

# Human-Agent Collectives

[www.orchid.ac.uk](http://www.orchid.ac.uk)

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# The Era of Ubiquity

- Increasing availability of networked devices that are:
  - on us and embedded into world around us
  - accessed at home, work and play
- These devices provide information:
  - from an ever more diverse range of sources, via ever more sensor types
  - that measures ever more of everything
  - that can be mashed-up in unforeseen ways
- Many endeavours require effective inter-working between individuals who are intimately intertwined with this ubiquitous information substrate
  - new models are needed to support these **epiphetic** partnerships



ORCHID, as an **epiphyte**, serves as a metaphor for the flourishing of a system that lives non-parasitically on and enhances an ecological substrate.

# New Ways of Working

(Jennings et al., 2014)

- Profoundly change ways we work with computers:
  - no longer issue instructions to passive machines that wait until they are asked before doing anything
  - work in tandem with highly inter-connected computational components (agents) that act autonomously and intelligently
  - coming together of cyber and physical systems
- Partnerships allow humans and agents to achieve individual and collective goals:
  - neither agents, nor humans are always in charge.
  - continually and flexibly establish and manage collaborative relationships.
  - motivate action by incentives, rather than dictat.

**Human-Agent Collectives (HACs)**

# Vision

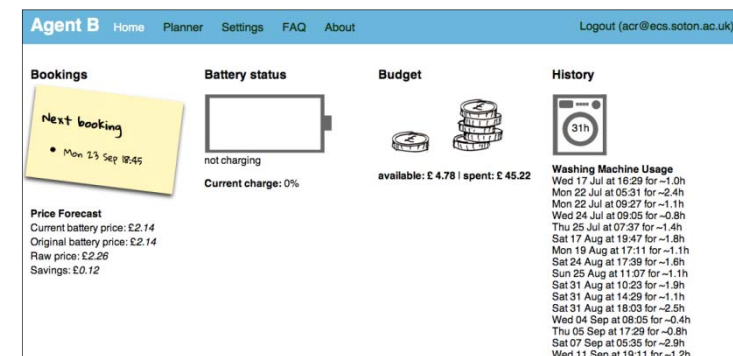
As systems based on **human-agent collectives** grow in scale, complexity and temporal extent, we require a **principled science** that allows us to reason about the computational and human aspects of these systems.

Delivering this science — *from theory to practice* — is the **core research objective** of ORCHID.

**[www.orchid.ac.uk](http://www.orchid.ac.uk)**

# Flexible Autonomy

- Agents sometimes take actions autonomously, without reference to their human owner.
- Other times guided by much closer human involvement in key decisions (*man-on-the-loop*).
- Vary depending on context



# Agile Teaming

Means by which groups of agents and humans can:

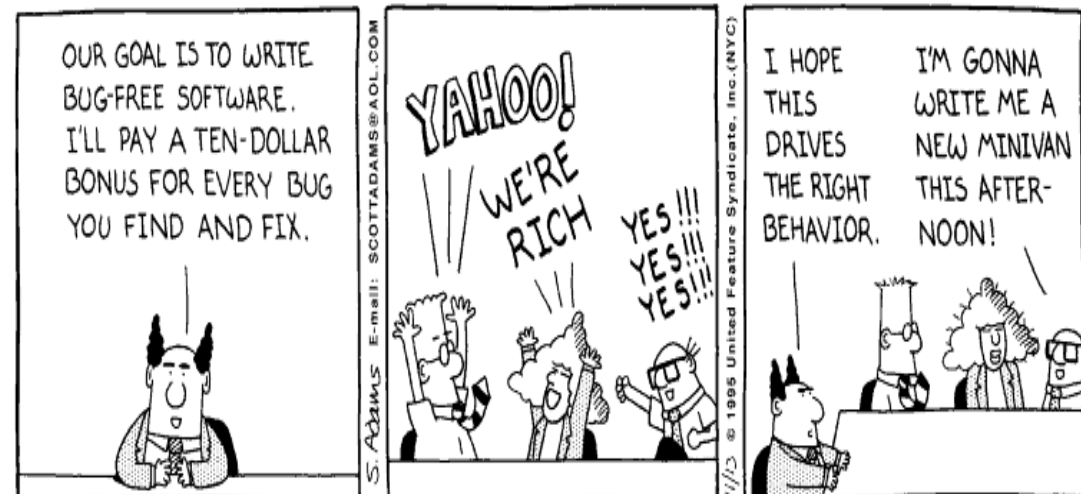
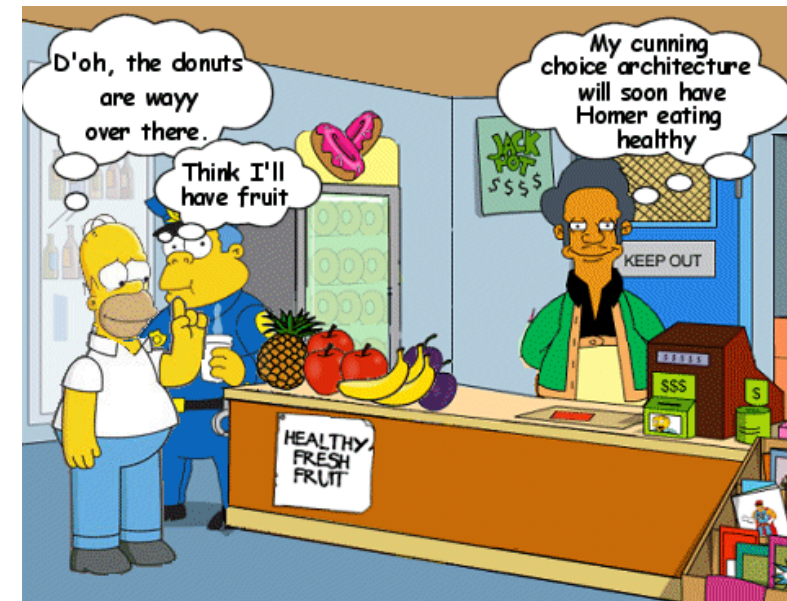
- Come together when needed to achieve joint goals that no individual can achieve in isolation
- Disband once cooperative action has been successful.





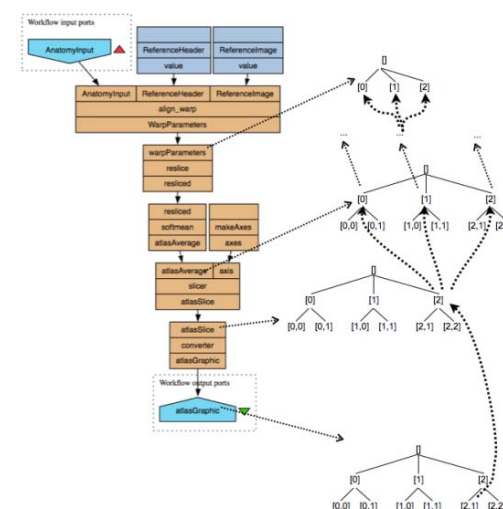
# Incentive Engineering

- Design actors' rewards so actions they are encouraged to take, when amalgamated, generate socially desirable outcomes.
- Consider what we need to know about humans to do this.



