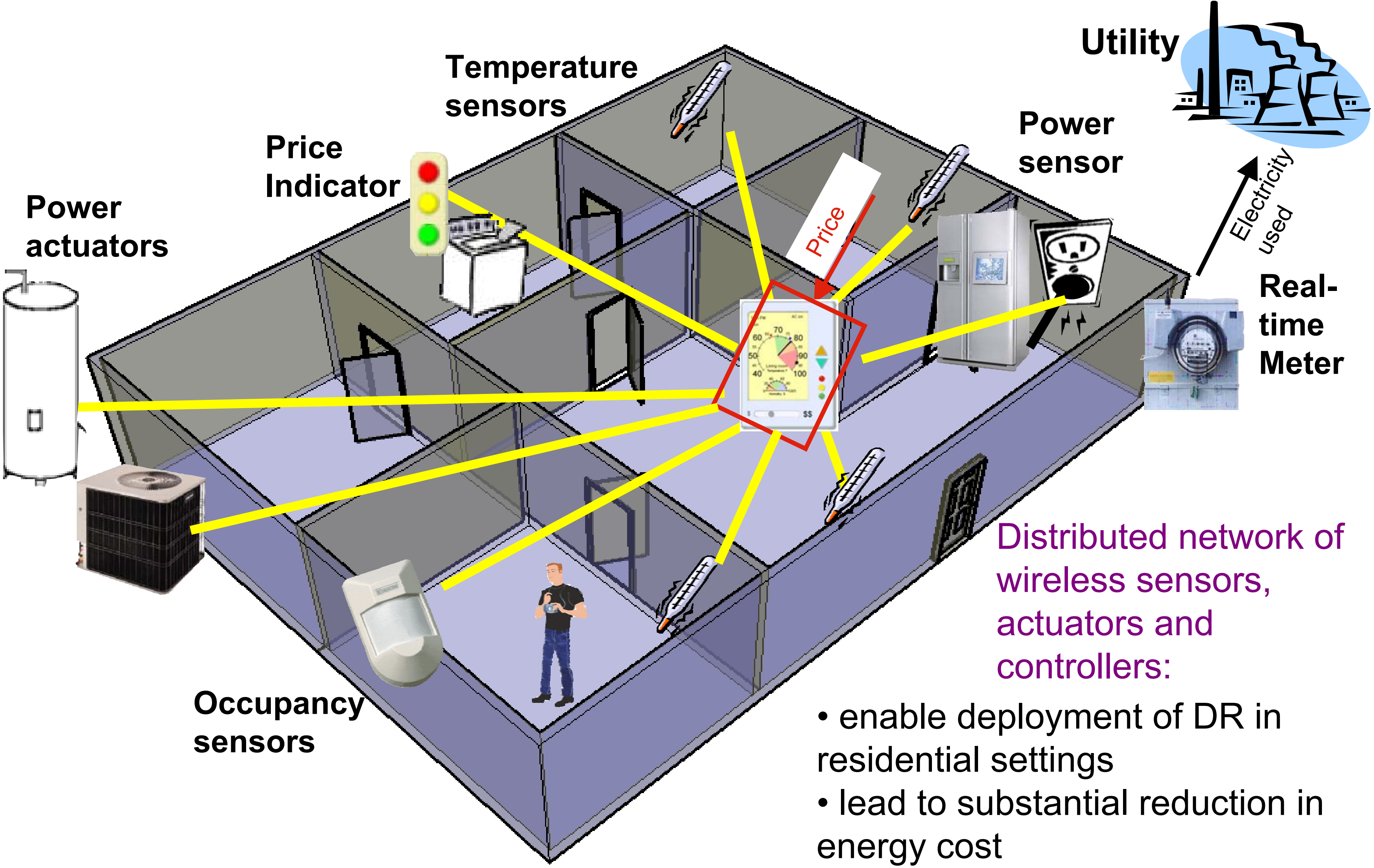
Service-Based Universal Application Interface for Demand Response Energy Systems

(UC Berkeley Project)

- **Goal: Develop and demonstrate an application development environment for a scalable and extendible demand response system**
- **Funding: $250 K**
- **Period of Performance: 4/15/2005 – 4/14/2006**
- **Multi-disciplinary Collaboration Team:**
  - Jan Rabaey: EECS
  - Paul Wright: Mech. Eng. Dept.
  - Ed Arens: Architecture
  - David Auslander: Mech. Eng.
  - David Culler: EECS
  - 5 Graduate Student Researchers

The Demand Response Scenario and the Energy-Cost Aware Home



Distributed network of wireless sensors, actuators and controllers:

- enable deployment of DR in residential settings
- lead to substantial reduction in energy cost

The Big Picture

- **Major Challenge:**
  - Proliferation of hardware and software options
  - Ease of application development
  - Ease of deployment
  - Ease of maintenance
- **Our Proposed Solution: A Universal Application Interface for ad-hoc wireless sensor and actuator networks**
  - Based on library of universal services
  - Called SNSP (sensor network service platform)
- **Project Goal:** Demonstrate
  - Portability of DR application over range of implementation platforms
  - Ad-hoc extensibility of functionality

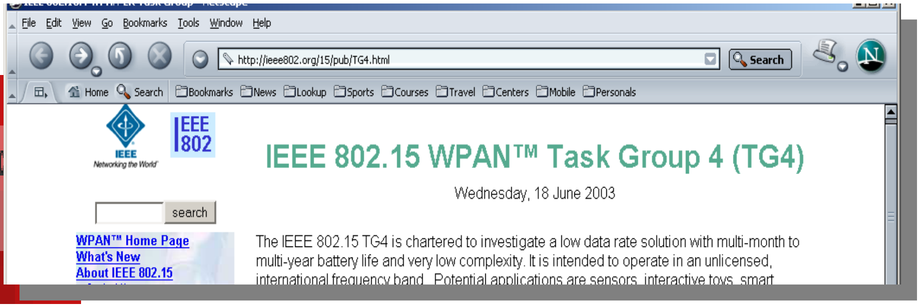
Execution Plan

- #1. DR Requirement Analysis
- #2. DR on MICA Nodes using SNSP abstraction.
- #3. Port DR on Telos Nodes using SNSP abstraction
- #4. Extended DR application on Mica, Telos and Infineon nodes

