

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.



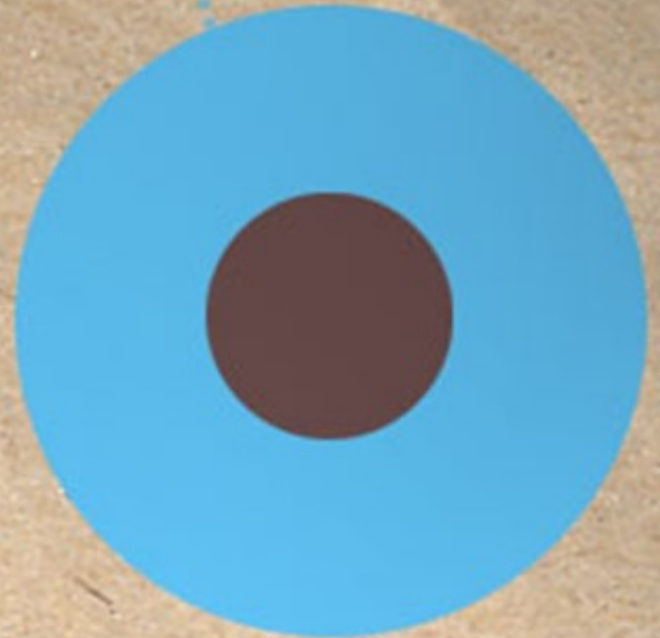
2003



2010



2015



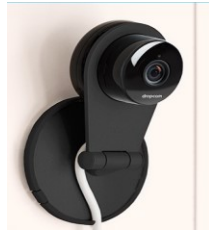
By 2020 there will be **50 billion**.

Internet of Things

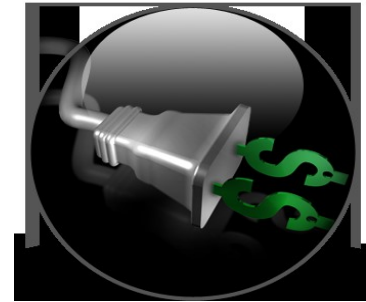
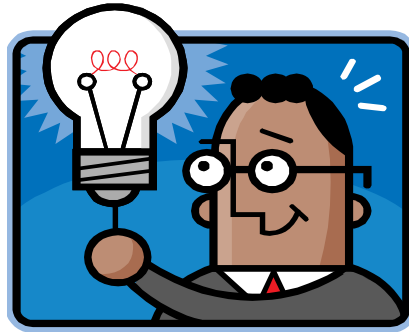
Networks of low-cost sensors and actuators for data collection, monitoring, decision making and process optimization. McKinsey Global Institute



Things for Home



Enable a range of applications



Long anticipated...



Microsoft Home of Future 1994



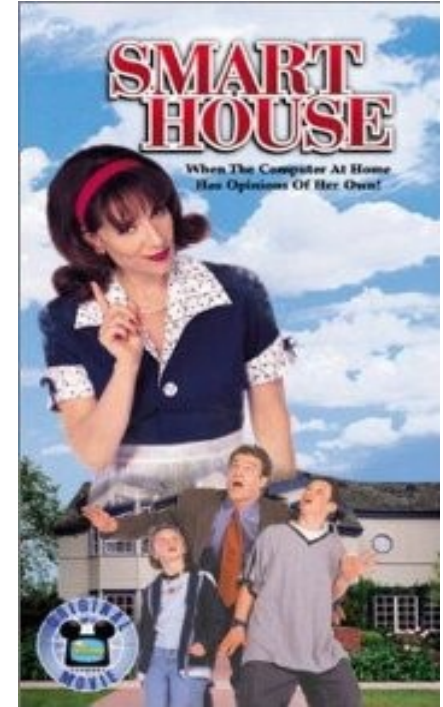
Georgia Tech Aware Home, 2000



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**

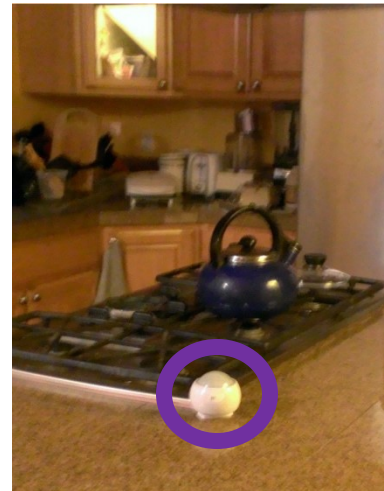


Families

Why homes & families?



Built-in prototyping lab



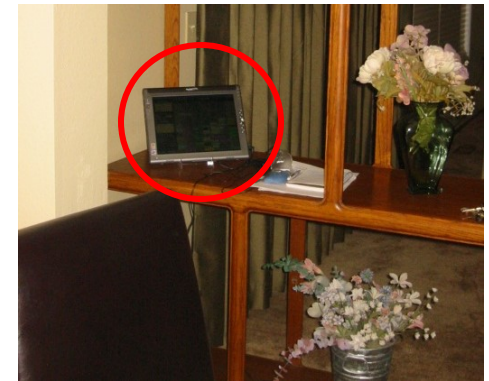
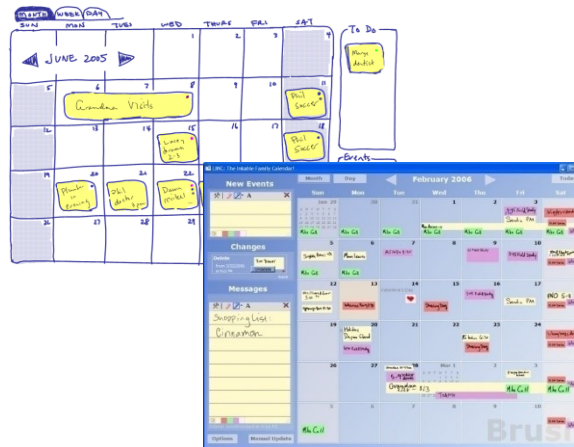
User-Centered Design

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)

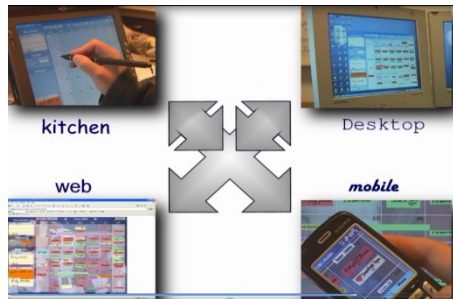
Understand
Current Behavior and
User Needs