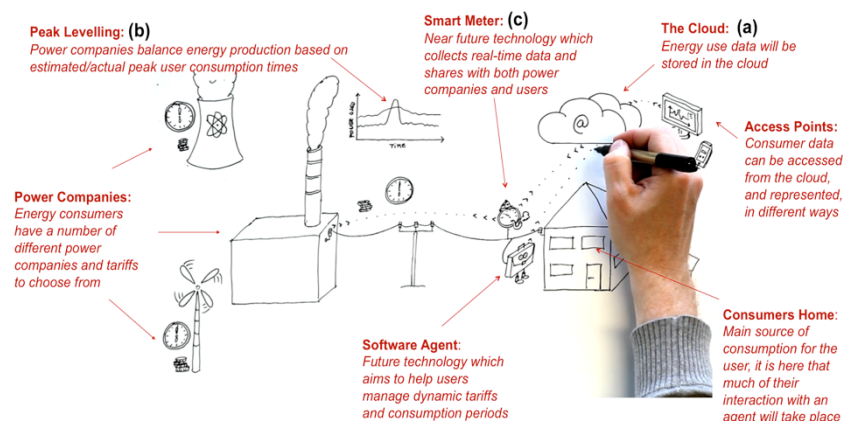
# Accountable Information Infrastructure

- Provide situational awareness by blending sensor and *crowd generated* content in robust and reliable way.
- Allow veracity and accuracy to be confirmed and audited, while maintaining appropriate privacy and ethics standards.





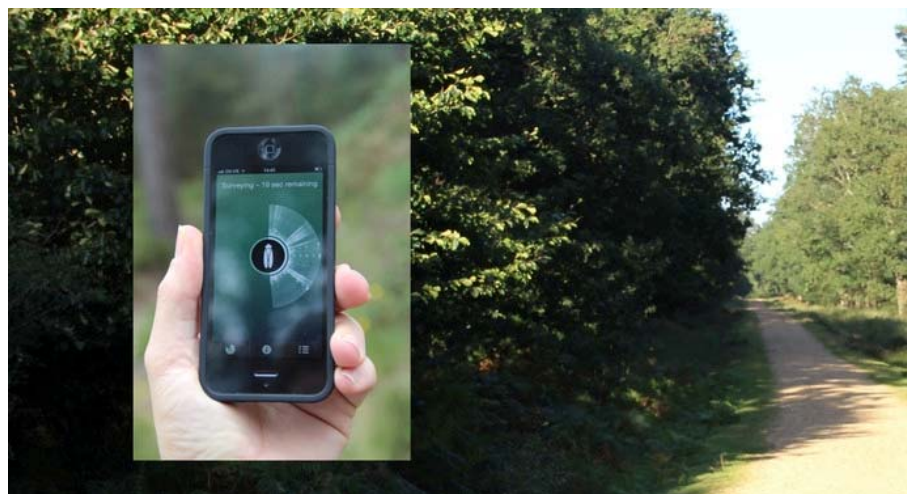
# Application Areas



## Smart Energy Systems



## Disaster Response



## Citizen Science



# HACs in Disaster Response



**Coordination and  
Task Allocation**



**Human-Agent  
Planning**



**Incentivising  
Action**

# In Situ Studies of First Responders

## Fort Widley, UK

- Command practices, information management and resource allocation



## Disaster City, Texas:

- Implicit coordination among team members
- Shared practices
- Diligence to safety



## Rescue Global @ Angel Thunder

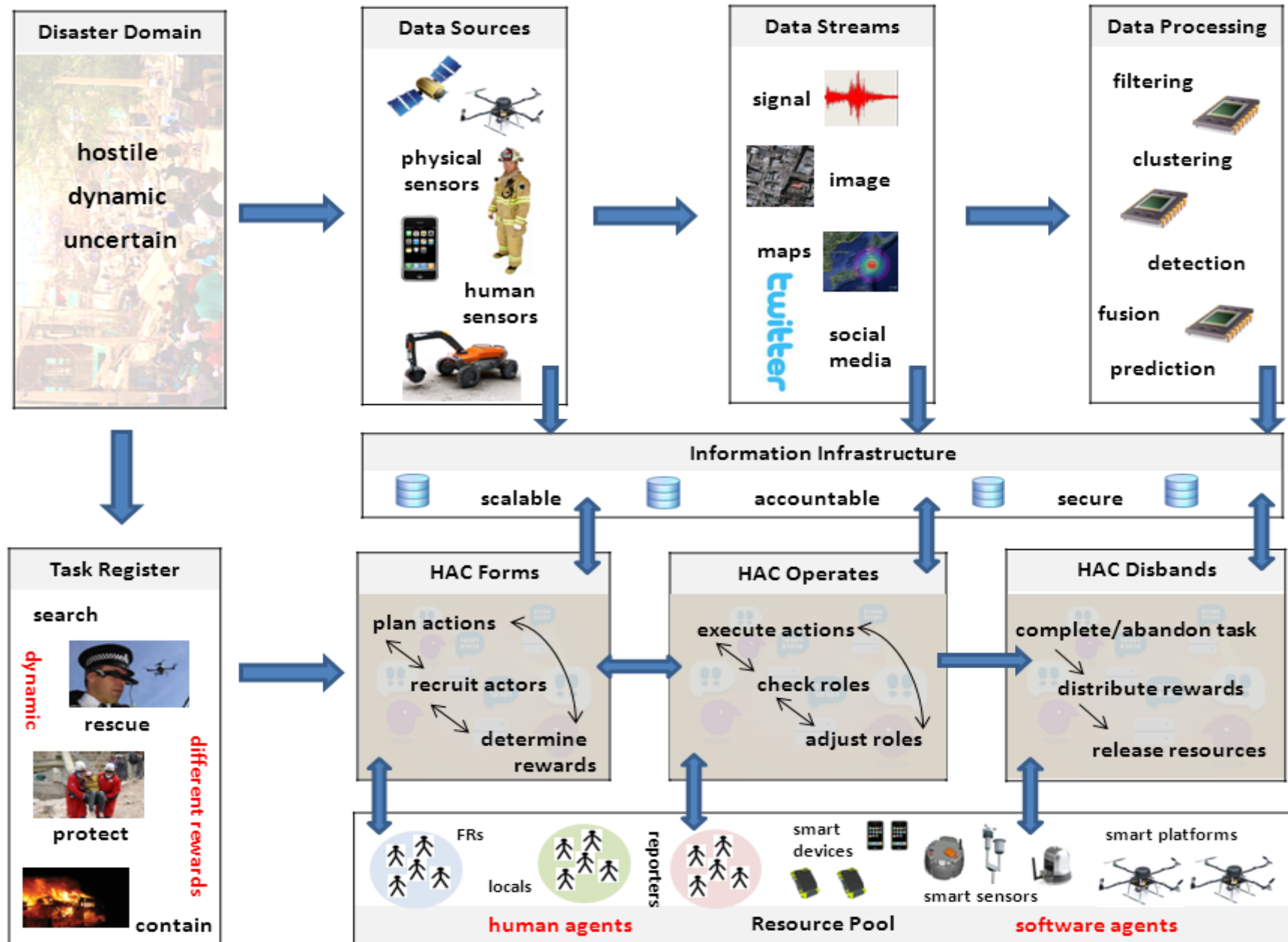
- 2 week international multi-agency SAR exercise (planning to execution)
- Detailed planning procedures according to ISO 9001
- Collaborative mapwork
- Information management
- Communications between Silver and Pathfinders



## Hampshire Fire Rescue

- Use of simulation software
- Fast pace & various stakeholders involved make information management and communication challenging