A Crucial Challenge

Ensuring portability, scalability and true ad-hoc deployment

A plethora of implementation strategies emerging, some of them being translated into standards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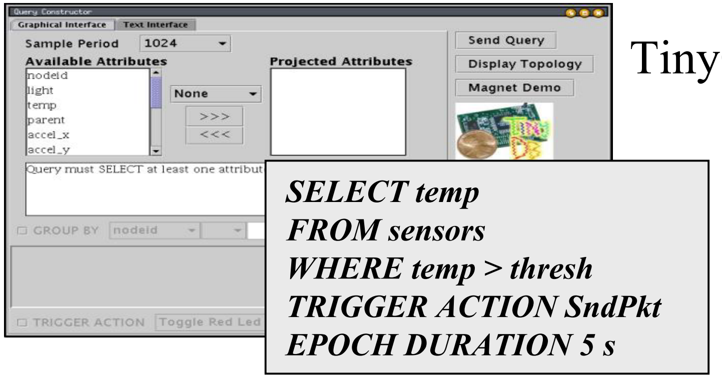
IEEE 802.15 WPAN™ Task Group 4 (TG4)

Wednesday, 18 June 2003

WPAN™ Home Page
What's New
About IEEE 802.15

The IEEE 802.15 TG4 is chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. It is intended to operate in an unlicensed, international frequency band. Potential applications are sensors, interactive toys, smart



Sample Period 1024

None

Query must SELECT at least one attribut

GROUP BY nodeid

TRIGGER ACTION Toggle Red Led

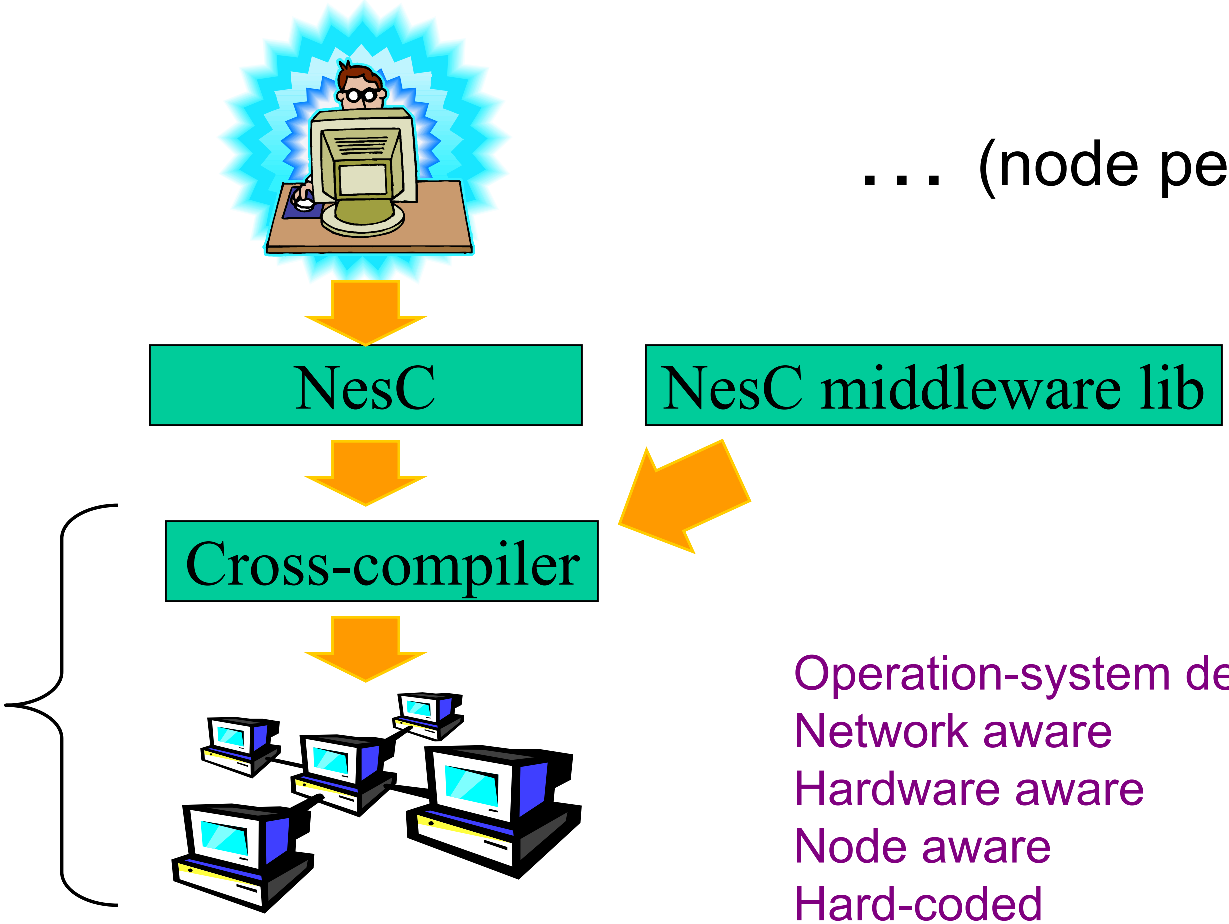
SELECT temp
FROM sensors
WHERE temp > thresh
TRIGGER ACTION SndPkt
EPOCH DURATION 5 s

TinyOS/TinyDB

- **Bottom-up definition without perspective on interoperability and portability**
- **Little reflection on how this translates into applications**

How sensor networks are currently programmed

… (node per node)



