Project-Based Learning for Signal Processing and Communications with MATLAB and Simulink

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Agenda

- Project-based learning & signal processing
- Case studies
  - Signal analytics and classification
  - Heart rate monitoring: from algorithms to prototyping on ARM® hardware
  - Over-the-air testing of wireless waveforms with software-defined radios (SDR)
- Summary

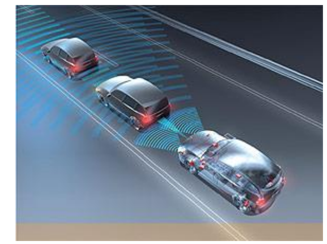
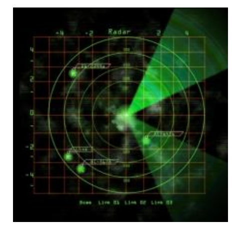
Project-based learning

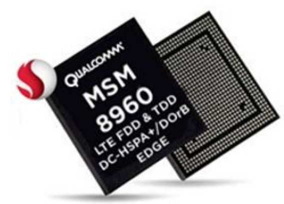
- Learning-by-doing
- Deepens understanding
- Excites & motivates
- Fosters collaboration

Project-based learning & signal processing

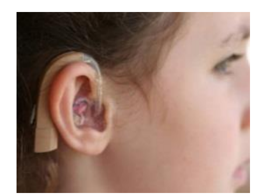
- Connected everything
- Live signals available
- Mobile internet everywhere
- Algorithms in everything

- Easily design projects that involve signal processing & communications







1

Signal analytics & classification on data from wearable and mobile devices

2

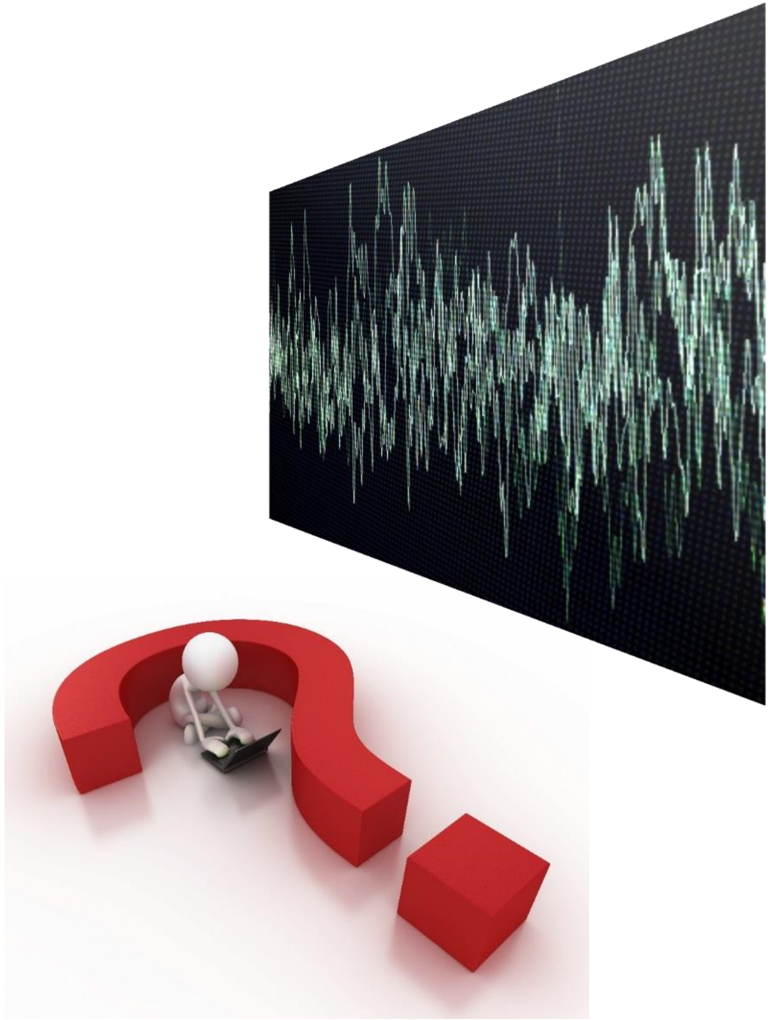
Heart rate monitoring - from desktop processing to prototyping on ARM® Cortex®-M &Cortex®-A

