SensorLab

The web of things

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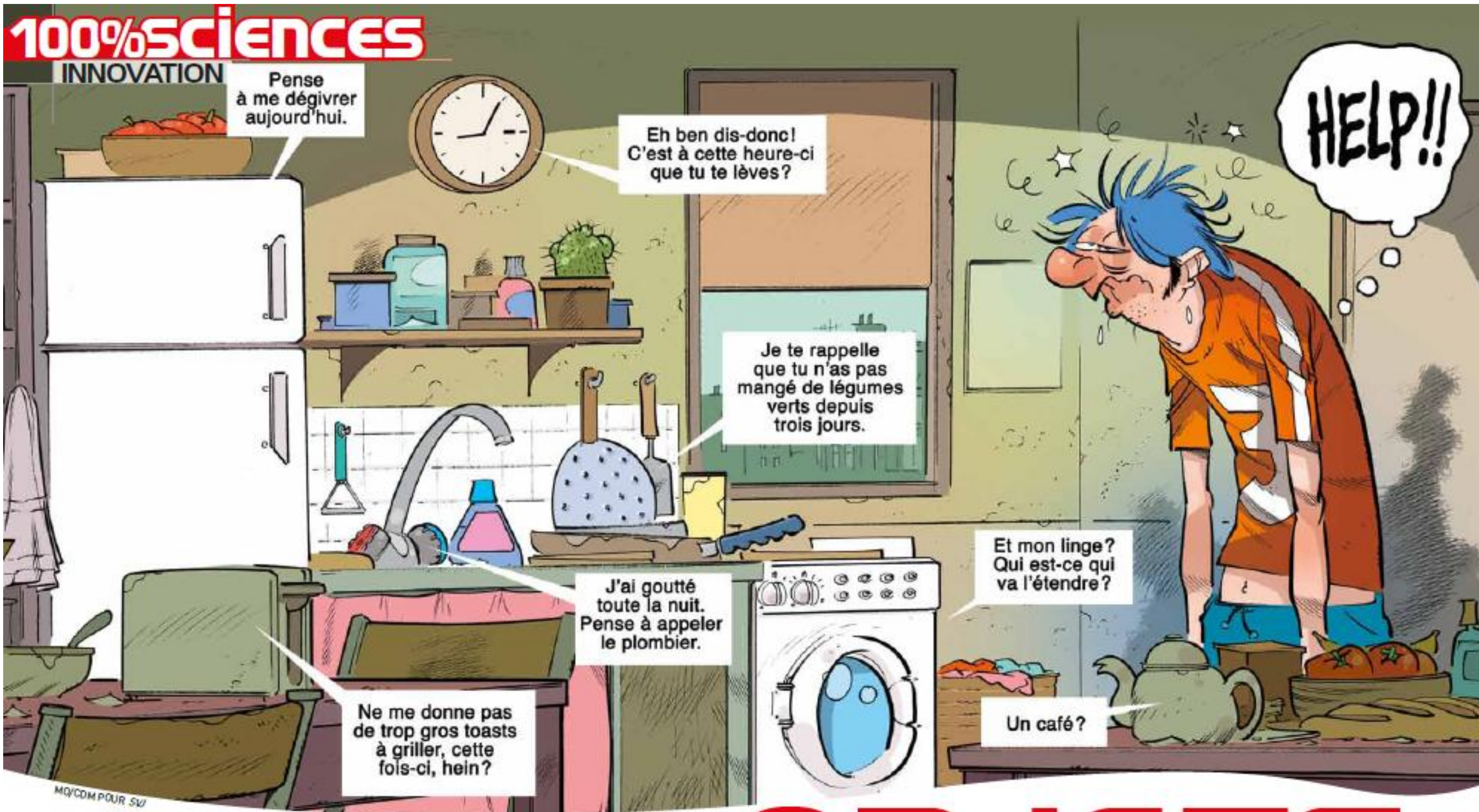
The WoT explained to children



L'Internet des Objets, SVJ 268

A case for the web of things

Facts:

- March 11, 2011: Tōhoku earthquake and tsunami in Japan
- Nuclear reactors were affected: explosions and radioactive pollution
- Confusing information about the **levels of radioactivity** from authorities
- **Radiation level maps** based on Geiger counter data started to appear

http://en.wikipedia.org/wiki/2011_Tōhoku_earthquake_and_tsunami

http://wikileaksreputationcrisis.wordpress.com/2011/03/13/fukushima-nuclear-crisis-media-coverage-evolution/

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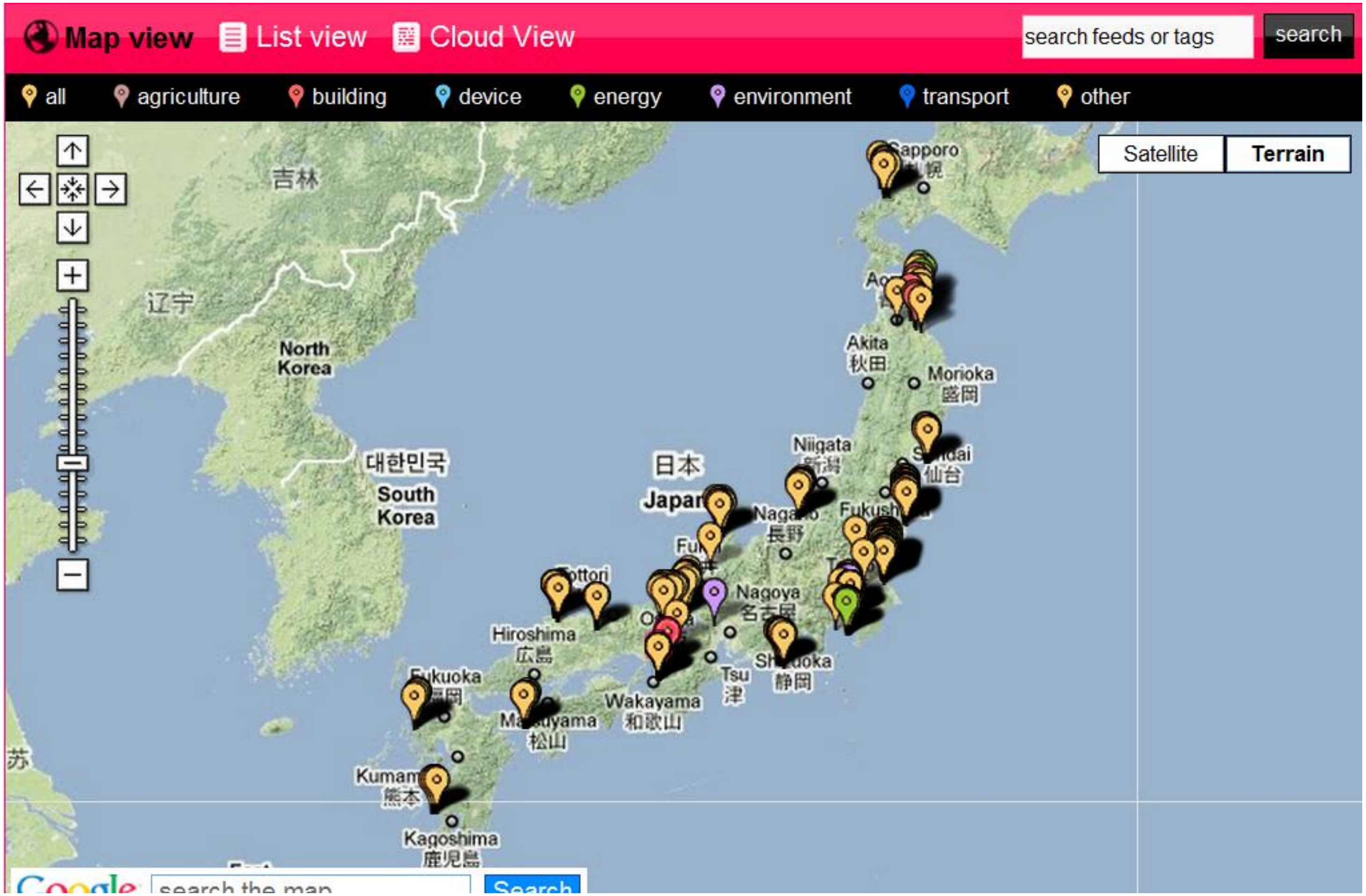
Radiation level map



http://blog.pachube.com/2011/03/real-time-radiation-monitoring-in-japan.html

Radiation level map

http://japan.failedrobot.com/

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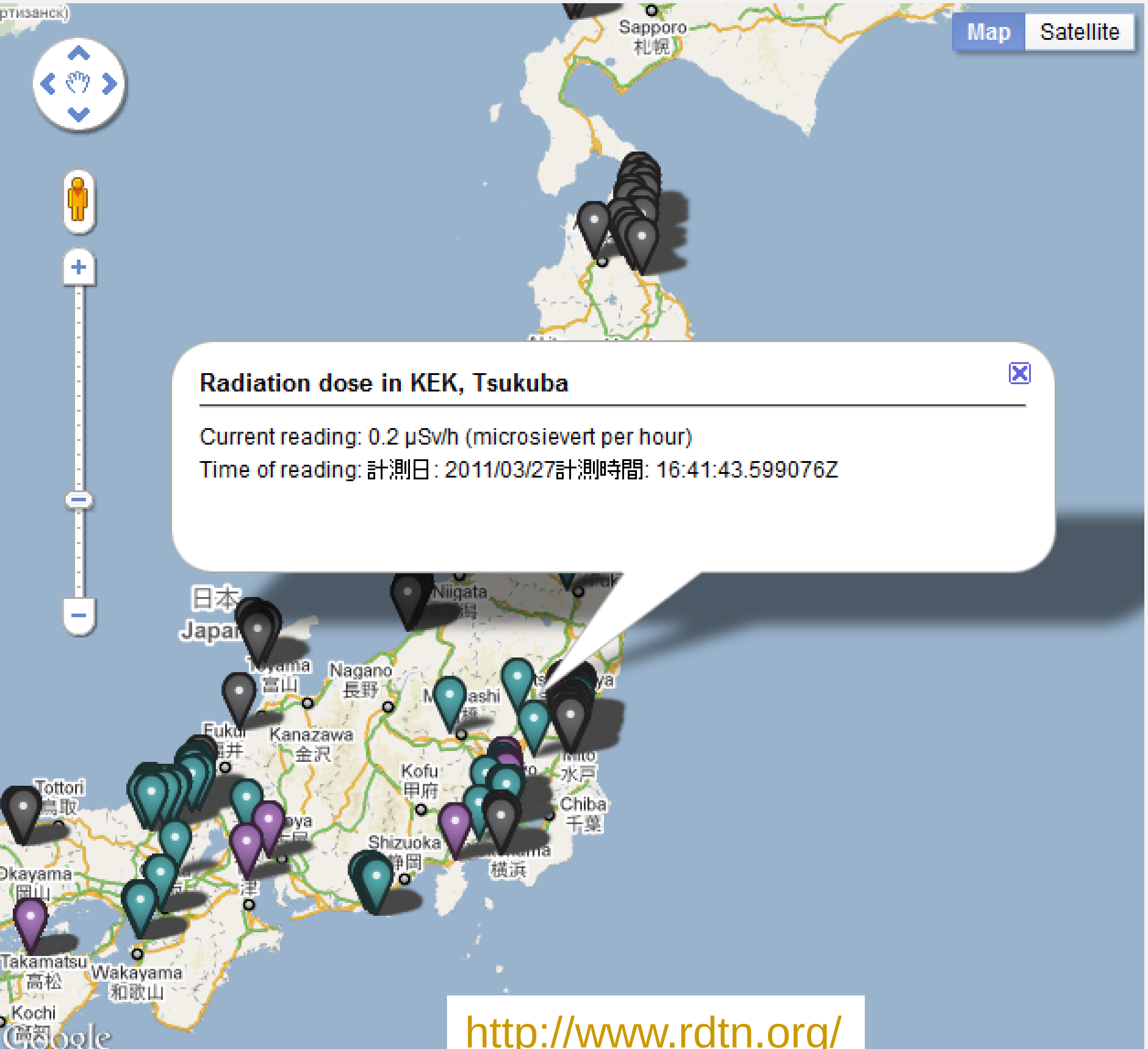
Radiation level map



http://www.rdtn.org/

Readings

We too have been watching events unfold in Japan. We have created this site in an effort to display the reliable data readings as they become available. Although we are careful to evaluate new data sources, we welcome new reliable data from those on the ground in this crisis.

To submit readings

1) Purchase a radiation detection device.

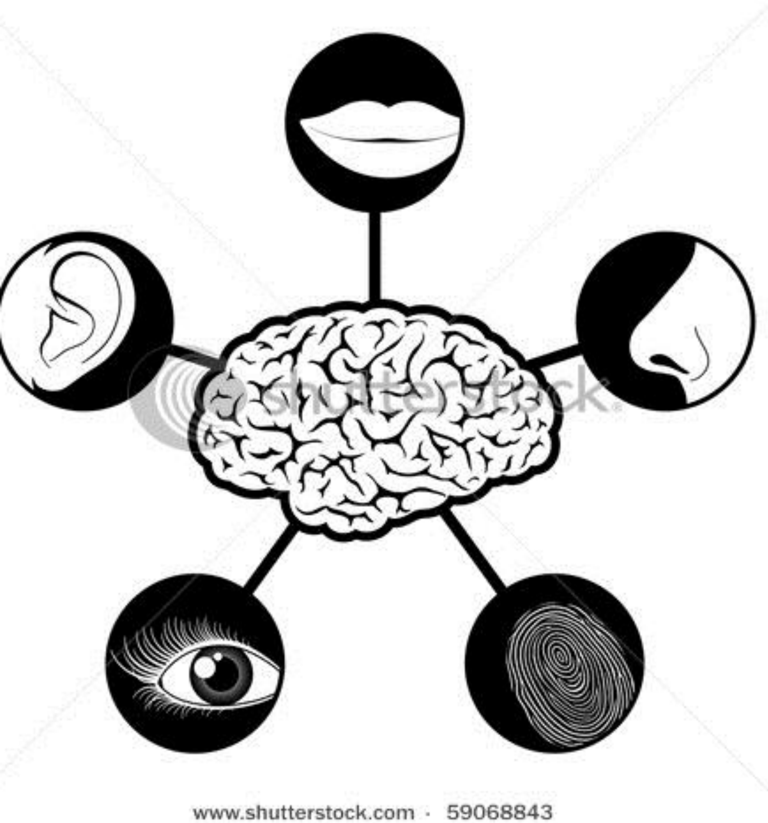
- INTERNATIONAL MEDCOM
- AMAZON
- LAB SAFETY SUPPLY
- COLE-PARMER

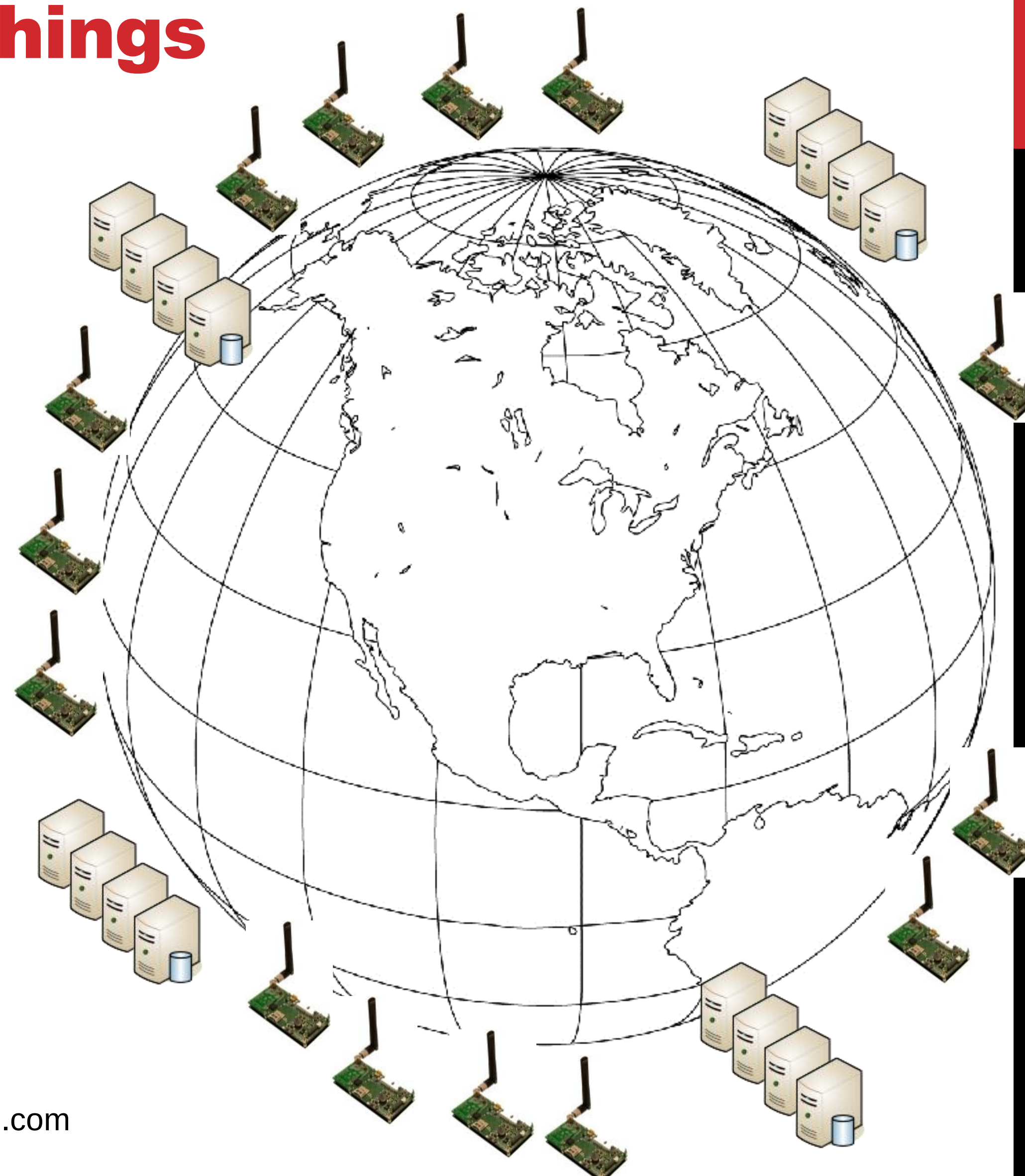
2) Take readings in your area.

3) Post readings to RDTN.

SUBMIT A READING ›

Analogy humans - things





Pictures: http://www.shutterstock.com, freeusandworldmaps.com

Fortuna et al., Towards Building a Global Oracle: a Physical Mashup Using Artificial Intelligence Technology, International Workshop on the Web of Things, 2012.

Outline

Part I. Motivation & background

Part II. Technology and tools for exploiting the WoT

Part III. Demos, tools & research directions

Part I. Motivation & background outline

Web Of Things

- What is it? What problems can it solve?

Architectural considerations

- How it looks like? What are its components?

The “Things”

- What are the ingredients?

The “Glue”

- How do things stick together?

Applications and services

- What can be built on top of it?

Quick start recipes

- How does the “Hello World!” look like?

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How Web-of-things fits on the map?

	Description	Technologies
Web 1.0	**Static** HTML pages (web as we first learned it)	HTML, HTTP
Web 1.5	**Dynamic** HTML content (web as we know it)	Client side (JavaScript, DHTML, Flash, …), server side (CGI, PHP, Perl, ASP/.NET, JSP, …)
Web 2.0	**Participatory** information sharing, interoperability, user-centered design, and collaboration on the World Wide Web (web of people)	weblogs, social bookmarking, social tagging, wikis, podcasts, RSS feeds, many-to-many publishing, web services, … URI, XML, RDF, OWL, SparQL, …
Web 3.0	…definitions vary a lot – from Full Semantic Web to AI (web as we would need it)	http://en.wikipedia.org/wiki/Web_3.0#Web_3.0
Web of Things	Everyday devices and objects are connected by fully integrating them to the Web. (web as we would like it)	Well-accepted and understood standards and blueprints (such as URI, HTTP, REST, Atom, etc.) http://en.wikipedia.org/wiki/Web_of_Things

Web of Things vs Internet of Things: what is the difference?

Internet = Interconnected networks

- They are interconnected via IP (Internet Protocol)
- There are IP addresses in the internet, no domain names such as wikipedia.org
- Started around 1950 in a effort to make two computers talk to each other

Web = Linked documents and resources

- Uses HTTP
- The web needs the Internet underneath to function
- Started around 1980 in an effort to help people share data over the Internet

Transition towards machine generated information

Past:

"manual input of information by 500 million or a billion users"[1]

Future:

"new information can be created automatically without human data entry… the next generation of sensor networks can monitor our environment and deliver relevant information – automatically.[1]

[1] Pete Hartwell, How a Physically Aware Internet Will Change the World, Mashable, October 13, 2010.

Web of things use cases

Motivated by an increased interest in automatic management of large systems

- Commercial use cases[1] (non-exhaustive list):
  - Power grids
  - Transport systems
  - Water distribution
  - Logistics
  - Industrial automation
  - Health
  - Environmental intelligence
- Academic
  - Distributed sensing infrastructure

Alternative solutions

Ethical issues and abuse[1]

[1] Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

Commercial use case: Power grids[1]

“If the power grid in America alone were just 5% more efficient, it would save greenhouse emissions equivalent to 53m cars (IBM).“

Solutions:

- demand pricing – 10-15% peak hour demand cut
  - Energy consumption monitoring with smart meters encourage shifting consumption to off-peak hours through personalized price plans
- demand response – extra 10-15% cut
  - Save energy by sensing and actuation: smart meters + actuators turn off air-conditioning systems when demand for electricity is high

[1]Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

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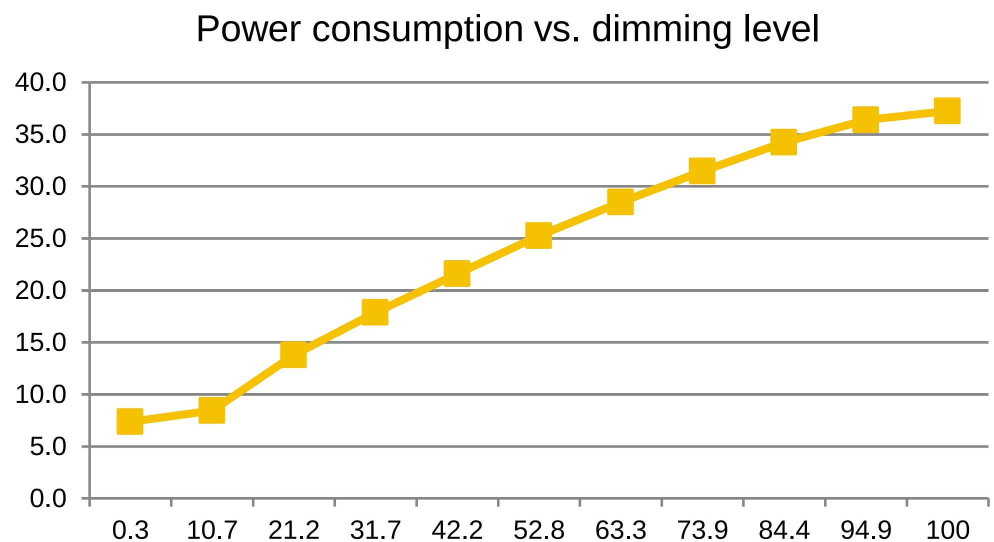
Public lighting control: greener lights + control

Dimming level [%]	Power consumption [W]
0,3	7,4
10,7	8,4
21,2	13,8
31,7	17,9
42,2	21,6
52,8	25,2
63,3	28,5
73,9	31,5
84,4	34,2
94,9	36,4
100	37,2



SGA LSL 30 main characteristics

- the number of LED: 30*1w
- consumption: 35W (at full power)
- colour of the light: 4200K
- light current: 2700lm
- life-expactancy: min. 60.000h
- IP66
- NET mass: 4,8k

Public lighting control: lights dimming

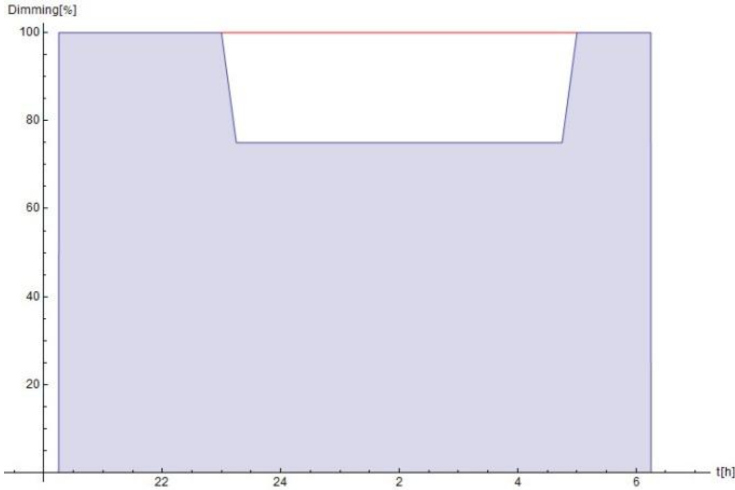
Lights dimmed to 75% luminosity between 23:00 and 5:00 with smooth 15-minute linear transitions.

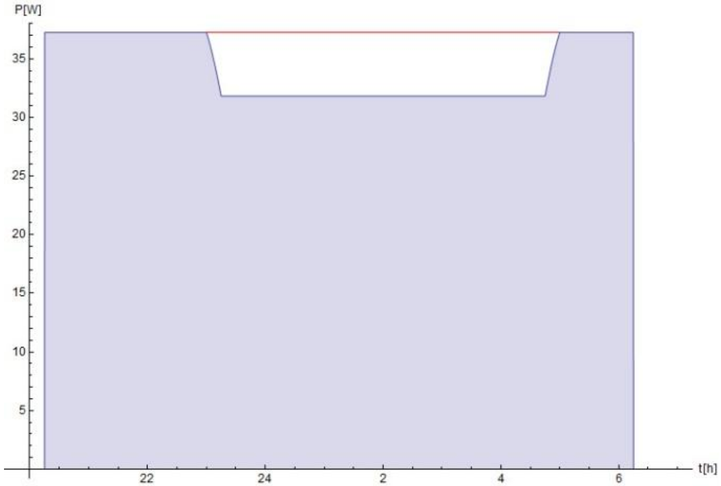
$$P(not\ dimmed) = 37.2W$$
$$P(dimmed) = 31.8W$$

Electricity consumption per night:

$$A_e(no\ dimming) = 0.372kWh$$
$$A_e(dimming) = 0.341kWh$$

Reduced by ~ 8,3%.





Dimming and power in time. Red line represents light poles with no dimming.

Commercial use case: Transport systems[1]

"In 2007 its congested roads cost the country 4.2 billion working hours and 10.6 billion litres of wasted petrol (Texas Transportation Institute)" [1]

Solutions:

- Charging for city centers and busy roads
  - London, Stockholm, Singapore, etc.
- Green wave
  - Adjustment of traffic lights to suit the flow of vehicles
- Automatic parking guidance
  - Singapore is developing a parking-guidance system (cars looking for somewhere to park are now a big cause of congestion).
- Real-time dynamic pricing
  - Singapore

[1] Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

Commercial use case: Water distribution[1]

Utilities around the world lose between 25% and 50% of treated water to leaks (Lux Research).

Solutions:

- Renew infrastructure
  - London, UK, Thames Water was losing daily nearly 900m litres of treated water and had to fix 240 leaks due to aging infrastructure[1].
- Install sensors for monitoring the pipe system
  - Automatically detect leaks fast (instead of customers calling and reporting leaks). London, Singapore, etc.
- Automate the management and maintenance process
  - Automatic scheduling of work crews and automatic alerts (i.e. text messages to affected customers)

[1] Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

Water distribution

WaterWiSe in Singapore

- develop generic wireless sensor network capabilities to enable real time monitoring of a water distribution network.
- three main applications:
  - On-line monitoring of hydraulic parameters within a large urban water distribution system.
  - Integrated monitoring of hydraulic and water quality parameters.
  - Remote detection of leaks and prediction of pipe burst events.

http://aqueduct.nus.edu.sg/waterwise/

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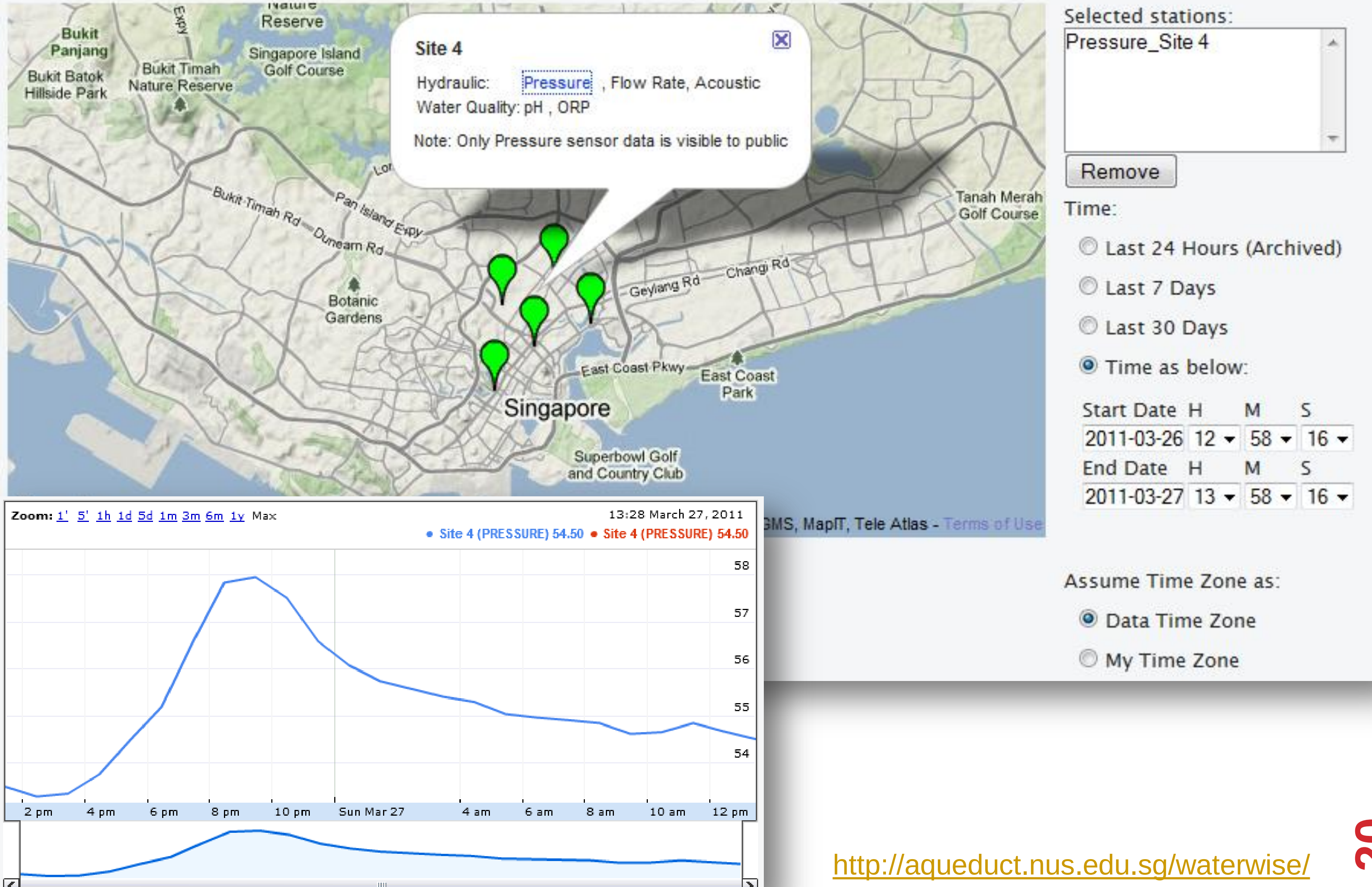
You are free to play with a limited data sets from a few deployment sites you see on the interactive map. We are streaming a lot more data for many more hydraulic, water quality and derived parameters from many other locations that are not available through this public portal.



http://aqueduct.nus.edu.sg/waterwise/

Commercial use case: Logistics

Cargo loss due to theft or damage is significant, estimates that the global financial impact of cargo loss exceeds $50 billion annually (The National Cargo Security Council)1. The cost is eventually passed to the customers.

Solutions:

- Automatic track and trace
  - Tag and trace their wares all along the supply chain (RFIDs and sensors) - and consumers to check where they come from (i.e. FoodLogiQ, SenseAware)[2]
- Event detection and mitigation
  - Detect events that affect the cargo (i.e. delay, inappropriate transport conditions) and minimize damage (i.e. re-route)

[1] Tom Hayes, The Full Cost of Cargo Losses

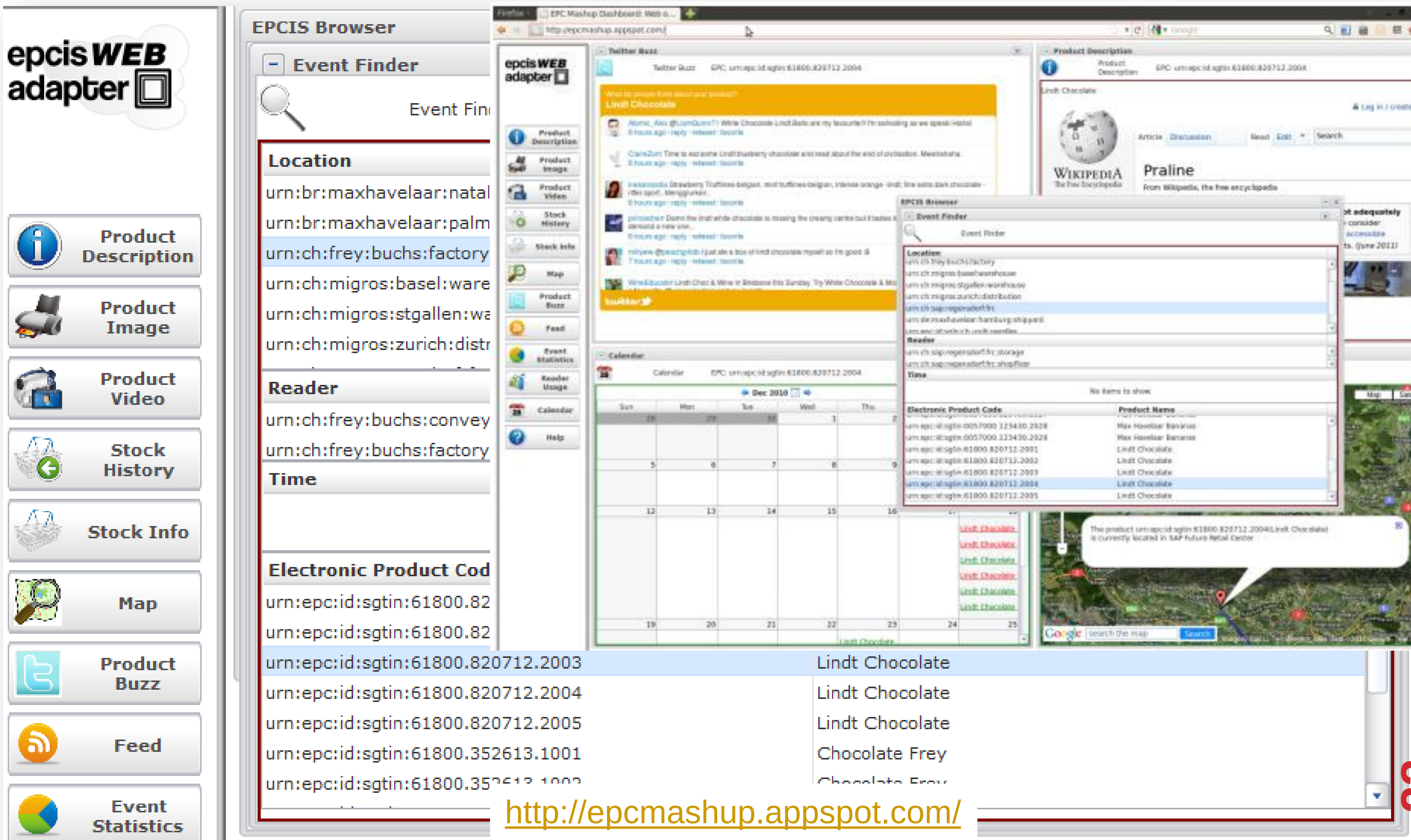
[2] Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

Logistics

- SenseAware
  - temperature readings
  - shipment’s exact location
  - shipment is opened or if the contents have been exposed to light
  - real-time alerts and analytics between trusted parties regarding the above vital signs of a shipment

http://www.senseaware.com/

Supply chain mash-up



http://epcmashup.appspot.com/

Commercial use case: Industrial automation

The integration gap between the production and business processes comes at a high cost, especially in multi-site enterprises.

