A CC licensed workshop by @tamberg, first held 07.07.2012 at SGMK MechArtLab Zürich, Switzerland,
in collaboration with Zürich IoT Meetup, Perey Research & Consulting, Thomas Brühlmann and SGMK.

Internet of Things Workshop

with Arduino

@tamberg, 11.09.2014

Internet

Computers, connected through Internet protocols

Display or manipulate **documents**

http://blog.com/2011-09-15/todays-post.html

Internet of Things (IoT)

Computers, **sensors** and **actuators** connected through Internet protocols

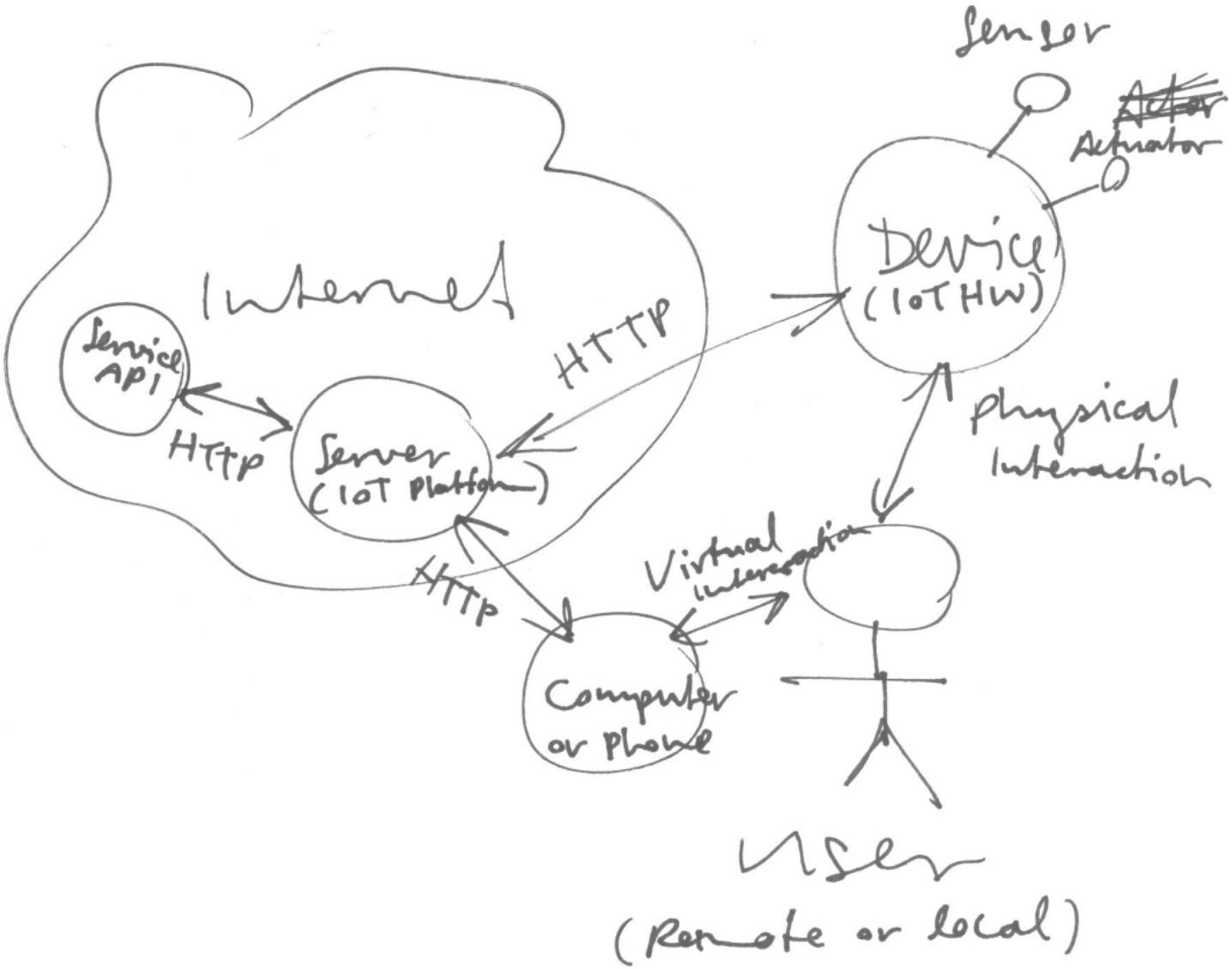
Measure or manipulate **physical properties**

http://e-home.com/tamberg/kitchen/light

Internet-connected devices

John Romkey's Toaster (1990, Ethernet)
Ambient Orb (2002, via pager network)
iPod (2001), iTunes Store (2003, via USB/PC)
Nike+ iPod (2006), Bracelet (2008 via USB/PC)
Rafi Haladjian's Nabaztag (2006, Wifi)
Rob Faludi's Botanicalls (2006, Ethernet)
Schulze&Webb Availabot (2006, via USB/PC)
iPhone (2007, GSM)
Amazon Kindle (2007, 3G)
Wafaa Bilal's Shoot an Iraqi (2007, ?)
Withings BodyScale (2008, Wifi)
Vitality GlowCap (2008, Wifi; 2011, 3G)
BakerTweet (2009, 3G)
Adrian McEwen's Bubblino (2009, Ethernet)
David Bowen's Telepresent Water (2011, ?)
Nest Thermostat (2011, Wifi)
BERG's Little Printer (2011, ?)
Supermechanical's Twine (2012, Wifi)
Olly & Polly (2012, via USB/PC)
Koubachi Sensor (2012, Wifi)
Descriptive Camera (2012, Ethernet)

IoT reference model



IoT hardware

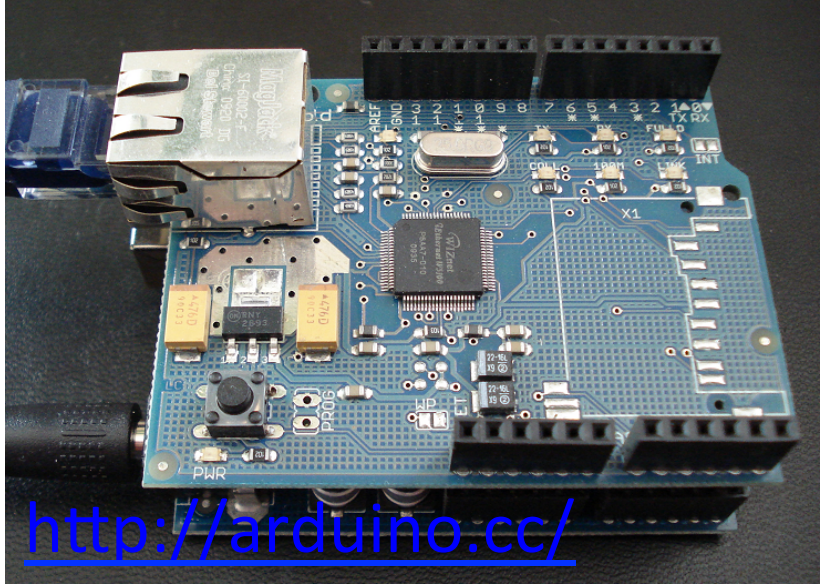
Any Internet-connected computer with an **interface to the real world** (sensors, actuators)

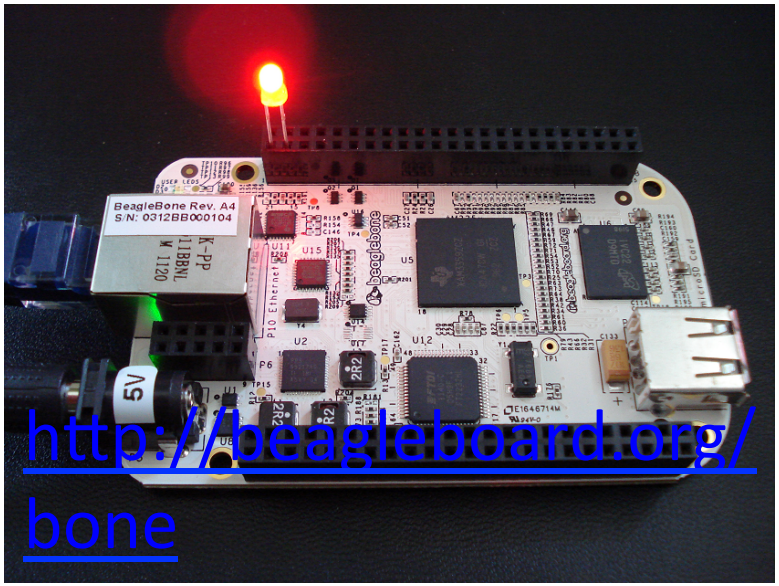
Small => can be **embedded into things**

