

# LOT

**LAB of THINGS**

SIGCSE  
Atlanta  
2014

A Devices Research and Teaching Platform  
for Home and Beyond

A.J. Brush, Senior Researcher  
Microsoft Research



# Thank you





W

Microsoft®

# Research Collaborators



Microsoft®

# Research

# Collaborators



# touchdevelop





What did the 0  
say to the 8?



What did the 0  
say to the 8?

Nice belt!

Industrial  
Internet

Internet of  
Everything

Ambient Data

M2M

Cyber-Physical  
Systems

# Internet of Things

Thinking  
Things

Smarter  
Planet

Cloud of  
Things

Intelligent  
Systems

System of  
Observations





# Connected things everywhere

During 2008, the number of **things** connected to the Internet exceeded the number of **people** on earth.



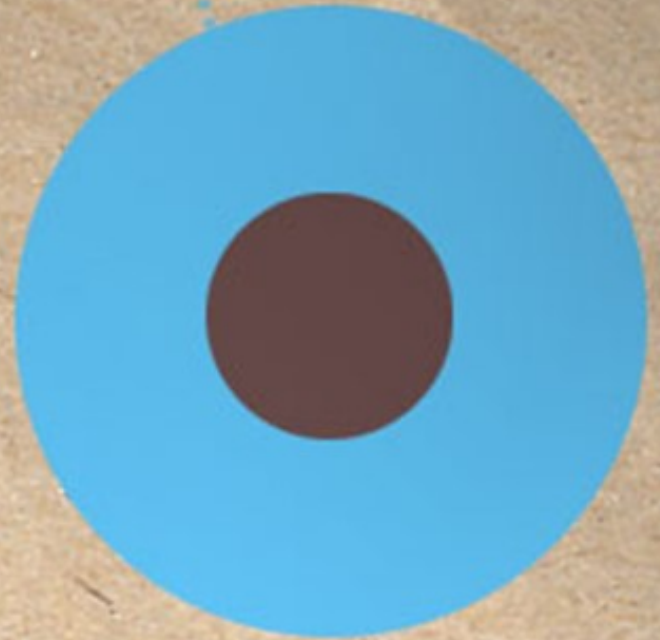
2003



2010



2015



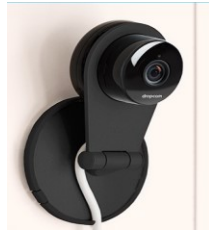
By 2020 there will be **50 billion**.

# Internet of Things

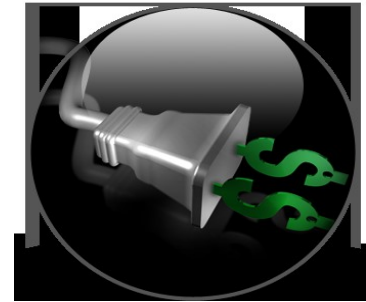
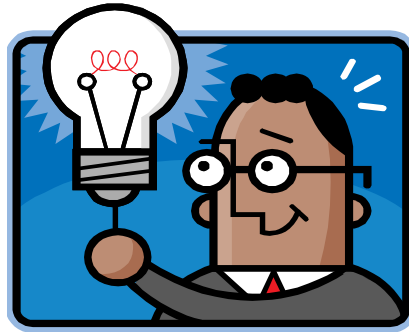
Networks of low-cost sensors and actuators for data collection, monitoring, decision making and process optimization. McKinsey Global Institute



# Things for Home



# Enable a range of applications



# Long anticipated...



Microsoft Home of Future 1994



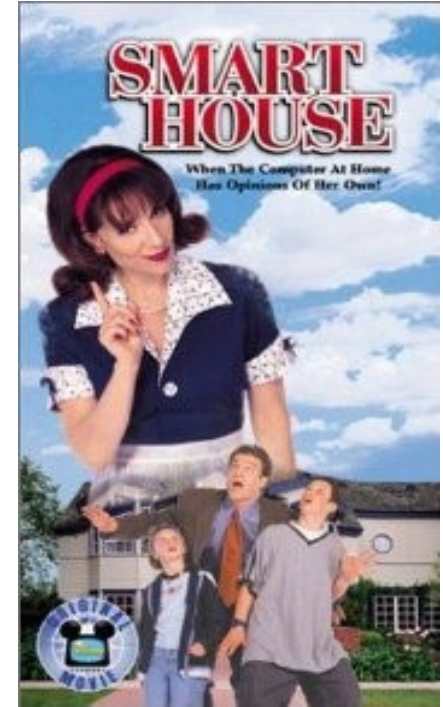
Georgia Tech Aware Home, 2000



The Adaptive House,  
Mozer et al., 1997



Duke Smart Dorm, 2007



Disney, 1999

# Why now?

Inexpensive devices  
Need no new wires  
Maturing standards  
Mobile devices



I study and build technologies for homes and families.

**Ubiquitous Computing**



**Home**



**Computer Supported  
Collaboration**



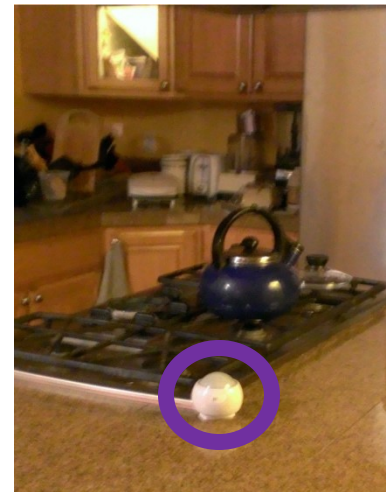
**Families**

# Why homes & families?





# Built-in prototyping lab



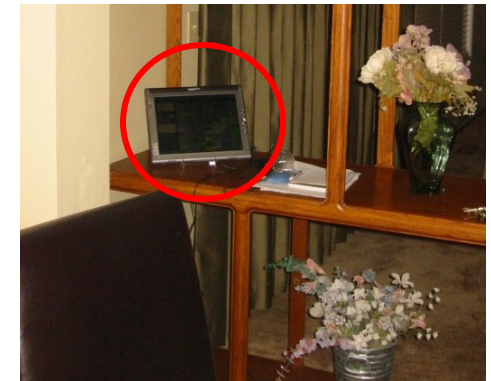
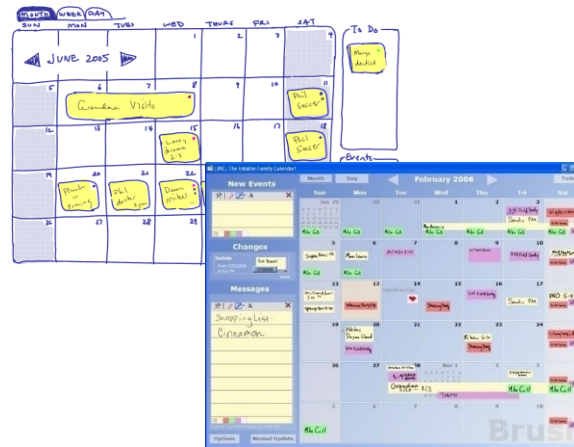
# User-Centered Design

Process in which the needs, wants, and limitations of end users of a product are given extensive attention at each stage of the design process. (Wikipedia)

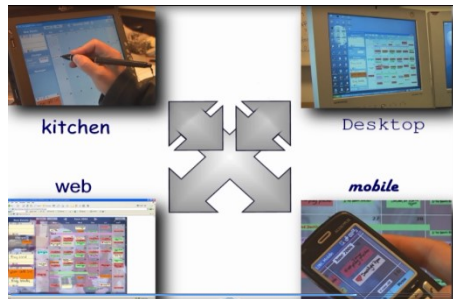
Understand  
Current Behavior and  
User Needs

Build Prototype

Does it work?  
Use of Technology



# Deployments, Deployments, Deployments



**LINC**



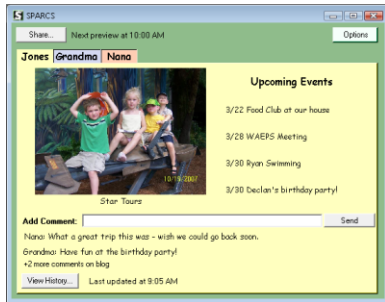
4 homes, 4 weeks



**Speech@Home**



6 homes, 2 weeks



**SPARCS**



14 homes, 5 weeks

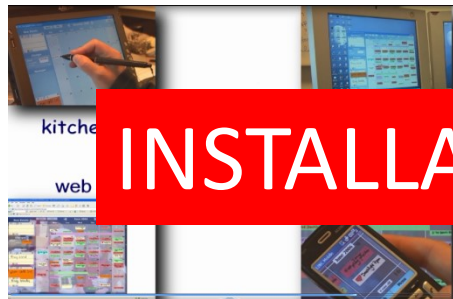


**PreHeat**



5 homes, 8 weeks+

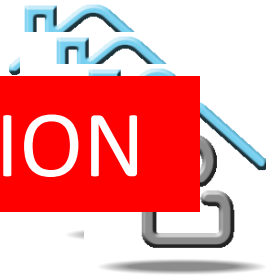
# ~~Deployments, Deployments,~~ pain pain pain ~~Deployments~~



**INSTALLATION**

**LINC**

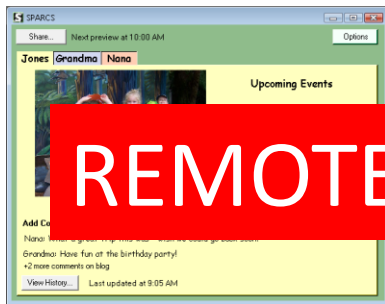
4 homes, 4 weeks



**LOST DATA**

**Speech@Home**

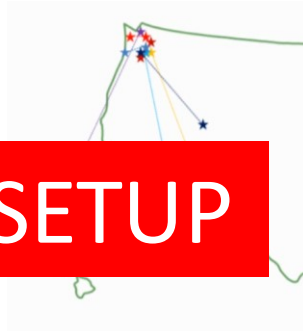
6 homes, 2 weeks



**REMOTE SETUP**

**SPARCS**

14 homes, 5 weeks



**ROBUSTNESS**

**PreHeat**

5 homes, 8 weeks+



# Other people feel deployment pain too



Limited access

Environmental

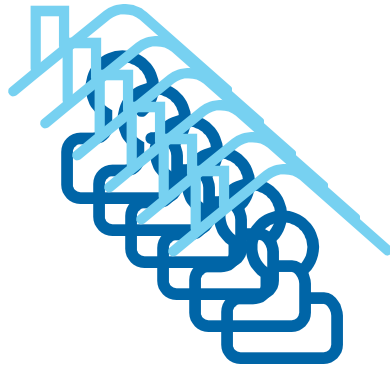
Hazards

Scarce Resources

Hnat, T., Srinivasan, V., Lu, J., Sookoor, T., Dawson R., Stankovic, J., Whitehouse, K. (2011) The Hitchhiker's Guide to Successful Residential Sensing Deployments. Paper presented at SenSys'11, 2-4, November 2011