# A HAC System for Disaster Response





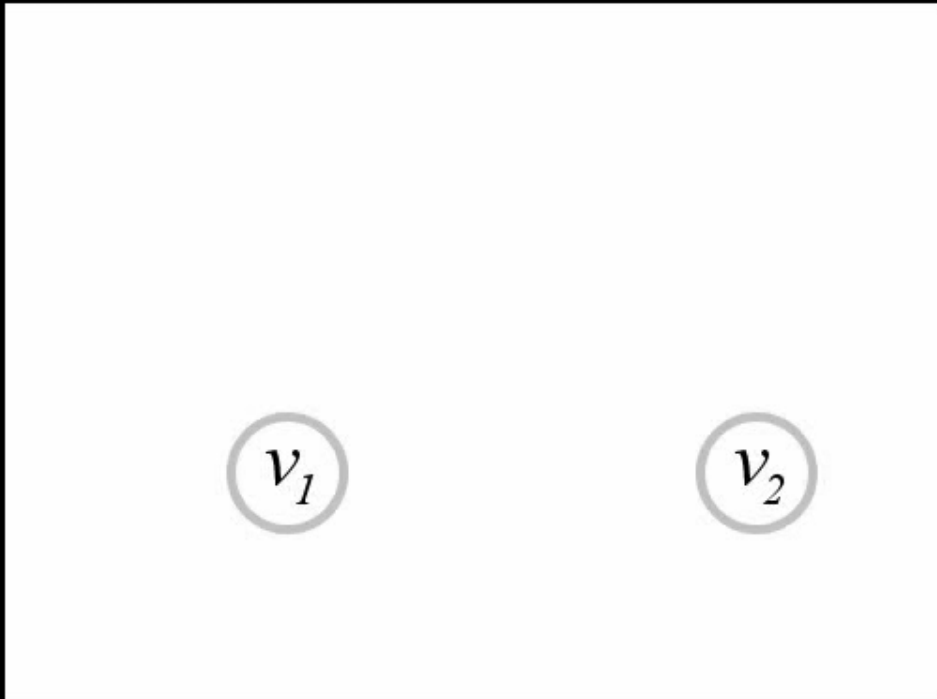
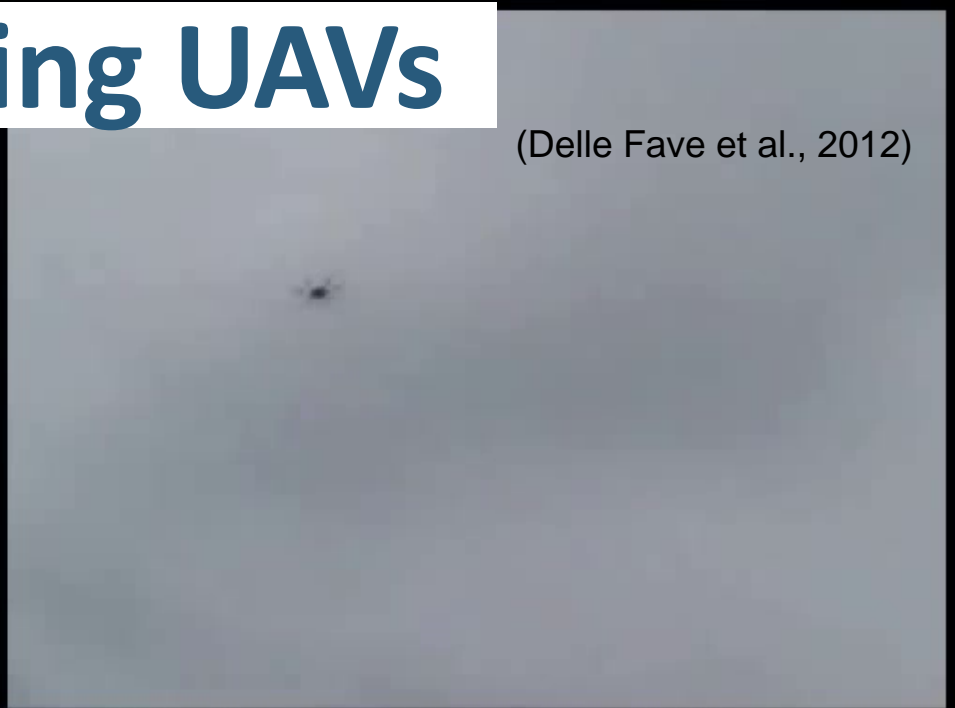
# Coordination and Task Allocation

Flexible Autonomy and Agile Teaming  
for UAVs



# Coordinating UAVs

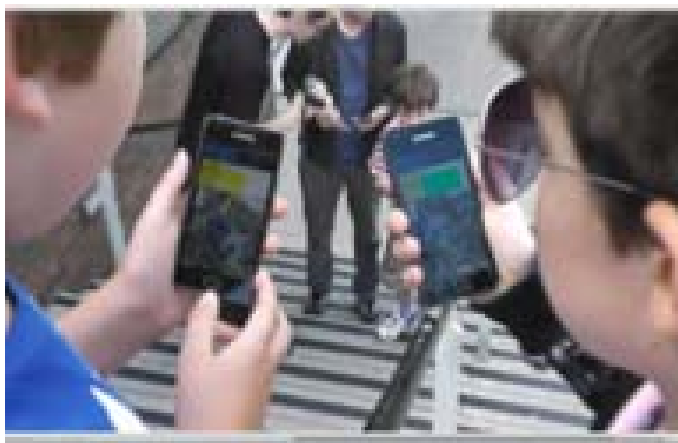
(Delle Fave et al., 2012)



# Human-Agent Planning

(Fischer et al., 2014)