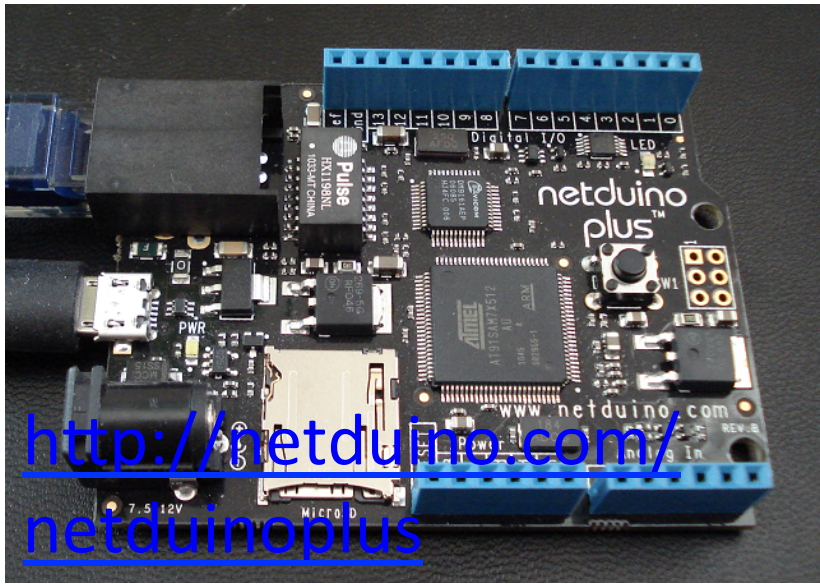
Small computer = **microcontroller** (or **board**), e.g. Arduino, Netduino Plus, BeagleBone, …

Note: connecting your board to the Internet via a desktop PC and USB is also fine, just a bit overkill

IoT hardware







Note: Thanks to TCP/IP & HTTP, any client can talk to any service, no matter which hardware you choose

IoT infrastructure services

Thingspeak and **Xively** to store and use sensor measurements

e.g. https://thingspeak.com/channels/9

Twitter allows objects to talk to humans or receive commands

e.g. @twrbrdg_itself (f.k.a. @towerbridge)

Yaler enables remote access to Internet-connected devices

e.g. http://try.yaler.net/~arduino/led *(Disclosure: I'm a founder)*

Zapier and **IFTTT** allow mash-ups of Webservices

e.g. http://goo.gl/7Y8a7z

Just a beginning

Reactive buildings, flying / crawling IoT devices, underused devices selling themselves on Ebay…

Connected products become service avatars, or "everything becomes a service" (e.g. car sharing, home sharing, shoe sharing)

"Once it's here it will no longer be called the Internet of Things" Open IoT Assembly 2012

Topics of this workshop

Getting started
(setup and programming of IoT hardware)

Measuring and **manipulating**
(physical computing: sensors and actuators)

Connecting your device **to the Internet**
(IoT: monitoring sensors, controlling actuators)

Mash-ups with Web-enabled devices

(together, if time permits)

How the Internet works under the hood

Hands on

Broad range of topics => **learn by doing**

Copy&paste examples, make 'em work for you,
https://bitbucket.org/tamberg/iotworkshop/get/tip.zip

Focus on **end-to-end results, not details**

Google, help each other, ask us

Getting started

The **IDE** (**I**ntegrated **D**evelopment **E**nvironment) allows you to **program** your board, i.e. “make it do something new”

You **edit** a program on your computer, then **upload** it to your board where it’s stored in the program memory (flash) and **executed** in RAM

Note: Once it has been programmed, your board can run on its own, without another computer

Getting started with Arduino

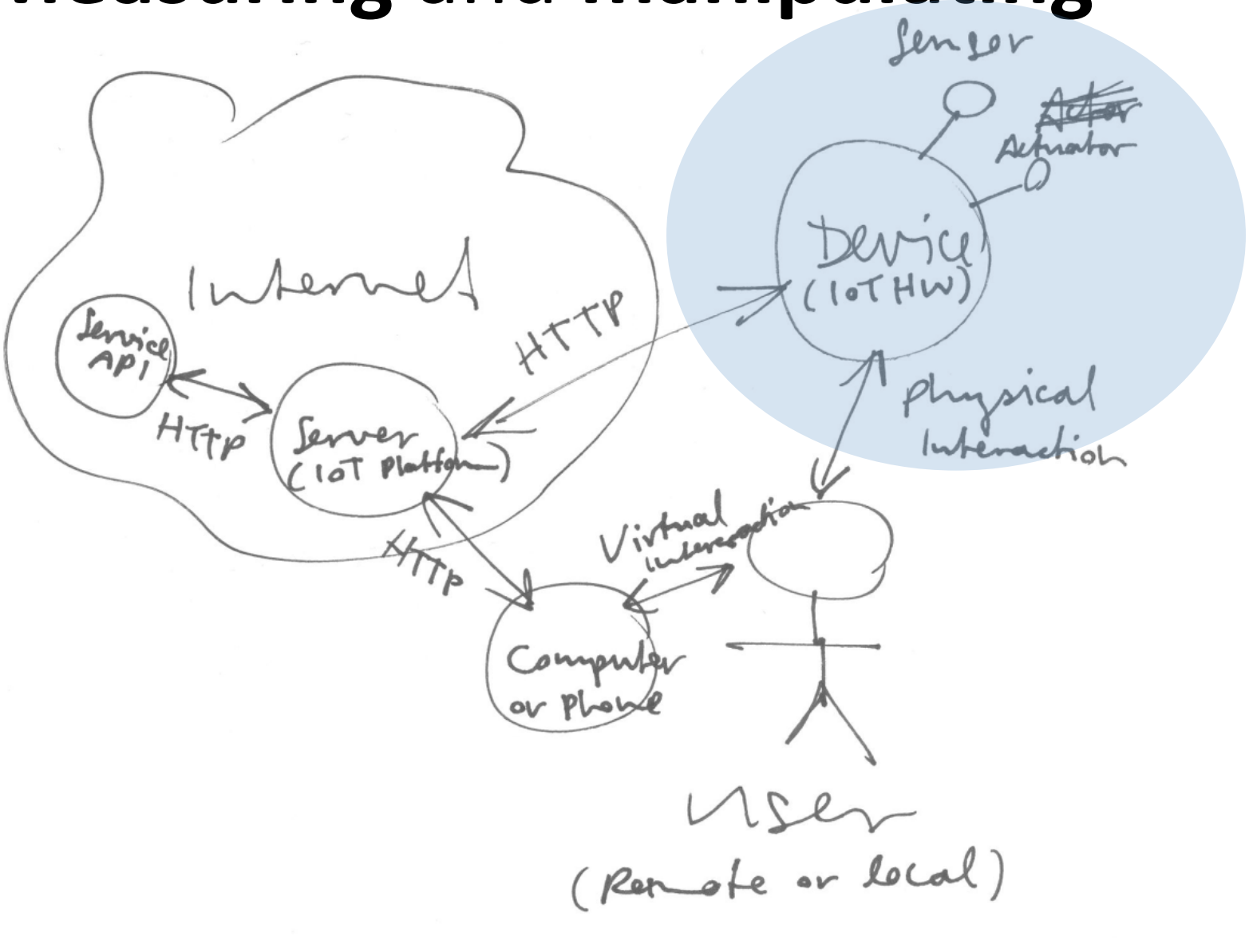
To install the Arduino IDE and connect your Arduino board to your computer via USB, see

http://arduino.cc/en/Guide/MacOSX or

http://arduino.cc/en/Guide/Windows or

http://arduino.cc/playground/Learning/Linux

Measuring and **manipulating**



Measuring and **manipulating**

IoT hardware has an **interface to the real world**

GPIO (**G**eneral **P**urpose **I**nput/**O**utput) pins

Measure: **read** sensor value from **input** pin

Manipulate: **write** actuator value to **output** pin

Inputs and outputs can be **digital or analog**

The resistor

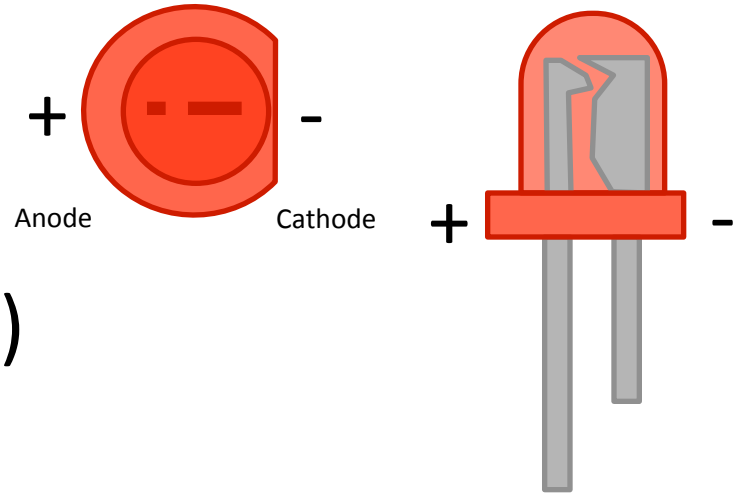
Resistors are the **workhorse of electronics**

Resistance is **measured in Ω** (Ohm) and adds up in series; a resistors orientation doesn't matter