# It's hard to deploy technology in homes

Limited number of homes often without geographic diversity

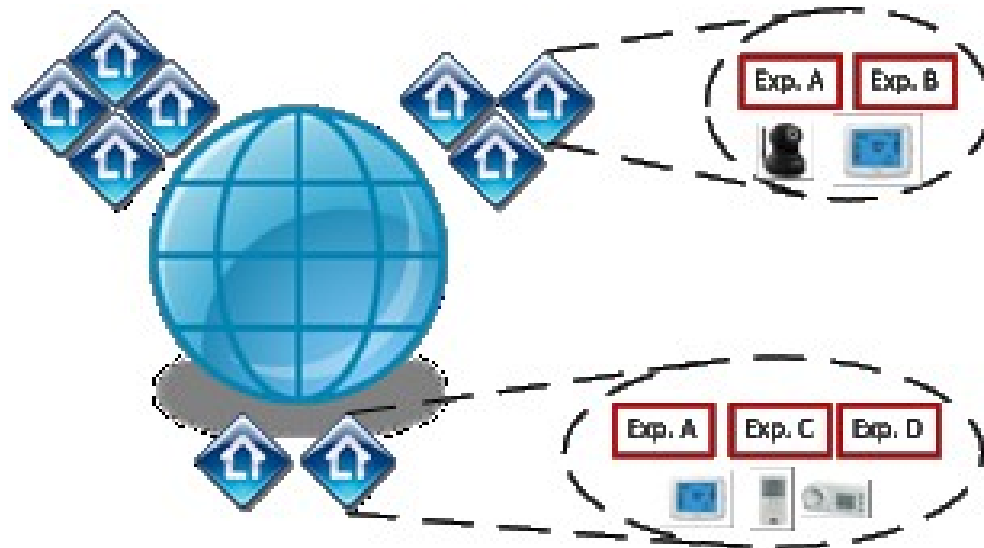


Large engineering effort that is not easily re-used



# Lab of Things

**Change the scale and pace of research on connected devices in homes**



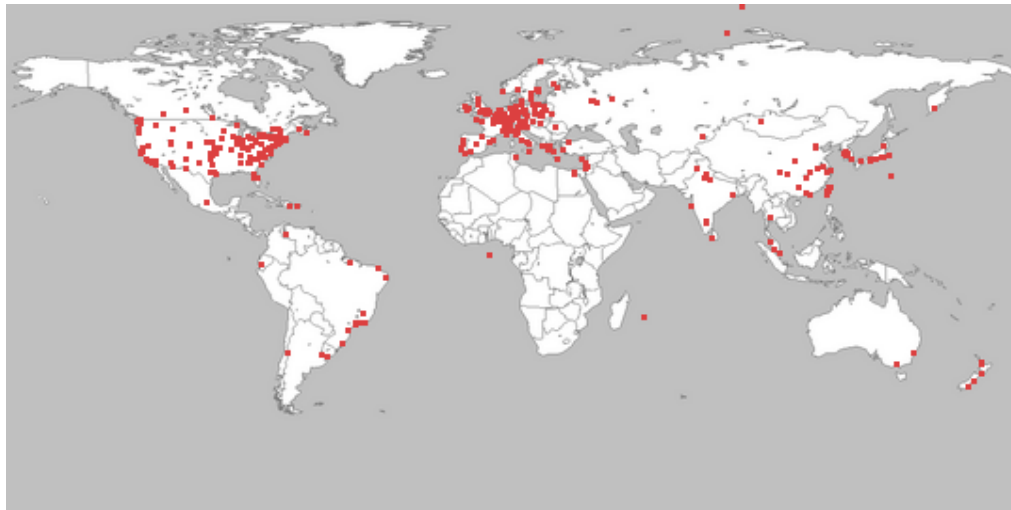
A large number of geographically distributed households, each running a common, flexible framework in which experiments are implemented.

# Inspiration



PLANETLAB

An open platform for developing, deploying, and accessing planetary-scale services



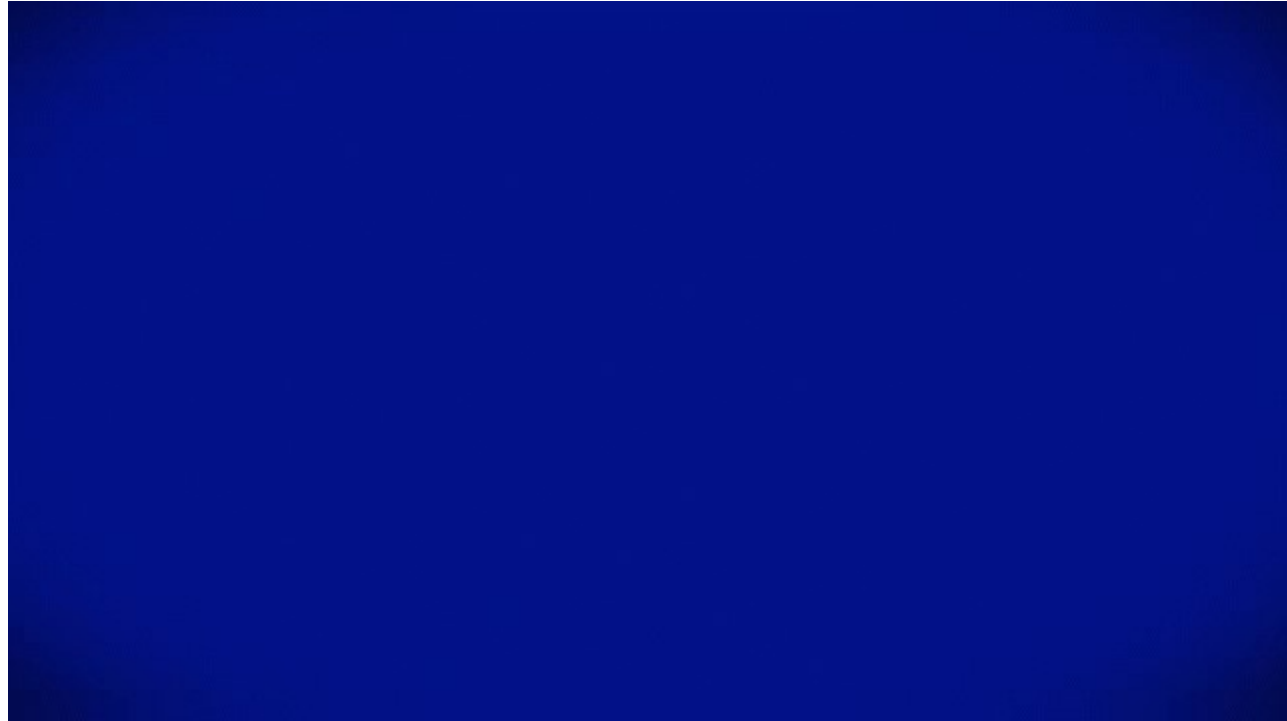
PlanetLab is a global research network that supports the development of new network services. Since the beginning of 2003, more than 1,000 researchers at top academic institutions and industrial research labs have used PlanetLab to develop new technologies for distributed storage, network mapping, peer-to-peer systems, distributed hash tables, and query processing.



Video available [here](#)

# LoT

LAB of THINGS



Enable research and student projects  
that use connected devices in homes and beyond

# Lab of Things

<http://www.lab-of-things.com>

<https://labofthings.codeplex.com>

The screenshot shows the Microsoft Research website for Lab of Things. At the top, it says "Microsoft Research". Below that is a large red banner with the "LOT LAB of THINGS" logo. To the right of the logo is a video player showing a cartoon illustration of a house with various devices connected to a central "LOT" hub. Below the video is a blue button with a white download icon and the text "Download the Lab of Things SDK (Beta 1)".

Below the main banner are three navigation buttons: "Get started with The Lab of Things", "Who is using The Lab of Things", and "FAQ about The Lab of Things".

The main content area features a diagram of a house with a "Field study" label above it. Inside the house, there is a "HomeOS" layer, and below that, "Deploy diverse devices in homes using HomeOS". To the right of the diagram is a section titled "What is the Lab of Things?" which describes the platform as a flexible platform for experimental research that uses connected devices in homes. It lists several capabilities:

- LOT enables easy interconnection of devices and implementation of application scenarios, using HomeOS.
- LOT enables easy deployment and monitoring of field studies and analysis of data from experiments.
- LOT enables easy sharing of data, code, and participants, further lowering the barrier to evaluating ideas in a diverse set of homes.

At the bottom of the page, there is a footer with links for "Contact us", "Privacy & cookies", "Terms of use", "Trademarks", "Code of conduct", "Feedback", "Mobile", and "©2013 Microsoft".

The screenshot shows the CodePlex repository page for Lab of Things. The page title is "CodePlex Project Hosting for Open Source Software". The main header features the "LOT LAB of THINGS" logo and a navigation menu with links for "HOME", "SOURCE CODE", "DOWNLOADS", "DOCUMENTATION", "DISCUSSIONS", "ISSUES", "PEOPLE", and "LICENSE".

Below the navigation menu is a search bar and a "download" button. The "Project Description" section states: "Lab of Things (LoT) is a flexible platform for research that uses connected devices in homes." It lists three key features:

- LoT enables researchers to easily interconnect devices and implement application scenarios.
- LoT enables field studies at scale through cloud services that can monitor and update experiments, and provide easy access to collected data
- LoT enables researchers to share data, code, and participants, lowering the barrier to evaluating ideas in a diverse range of settings

The page also includes a "CURRENT" version section with the following details:

CURRENT	vBeta1
DATE	Mon Jul 15, 2013
STATUS	Beta
DOWNLOADS	3,197
RATING	★ ★ ★ ★ ★ 1 rating

Below this is an "ACTIVITY" table:

PAGE VIEWS	VISITS	DOWNLOADS
590	222	203

The page also includes a "RELATED PROJECTS" section with links to "HomeOS" and "Microsoft Lab of Things Analytics Engine".

# Taste of student projects



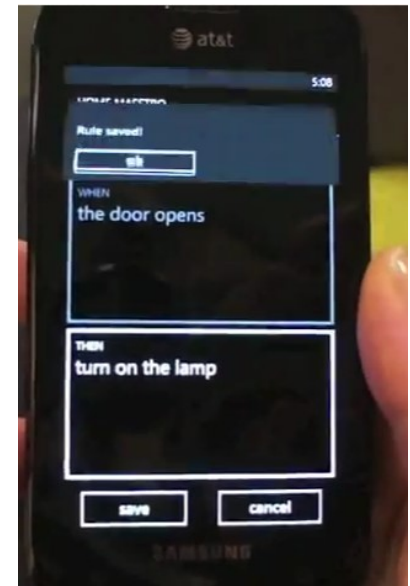
## Home Energy Models

Omid Ardakanian, Ryan Case  
University of Waterloo  
May 2010



## Gesture Controlled Lights

Jehad Affoneh, Sterling Swigart,  
David Nufer  
CSE 481m, Spring '11  
University of Washington



## Rules by Example

Shaun Salzberg  
MIT, Feb. 2012



What did the  
fish say when  
he ran into the  
wall?

