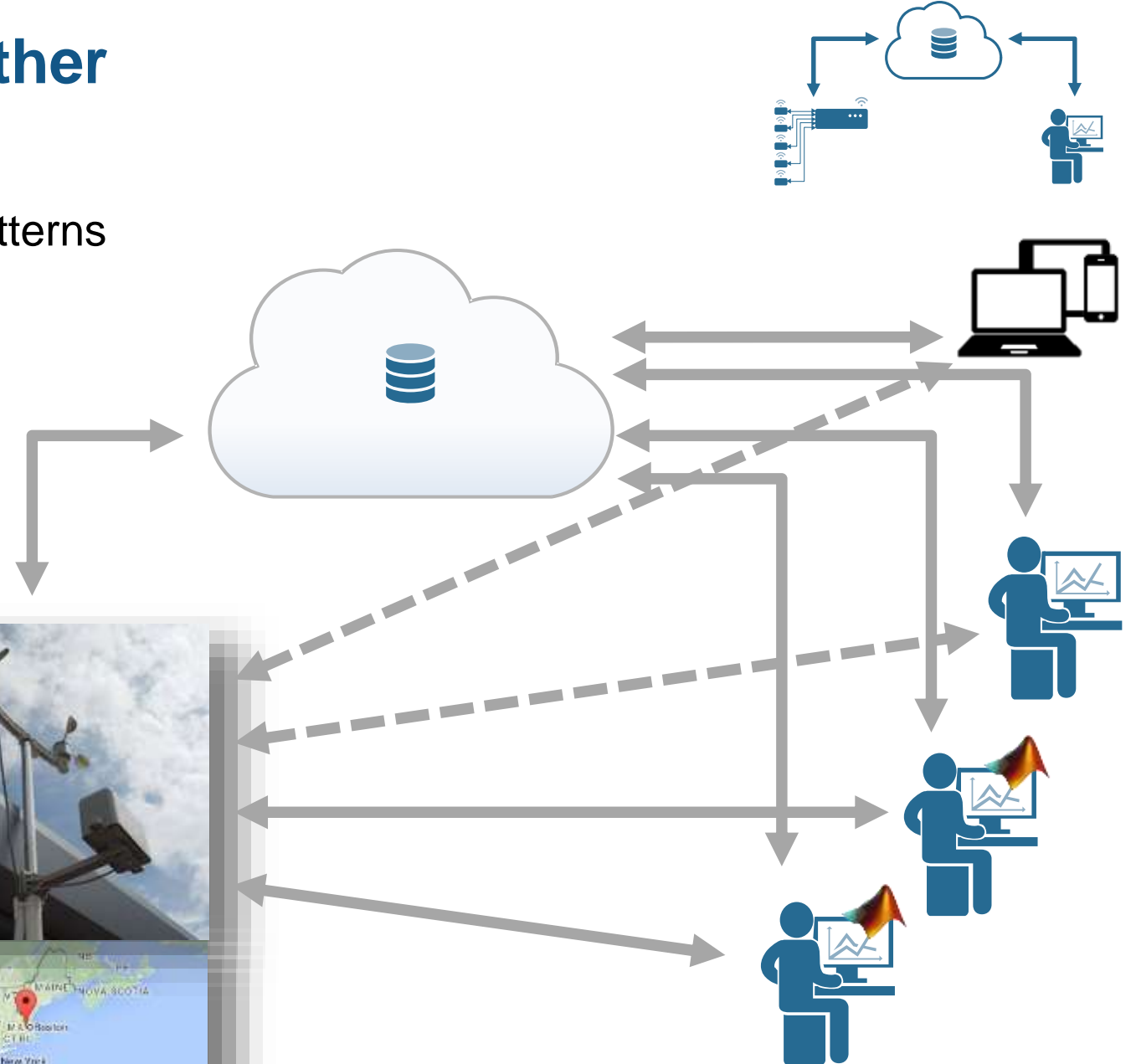
Example 1: Monitoring Weather

Objectives

- Measure, explore, discover weather patterns
- Provide niche weather service

Solution

- Arduino station with weather sensors
- Cloud-based aggregation and analysis
- Full example available at makerzone.mathworks.com