A resistors Ω value is **color-coded** right on it

Note: color codes are great, but it's easier to use a multi-meter if you've got one, and just measure Ω

The LED



The **LED** (**L**ight **E**mitting **D**iode)

is a simple, digital **actuator**

LEDs have a **short leg** (**-**) and a **long leg** (**+**)

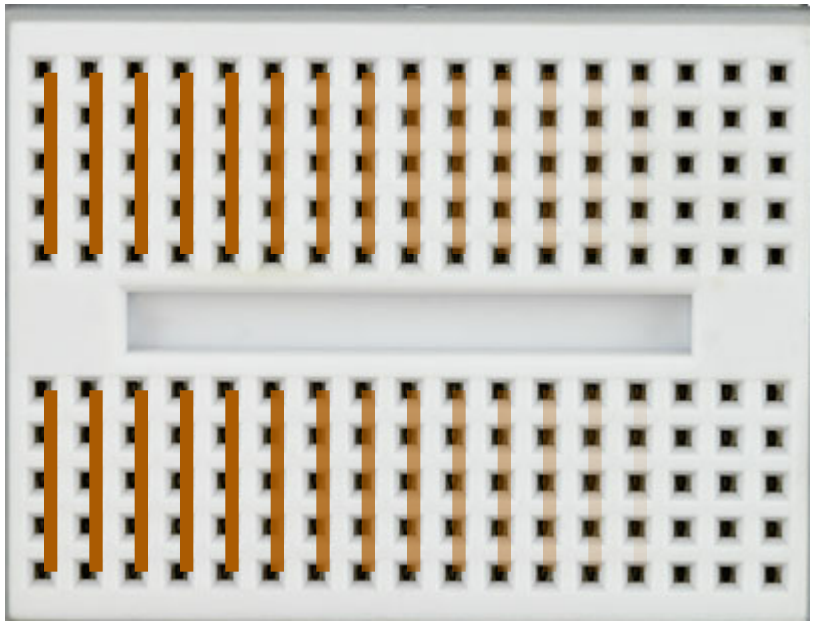
and it matters how they are oriented in a circuit

To prevent damage, LEDs are used together with a 1KΩ **resistor** (or anything from 300Ω to 2KΩ)

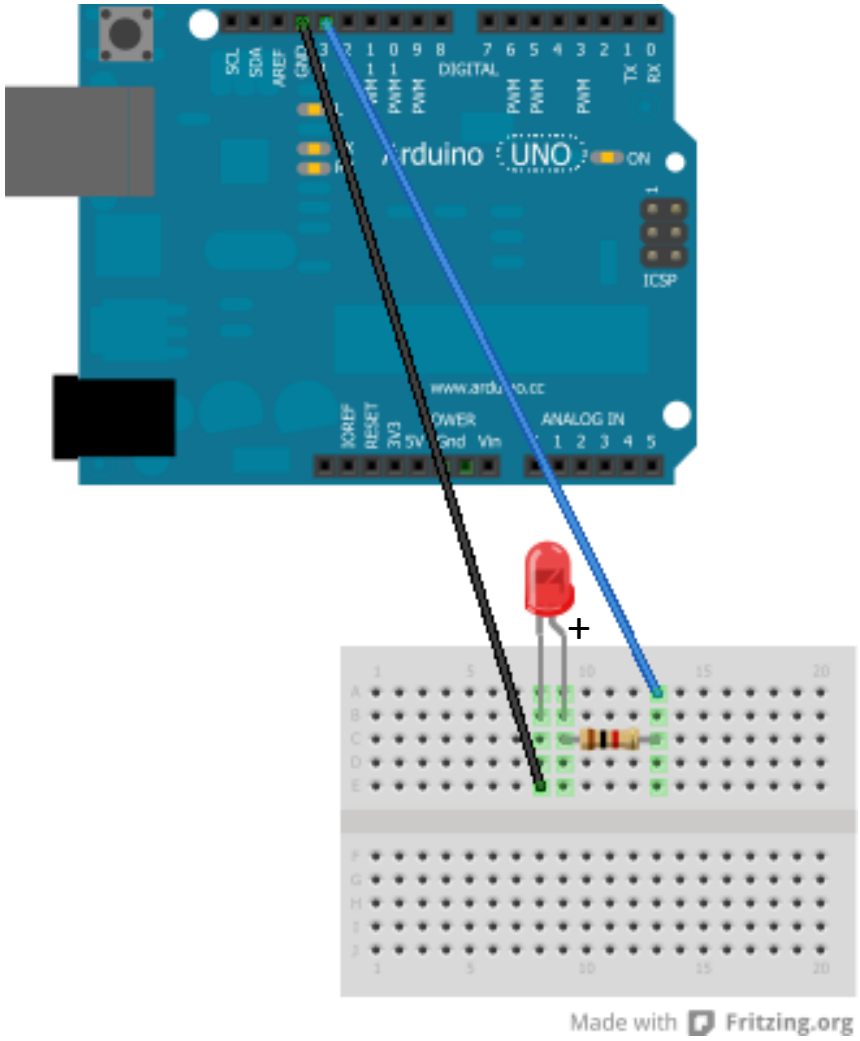
The breadboard

A breadboard lets you wire electronic components without any soldering

Its holes are connected “under the hood” as shown here



Wiring a LED with Arduino



Note: the additional **1K Ω** resistor should be used to prevent damage to the pins / LED if it's reversed

The long leg of the LED is connected to **pin 13**, the short leg to ground (**GND**)

The Ethernet Shield is not needed here

Digital output with Arduino

```
int ledPin = 13;
void setup () {
    pinMode(ledPin, OUTPUT);
}
void loop () {
    digitalWrite(ledPin, HIGH);
    delay(500); // wait 500ms
    digitalWrite(ledPin, LOW);
    delay(500);
}
```

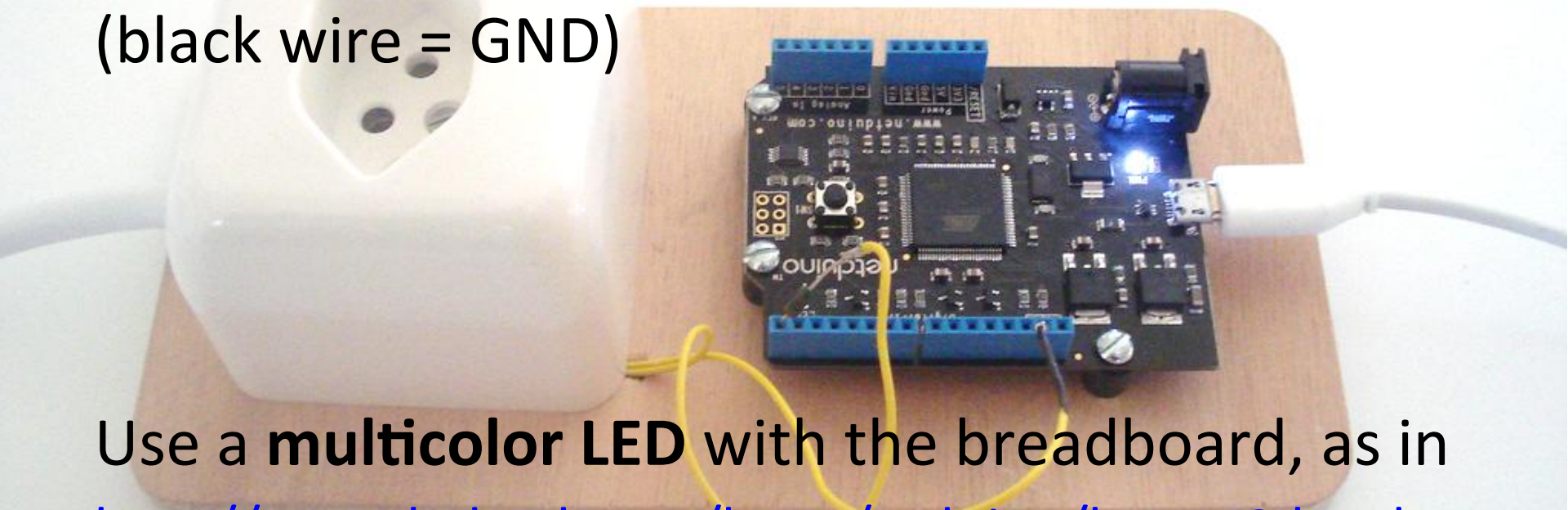
Note: blinking a LED is the *Hello World* of embedded software

Set *ledPin* as wired in your LED circuit

HIGH = digital 1 (5V) means LED is **on**, **LOW** = digital 0 (0V) means LED is **off**

Actuator bonus stage

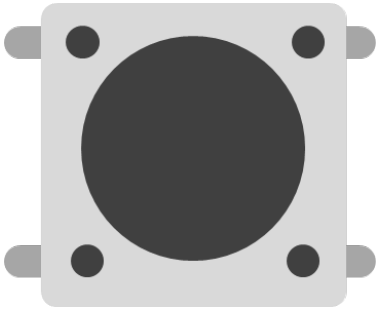
Try a **switched power outlet** instead of a LED (black wire = GND)