Build Prototype

Does it work?
Use of Technology



Deployments, Deployments, Deployments



LINC



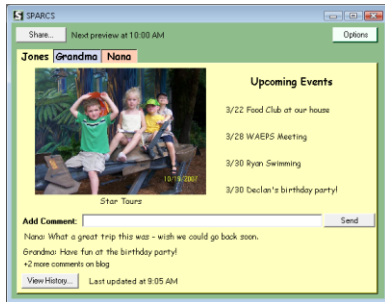
4 homes, 4 weeks



Speech@Home



6 homes, 2 weeks



SPARCS



14 homes, 5 weeks

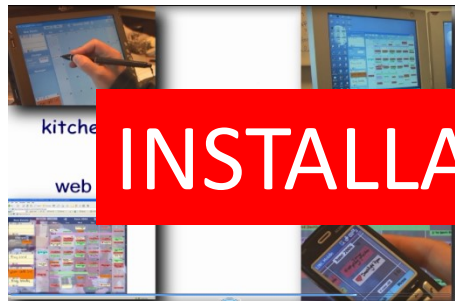


PreHeat



5 homes, 8 weeks+

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



INSTALLATION

LINC

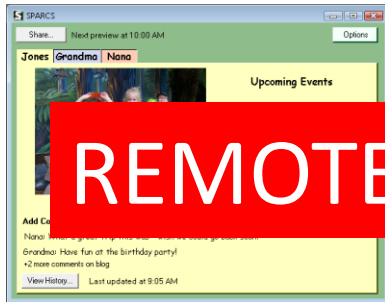
4 homes, 4 weeks



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

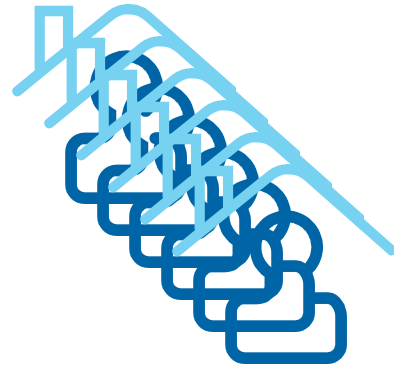
Hazards

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

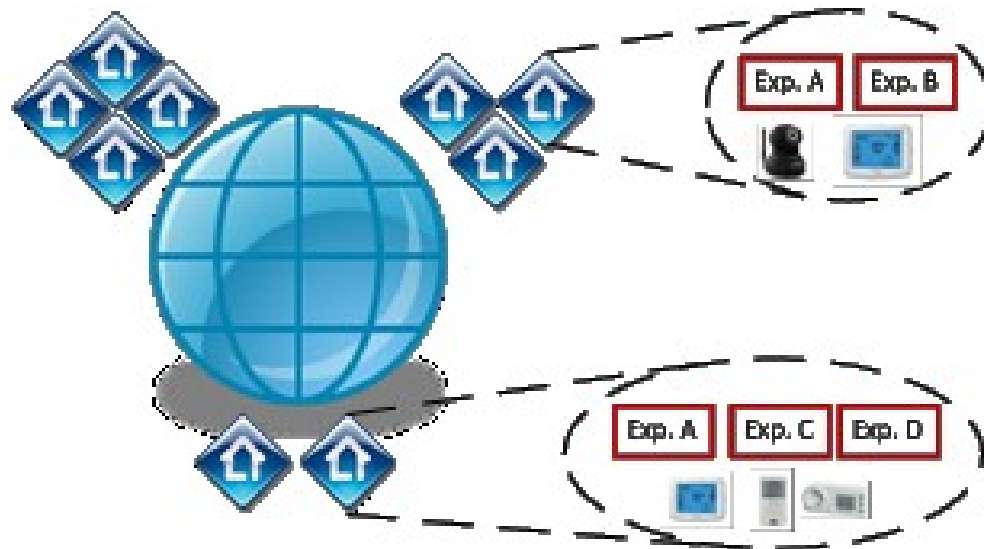


Large engineering effort that is not easily re-used



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

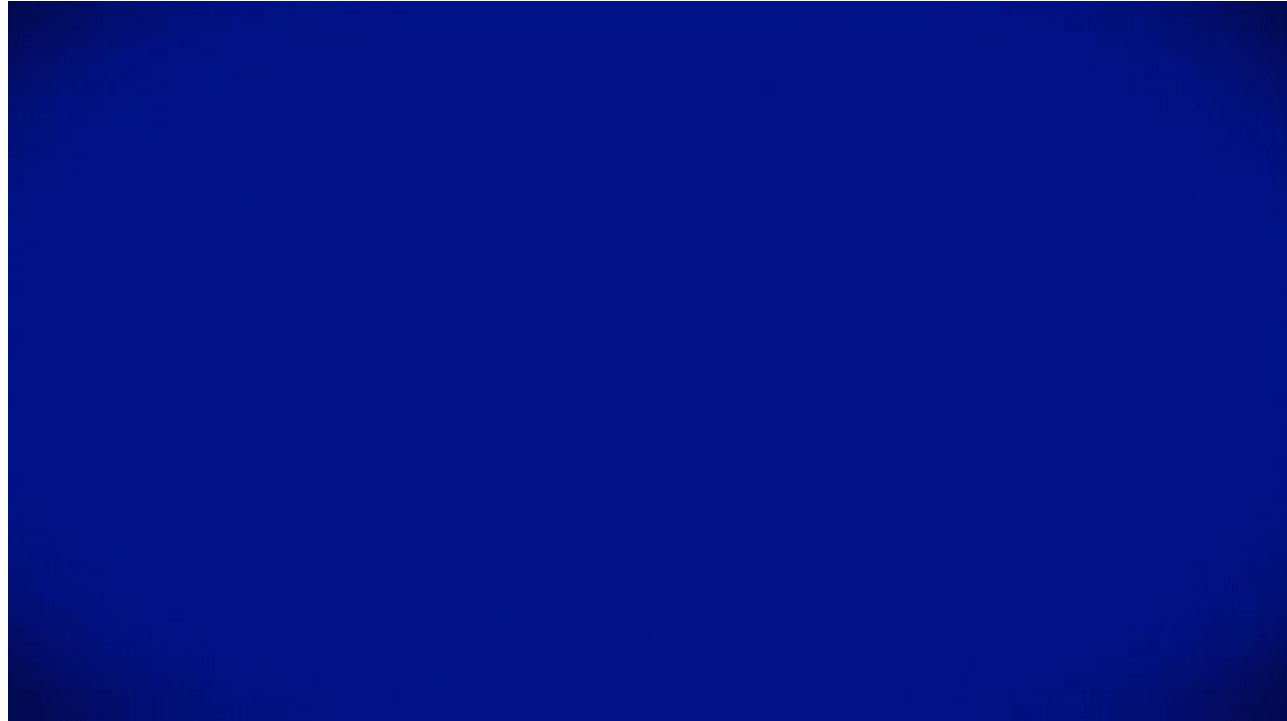


PlanetLab is a global research network that supports the development of new network services. Since the beginning of 2003, more than 1,000 researchers at top academic institutions and industrial research labs have used PlanetLab to develop new technologies for distributed storage, network mapping, peer-to-peer 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 "HomeOS" layer. Above the house, there are icons for "Field study" and "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. At the top, it says "CodePlex Project Hosting for Open Source Software". Below that is the "LOT LAB OF THINGS" logo. The page has 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 main content area is titled "Project Description" and contains the following text:

Lab of Things (LoT) is a flexible platform for research that uses connected devices in homes.

- 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

Below the description is a section titled "Activity" which shows the following information:

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

Below the activity section is a table showing "PAGE VIEWS", "VISITS", and "DOWNLOADS" for the last 7 days. The table shows 590 page views, 222 visits, and 203 downloads.

At the bottom of the page, there is a section titled "Guideline for Contributing to the LoT Repository" which states: "To maintain overall stability and consistency of the platform, the team at Microsoft Research will be working in the core areas of the platform for enhancements, new features, and bug fixes regularly. We welcome you to share driver and app modules with the community. Please check your code only in the following directories:"

Taste of student projects



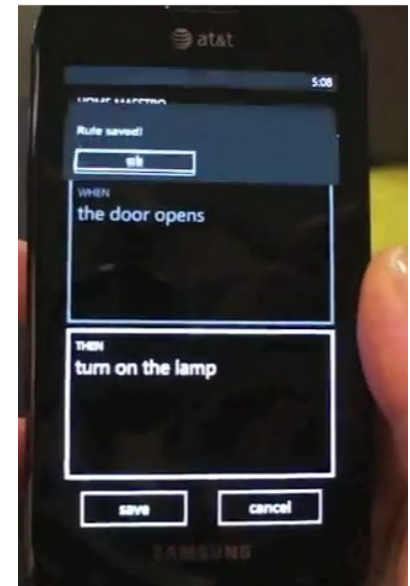
Home Energy Models

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?

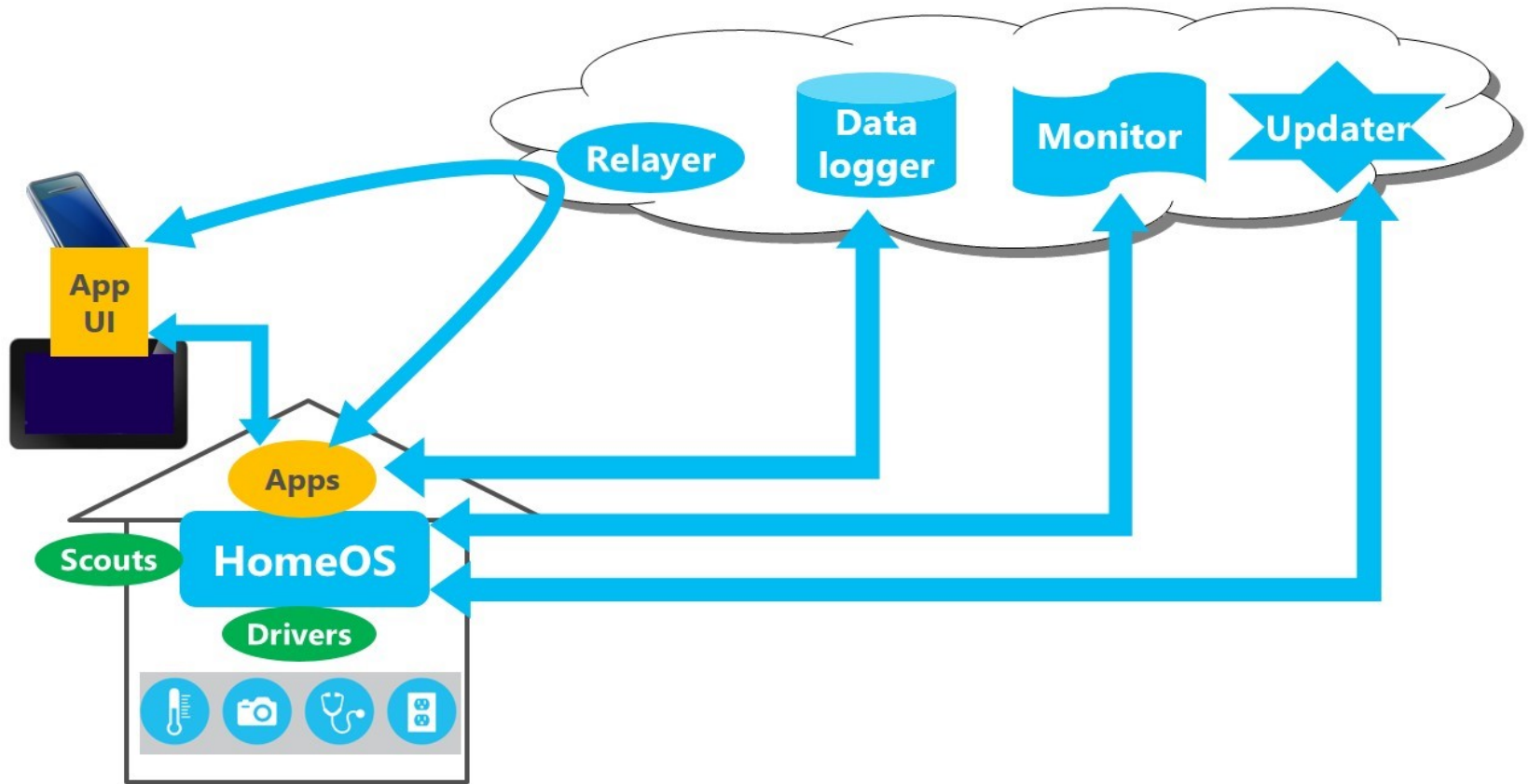


What did the
fish say when
he ran into the
wall? Dam!