Solutions:

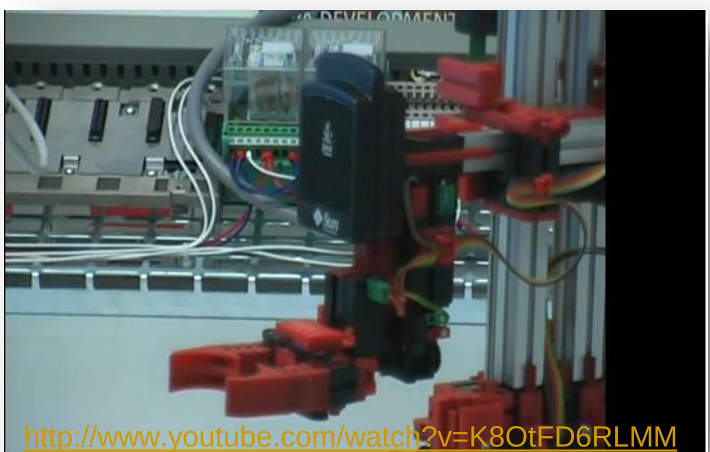
- Automatic monitoring of the production process
  - Monitor the devices on the production floor (i.e. robotic arm overheating)[1]
- Automatic event detection and notification
  - Process the measurements, detect anomalies and notify the business process (i.e. production at site interrupted, relocate)
- Productivity comparison
  - Machines equipped with sensors allow productivity comparison based on sensed data (i.e. Heidelberger Druckmaschinen)[2]
- Dynamic production optimization
  - 5% increase in paper production by automatically adjusting the shape and intensity of the flames that heat the kilns for the lime used to coat paper[2]

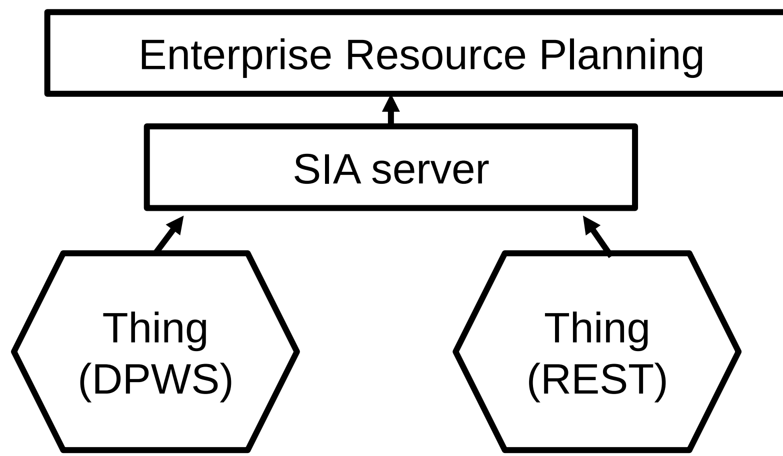
[1]SOCRADES project, http://www.socrades.eu/

[2]Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

Process integration

- SunSpot on Robotic ARM, exposing measurements as Web service
- SunSpot GW connected to Windows machine, then to the Enterprise Network or Internet
- Failure, production interruption alarm – moving to alternative production site





[1]SOCRADES project, http://www.socrades.eu

[2]D. Guinard, V. Trifa, S. Karnouskos, P. Spiess, D. Savio, Interacting with the SOA-based Internet of Things: Discovery, Query, Selection and On-Demand Provisioning of Web Services, IEEE Transactions on Services Computing, Vol. 3, July-Sept 2010.

Discover things

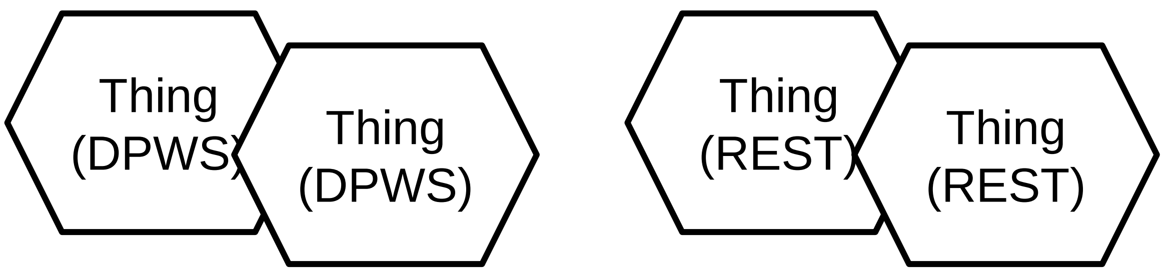
Automatic context data collection

Device Profile for Web Services (DPWS)

- Subset of Web Service standards (WSDL and SOAP)
- Successor of Universal Plug and Play (UPnP)

Representational State Transfer (REST)

- Lightweight, suitable for less complex services



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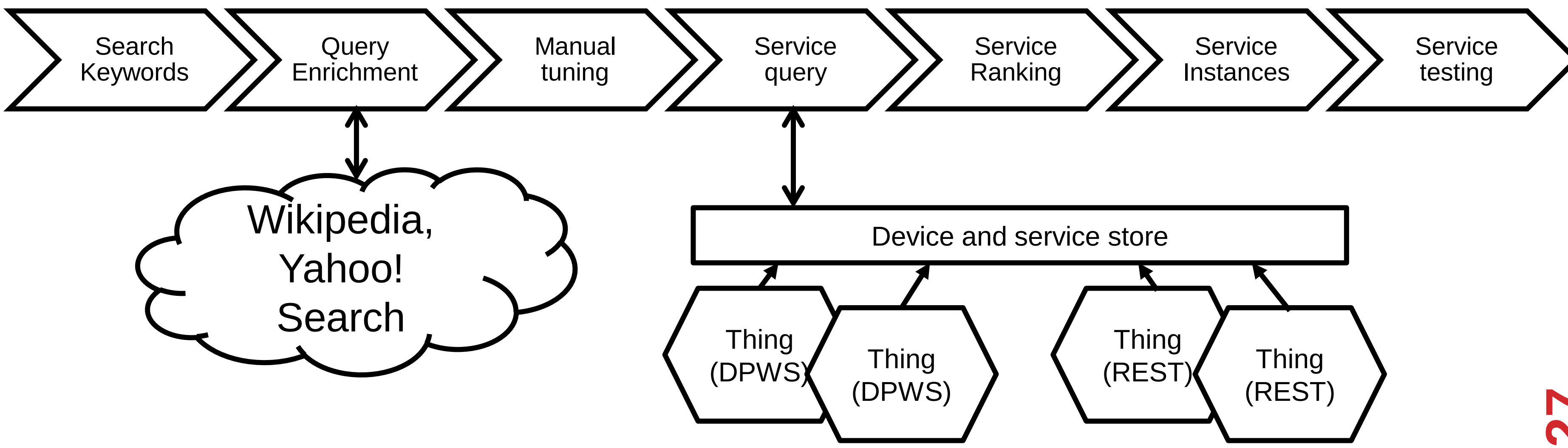
Query embedded services

- Insert search keywords, perform query enrichment (augmentation)
  - Tested 2 strategies: Wikipedia and Yahoo! Search
- Manually tune the augmented query by adding/deleting keywords
- Search services in the store and rank them according to some criteria (i.e. QoS)



Commercial use case: Health

In health care, sensors and data links offer possibilities for monitoring a patient's behavior and symptoms in real time and at relatively low cost.[1]

Solutions:

- Patient monitoring
  - When suffering from chronic illnesses can be outfitted with sensors to continuously monitor their conditions as they go about their daily activities.
    - Asthma, diabetes, heart-failure
- Extended healthcare for elders
  - Needs to extend from hospital to home care to ensure cost efficient provisioning and improve quality of living (ambient assisted living).
    - Fall detection, emergency call, user localization, hazard monitoring (toxic gases, water, fire)
- Fitness monitoring for personalized fitness scenario

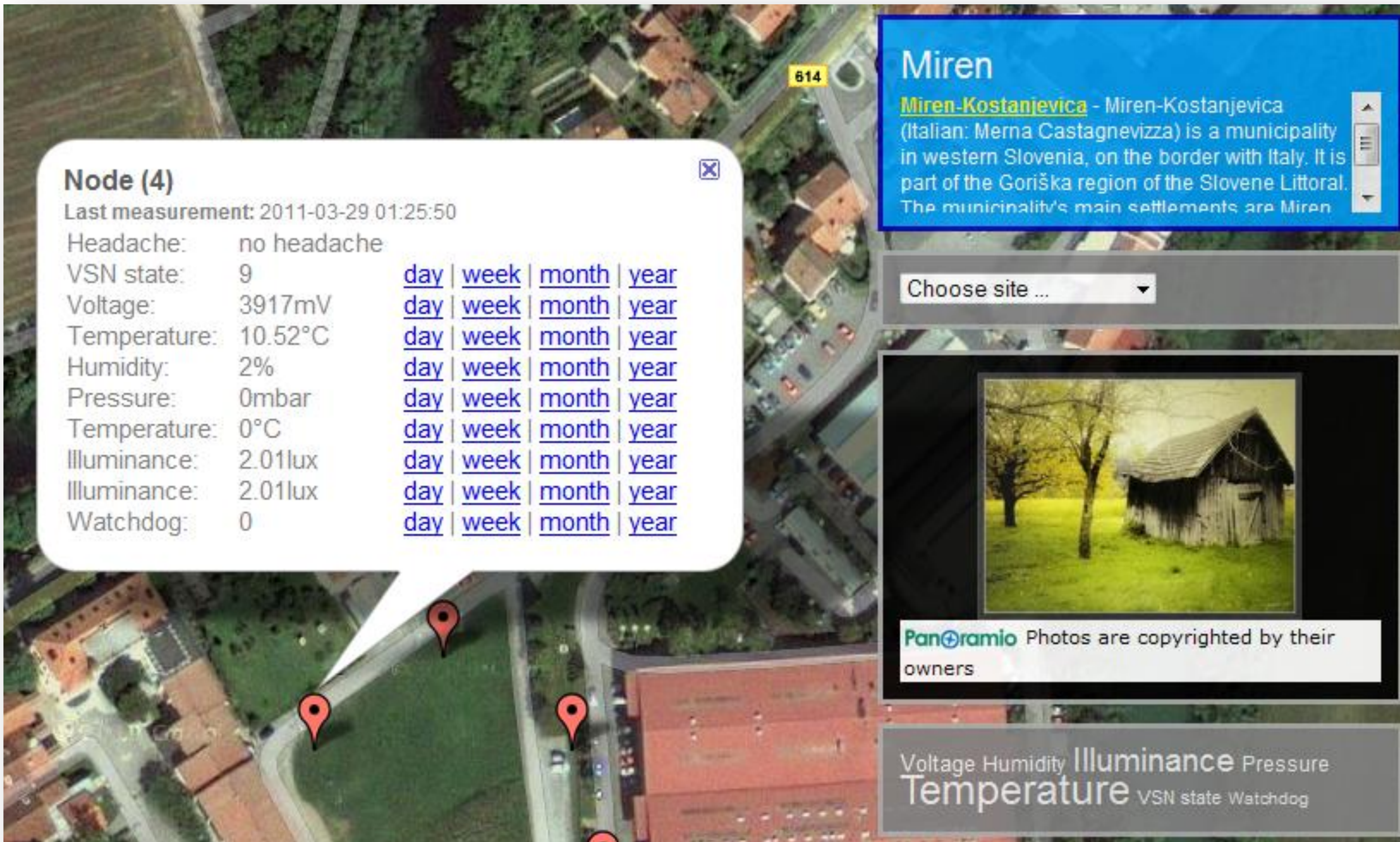
Commercial use case: Environmental intelligence

Data from large number of sensors deployed in infrastructure (such as roads) or over other area of interest (such as agriculture fields) can give decision makers a real-time awareness on the observed phenomena and events.

Solutions:

- Remote monitoring of cultures, soil moisture, insect infestations or disease infections
- Irrigation and pesticide spraying in precision agriculture
- Livestock monitoring for maximizing production (meat, milk, eggs) and achieve higher reproduction rates

Videk – AI mash-up



http://sensors.ijs.si/

Environmental monitoring

http://www.swiss-experiment.ch/index.php/Main_Page

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Coastal flood prediction

http://webgis1.geodata.soton.ac.uk/flood.html

Academic: Distributed sensing infrastructure

Scientists defines their hypothesis, collect the necessary data and then try to validate the hypothesis. Manually collected data is generally expensive to get[1] while access to large datasets is generally restricted by the owners.

Solution:

- Deploy sensors in small and medium size testbeds
  - On a riverbed, volcano, mountain, etc.
- Build an open data publishing and sharing platform which can federate the testbeds
- Share your data with others so that also others share it with you

[1]Matt Welsh, Sensor Network for the Sciences, Communications of the ACM, November 2010, Vol. 53, No. 11.

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Use Cases: Alternative solutions

Several of the previously mentioned use cases can be solved by other approaches, crowdsourcing being one of the most obvious.

Roadify, Waze are using real time traffic information reported by participants in traffic may solve traffic congestion problems

- Human “sensor” reporting and consuming via handheld terminals
- Costs and benefits will determine the best solution.

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Use Cases: Ethical issues and abuse[1]

- For every technology created for a noble purpose, less noble applications can be found and vice-versa.
- Smart systems may be used for privacy invading applications, for restricting the liberty of people, for creating chaos, misinformation, false alarms, etc.

[1] Ludwig Siegele, A special report on smart systems, The Economist, Nov. 4 2010.

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Part I. Motivation & background outline

Web Of Things

- What is it? What problems can it solve?

Architectural considerations

- How it looks like? What are its components?

The “Things”

- What are the ingredients?

The “Glue”

- How do things stick together?

Applications and services

- What can be built on top of it?

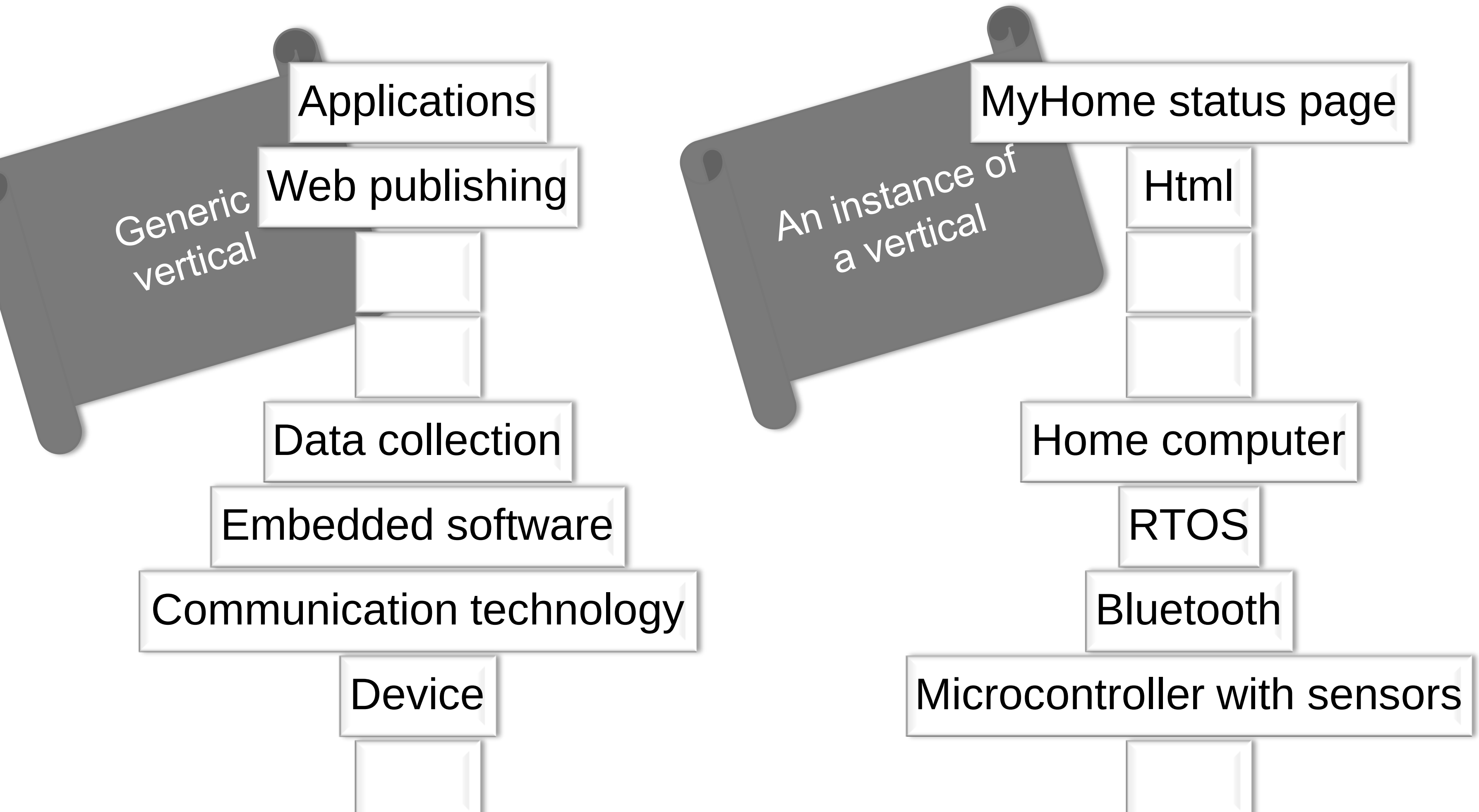
Quick start recipes

- How does the “Hello World!” look lilke?

Architectural considerations

Generic vertical	An instance of a vertical
Applications	Traffic today app
Web publishing	RSS feed
Data processing	Real time event detection software
Data storage	Utility company data center
Data collection	Utility company server
Embedded software	Proprietary firmware
Communication technology	6LoWPAN
Embedded device	Microcontroller with sensors
Physical object	Public light pole

Architectural considerations



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Main Components of a vertical

Layer	Component	Example
Apps and Services	Applications	Traffic today app
Apps and Services	Web publishing	RSS feed
“Glue”	Data processing	Real time event detection software
“Glue”	Data storage	Utility company data center
“Glue”	Data collection	Utility company server
“Glue”	Embedded software	Proprietary firmware
“Glue”	Communication technology	6LoWPAN
“Things”	Embedded device	Microcontroller with sensors
“Things”	Physical object	Public light pole

Part I. Motivation & background outline

- ✓ **Web Of Things**
  - What is it? What problems can it solve?
- ✓ **Architectural considerations**
  - How it looks like? What are its components?
- **The “Things”**
  - What are the ingredients?
- **The “Glue”**
  - How do things stick together?
- **Applications and services**
  - What can be built on top of it?
- **Quick start recipes**
  - How does the “Hello World!” look lilke?

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The "things"

"Things"

Embedded device

Physical object

Microcontroller with sensors

Public light pole

= embedded device + physical object (smart public light pole)

= sensor node (SunSpot, MicaZ, Sensinode, VESNA, WASPMote, etc)

= mobile phone

= a set of sensor nodes and/or embedded device + physical things which are abstracted as one "thing" (large water tank + set of sensor nodes monitoring water level, temperature and purity)

Definitions of components related to things

physical object

- An object built for fulfilling other tasks than computing
  - Coffee mug, show, light pole, washing machine, electric oven, fruit press, water tank

sensor

- a material or passive device which changes its (conductive) properties according to a physical stimulus
  - Thermo couple (temp->voltage), photo resistor (light->resistance variations), etc.

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Definitions of components related to things

embedded system

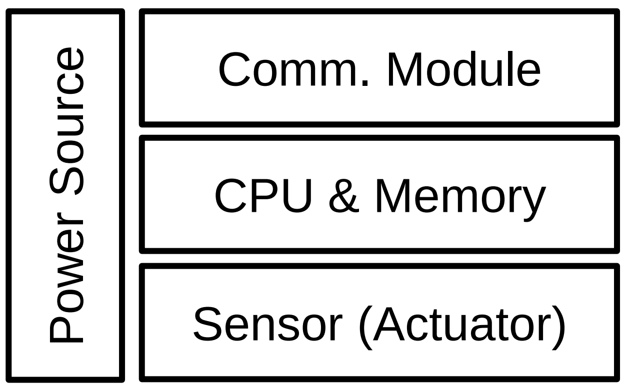
- A simple or complex system built into a physical device to perform dedicated functions and enhance the functionality through computation. It features actuators and/or sensors.
    - Microprocessor, microcontroller, DSP, FPGA or PLC based system built into a variety devices, including washing machines, electric ovens, industrial robots etc.

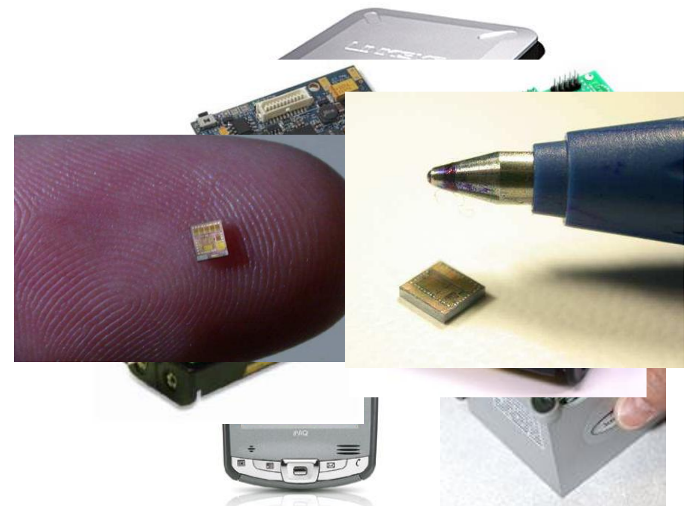
sensor node

- A computing and communicating device equipped with sensors and possibly actuators whose functionality revolves around measuring, reporting and possibly actuating. It can be standalone or embedded into physical objects.
    - Typically a device composed of microcontroller, power supply, communication interface and sensors/actuators.

Sensor nodes and their structure

= Sensors + Microcontroller + Communication Module + Power Source

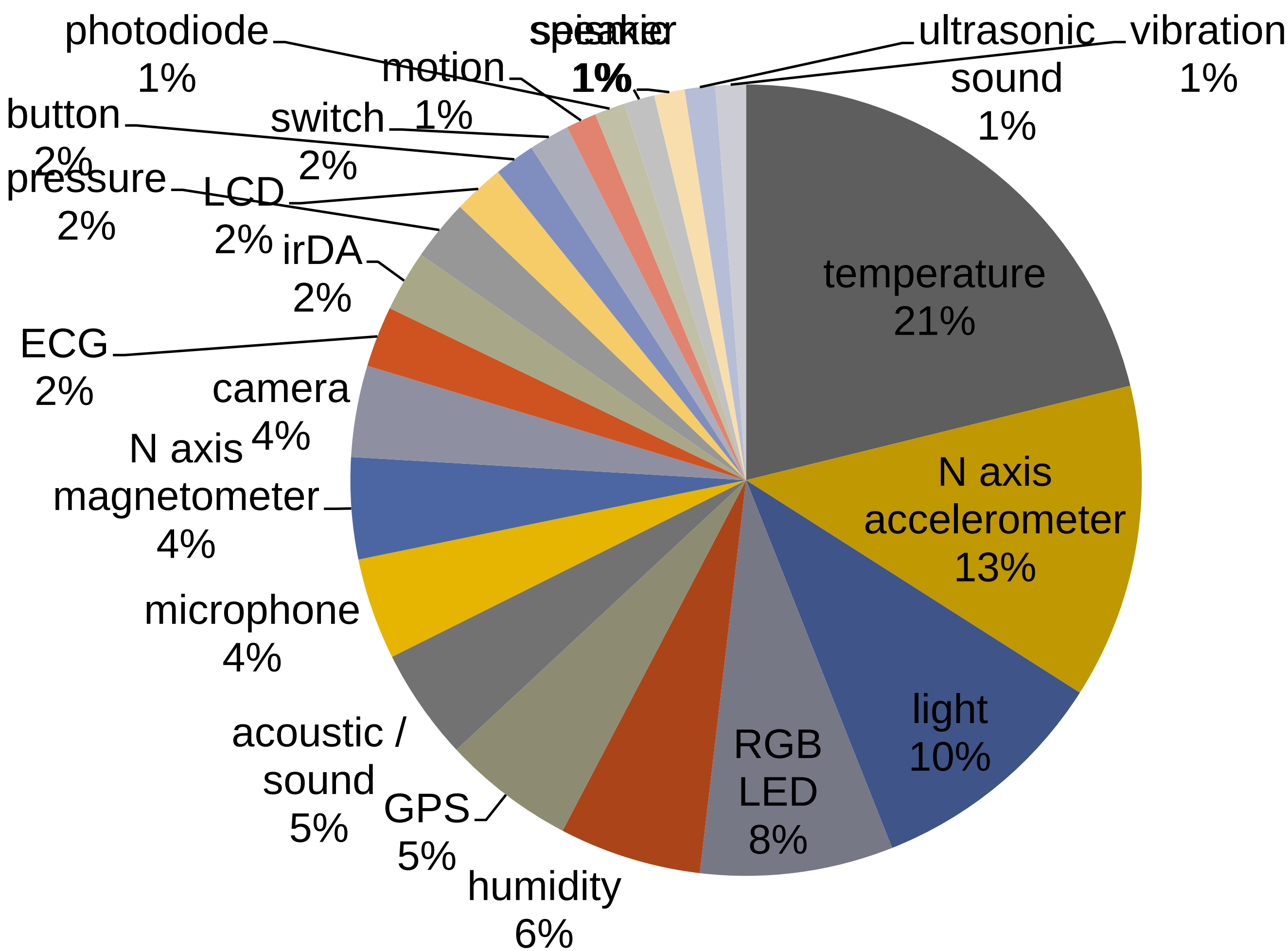




Classification:

- adapted/augmented general-purpose computers
- embedded sensor modules
- system on chip (SoC) solutions

Common types of sensors found in the literature



Existing solutions for sensor nodes

Solutions developed in **research community or by groups of enthusiasts**.

- Combine HW components from different produces (for radio, it seems that TI chips are used in vast majority of ‚products‘).
- open-source experimental software such as Contiki OS, TinyOS (& NesC), Nano-RK, FreakZ stack (except for Arduino/Libelium where OEM radio is used whilst crowdsourcing is happening on the level of easy microcontroller programming.
- open source development tools are usually used.

Commercial solutions from particular producers (TI, Atmel, Microchip,…)

- composed of components sold by produces themselves.
- development kits can usually be used with proprietary integrated development environments and allow compiling of certified stacks (most often Zigbee).

Modules assembled by **companies trying to sell software solu**tions

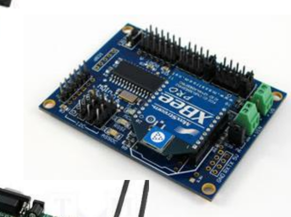
- Sun is in this case promoting the use of Java for sensor networks
- Sensinode is selling one of the 6LoWPAN ports.

Examples of the three categories of solutions

- FreakLabs Chibi
- Memsic (ex. Crossbow) MICAz/ MICA2, IRIS, TelosB, eKo kit
- CMU FireFly
- GINA
- Arduino/Libelium (XBee)

- TI eZ430-RF2500
- Microchip PICDEM Z
- Atmel RZ600
- Ember InSight
- Jennic JN5148

- SunSPOT
- Sensinode
- NanoSensor



Developer friendly hardware solutions for WoT compared

Solution	Pro	Con	Cost
Arduino	big community, open-source hw, documentation	Computational power	25-90 €
Nanode	built-in web connectivity, open-source hw, Arduino compatible	Computational power, documentation	~ 35 €
openPICUS	built-in web connectivity, good documentation, support	Computational power, development windows oriented	~ 70 €
Netduino	open-source hw, documentation, arduino compatible, .NET programming	Computational power, development windows oriented	25-90 €
libelium	documentation, solid, radio boards, sensors boards, over the air programming, libelium support.	Computational power	~ 150 €

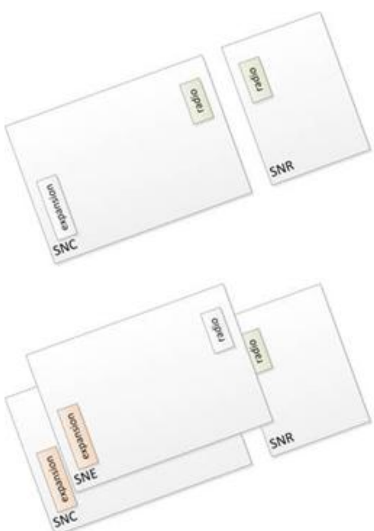
Hacking the Internet of Things, Hardware solutions compared, Lelylan Chief, Mar 09, 2012.

VESNA Sensor Node

Built at JSI, used for some of the demos presented in Part 3 of the tutorial.

Modular platform for wireless sensor networks (SNCore + SNRadio + SNApplication + SNPower = VESNA sensor node)

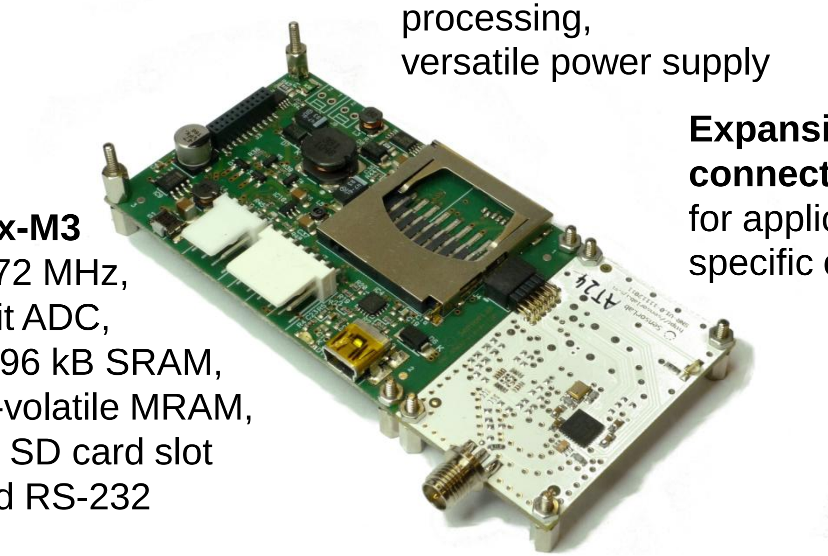
- High processing power and low energy consumption
- Sensor node & gateway (multi-tier / IP) capability
- Battery, solar or external power supply
- Re-configurable radio



Sensor Node Core (SNC)
data acquisition and processing,
versatile power supply

Expansion connector
for application specific circuits

ARM Cortex-M3
clock up to 72 MHz,
1 MHz 12-bit ADC,
1 MB flash, 96 kB SRAM,
128 kB non-volatile MRAM,
SD or micro SD card slot
USB 2.0 and RS-232 interface



VESNA Sensor Node

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SN-Core

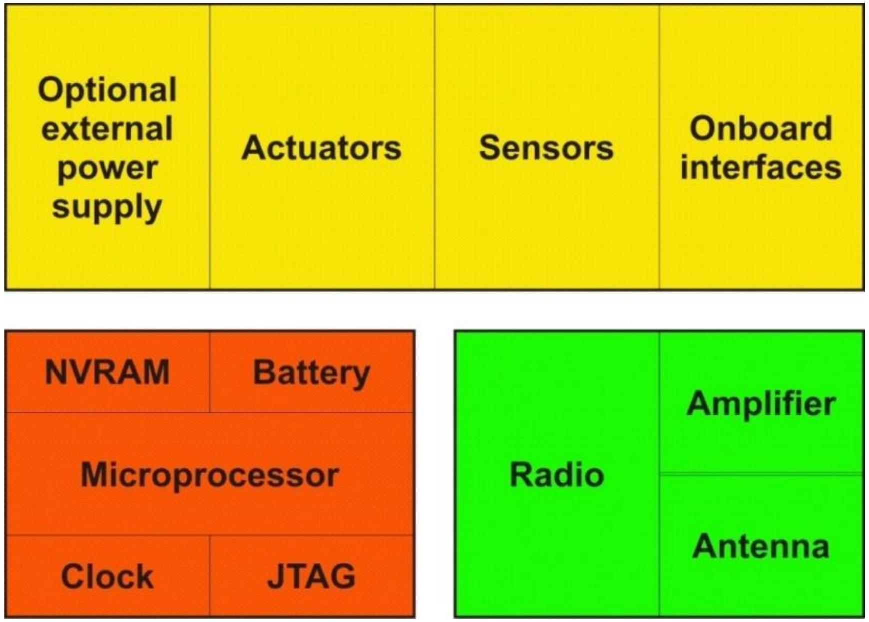
- Analog and digital sensor/actuator interfaces
- Possibility to use operating system (real-time, event-driven)
- Multiple expansion options
- Open C/C++ code libraries
- Onboard memory

SN-Radio

- 300-900 MHz, 2.4 GHz radio interface (all ISM bands)
- ZigBee, 6LoWPAN and other IEEE 802.15.4 based solutions

SN-Expansion

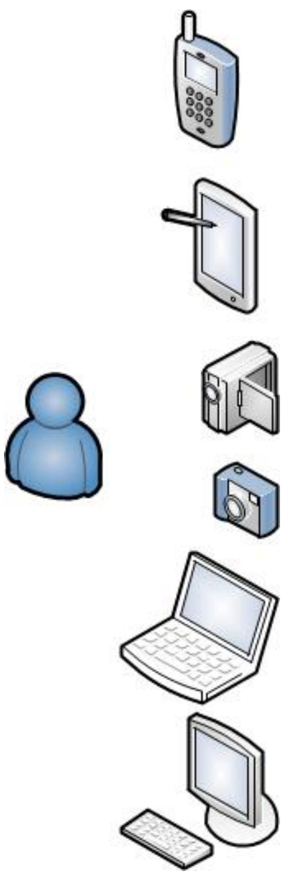
- Bluetooth, Wi-Fi, Ethernet, GSM/GPRS
- Sensors/actuators
- PoE



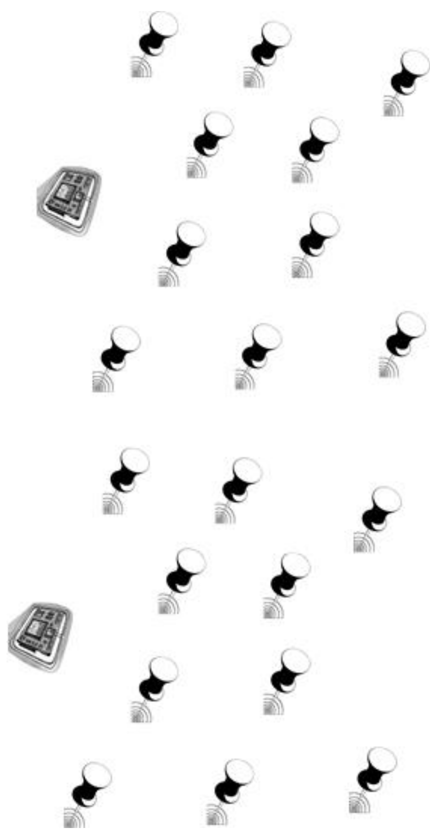
Why are sensor nodes different than other computing devices?