Platform specific

Operation-system dependent
Network aware
Hardware aware
Node aware
Hard-coded

Example: The DR Scenario

Mote Processor Handles 3-sets of Data

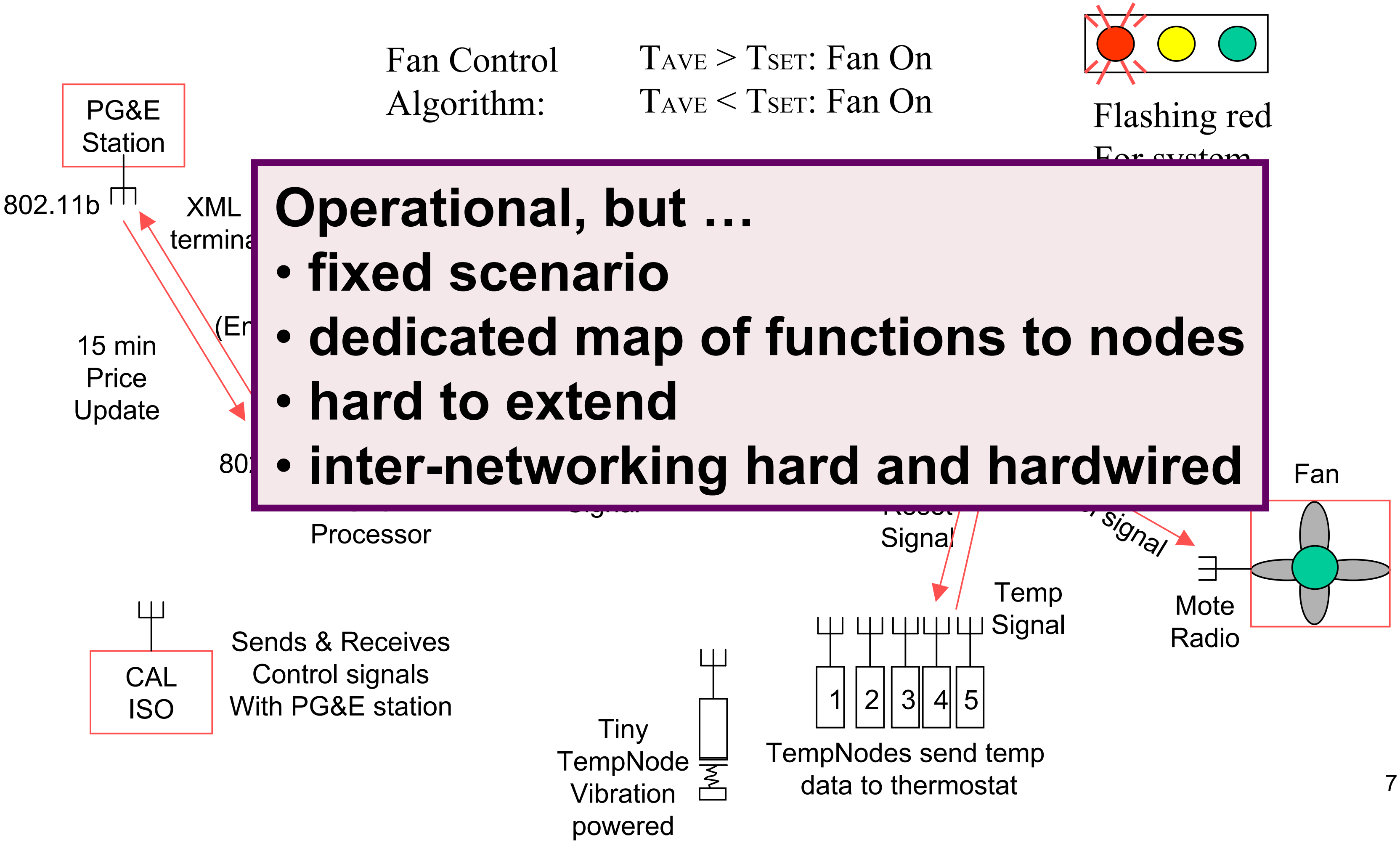
1. TempNode Data
2. Slider Bar Position
3. 15-min Price update

(note: for demo 1-min price signal)

Note: Mote also controls LED traffic lights For user interface

Fan Control Algorithm:

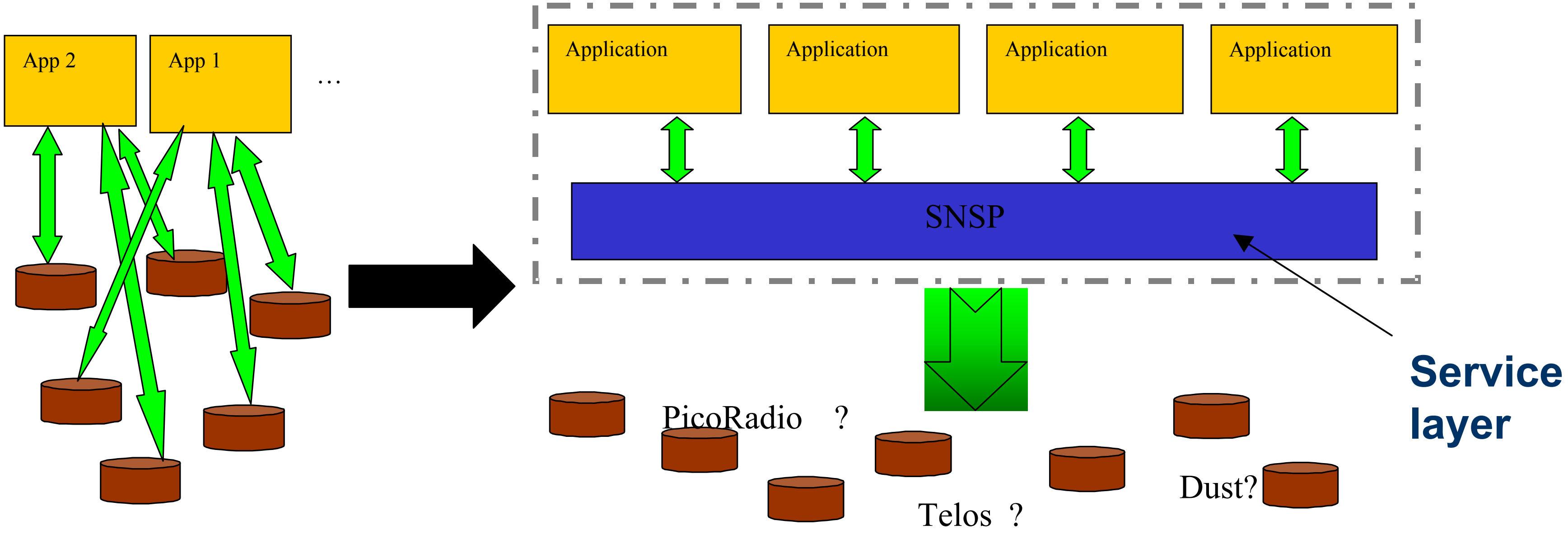
TAVE > TSET: Fan On
TAVE < TSET: Fan On



Operational, but …

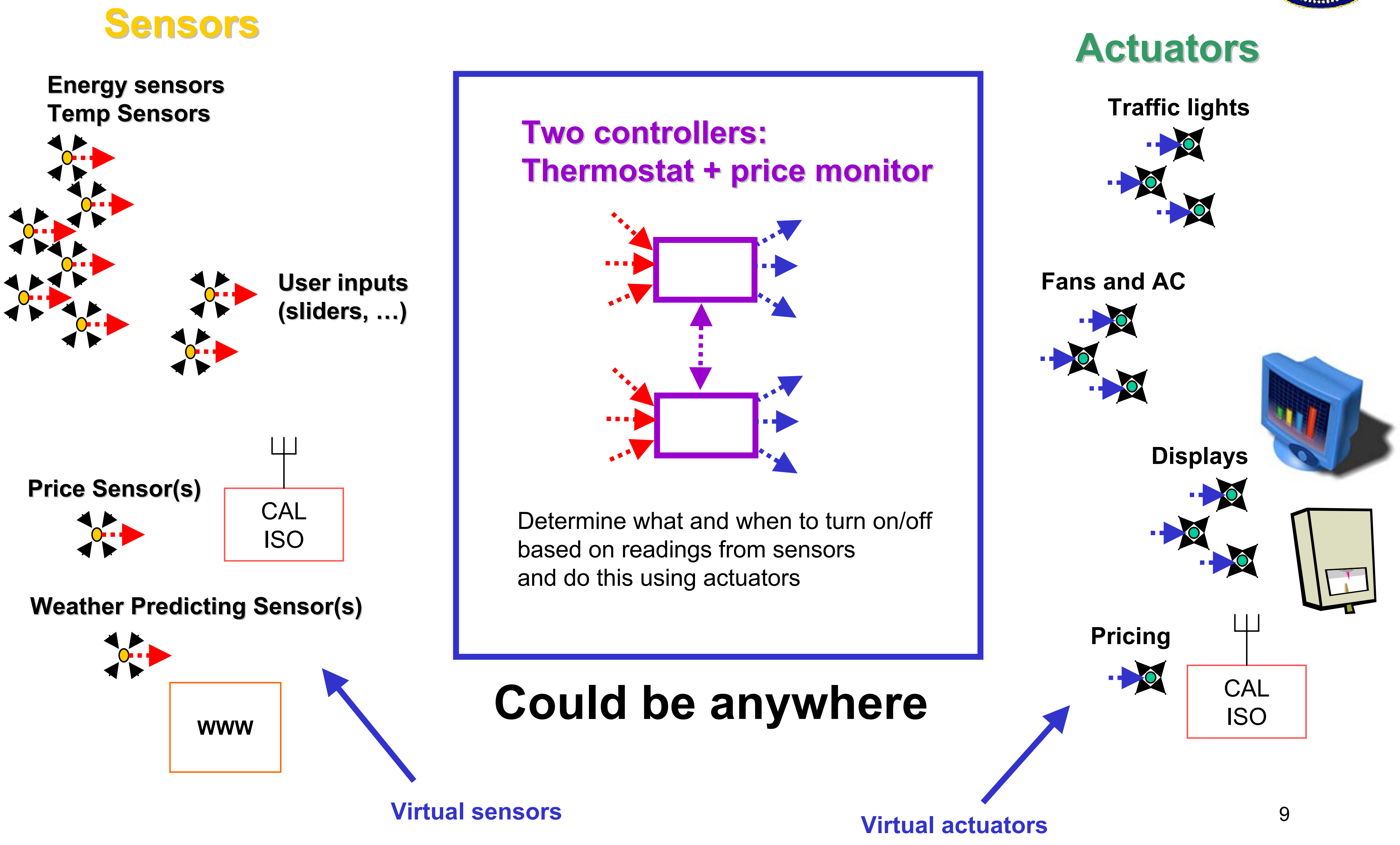
- **fixed scenario**
- **dedicated map of functions to nodes**
- **hard to extend**
- **inter-networking hard and hardwired**

Platform-Independent Programming



- Service layer abstracts hardware and networking from application programmer
- Currently made available as set of *TinyServices* on top of TinyOS

A Functional View of DR



Sensors

Energy sensors
Temp Sensors

User inputs
(sliders, …)

Price Sensor(s)

CAL
ISO

Weather Predicting Sensor(s)

www

Virtual sensors

Two controllers:
Thermostat + price monitor

Determine what and when to turn on/off based on readings from sensors and do this using actuators