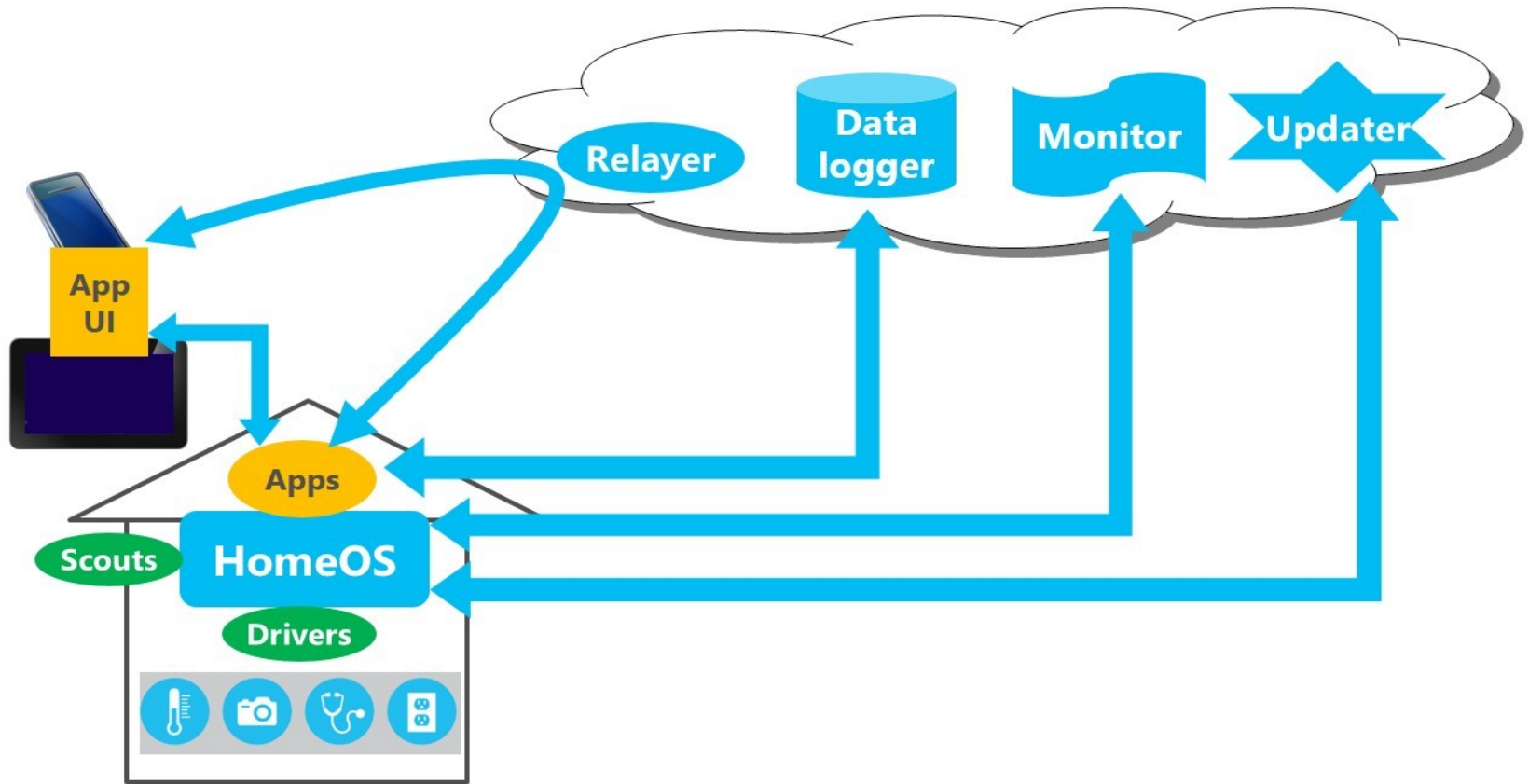


What did the  
fish say when  
he ran into the  
wall?            Dam!

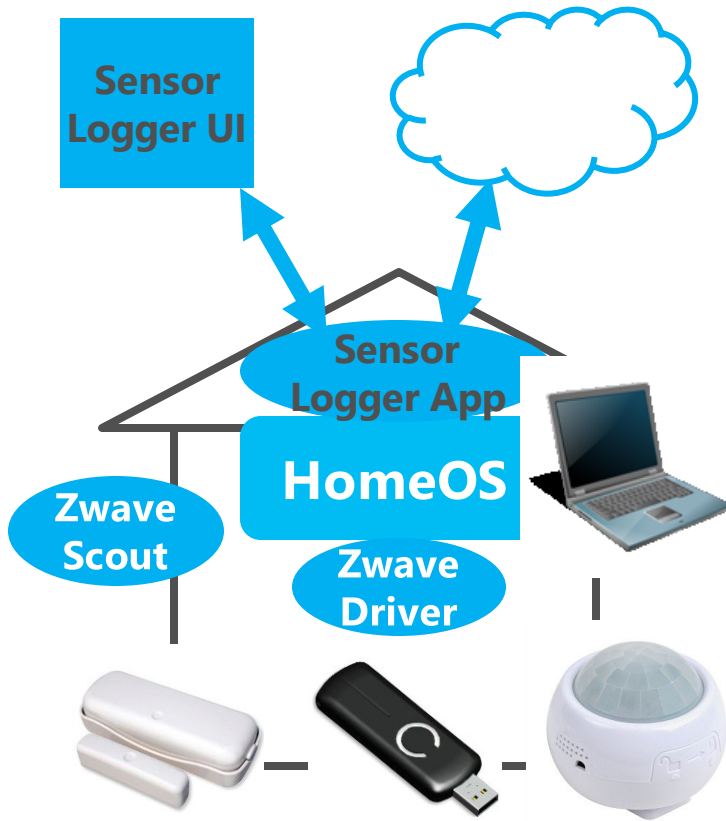
# Lab of Things Design Goals

- 1. Easy setup of an extensible range of devices including custom ones.**
- 2. Monitoring and updating**
- 3. Ongoing data collection**
- 4. Scale and diversity of deployment sites**

# LoT Platform



# How often do you use your main door? (Simple Study #1)



8 homes, 2 weeks+



# Simple Study #1 Setup

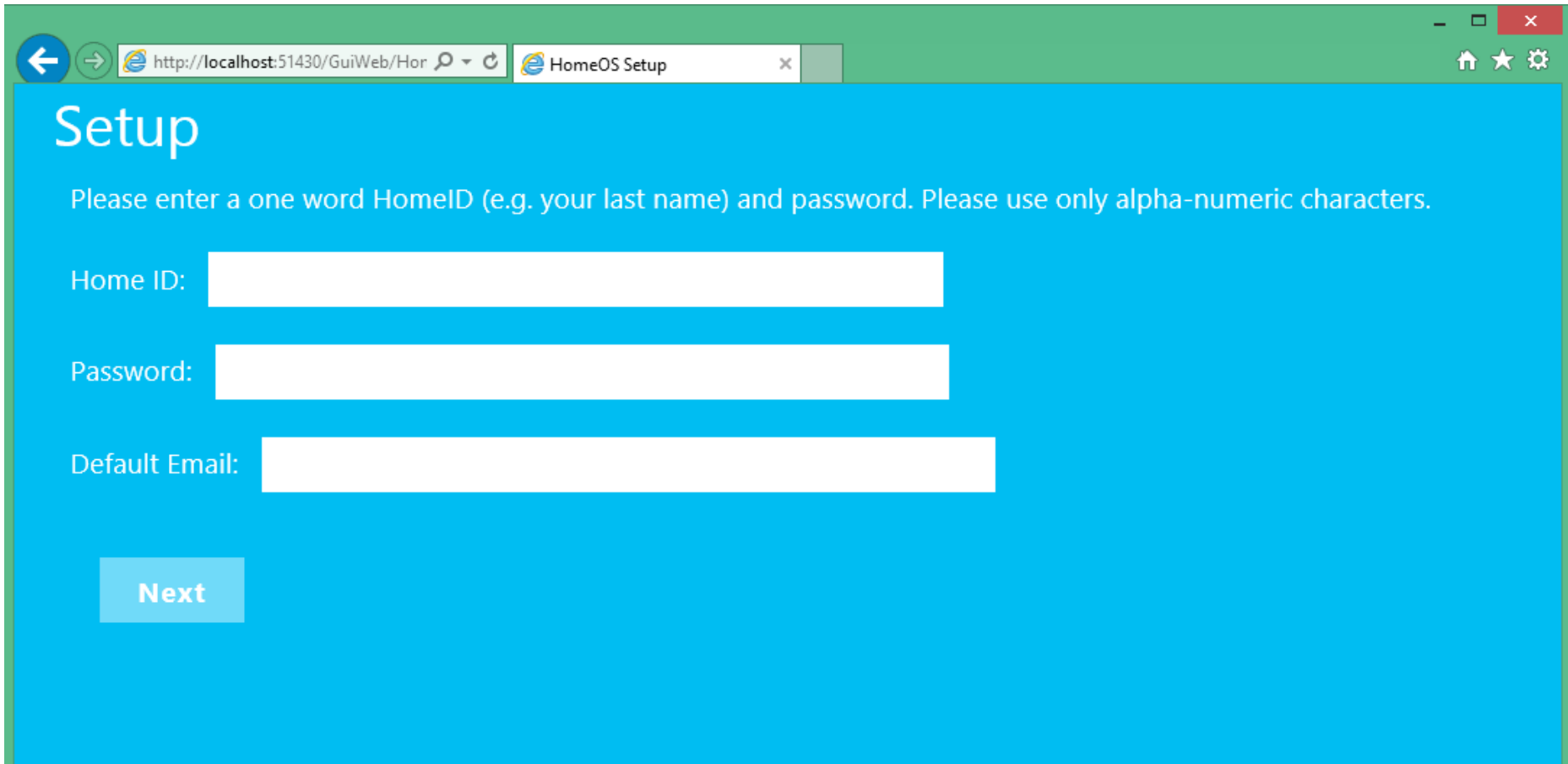
Setup

Welcome!

Please select your wireless network:

Network Security Key:

# Simple Study #1 Setup



http://localhost:51430/GuiWeb/Hor HomeOS Setup

## Setup

Please enter a one word HomeID (e.g. your last name) and password. Please use only alpha-numeric characters.