- Most SNs are application specific.
- Asymmetric, highly directional information flow (data fusion).
- Energy is highly constrained.
- Networks of SNs may have huge amount of nodes.
- Application run-time is extremely long.

Sensor nodes vs computing devices



Personal devices



Sensor nodes

Diminishing maintenance costs:

- Integrating sensors into personal computing devices such as phones/laptops
- Efficient remote configuration and management
- Disposable

Part I. Motivation & background outline

- ✓ **Web Of Things**
  - What is it? What problems can it solve?
- ✓ **Architectural considerations**
  - How it looks like? What are its components?
- ✓ **The “Things”**
  - What are the ingredients?
- **The “Glue”**
  - How do things stick together?
- **Applications and services**
  - What can be built on top of it?
- **Quick start recipes**
  - How does the “Hello World!” look lilke?

The “glue”

The communication

- The communication medium
- The network

Node centric programming

- operating system
- virtual machine

System level programming (macro-programming)

- distributed/centralized storage and retrieval
- content management

“Glue”

Data processing

Data storage

Data collection

Embedded software

Communication technology

Real time event detection software

Utility company data center

Utility company server

Proprietary firmware

6LoWPAN

Communication medium

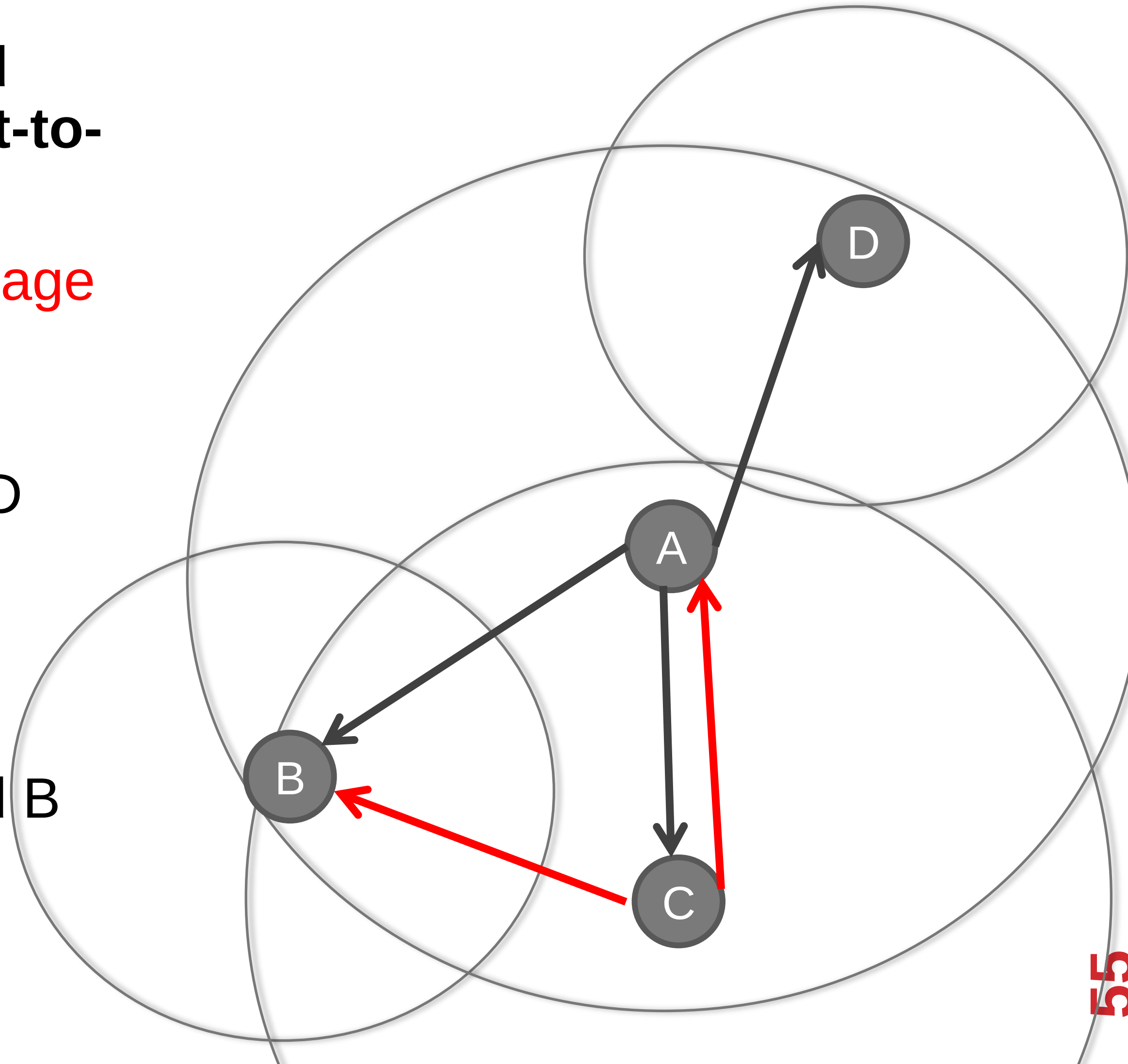
Wireless and/or Wired point-to-point or point-to-multipoint

B, C and D in the coverage range of A

- When A sends a message, B, C and D receive it

A, B in the range of C

- When C sends a message, only A and B receive it



Communication medium: open wireless standards

Wireless

- Mostly performed in **unlicensed bands according to open standards**
  - Standard: IEEE 802.15.4 - Low Rate WPAN
    - 868/915 MHz bands with transfer rates of 20 and 40 kbit/s, 2450 MHz band with a rate of 250 kbit/s
    - Technology: **ZigBee, WirelessHART**
  - Standard: ISO/IEC 18000-7 (standard for active RFID)
    - 433 MHz unlicensed spectrum with transfer rates of 200 kbit/s
    - Technology: **Dash7**
  - Standard: IEEE 802.15.1 – High Rate WPAN
    - 2.40 GHz bands with transfer rates of 1-24 Mbit/s
    - Technology: **Bluetooth** (BT 3.0 Low Energy Mode)
  - Standard: IEEE 802.11x – WLAN
    - 2.4, 3.6 and 5 GHz with transfer rates 15-150 Mbit/s
    - Technology: **Wi-Fi**

Communication medium: licensed bands

Wireless

- Sometimes in **licensed bands**
  - Standard: 3GPP – WMAN, WWAN cellular communication
    - 950 MHz, 1.8 and 2.1 GHz bands with data rate ranging from 20 Kbit/s to 7.2 Mbit/s, depending on the release
    - Technology: **GPRS, HSPA**

Communication medium: proprietary standards

Wireless

- Sometimes according to **proprietary standards and protocols**
  - **Z-Wave** – for home automation
    - 900 MHz band (partly overlaps with 900 MHz cellular) with data rates of 9.6 Kbit/s or 40 Kbit/s
  - **ANT** – for sportsmen and outdoor activity monitoring, owned by Garmin
    - 2.4 GHz and 1 Mbit/s data rates
  - **Wavenis** – for M2M periodic low data rate communication
    - 868 MHz, 915 MHz, 433 MHz with data rates from 4.8 Kbits/s to 100 Kbits/s
    - most Wavenis applications communicate at 19.2 kbits/s.
  - **MiWi, SimpliciTI, Digi** xxx, …

Communication medium: standards for wired communication

Wired

- Standard: IEEE 1901 - Power Line Communications (PLC) standard used for transmitting data on a conductor also used for electric power transmission
  - Frequencies and data rates vary, >100 MHz, data rates of up to 500 Mbit/s
  - Technology: **HomePlug**
- Standard: ITU G.hn – PLC for home grids
  - 100-200 MHz with data rate up to 1 Mbit/s
  - Technology: **HomePNA**
- Standard: IEEE 802.3 – High speed LAN
  - 10 Mbit/s – 100 Gbit/s
  - Technology: **Ethernet**

Communication technology: implementation aspects

Implementation of the technologies

- Traditionally HW
- Mostly HW + some SW
- Trend towards HW + mostly software

Communication Standard	Protocol Stack Implementation
IEEE 802.15.4	“Implementation of IEEE 802.15.4 protocol stack for Linux”
ZigBee	Z-Stack, Open-ZB, FreakZ, Microchip Stack
IEEE 802.11	smxWiFi
WirelessHART	“WirelessHART- Implementation and Evaluation on Wireless Sensors”, “WirelessHART: Applying Wireless Technology in Real-Time Industrial Process Control”
ISA100.11a	NISA100.11a
Bluetooth	TinyBT, Axis OpenBT, BlueZ, Affix

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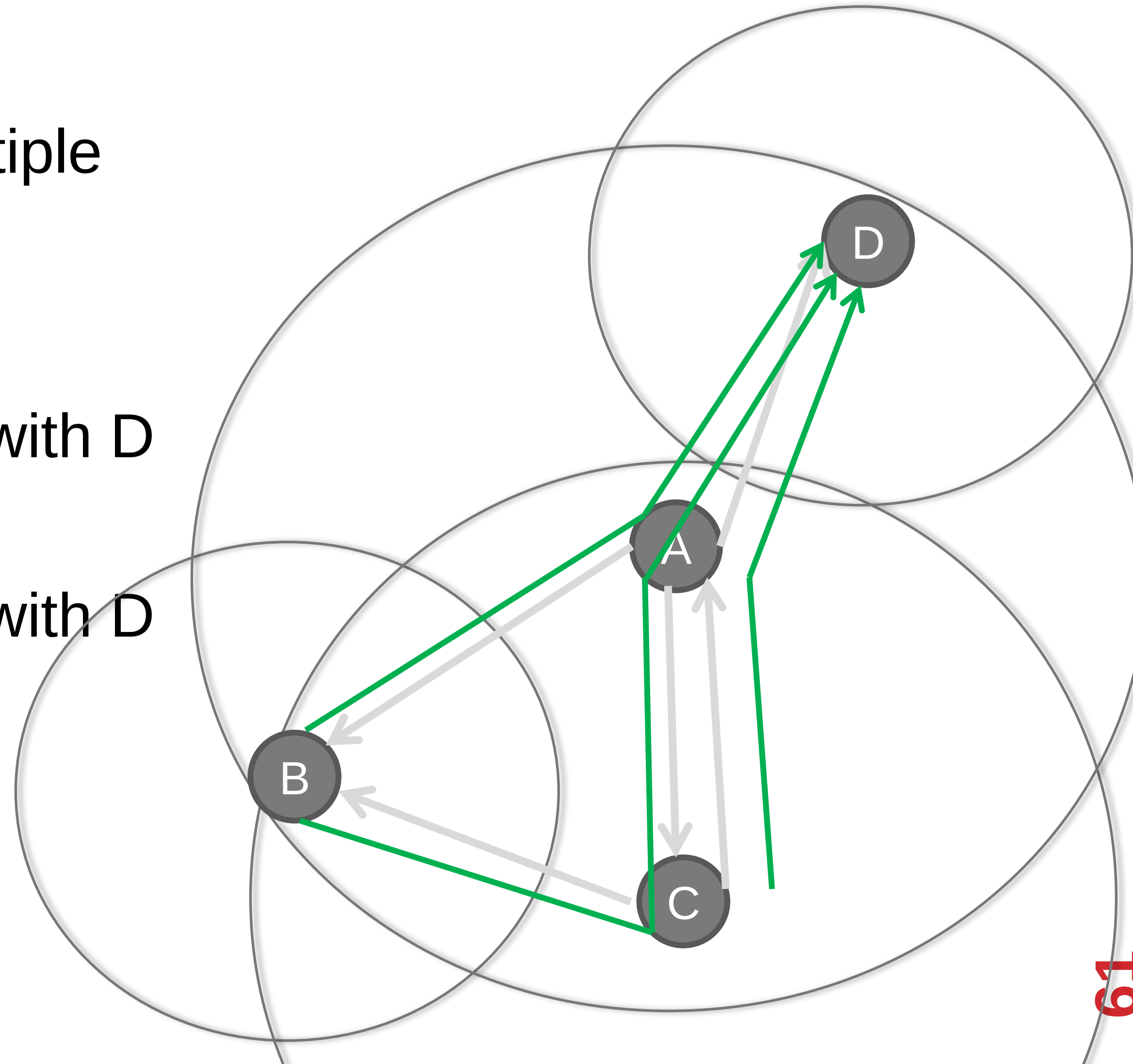
The network

The connections are **logical** (typically multiple physical hops).

C can communicate with D via A

C can communicate with D via A or via C and A



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The network: abstraction

The network (or OSI Layer 3 abstraction) provides an abstraction of the physical world.

- Devices which are not physically “connected” via the communication medium can “talk” to each other
- At the network layer, only the devices and the links between them can be seen, the communication medium is hidden
- Communication protocol
  - defines the functions that have to be implemented and services that have to be provided by the parties involved in the information exchange.
  - In computer and sensor networks, protocols are organized as a stack and the number of layers in the stack is standard specific.

The network: standards

Global network level standard: IPv4 (towards IPv6)

Also a version for low power devices exists: 6LoWPAN.

It is unlikely that all things will eventually use a version of IP

- We foresee island of things implementing some kind of network layer protocol
    - Centralized: a central sink node collects all the data coming from the “things” of the network
    - Decentralized: Data aggregation is performed locally at each “thing” using only the measurements coming from neighbouring “things”
    - Hierarchical: Nodes are divided in hierarchical levels. Data move from the lower levels (sensor nodes) to the higher ones (sink nodes)
- Android@home is a good example of this
- The islands will be connected at higher levels of abstraction

The network: implementation aspects

Implementation of the technologies

- SW
  - On the microcontroller on the communication interface (system on chip (SoC) and CPU+ OEM radio devices)
  - On the device’s CPU (Microcontroller + PHY/MAC Radio devices)
- Stand alone protocol stack vs compatible/integrated with the OS

Communication Standard	Protocol Stack Implementation
ZigBee	Z-Stack, Open-ZB, FreakZ, Microchip Stack
6LoWPAN	NanoStack2.0, Mantus, µIPv6, BLIP

Node centric abstractions

- **Operating System (OS)**
  - abstracts task synchronization and memory management among others from the programmer
- **Virtual Machine (VM)**
  - another level of abstraction which further hides hardware specific issues from the programmer, for instance abstracting while loops with listeners

Embedded Operating system

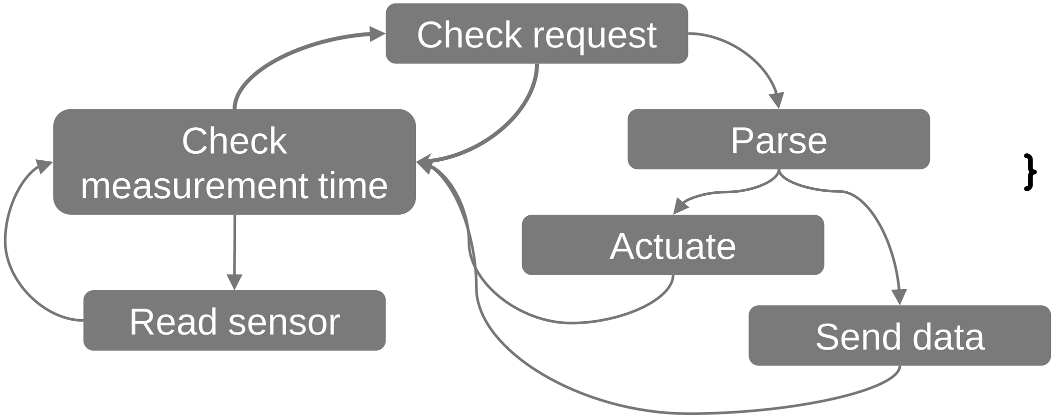
- **OS running on devices with restricted functionality**
  - In the case of sensor nodes, there devices typically also have limited processing capability
- **Restricted to narrow applications**
  - industrial controllers, robots, networking gear, gaming consoles, metering, sensor nodes…
- **Architecture and purpose of embedded OS changes as the hardware capabilities change (i.e. mobile phones)**

Embedded Operating system

Abstracts the hardware configuration, task synchronization and memory management

- Example: web service with one sensor and one actuator
  - Data from the sensor can be requested
  - Actuator can be commanded
- Without an OS, all the program states have to be manually prepared

```
while(1){
  if(got_request()){
    parse_request();
    if(got_data_request())
      send_data();
    if(got_command())
      actuate();
  }
  if(time_for_measurement())
    read_sensor();
}
```



Embedded Operating system

Abstracts the hardware configuration, task synchronization and memory management

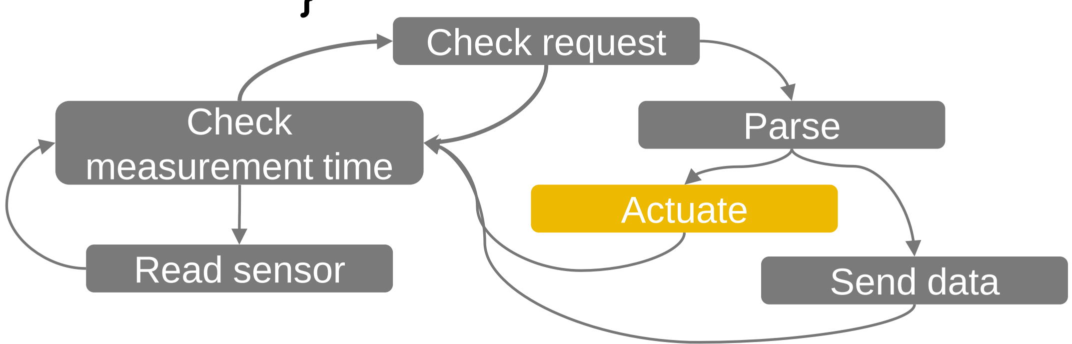
•What happens if the actuate function takes too much time?

  •The system won't respond to requests

Example code:

```
void actuate(){
  actuate_start();
  delay(1000);
  send_command1();
  delay(1000);
  send_command2();
  delay(1000);
  send_command3();
}
```

```
while(1){
  if(got_request()){
    parse_request();
    if(got_data_request())
      send_data();
    if(got_command())
      actuate();
  }
  if(time_for_measurement())
    read_sensor();
}
```

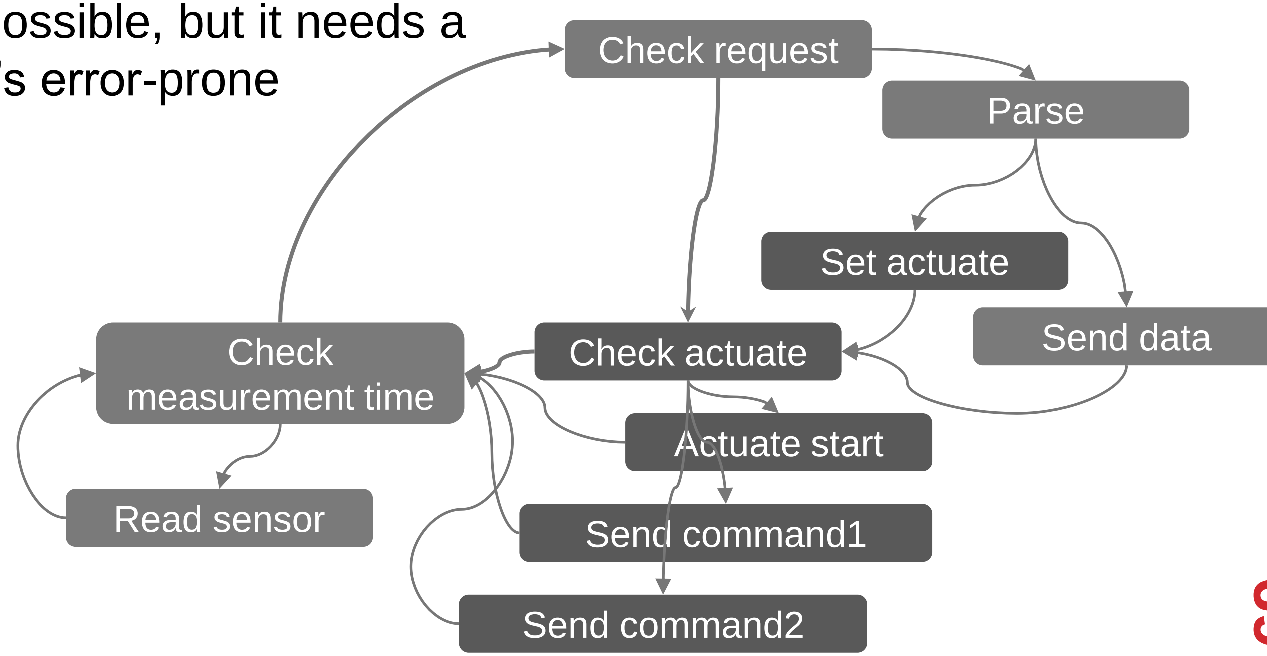


Embedded Operating system

Abstracts the hardware configuration, task synchronization and memory management

- What happens if the actuate function takes too much time?
  - The system won't respond to requests
  - Workaround is possible, but it needs a lot of effort and it's error-prone

```
void actuate(){
  actuate_start();
  delay(1000);
  send_command1();
  delay(1000);
  send_command2();
  delay(1000);
  send_command3();
}
```



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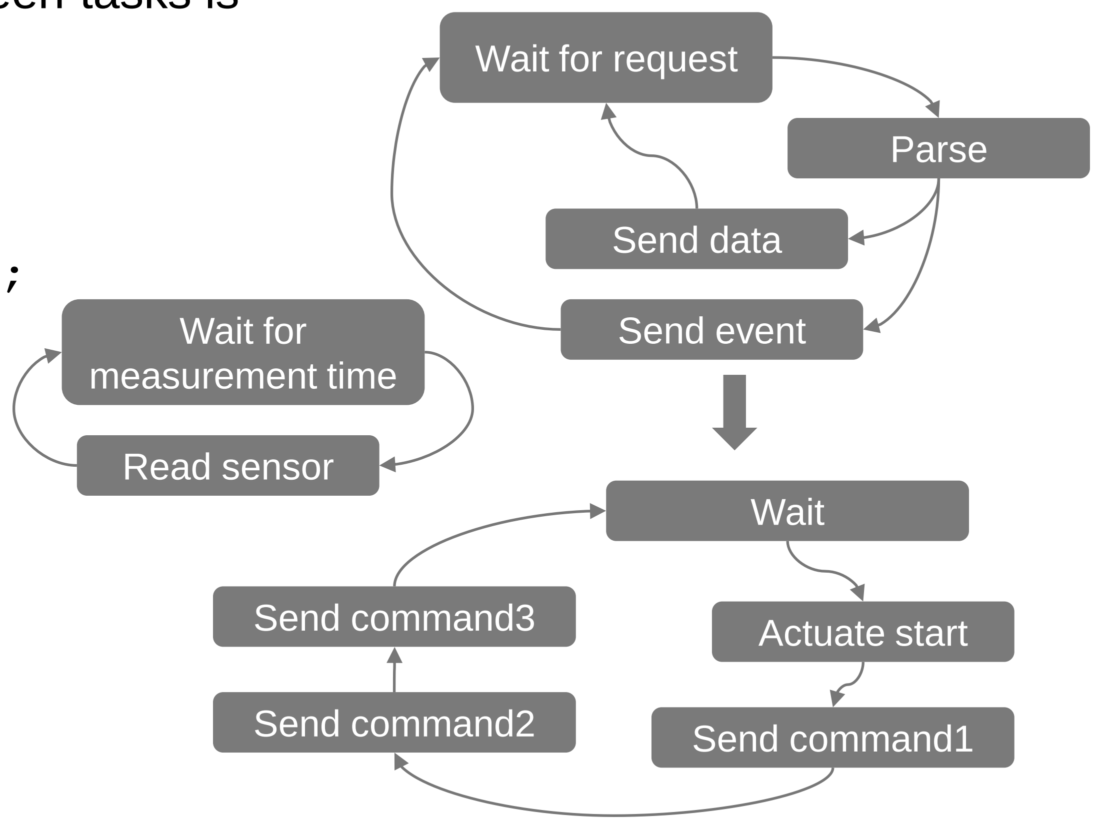
Embedded Operating system

Abstracts the hardware configuration, task synchronization and memory management

- With an OS, switching between tasks is simple

```
PROCESS_THREAD(actuate){
  while(1){
    PROCESS_WAIT_EVENT();
    actuate_init();
    PROCESS_WAIT(1000);
    send_command1();
    PROCESS_WAIT(1000);
    send_command2();
    PROCESS_WAIT(1000);
    send_command3();
  }
}
```



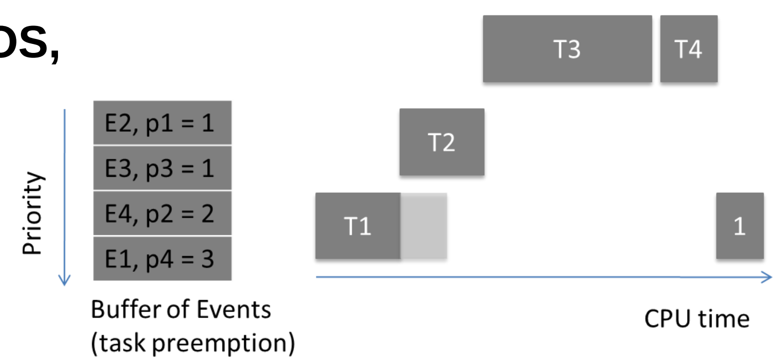
Embedded OS Classification by scheduling model

Event driven model (Contiki, TinyOS, SOS)

- No locking - only one event running at a time
- One stack – reused for every event handler
- Requires less memory
- Synchronous vs. asynchronous events

Thread driven model (FreeRTOS, eCOS, Nut/OS, eCOS)

- Each thread has its own stack
- Thread stacks allocated at creation time (Unused stack space wastes memory)
- Locking mechanisms - to prevent modifying shared resources



Embedded OS classification by system image

- **Monolithic (TinyOS, FreeRTOS, eCOS, uC/OS-II, Nut/OS)**
  - One system image : (kernel) + modules + application compiled together
  - Efficient execution environment (optimization at compilation)
  - High energy costs for updating

- **Modular (Contiki, SOS)**
  - Static image: (kernel) + loadable component images
  - Lower execution efficiency (no global optimization at compilation time)
  - Updates are less expensive (smaller size) - energy and time

Embedded OS comparison

Name	Sched.	Mem. Mgmt.	Kernel	Image/Re (programming)	Foot print	Protocol stack	VM	Dev. status/ reliability	Doc and supp
eCOS	Thread, preempt	Multiple stacks, static	Yes	Monolithic, no	variable	lwIP, FreeBSD TCP/IP	(yes)	Yes/(yes)	yes
uC/OS-II	Thread, preempt	Multiple stacks, static	Yes	(Monolithic, no)	variable	uC/TCP-IP	(no)	Yes/(yes)	limited
FreeRTOS	Thread, preempt	(Multiple stacks, static)	Yes	(Monolithic, no)	variable	lwIP	(no)	Yes/(yes)	yes
Nut/OS	Thread, preempt	Multiple stack, Dynamic	Yes	Monolithic, (no)	variable	BTNut, Nut/Net (TCP/IP)	(no)	Yes/(yes)	limited
TinyOS	Event, (thread)	Single stack, Static	No	Monolithic, wireless	variable	CC100, CC2420, TinyBt, serial	yes	Yes/yes	yes
SOS	Event	Single, dynamic	Yes	Modular,	variable	message	(no)	No/no	limited
Contiki	Event, thread		Yes	Modular, wireless	variable		yes	Yes/(no)	yes

Virtual machine

A virtual machine is a software implementation of a machine and provides a level of abstraction over the physical machine.

VM for embedded systems

- Replace the operating system
- Add extra functionality to the operating system (memory management)
- Provide a friendlier application development environment

Classification of virtual machines

- **System VM**
  - virtualize hardware resources and can run directly on hardware.
  - In embedded systems they implement functions of the OS and completely replace it
  - Squawk, .NET Micro
- **Application (process) VM**
  - typically run on top of an OS as an application and support a single process.
  - Mate, Darjeeling, VM*, SwissQM, CVM, DVM

Virtual machine comparison

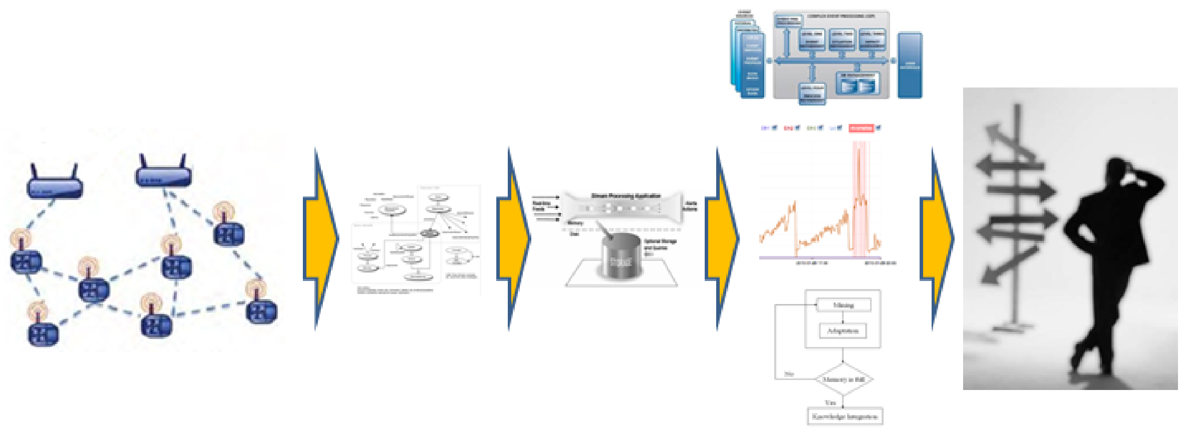
Name	OS	ASVM	Platform	Memory	Multi thread	Supported PL
Mate	TinyOS	no	Rene2 and Mica	1KB RAM 16KB ROM 7.5KB ROM, 600B RAM	yes	TinyScript
.NET Micro	With/without OS TinyOS	No ?	Imote2	300KB RAM 512MB of flash memory	yes	C#
Darjeeling	TinyOS, Contiki, FOS	No (?)	Tnode,Tmote Sky, Fleck3/Fleck3B	2K RAM	Yes	Java subset
Squawk	With (Solaris, Windows, MAC OS X, linux systems) /without	Yes ?	SunSpots Java Card 3.0	Core 80KB RAM Libraries: 270 Kb flash	yes	Java mostly
VM*	OS*	yes	Mica, ongoing work: Telos, XYZ, Stargate and handheld devices	6kb code 200 bytes data (depends on the app req)	no	Java
SwissQM	TinyOS	Yes	Mica2 and tmote sky	33kb flash and 3kb SRAM(on Mica2)	Yes	Subset of Java (37 instructions + 22 specific)
CVM	Contiki			8 RAM 1344 ROM		

Are virtual machines necessary?

- **Trade-off between the resources needed and the services they provide**
- **Advantage**
  - Reduce the distribution energy costs for software updates
    - VM code smaller than native machine code
    - Simpler reprogramming process
- **Disadvantage**
  - Additional overhead
    - Increased time and memory requirements for execution
    - Increased energy spent in interpreting the code

What happens with the data? Macro-programming abstractions

- Data, once generated, serve decision makers to understand the observed environment
- To bring the data to the decision maker, we need several macro programming abstractions
  - …this includes technologies like: conceptualization, storage, stream mining, complex event detection,



Sensor network | Conceptualization (ontology) | Streaming Storage | Stream Mining; Complex Events; Anomaly Detection | Decision maker

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Macro-programming abstractions

- **Semantic streams**
  - K. Whitehouse, F. Zhao, J. Liu, *Semantic Streams: a Framework for Composable Semantic Interpretation of Sensor Data*, 2005.
- **TinyDB**
  - A Declarative Databse for Sensor Networks, http://telegraph.cs.berkeley.edu/tinydb/
- **Logical neighbourhoods**
  - L. Mottola, *Programming Wireless Sensor Networks: From Physical to Logical Neighborhoods*, PhD Thesis, 2009.