- Time-critical tasks
- Physical stress



- Human psychological characteristics
- Disaster response

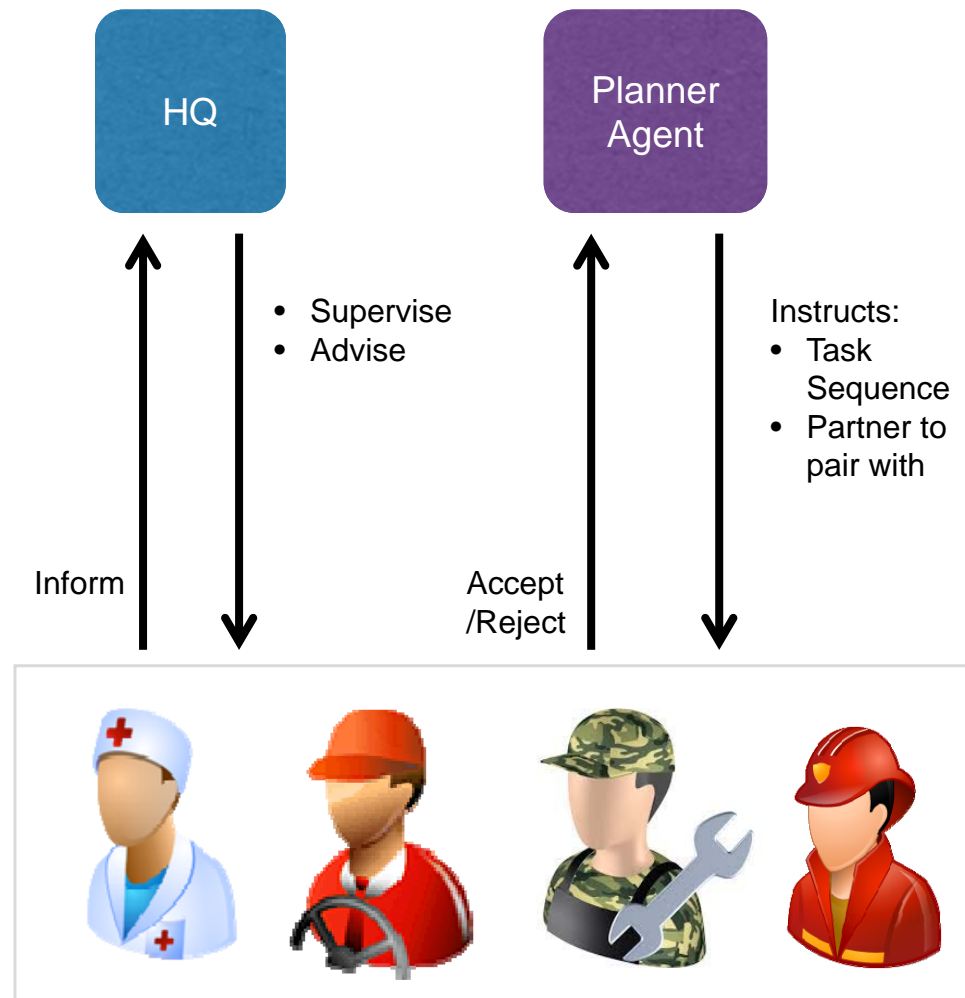
# Planner Agent

- **Path Planning**

- Under uncertainty in task deadlines and task performance
- Models and predicts radioactive cloud
- Uses MDP to optimise path for each player using predictions to minimise time to complete all tasks.

- **Team Allocation**

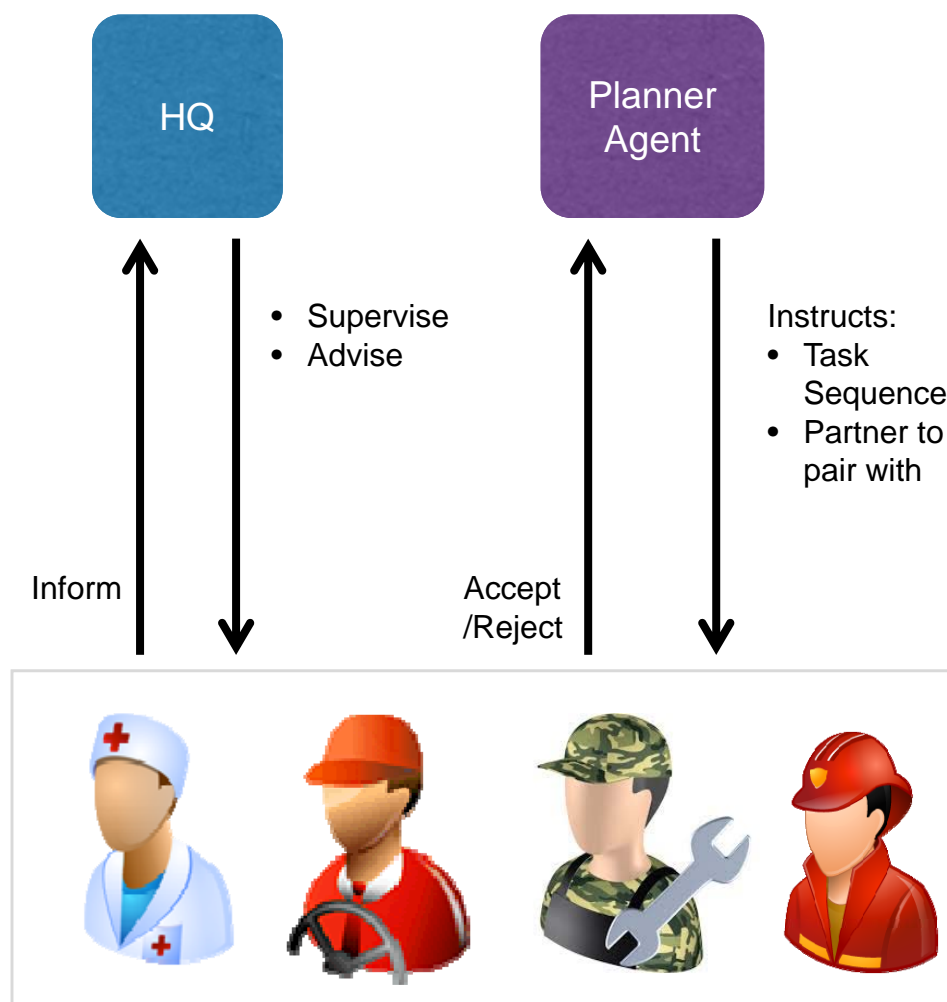
- Under uncertainty in team performance
- Coalition formation algorithm pairs players to maximise no. of tasks completed and player health
- HQ perceives instructions and advises players through chat app



# Planner Agent

(Jiang et al., 2014)

- when agent takes on task allocation:
  - human **HQ** is freed up to deal with **more complex side conditions and contingencies** (e.g. when a responder does not have a fitting team mate)
- see **division of labor** and **collaboration** between **humans and the agent**.

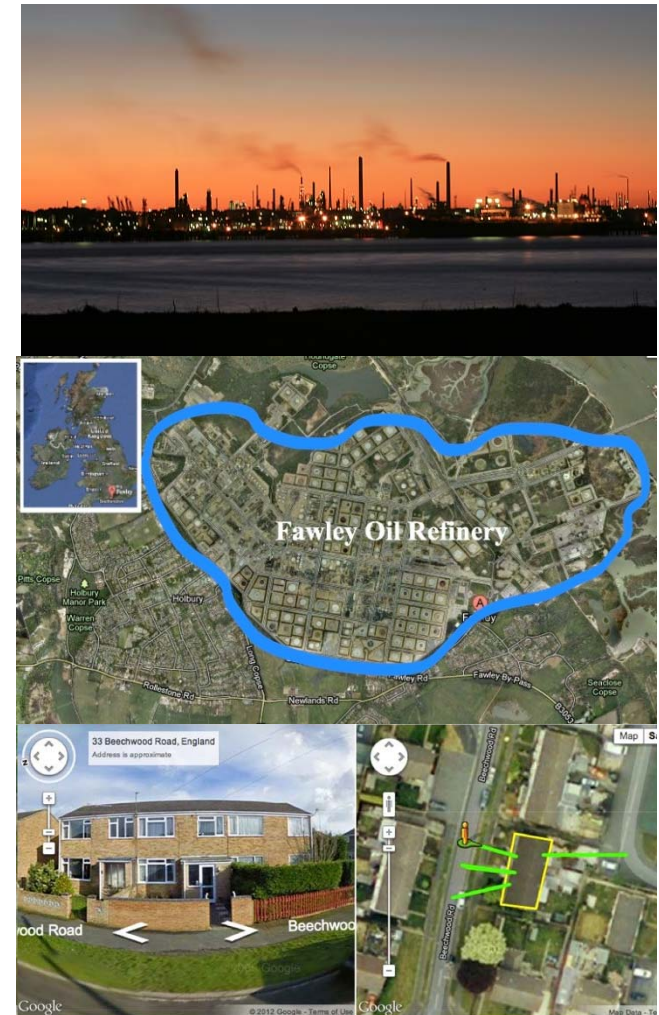


# Incentivising Data Generation

[www.collabmap.org](http://www.collabmap.org)

(Stranders et al., 2011)