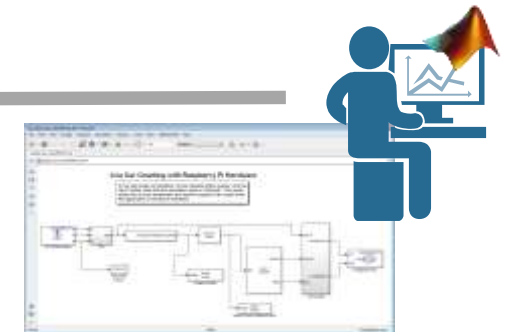
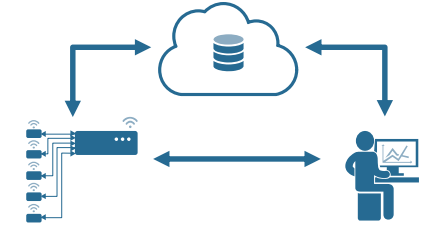
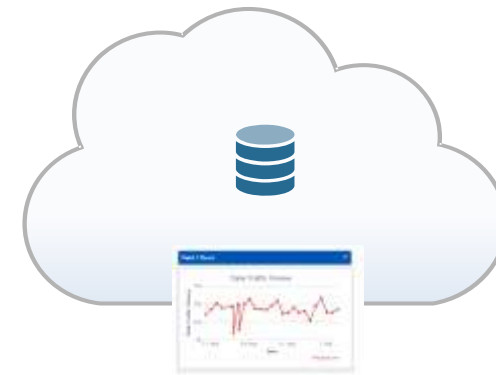
Example 2: Monitoring Traffic

Objectives

- Measure, explore, discover traffic patterns
- Provide live local traffic information service