Use a **multicolor LED** with the breadboard, as in http://www.ladyada.net/learn/arduino/lesson3.html

Or **solder** resistors to a multicolor LED, as in http://www.instructables.com/id/Arduino-Web-LED/

The switch



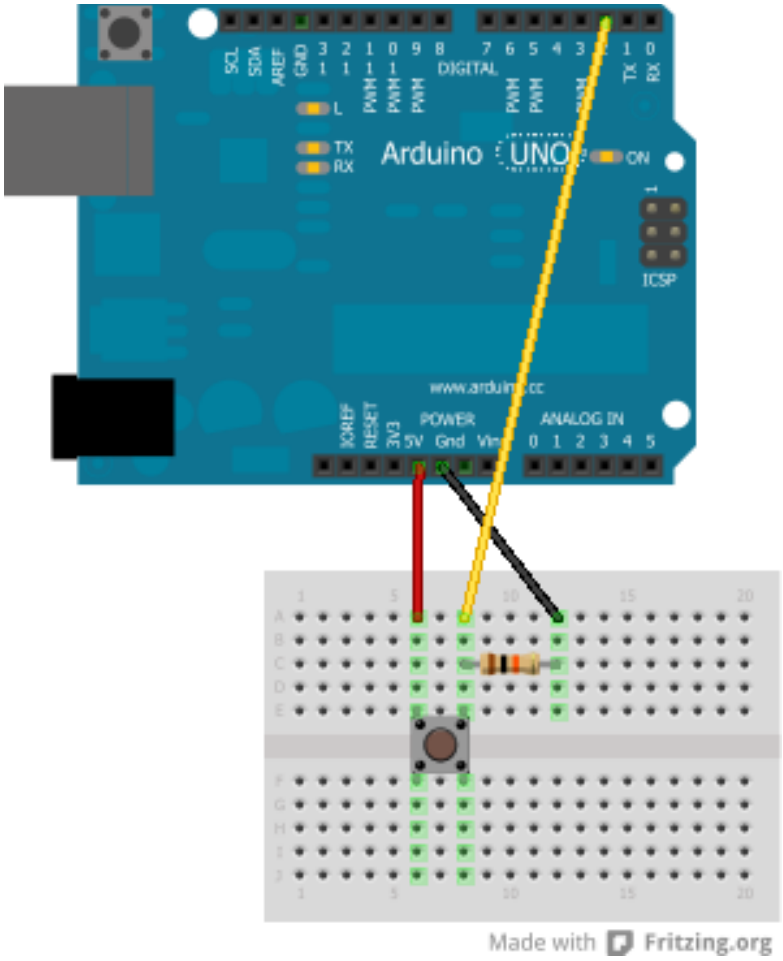
A switch is a simple, digital **sensor**

Switches come in different forms, but all of them in some way **open** or **close** a gap in a wire

The **pushbutton** switch has four legs for easier mounting, but only two of them are needed

Note: you can also easily build your own switches, for inspiration see e.g. http://vimeo.com/2286673

Wiring a switch with Arduino



Note: the resistor in this setup is called *pull-down* ‘cause it pulls the pin voltage down to GND (0V) if the switch is open

Pushbutton **switch**
10K Ω resistor
5V
GND
D2 (max input 5V!)

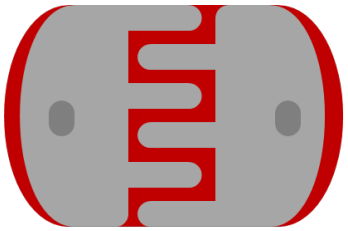
Digital input with Arduino

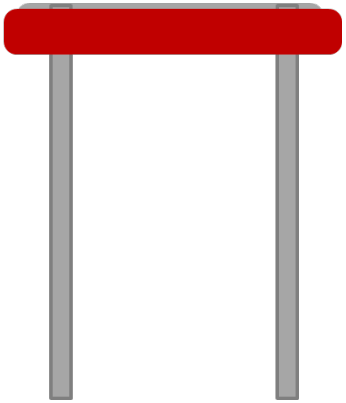
```
int sensorPin = 2; // e.g. button switch

void setup () {
   Serial.begin(9600); // setup log
   pinMode(sensorPin, INPUT);
}

void loop () {
   int sensorValue = digitalRead(sensorPin);
   Serial.println(sensorValue); // log 0 or 1
}
```

Open the Arduino IDE serial monitor to see log output

Or run Arduino IDE *> File > Examples > Digital > Button* for an example of how to switch an LED

Photoresistor (LDR)



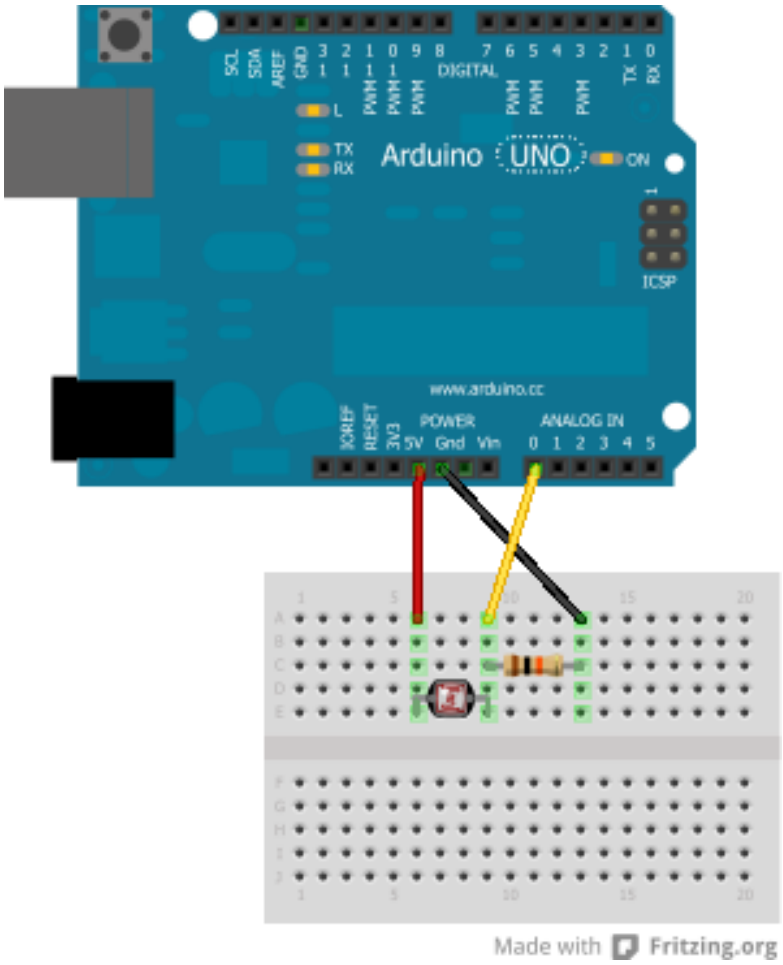


A photoresistor or **LDR** (**l**ight **d**ependent **r**esistor) is a resistor whose resistance depends on light intensity

An LDR can be used as a simple, **analog sensor**

The orientation of an LDR does not matter

Wiring an LDR with Arduino



Note: this setup is a *voltage-divider*, *as* the 5V total voltage is divided between LDR and resistor to keep 0V < **A0** < 2.5V