- Crowdsourced development of evacuation routes.
- Deployed within:
  - Local community: **low participation**, **high quality**
  - Student population: **high participation**, **average quality**
  - Amazon Mechanical Turk: **high participation**, **low quality**
- Adopted different incentive mechanisms:
  - Lottery v/s Lottery+Gamification
- **38,000 tasks** completed over 2 months with more than **100** local community members and students
- **8000 tasks completed in 4 hours** with AMT with more than **150 participants**
- Identified challenges with:
  - Community engagement: how to incentivise local participants
  - Incentivisation for quality and quantity of work
  - Workflow design for dynamic participation (arrival rates vary)
  - Trust modelling to root out poor performers

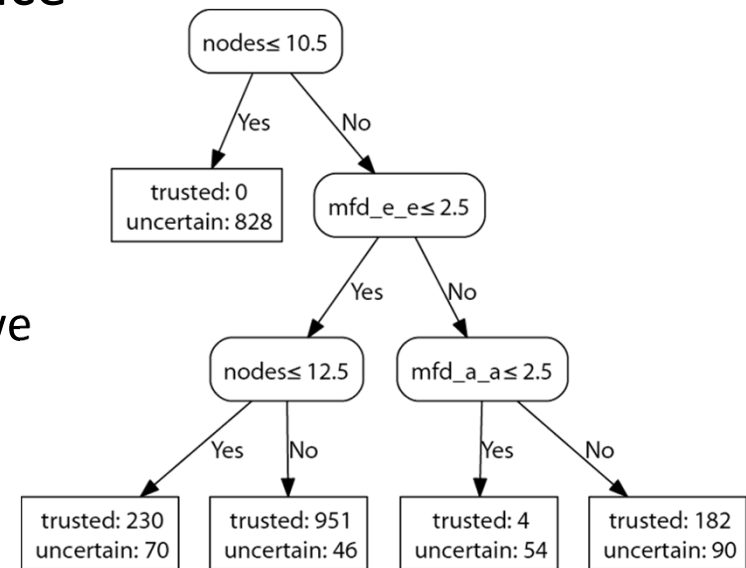




# Provenance of Crowdsourced Data

(Ebden et al., 2012)

- How to track, record and query provenance of crowdsourced data.
- Devise generic methods to interpret provenance data
  - Build upon W3C PROV specification, which we led development of.
- Evaluation on CollabMap data using provenance network metrics
  - Over 95% accuracy in trust assessments of buildings and routes (as compared against user votes).
  - Trained decision trees provide clues on the provenance characteristics of trusted data.



# Fusing Crowdsourced Data

(Venanzi et al., 2013)

- Crowdsourced sensor network:**

Less than two weeks, **557** sensors deployed, reporting Geiger counter readings through Cosm

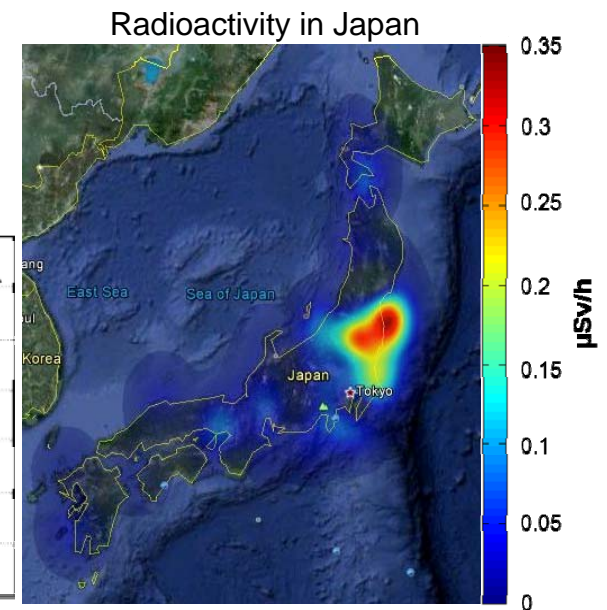
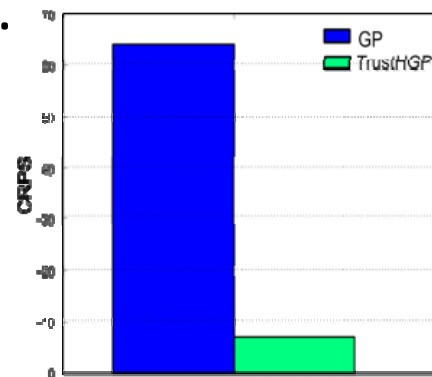
- Sensors built using commercial hardware & Arduino boards



- Spatial radioactivity estimation**

Designed Gaussian Process based model to estimate radiation levels spatially and learn trustworthiness of the sensors.

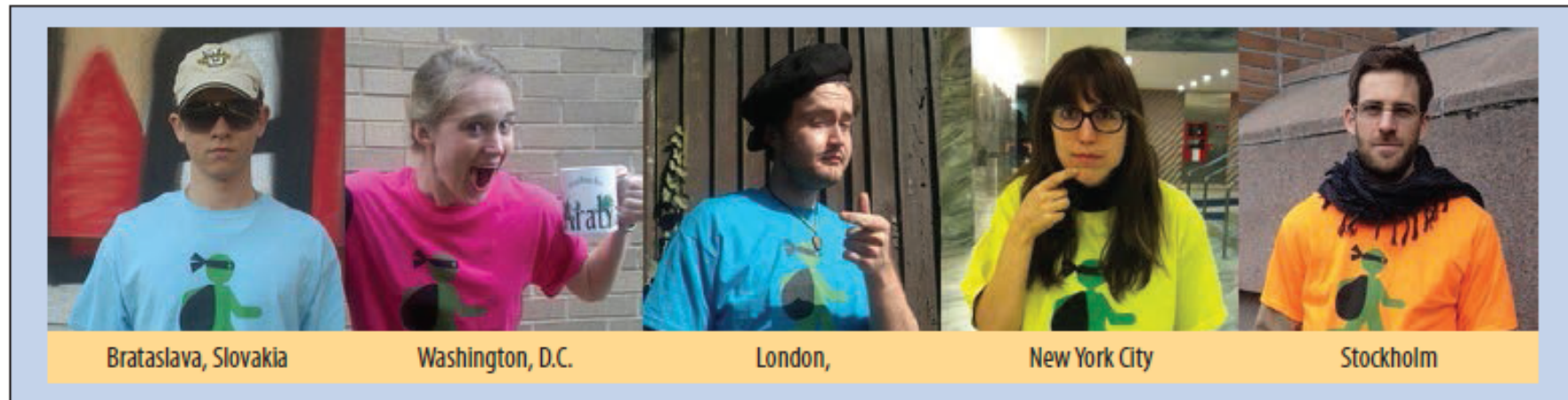
- Combined with 2122 official sensors
- Prediction improved by up to 90%.
- 89% of Cosm sensors trustworthy.



# Incentivising Social Mobilization

[en.wikipedia.org/wiki/Tag\\_Challenge](https://en.wikipedia.org/wiki/Tag_Challenge)

(Rahwan et al., 2013)



**Figure 1.** Target mug shots. Participating teams received a single mug shot of each "suspect" at 8:00 a.m. local time on the day of the competition.



# Incentivising Social Mobilization

[en.wikipedia.org/wiki/Tag\\_Challenge](https://en.wikipedia.org/wiki/Tag_Challenge)

(Rahwan et al., 2013)



Figure 2. Location of the five targets and local time when the three targets were found.