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Part I. Motivation & background outline

- **Web Of Things**
  - What is it? What problems can it solve?
- **Architectural considerations**
  - How it looks like? What are its components?
- **The “Things”**
  - What are the ingredients?
- **The “Glue”**
  - How do things stick together?
- **Applications and services**
  - What can be built on top of it?
- **Quick start recipes**
  - How does the “Hello World!” look lilke?

Apps and services

Apps and Services

Applications

Web publishing

Traffic today app

RSS feed

Combine data, presentation or functionality from several sources (mash-up) to create new services.

Things generate only part of the data sources

Selected demos shown throughout the presentation.

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Part I. Motivation & background outline

- ✓ **Web Of Things**
  - What is it? What problems can it solve?
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  - How it looks like? What are its components?
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  - What are the ingredients?
- ✓ **The “Glue”**
  - How do things stick together?
- ✓ **Applications and services**
  - What can be built on top of it?
- **Quick start recipes**
  - How does the “Hello World!” look like?

Programing the “things”

Complex and time consuming process

- tool chain: IDE, compiler, debugger
- microcontroller is programmed and executes the code
- radio chip is not programmed, but controlled by microcontroller, usually via SPI which sets/reads registers
- compiled code is loaded to the microcontroller using bootloader or JTAG
- protocol stack may be precompiled and available through API or available as library
- operating system (not needed for simple tasks)
- virtual machine (optional)

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Decision process

Before starting, the following questions should be answered:

What is the scope or application?

- Monitoring measurements?

What is the scenario?

- A thing with embedded web service?
- A set of things connected through a gateway?

What programming language?

- Options: C, nesC, Java. C#

What is the publishing infrastructure?

- None, custom, third party.

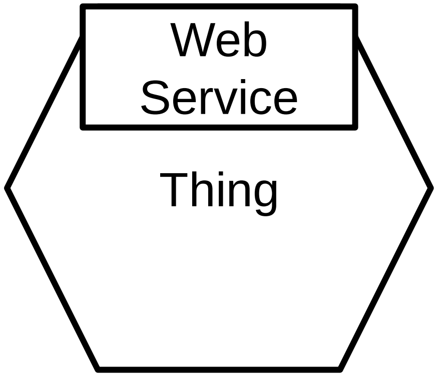
Embedded web service

What is the scope?

- Expose measurements as embedded web service.

What is the scenario?

- SunSpot with embedded web service.



What programming language?

- Java.

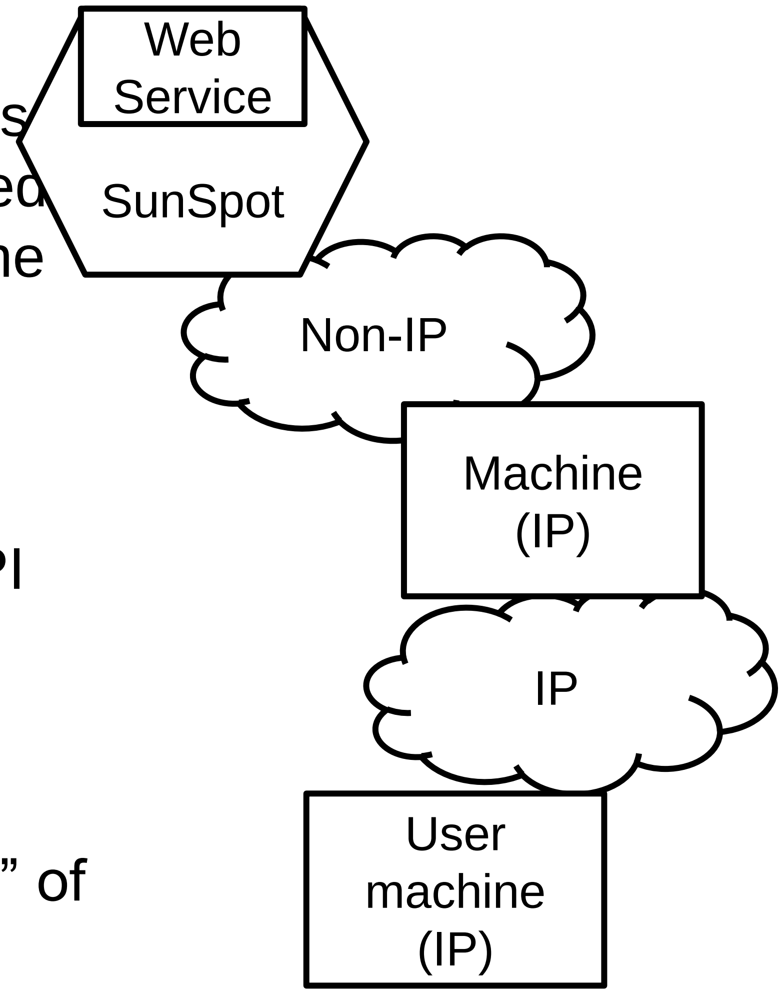
What is the publishing infrastructure?

- None.

SunSpot, http://www.sunspotworld.com/

Embedded web service

- the easiest implementation assumes connecting the thing to an IP enabled machine through which access to the embedded web service can be provided from the internet
- Direct integration via HTTP/TCP/IP possible starting from SunSPOT API V6.0
- Request: http://.../spot1/sensors/temperature requests the resource "temperature" of the resource "sensor" of "spot1"[1]



GET http://IP:Port/service

[1]D. Guinard, V. Trifa, S. Karnouskos, P. Spiess, D. Savio, **Interacting with the SOA-based Internet of Things: Discovery, Query, Selection and On-Demand Provisioning of Web Services**, IEEE Transactions on Services Computing, Vol. 3, July-Sept 2010.

Publish measurements

What is the scope?

- Publish measurements on the web.

What is the scenario?

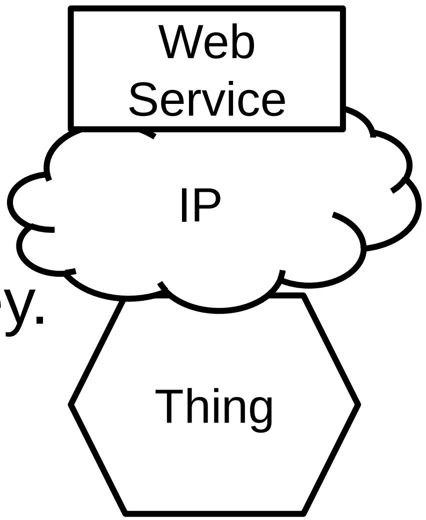
- SunSpot.
- Pachube account, registered feed, API key.

What programming language?

- Java.

What is the publishing infrastructure?

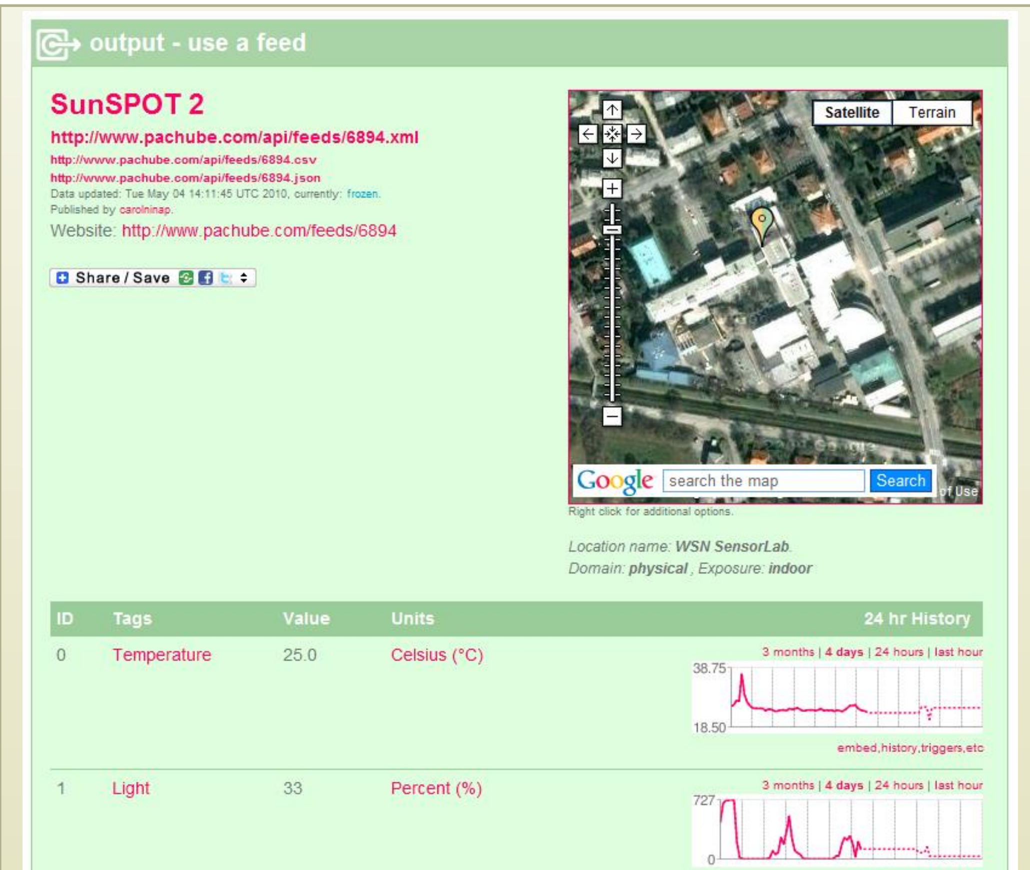
- Pachube.



SunSpot, http://www.sunspotworld.com/

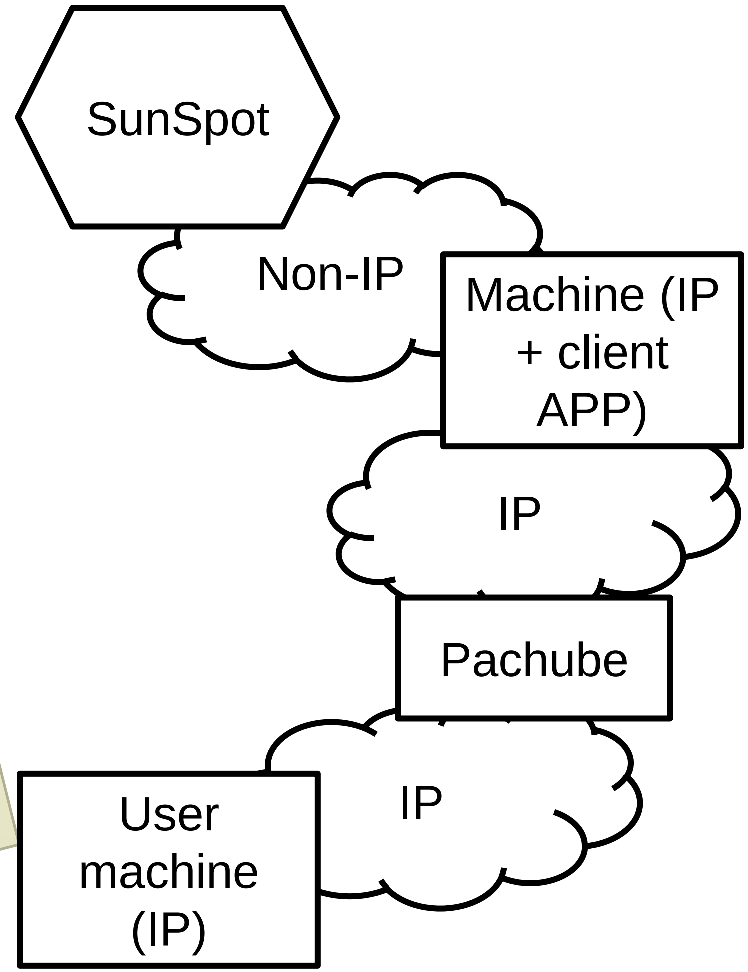
Pachube, http://www.pachube.com/ (rebranded to COSM)

Sunspot + Pachube



SunSpot, http://www.sunspotworld.com/

Pachube, http://www.pachube.com/



Publish measurements

What is the scope?

- Expose measurements as web service.

What is the scenario?

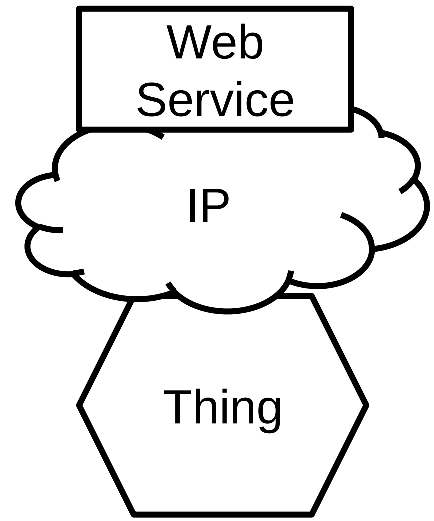
- Arduino Ethernet shield with board and sensors.
- Pachube account, registered feed, API key.

What programming language?

- C.

What is the publishing infrastructure?

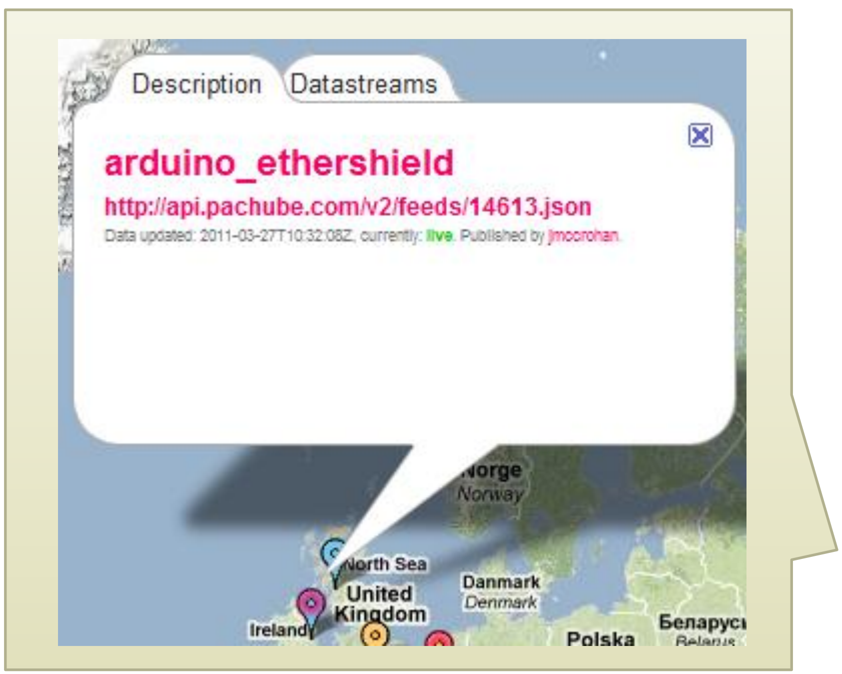
- Pachube.

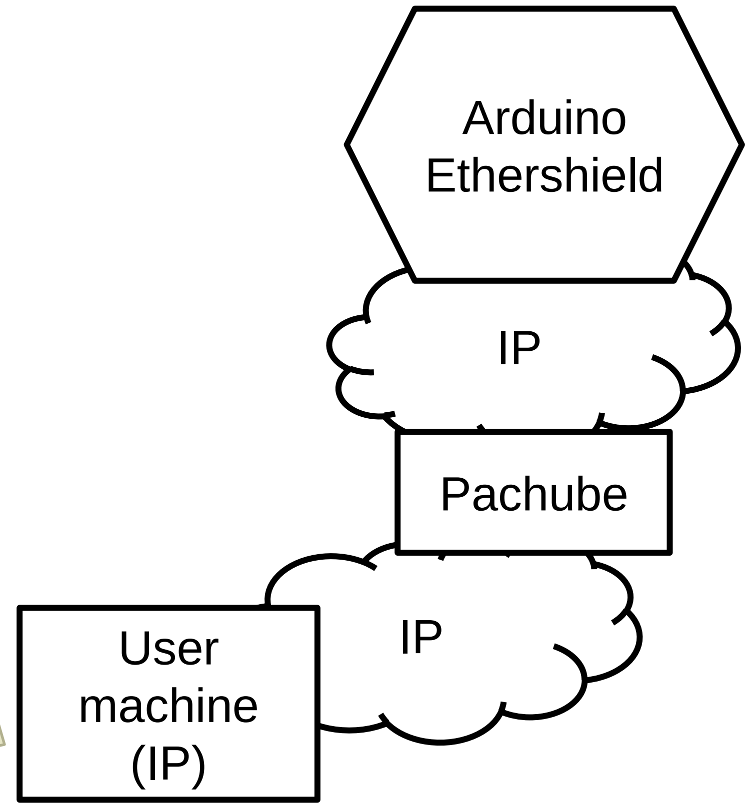


Arduino, http://www.arduino.cc/ Pachube, http://www.pachube.com/

Pachube Client on Arduino, http://arduino.cc/en/Tutorial/PachubeCient

Arduino + Pachube





Arduino, http://www.arduino.cc/ Pachube, http://www.pachube.com/

Pachube Client on Arduino, http://arduino.cc/en/Tutorial/PachubeCient

Publish measurements

What is the scope?

- Publish measurements on the web.

What is the scenario?

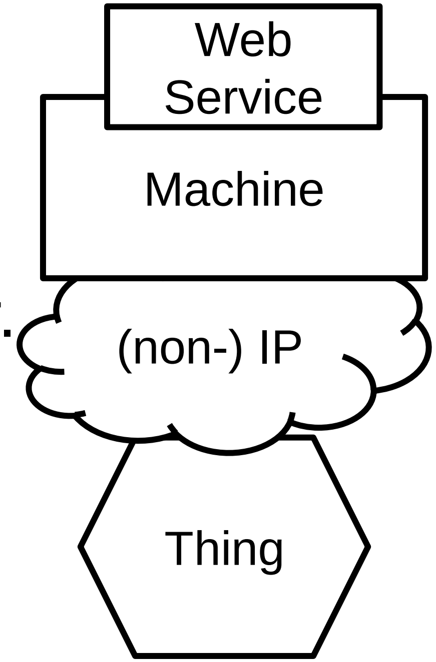
- SunSpot (and/or Arduino).
- GSN installation and adequate wrapper.

What programming language?

- Java (and/or C).

What is the publishing infrastructure?

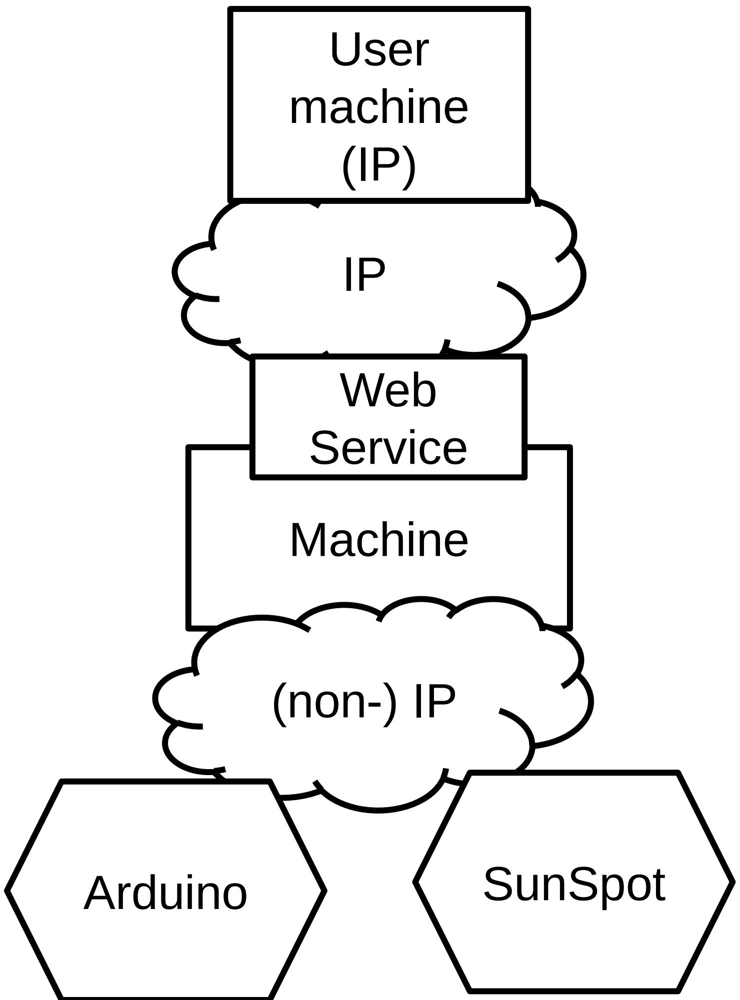
- GSN.

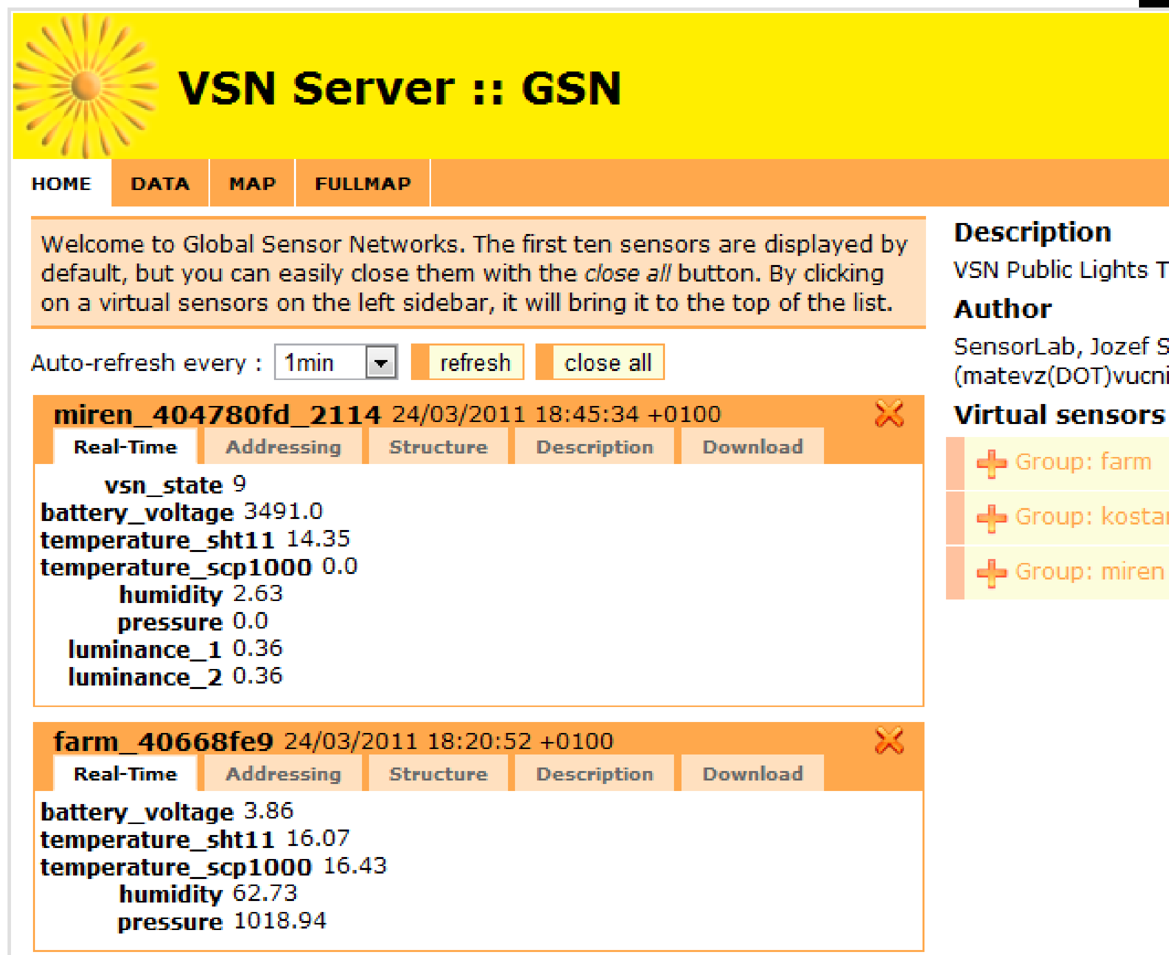


SunSpot, http://www.sunspotworld.com/

Global Sensor Network, http://apps.sourceforge.net/trac/gsn/

Thing + GSN





http://gsn.ijs.si/

How to start?

Do you want to work with “things” that are under your direct control?

Things:

- Easy to use with a wide community support are Arduino and SunSpot.
- Crossbow, Libellium, Sensinode, etc. are also possible solutions but may require more effort.
- For very specific solutions you may need to go for hardware design.

How to start?

Do you want to just publish the data?

Solutions:

- Pachube is straightforward but functionality is limited. There are various types of fee based accounts which offer additional functionality.
- GSN is free and can be customized, the code is open source.
- Nimbits promises to connect people, sensors and devices.
- Sensorpedia, Sensor.Network and other solutions are still in early stages or discontinued.

Summary

The concept of Web of Things was discussed

A list of relevant use cases and application areas

- Power grids
- Transport systems
- Water distribution
- Logistics
- Industrial automation
- Health
- Environmental intelligence

Architectural considerations and possible components of vertical systems were discussed and the components classified in:

- The “Things”
- The “Glue”
- Apps & Services

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Summary

A decision process for how to start setting up a Web of Things system

- Programming things is time consuming

Quick start scenarios were presented in increasing order of complexity

- Things with embedded web services
- Things to an existing data management infrastructure
- Things to self deployed data management infrastructure

Outline

Part I. Motivation & background

Part II. Technology and tools for exploiting the WoT

Part III. Demos, Tools & Research directions

Outline

Part II. Technology and tools for WoT data

Information infrastructure for “Web of Things”

Conceptualization of sensors domain

Stream Data Processing

Stream Mining

Complex Event Processing

Anomaly Detection

INFORMATION INFRASTRUCTURE FOR "WEB OF THINGS"

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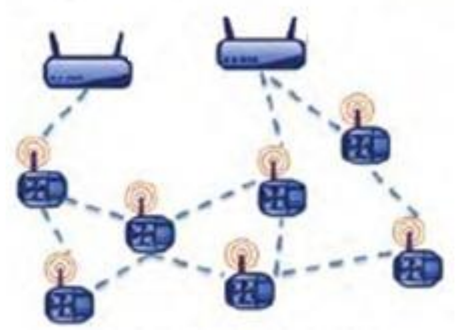
Why we need WoT?

…the key objective is to make decision maker more efficient by understanding observed environment



Sensor network

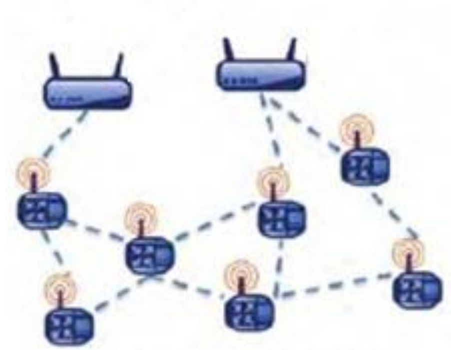
Decision maker

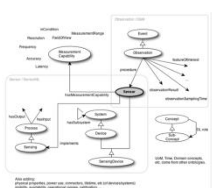
SensorLab

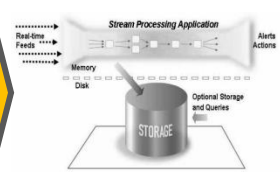
Why we need WoT?

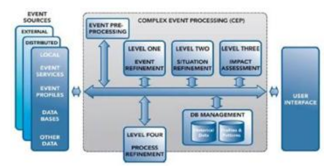
…the key objective is to make decision maker more efficient by understanding observed environment

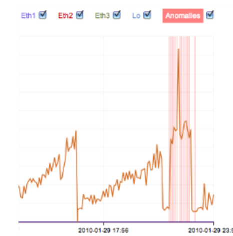
To achieve this, we need to introduce several information layers between sensor setup and decision maker:

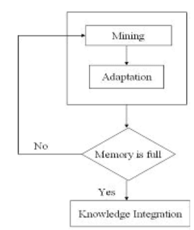












Sensor network

Conceptualization (ontology)

Streaming Storage

Stream Mining; Complex Events; Anomaly Detection

Decision make

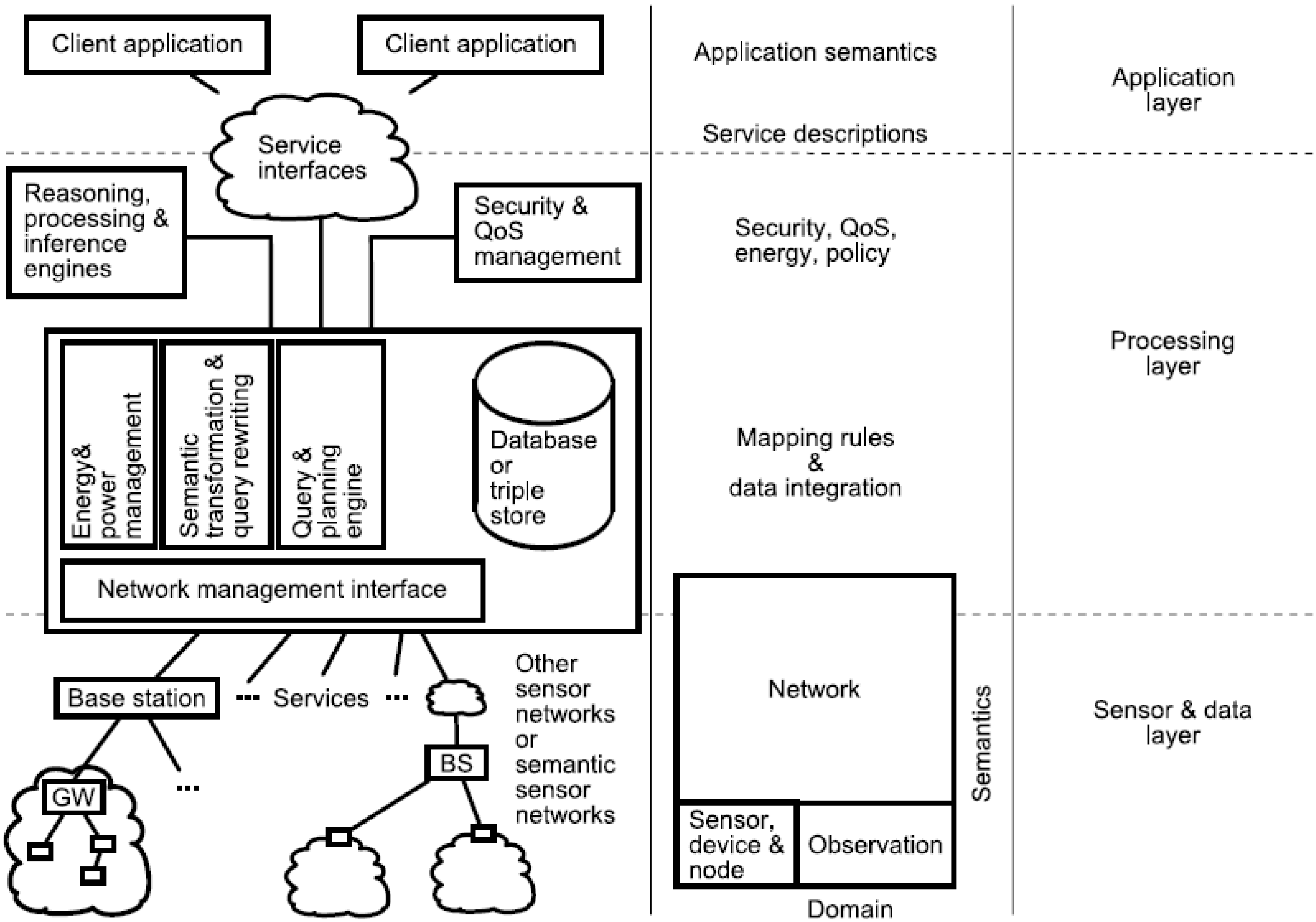
Outline of this part of the talk

In this part we will review approaches on

- How to conceptualize sensor domain?
- How to process streaming data?
  - How to detect complex events?
  - How to perform mining on streaming data?
  - How to detect anomalies?