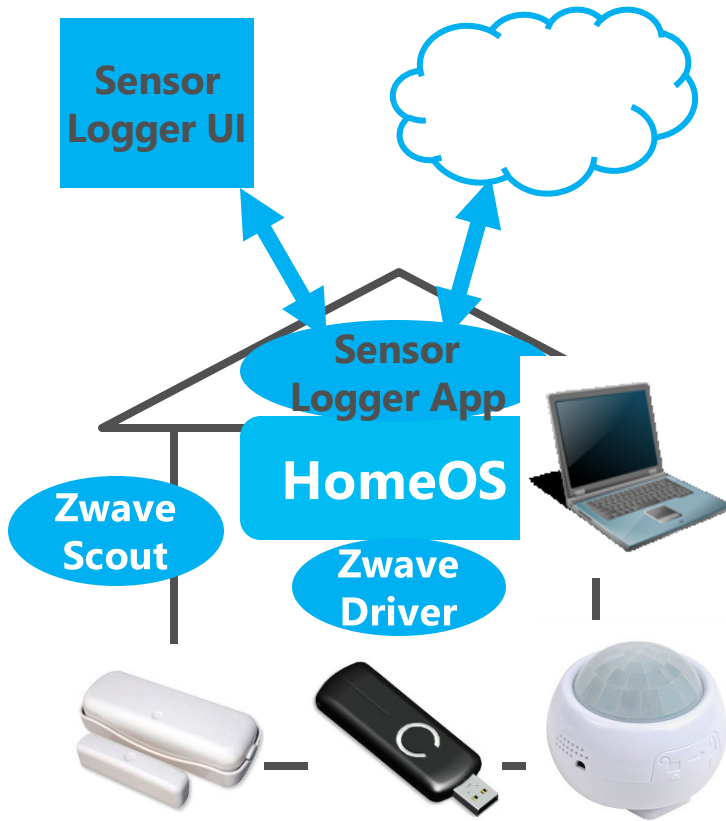
Lab of Things Design Goals

- 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

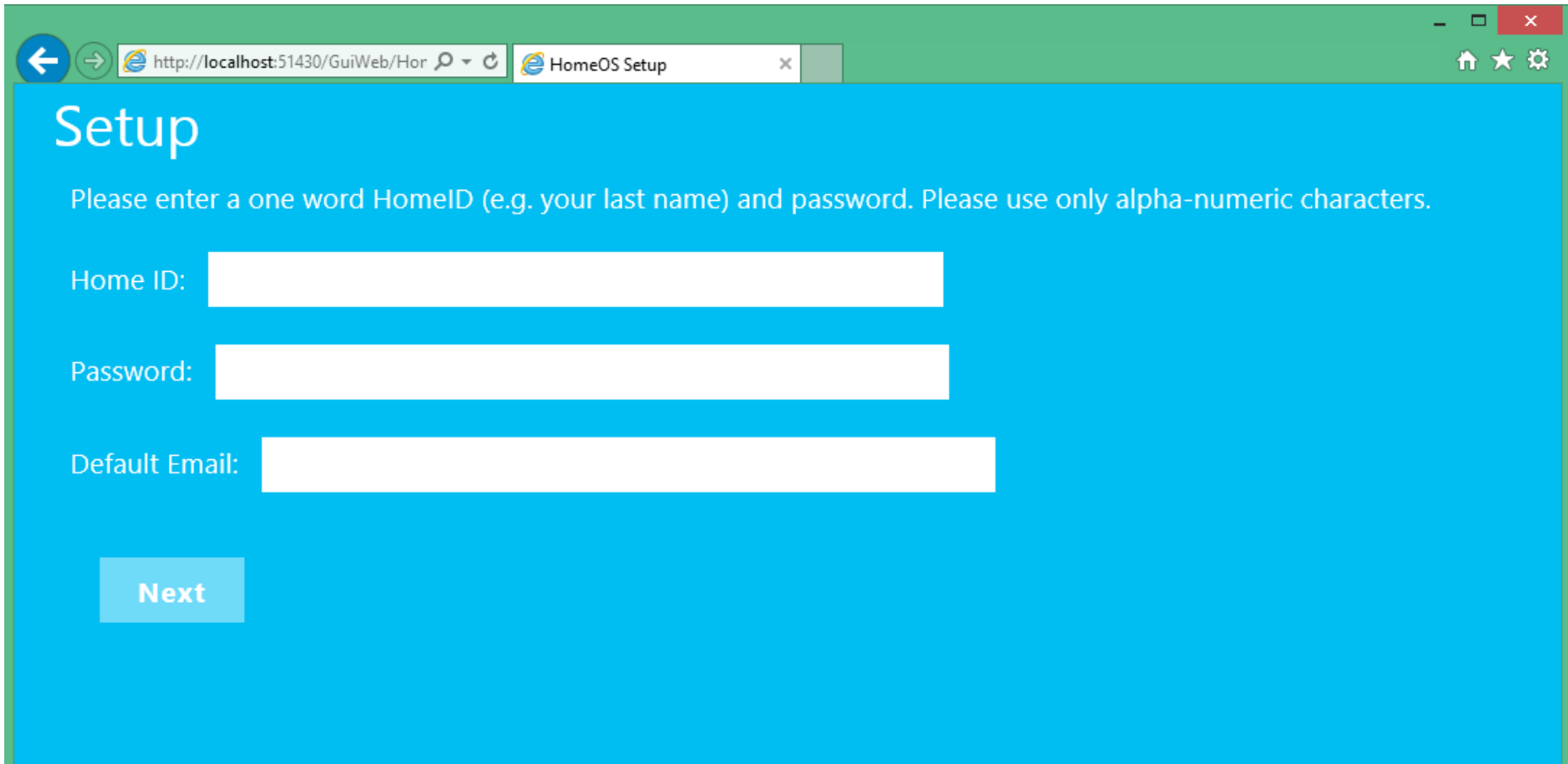
Setup

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.

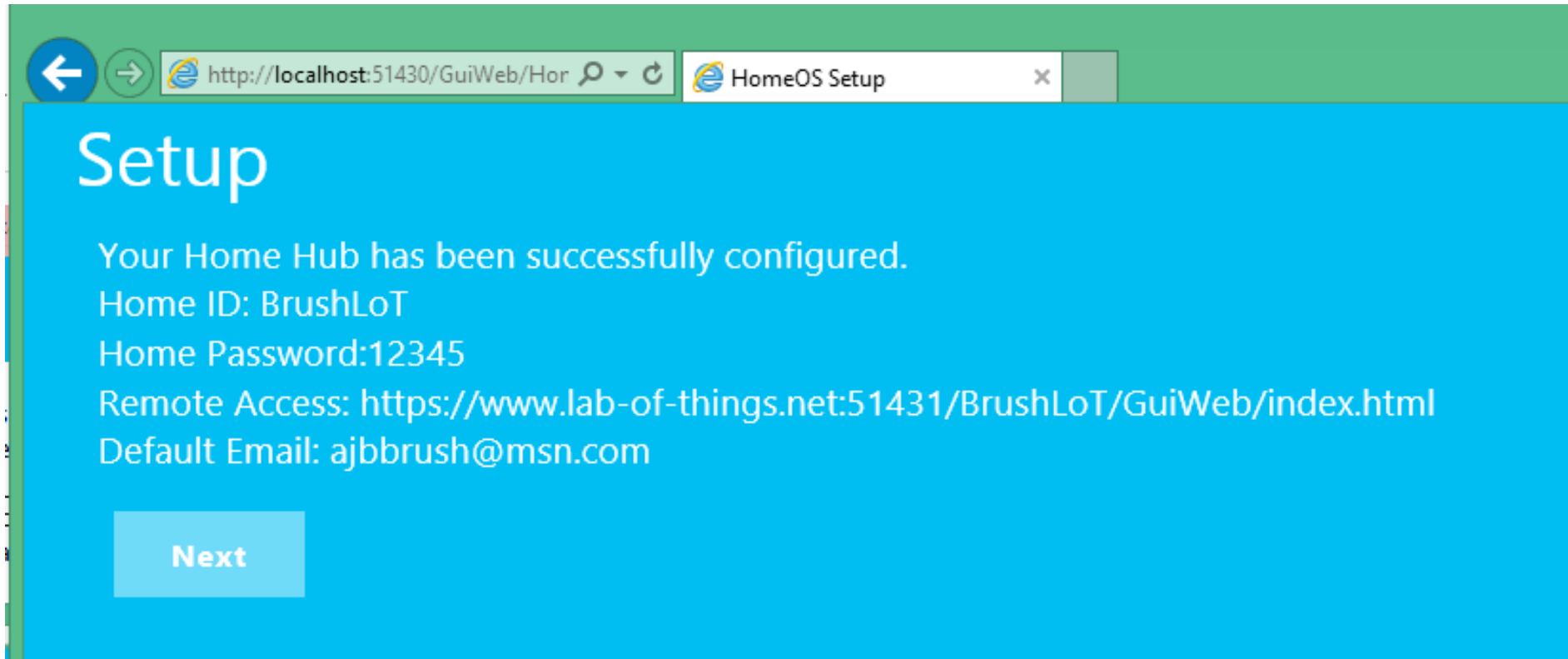
Home ID:

Password:

Default Email:

[Next](#)

Simple Study #1 Setup



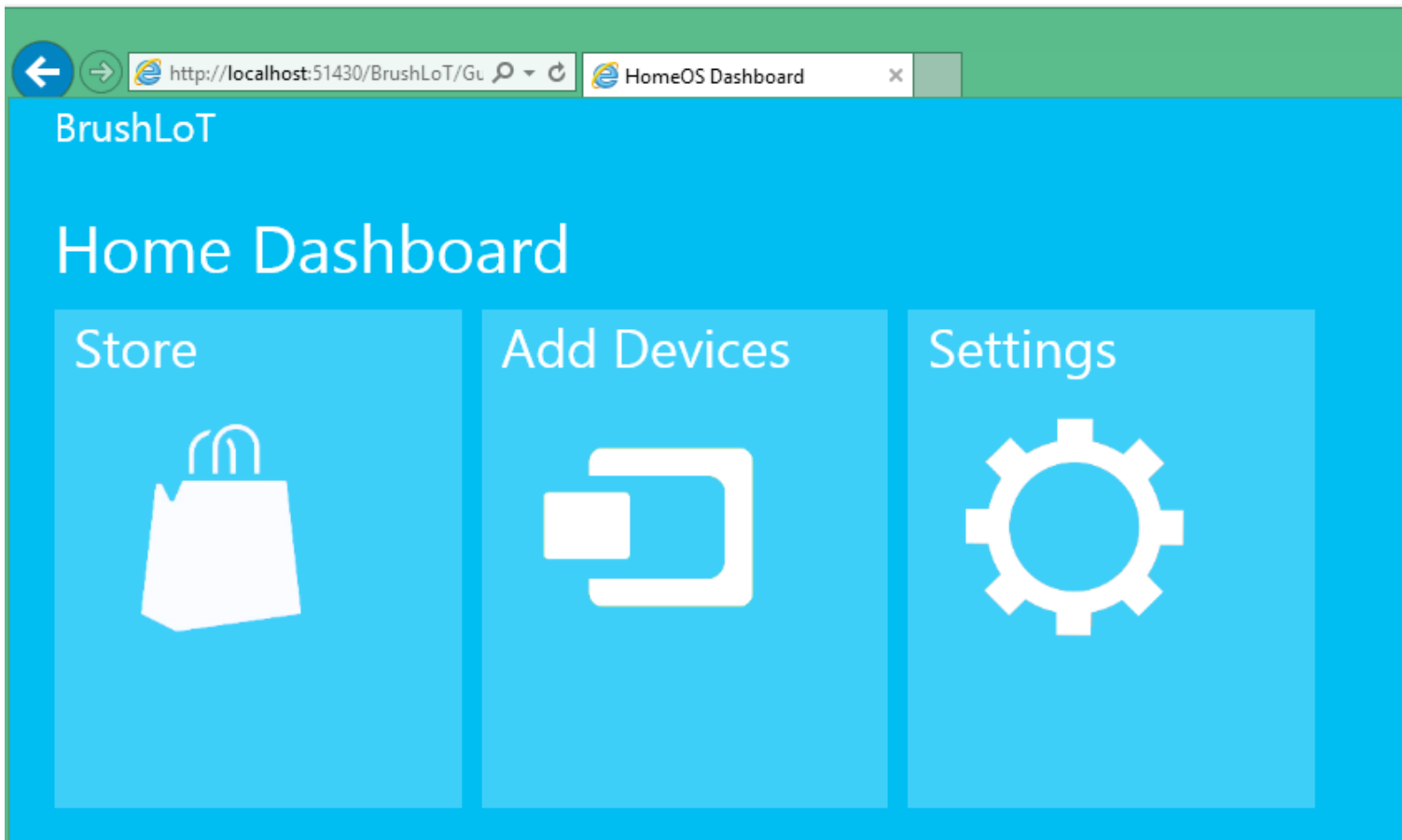
The image shows a web browser window with a green header bar. The address bar contains the URL `http://localhost:51430/GuiWeb/Hor` and the page title is "HomeOS Setup". The main content area has a blue background and displays the following information:

Setup

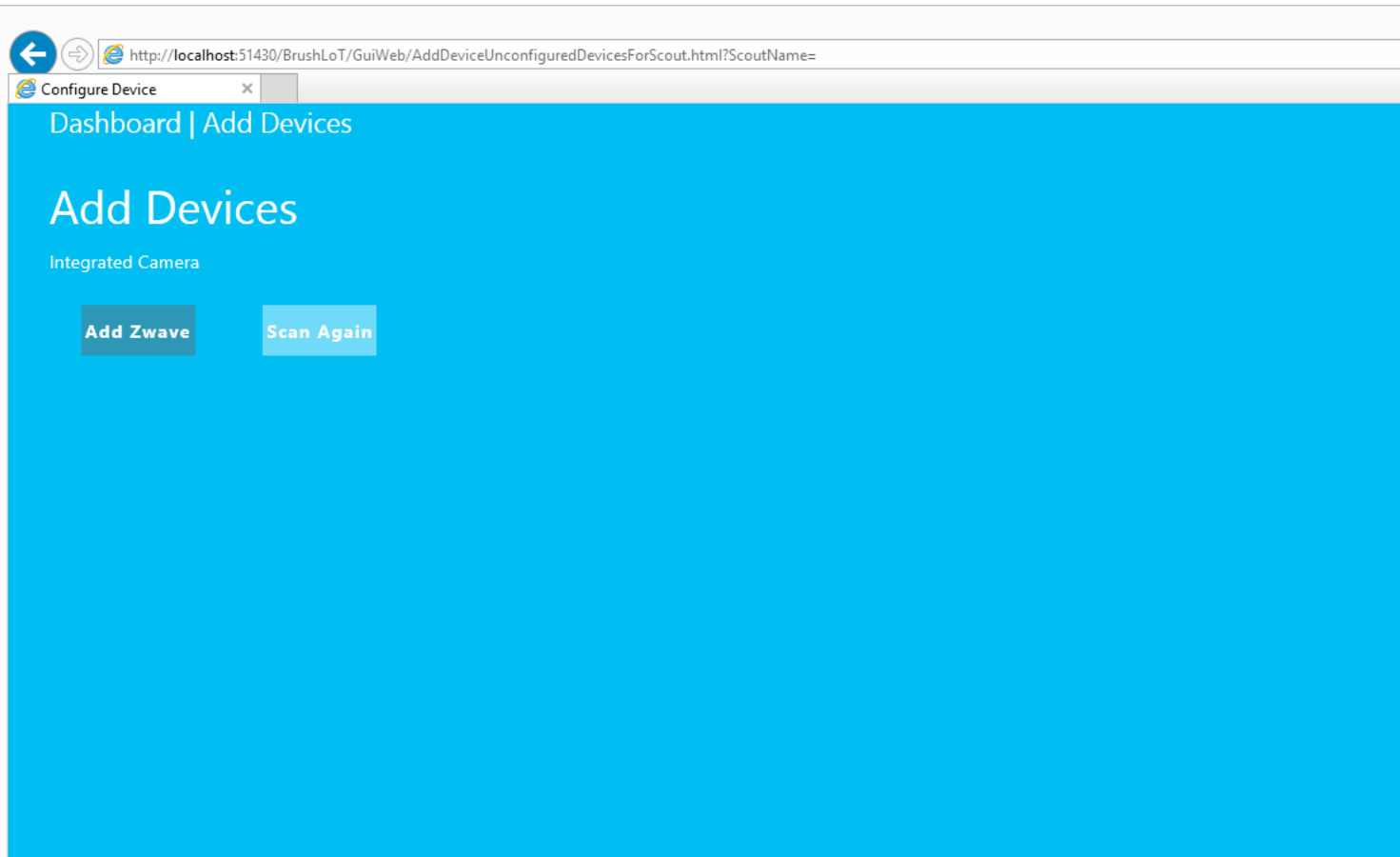
Your Home Hub has been successfully configured.
Home ID: BrushLoT
Home Password:12345
Remote Access: <https://www.lab-of-things.net:51431/BrushLoT/GuiWeb/index.html>
Default Email: ajbbrush@msn.com

A light blue button labeled "Next" is positioned at the bottom left of the content area.