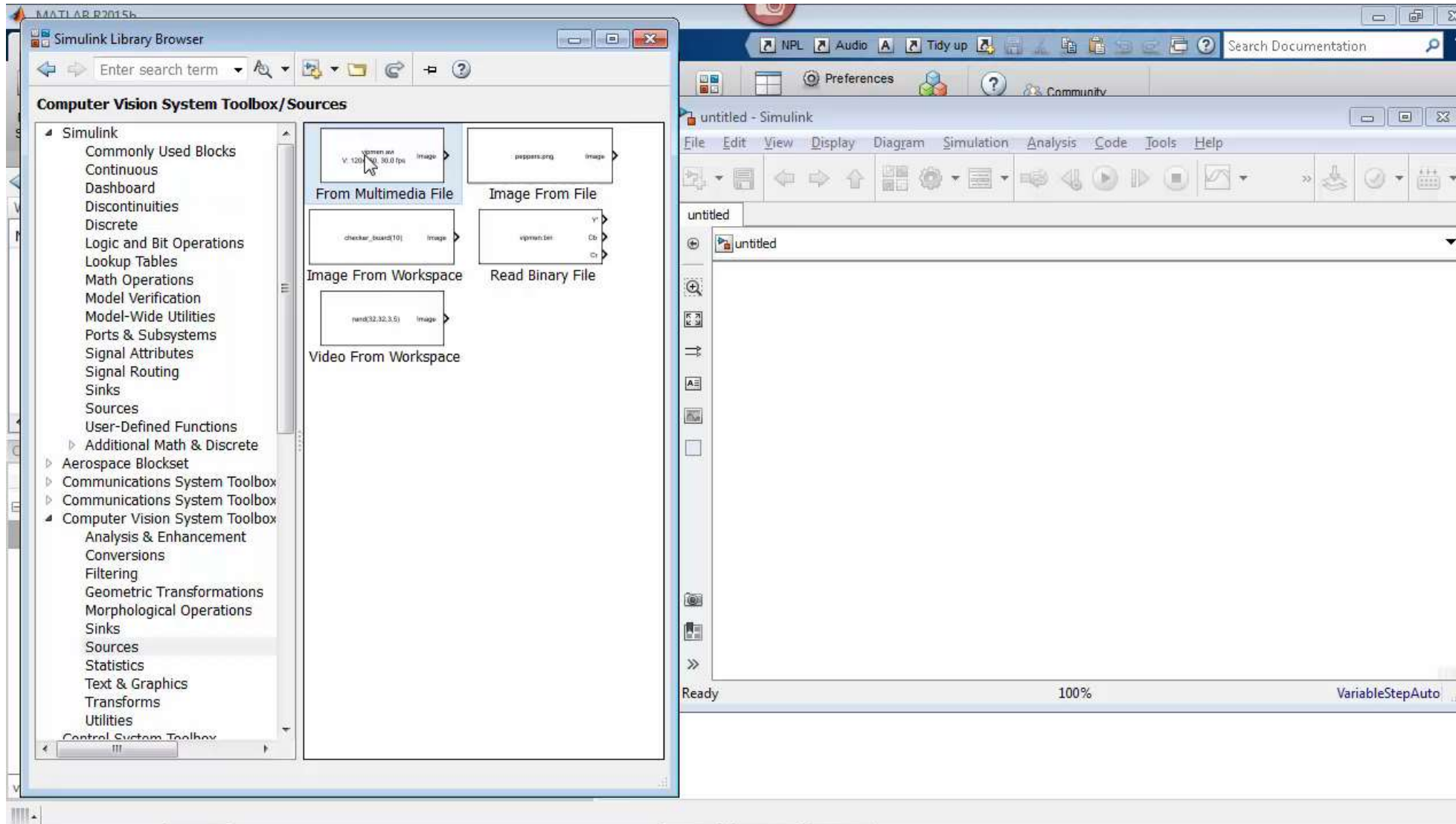
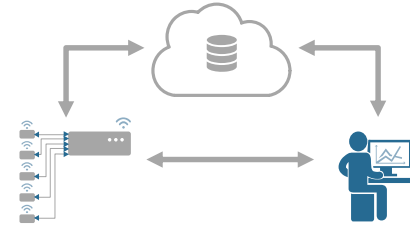
Solution

- RaspberryPi + webcam
- **Automated deployment of vision algorithms on embedded sensor**
- Full example available at makerzone.mathworks.com