CONCEPTUALIZATION OF SENSOR DOMAIN

Semantic Sensor Network architecture



http://lists.w3.org/Archives/Public/public-xg-ssn/2009Aug/att-0037/SSN-XG_StateOfArt.pdf

Sensor ontologies

Several ontologies are covering sensor domain

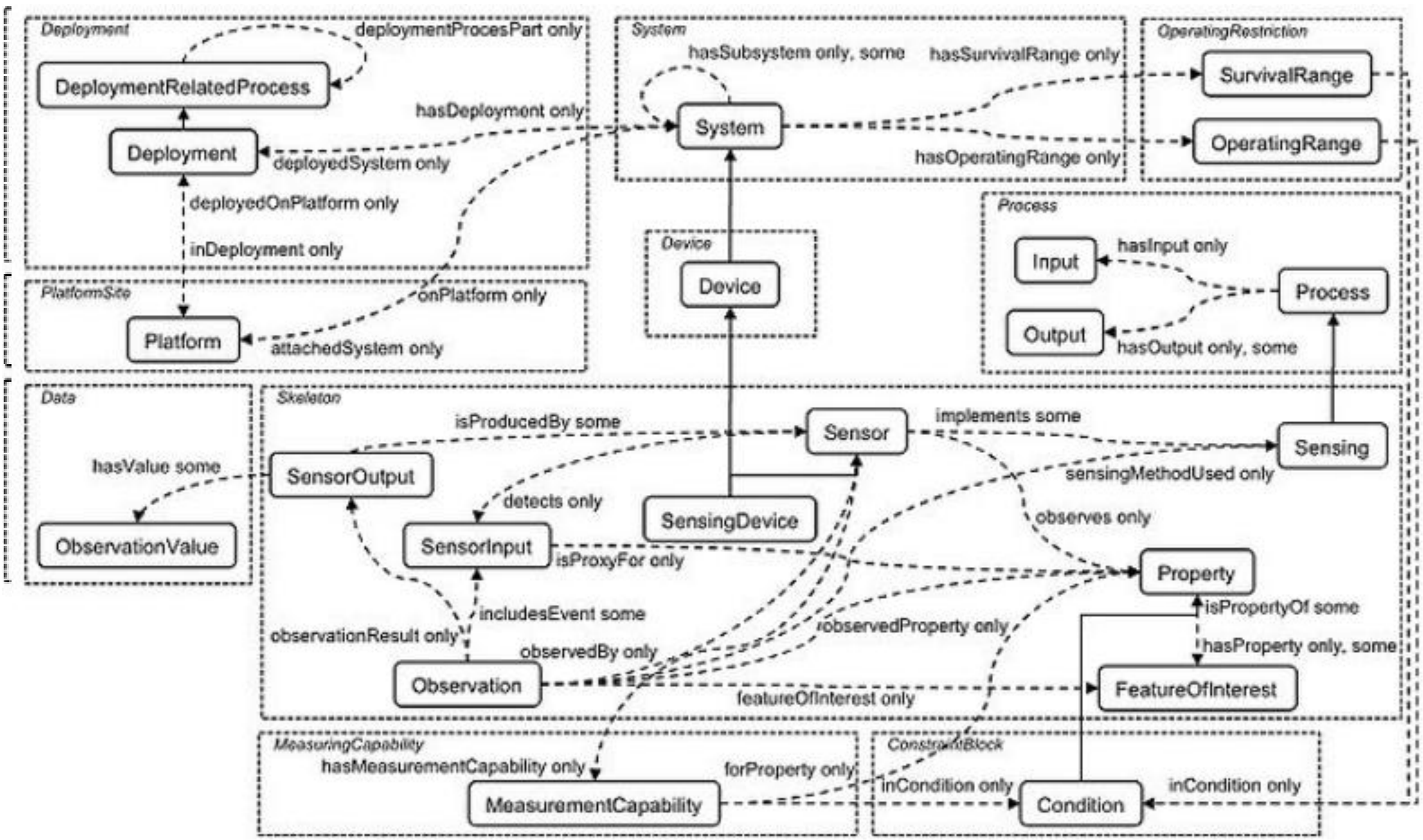
- …most of them only parts

W3C Semantic Sensor Network (SSN) Ontology (next slide) is an attempt to cover complete domain

		sensor								physical					observation					domain			
ontology	base concepts	sensor hierarchy	identity & manufacturing	contacting & software	deployment	configuration	history	components	action & process	location	power supply	platform	dimension, weight, etc.	operating conditions	data/observation	accuracy	frequency	response model	field of view/sensing	units of measurement	feature/quality	sampled medium	time
MMI	sensor (system) & process		✓		✓	✓		✓	✓			✓	✓	✓		✓	✓	✓			✓	✓	
CSIRO	sensor & process	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		
OOSTethys	component, system & process							✓	✓			✓			✓						✓	✓	
CESN	sensor	✓			✓					✓					✓						✓		✓
SWAMO	agent, process & sensor			✓				✓	✓	✓		✓			✓				✓	✓	✓		✓
Kim	sensor					✓				✓					✓	✓	✓		✓		✓		
OntoSensor	component & sensor	✓				✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓
Eid	sensor		✓			✓				✓	✓				✓	✓	✓	✓	✓				
Matheus	system & sensor	✓		✓					✓	✓					✓		✓						
Avancha	sensor			✓						✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	
ISTAR																							

http://lists.w3.org/Archives/Public/public-xg-ssn/2009Aug/att-0037/SSN-XG_StateOfArt.pdf

W3C Semantic Sensor Network (SSN) ontology structure



http://www.w3.org/2005/Incubator/ssn/wiki/Main_Page

So, how does a value look like?

Having all the semantic infrastructure in place, how an observed value is encoded in SSN?


```xml
<owl:Thing rdf:about="http://purl.oclc.org/NET/ssnx/product/smart-knife#WiTilt30MeasurementRange_3MinValue">
   <rdf:type rdf:resource="http://purl.oclc.org/NET/ssnx/product/smart-knife#AccelerationValue"/>
   <smart-knife:hasQuantityValue rdf:datatype="http://www.w3.org/2001/XMLSchema#float">-4</smart-knife:hasQuantityValue>
</owl:Thing>
```


The observed value

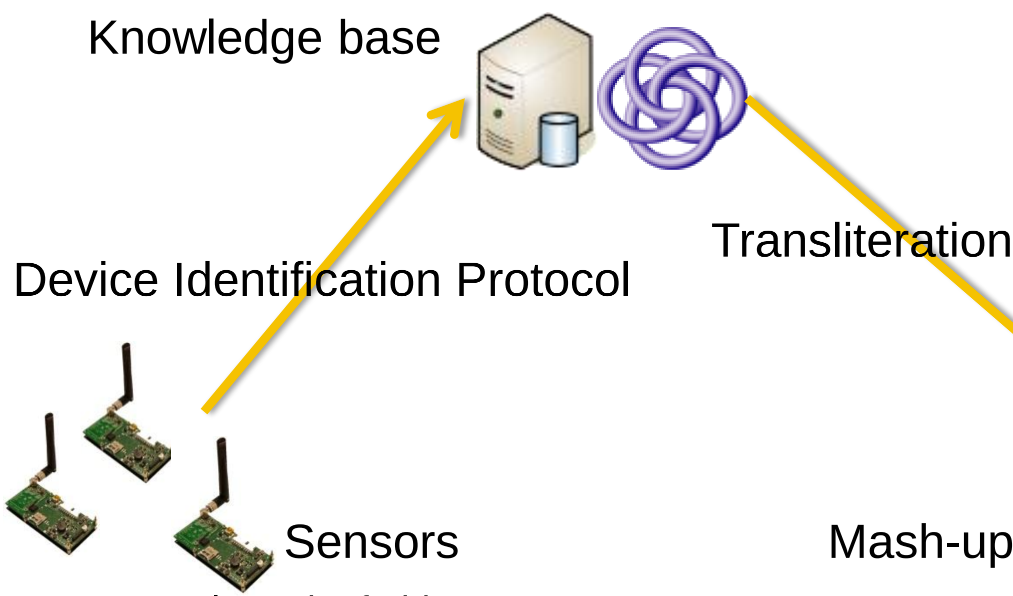
http://www.w3.org/2005/Incubator/ssn/wiki/Main_Page

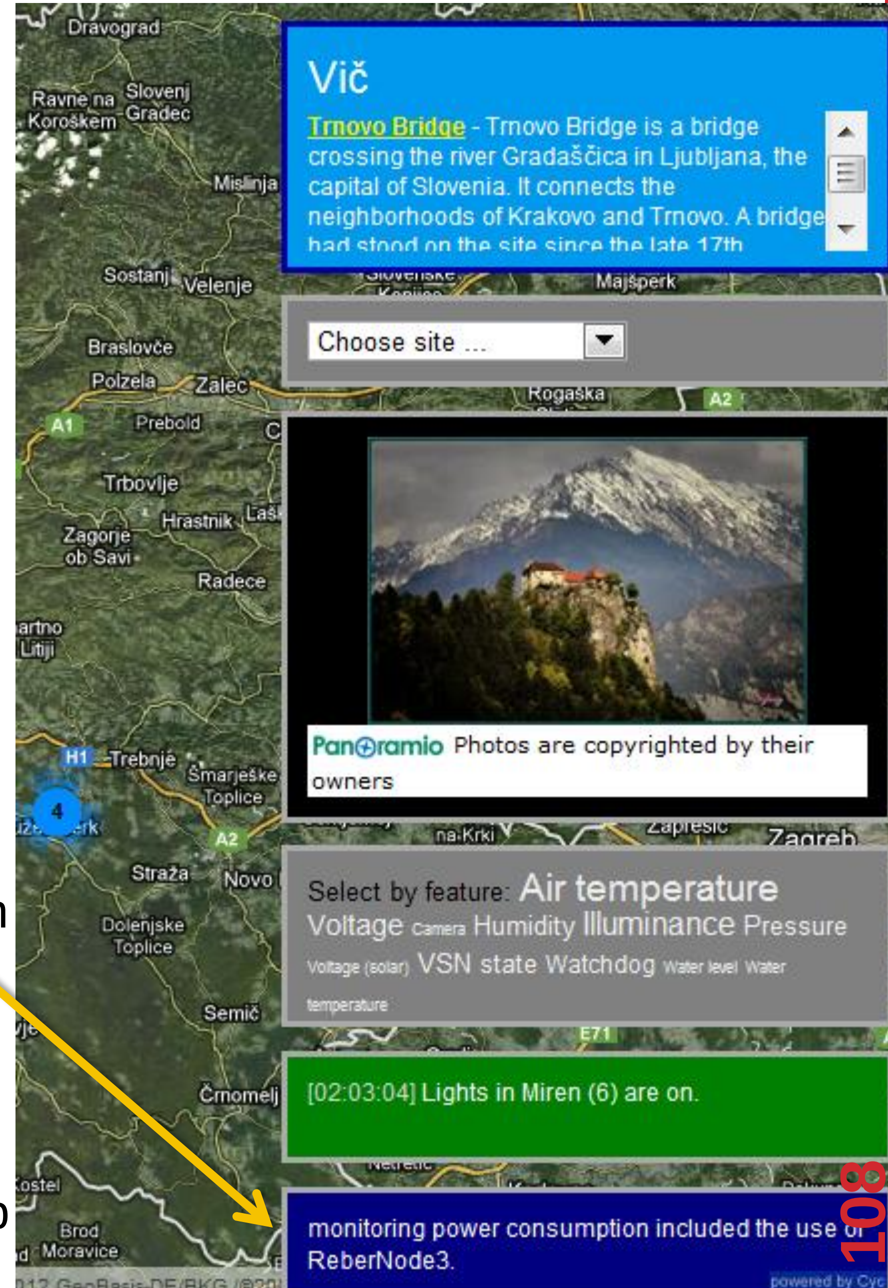
Sensors, knowledge modeling and transliteration

Individual : VicNode1 CURE

on the term

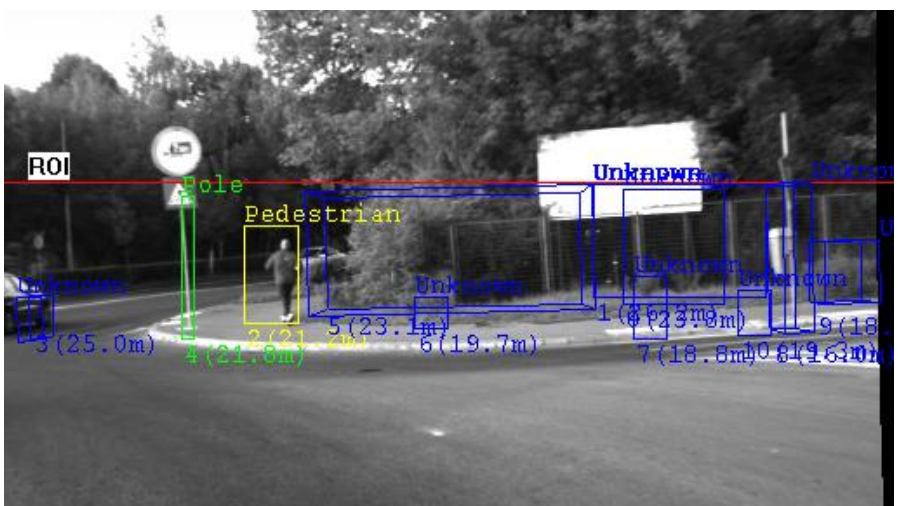
isa : ElectronicDevice
isa : Computer
connectedTo : virtualsensor3VicNode1 TSL2561VicNode1 sht11VicNode1
(connectedTo scp1000VicNode1 VicNode1)
(connectedTo virtualsensor2VicNode1 VicNode1)
(connectedTo virtualsensor1VicNode1 VicNode1)
(deviceUsed Testing VicNode1)
hasDevices : virtualsensor3VicNode1 TSL2561VicNode1 scp1000VicNode1 sht11VicNode1 virtualsensor2VicNode1 virtualsensor1VicNode1
latitude : (Degree-UnitOfAngularMeasure 46.042873)
longitude : (Degree-UnitOfAngularMeasure 14.487469)
nameString : "VicNode1"
objectFoundInLocation : IndoorMounting Vic
physicalParts : virtualsensor3VicNode1 TSL2561VicNode1 scp1000VicNode1 sht11VicNode1 virtualsensor2VicNode1 virtualsensor1VicNode1
(queryHasVeryHighPertinenceForThing GetLinkToMap VicNode1)
supportedBy : VicBuilding1

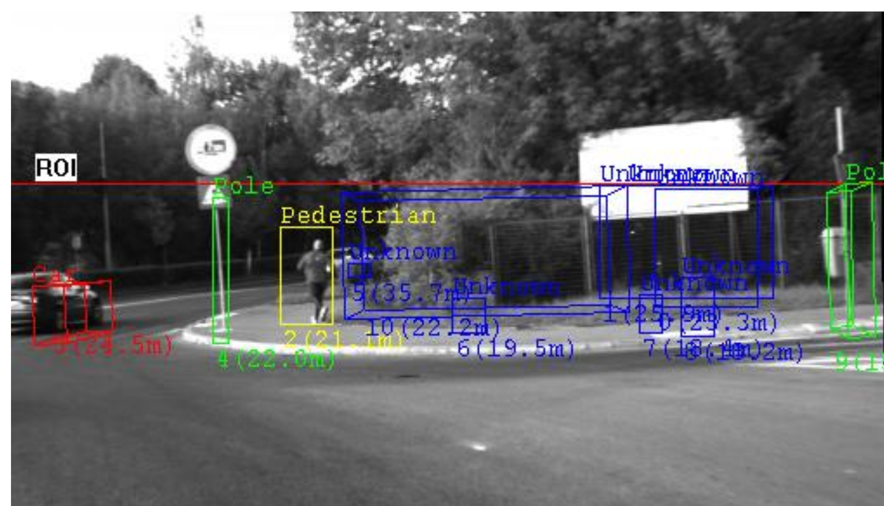




Fortuna et al., Web of Things, 2012.

Traffic Scene Object Detection





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Traffic Scene Understanding

QUESTION: Image depicts Person?

ANSWER: PEDESTRIAN2A000282 is a person.

QUESTION: Image depicts UtilityPole?

ANSWER: UNCLASSIFIED0A000282 is a utility pole. POLE4A000282 is a utility pole. UNCLASSIFIED6A000282 is a utility pole. UNCLASSIFIED7A000282 is a utility pole. UNCLASSIFIED8A000282 is a utility pole. UNCLASSIFIED9A000282 is a utility pole. UNCLASSIFIED10A000282 is a utility pole.

QUESTION: Image depicts Automobile?

ANSWER: UNCLASSIFIED3A000282 is a car.

QUESTION: Image depicts Person?

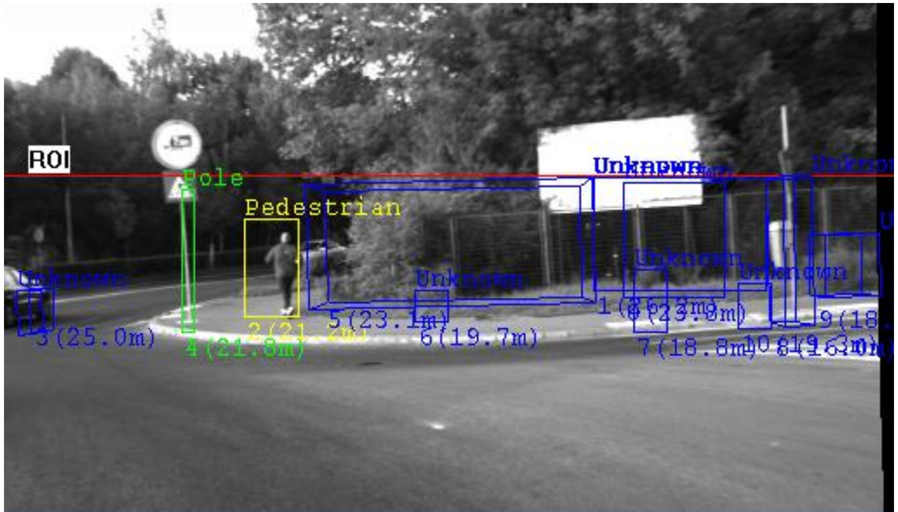
ANSWER: PEDESTRIAN2A000283 is a person.

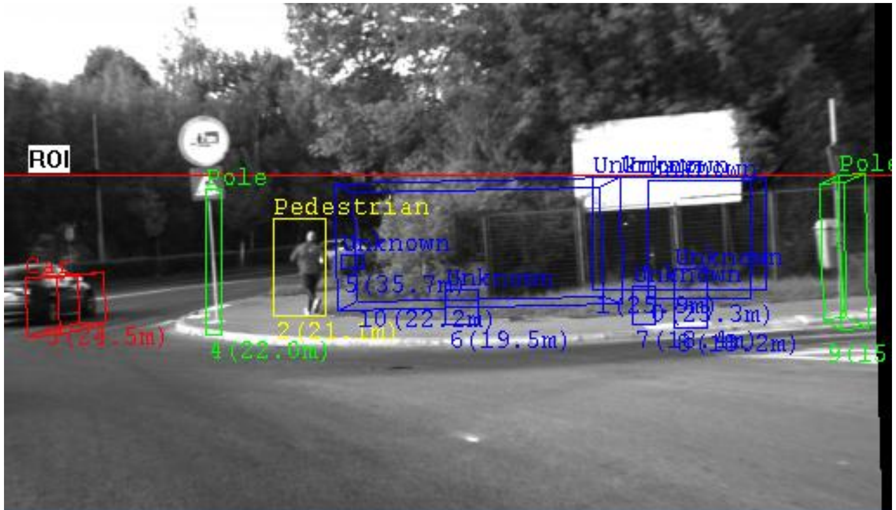
QUESTION: Image depicts UtilityPole?

ANSWER: UNCLASSIFIED0A000283 is a utility pole. POLE4A000283 is a utility pole. UNCLASSIFIED6A000283 is a utility pole. UNCLASSIFIED7A000283 is a utility pole. UNCLASSIFIED8A000283 is a utility pole. POLE9A000283 is a utility pole.

QUESTION: Image depicts Automobile?

ANSWER: UNCLASSIFIED3A000282 is a car.





Traffic Scene Understanding

QUESTION: Image depicts ObjectWithUse?

ANSWER:

UNCLASSIFIED0A000283 is a utility pole, every utility pole is a post, every post is a shaft, every shaft is a rod, every rod is an implement, every implement is a device, every device is an object with uses.

CAR3A000283 is a car, every car is a device that is not a weapon, every device that is not a weapon is a device, every device is an object with uses.

POLE4A000283 is a utility pole, every utility pole is a post, every post is a shaft, every shaft is a rod, every rod is an implement, every implement is a device, every device is an object with uses.

Brehar et al, Spatio-temporal reasoning for traffic scene understanding. 2011 IEEE 7th International Conference on Intelligent Computer Communication and Processing.

STREAM DATA PROCESSING

Stream data processing

Applications that require real-time processing of high-volume data steams are pushing the limits of traditional data processing infrastructures

In the following slides we present the requirements of that system…

- …based on the paper "**The 8 Requirements of Real-Time Stream Processing**" by Stonebraker, Çetintemel, Zdonik; ACM SIGMOD Record Volume 34 Issue 4

Eight rules for stream processing (1/2)

Rule 1: Keep the Data Moving

- *Processing messages "in-stream", without requirements to store them; ideally the system should also use an active (i.e., non-polling)*

Rule 2: Query using SQL on Streams

- *High-level SQL like language with built-in extensible stream oriented primitives and operators*

Rule 3: Handle Stream Imperfections

- *Dealing with stream "imperfections", including missing and out-of-order data, which are commonly present in real-world data streams*

Rule 4: Generate Predictable Outcomes

http://www.complexevents.com/2006/06/30/the-eight-rules-of-real-time-stream-processing/

Eight rules for stream processing (2/2)

Rule 5: Integrate Stored and Streaming Data

- Combining stored with *live streaming data*

Rule 6: Guarantee Data Safety and Availability

- *Integrity of the data maintained at all times, despite failures*

Rule 7: Partition and Scale Applications Automatically

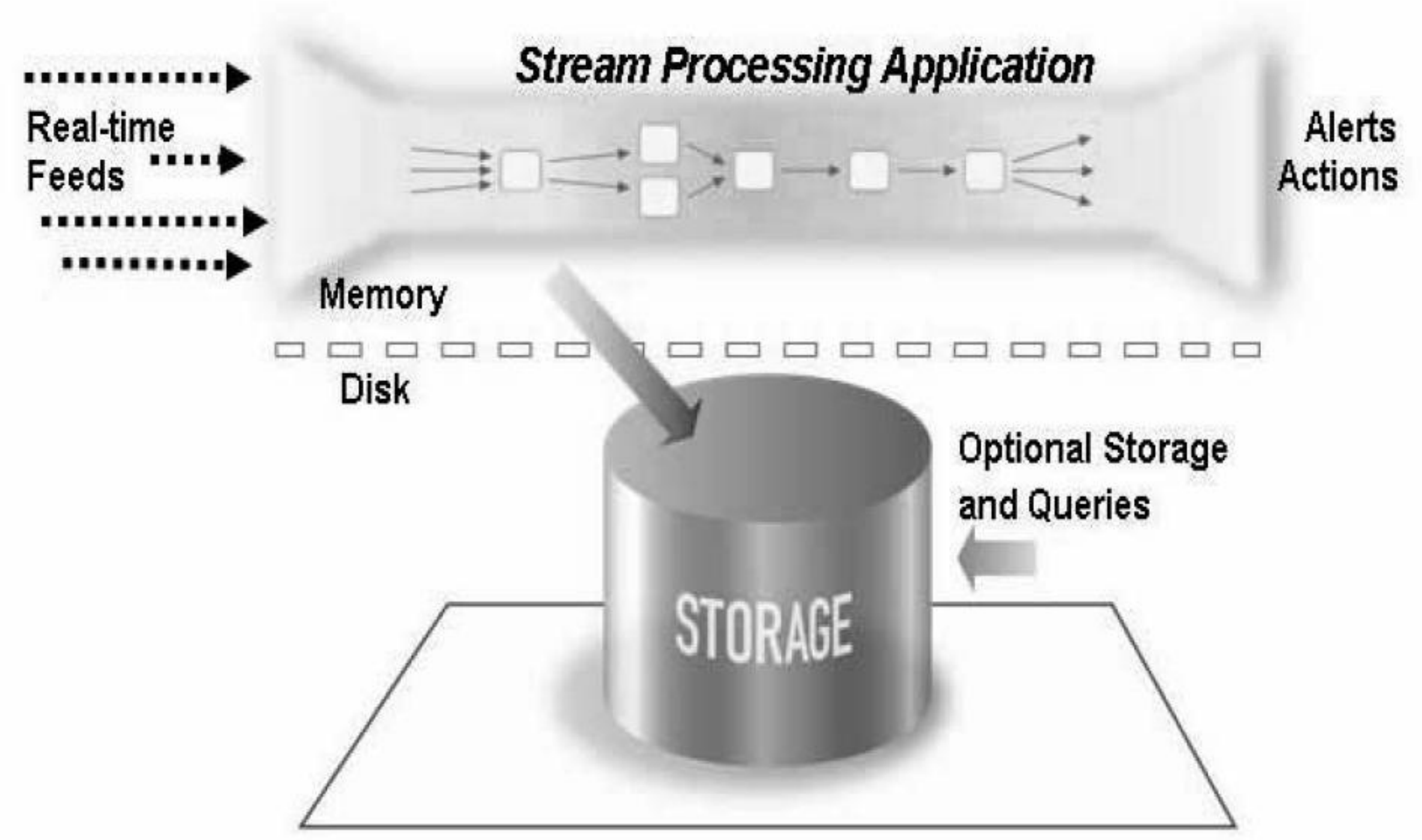
- *Distribute its processing across multiple processors and machines to achieve incremental scalability*

Rule 8: Process and Respond Instantaneously

- *Minimal-overhead execution engine to deliver real-time response*

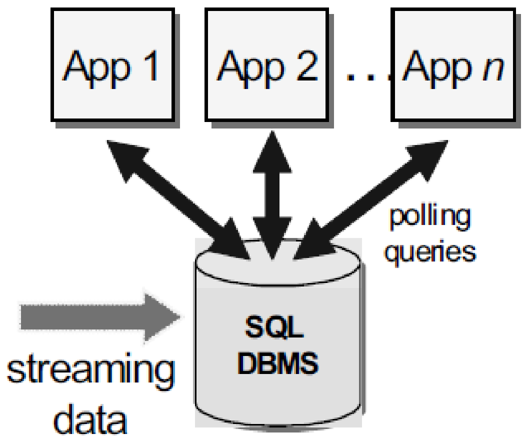
http://www.complexevents.com/2006/06/30/the-eight-rules-of-real-time-stream-processing/

“Straight-through” processing of messages with optional storage

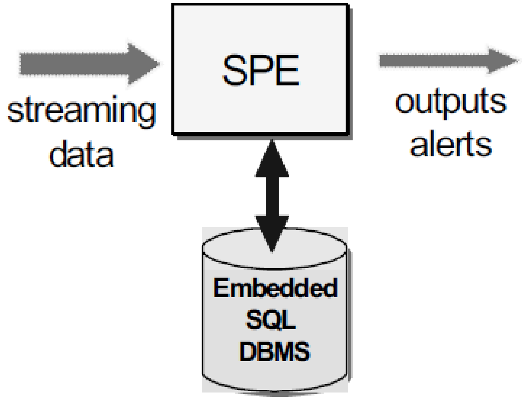


http://www.complexevents.com/2006/06/30/the-eight-rules-of-real-time-stream-processing/

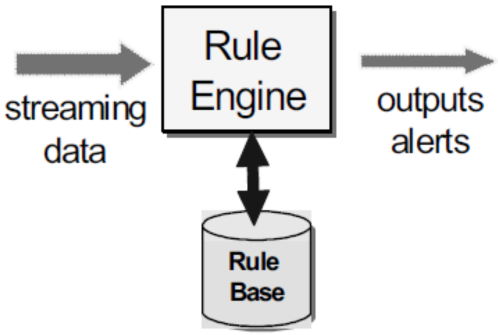
Basic architectures for stream processing databases



Traditional DBMS system



Stream processing engine



Rule engine

http://www.complexevents.com/2006/06/30/the-eight-rules-of-real-time-stream-processing/

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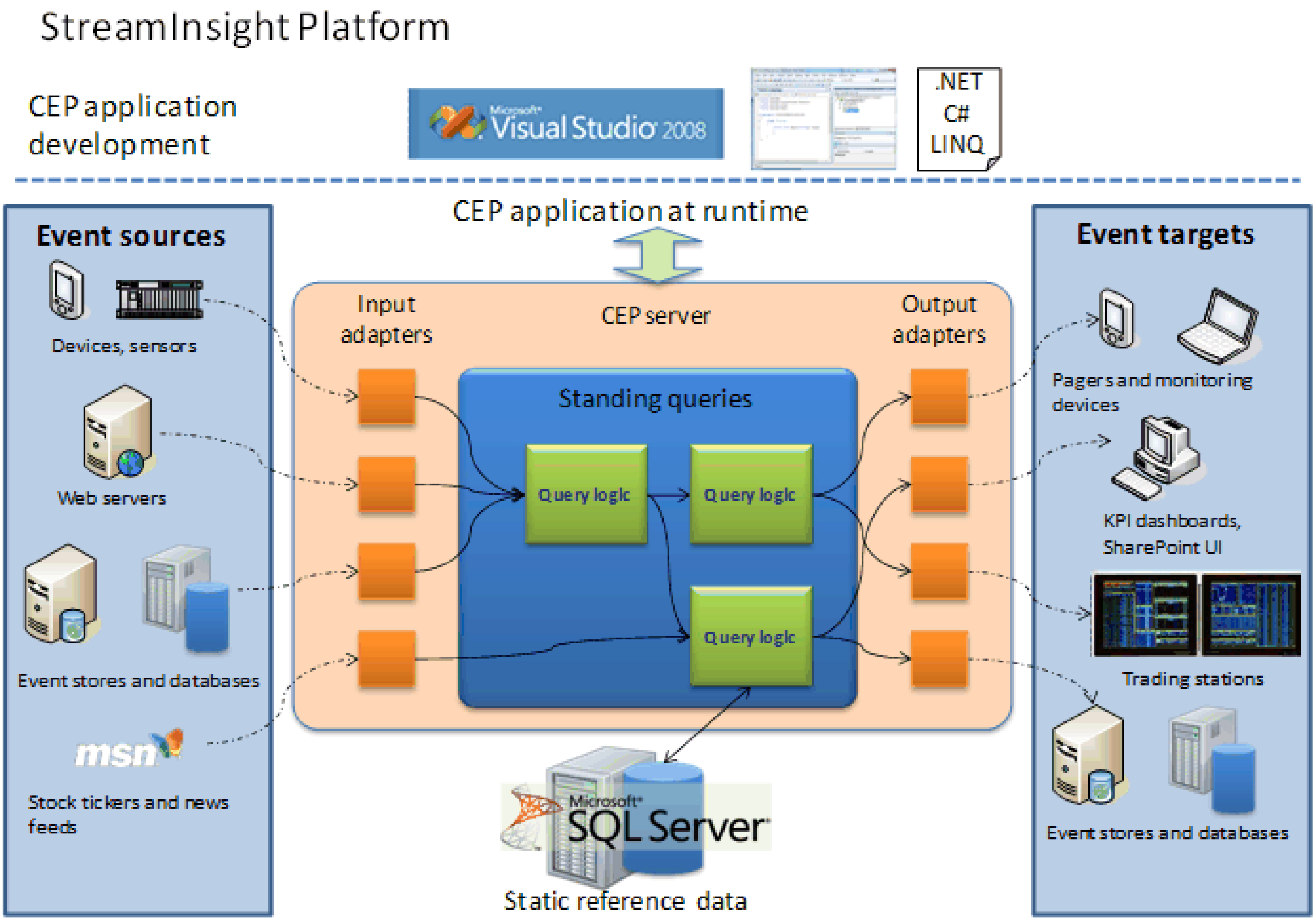
The capabilities of various systems software

	DBMS	Rule engine	SPE
Keep the data moving	No	Yes	Yes
SQL on streams	No	No	Yes
Handle stream imperfections	Difficult	Possible	Possible
Predictable outcome	Difficult	Possible	Possible
High availability	Possible	Possible	Possible
Stored and streamed data	No	No	Yes
Distribution and scalability	Possible	Possible	Possible
Instantaneous response	Possible	Possible	Possible

http://www.complexevents.com/2006/06/30/the-eight-rules-of-real-time-stream-processing/

COMPLEX EVENT PROCESSING

Microsoft *StreamInsight* Architecture



http://msdn.microsoft.com/en-us/sqlserver/ee476990

Steps in processing events

Data filtering

- Low level filtering
- Semantic filtering

Data transformation and aggregation

- Database updates
- Creating relationships among objects

Complex event definition

- Event constructors specifying the constituent events (non-temporal and temporal)

Processing of non-spontaneous events

- Pseudo-events as objects containing temporal constraints

Wang, F., S. Liu, and P. Liu, Complex RFID event processing. The VLDB Journal, 2009.

Good practices in distributed CEP

Data centric storage – data mapped to different locations

- Data lookup – multi-level hashing
- Data robustness – replication

Data caching – multiple copies of the most requested data

- Consistency – response time trade-off

Group management - cooperation among group of nodes

- Provide higher reliability
- Anomaly detection

Publish/subscribe for event subscription

- Loose coupling

Li, S., et al., Event Detection Services Using Data Service Middleware in Distributed Sensor Networks. Telecommunication Systems, 2004.