Could be anywhere

Actuators

Traffic lights

Fans and AC

Displays

Pricing

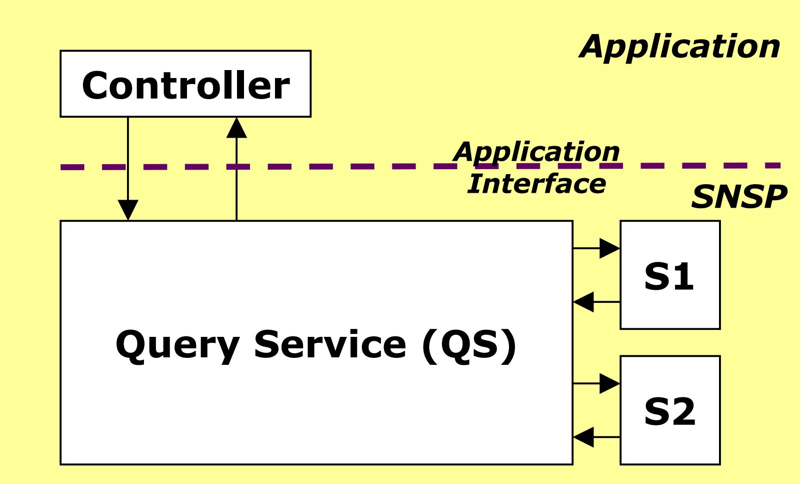
CAL
ISO

Virtual actuators

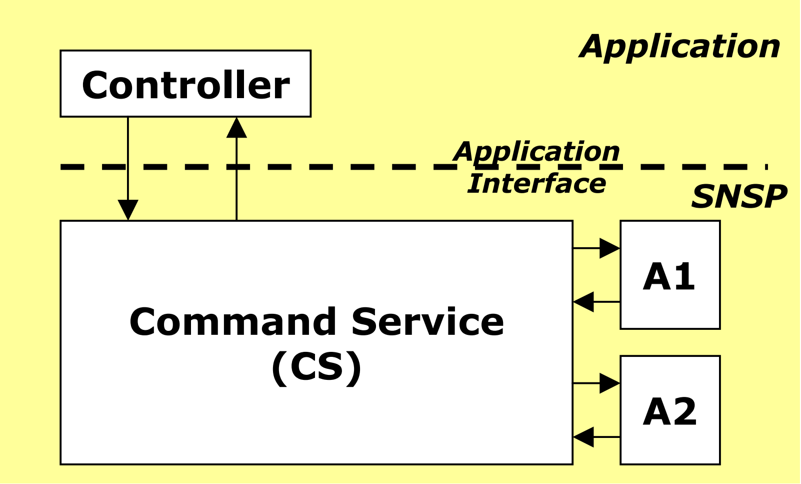
The Sensor Network as a Distributed Database

The query as the basic access mechanism

“*Get the temperature in the kitchen*”



QS allows a controller to obtain the state of a group of components

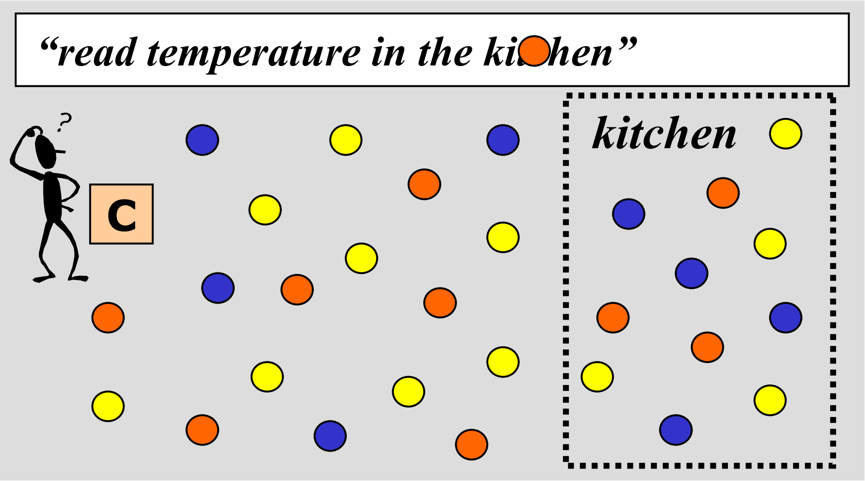


Augmented with a command mechanism

“*Close the blinds in the living room*”