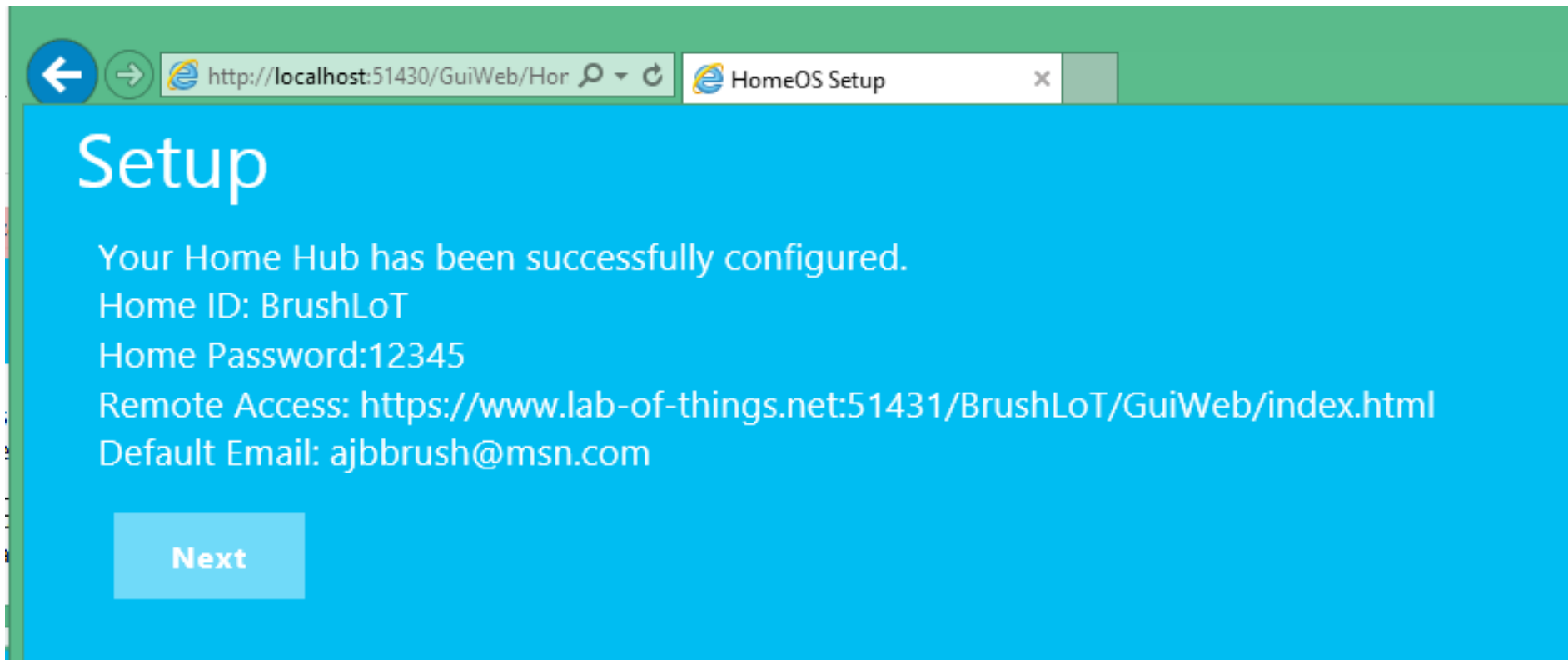
Home ID:





Password:

Default Email:

**Next**

# Simple Study #1 Setup



← →  http://localhost:51430/GuiWeb/Hor    HomeOS Setup ×

## Setup

Your Home Hub has been successfully configured.

Home ID: BrushLoT

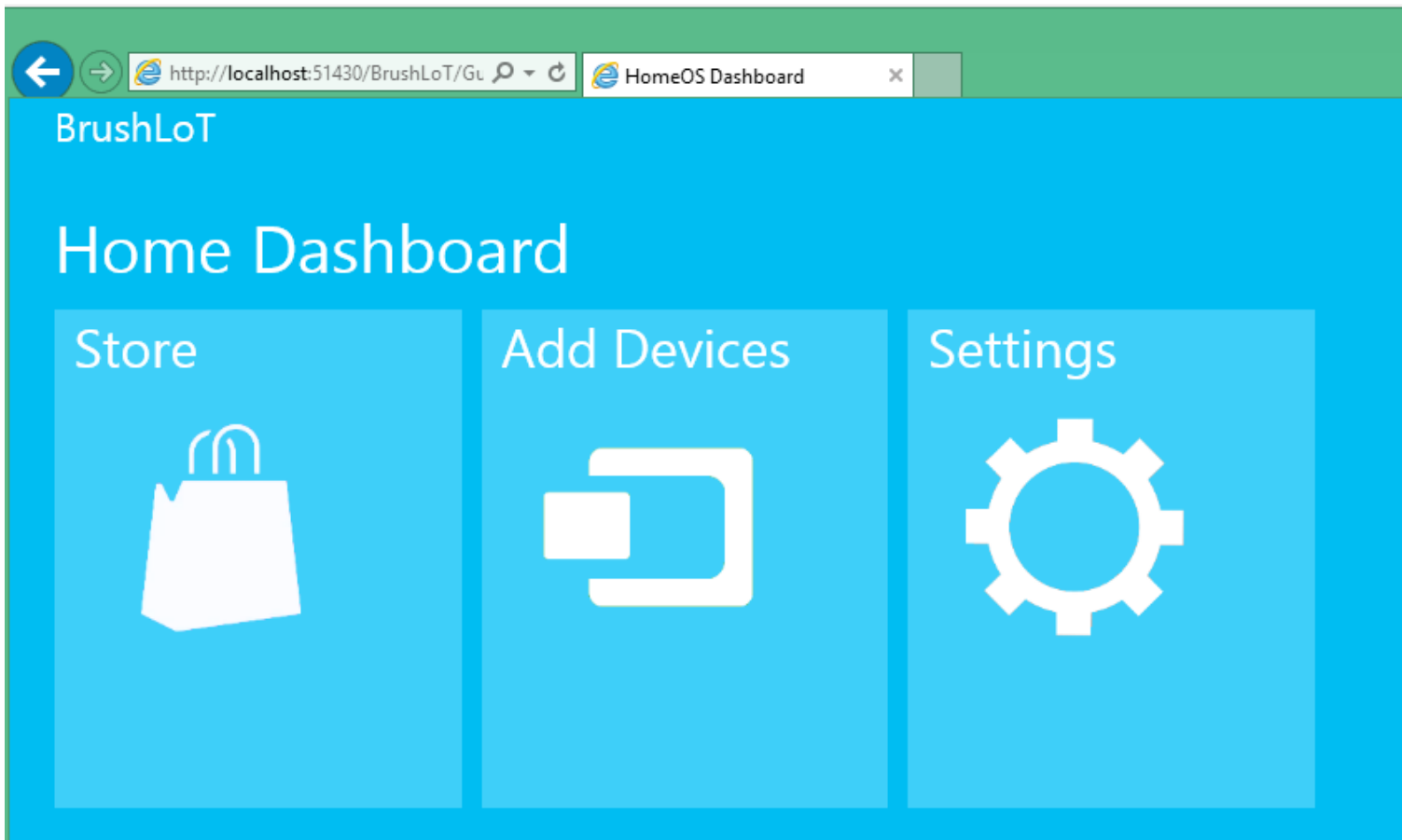
Home Password:12345

Remote Access: <https://www.lab-of-things.net:51431/BrushLoT/GuiWeb/index.html>

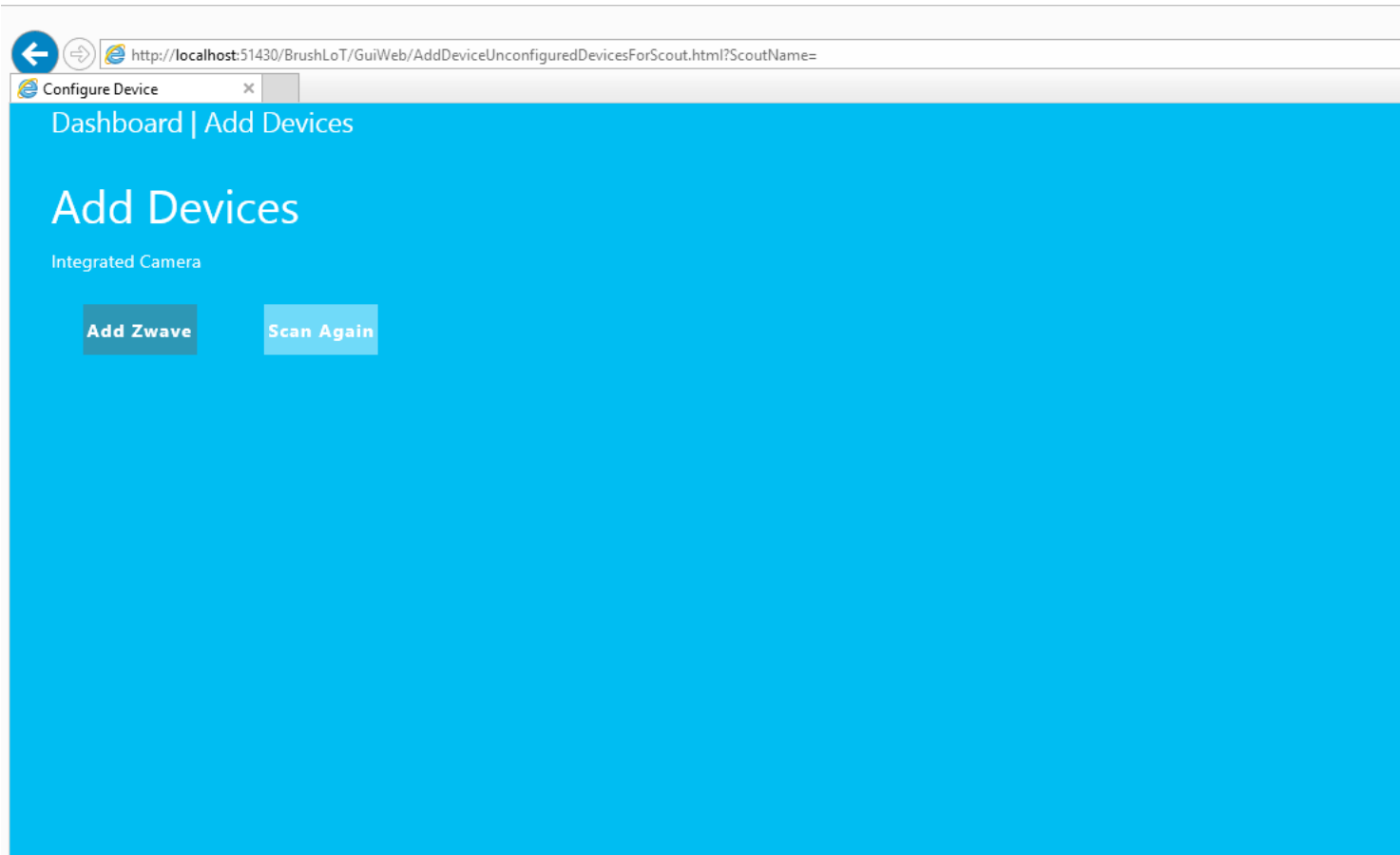
Default Email: [ajbbrush@msn.com](mailto:ajbbrush@msn.com)

**Next**

# Simple Study #1 Add Devices



# Simple Study #1 Add Devices



# Simple Study #1 Add Devices

Dashboard | Add Devices | Add Zwave

## Add Zwave Device

To install a z-wave sensor:

1. Select the Zwave Device Type or leave as unknown.
2. Press the Pair button
3. Within 10 seconds, press the program button on your z-wave sensor

Zwave Device Type:

# Final Device Setup

Name:

Location:  ▼

[Add New Location](#)

## Install these applications:

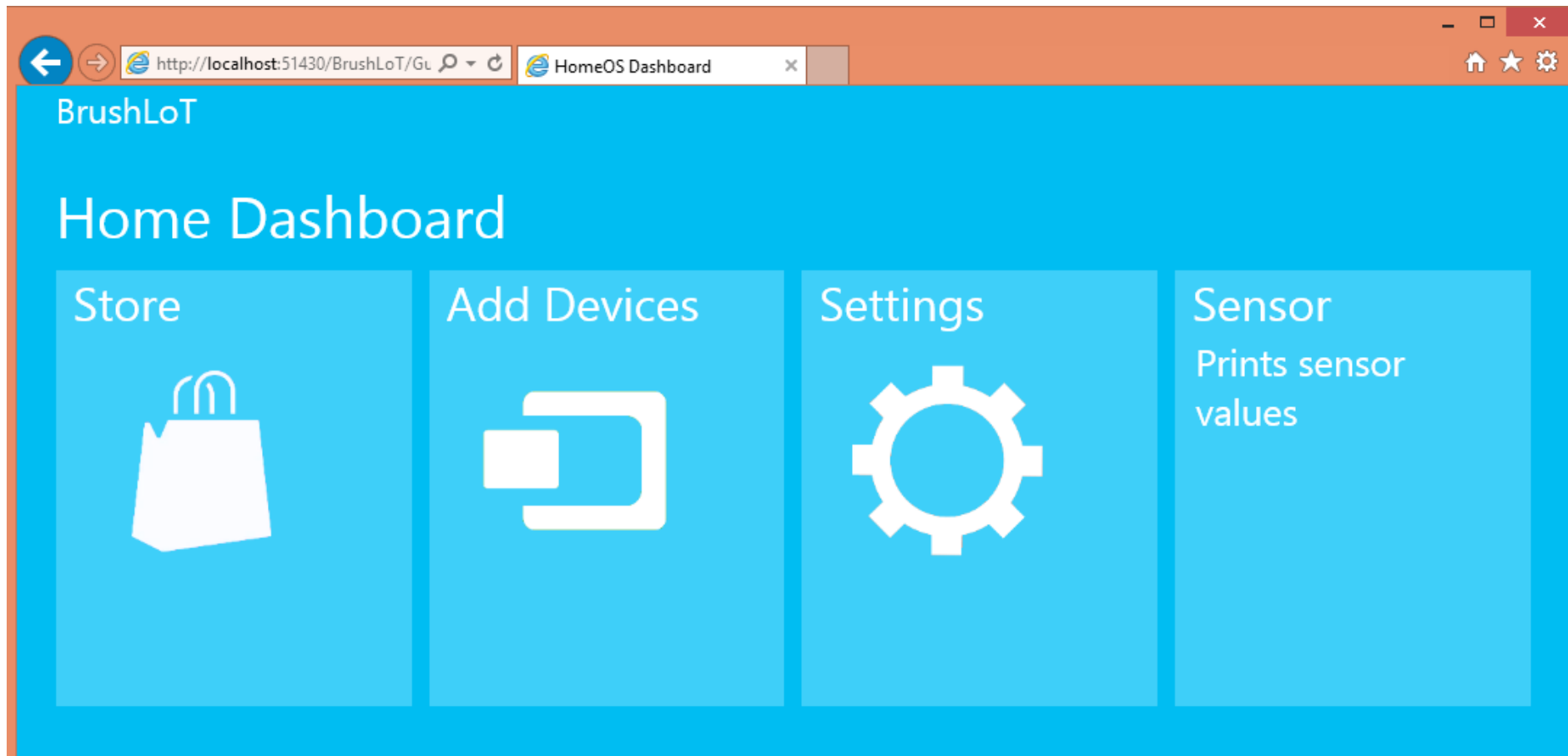
Sensor

## Permit these applications to use this device:

No applications to permit.

[Done](#)

# Simple Study #1 Dashboard





# Sensor Logger Application

Most recent sensor readings (100 max):

```
11/30/2013 10:07:26 AM msh0:sensor;0
11/30/2013 10:07:24 AM msh0:sensor;255
11/30/2013 10:05:40 AM msh0:sensor;0
11/30/2013 10:05:37 AM msh0:sensor;255
11/30/2013 10:05:29 AM dwh0:sensor;255
11/30/2013 10:05:29 AM dwh0:sensor;0
11/30/2013 10:05:25 AM msh0:sensor;0
11/30/2013 10:05:23 AM msh0:sensor;255
11/30/2013 10:05:09 AM msh0:sensor;0
11/30/2013 10:05:07 AM msh0:sensor;255
11/30/2013 10:04:52 AM msh0:sensor;0
11/30/2013 10:04:50 AM msh0:sensor;255
11/30/2013 10:04:37 AM msh0:sensor;0
11/30/2013 10:04:35 AM msh0:sensor;255
11/30/2013 10:03:28 AM dwh0:sensor;255
11/30/2013 10:03:28 AM dwh0:sensor;0
11/30/2013 10:03:04 AM dwh0:sensor;255
11/30/2013 10:03:03 AM dwh0:sensor;0
```


← → <http://localhost:51430/BrushLoT/Se> Sensor Logger

Dashboard | Sensor

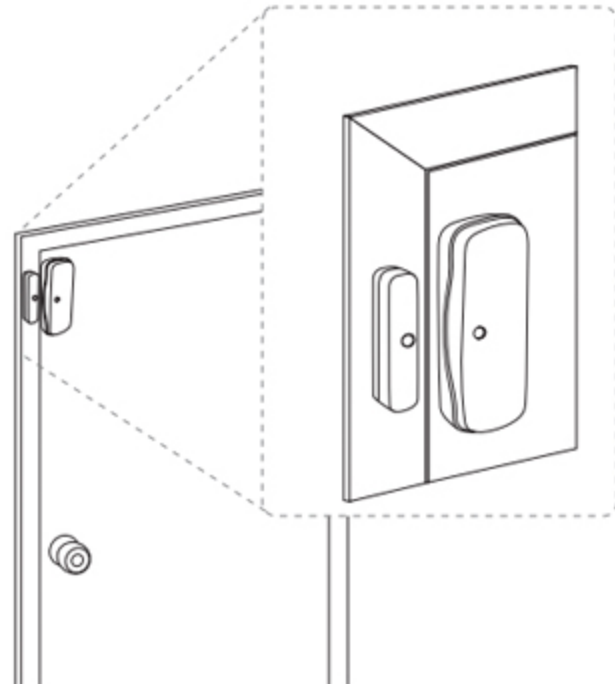
# Sensor Logger Application

Most recent sensor readings (100 max):

```
11/30/2013 10:07:26 AM msh0:sensor;0
11/30/2013 10:07:24 AM msh0:sensor;255
11/30/2013 10:05:40 AM msh0:sensor;0
11/30/2013 10:05:37 AM msh0:sensor;255
11/30/2013 10:05:29 AM dwh0:sensor;255
11/30/2013 10:05:29 AM dwh0:sensor;0
11/30/2013 10:05:25 AM msh0:sensor;0
11/30/2013 10:05:23 AM msh0:sensor;255
11/30/2013 10:05:09 .
11/30/2013 10:05:07 .
11/30/2013 10:04:52 .
11/30/2013 10:04:50 .
11/30/2013 10:04:37 .
11/30/2013 10:04:35 .
11/30/2013 10:03:28 .
11/30/2013 10:03:28 .
11/30/2013 10:03:04 .
11/30/2013 10:03:03 .
```



The diagram shows a door handle assembly with a dashed box highlighting the handle and lock mechanism. A red arrow points from the sensor readings list to the handle assembly, indicating the location of the sensor.





## Getting Started - Introductory Videos



**Topic:** What is the Lab of Things?  
**Speaker:** Arjmand Samuel

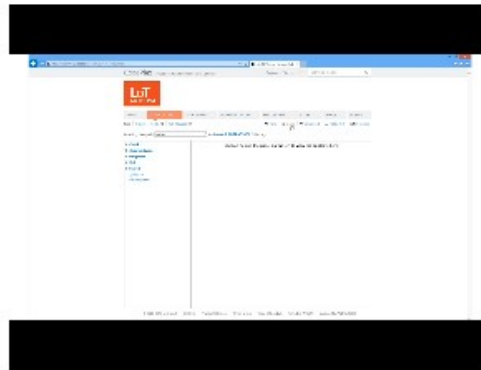


**Topic:** Demo of the Lab of Things  
**Speaker:** AJ Brush

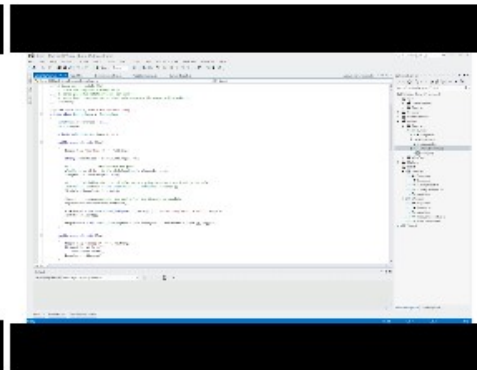


**Topic:** Architectural overview of the Lab of Things  
**Speaker:** Ratul Mahajan

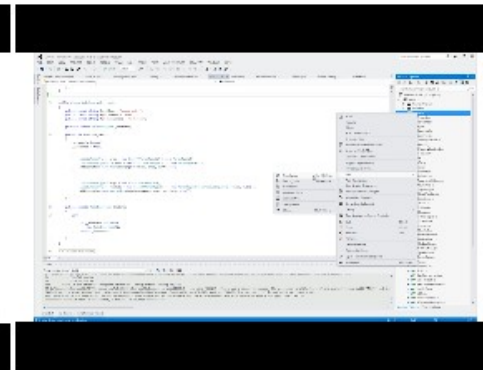
## Working with the Lab of Things code



**Topic:** Getting started with the Lab of Things - code overview  
**Speaker:** Ratul Mahajan



**Topic:** Developing applications for the Lab of Things  
**Speaker:** Ratul Mahajan



**Topic:** Contributing code to the Lab of Things  
**Speaker:** Ratul Mahajan

# DG #2: Monitoring & Updating

The screenshot shows a web browser window with the URL <https://www.lab-of-things.net/>. The page title is "Remote Management Portal" and it features a "Sign in" button. The main content is divided into two sections: "Hub Status" for "Study ID: Default" and "Study ID: SS1".