Two main CEP Query Languages

Stream oriented

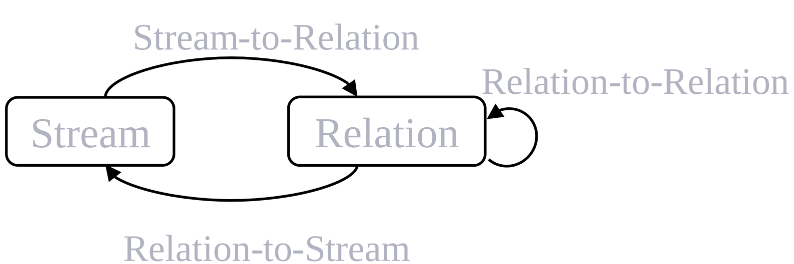
Typically used in DSMS

Evolved from SQL like languages

Transforming language

Main Operators

- S-to-R: sliding window
- R-to-R: select, project, join, union, etc. (SQL based)
- R-to-S: insert, delete, relation



Rule oriented

Typically used in today's CEP systems

Evolved from Active DBMS, rule base systems

Detecting language

Main Operators:

- Logic operators (AND, OR)
- Sequence (variations of SEQ)

On event

IF condition

Do Action

Complex Event Processing Application Development

1. **Defining event sources and event targets (sinks)**
2. **Creating an input adapter to read the events from the source into the CEP server**
3. **Creating an output adapter to consume the processed events for submission to the event targets**
4. **Creating the query logic required to meet your business objectives**
    1. **binding the query to the adapters** at runtime, and
    2. to **instantiate the query** in the CEP server

http://msdn.microsoft.com/en-us/sqlserver/ee476990

Examples of Queries in Microsoft StreamInsight (1/2)

Filtering of events

- from e in inputStream where e.value < 10 select e;

Calculations to introduce additional event properties

- from e in InputStream select new MeterWattage {wattage=(double)e.Consumption / 10};

Grouping events

- from v in inputStream group v by v.i % 4 into eachGroup from window in eachGroup.Snapshot() select new { avgNumber = window.Avg(e => e.number) };

Aggregation

- from w in inputStream.Snapshot() select new { sum = w.Sum(e => e.i), avg = w.Avg(e => e.f), count = w.Count() };

http://msdn.microsoft.com/en-us/sqlserver/ee476990

Examples of Queries in Microsoft StreamInsight (2/2)

Identifying top *N* candidates

- (from window in inputStream.Snapshot() from e in window orderby e.f ascending, e.i descending select e).Take(5);

Matching events from different streams

- from e1 in stream1 join e2 in stream2 on e1.i equals e2.i select new { e1.i, e1.j, e2.j };

Combining events from different streams in one

- stream1.Union(stream2);

User defined functions

- from e in stream where e.value < MyFunctions.valThreshold(e.Id) select e;

http://msdn.microsoft.com/en-us/sqlserver/ee476990

Event Models in Microsoft StreamInsight

Interval model

- Event has predefined duration

Event Kind	Start Time	End Time	Payload (Power Consumption)
INSERT	2009-07-15 09:13:33.317	2009-07-15 09:14:09.270	100
INSERT	2009-07-15 09:14:09.270	2009-07-15 09:14:22.253	200
INSERT	2009-07-15 09:14:22.255	2009-07-15 09:15:04.987	100

Point model

- Event is occurrence in a point in time

Event Kind	Start Time	End Time	Payload (Consumption)
INSERT	2009-07-15 09:13:33.317	2009-07-15 09:13:33.317	100
INSERT	2009-07-15 09:14:09.270	2009-07-15 09:14:09.270	200
INSERT	2009-07-15 09:14:22.255	2009-07-15 09:14:22.255	100

Edge model

- Only start time known upon arrival to server; end-time is updated later

Event Kind	Edge Type	Start Time	End Time	Payload
INSERT	Start	t0	∞	a
INSERT	End	t0	t1	a
INSERT	Start	t1	∞	b
INSERT	End	t1	t3	b
INSERT	Start	t3	∞	c

http://msdn.microsoft.com/en-us/sqlserver/ee476990

CEP and Sensor Networks

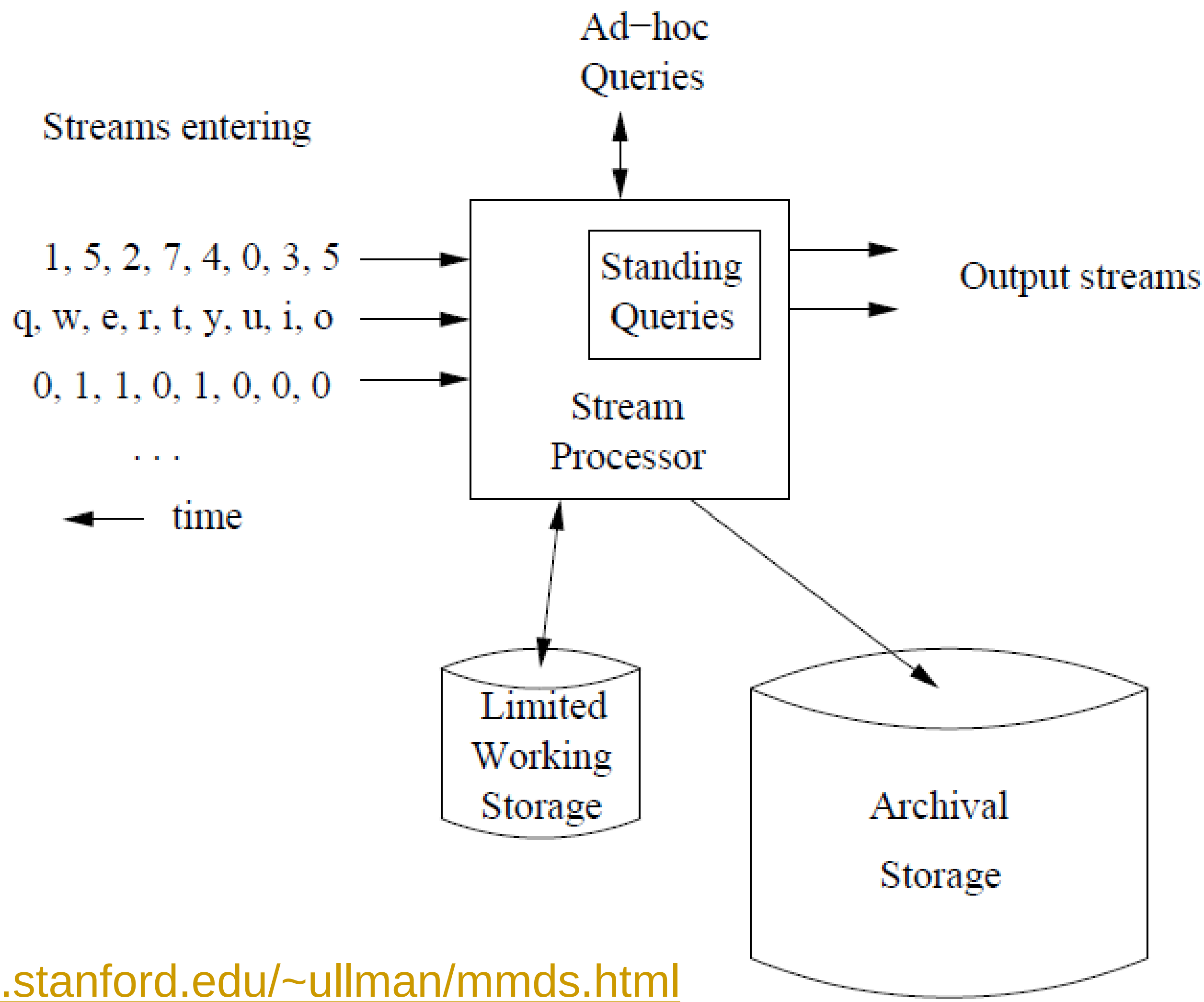
CEP role is to discovering meaningful information from sensor data

- observations – raw outputs of sensors
- event – detected and of interest for the application
- centralized vs. distributed processing

STREAM MINING

Typical stream mining architecture

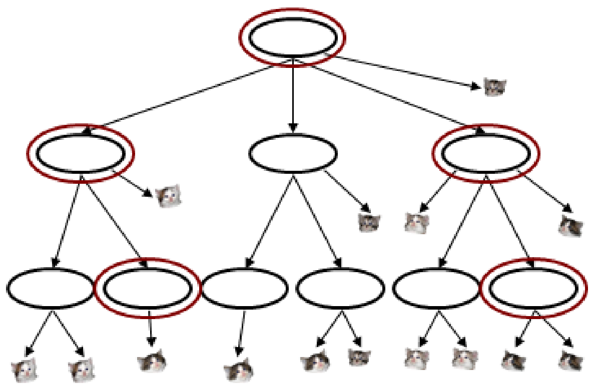
- Streams can include different types of data
- We can prepare system ahead of time for “Standing Queries”
- We can prepare only for certain class of “Ad-hoc Queries”

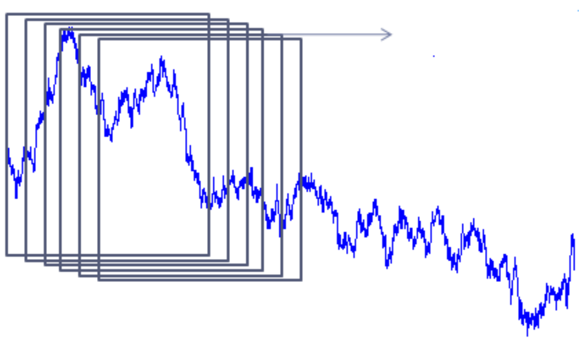


http://infolab.stanford.edu/~ullman/mmds.html

How we mine streams?

- Maintain **summaries of the streams**, sufficient to answer the expected queries about the data
    - …summaries can be in various forms: clusters (flat or hierarchic, statistical aggregates, …)
- Maintain a **sliding window** of the most recently arrived data
    - …operations on a sliding window mimic more traditional database/mining operations





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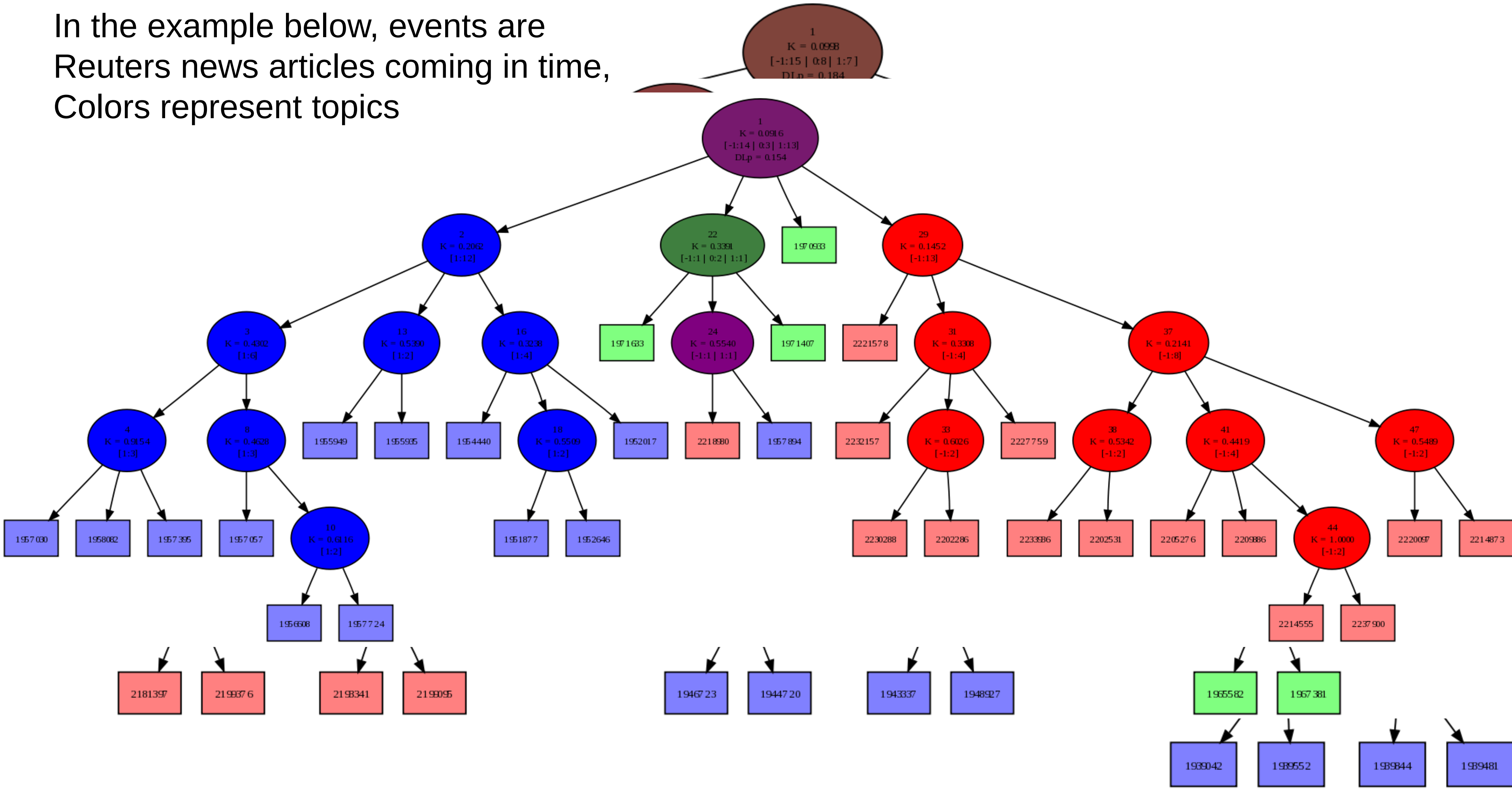
Example: Stream summarization by incremental hierarchical clustering

The goal is to maintain summary of data from stream in a form of a taxonomy of prototype clusters – each new events updates the taxonomy

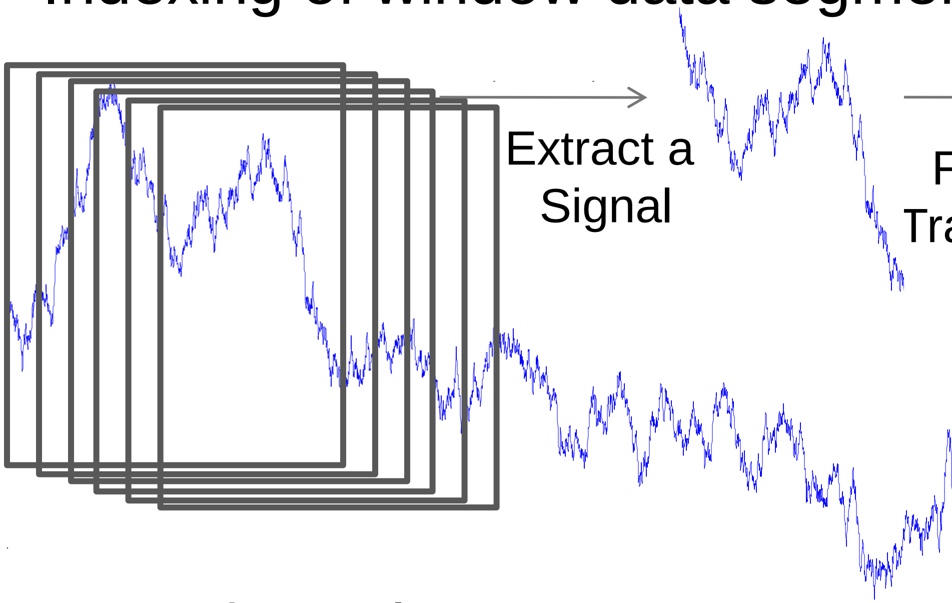
In the example below, events are Reuters news articles coming in time, Colors represent topics



[Blaz Novak, 2008]

Example: Stream processing on sliding window

- Indexing of window data segments

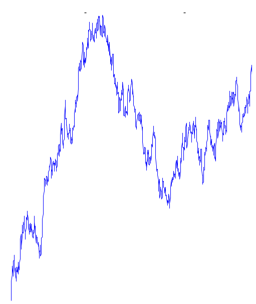


Database

11.3	**9.0**	**6.0**
12.3	**10.0**	**11.0**
2.3	**1.0**	**9.0**

Matching with one of distance metrics – if data and query are similar trigger an alert

- Query/Template Pattern Preprocessing



Fourier Transform

10.0	**9.5**	**60**

[Faloutsos, 1994]

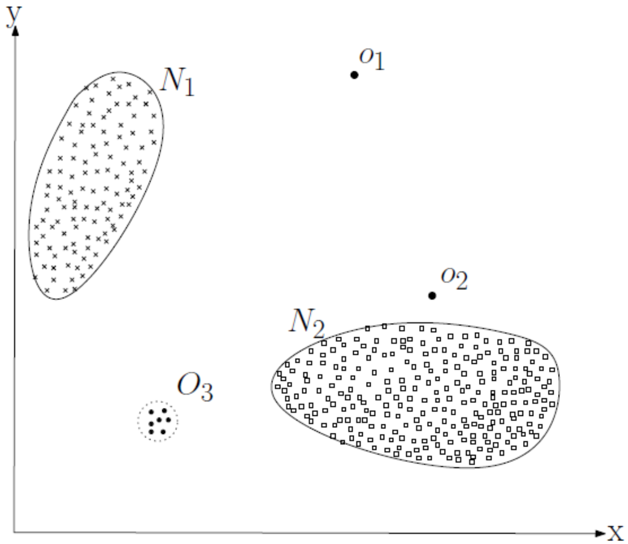
Slide taken from [Pramod Vemulapalli: Pattern Matching with Acceleration Data]

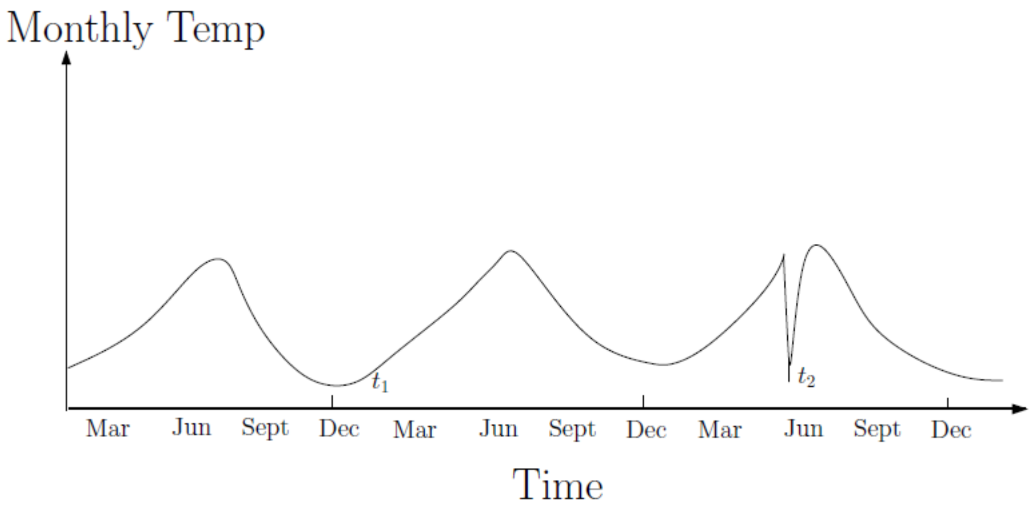
Data reduction stream mining tasks

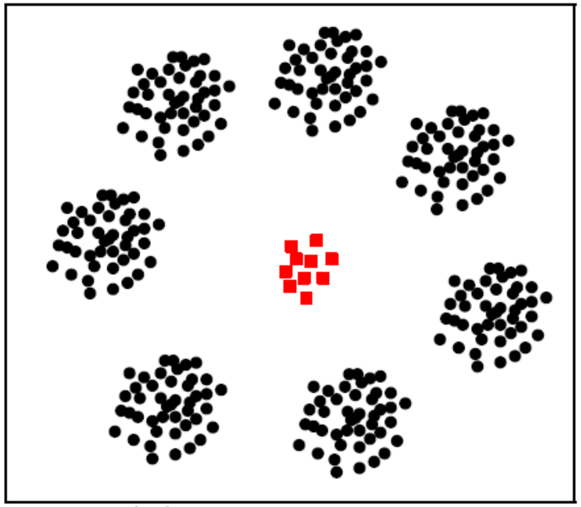
- **Sampling**
  - …challenge is to obtain representative data sample (i.e., enabling to perform correctly required operations on data)
- **Filtering**
  - …simple filters are easy to implement (e.g. simple conditions like “x<10”)
  - …filtering by a membership of a set which doesn’t fit in the main memory requires more sophisticated algorithms (e.g. Bloom filtering)
    - (example of set membership: list of spam URLs)

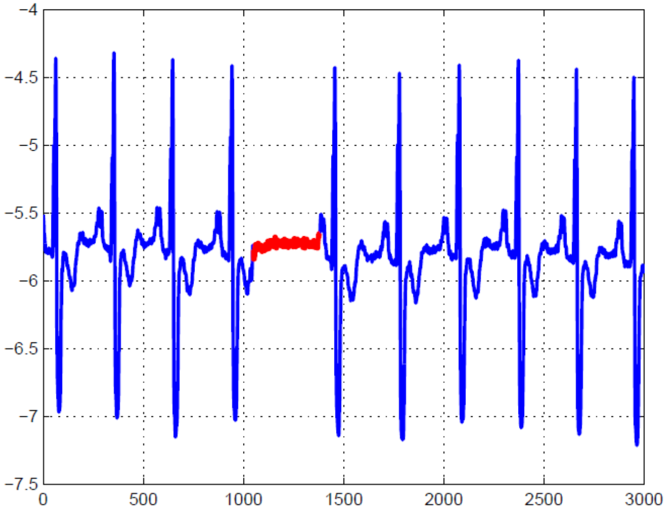
ANOMALY DETECTION

What are anomalies?





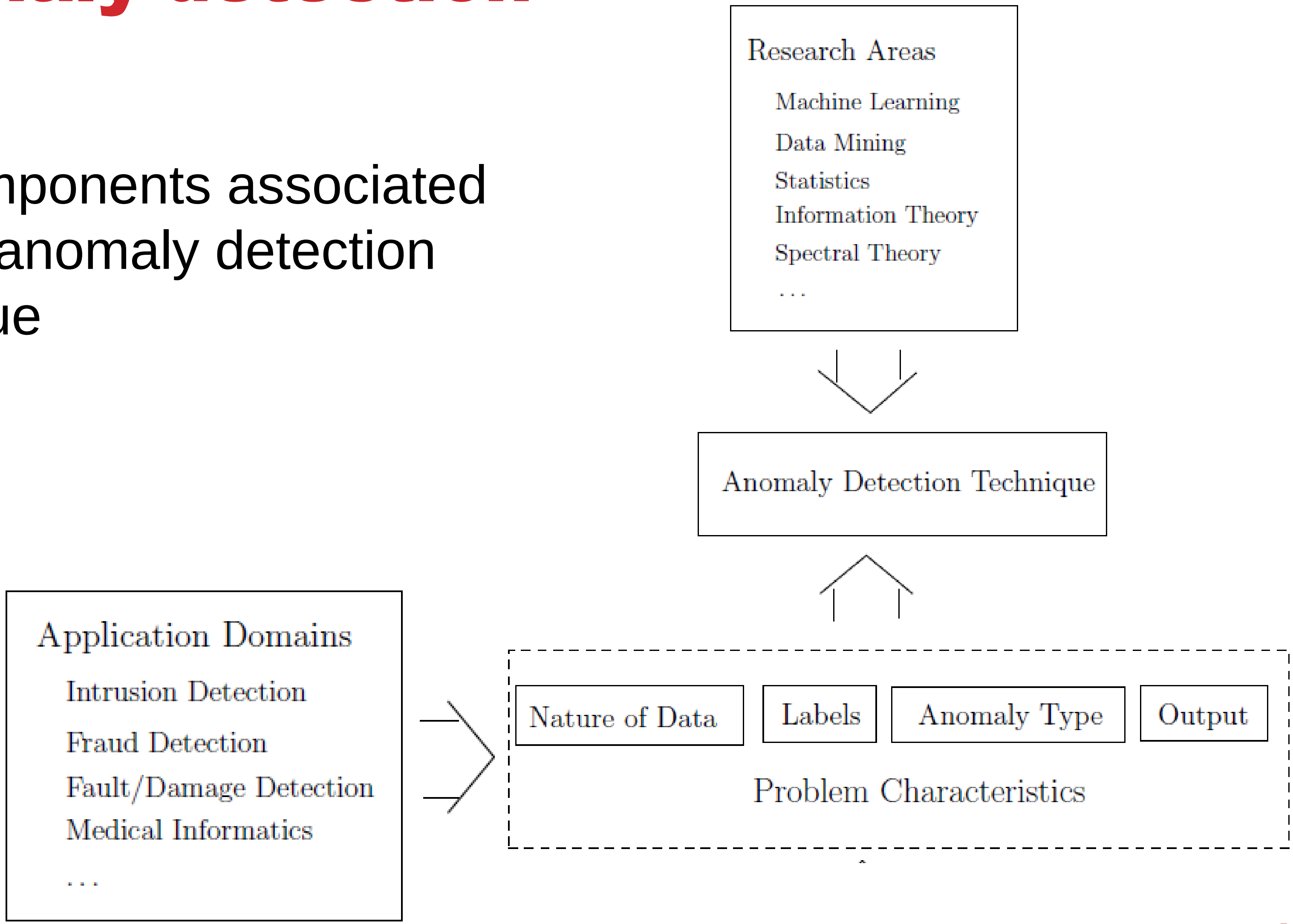




http://www.dtc.umn.edu/publications/reports/2008_16.pdf

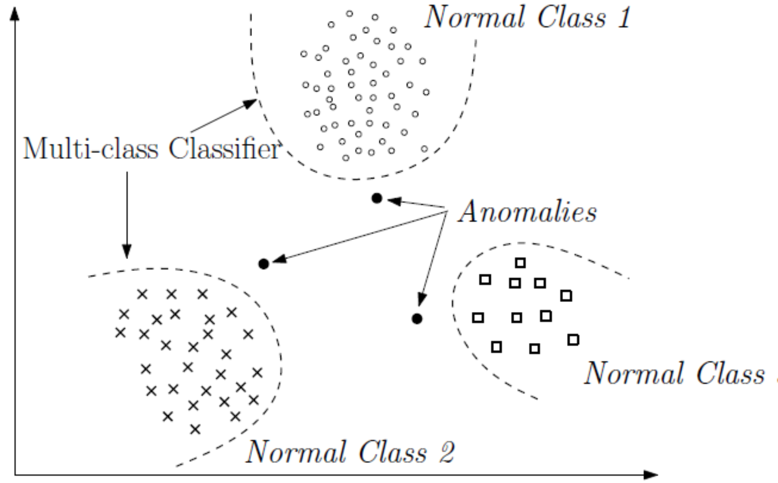
Anomaly detection

Key components associated with an anomaly detection technique



http://www.dtc.umn.edu/publications/reports/2008_16.pdf

Techniques to detect anomalies



Classification based

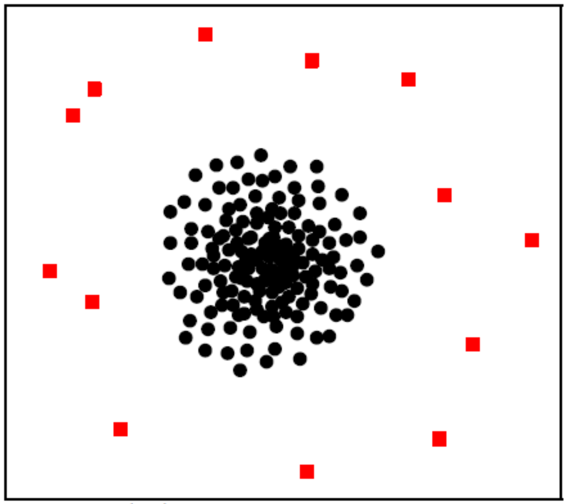
- A pre-trained classifier can distinguish between normal and anomalous classes

Clustering based

- Normal data instances belong to large and dense clusters, while anomalies either belong to small or sparse clusters

Nearest neighbor approaches

- *Normal data instances occur in dense neighborhoods, while anomalies occur far from their closest neighbors*



Statistical approaches

- *Normal data instances occur in high probability regions of a stochastic model, while anomalies occur in the low probability regions*

Information theoretic approaches

- *Anomalies in data induce irregularities in the information content of the data set*

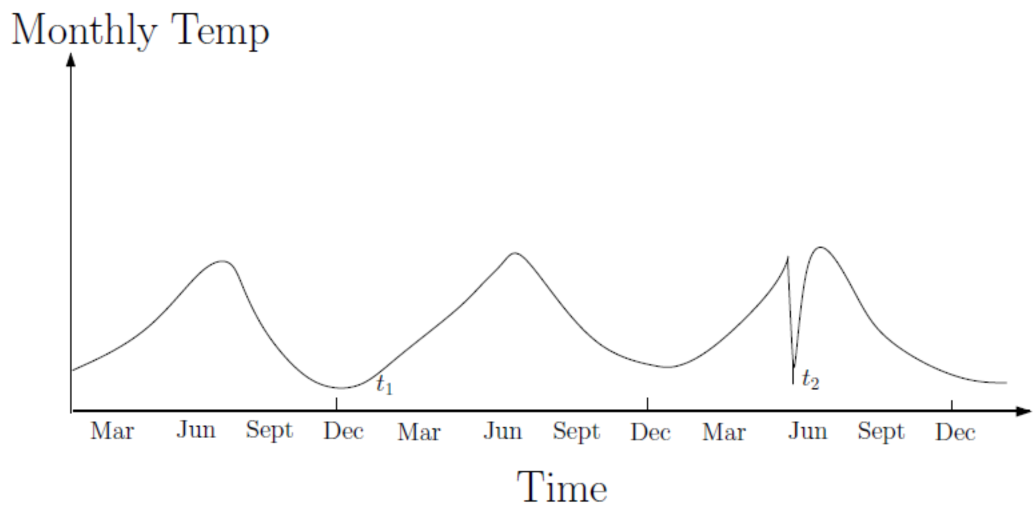
Spectral methods

- *Normal instances appear in a lower dimensional subspace, anomalies in the rest (noise)*

http://www.dtc.umn.edu/publications/reports/2008_16.pdf

The key to a successful anomaly detection is proper feature engineering!

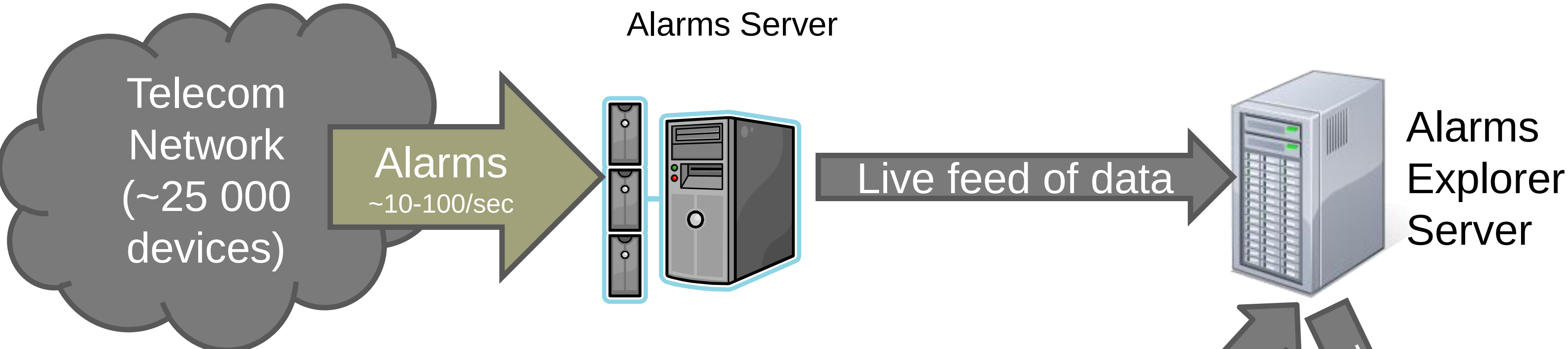
Anomalies are detectable if data instances are represented in an informative feature space



Contextual anomaly *t*2 in a temperature time series. Note that the temperature at time *t*1 is same as that at time *t*2 but occurs in a different context and hence is not considered as an anomaly.

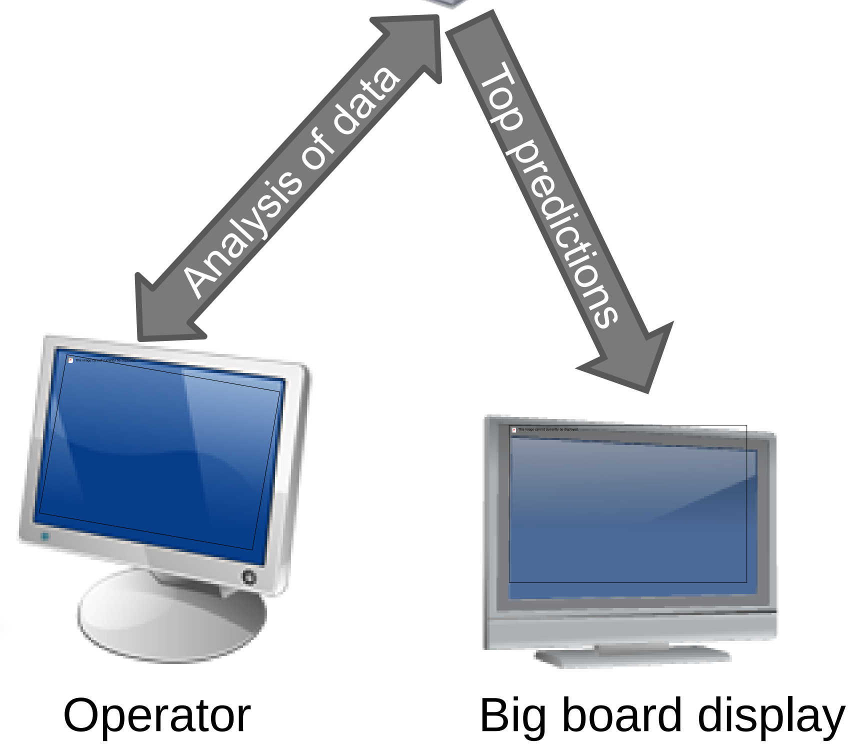
http://www.dtc.umn.edu/publications/reports/2008_16.pdf

Application: Telecommunication Network Monitoring



Alarms Explorer Server implements three real-time scenarios on the alarms stream:

1. **Root-Cause-Analysis** – finding which device is responsible for occasional “flood” of alarms
2. **Short-Term Fault Prediction** – predict which device will fail in next 15mins
3. **Long-Term Anomaly Detection** – detect unusual trends in the network



Outline

Outline

Part III. Demos, Tools & Research directions

Use cases

- What systems and prototypes exist?

Open problems

- Are there unsolved problems?

Summary

- What was this tutorial about?

List of sources for further studies

- Where to start digging?

Use cases

Environmental intelligence

Others

- Intelligent buildings
- Smart cities
- Smart infrastructures
- …

Environmental intelligence

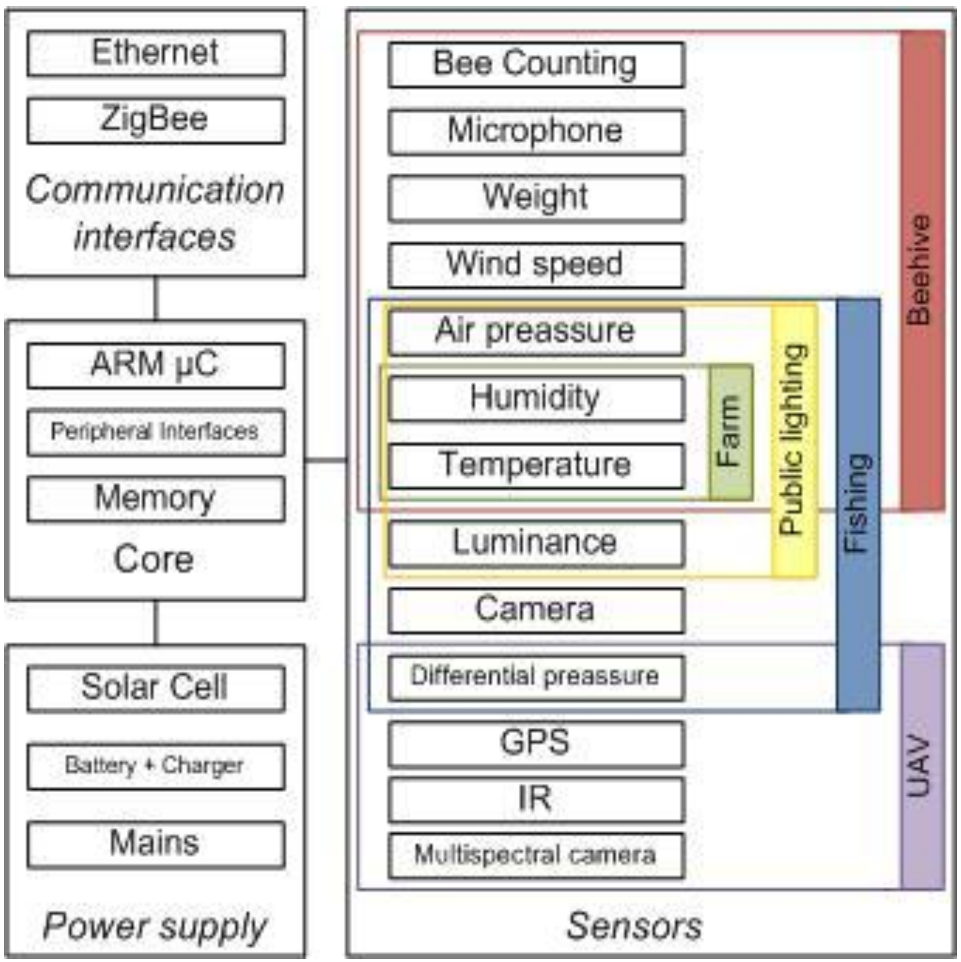
Data from large number of sensors deployed in infrastructure (such as roads) or over other area of interest (such as agriculture fields) can give decision makers a real-time awareness on the observed phenomena and events.