CS allows a controller to set the state of a group of components

Using Semantic Addressing

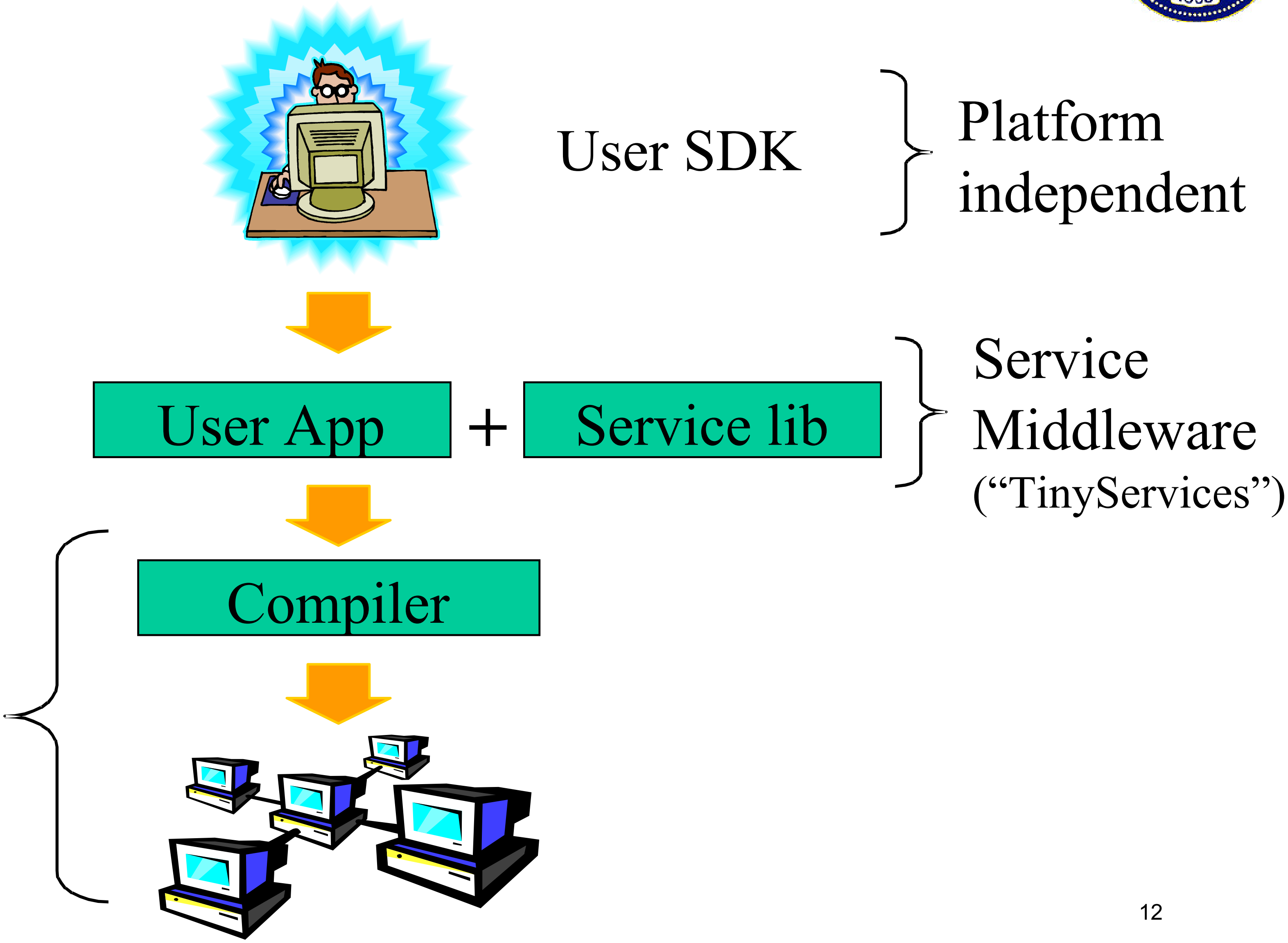


Name = attribute + scope (temperature:kitchen)

- Names are *not unique*
- Names *may change* during network operation

Enables ad-hoc operation and provides robustness

A Programming Abstraction



User SDK

Platform independent

User App + Service lib

Service Middleware (“TinyServices”)

Compiler

Platform specific

Pseudo-code Control

Cooling Control

```
Global temp;
ACCntl(short id, short rate){
    sensorRequestQuery(kitchen,
   TempSense.samplerate = rate);
            ...
    //receive results
   sensorResponse(temp);
   if temp > 70
       act = ON;
   else
       act = OFF;
   actuatorRequestCommand(kitchen,
   ACCntl.activate = act);
}
```

Price Display Control

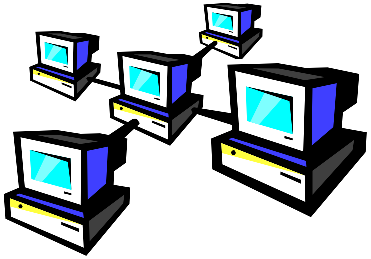
```
Global price;
PriceDisplayCntl(short id){
   sensorRequestQuery(PG&E,
   PriceSense, );
         ...
    //receive results
   sensorResponse(price);

   actuatorRequestCommand(LR,
   PriceDisp.price = price);
}
```

These functions are capabilities & can be re-used

tinyServices

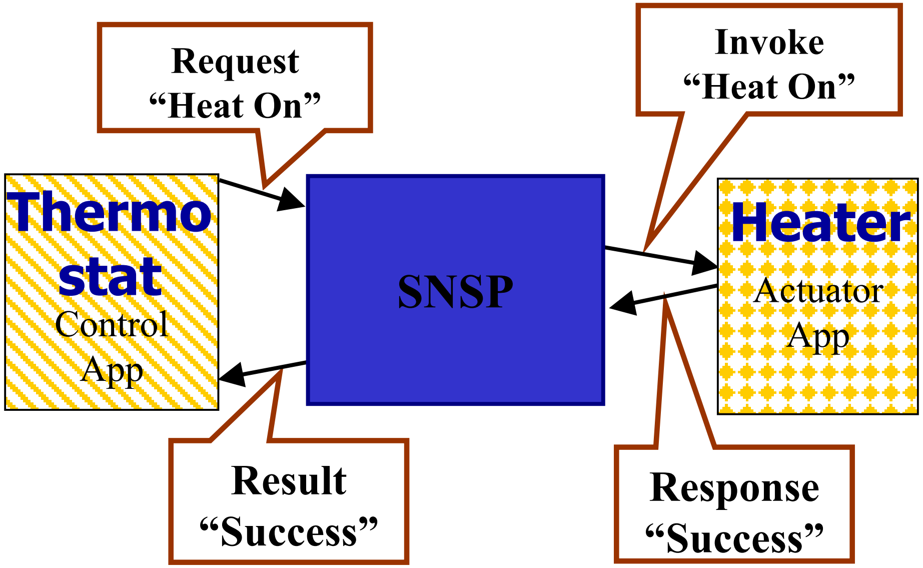
- **User Interface**
  - Initiating application:
    - Request
    - Result
  - Responding application
    - Invoke
    - Response
  - Concept Repository

- **Middleware:**
  - Manages queries/commands
  - Interfaces with routing & app
  - Keeps track of repository