3

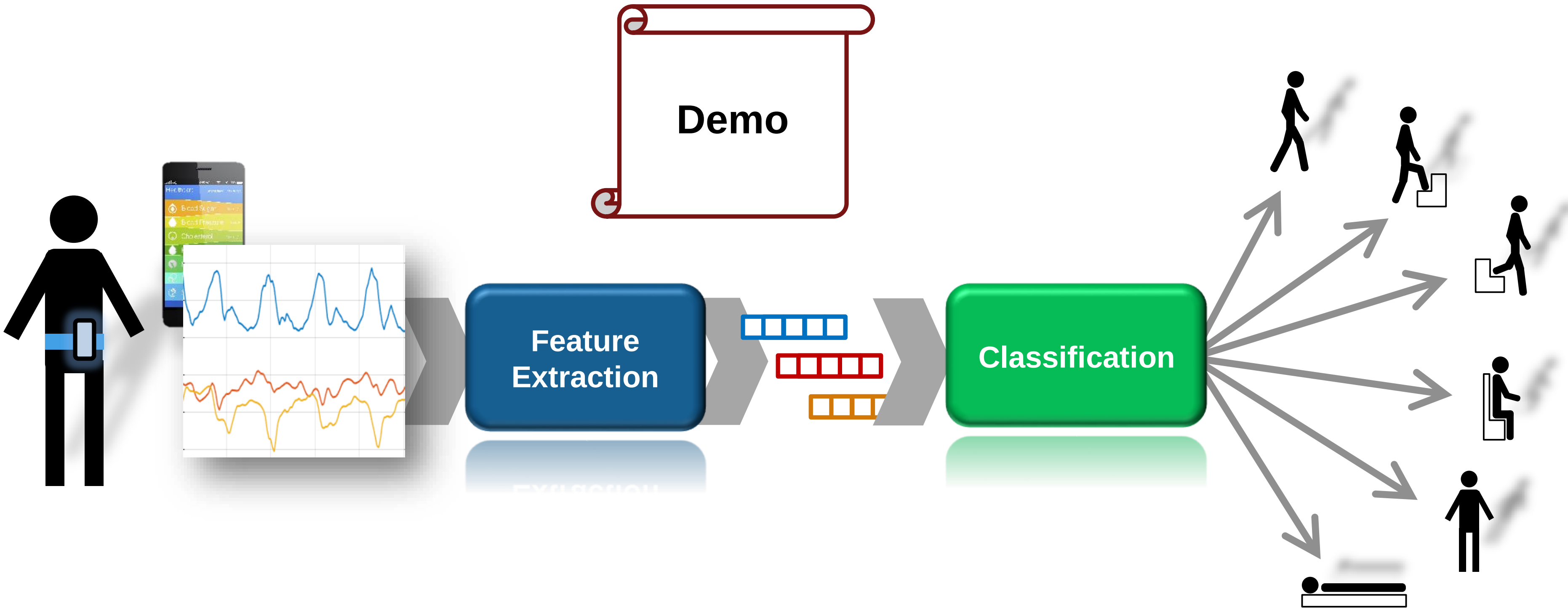
Over-the-air testing of wireless signals – Software-defined radios (SDR) & RF instruments

Challenges with Signal Analytics

- Data analytics on sensor signals
- Need domain-specific knowledge
- Open-ended problem and long discovery cycles
- You can use offline pre-recoded training and validation data sets