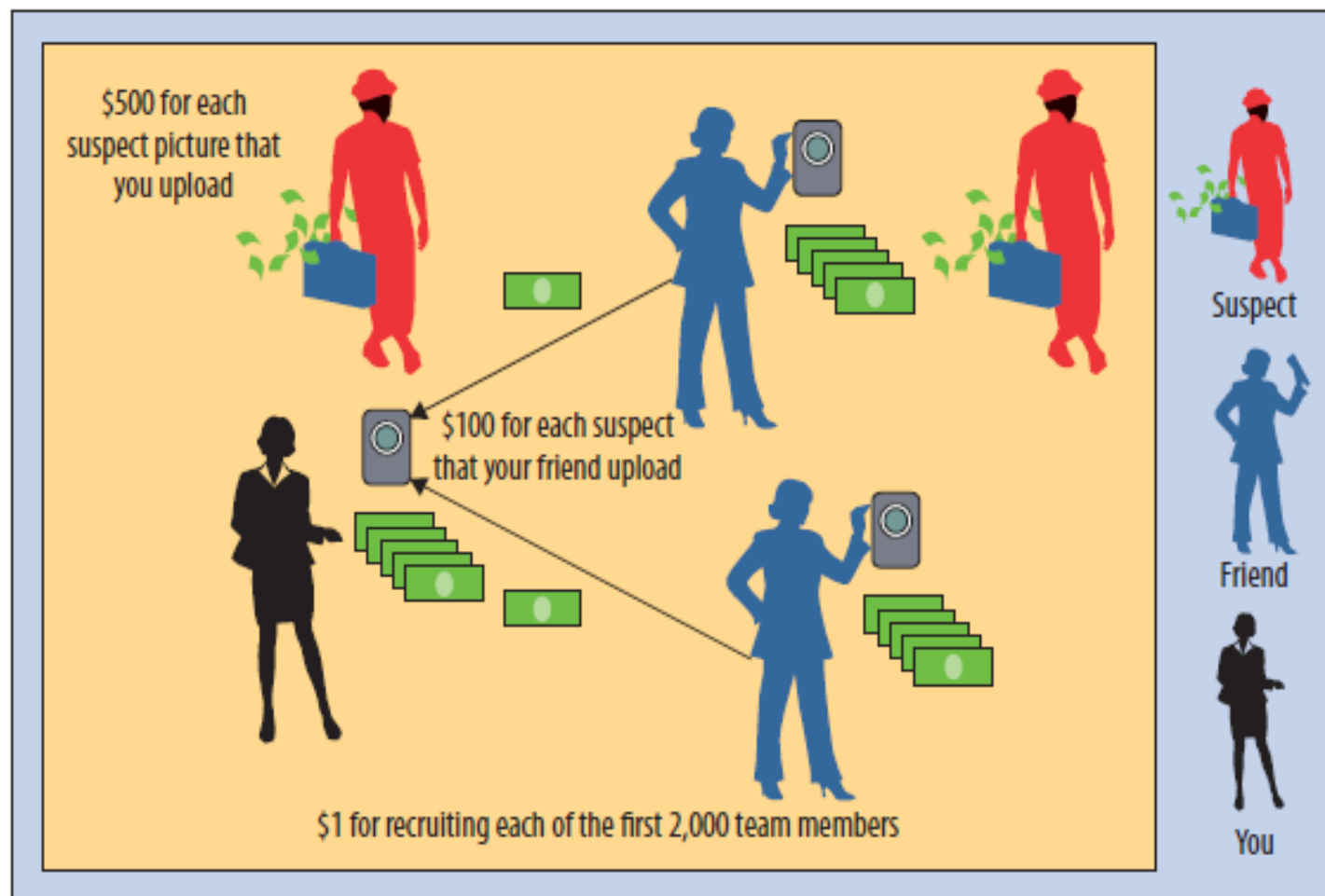
**We found 3 out of 5 people and won!!**



# Incentivising Social Mobilization

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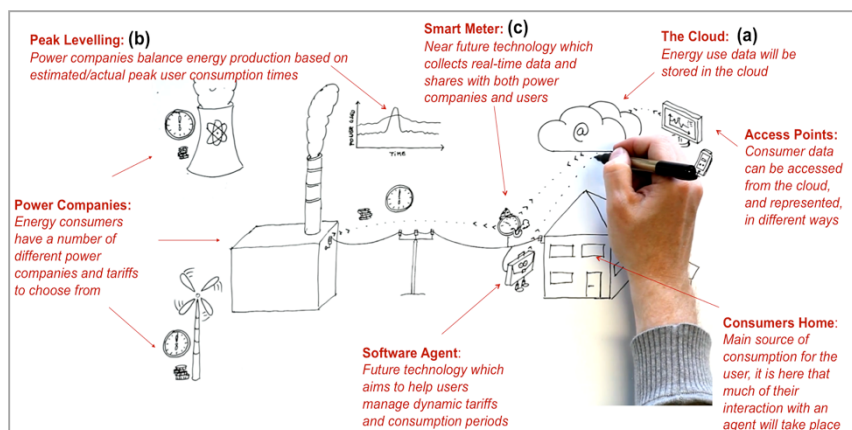
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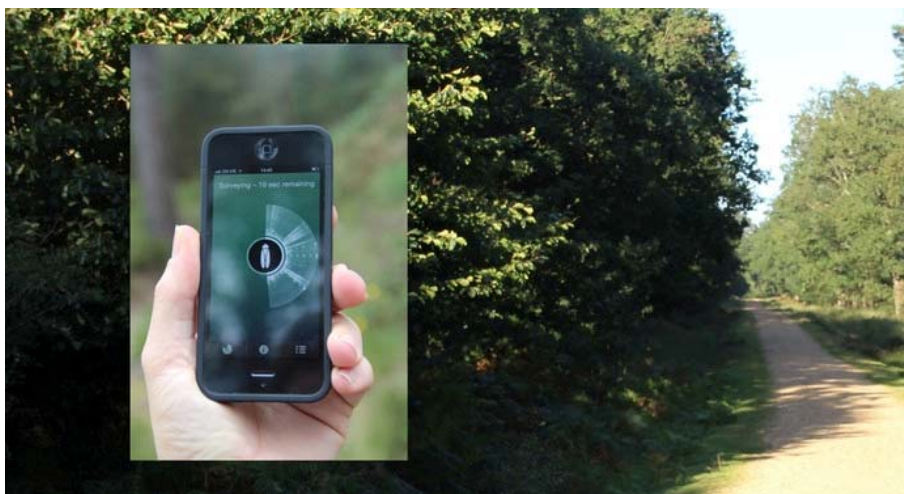
# Application Areas



## Smart Energy Systems



## Disaster Response



## Citizen Science



# HACs in Smart Energy Systems



**Smart Heating  
Control**



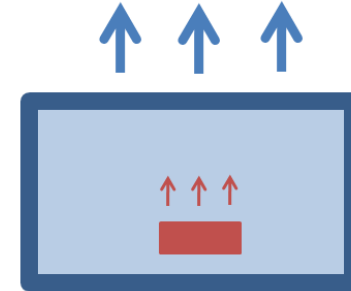
**Personalised  
Recommendations  
& Advice Giving**



**Electric Vehicle  
Charging**

# Smart Heating Control

- Build thermal model of home
  - Thermal leakage rate
  - Heater output
- Predict local weather conditions
  - External air temperature
  - Combine local observation and weather forecast with Gaussian processes
- Optimise energy use to maintain comfort whilst
  - Provide real-time energy feedback
  - Heat the room while energy is cheap