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:



http://localhost:51430/GuiWeb/Add

Final Device Setup

Dashboard | Add Device | Final Device Setup

Final Device Setup

Name:

Location:



[Add New Location](#)

Install these applications:

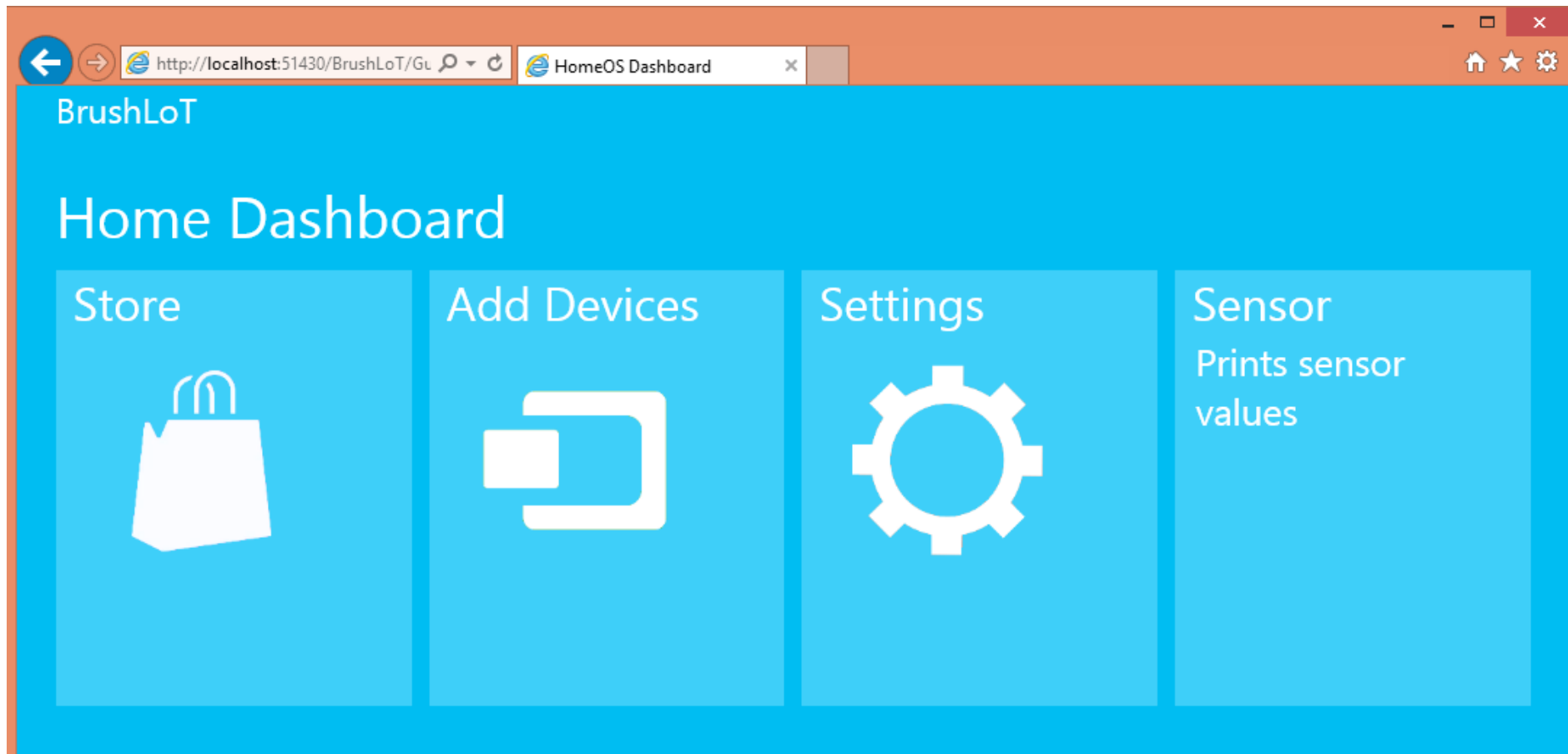
Sensor

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

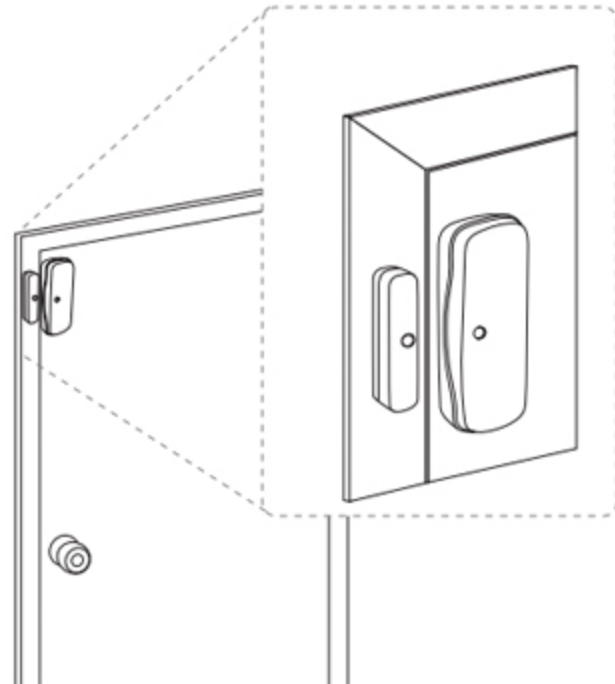
Sensor Logger Application

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.



Getting Started - Introductory Videos



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

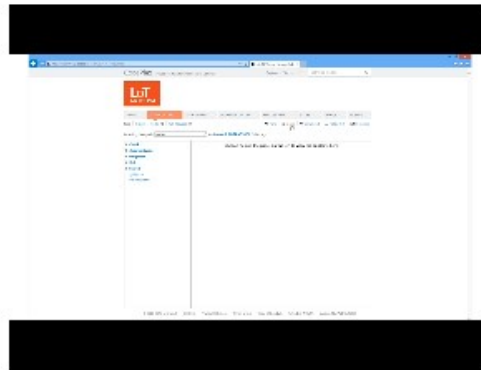


Topic: Demo of the Lab of Things
Speaker: AJ Brush

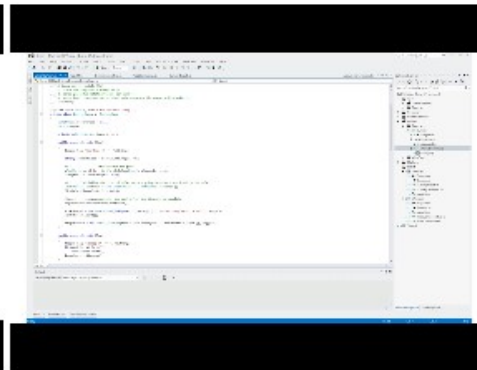


Topic: Architectural overview of the Lab of Things
Speaker: Ratul Mahajan

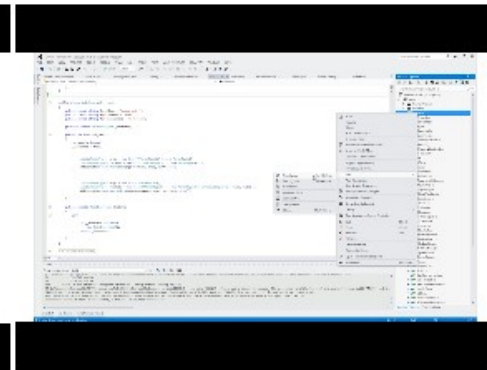
Working with the Lab of Things code



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 area is titled "Hub Status" and is divided into two sections: "Study ID: Default" and "Study ID: SS1".

Study ID: Default

Home ID	Last Heartbeat	Details	Remote Access
B111	0 Days 0 Hrs 1 Mins	Details	Remote Access
BrushLoT	0 Days 20 Hrs 40 Mins	Details	Remote Access
arjhome11	0 Days 0 Hrs 1 Mins	Details	Remote Access

Study ID: SS1

Home ID	Last Heartbeat	Details	Remote Access
SS1H1	0 Days 0 Hrs 0 Mins	Details	Remote Access
SS1H2	0 Days 0 Hrs 0 Mins	Details	Remote Access
SS1H6	0 Days 0 Hrs 0 Mins	Details	Remote Access
SS1H7	0 Days 0 Hrs 0 Mins	Details	Remote Access
ss1H9	0 Days 0 Hrs 0 Mins	Details	Remote Access
ss1h3	0 Days 0 Hrs 0 Mins	Details	Remote Access
ss1h4	0 Days 0 Hrs 1 Mins	Details	Remote Access
ss1h8	0 Days 0 Hrs 0 Mins	Details	Remote Access