Example:
Human Kinetic Activity Analysis/Classification

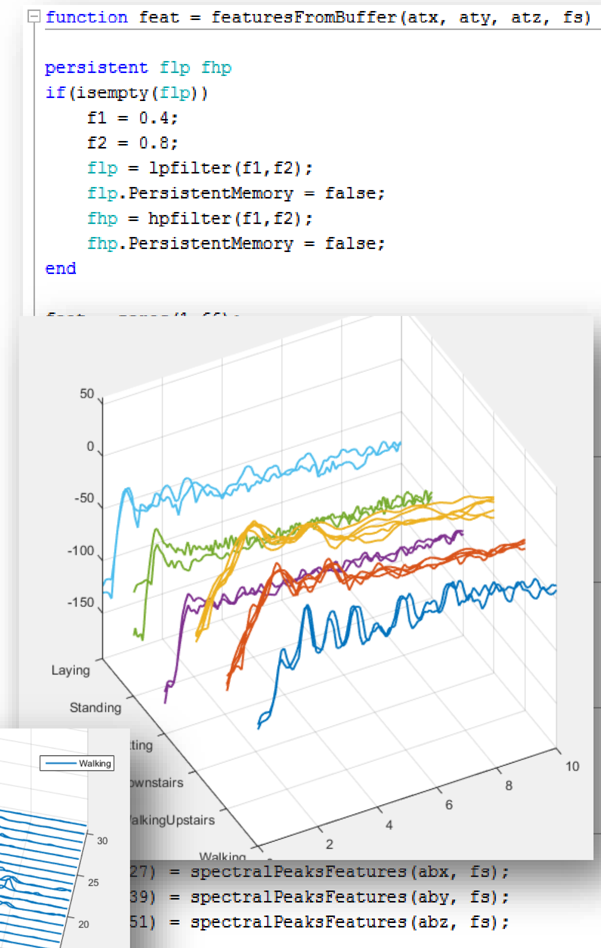


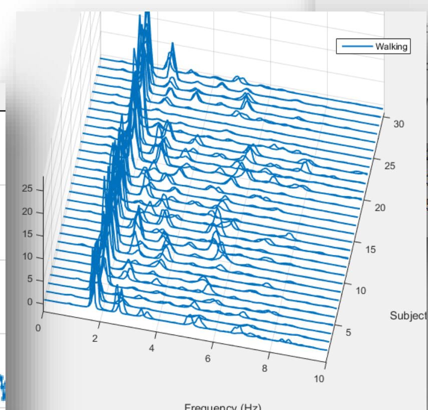
Dataset courtesy of:
Davide Anguita, Alessandro Ghio, Luca Oneto, Xavier Parra and Jorge L. Reyes-Ortiz.
Human Activity Recognition on Smartphones using a Multiclass Hardware-Friendly Support Vector Machine.
International Workshop of Ambient Assisted Living (IWAAL 2012). Vitoria-Gasteiz, Spain. Dec 2012
http://archive.ics.uci.edu/ml/datasets/Human+Activity+Recognition+Using+Smartphones

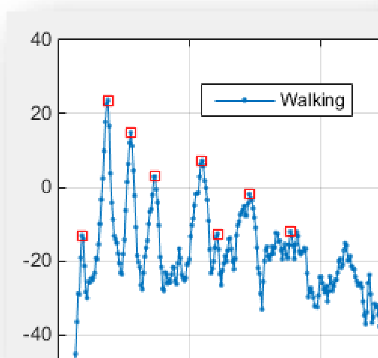
Human Kinetic Activity Analysis/Classification

Solution

- Only core built-in Signal Processing algorithms
- 66 high-quality features extracted with only 65 lines of code!
- Visualization and automation accelerate insight iterations







Leverage built-in algorithms

Do you want to re-invent the wheel?

- **Signal Processing Toolbox 7.0**
  - Simplified interface and examples for casual users
  - Analysis of non-evenly sampled data (IoT)
  - New functions for signal measurements, filter design
- Neural Network Toolbox
- Statistics & Machine Learning Toolbox

- `cheby2`
- `filter`
- `rms`
- `pwelch`
- `periodogram`
- `xcov`
- `findpeaks`
- …

$$|H(j\omega)|^2 = \frac{\varepsilon^2 C_N^2(\omega_s/\omega)}{1 + \varepsilon^2 C_N^2(\omega_s/\omega)}$$

$$C_N(\omega_s/\omega) = \begin{cases} \cos[N \cos^{-1}(\omega_s/\omega)], & |\omega| \geq \omega_s \\ \cosh[N \cosh^{-1}(\omega_s/\omega)], & |\omega| \leq \omega_s \end{cases}$$

$$P_{xx}(f) = \frac{1}{LF_s} \left| \sum_{n=0}^{L-1} x_L(n) e^{-j2\pi fn/F_s} \right|^2$$

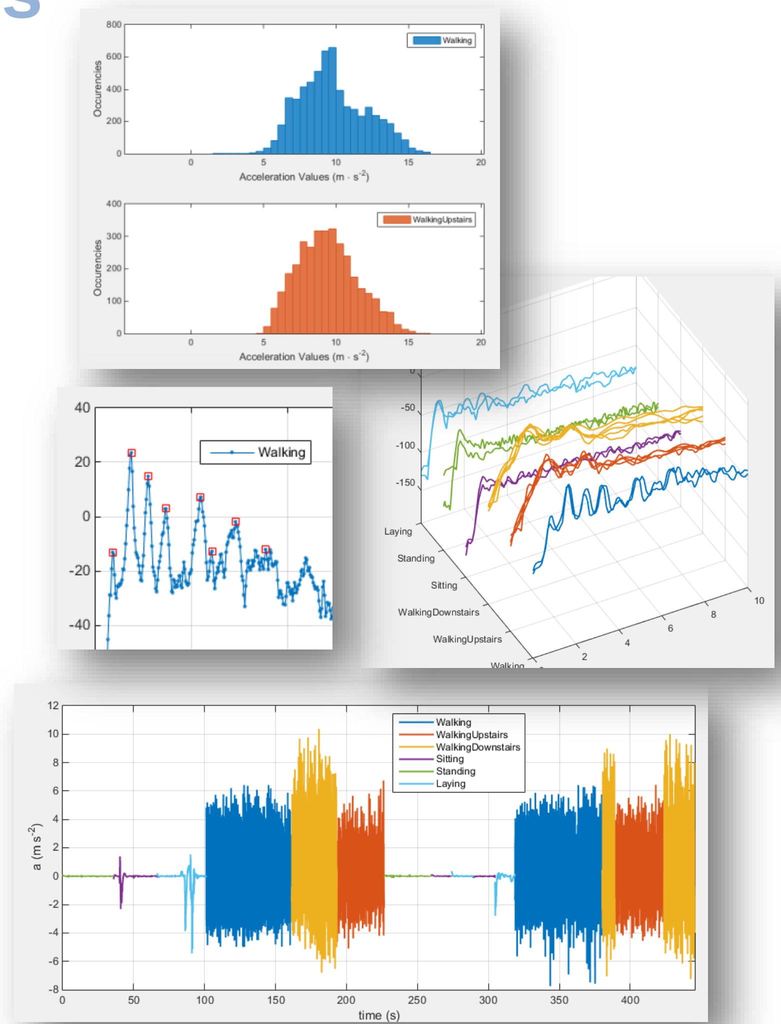
$$f_k = \frac{kF_s}{N} \quad k = 0, 1, \ldots, N-1$$