**Study ID: Default**

Home ID	Last Heartbeat	Details	Remote Access
B111	0 Days 0 Hrs 1 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
BrushLoT	0 Days 20 Hrs 40 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
arjhome11	0 Days 0 Hrs 1 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>

**Study ID: SS1**

Home ID	Last Heartbeat	Details	Remote Access
SS1H1	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
SS1H2	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
SS1H6	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
SS1H7	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
ss1H9	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
ss1h3	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
ss1h4	0 Days 0 Hrs 1 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>
ss1h8	0 Days 0 Hrs 0 Mins	<a href="#">Details</a>	<a href="#">Remote Access</a>

© 2013 - Lab of Things Remote Management Portal

- Hub sends a heartbeat
- Get alerts
- SS1 problems:
  - Hub not on wireless
  - Hub not sending heartbeats

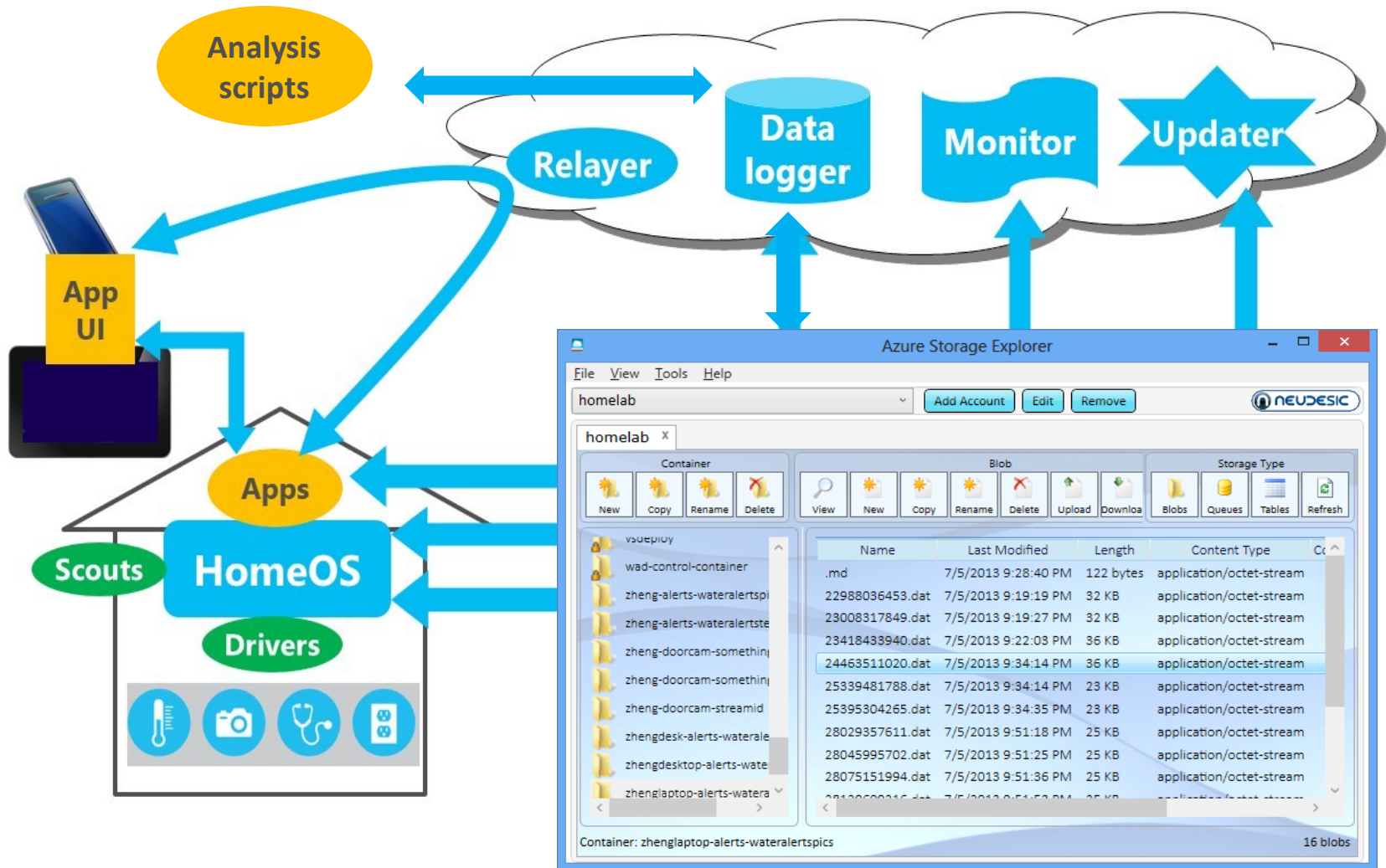
# DG #2: Monitoring & Updating

The screenshot shows the 'Set Up' tab of the LoT Update Manager. It features a sidebar with configuration options: 'Org ID' (msriot), 'Study ID' (Default), and 'Home ID' (All, BrushLoT, HomeLab12). The main area is titled 'What has changed?' and contains two columns of 'Actual' and 'Desired' buttons for each Home ID option. At the bottom, there are 'Refresh', 'Validate', and 'Update' buttons.

The screenshot shows the 'Modules/Scouts' tab of the LoT Update Manager. It displays a table comparing versions of various modules on the FTP server versus the local system. Each row includes an 'Add' button. A 'Present' button is visible for the 'HomeOS.Hub.Apps.Dummy' module.

	On FTP	Local	
<b>APPS</b>			
HomeOS.Hub.Apps.Alerts	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.AlertsTS	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.Doorjamb	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.Dummy	1.0.0.0	1.0.0.0	Present
HomeOS.Hub.Apps.EmotoCouch	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.Rules	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.Sensor	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.SmartCam	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.SpeechInteraction	0.0.0.0	0.0.0.0	Add
HomeOS.Hub.Apps.Switch	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Apps.Thermometer	0.0.0.0	1.0.0.0	Add
<b>DRIVERS</b>			
HomeOS.Hub.Drivers.AxisCamera	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Drivers.BLEProximity	0.0.0.0	1.0.0.0	Add
HomeOS.Hub.Drivers.Doorjamb	0.0.0.0	1.0.0.0	Add

# DG #3: Ongoing Data Collection

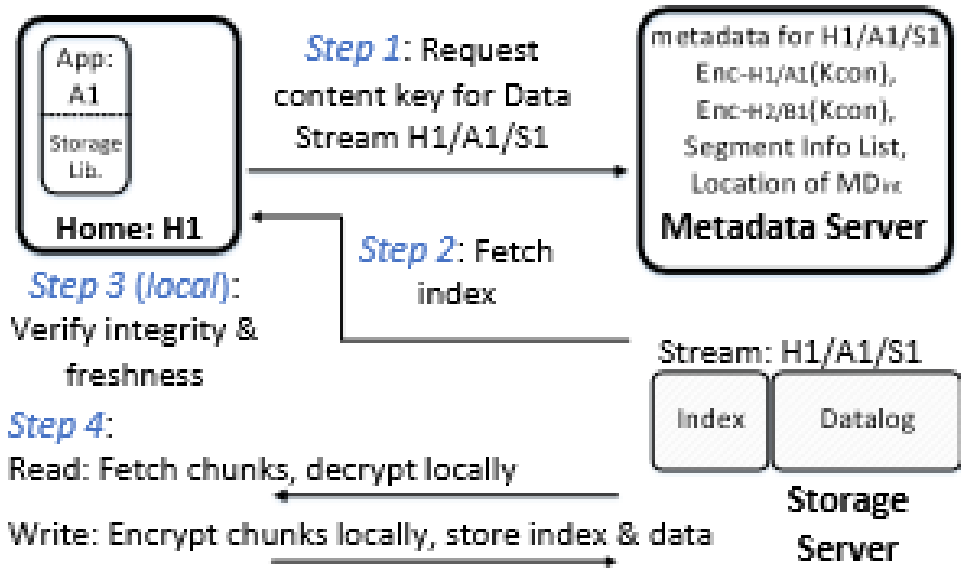


# Data management using Bolt

Simple storage abstraction:  
stream of time-tag-value  
records.

Specify where you want data  
stored. Encrypt data if you don't  
trust the storage providers.

Efficiently **\*share\*** data across  
applications and homes.

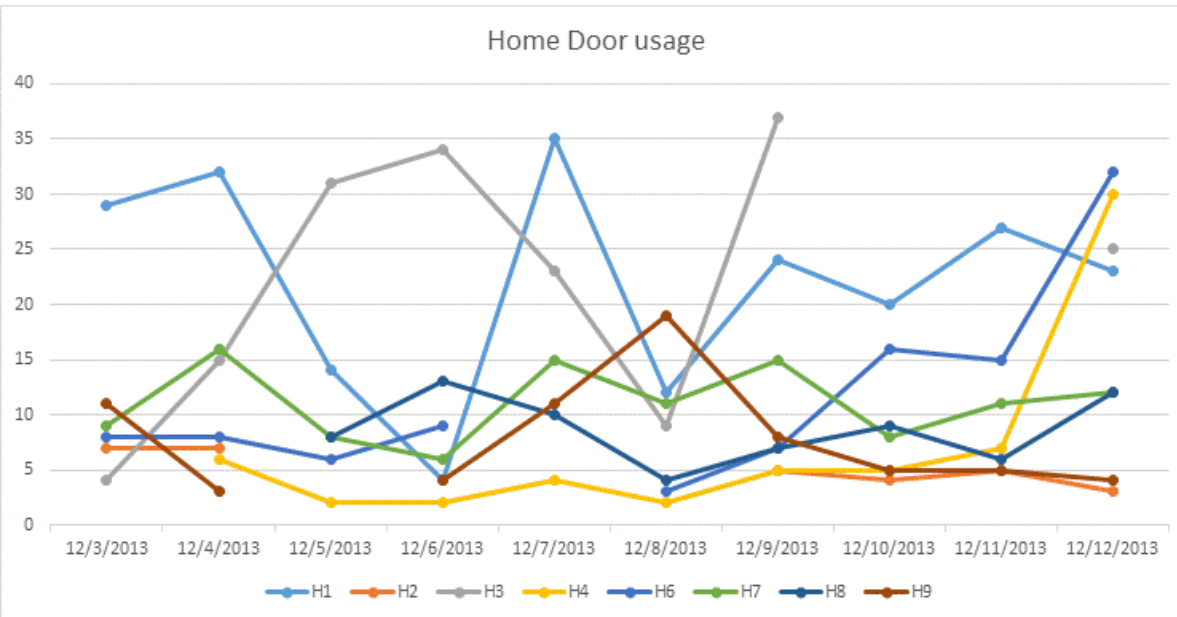


Bolt is up to 40 times faster than OpenTSDB, a popular time-series database system, while requiring 3–5 times less storage space.