© 2013 - Lab of Things Remote Management Portal

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

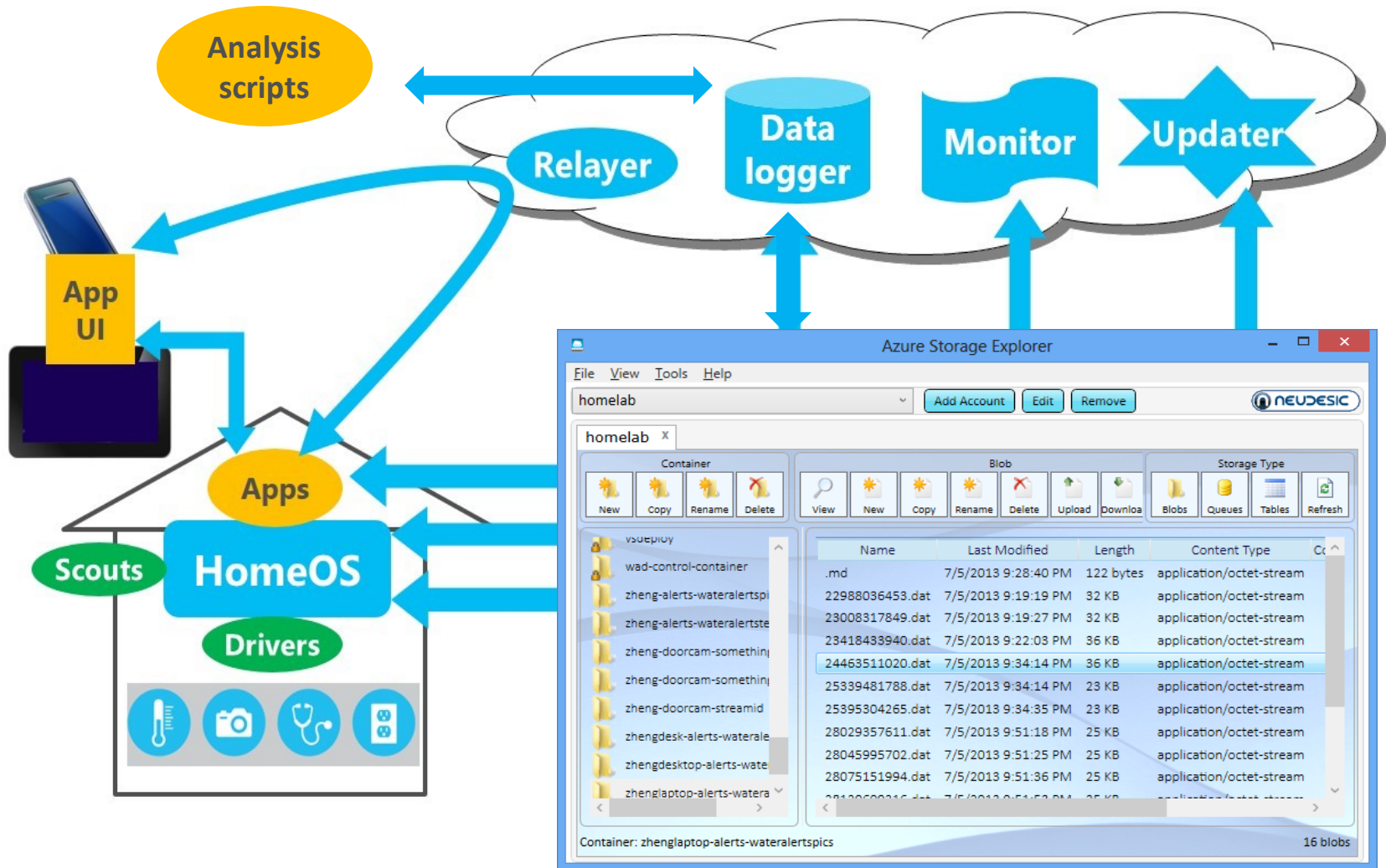
DG #2: Monitoring & Updating

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 'Home ID' section includes 'Actual' and 'Desired' buttons for each option. The main area is titled 'What has changed?' and contains 'Refresh', 'Validate', and 'Update' buttons at the bottom.

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	
APPS			
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
DRIVERS			
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

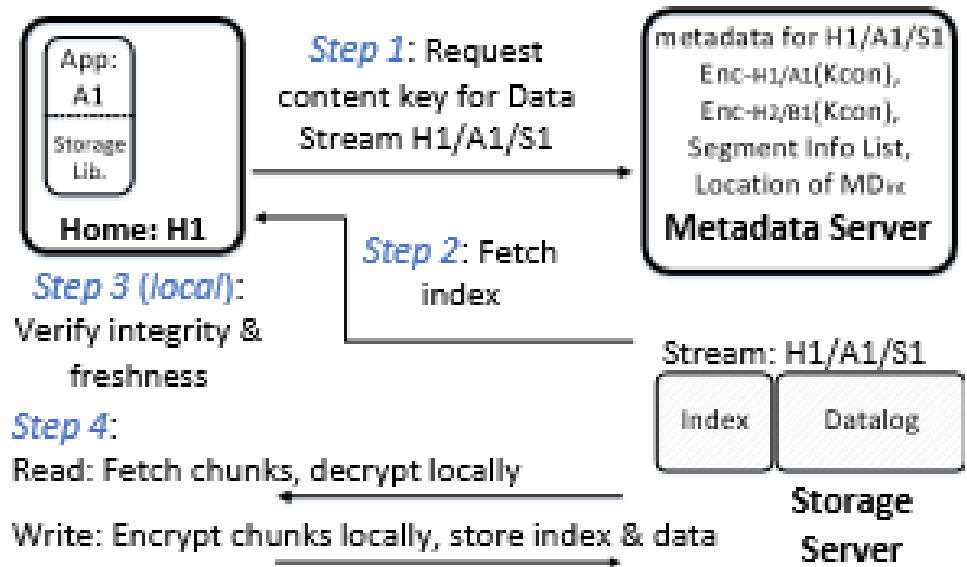


Data management using Bolt

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.

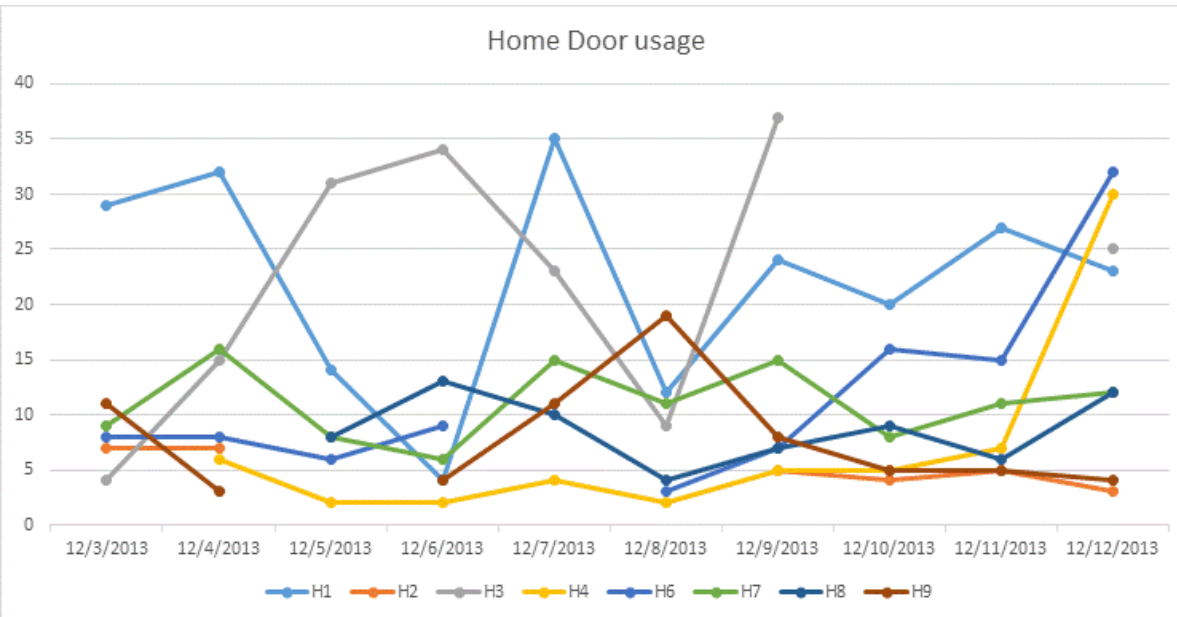
Efficiently ***share*** data across
applications and homes.



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

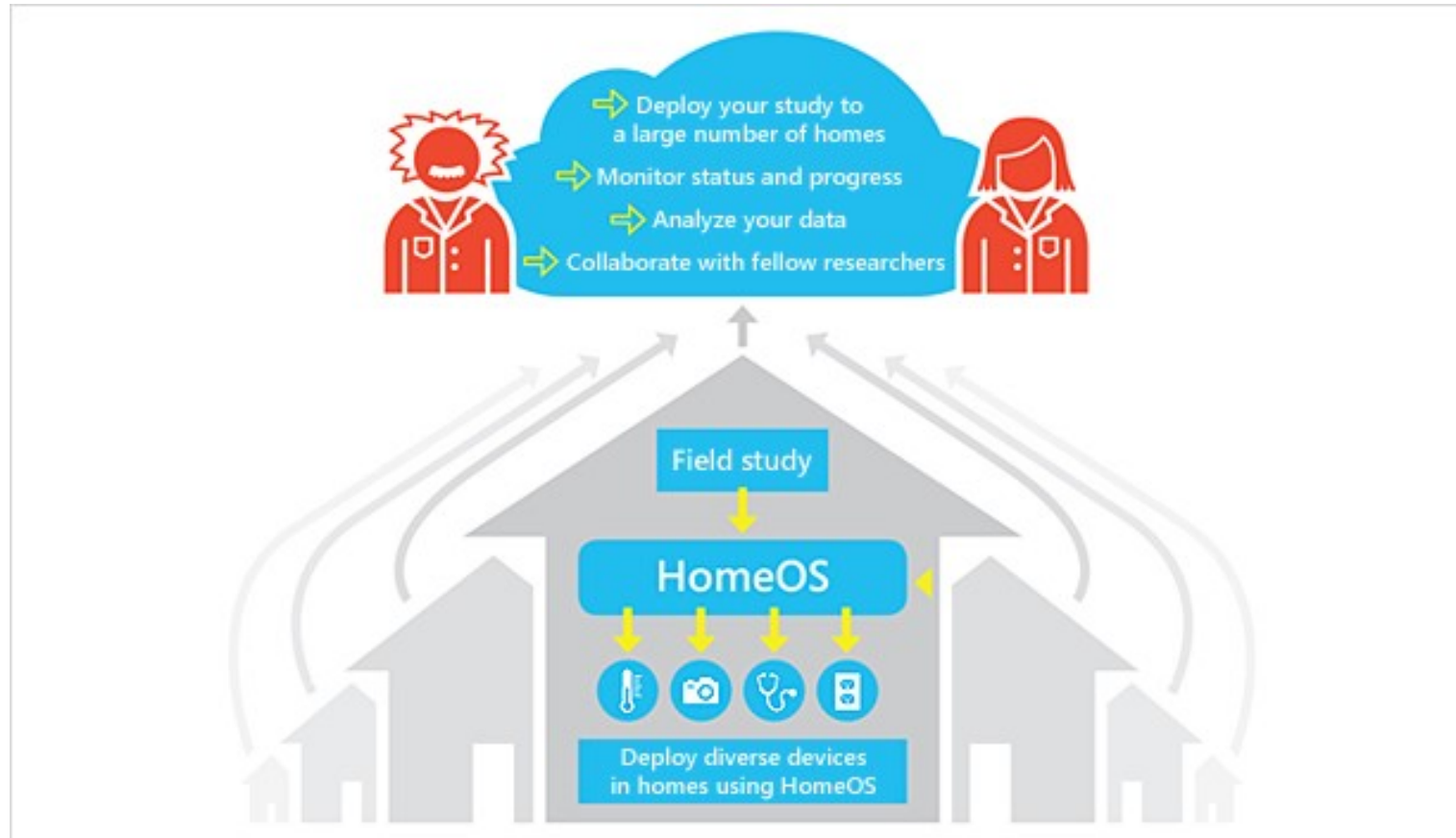
Gupta, Singh, Phanishayee, Jung, and Mahajan, Bolt: Data management for connected homes, To appear in NSDI 2014