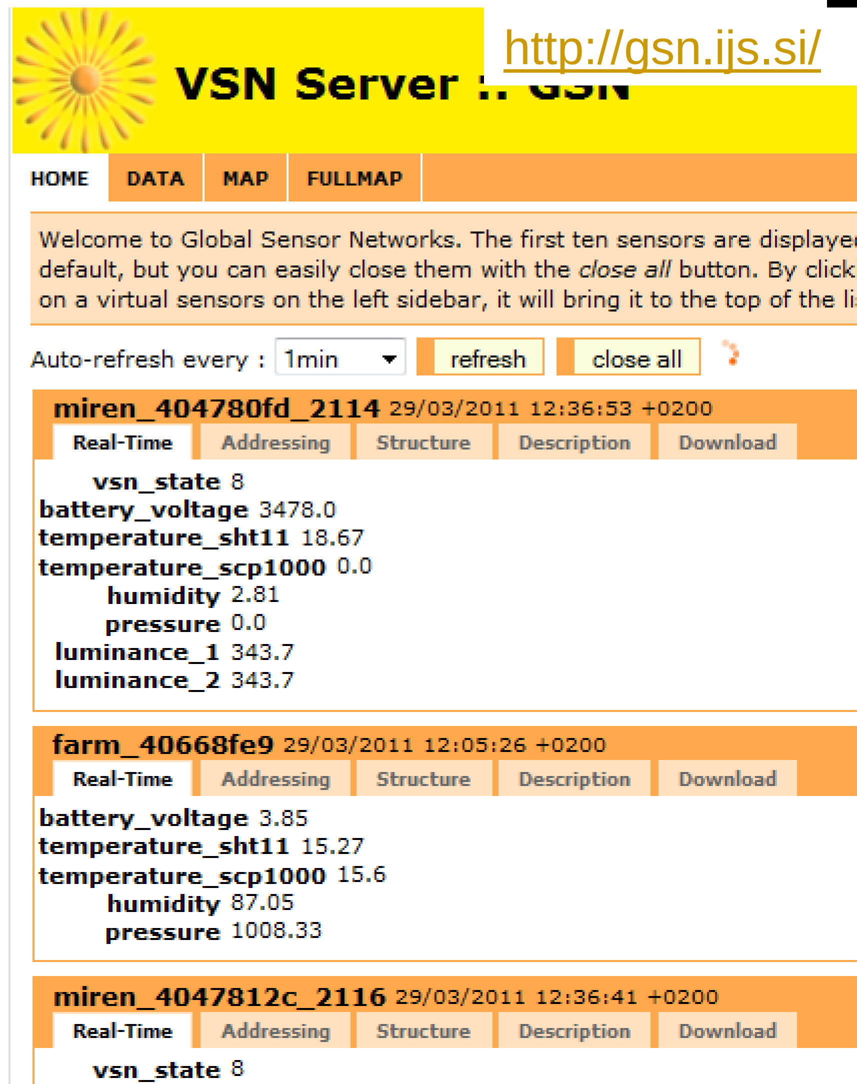
Solutions:

- Remote monitoring of cultures, soil moisture, insect infestations or disease infections
- Irrigation and pesticide spraying in precision agriculture
- Livestock monitoring for maximizing production (meat, milk, eggs) and achieve higher reproduction rates

Our quick start

VESNA Sensor Node

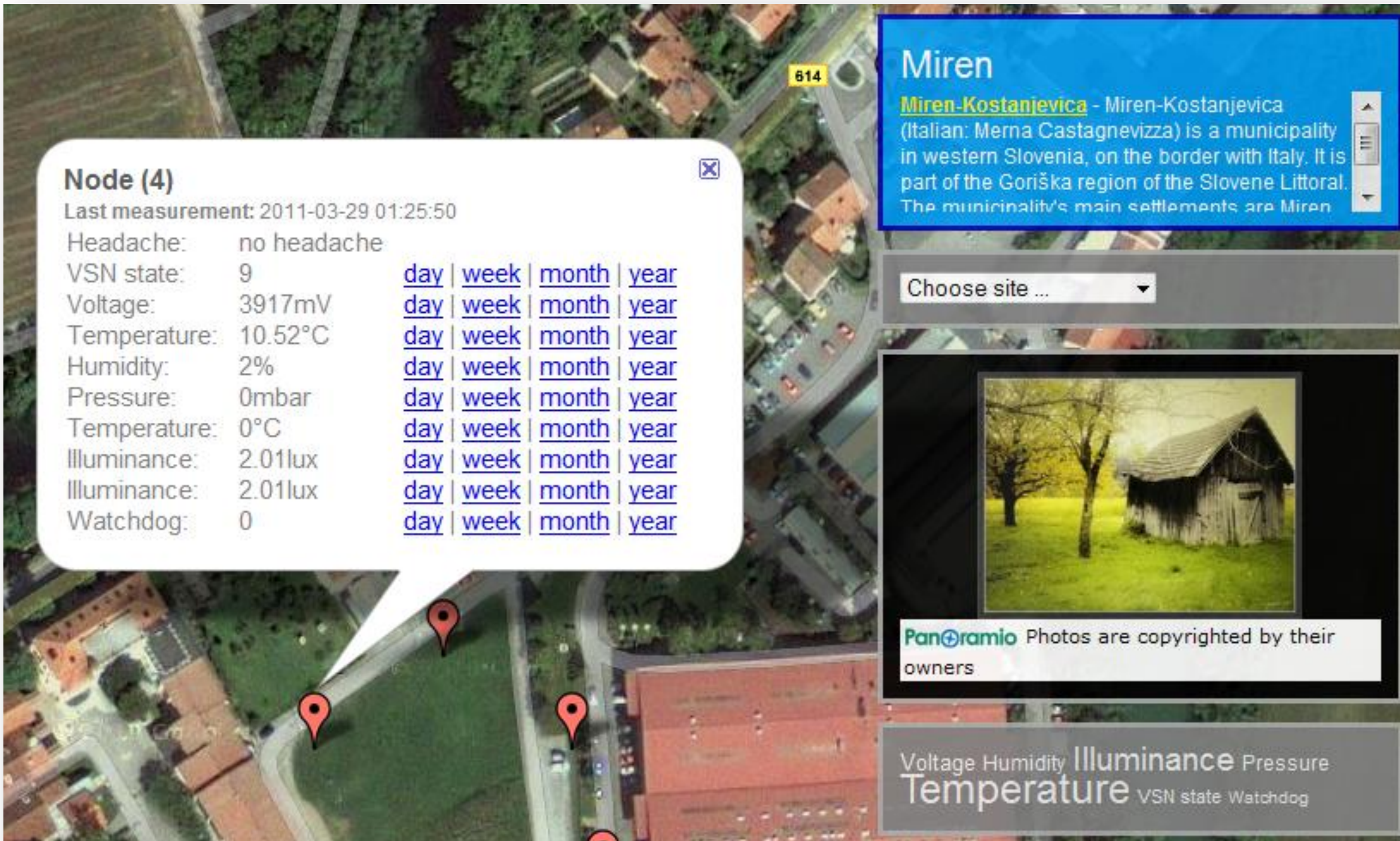




Environmental monitoring and lights control testbed

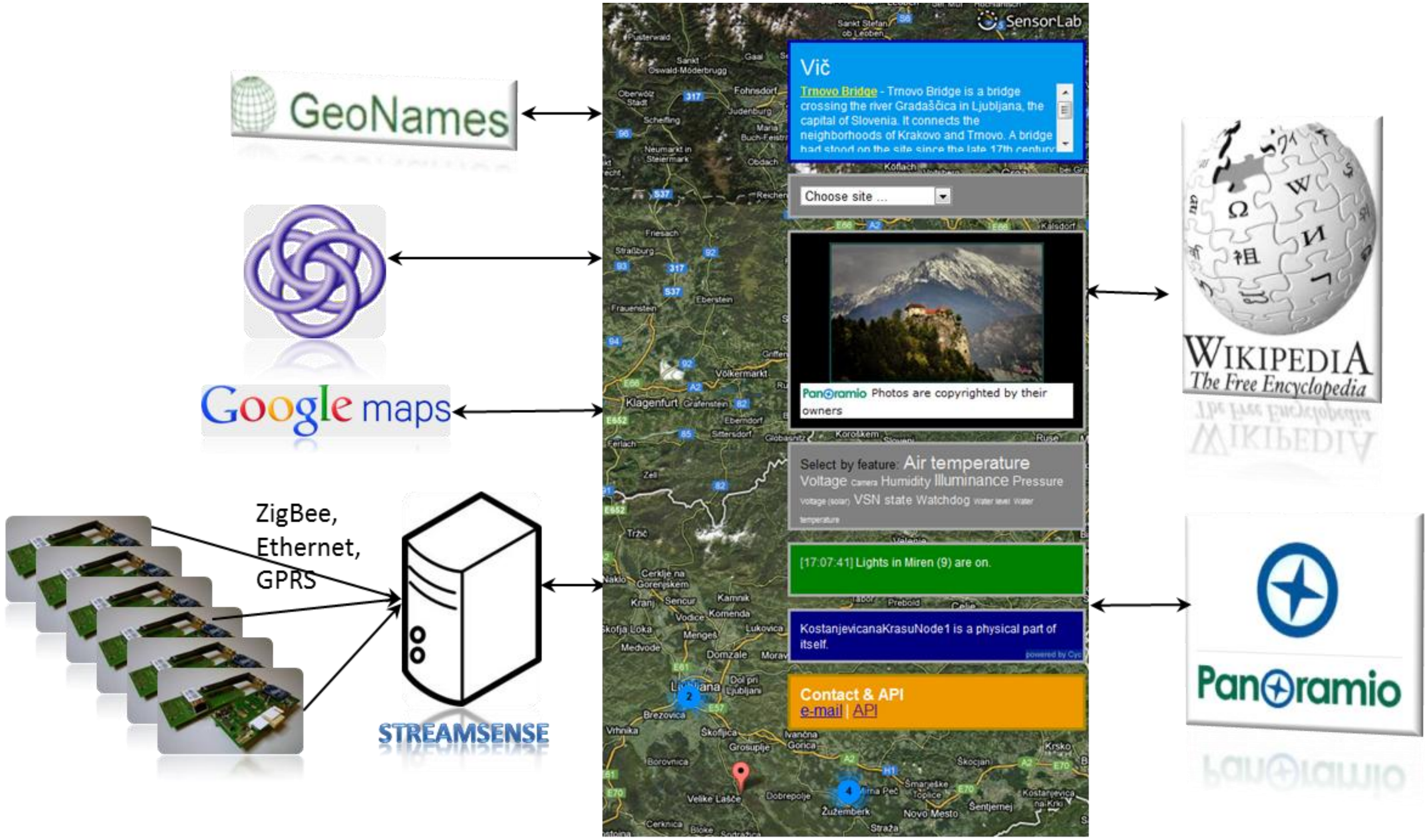
- Location: Slovenia, Europe (project started August 2010)
- The “things”: public light poles + VESNA sensor nodes
- Sensors: temperature, humidity, pressure, illuminance, etc.
- Actuator: dim the intensity of the light (pulse width modulation)

Videk: mash-up for environmental intelligence



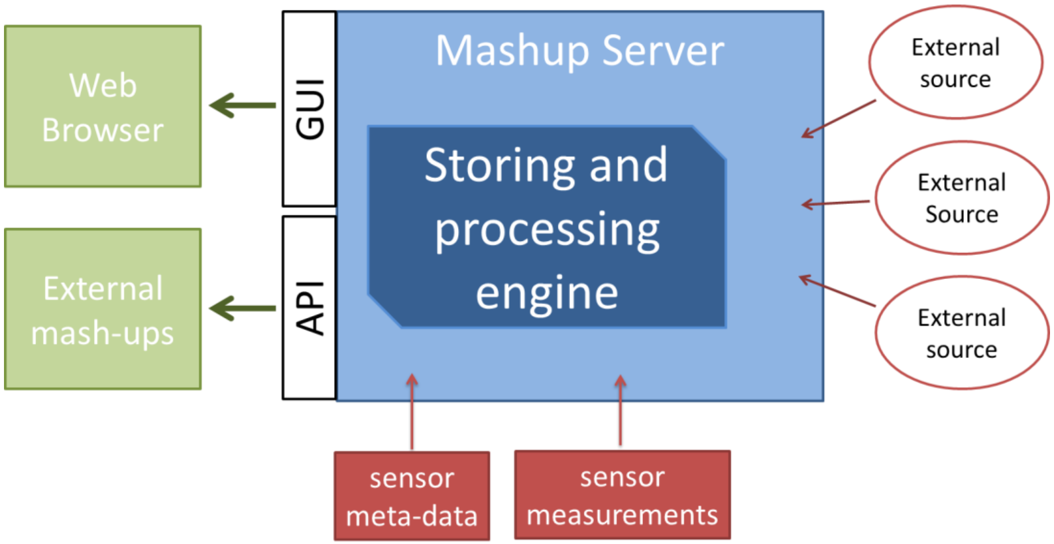
http://sensors.ijs.si/

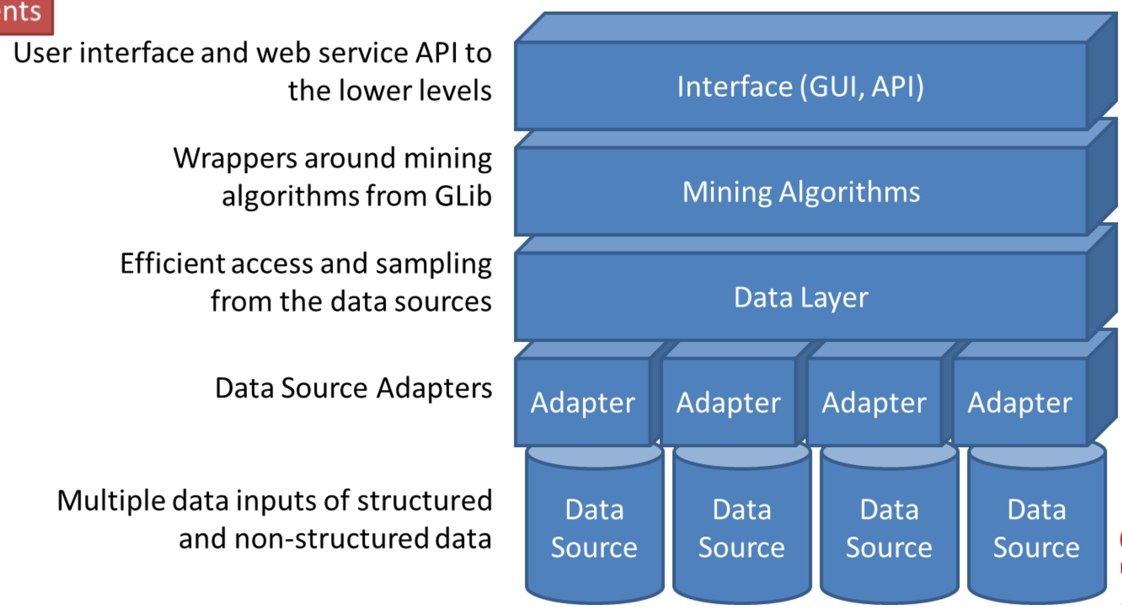
Videk: mashed sources of data



http://sensors.ijs.si/

Technology behind Videk



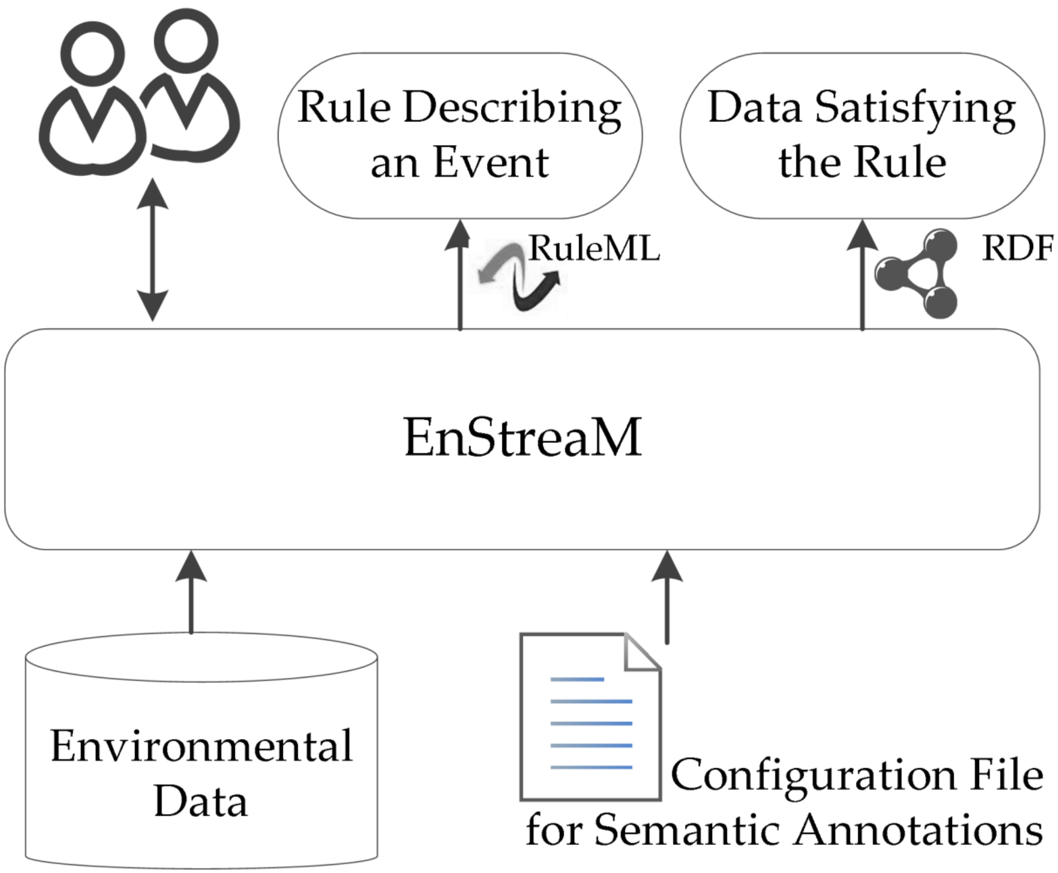


Rule generation and validation on environmental data

- The supporting architecture is capable of handling large amounts of data
- The system is meant for domain experts to generate and validate rules that describe specific events
- Applied in environmental scenarios: landslides, oil spills and river floods, where main source of data comes from sensors

Also a ESWC 2012 demo: Supporting Rule Generation and Validation on Environmental Data in EnStreaM

System Overview



- Input: **sensor data** and **event data**
  - e.g.: volume of rainfall for a given geographical location and landslides that occurred
- Output: **rules** and the related **dataset**, semantically annotated

SensorLab

Data Layer Schema

Node

- Name, URN
- GPS Latitude, Longitude, Altitude, Sattelite No., Speed
- Description, Geolocation (string), Owner

Sensor

- SensorNodeId
- SensorTypeId
- CurrentState fields (current aggregates)
- LastMeasurementId

Type

- Name, Measured Phenomena, URN
- Sampling information, Reporting interval, feature of interest, unit of measurement

Measurement

- SensorId
- Value
- Timestamp

Aggregate

- SensorId
- Value
- Aggregate type
- Timespan
- Timestamp

Events

- Name, URN
- Timestamp
- GPS latitude, longitude

SensorLab

Aggregates

Saves aggregates after transition into a new time window: Count, Average, Sum, Min, Max, Standard deviation

Primary aggregates

Calculated from raw measurements, fine grained.

Secondary aggregates

Calculated from other aggregates (only possible to use with on-line type).

```xml
<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <timespans>
    <timespan id="1" timewindow="3600" />
    <timespan id="2" pid="1" timewindow="24" interval="1"/>
    <timespan id="3" pid="2" timewindow="7" interval="1"/>
    <timespan id="3" pid="2" timewindow="30" interval="1"/>
    <timespan id="4" pid="2" timewindow="365" interval="1"/>
  </timespans>
  <aggregates>
    <aggregate type="MAX"/>
    <aggregate type="MIN">
      <timespan id="1" timewindow="3600">
      <timespan id="2" pid="1" timewindow="48" interval="24"/>
    </aggregate>
    <aggregate type="AVG"/>
    <aggregate type="SUM"/>
    <aggregate type="STD"/>
    <aggregate type="MED"/>
    <aggregate type="1QU"/>
    <aggregate type="3QU"/>
    <aggregate type="CNT"/>
  </aggregates>
  <sensortypes>
    <sensortype id="1">
      <aggregate type="MAX"/>
      <aggregate type="SUM"/>
    </sensortype>
  </sensortypes>
  <sensors>
    <sensor id="1">
      <aggregate type="MAX"/>
      <aggregate type="SUM"/>
    </sensor>
  </sensors>
</configuration>
```

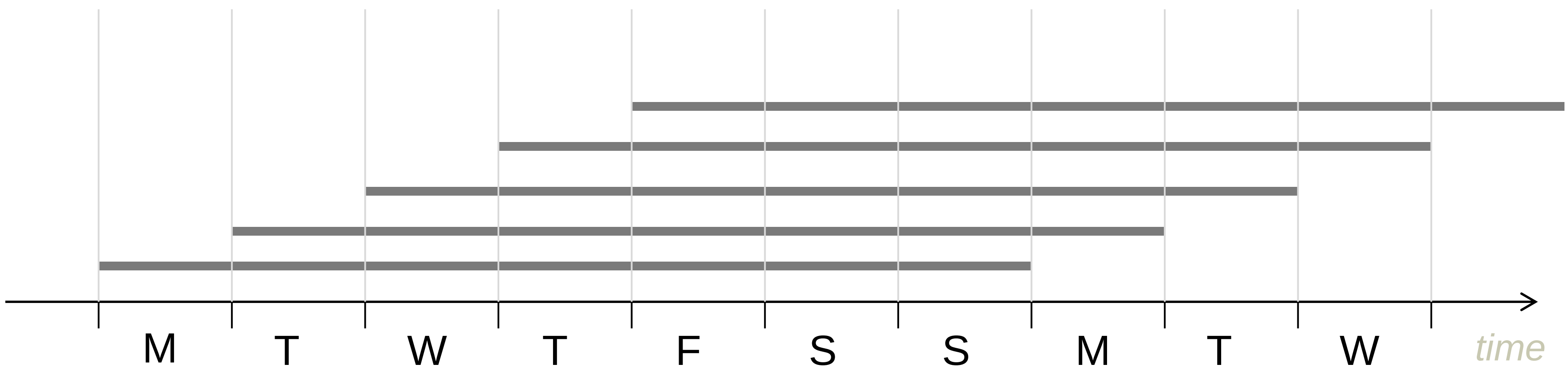
Time windows & intervals

- Time windows of aggregates can overlap
- Overlapping interval is set in configuration file (interval)
- For example:
  - Weekly aggregates can be calculated from Monday to Monday, from Tuesday to Tuesday, etc.

```
<timespan id="1" timewindow="3600" />

<timespan id="2" pid="1"
 timewindow="24" interval="1"/>

<timespan id="3" pid="2"
 timewindow="7" interval="1"/>
```

7-day time window

Overlap/update interval is 1 day



Example queries

Easy and fast detection of events on current state data (very simple rules)

Fog forming example

```
If

      (humidity[AVG,1h] < 90%) &
      (humidity[AVG,10m] > 95%)

Then

      trigger fog forming risk event.
```

Simple validation of more complex event queries (using current state and previous aggregates)

Road Icing example

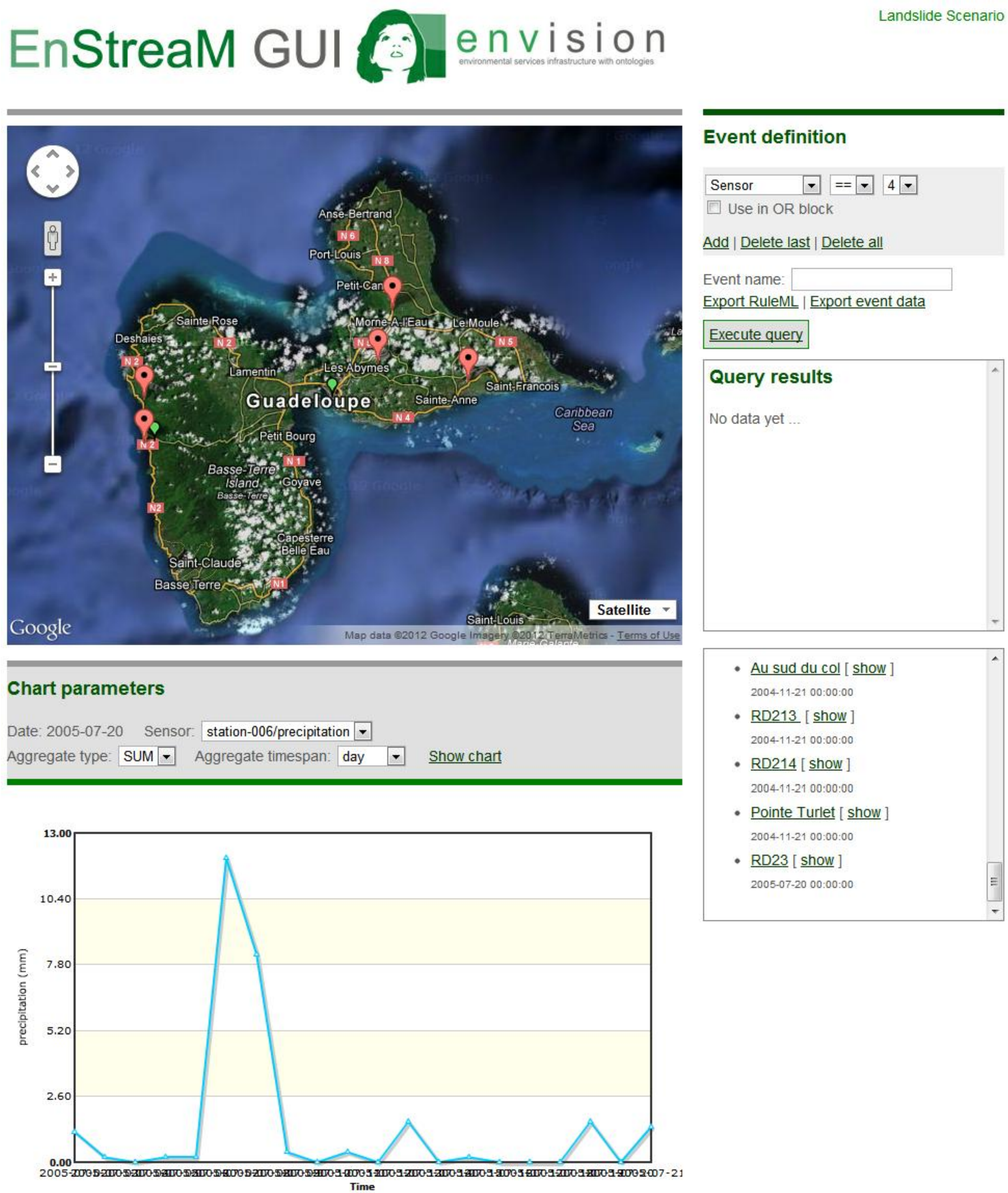
```
If

      (precipitation[SUM,12h,6h ago] > X) &
      (temparature[MAX,12h,6h ago] > 0) &
      (temperature[MIN, 6h]) < 0)

Then

      trigger road icing risk event.
```

Can handle time queries

Time example

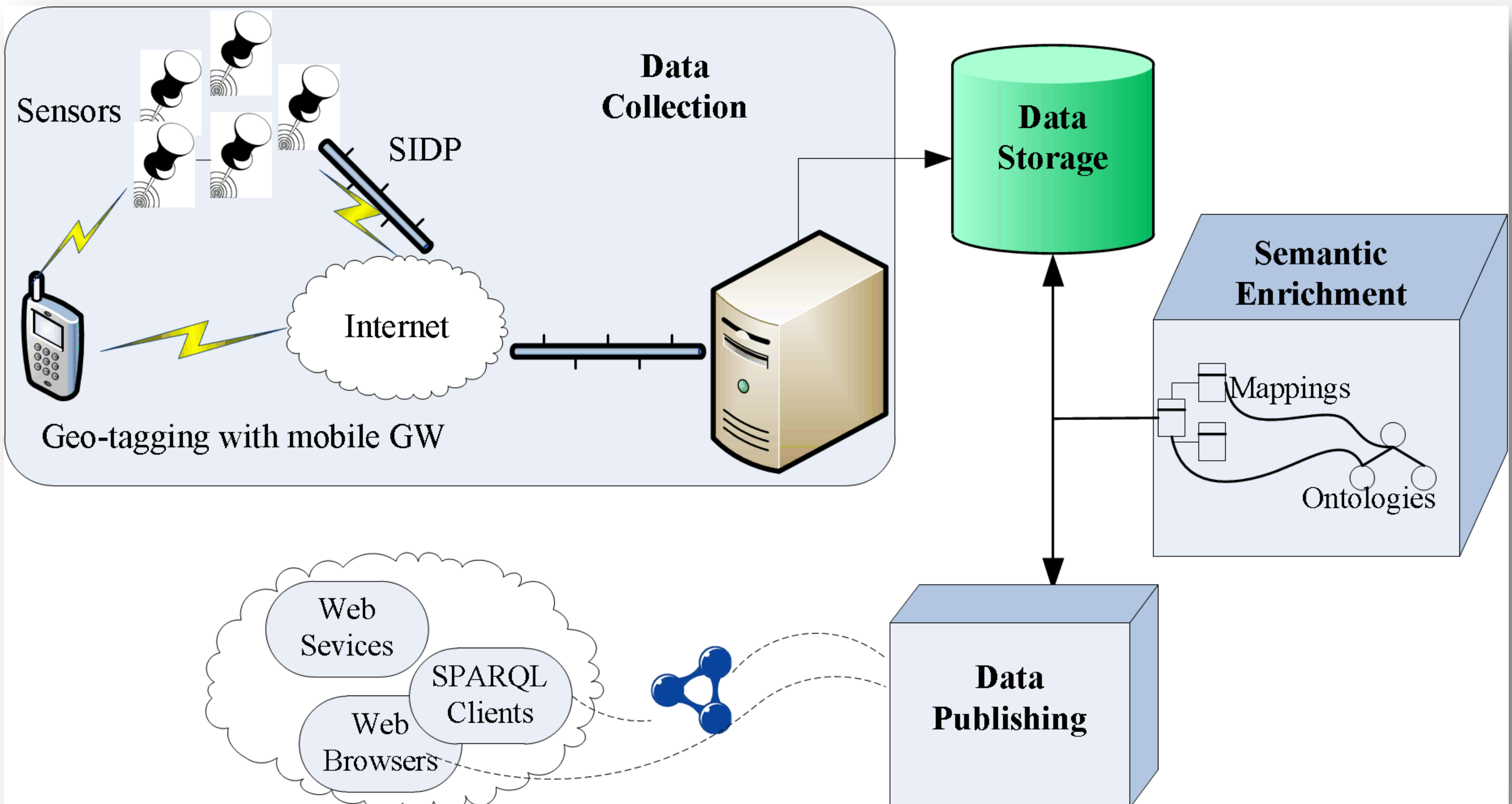
```
If

      (temperature[AVG,1w,3d ago] <-5) &
      (temperature[AVG,24h,2d ago] < 5) &
      (temperature[AVG,24h,1d ago] < 5) &

Then

      trigger lake still frozen event.
```

System GUI



Landslide Scenario
EnStreaM GUI
envision
environmental services infrastructure with ontologies
Anse-Bertrand
Port-Louis
Petit-Canal
Sainte-Rose
Deshaies
Morne-A-l'Eau
Le Moule
Lamentin
Les Abymes
Guadeloupe
Saint-Francois
Sainte-Anne
Caribbean Sea
Petit Bourg
Basse-Terre Island
Goyave
Capesterre Belle Eau
Saint-Claude
Basse Terre
Saint-Louis
Satellite
Google
Map data ©2012 Google Imagery ©2012 TerraMetrics - Terms of Use
Event definition
Sensor
==
4
Use in OR block
Add | Delete last | Delete all
Event name:
Export RuleML | Export event data
Execute query
Query results
No data yet ...
Au sud du col [show]
2004-11-21 00:00:00
RD213 [show]
2004-11-21 00:00:00
RD214 [show]
2004-11-21 00:00:00
Pointe Turlet [show]
2004-11-21 00:00:00
RD23 [show]
2005-07-20 00:00:00
Chart parameters
Date: 2005-07-20
Sensor: station-006/precipitation
Aggregate type: SUM
Aggregate timespan: day
Show chart
13.00
10.40
7.80
5.20
2.60
0.00
precipitation (mm)
Time

Environmental intelligence: SemSense system architecture



Moraru et al, Exposing Real World Information for the Web of Things, IIWeb (WWW2011), Hyderabad, India.

Environmental intelligence: SemSense implementation details

Scenario

- architecture for collecting real world data from a physical system of sensors and publishing it on the Web

Implementation:

- VESNA Sensor Nodes platform are the “things”
- Self-Identification Protocol
  - Custom protocol for collecting meta-data and data
- MySQL database for storage of data and meta-data
- Meta-data semantic enrichment component
  - RDF representation
  - Semantic Sensor Network (SSN) ontology, Basic GeoWGS84 Vocabulary, GeoNames and FOAF as vocabulary
  - Linking to Linked Opened Data Cloud
  - D2R for mapping the database schema

A. Moraru, M. Vucnik, M. Porcius, C. Fortuna, M. Mohorcic, D. Mladenic, Exposing Real World Information for the Web of Things, IIWeb (WWW2011), Hyderabad, India.

Environmental intelligence: browse the semantic representation

JSI SensorLab

Running at http://sensorlab.ijs.si:2020/

Home | Archive-1Day-Sampling DeviceType Observation ObservationValue Platform Property SensingDevice SensorOutput System

This is a database published with D2R Server. It can be accessed using

1. your plain old web browser
2. Semantic Web browsers
3. SPARQL clients.

1. HTML View

You can use the navigation links at the top of this page to explore the database.