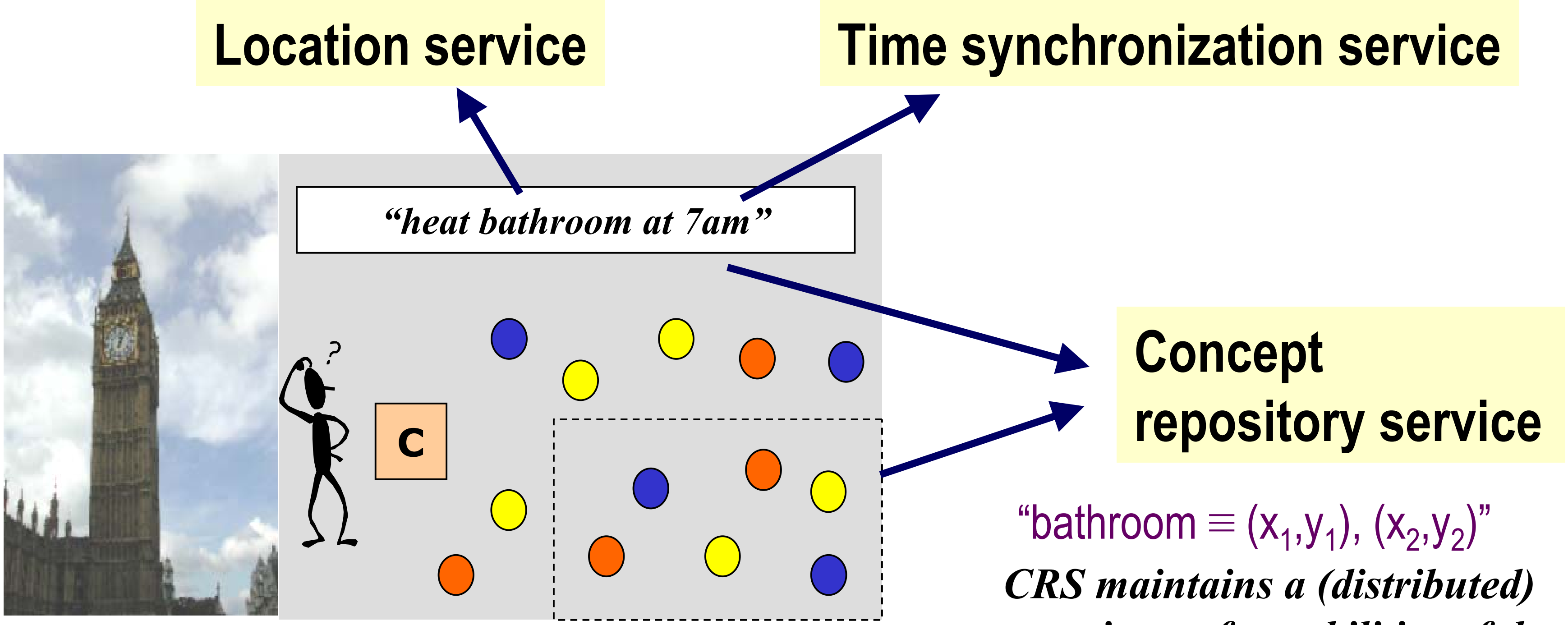


tinyServices User Interface

- Interface for application to access capability
- Interface for capability to respond



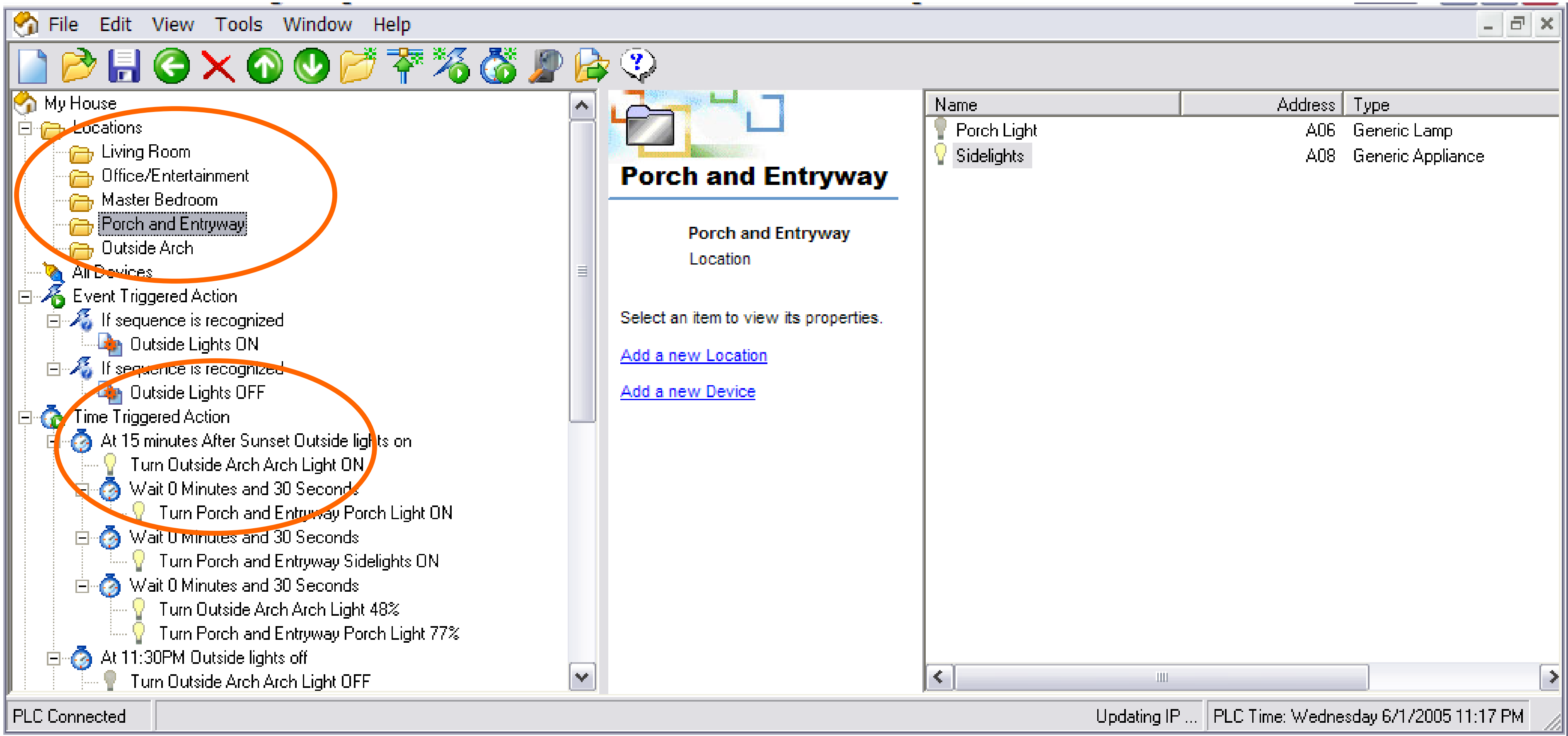
Auxiliary Services provide Sense of Space, Time and Concept