$$c_{xy}(m) = \begin{cases} \sum_{n=0}^{N-|m|-1} \left(x(n+m) - \frac{1}{N} \sum_{i=0}^{N-1} x_i \right) \left(y_n^* - \frac{1}{N} \sum_{i=0}^{N-1} y_i^* \right) & m \geq 0 \\ c_{yx}^*(-m) & m < 0 \end{cases}$$

Summary

MATLAB for Signal Analytics

- Signal Processing Toolbox has an extensive set of functions for signal processing and analysis
- Visualisation and App-driven automation accelerate insight iterations
- All this comes with compact & concise MATLAB language and extensive documentation
- Applicable to Internet-of-Things (IoT) projects



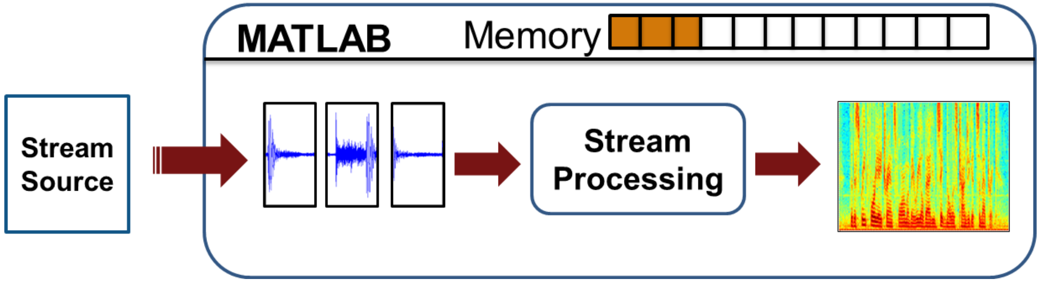
1 Signal analytics & classification on data from wearable and mobile devices

2 **Heart rate monitoring - from desktop processing to prototyping on ARM® Cortex®-A**

3 Over-the-air testing of wireless signals – Software-defined radios (SDR) & RF instruments

Challenges with streaming DSP

- Stream real-world data into and out of MATLAB
- Algorithms must keep up with rate of incoming frames of data
- Need domain-specific knowledge for both algorithms and data I/O

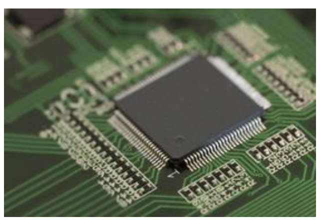


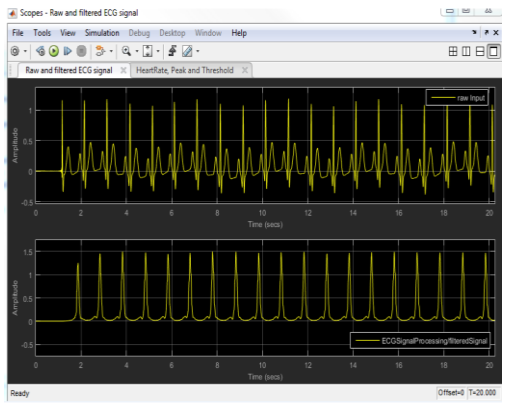
MathWorks

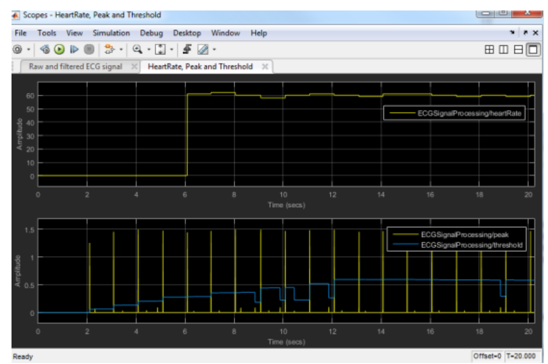
Example:
Smart Sensor for Heart Rate Monitoring