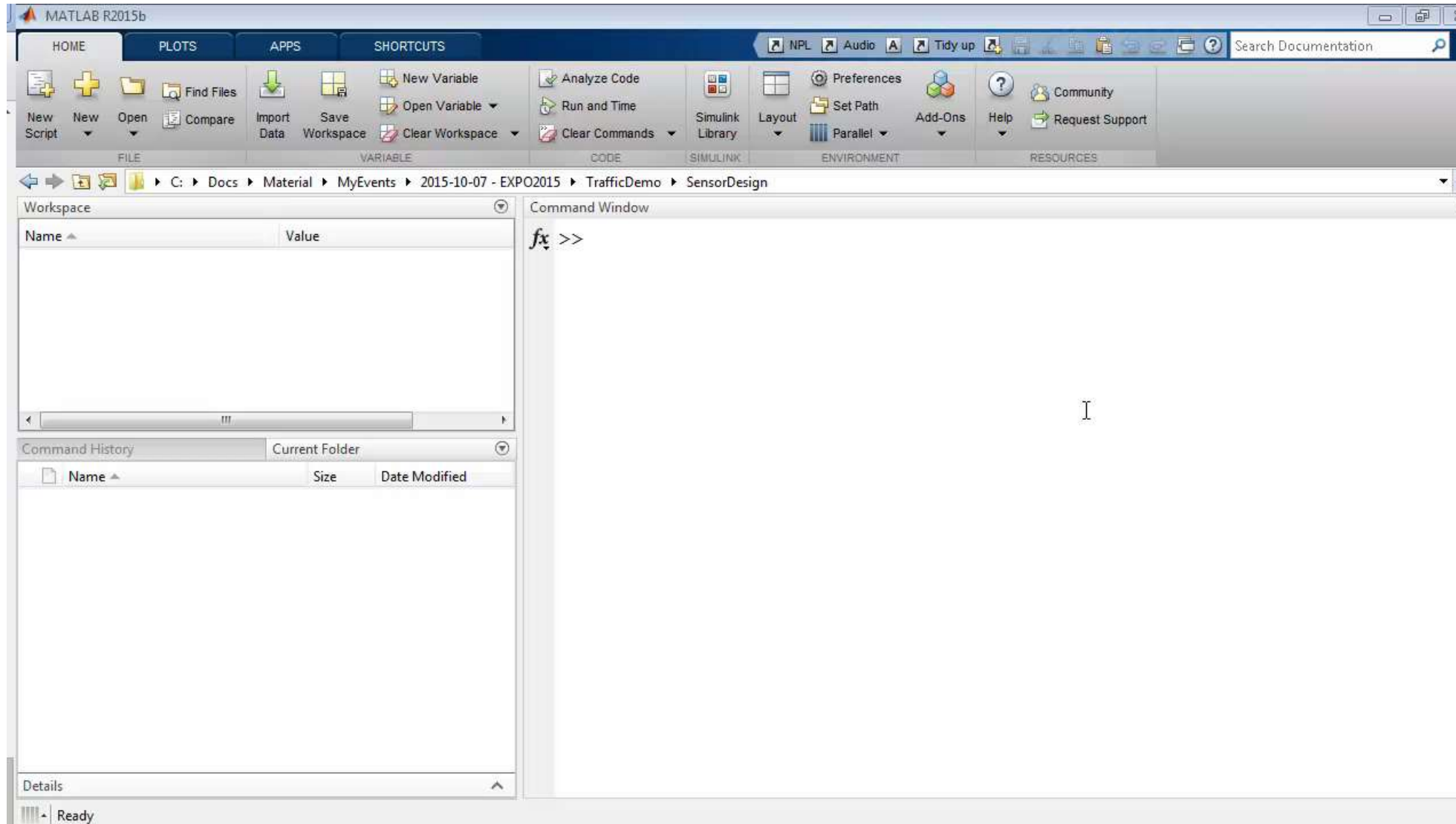
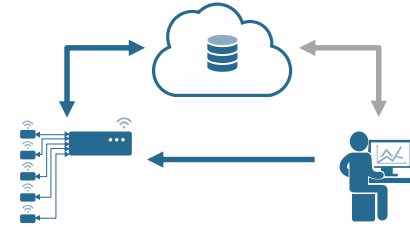
Traffic sensor – step 1