2. RDF View

You can also explore this database with **Semantic Web browsers** like Tabulator or Disco. To start browsing, open this entry point URL in your Semantic Web browser:

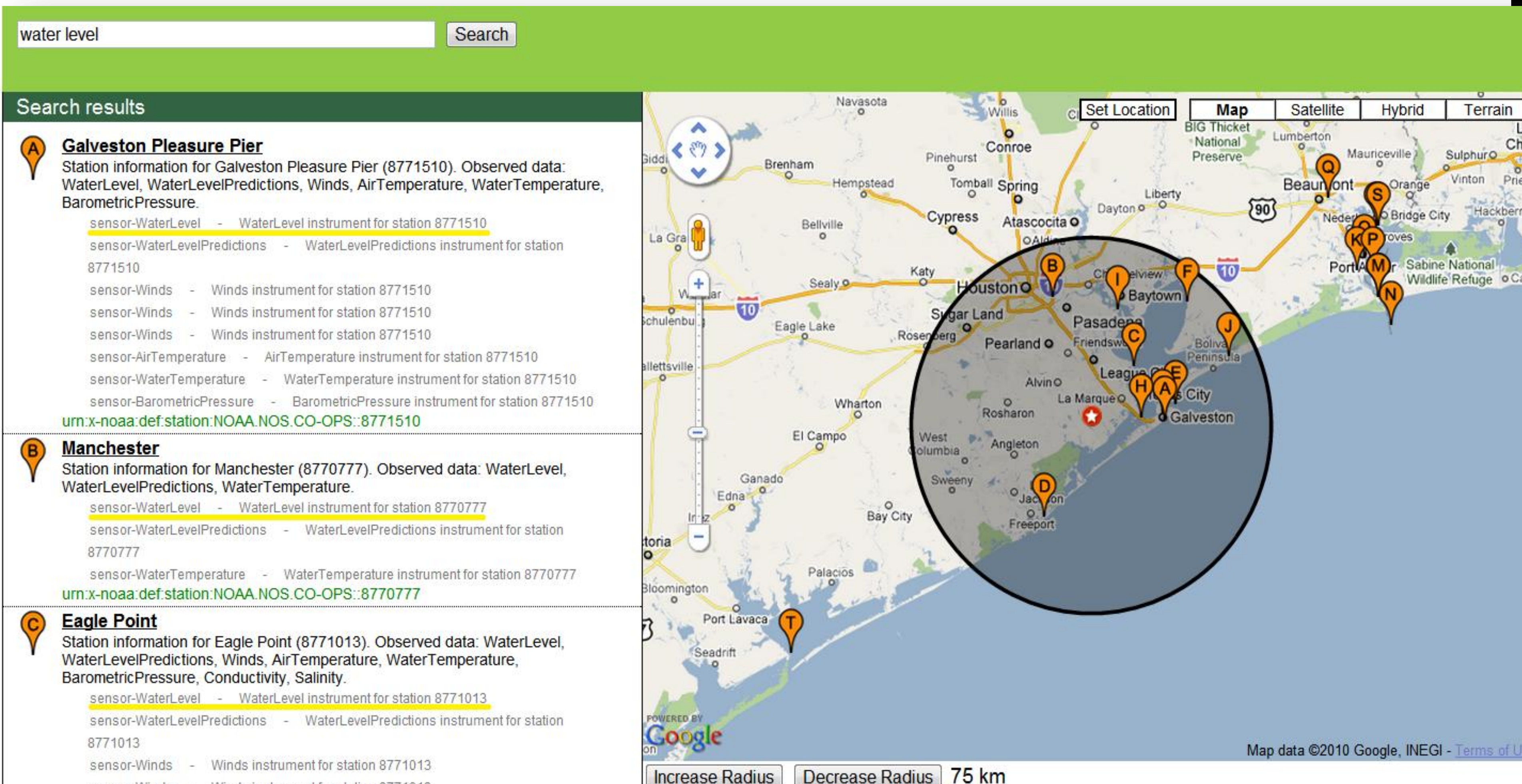
http://sensorlab.ijs.si:2020/all

3. SPARQL Endpoint

Browse at: http://sensors.ijs.si:2020/

SensorLab

Sensor Search Example



http://sensors.ijs.si/static/index.html

Sensor search and ranking

The goal of the search

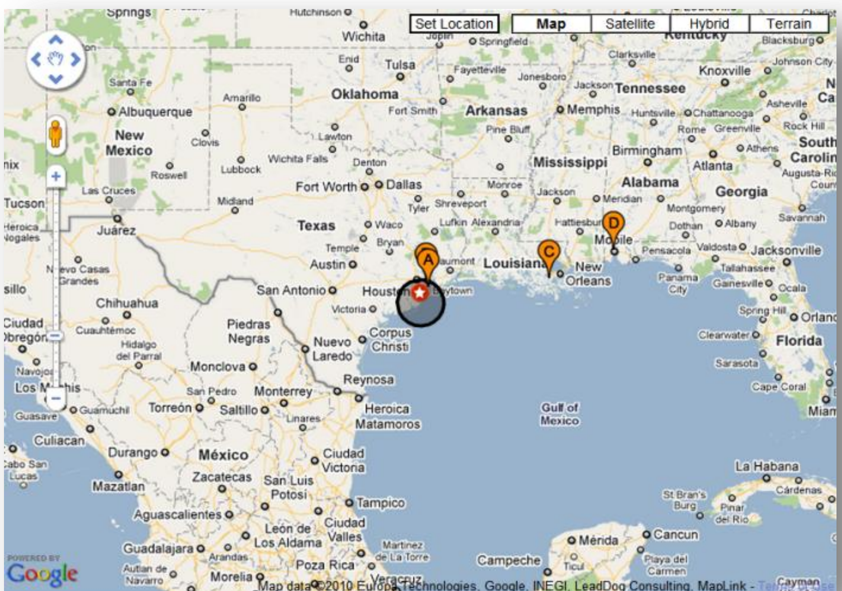
- retrieve and rank a list of sensors based on the user's request
- Input:
    - keyword query
    - geographic location (given by latitude and longitude coordinates)
    - distance (interpreted as a radius around the location)
- Output:
    - list of ranked sensors

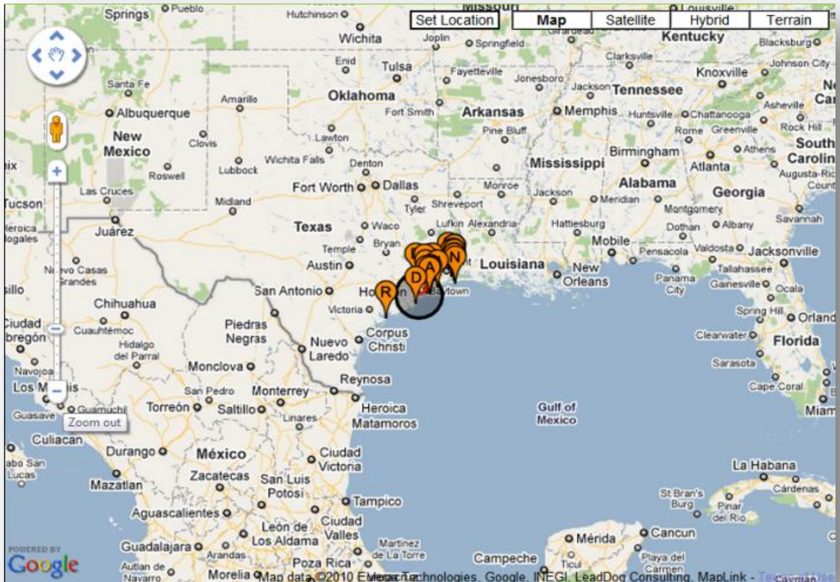
L. Dali, A. Moraru, D. Mladenic , Using Personalized PageRank for Keyword Based Sensor Retrieval, SemSearch (WWW2011), Hyderabad, India.

Sensor Search Example

Performing the proposed ranking results in obtaining more platforms closer to the area of interest

- we consider relevant also sensors located on the same platform or those that are in the same deployment



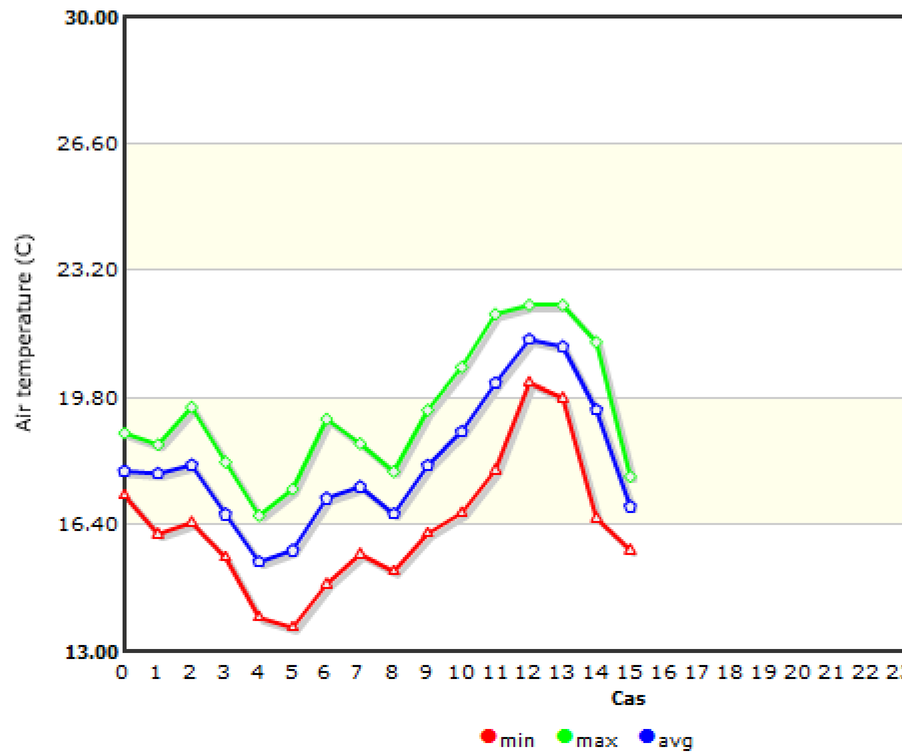


L. Dali, A. Moraru, D. Mladenic , Using Personalized PageRank for Keyword Based Sensor Retrieval, SemSearch (WWW2011), Hyderabad, India.

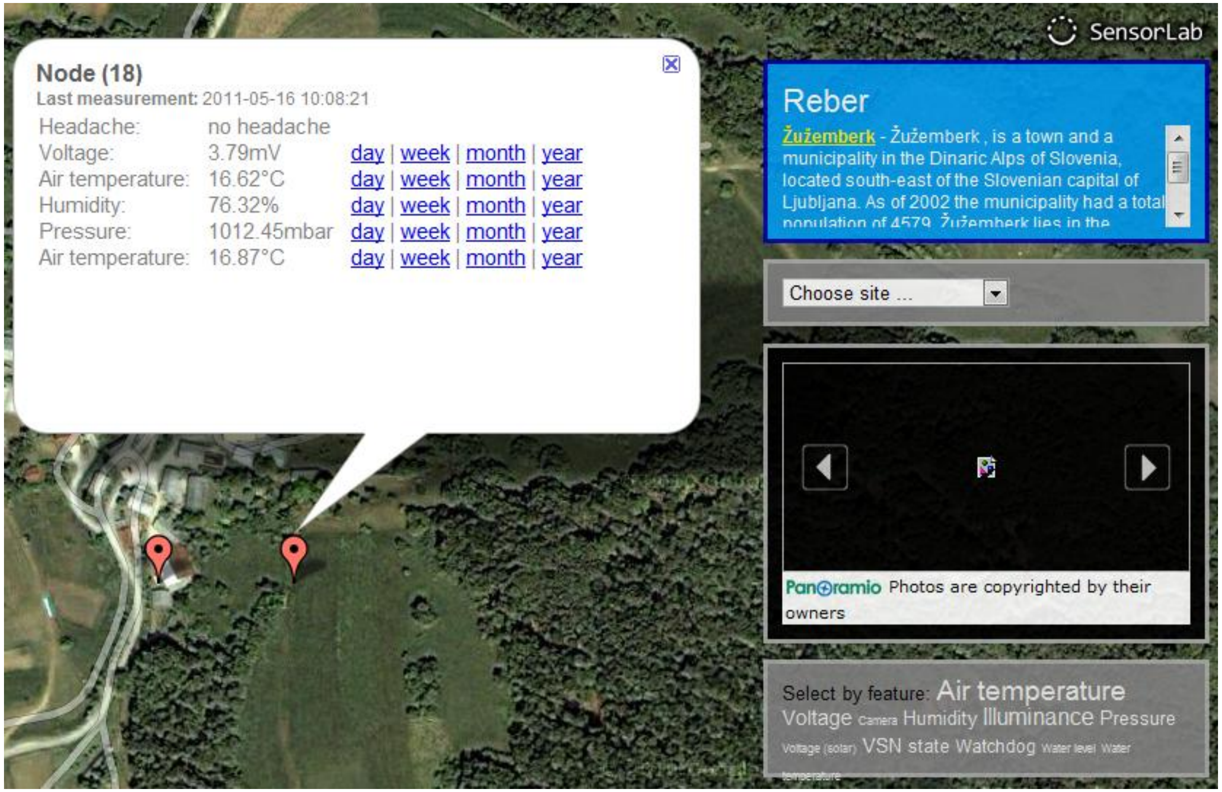
SensorLab

Hyperthermia detection in stables

- The goal is to measure temperature and humidity inside and outside stables in order to detect the danger of hyperthermia at cows and issue an early warning.



Hyperthermia detection in stables



http://sensorlab.ijs.si/sl/demos.html

Remote observation of sport-fishing conditions

By using WSN technology information on water level, picture of a fishing spot and water and outside temperature can be provided

http://sensorlab.ijs.si/sl/demos.html

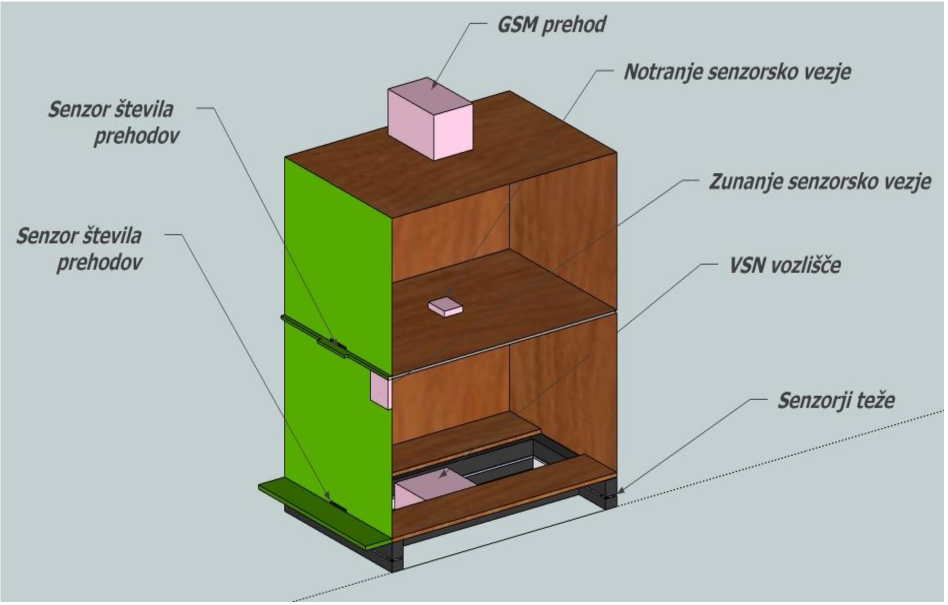
Remote observation of sport-fishing conditions

http://sensorlab.ijs.si/sl/demos.html

Beehive local climate conditions

The purpose of this testbed is to monitor climate conditions inside (temperature and humidity) and outside (temperature, humidity, air pressure, wind direction and speed) of the beehives.

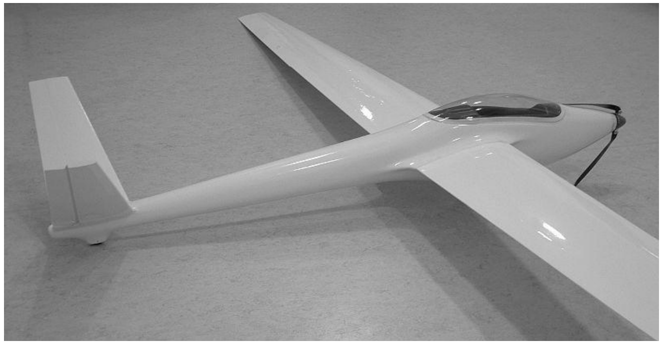
Through bee counting sensor presence of pesticides in the vicinity can be detected. For the test purposes also sound monitoring is possible



Multispectral imaging and data harvesting over Unmanned Aerial Vehicle (UAV)

Data harvesting over large areas where deployed WSNs have no Internet connection can be a very time consuming and expensive task.

Our solution uses Unmanned Aerial Vehicles (UAV) equipped with a gateway sensor node. In addition, UAV is used to collect multispectral images with a Tetracam ADC camera.



Use cases

Environmental intelligence

Others

- Intelligent buildings
- Smart cities
- Smart infrastructures
- …

Intelligent building

Berkley: Motescope*

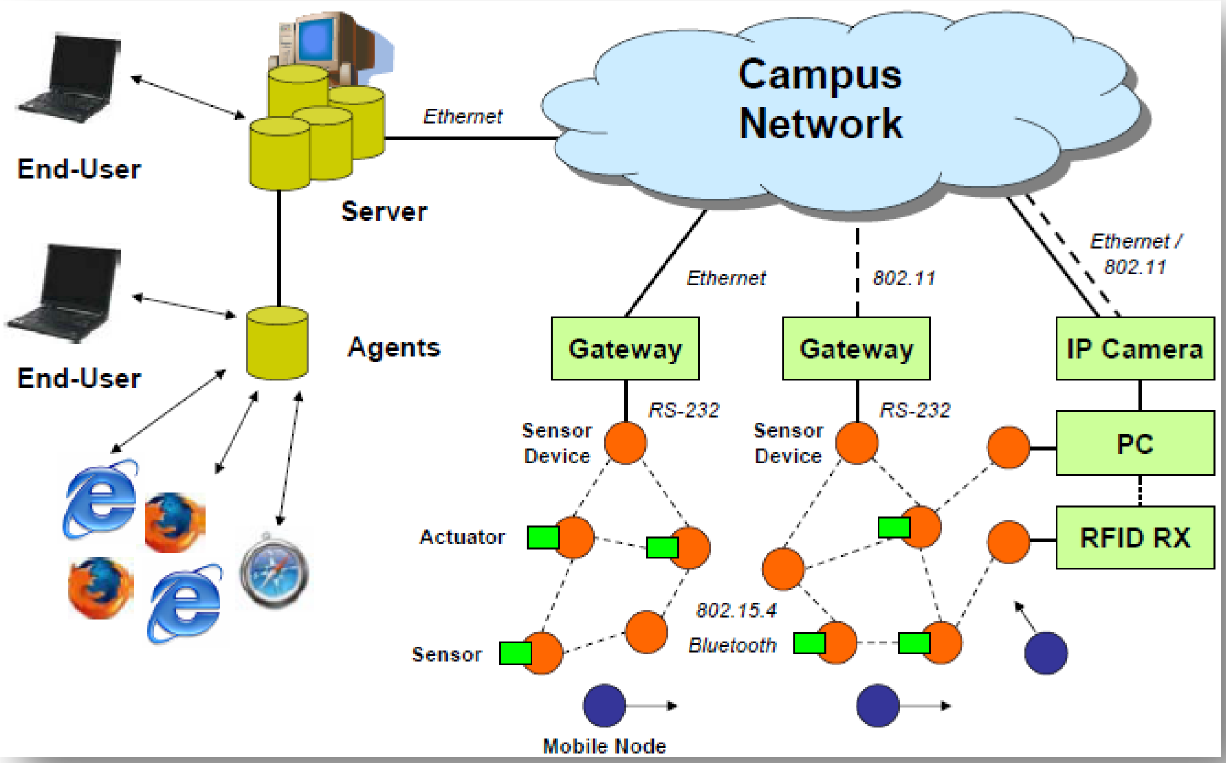
- Soda Hall, the Computer Science building
- Permanent testbeds for research, development and testing
- 78 Mica2DOT nodes

*According to web site visited on Oct 2010.

University campus

CMU: SensorAndrew*

- campus-wide testbed
- Firefly nodes
- Unknown scale



* According to web site on Oct 2010 and tech report from 2008.

Smart city

MIT: Senseable City Lab*

- Sensor nodes built into the wheels of bikes
- Unknown number

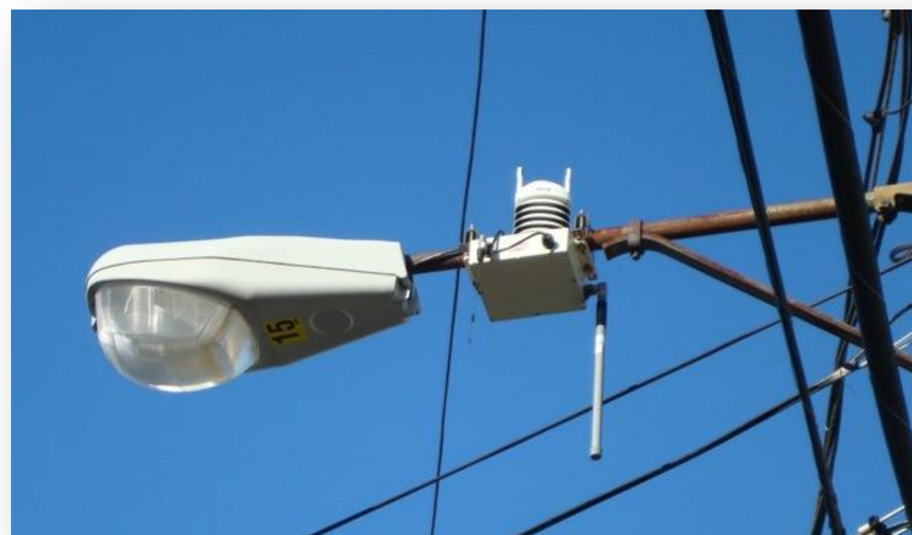
*Neil Savage, Cycling through Data, Communications of the ACM, Sept 2010.

SensorLab

Smart infrastructure

Harward, BBN: CitySense*

- 100 wireless sensors deployed across a city
- Sensor nodes are embedded PC, 802.11a/b/g interface, and various sensors for monitoring weather conditions and air pollutants
- open testbed



* According to web site visited on Oct 2010, last modified in 2008.

SensorLab

Federation of Sensor deployments

Pachube*

- 3700 sensor nodes, over 9400 data streams (April 2010)
- Sensor data and meta-data
- Open to upload/download

Sensorpedia*

- Similar to Pachube, limited testing Beta

Global Sensor Network*

- Framework for federated testbeds
- Used in the Swiss Experiment

* According to web site visited on Oct 2010.

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✓ **Use cases**

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Current state and open problems with respect to Sensor Nodes

WSN is

- Well developed field with many degrees of freedom
- Complex, large-scale, resource constrained systems
- Focus is on intra network communications

Efficient management and maintenance of the “things”

- Remote reconfiguration of parameters
- Remote software updates
- Real implementations solving real problems, particularly large scale (see next slide)

SensorLab

Myths & lessons regarding Sensor Networks

Myth #1: Nodes are deployed randomly.

Myth #2: Sensor nodes are cheap and tiny.

Myth #3: The network is dense.

Lesson #1: It’s all about the data.

Lesson #2: Computer scientists and domain scientists need common ground.

Lesson #3: Don’t forget about the base station!

M. Welsh, **Sensor Networks for the Sciences**, Communications of the ACM, Nov. 2010.

Challenges with respect to conceptualization

WoT covers a long pipeline of technologies from sensors to high level services

- ...current ontologies are covering just parts of the space and are yet to be interlinked
- ...ideally, sensor network domain should be linked to general common-sense ontologies and further to domain specific service ontologies

Challenges with respect to analytics & CEP

- Traditional mining and analytic techniques are not ready for the scale and complexity coming from large sensor setups
- ...in particular:
  - connection to background knowledge (ontologies) for enrichment of sensor data for expressive feature representations needed for analytic techniques
  - "complex events" are in the context of WoT much more complex compared to traditional "complex events" research
  - real-time response on complex events appearing in WoT setups

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Summary

The tutorial had 3 parts:

1. Motivation & background
   - Problems that the Web of Things can solve
   - Components and complexity of the system, from “Things” to Apps and Services
   - Quick start recipes
2. Technology and tools for exploiting the WoT
   - Semantic aspects
   - Analytic aspects
   - Services
3. Demos, Tools & Research directions
   - Overview of existing setups and tools used for their implementation
   - Research directions

Outline

Part III. Demos, Tools & Research directions

✓ **Use cases**

- What systems and prototypes exist?

✓ **Open problems**

- Are there unsolved problems?

✓ **Summary**

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Relevant Conferences

- **WWW** - International World Wide Web Conferences
- **ICML** – International Conference of Machine Learning
- **NIPS** – Neural Information Processing Systems
- **KDD** – ACM Knowledge Discovery in Databases
- **ICWS** - IEEE International Conference on Web Services
- **ISWC** – International Semantic Web Conference

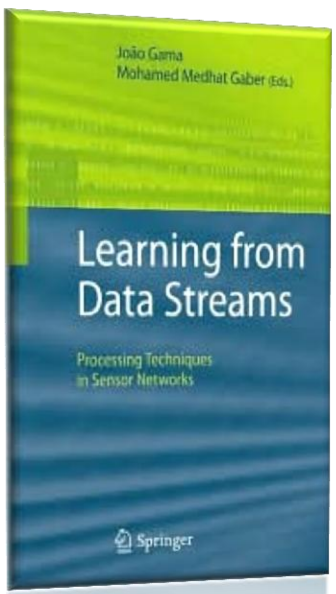
- **IPSN** – Information Processing in Sensor Networks
- **Percom** - IEEE Pervasive Computing and Communication
- **SenSys** - ACM Conference on Embedded Networked Sensor Systems
- **MobiSys** - International Conference on Mobile Systems, Applications, and Services
- **INSS** – International Conference on Networked Sensing Systems
- **DCOSS** - International Conference on Distributed Computing in Sensor Systems

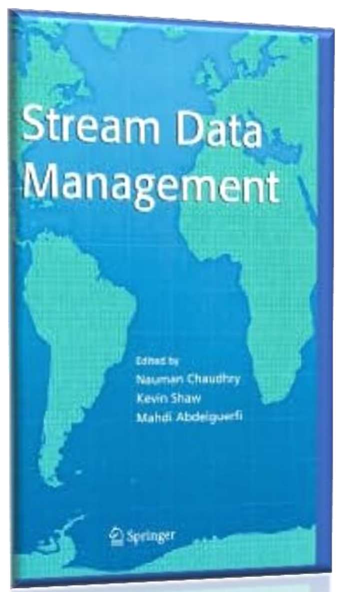
- **iThings** - IEEE International Conference on Internet of Things

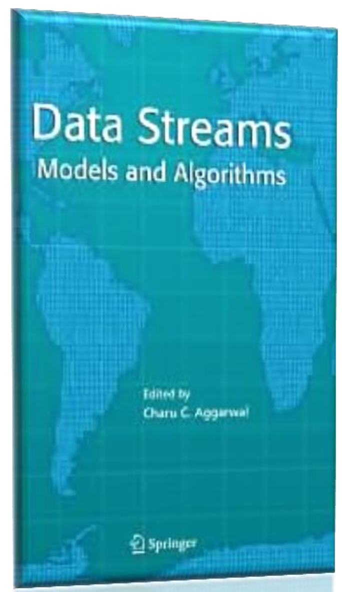
Relevant Workshops

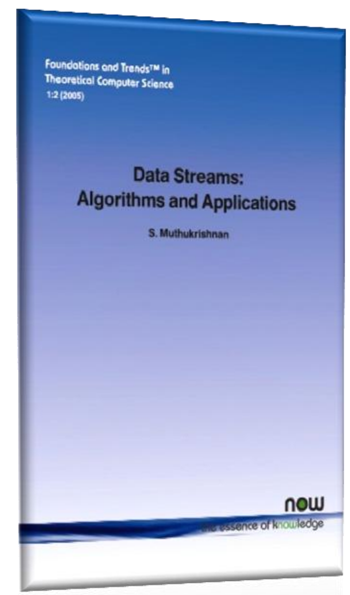
- **WebOfThings** - International Workshop on the Web of Things
- **SensorKDD** - International Workshop on Knowledge Discovery from Sensor Data
- **PURBA** - Workshop on Pervasive Urban Applications
- **Urban-IOT** – the Urban Internet of Things Workshop
- **Web Enabled Objects** - International Workshop on Web-Enabled Objects
- ….

Books on data streams

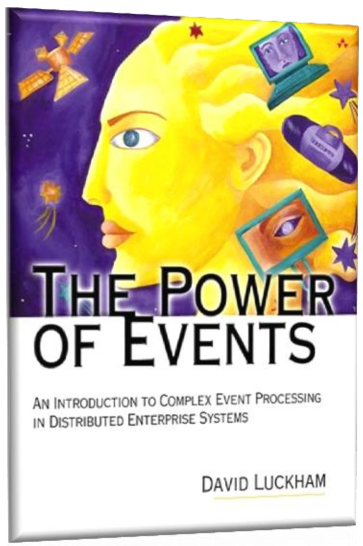


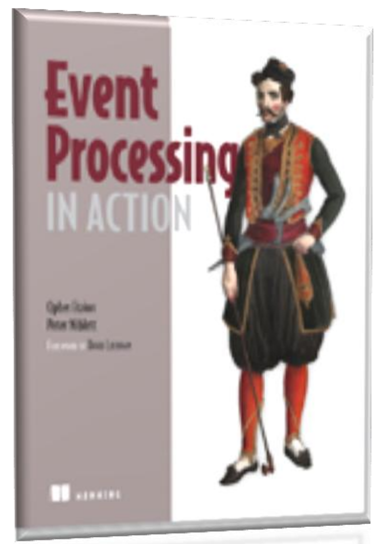




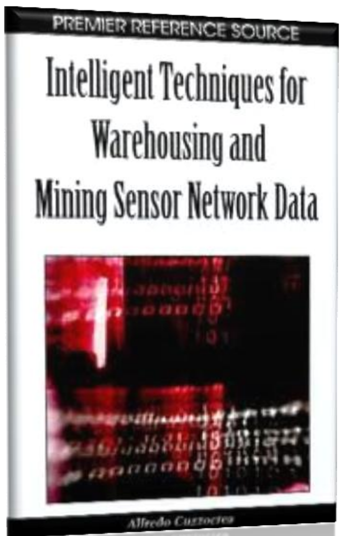


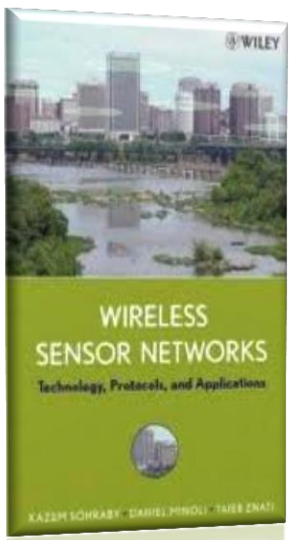
Books on event processing

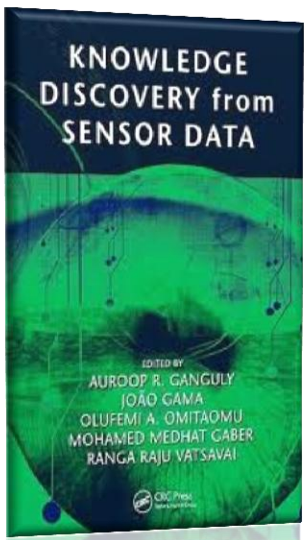




Books on sensor networks







Relevant blogs

- Web of Things Blog
- Wireless Sensor Network Blog
- The Internet of Things
- Dust Networks – In the News
- ReadWriteWeb

Related Wikipedia Links

Data Stream Mining:
http://en.wikipedia.org/wiki/Data_stream_mining

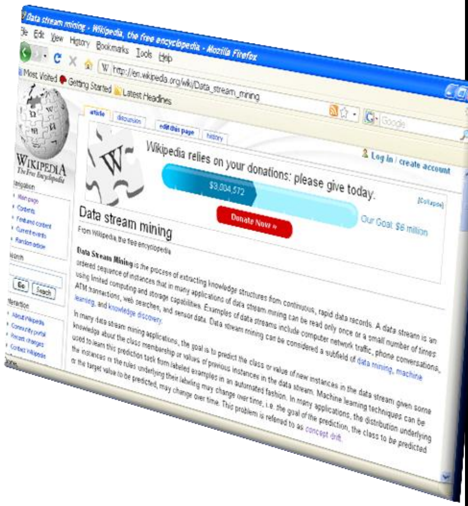
Complex Event Processing:
http://en.wikipedia.org/wiki/Complex_Event_Processing

Real Time Computing: http://en.wikipedia.org/wiki/Real-time_computing

Online Algorithms:
http://en.wikipedia.org/wiki/Online_algorithms

Worst Case Analysis:

http://en.wikipedia.org/wiki/Worst-case_execution_time



Related Wikipedia Links

Web of Things:

http://en.wikipedia.org/wiki/Web_of_Things

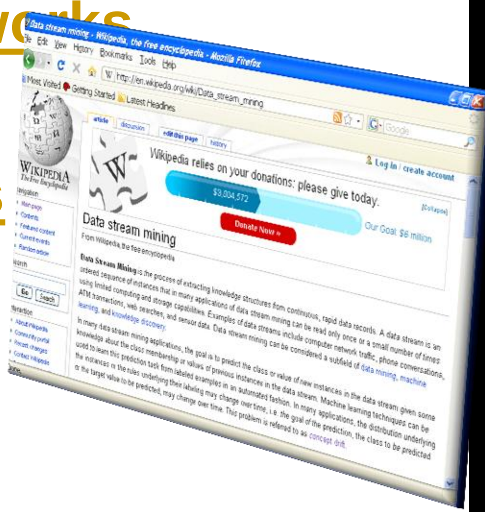
Internet of Things:
http://en.wikipedia.org/wiki/Internet_of_Things

Wireless Sensor Networks:
http://en.wikipedia.org/wiki/Wireless_Sensor_Networks

Major Appliance:
http://en.wikipedia.org/wiki/Household_appliances

RFID – Radio Frequency Identification:

http://en.wikipedia.org/wiki/RFID



Video Tutorials

State of the Art in Data Stream Mining: Joao Gama, University of Porto

- http://videolectures.net/ecml07_gama_sad/

Data stream management and mining: Georges Hebrail, Ecole Normale Superieure

- http://videolectures.net/mmdss07_heb

Outline

Part III. Demos, Tools & Research directions

- **Use cases**
  - What systems and prototypes exist?
- **Open problems**
  - Are there unsolved problems?
- **Summary**
  - What was this tutorial about?
- **List of sources for further studies**
  - Where to start digging?

Thank you!

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Help us improve the tutorial!

Send comments and relevant info to carolina.fortuna@ijs.si

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Planet Data

opcomm
living bits and things

Javna agencija za raziskovalno dejavnost Republike Slovenije

envision
environmental services infrastructure with ontologies