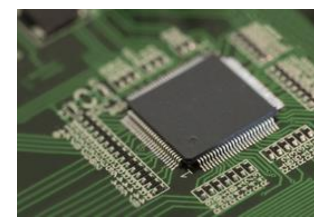
Demo

Real-time Sensor Data Capture → **Streaming Signal Processing** → **Test/Validate** → **Deploy/ Implement**









Acquire streaming sensor data (ECG) in real-time with BeagleBone Black (BBB) using ARM Cortex-A

Streaming algorithms: filtering, sample rate conversion, detection and classification in real-time

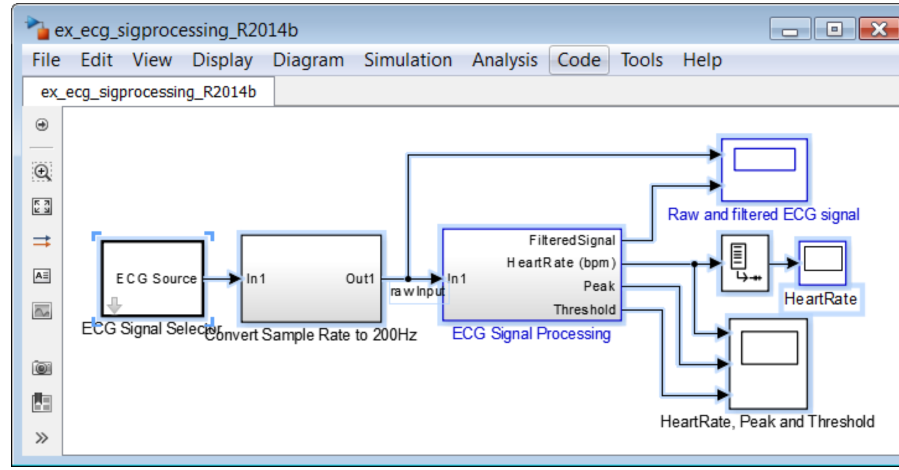
Prototype: Test algorithms using External-mode

Implement and deploy on ARM Cortex-A BBB board

Smart Sensor for Heart Rate Monitoring

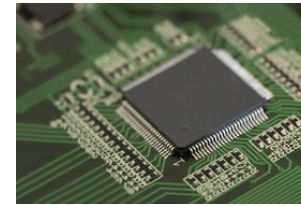
Solution

- A Model-Based Design Workflow
- Executable specification & simulation: pre process, filter & detect ECG Signal
- Code Generation: Create a PIL block with optimized code on ARM Cortex-A processor
- Verification: Perform real-time processing with BeagleBone Black



Summary

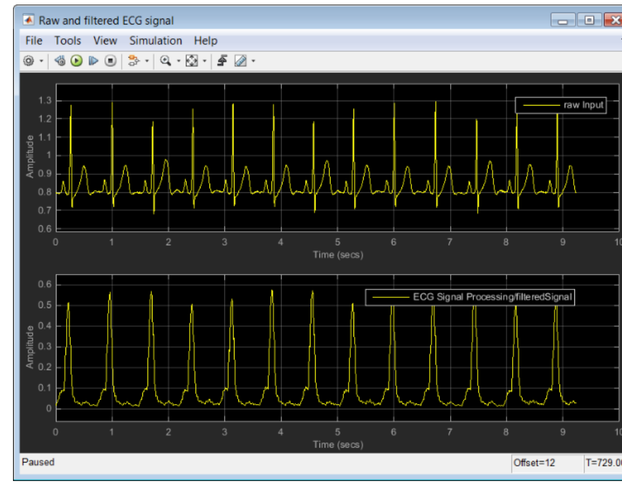
MATLAB/Simulink for Streaming DSP

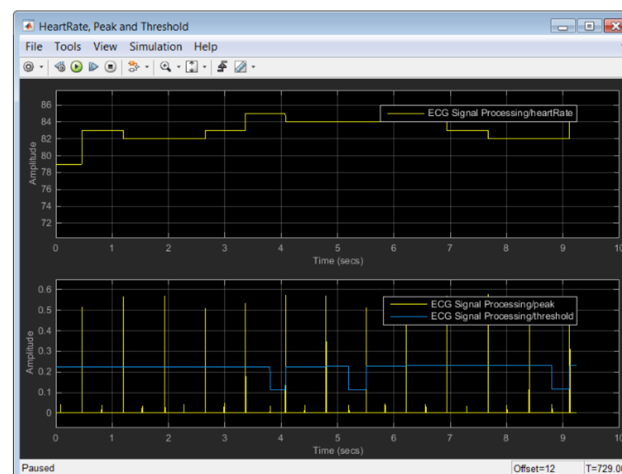


- DSP System Toolbox provides streaming capabilities for design and simulation of real-time sensor processing in MATLAB and Simulink

- Once your design works in your desktop, you can deploy it to Low-cost Hardware such as BeagleBone Black, Raspberry Pi, etc.