Day	From	Until	Temp	Feels	UV	Rain	Cloud	Dir	Speed	Gust	Weather
Thu 2 Dec	0:00	2:59	-3 °C	-9 °C	0	0.0 mm	96 %	↓	11 mph	14 mph	☁
	3:00	5:59	-3 °C	-9 °C	0	0.0 mm	97 %	↓	11 mph	13 mph	☁
	6:00	8:59	-2 °C	-7 °C	0	0.0 mm	99 %	↓	11 mph	13 mph	☁
	9:00	11:59	2 °C	-4 °C	0	0.2 mm	98 %	↓	15 mph	18 mph	☁
	12:00	14:59	2 °C	-6 °C	1	0.1 mm	91 %	↓	12 mph	14 mph	☁
	15:00	17:59	2 °C	-8 °C	0	0.1 mm	67 %	↓	11 mph	13 mph	☁
	18:00	20:59	-4 °C	-9 °C	0	0.0 mm	14 %	↓	10 mph	12 mph	☁
	21:00	23:59	-8 °C	-10 °C	0	0.0 mm	7 %	↓	9 mph	11 mph	☁



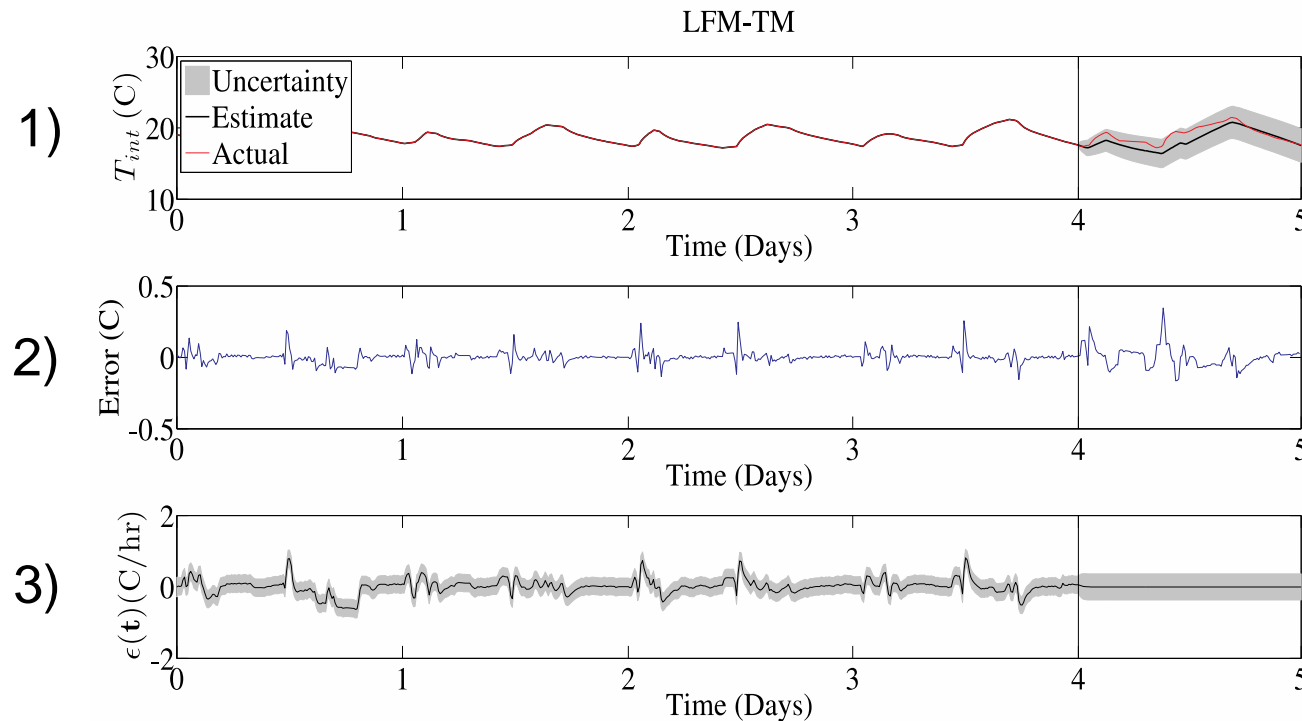
# Developed adaptive and bespoke latent force thermal models of homes using real data

(Reece et al., 2014)

LFM-TM  $\eta^t = \eta_{on}^t r_h - \phi(T_{in}^t - T_{ext}^t) + \epsilon^t$   $T_{in}^{t+1} = T_{in}^t + \frac{\eta^t \Delta t}{c_{air} m_{air}}$

Components of a simple thermal model

Extra residual term introduced in LFM-TM to model any a priori unknown dynamics or latent force



- 1) Accurate day-ahead internal temperature predictions
- 2) Unknown latent forces that affect the thermal dynamics
- 3) Gaussian Process used to model the unknown latent forces from data



# Smart Heating Controller



Rogers, A., Maleki, S., Ghosh, S. and Jennings, N. R. **An intelligent agent for home heating management [Demo]**. AAMAS 2012.



# Personalised Recommendations

(Fischer et al., 2013)



## Welcome to AgentSwitch

Developed by experts in Artificial Intelligence, AgentSwitch uses its advanced algorithms to analyse your real-time energy usage and provide you with tariff switching and energy usage recommendations.

Login

Create an account

Find the cheapest tariff based on your energy use:



1

### Data collection

AgentSwitch collects real-time energy usage data from your home using low-cost energy monitoring devices.

[Find out more](#)



2

### Usage prediction

Intelligent algorithms analyse your data to extract your energy usage behaviour and predict your future usage.

[Find out more](#)



3

### Get recommendations

AgentSwitch compares hundreds of tariffs from all major suppliers to provide you with tariff switching advice and more.

[Find out more](#)

# Personalised Recommendations

(Fischer et al., 2013)

Dashboard Welcome, roncallim

## Your cheapest tariffs

AgentSwitch applied its smart algorithms on your historical data, and found out:

Predicted energy use

Peak time

1481 kWh

Off-peak time

460 kWh

White goods loads

Runs per month

14 / 5.50 kWh

Peak time cost yearly

£7.15

✓

Data collection

✓

Prediction

3

Recommendations

## Tariffs available to you

The following tariffs are available in your area:

Standard tariffs ✓

Economy7 tariffs

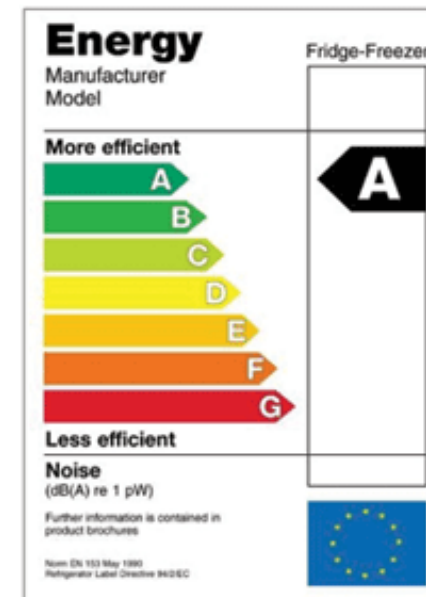
Supplier	Plan	Estimated Annual Cost																				
	<b>Pocket + Energy Online October 2014</b> <div> <div>⚡ Electricity total</div> <div>£329.56</div> </div> <div> <div>🔥 Gas total</div> <div>£574.21</div> </div> <div> <div>Total Combined</div> <div>£991.02</div> </div> <div> </div>	<div> <div>Estimated Annual Breakdown</div> <table> <thead> <tr> <th>Rate</th> <th>Price (p per kWh)</th> <th>Usage (kWh)</th> <th>Cost (£)</th> </tr> </thead> <tbody> <tr> <td>⚡ Electricity rate</td> <td>10.38</td> <td>3175</td> <td>329.56</td> </tr> <tr> <td>🔥 Gas rate</td> <td>3.60</td> <td>15937</td> <td>574.21</td> </tr> <tr> <td colspan="3">VAT/discounts</td> <td>87.25</td> </tr> <tr> <td colspan="3"><b>Total</b></td> <td><b>£991.02</b></td> </tr> </tbody> </table> </div>	Rate	Price (p per kWh)	Usage (kWh)	Cost (£)	⚡ Electricity rate	10.38	3175	329.56	🔥 Gas rate	3.60	15937	574.21	VAT/discounts			87.25	<b>Total</b>			<b>£991.02</b>
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[www.agentswitch.com](http://www.agentswitch.com)