Design a car counter in Simulink

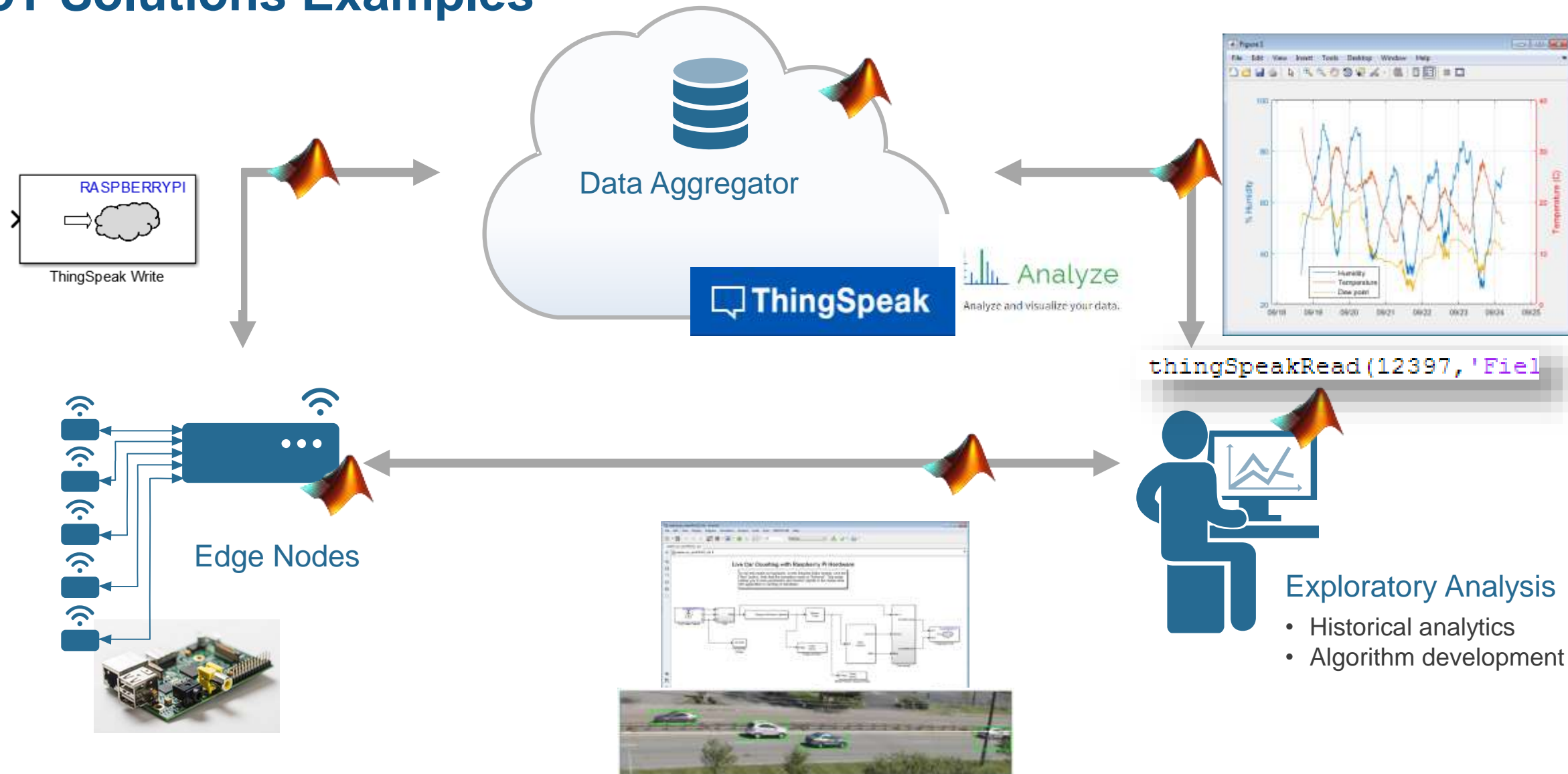


Traffic sensor – step 2

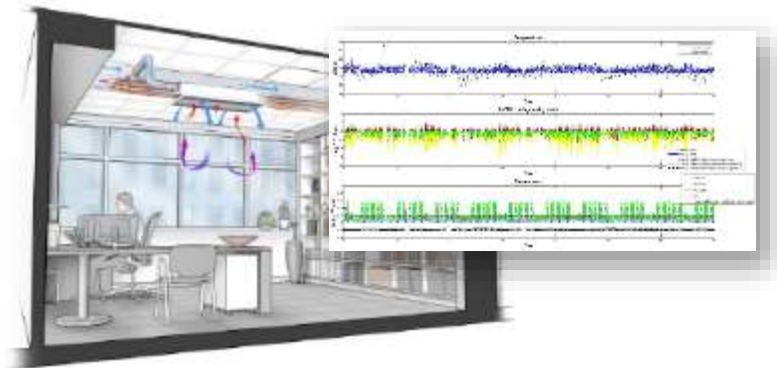
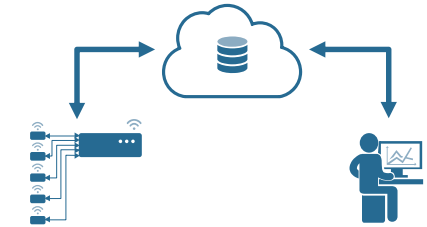
Port it to Raspberry Pi