Gupta, Singh, Phanishayee, Jung, and Mahajan, Bolt: Data management for connected homes, To appear in NSDI 2014

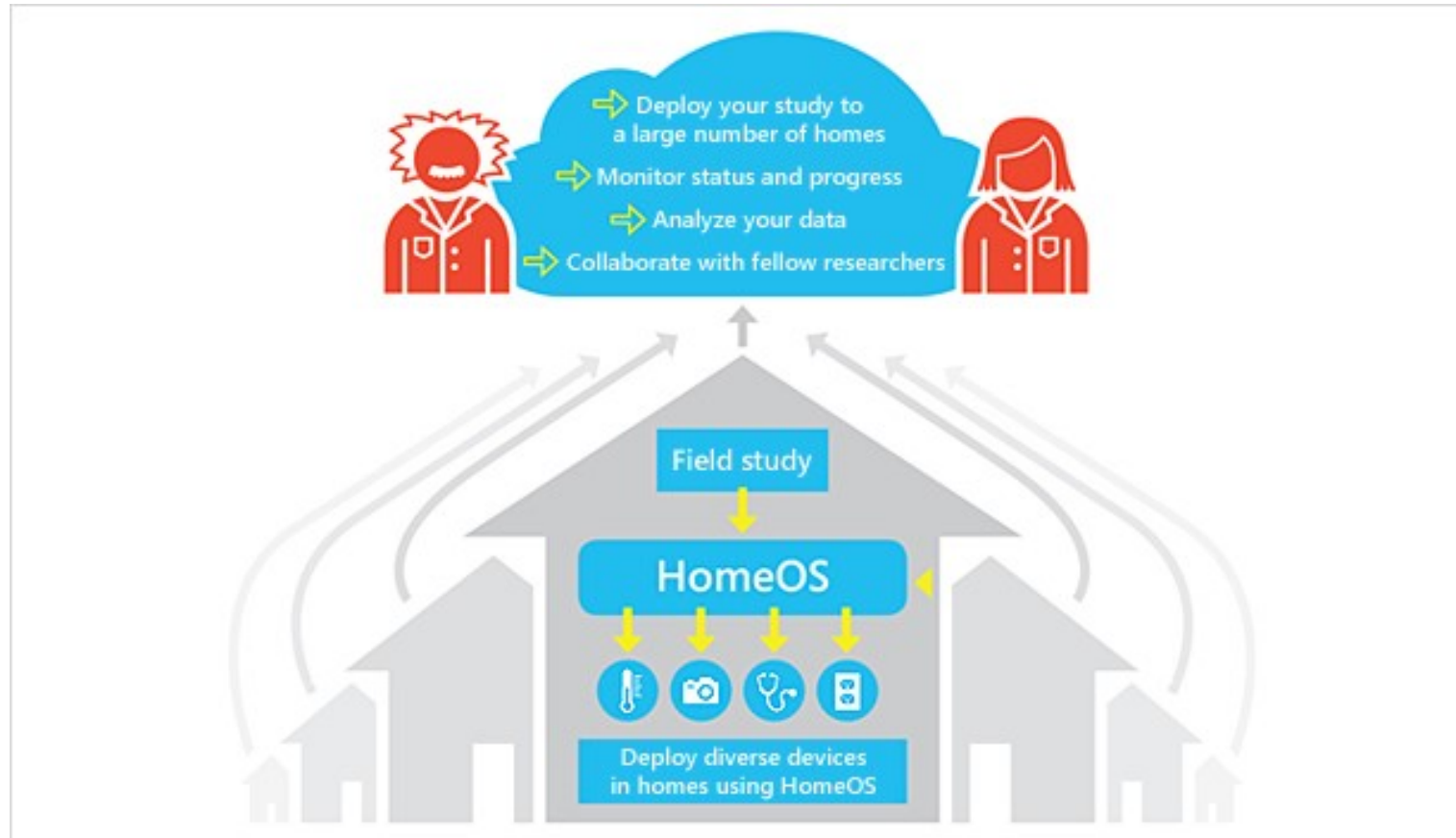


# How often do you use your main door?



	People	Median per day
H4	1	5
H9	1	5
H2	2	5
H7	2	11
H8	2	8.5
H1	4	23.5
H3	4	24
H6	4	8

# DG #4: Scale & Diversity



Focus on the aspect that is interesting to you.

# Lab of Things Usage

More than 6,000 code downloads  
156 OrgIds registered (37 academic)

Teaching:  
Used by 80+ student developers  
Several classes taught

Research:  
Ongoing academic research  
deployments



**Project title:** Lab of Things Analytics Engine  
**PI:** [Dean Mohamedally](#), University College London  
**URL:** [Lab of Things Analytics Engine CodePlex site](#)  
**Blog:** [Students develop analytics engine for the Lab of Things](#)

**Project title:** SOLACE (Supporting Older Low-ses Adults and their Caregivers Electronically) deployment using Lab of Things  
**PI:** [Kay Connelly](#), Indiana University  
**URL:** <http://phitlab.org/>

**Project title:** Evaluating Smart Home Sensor Technology and the use of HomeOS for Monitoring Mobility Among Community-Dwelling Older Adults  
**PI:** [George Demiris](#), University of Washington

**Project title:** Scalable Radiator Valve Control for HomeOS  
**PI:** [Mike Hazas](#), Lancaster University  
**URL:** [Project Webpage](#)

**Project title:** Intelligent and Scalable Monitoring/Control Platform for Home Energy Management  
**PI:** [Lanshun Nie](#), Harbin Institute of Technology

**Project title:** SoftUPS: Virtualizing the home UPS solution to enable efficient peak load sharing in developing world  
**PI:** [Affan Syed](#), FAST-NUCES, Pakistan  
**URL:** <http://www.sysnet.org.pk/w/SoftUPS>

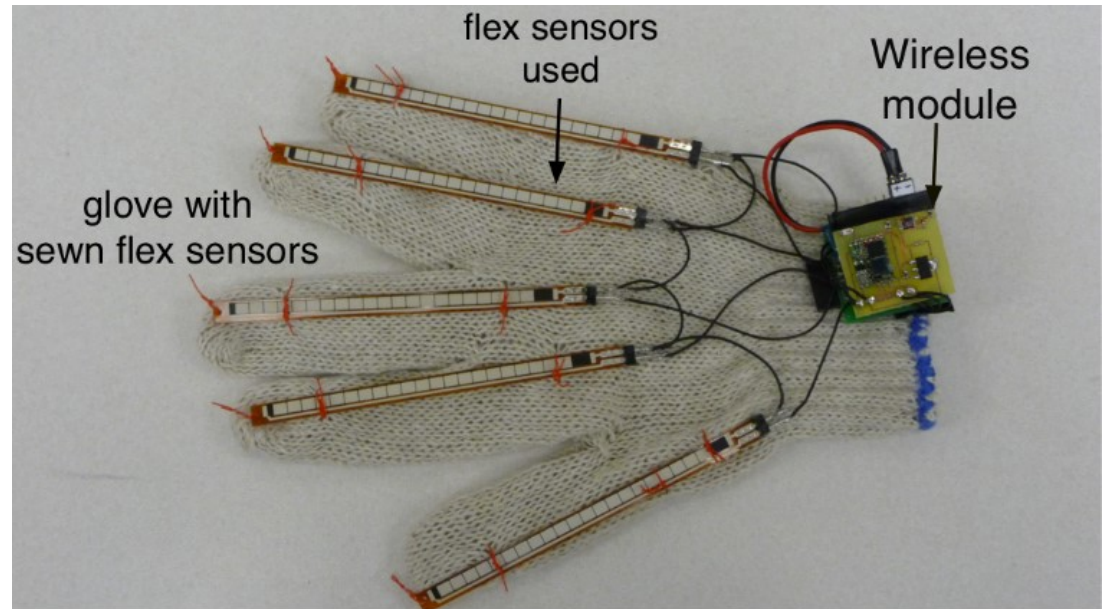
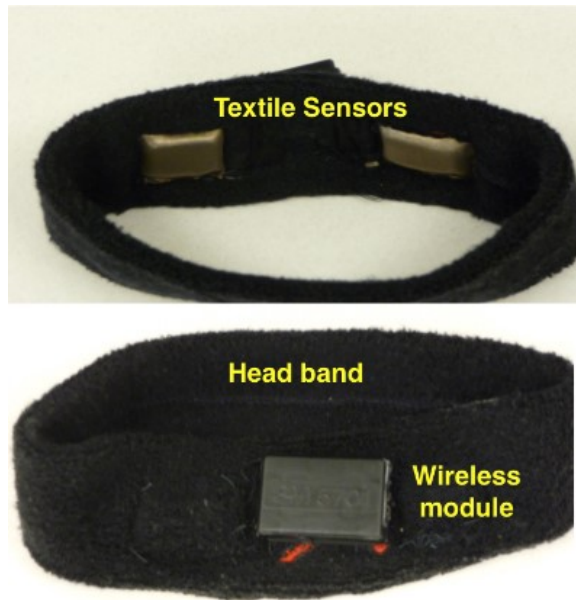
**Project title:** Supporting User Control of Intelligent Home Systems  
**PI:** [Mark Newman](#), University of Michigan  
**URL:** <http://mwnewman.people.si.umich.edu/projects.html>

**Project title:** Wearable Multi-Sensor Gesture Recognition in Assistive Devices for Paralysis Patients  
**PI:** [Nilanjan Banerjee](#), University of Maryland  
**URL:** [Mobile, Pervasive and Sensor Systems Laboratory](#)  
**Course:** CMSC 691: Systems for Smart Home Automation

**Project title:** Intelligent Agents for Home Energy Management  
**PI:** [Alex Rogers](#), Southampton University  
**URL:** [Project Webpage](#)

<http://www.lab-of-things.com/community.html>

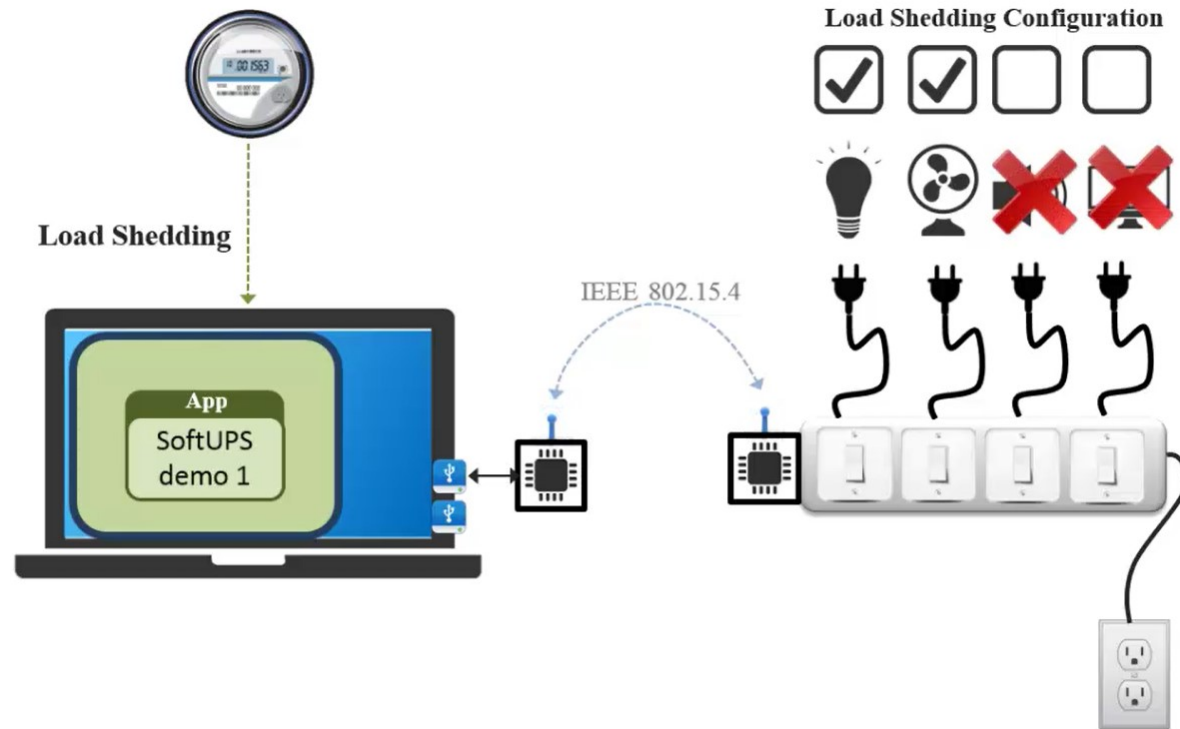
# Case Study 1: Allowing paralysis patients to control their environment



Nelson, A., Shyamkumar, P., Wilkins, W., Lachut, D., Banerjee, N., Rollins, S., Parkerson, J., Varadan, V., (2013) "Wearable Multi-Sensor Gesture Recognition for Paralysis Patients," Presented at IEEE Sensors '13, 4-6 November 2013.