- With Embedded Coder you can configure your embedded application and implement, test and validate on hardware





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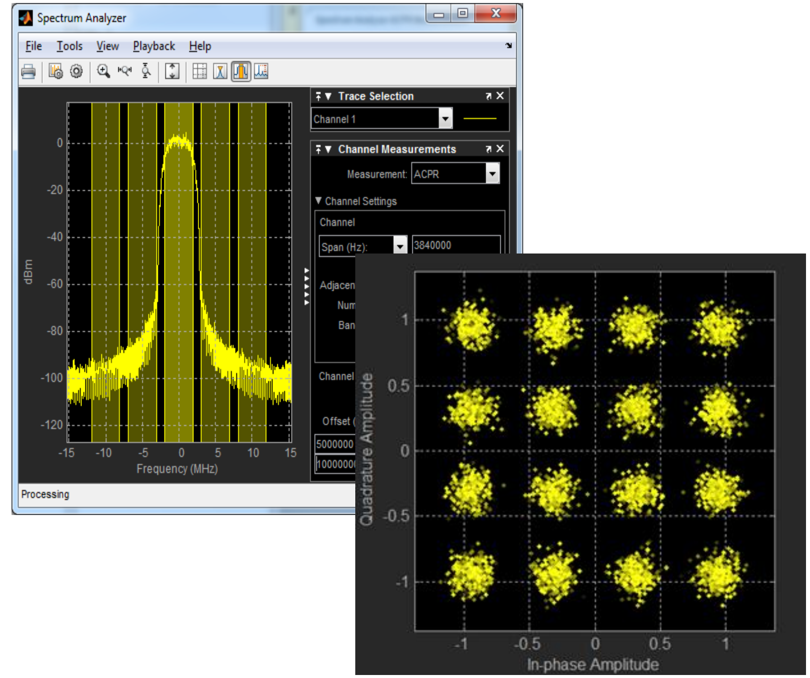
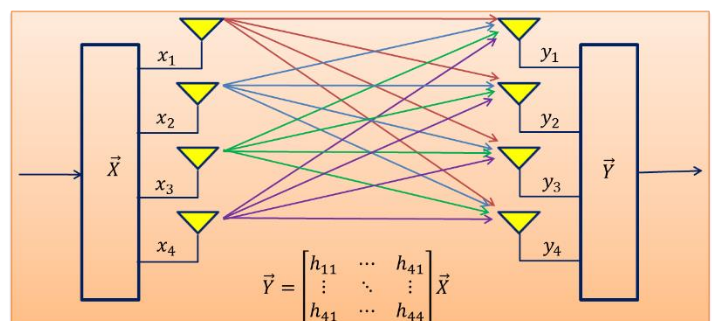
Wireless Over-the-air testing – Software-defined radios (SDR) & RF instruments

Challenges of Wireless Communications

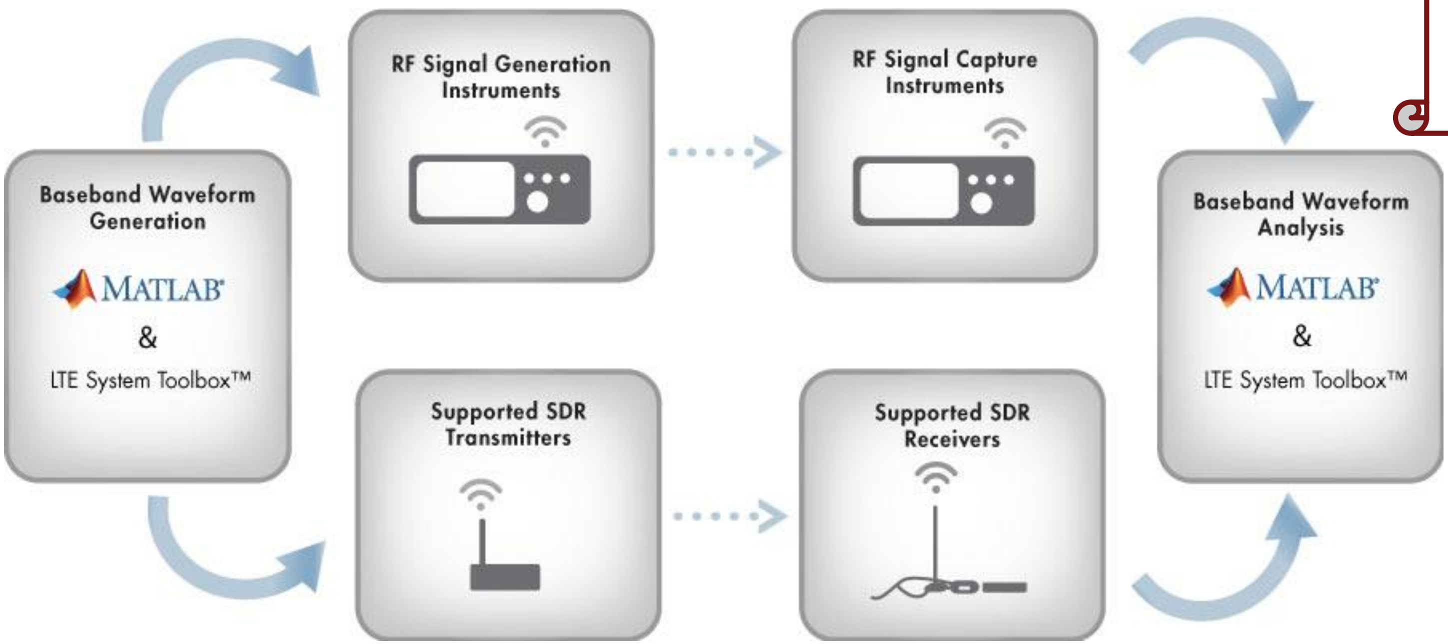
- Need multi-domain (Digital, RF, Antenna) knowledge
- Jointly optimize Digital Baseband, RF circuits and antenna patterns
- Simulate first with channel modelling. Is your channel mode accurate?
- Test it with over-the-air transmission and reception of RF signals