Photoresistor (LDR)
10K Ω resistor
5V
GND
A0

Analog input with Arduino

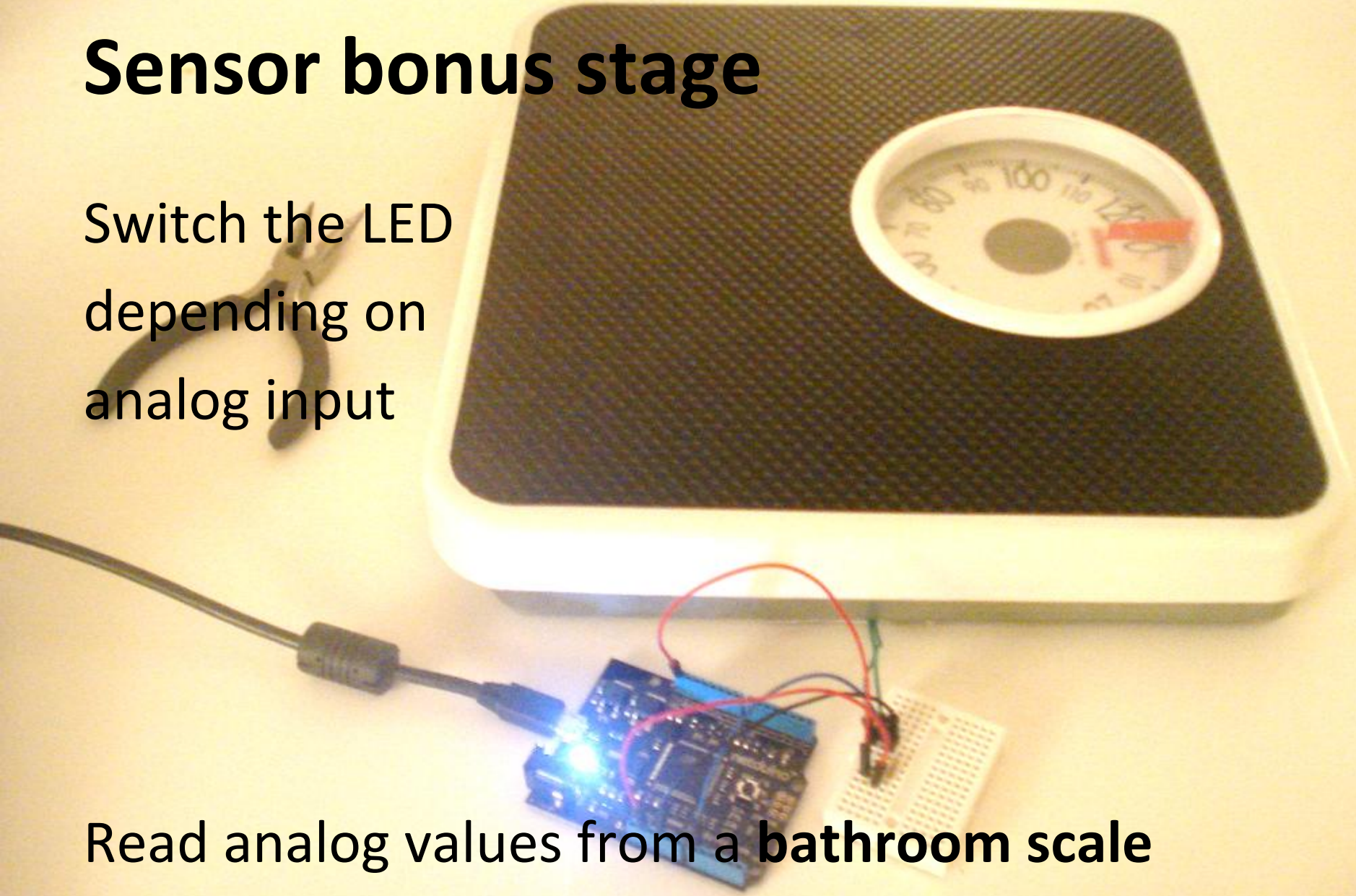
```
int sensorPin = A0; // e.g. LDR

void setup () {
   Serial.begin(9600); // setup log
}

void loop () {
   int sensorValue = analogRead(sensorPin);
   Serial.println(sensorValue); // log value
}
```

Open the Arduino IDE serial monitor to see log output

Note: use e.g. Excel to visualize values over time

Sensor bonus stage

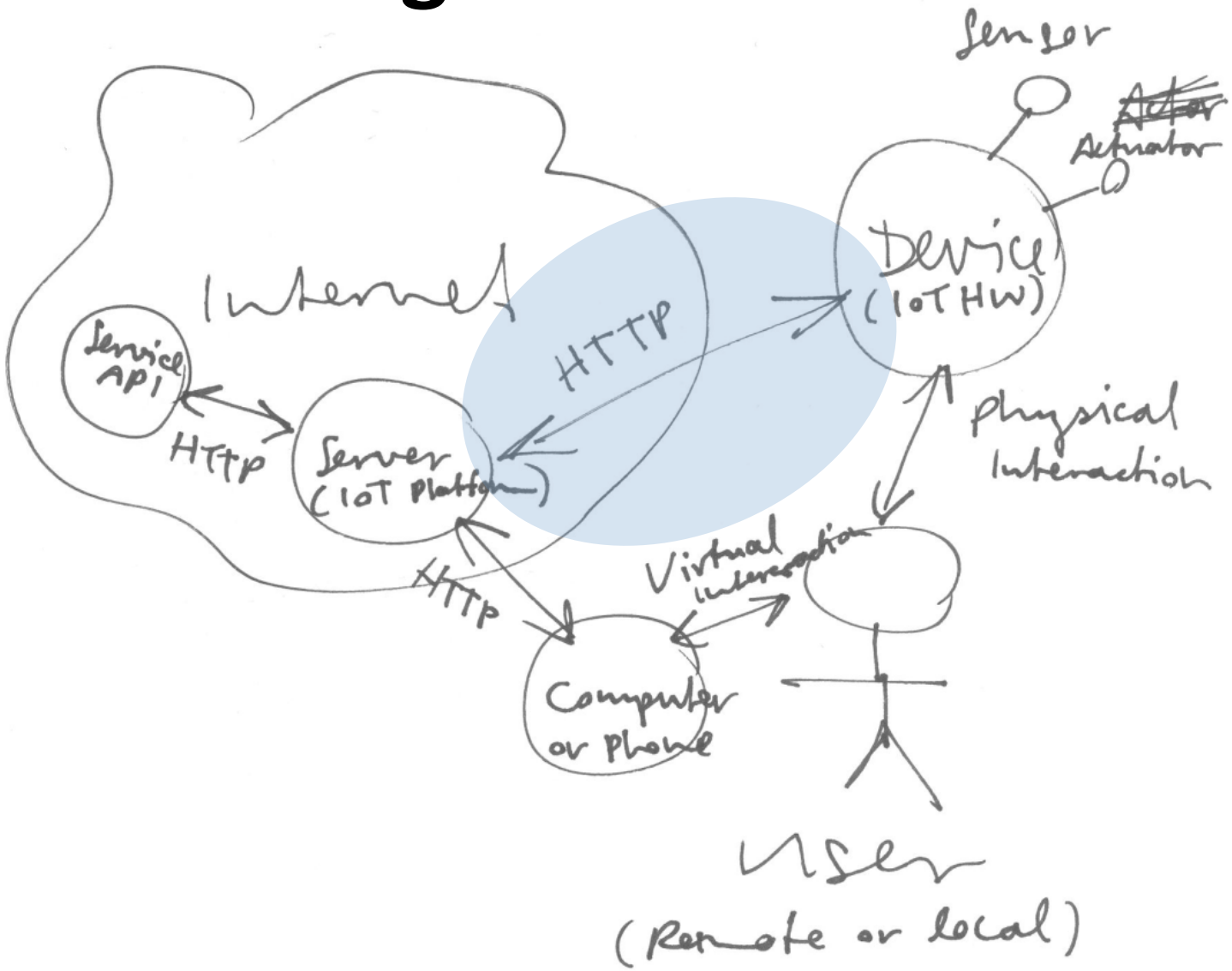
Switch the LED depending on analog input



Read analog values from a **bathroom scale**

Or use sensors with other wire protocols, e.g. i2c

Connecting to the Internet



Connecting to the Internet

Ethernet (built-in or shield), plug it in anywhere

Wi-Fi (module), configured once per location

3G (module), configured once, easy to use

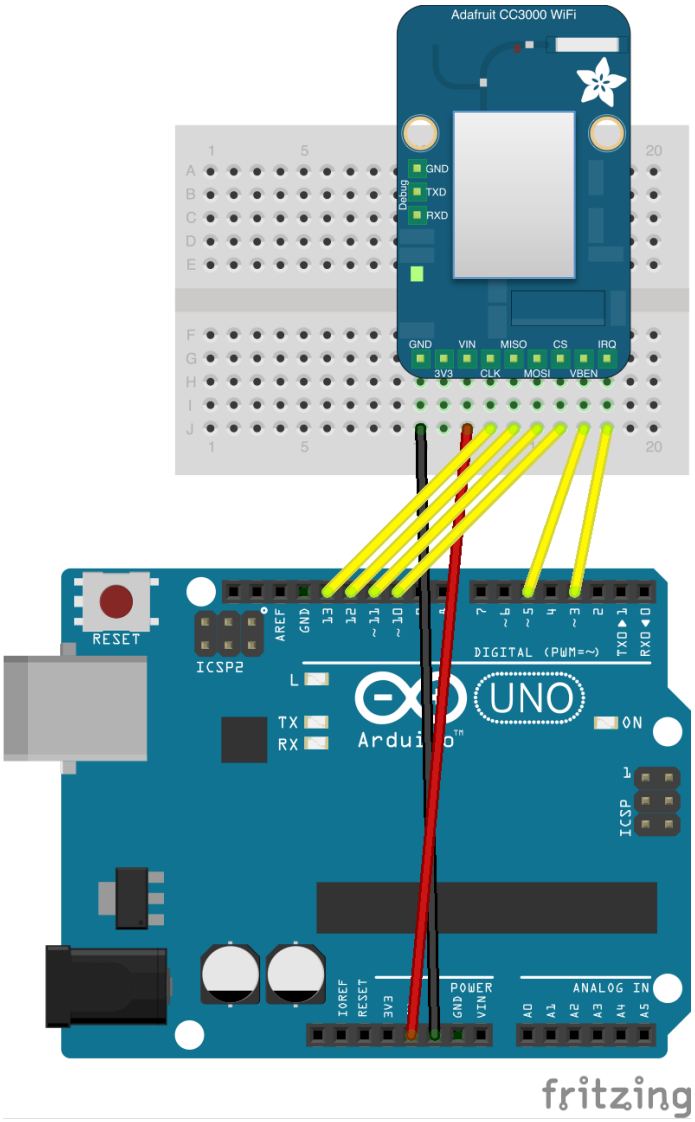
Bluetooth/BLE (module), via 3G/Wi-Fi of phone