"bathroom ≡ $(x_1,y_1), (x_2,y_2)$"

CRS maintains a (distributed) repository of capabilities of the network and meta-objects

Example (from X11 environment)



My House
Locations
Living Room
Office/Entertainment
Master Bedroom
Porch and Entryway
Outside Arch
All Devices
Event Triggered Action
If sequence is recognized
Outside Lights ON
If sequence is recognized
Outside Lights OFF
Time Triggered Action
At 15 minutes After Sunset Outside lights on
Turn Outside Arch Arch Light ON
Wait 0 Minutes and 30 Seconds
Turn Porch and Entryway Porch Light ON
Wait 0 Minutes and 30 Seconds
Turn Porch and Entryway Sidelights ON
Wait 0 Minutes and 30 Seconds
Turn Outside Arch Arch Light 48%
Turn Porch and Entryway Porch Light 77%
At 11:30PM Outside lights off
Turn Outside Arch Arch Light OFF

Porch and Entryway

Porch and Entryway
Location

Select an item to view its properties.

Add a new Location

Add a new Device

Name	Address	Type
Porch Light	A06	Generic Lamp
Sidelights	A08	Generic Appliance

PLC Connected | Updating IP ... | PLC Time: Wednesday 6/1/2005 11:17 PM

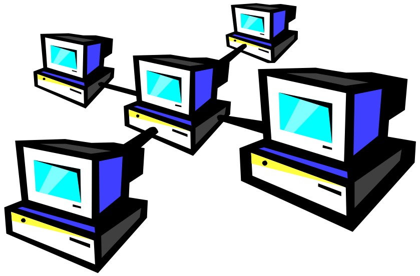
Concept Repository: Enabling true ad-hoc deployment

Goals:

- Avoid large set-up efforts, eases parameterization
- Introduce meta-concepts such as “kitchen” and “dawn”
- Enable dynamic extension of functionality
  - E.g. Addition of humidity sensors
- Present up-to-date overview of network capabilities

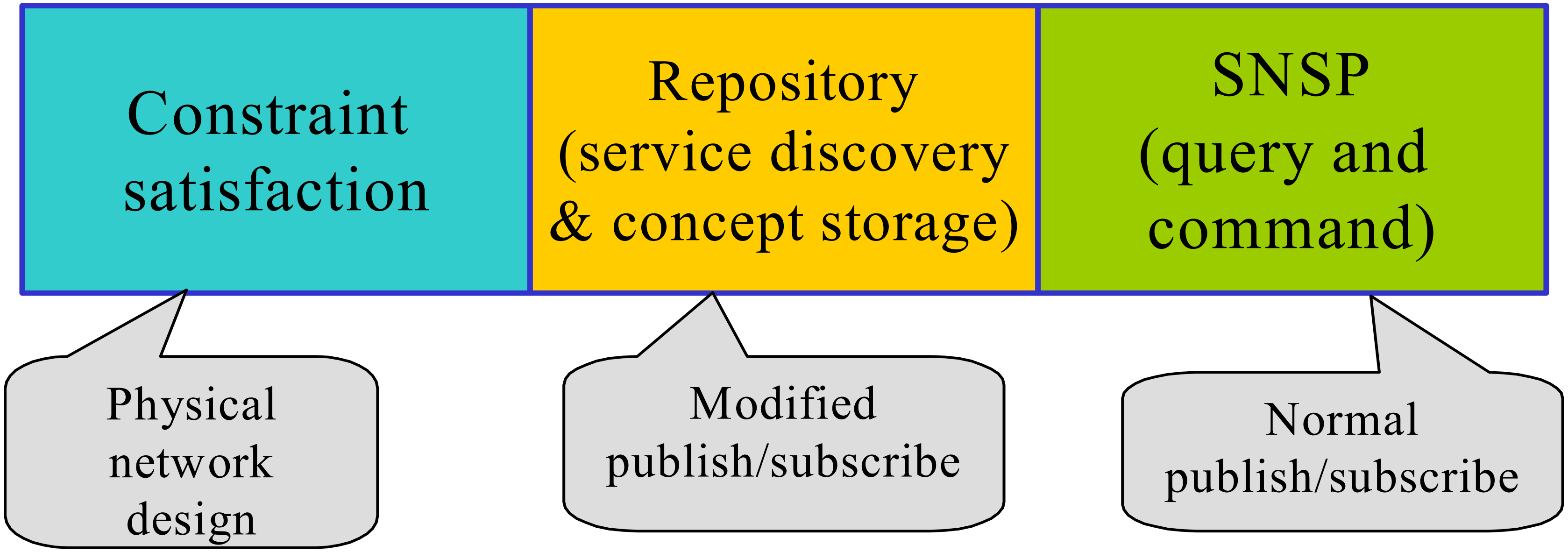
Sensors Repository Rep

	Temperature Sensor	Price Sensor
Primitive	***Temperature***	***Price***
Concept	**Capability**	**Capability**
Name	**TempSense**	**PriceSense**
Inputs	**Name: SampleRate** **Type: Short**	**--**
Outputs	**Name: *Temperature*** **Type: Short** **Descript Name: Units** **Descript Val: Celsius**	**Name: *Price*** **Type: Short** **Descript Name: Max** **Descript Val: 1**
Descriptors	**Name: manufacturer** **Value: Honeywell** **Type: string**	**--**



tinyService Middleware

- Middleware provides 3 functionalities



Constraint satisfaction

Repository (service discovery & concept storage)

SNSP (query and command)

Physical network design

Modified publish/subscribe

Normal publish/subscribe

Status

- Implemented First-Order Version of TinyServices
- Demonstrated DR application on MICA

Next:

- Porting to other platforms
- Full implementation of Concept Repository and other supporting services (location, time)
- Demonstration of functional extensibility