Example:
Over-the-air testing with SDRs & RF instruments

Demo



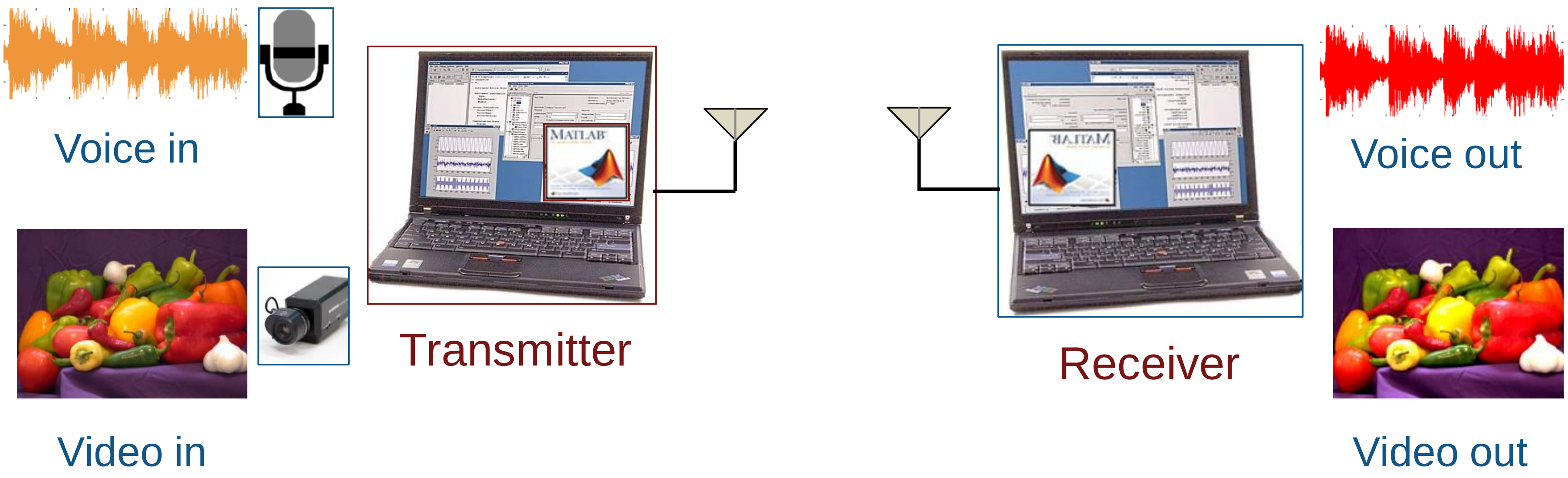
Process original data bits and generate custom digital baseband waveforms in transmitter