ZigBee (module), via ZigBee gateway

USB (built-in), via desktop computer

Note: in this workshop we focus on Ethernet and Wi-Fi

Wiring CC3000 Wi-Fi with Arduino



Note: make sure to use a reliable power source, e.g. plug the Arduino via USB or use a LiPo battery

CC3000 **VIN** to **5V**

GND to **GND**

CLK to **D13**, **MISO** to **D12**, **MOSI** to **D11**, **CS** to **D10**, **VBEN** to **D5**, **IRQ** to **D3**

Using CC3000 Wi-Fi with Arduino

http://learn.adafruit.com/adafruit-cc3000-wifi/cc3000-library-software

File > Examples > Adafruit_CC3000 > WebClient

```
#define WLAN_SSID "..." // set your network
#define WLAN_PASS "..." // set your password
```

Note: open the serial monitor window to see the log

Using Ethernet with Arduino

Add an **Ethernet shield** to the Arduino, plug it in

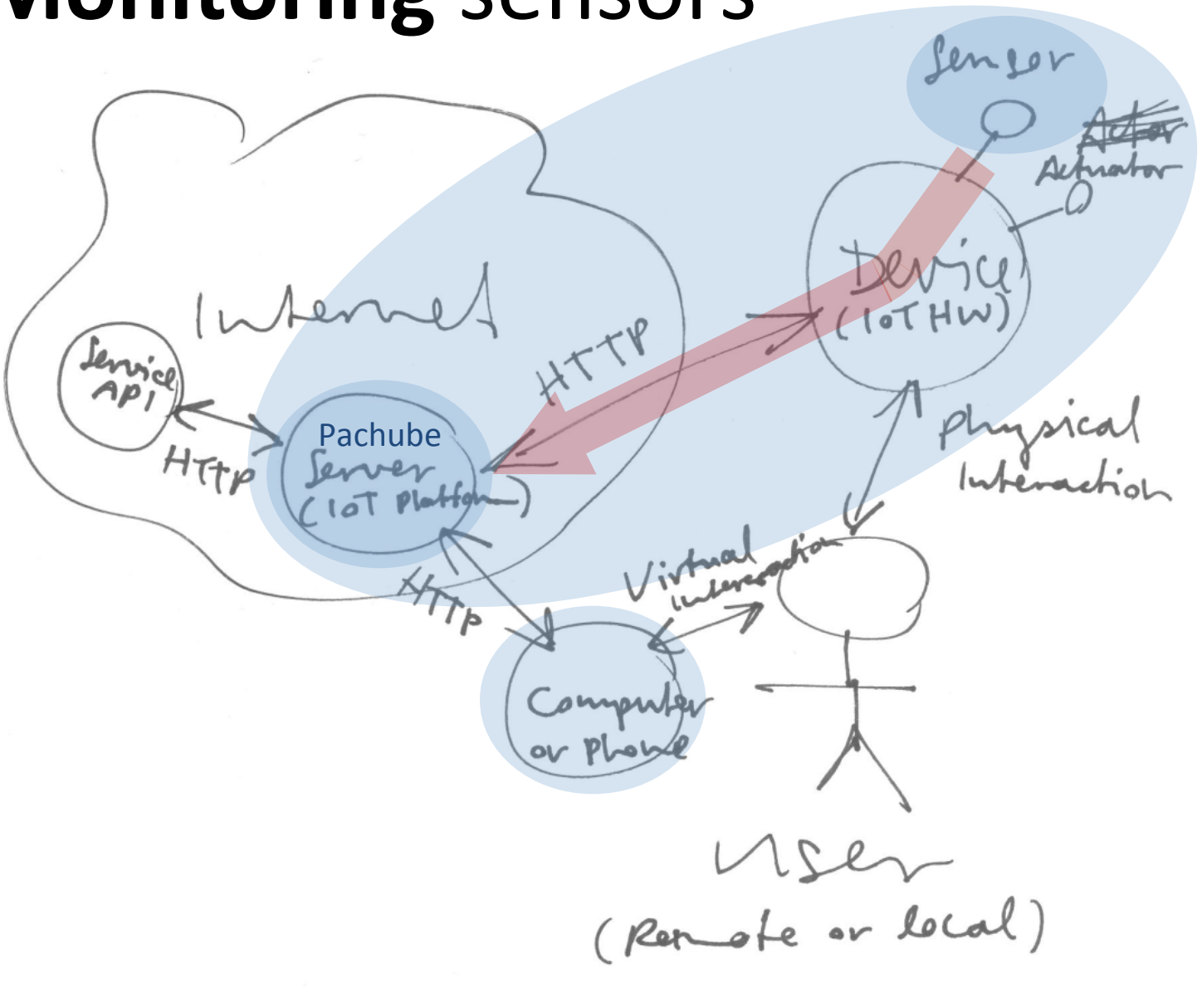
File > Examples > Ethernet > WebClient

*byte mac[] = { ... }; // set a **unique MAC** address*

*IPAddress ip(...); // set a **local, unique IP** address*

Note: please ask for assistance to get a unique address

Monitoring sensors



Monitoring sensors

Devices read (and cache) **sensor** data

Devices **push** data to a service with POST, PUT

Some services **pull** data from devices with GET

Service stores measurements, to be consumed by humans or computers (incl. other devices)

Pachube (now **Xively**)

The Pachube (now Xively) service lets you store, **monitor** and share **sensor data** in open formats

PUT /v2/feeds/*<your feed id>*.csv HTTP/1.1\r\n
Host: api.xively.com\r\n
X-ApiKey: *<your API key>*\r\n
Content-Length: *<content length>*\r\n
\r\n
<sensor name>,<sensor value>

GET /v2/feeds/<feed id>.json HTTP/1.1\r\n
Host and X-ApiKey as above…\r\n\r\n

Note: please visit http://xively.com/ to sign up, create a feed with a data stream per sensor and get an API key

Pachube with Arduino + Ethernet

Use **Xively's template** or open Arduino IDE > *Examples > Ethernet > **PachubeClient***

Check *MAC*, *IP*, *FEED ID*, *API KEY* and the data stream's name

Analog input: **LDR** on **A0**

http://xively.com/feeds/<feed-id>

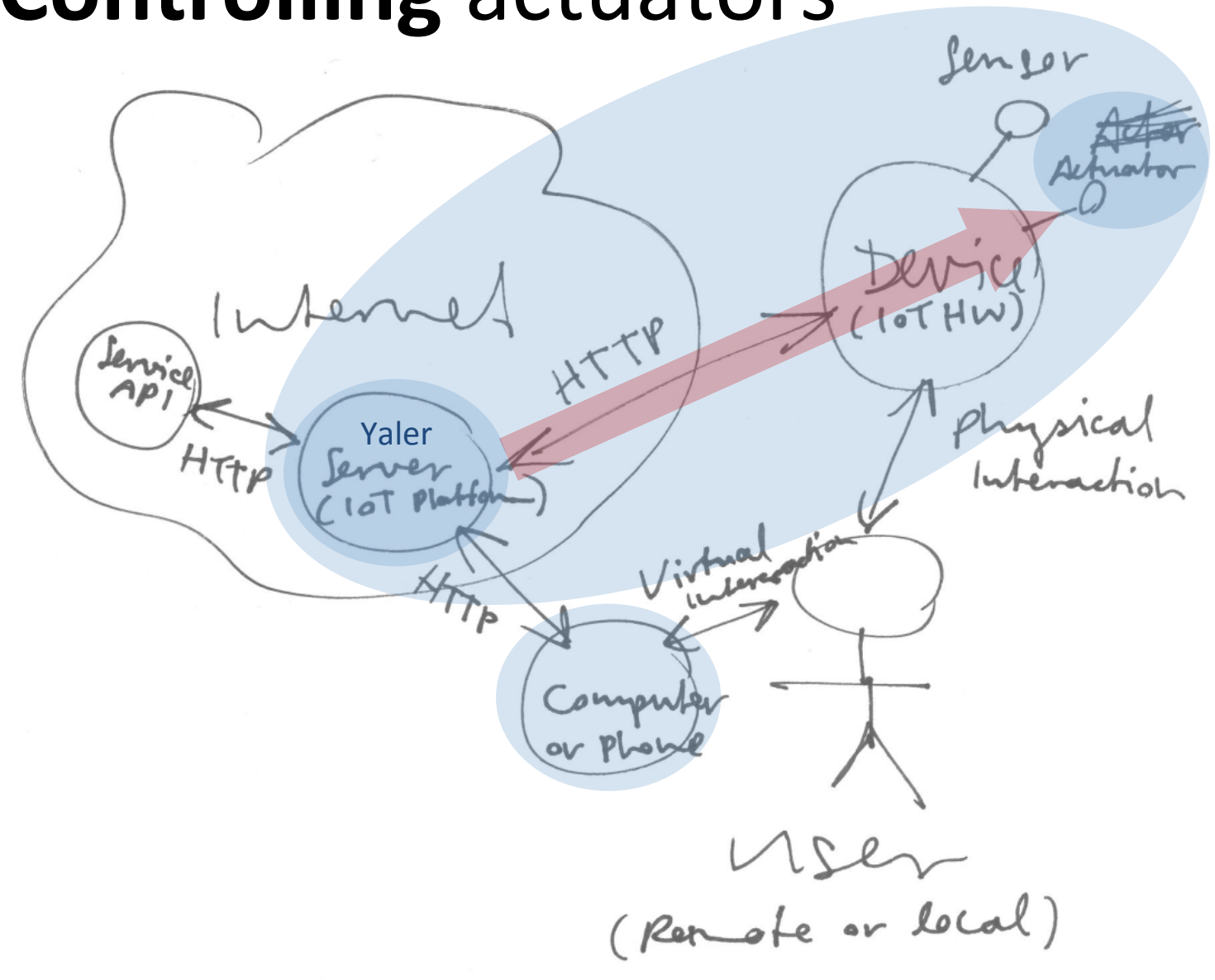
Note: to send data to xively.com make sure your Arduino is connected to the Internet