IoT Solutions Examples

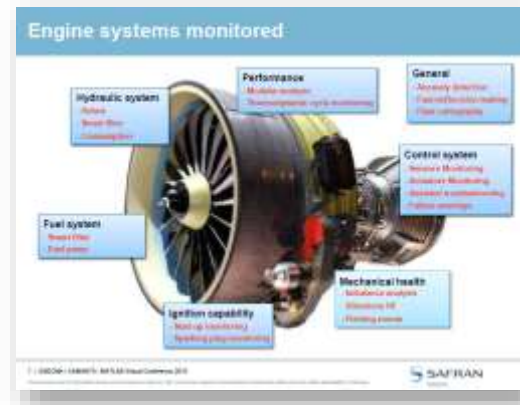


Industrial Customer Examples



Online optimization of building energy use

- Real-time, cloud-based system
- Combines analytics with optimization for predictive control of single-building HVAC
- Energy consumption reduced 15-25%



Online engine health monitoring

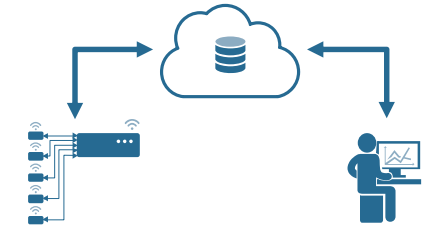
- Real-time analytics integrated with enterprise service systems
- Predict sub-system performance (oil, fuel, liftoff, mechanical health, controls)
- Improve aircraft availability and reduce maintenance costs



Cloud-based wheeze analysis

- Medical device to monitor and manage asthma and COPD
- Leverages analytics in cloud and embedded system

Customer Study: BuildingIQ Predictive Energy Optimization



Opportunity

- **Real-time, cloud-based system** for commercial building owners to reduce energy consumption of HVAC operation

Analytics Use

- **Data:** 3 to 12 months of data from power meters, thermometers, and pressure sensors, as well as weather and energy cost, comprising billions of data points
- **Machine learning:** SVM regression, Gaussian mixture models, k-means clustering
- **Optimization:** multi-objective, constrained

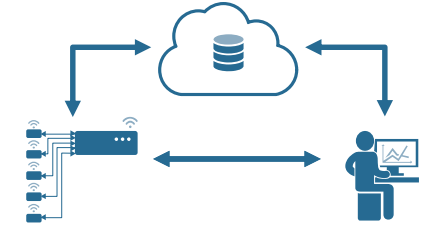
Benefit

- Typical energy consumption reduced 15-25%



Customer Study: iSonea

Cloud and Embedded Analytics



Opportunity

- Develop an acoustic respiratory monitoring system for wheeze detection and asthma management

Analytics in cloud and embedded

- Captures 30 seconds of windpipe sound and processes the data locally to clean up and reduce ambient noise
- Invokes spectral processing and pattern-detection analytics for wheeze detection on iSonea server in the cloud
- Provides feedback to the patient on their smartphone