Nelson, A. , Schmandt, J., Wilkins, W., Parkerson J., and Banerjee, N., (2013b) "System Support for Micro-Harvester powered Mobile Sensing," Presented at RTSS '13, 3-6 December, 2013

# Case Study 2: Peak Load Sharing

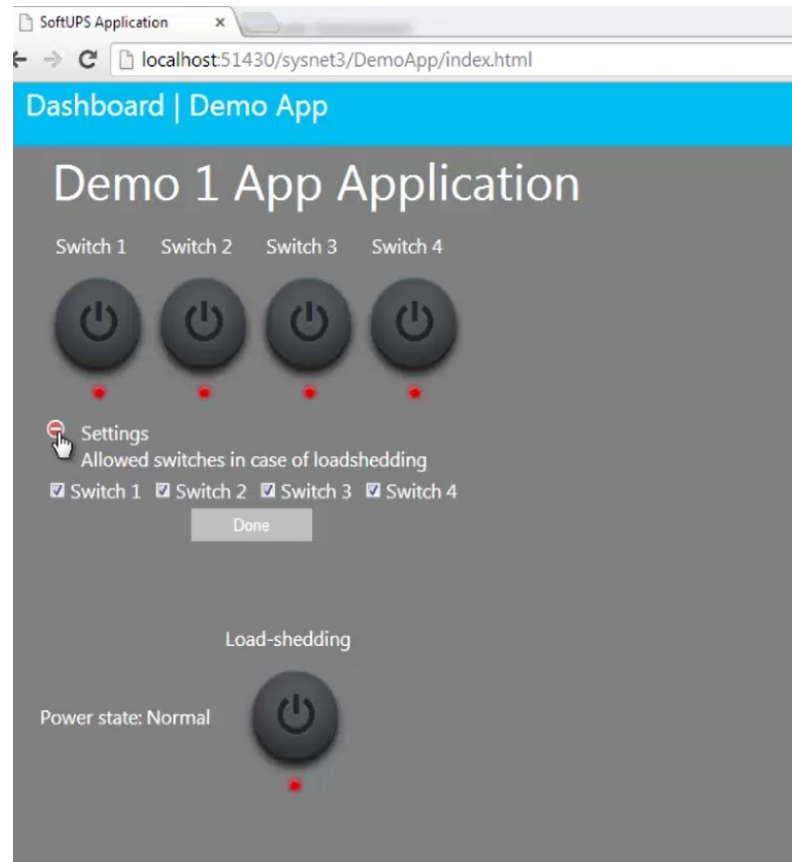
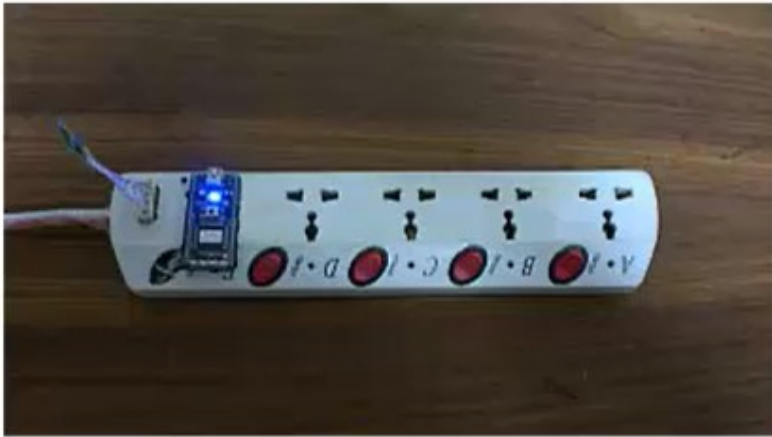


SoftUPS: Virtualizing the home UPS solution to enable efficient peak load sharing in developing world

Affan A. Syed Associate Professor and Director, SysNet Research Lab, National University of Computer and Emerging Sciences (NUCES)



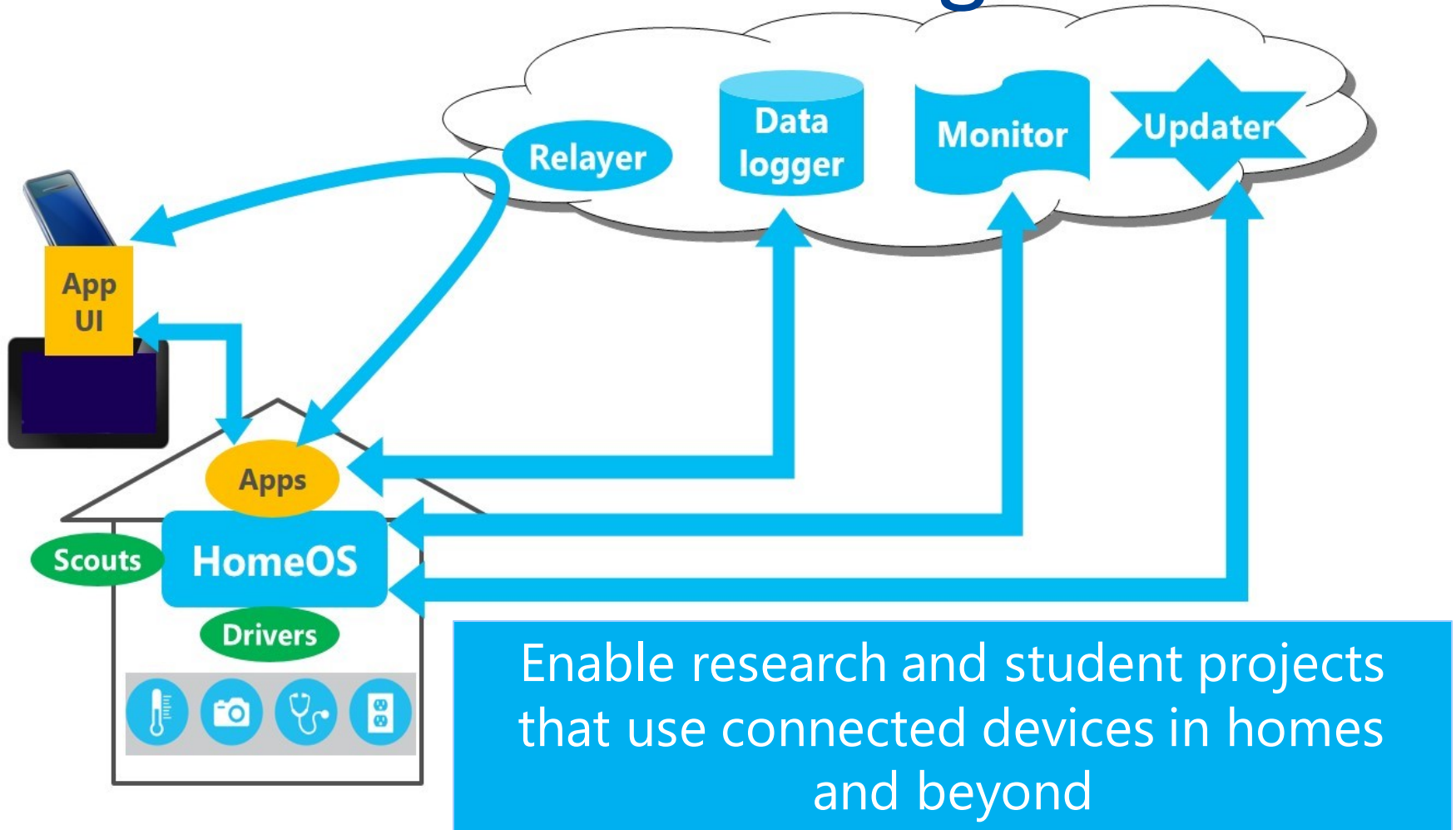
# Case Study 2: Peak Load Sharing



# Interactive Furniture

Video not yet publicly available

# Lab of Things





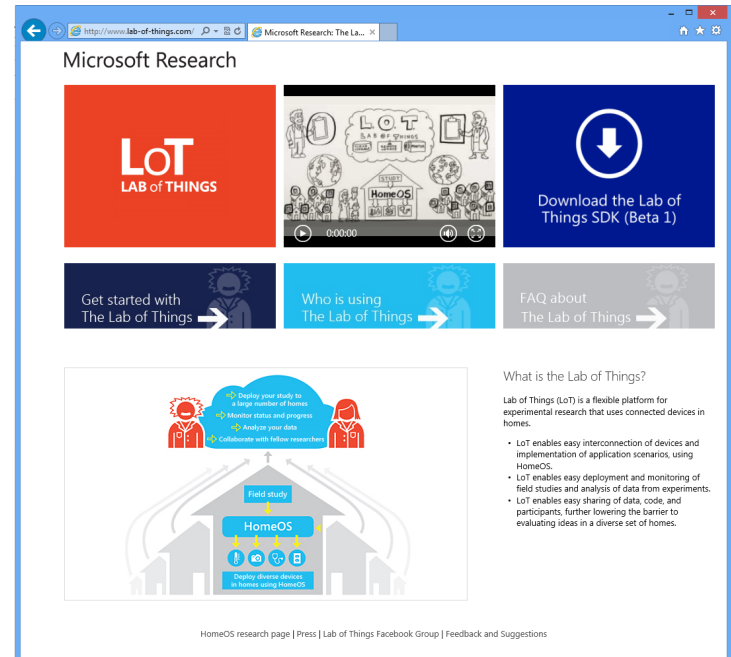
# Thanks

## More information:

<http://research.microsoft.com/~ajbrush>

<http://www.lab-of-things.com>

Join the LoT community!



# UBICOMP 2014