Open the Arduino IDE serial monitor to see log output

Pachube with Arduino + CC3000

To connect an Arduino to Pachube (now Xively) follow the steps in http://learn.adafruit.com/adafruit-cc3000-wifi-and-xively

Controlling actuators



Controlling actuators

Service offers **UI** or **API** to control actuators

Device **poll**s service for control data with GET

Or, service **push**es control data to device with POST or PUT

Device writes control data to **actuators**

Web service with Arduino

https://bitbucket.org/tamberg/iotworkshop/raw/e1a77b136284/Arduino/WebService/WebService.ino

Please change the MAC address, wait for DHCP to assign an IP and visit the URL displayed in the log

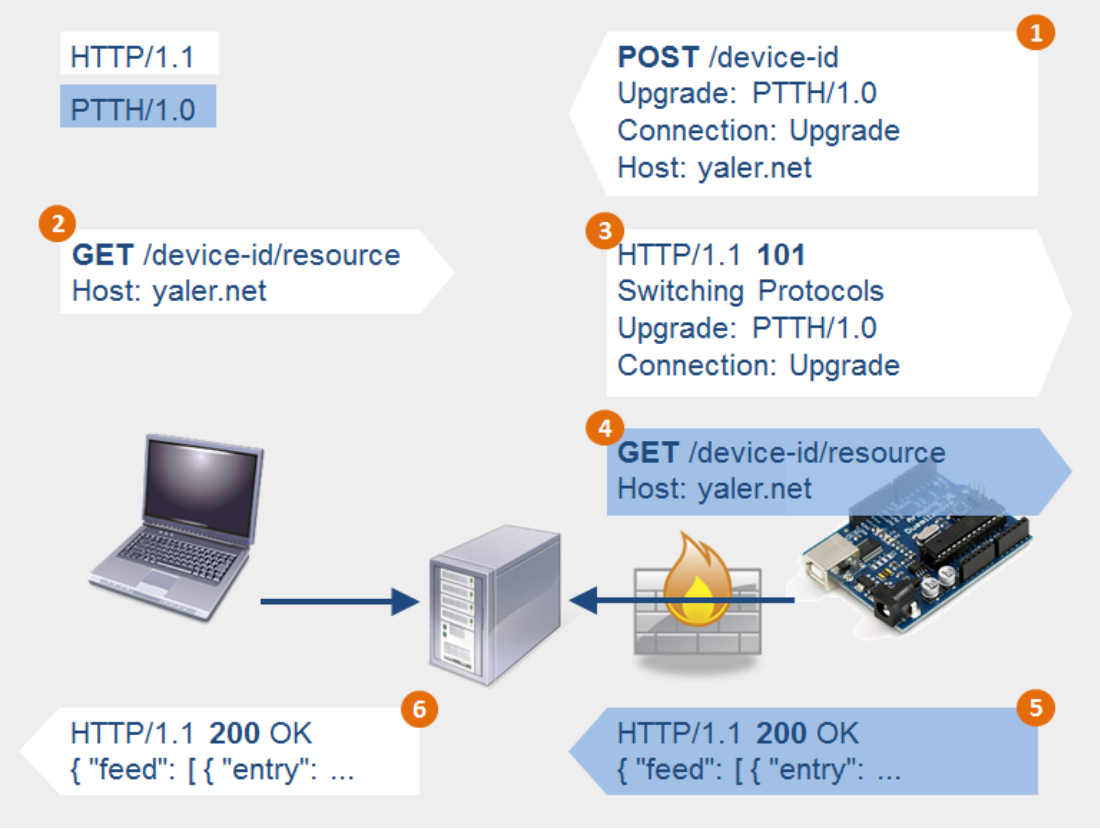
Make sure to add an EthernetShield to your Arduino & plug it into a LAN

Open the serial monitor window to see log output

Note: your Arduino is now a (local) Web server

Yaler

The **Yaler** relay provides a public and stable URL to access Web services behind a firewall or NAT



Note: please visit http://yaler.net/ and sign up to get your relay domain and API key (free)

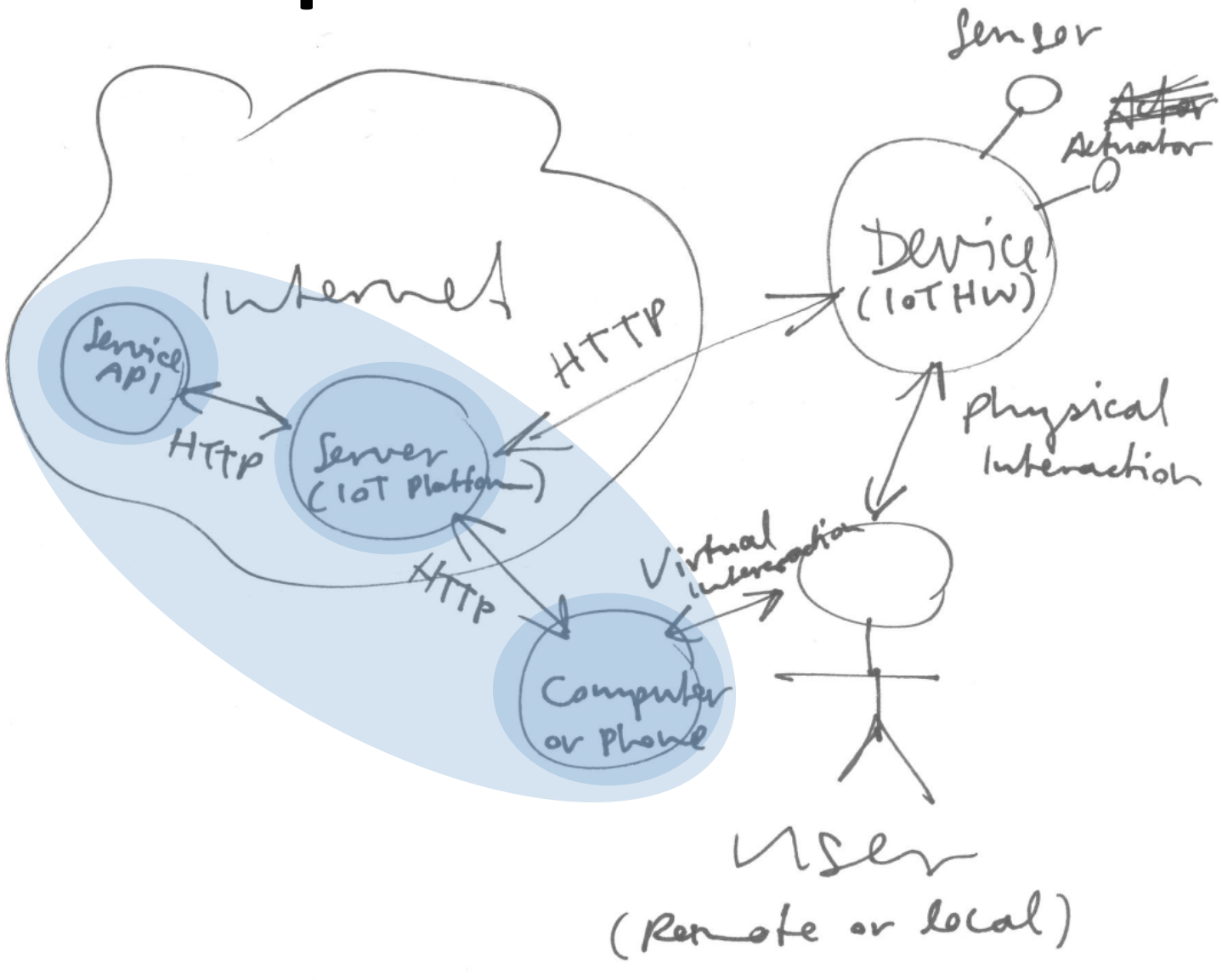
Yaler with Arduino

For remote Web access with Ethernet, see
https://yaler.net/arduino

For the WiFi shield, see
https://yaler.net/arduino-wifi

And for the CC3000, see
https://yaler.net/arduino-cc3000

Mash-ups



Mash-ups

A **mash-up** combines two or more Web services

Once **devices** have APIs, they **become scriptable**

Logic moves out of device, **into the Cloud**, e.g. Web-enabled LED + Yahoo Weather API = ambient weather notification