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>

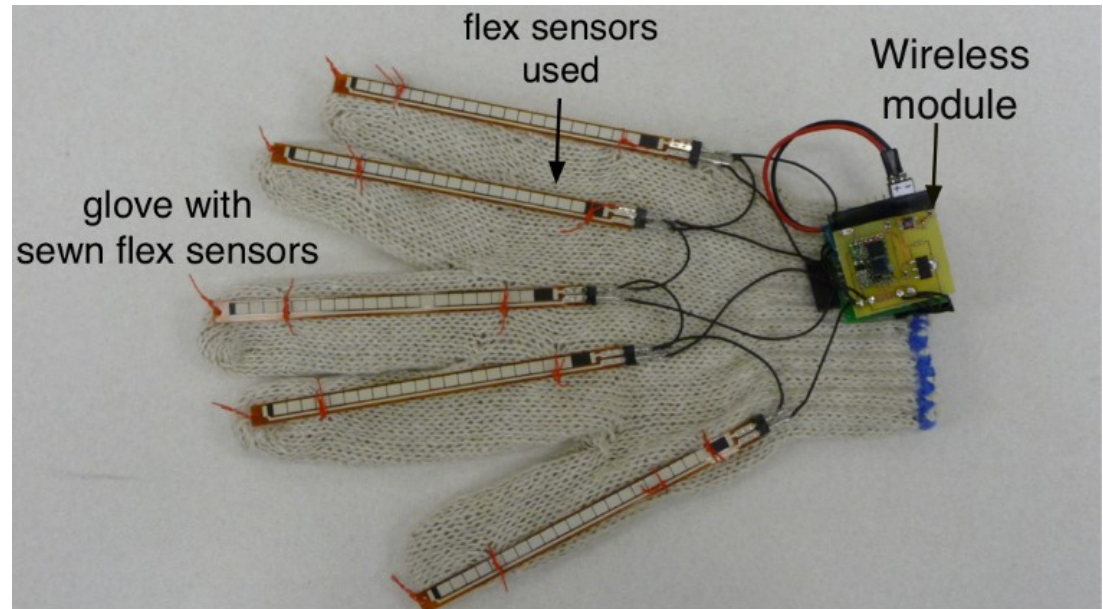
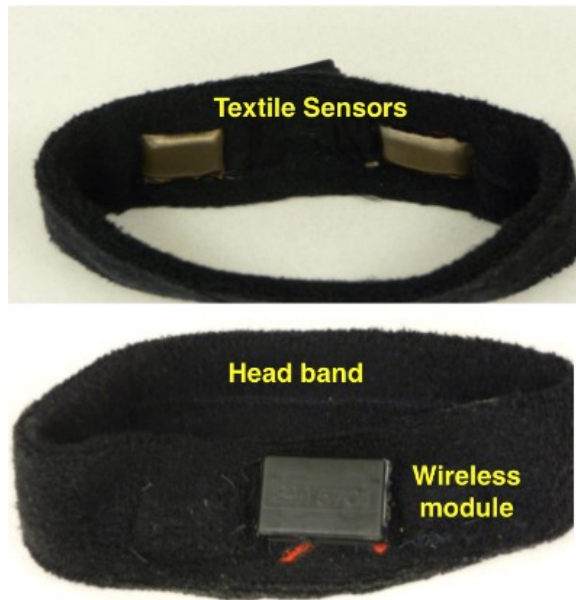
Project title: Supporting User Control of Intelligent Home Systems
PI: [Mark Newman](#), University of Michigan
URL: <http://mwnewman.people.si.umich.edu/projects.html>

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>

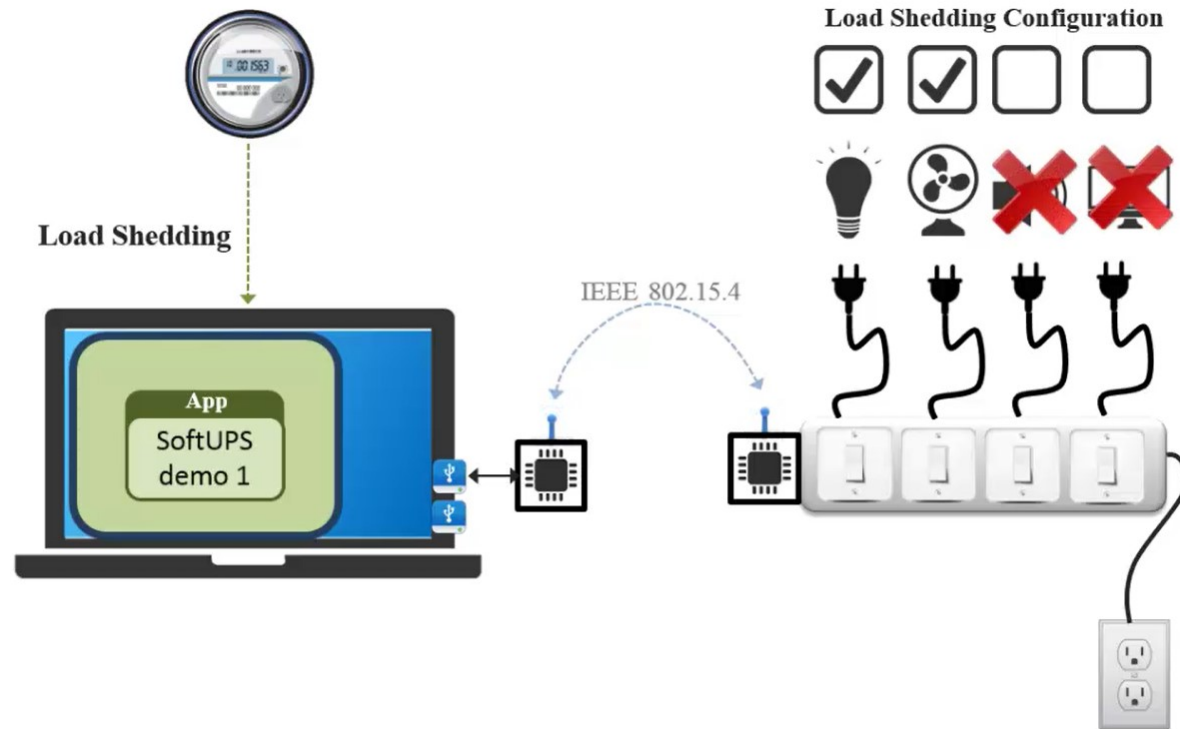
Case Study 1: Allowing paralysis patients to control their environment