Transmit waveform using SDR devices or RF instruments

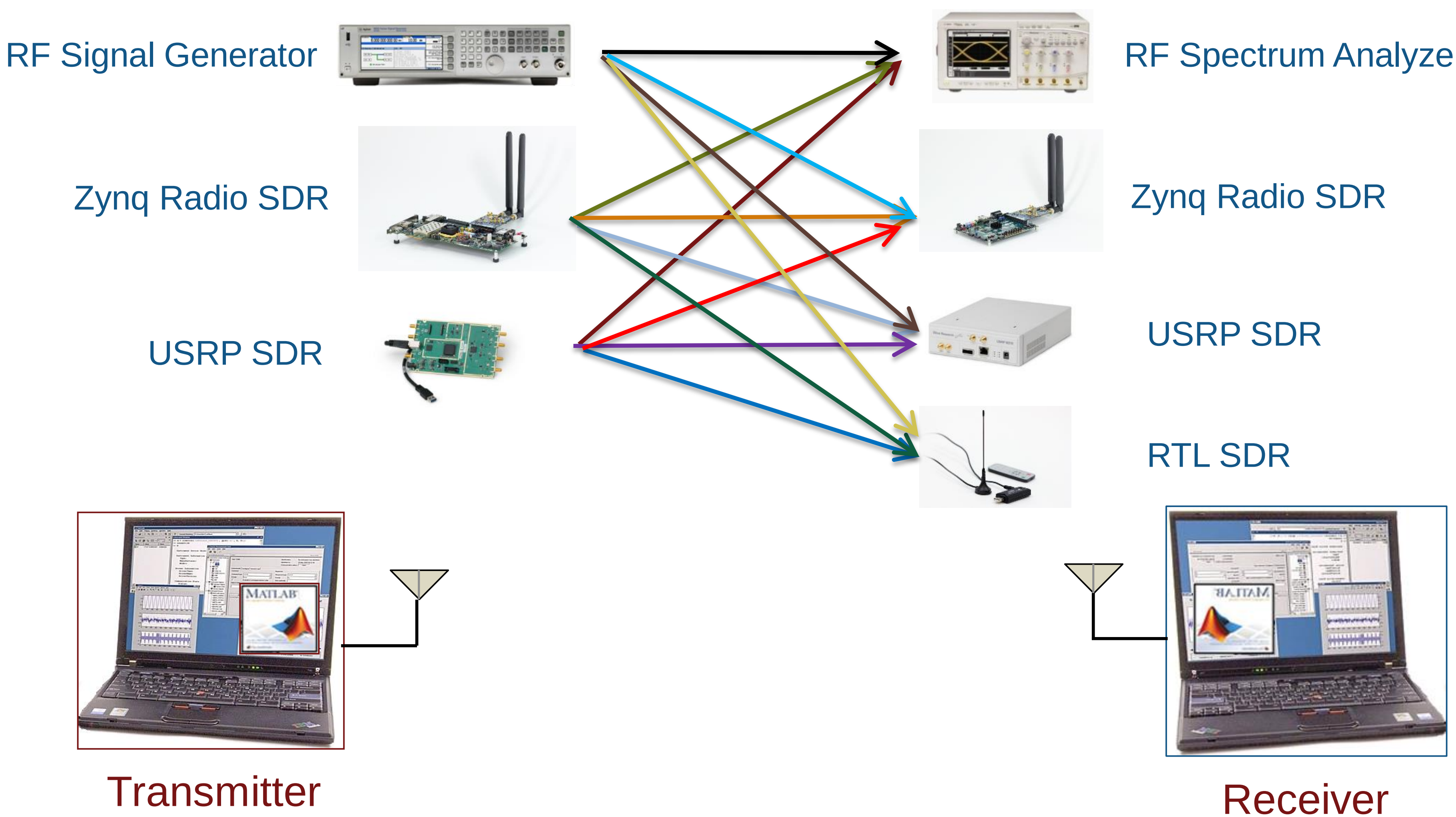
Capture received samples with SDR devices or RF instruments

Process received samples in receiver. Decode/recover original data

Over-the-air testing with SDRs & RF instruments
Solution

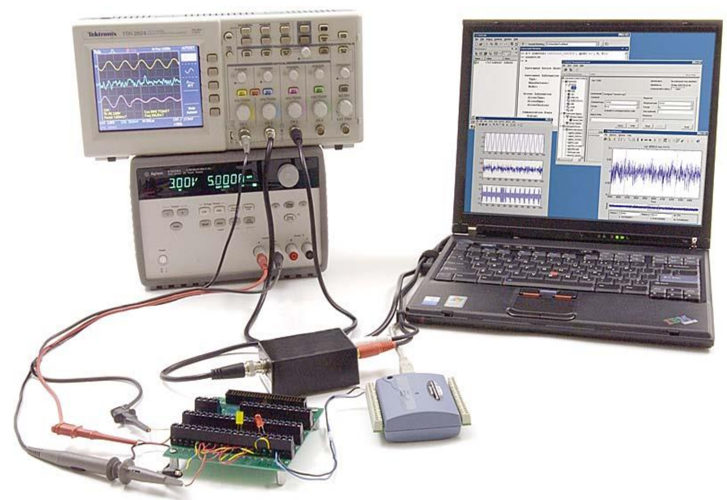


Supported SDRs & RF instruments



Summary
MATLAB/Simulink for Radio Connectivity

- Go beyond simulation
- Actually, transmit & receive wireless signals with MATLAB and Simulink
- Connect to SDRs
  - Communications System Toolbox hardware support packages
- Connect to RF instruments
  - Instrument Control Toolbox
- Perform over-the-air testing
- Verify your wireless designs



Thank You

Q & A