Note: the IoT enables physical mash-ups of things

Mash-ups

HTML combining data from multiple APIs **on the Web client**, using **Javascript** XMLHttpRequest to get data (in **JSONP**, to bypass same origin policy)

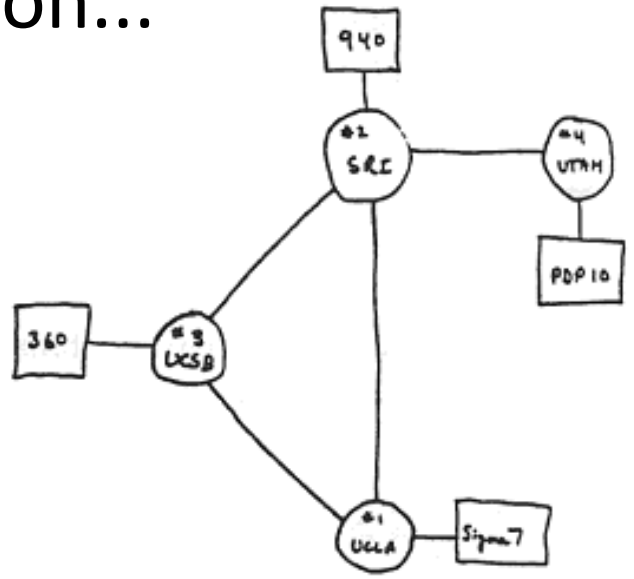
Scripting (C#, Python, Go, …) glue code hosted on a **desktop** or **in the cloud** (EC2, AppEngine …)

Mash-up platforms (IFTTT.com, Zapier.com, …)

Note: open data formats and APIs enable mash-ups

How the Internet works

If you wonder what TCP/IP, HTTP or DNS means - or care about the difference between protocol, data format and API, read on...



THE ARPA NETWORK

DEC 1969

Protocols

Parties need to agree on **how to exchange** data

(communicating = exchanging data according to a protocol)

e.g. **Ethernet** links local computers physically,

TCP/IP is the foundation of the **Internet**, and **HTTP** is the protocol that enables the **Web**

Note: protocols are layered, e.g. HTTP messages transported in TCP/IP packets sent over Ethernet

TCP/IP

IP (**I**nternet **P**rotocol) deals with host addressing (each host has an **IP address**) and packet routing

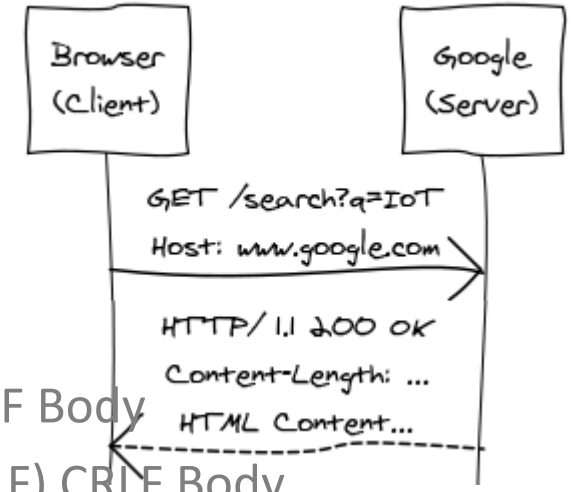
TCP (**T**ransmission **C**ontrol **P**rotocol): connection oriented, reliable data stream (**packets** in-order, errors corrected, duplicates removed, discarded or lost packets resent) from client to server

Note: *DHCP* assigns an *IP address* to your device which is mapped to the device's *MAC address*

HTTP

HTTP (**H**yper**t**ext **T**ransfer **P**rotocol) enables the distributed, collaborative system we call the **Web**

The **client** sends an HTTP **request**, the **server** replies with a **response**



HTTP Message = Request|Response

Request = (GET|POST|…) Path CRLF *(Header CRLF) CRLF Body

Response = "HTTP/1.1" (200|404|…) CRLF *(Header CRLF) CRLF Body

CRLF = "\r\n"

(Read the spec: http://tools.ietf.org/html/rfc2616)

Note: HTTP is human readable, i.e. it's easy to debug

URIs

The **URI** (**U**niform **R**esource **I**dentifier) is a string of characters used to identify a resource

scheme	authority = host [':' port]	path
http://	blog.tamberg.org	/2011-10-17/side-projects.html

(Read the spec: http://tools.ietf.org/html/rfc3986)

QR codes, ***NFC tags*** can contain a machine readable URI

IoT: URIs can refer to things or their physical properties

Note: good URIs can be hand-written on a napkin and re-typed elsewhere, without any ambiguity

DNS

DNS (**D**omain **N**ame **S**ystem) maps Internet domain names to one or more IP addresses

Try it in your desktop computer terminal, e.g.

*$ nslookup **google.com***

173.194.35.6 …

Note: if your device doesn't support DNS you can connect to the server's IP, but beware of changes

Data formats

Parties need to agree on **what is valid** content
(parsing = reading individual content tokens)

CSV: easy to parse, suited for tables, old school
JSON: easy to parse, de facto standard
XML: used by many services, W3C standard
Semi-structured text, e.g. Twitter's @user, #tag
Binary formats, e.g. PNG, MP3, …

RSS

In addition to generic data formats like CSV, JSON, XML there are refinements that **add semantics** to the document

RSS (or **Atom**) is a data format for **lists** of **items**

Invented for blogs, RSS is great for **data feeds**

Note: RSS documents are also XML documents, but not all XML documents contain valid RSS

HTML

HTML (**H**yper**t**ext **M**arkup **L**anguage) is a data format describing how a Web page should be structured and displayed

Look at the HTML (and Javascript) code of any Web page with "**view source**" in your browser

Note: HTML documents are not always valid XML documents, but Web browsers are very forgiving

APIs

An **API** (**A**pplication **P**rogramming **I**nterface), is an agreement between clients and providers of a service on **how to access a service**, how to **get data out** of it or **put data into it**

The **UI** (User Interface) of a service is made **for humans**, the **API** is made **for other computers**

Note: good APIs are documented or self-explanatory

REST

REST (**Re**presentational **S**tate **T**ransfer) is a style of designing an API so that it is easy to use

REST APIs use **HTTP methods** (GET, PUT, POST, DELETE) to let you perform actions on **resources**

REST APIs can be explored by following links

Note: good Web UIs are often built following the same principles, therefore REST APIs feel natural

Sharing network connections

Most newer computer operating systems allow sharing network connections with other devices

Mac OSX: *System Preferences > Sharing > Internet Sharing* > From *Wi-Fi* to *Ethernet*

Windows 7: *Control Panel > View network status and tasks > Change adapter settings* > right click *Wireless Network Connection > Properties > Sharing > [x] Allow other network users to connect … > Local Area Connection*

Note: helpful for demos, if there's Wi-Fi but no LAN

Debugging Web services

Chrome > *Inspect Element* > *Network, Console*

cURL for HTTP requests (http://curl.haxx.se/)

Requestbin for Webhooks (http://requestb.in/)

Fiddler (http://www.fiddler2.com/)

WireShark (http://www.wireshark.org/)

Debugging USB or Bluetooth

On Mac OSX and Linux

list connected devices with ***ls /dev/tty****

display output with ***screen /dev/tty... 9600***

On Windows

list devices, fix drivers with ***devmgmt.msc***

display serial output with **PuTTY**

Energy

Wall socket, Power over Ethernet (w/ adapters), batteries (direct or Minty Boost USB charger), LiPo batteries (also shields), solar panels, …

Low power: lets hardware sleep to save energy

Future: new battery technologies, ultra low power hardware, energy harvesting

Note: Moore's law does not apply to batteries

Learning more

Electronics: Ohm's law, Kirchhoff's current and voltage law (KCL & KVL), *Make: Electronics* by Charles Platt

Interaction Design: *Smart Things* by Mike Kuniavsky, *Emoticomp* blog post by Ben Bashford, BERG blog

Physical Computing: *Making Things Talk* by Tom Igoe

REST: *RESTful Web Services* by Leonard Richardson

Programming: read other people's code

IoT: *Designing the Internet of Things* by Adrian McEwen and Hakim Cassimally, Postscapes.com, IoTList.co

Note: MechArtLab Zürich has an OpenLab on Tuesdays

Reducing E-waste

Tired of hacking?

Donate your hardware to a local hackerspace…

e.g. MechArtLab

Hohlstrasse 52

8004 Zürich

DIY IOT FTW

Thank you