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

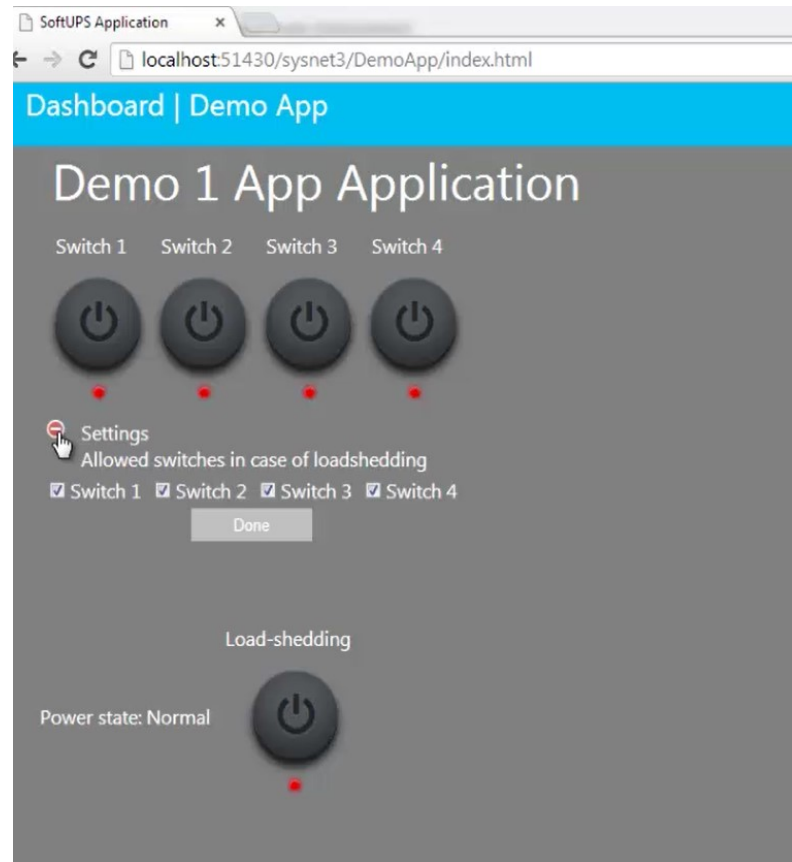
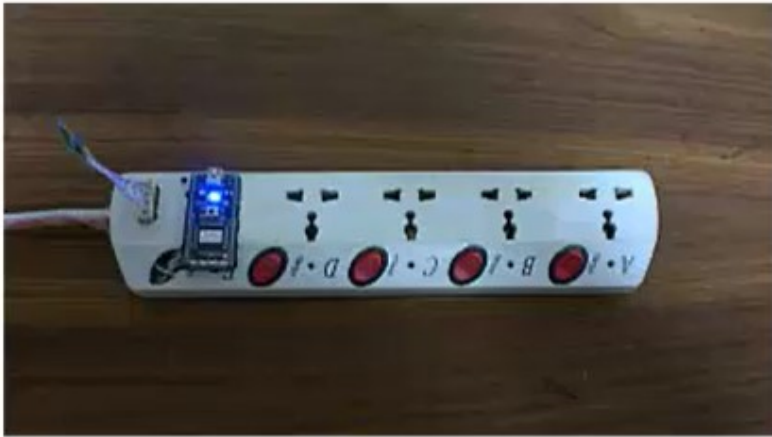


SoftUPS: Virtualizing the home UPS solution to enable efficient peak load sharing in developing world

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



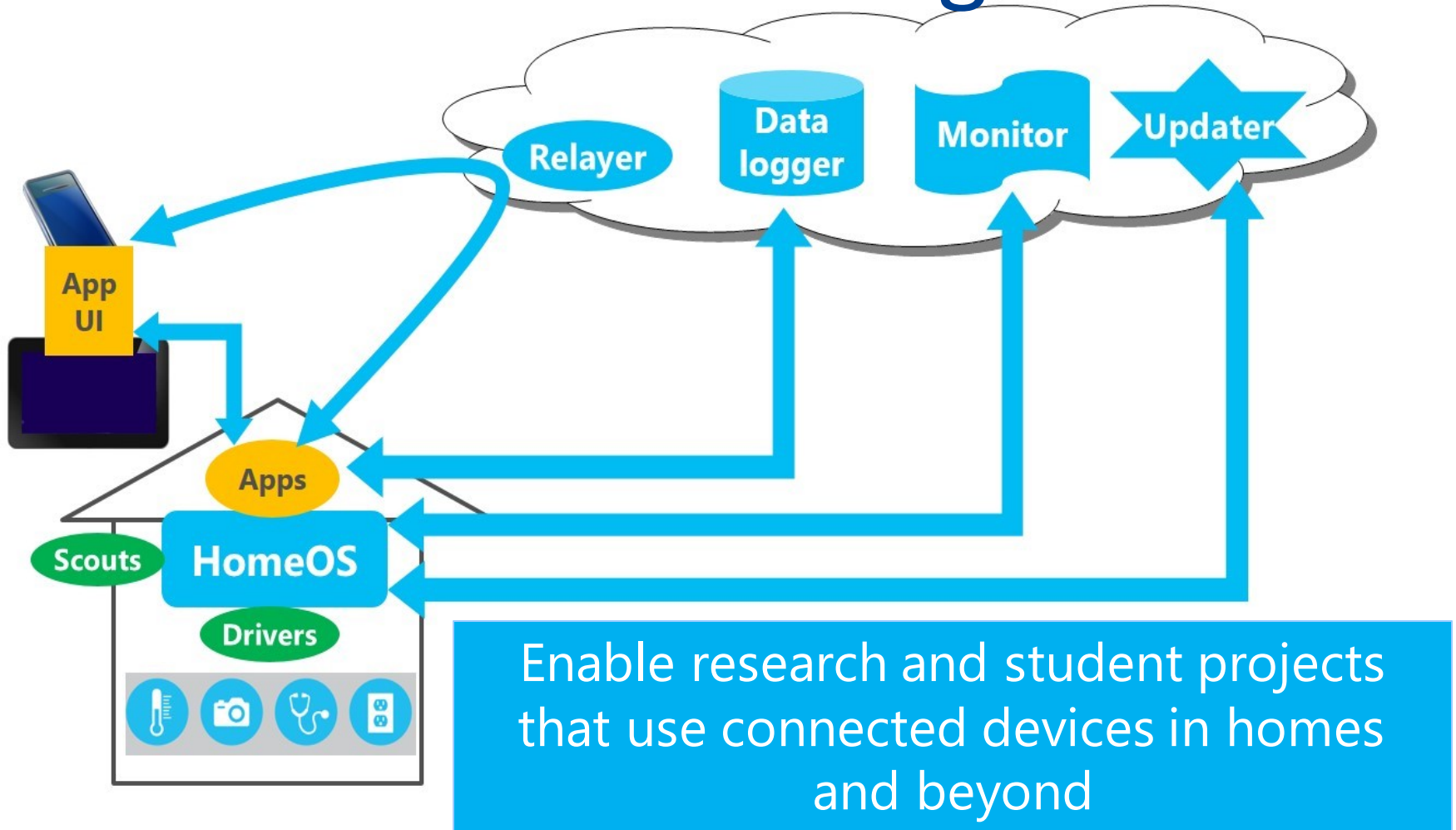
Case Study 2: Peak Load Sharing



Interactive Furniture

Video not yet publicly available

Lab of Things



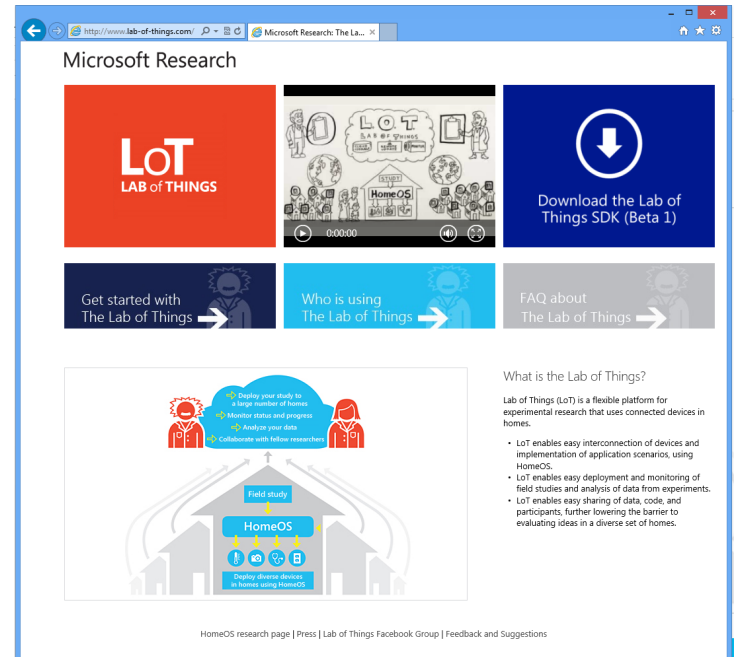
Thanks

More information:

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

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

Join the LoT community!



The screenshot shows the Microsoft Research Lab of Things website. At the top, there's a navigation bar with the Microsoft Research logo. Below it, there are several main sections: a red box with the 'LoT LAB OF THINGS' logo, a central image showing a house with various IoT devices and the text 'S.A.R.E. THINGS' and 'HomeOS', and a blue box with a download icon and the text 'Download the Lab of Things SDK (Beta 1)'. Below these are three smaller boxes: 'Get started with The Lab of Things', 'Who is using The Lab of Things', and 'FAQ about The Lab of Things'. A large diagram in the center shows a house with 'HomeOS' in the middle, and arrows pointing to 'Field study' and 'Deploy diverse devices in homes using HomeOS'. To the right of the diagram is a section titled 'What is the Lab of Things?' with a list of bullet points.

Microsoft Research

LoT LAB OF THINGS

Download the Lab of Things SDK (Beta 1)

Get started with The Lab of Things

Who is using The Lab of Things

FAQ about The Lab of Things

What is the Lab of Things?

Lab of Things (LoT) is a flexible platform for experimental research that uses connected devices in homes.

- 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.

HomeOS research page | Press | Lab of Things Facebook Group | Feedback and Suggestions

UBICOMP 2014

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