Benefit

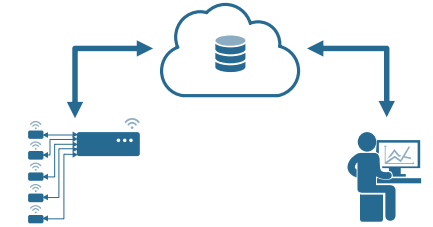
- Eliminates error-prone self-reporting and visits to the doctor

iSonea



Customer Study: iSonea

Cloud and Embedded Analytics



Opportunity

- Develop an acoustic respiratory monitoring system for wheeze detection and asthma management



Spectral processing and pattern-detection analytics for wheeze detection



Windpipe sound capture and processing to clean up and reduce ambient noise



MATLAB & Simulink Capabilities for IoT

Deployment

- .NET, COM components
- Java components
- Multicore and GPU systems
- Spreadsheet plug-ins
- Database plug-ins
- Hadoop
- Cloud services (AWS)
- ThingSpeak Apps
- Smartphone/tablet integration

File I/O

- Text
- Spreadsheet
- XML
- CDF/HDF
- Image
- Audio
- Video
- Geospatial
- Web content

Real-Time Sources

- Sensors
- GPS
- Instrumentation
- Cameras
- Communication systems
- Machines:
 - embedded systems
 - fieldbus
- Financial datafeeds

Repositories

- Databases (SQL)
- NoSQL
- Hadoop

Communication Protocols

- CAN
- DDS
- OPC
- XCP

Physical Component Modeling

- Electronic
- Mechanical
- Hydraulic, etc.

Communications Protocol Modeling

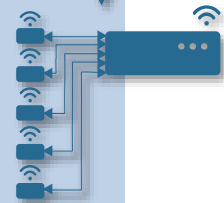
- LTE, Zigbee, 802.11, etc.

Automatic Code Generation

- Programmable chips (MCU, DSP, etc.)
- FPGAs

Verification/Validation and Process Support

- Model- and Code proving
- Lifecycle management tools



Data Clean-up

- Filtering
- Image processing
- Signal processing
- Telemetry
- RF sampling

Analysis, Modeling, Design

- Data visualization
- Statistics
- Regression
- Machine learning (supervised & unsupervised)
- Neural networks
- Optimization (gradient-based & stochastic)
- Symbolic computing
- Image analysis
- Financial analysis
- Geospatial computing
- Object recognition
- Speech recognition

Summary

- MATLAB and Simulink provide a broad range of capabilities for IoT
 - Performing interactive and advanced analytics
 - Deploying analytics to production environments
 - Developing real-time systems, from sensing and control nodes to complex devices
 - Designing communications, including simulation and real-time connectivity

- An open-system architecture
 - User-extensible, with well-documented APIs
 - Can be integrated with third-party edge-node platforms, aggregators, and production IT systems

IoT Web Resources

Discovery/ Landing Pages

- [Internet of Things Overview](#)
- [Developing and Testing Edge Node Devices](#)
- [Accessing and Aggregating IoT Data](#)
- [Analyzing IoT data and building predictive algorithms](#)
- [ThingSpeak Support from Desktop MATLAB](#)

Articles

- [Counting Cars and Analyzing Traffic with a Raspberry Pi, a Webcam and ThingSpeak](#)
- [MathWorks Weather Station – Revisited](#)
- [Real-Time Tide Gauge to Tweet Tidal Alerts](#)
- [Weather Station Data Analysis](#)
- [Soda Machine Analyzer](#)

User Stories

- [iSonea Develops Mobile App for Wheeze Detection and Asthma Management](#)
- [BuildingIQ Develops Proactive Algorithms for HVAC Energy Optimization in Large-Scale Buildings](#)

Videos

- [MATLAB and the Internet of Things \(IoT\): Collecting and Analysing IoT Data \(Highlights\)](#)
- [MATLAB and the Internet of Things \(IoT\): Collecting and Analysing IoT Data \(Full Video\)](#)
- [Introduction to ThingSpeak](#)
- [Signal Processing and Machine Learning Techniques for Sensor Data Analytics](#)
- [Data Analytics with MATLAB](#)