# Identifying Inefficient Appliances

(Parson et al., 2012)

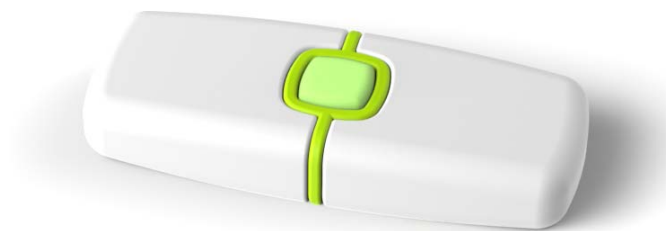
- Non-intrusive load monitoring
  - Disaggregate appliance energy consumption from smart meter data
- Challenges
  - Low data resolution
  - No training data
- Reduce household energy consumption by recommending inefficient appliances to be replaced



# Home Heating Advice

(Rogers et al., 2013)

- Sense temperature at thermostat
  - Infer heating operation and thermal performance
    - Compare to norms
    - Calculate impact of interventions
- Low cost easy to use logger
  - Can be returned after trial
  - No software to install (appears as a memory stick)
- BuildSys 2013 Best Paper Award



[www.joulo.com](http://www.joulo.com)

# Home Heating Advice

- Research trial with 750 users in winter 2012/2013
- Data collection for DECC smart heating control trial in 25 homes
- Won British Gas Connected Homes Startup Competition in September 2013
- Trials with three of the UK big six energy companies in winter 2013/2014
  - 1500 Joulo loggers
  - Re-designed analysis and feedback
  - Referral to insulation services, payment help, and upsell of additional controls



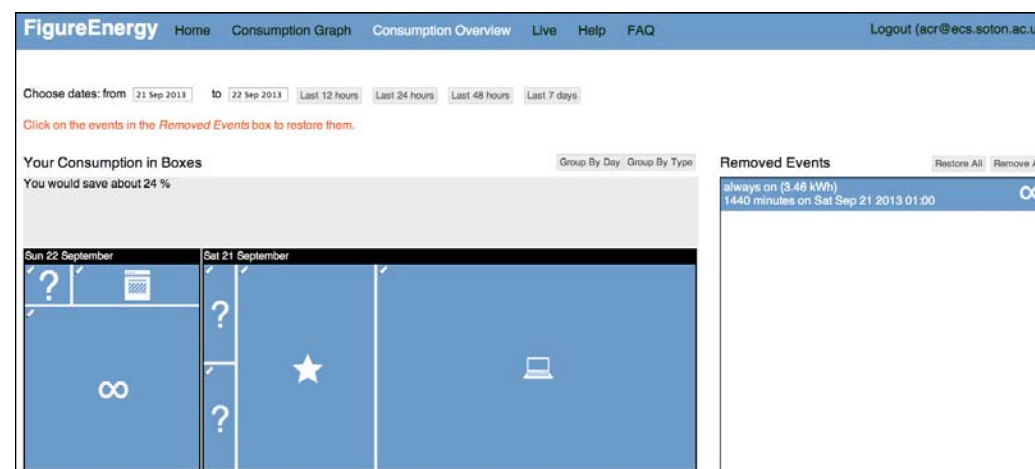
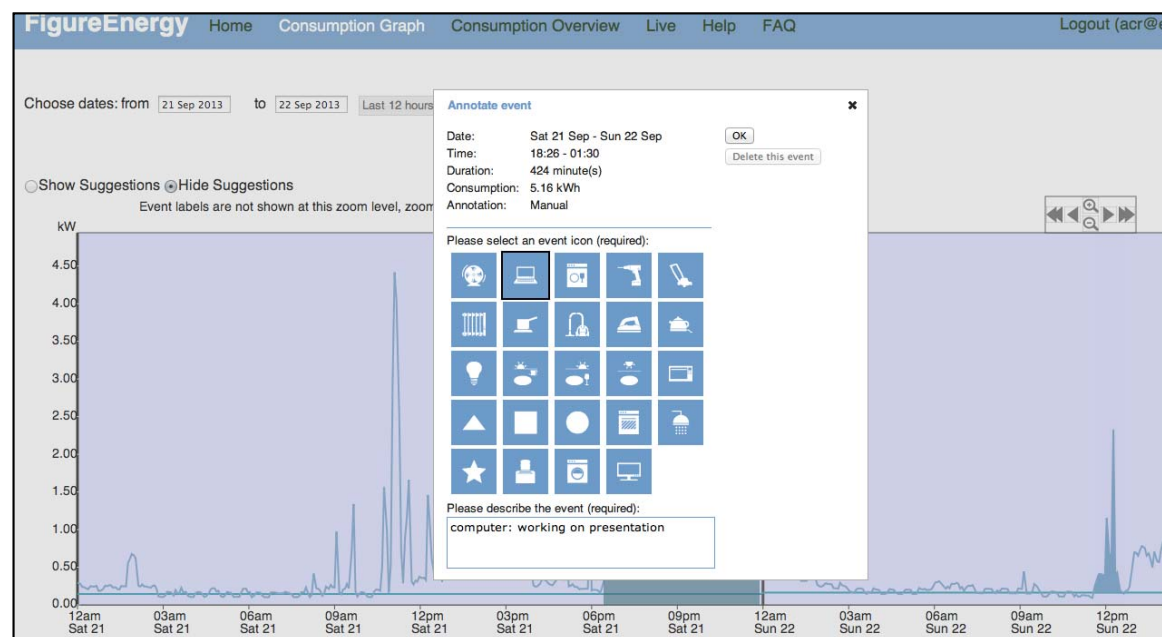
[www.joulo.com](http://www.joulo.com)



# Understanding Energy Consumption

(Costanza et al., 2012)

- Mixed human and automated system for understanding current energy usage.
- Explore options for savings.



# Users Interacting with Agents

## TariffAgent

Home

### Tariff

Your current tariff is **Fixed Tariff**.

Tomorrow's tariff is **Fixed Tariff**. You can change it before 9pm today.

**Predictions for Tomorrow:**

- ☐ 23.4 kWh - A lot more than yesterday
- ☐ 18.7 kWh - More than yesterday
- ☒ 15.6 kWh - **Same as yesterday**
- ☐ 10.9 kWh - Less than yesterday
- ☐ 7.8 kWh - A lot less than yesterday

Estimated Consumption:

Estimated Wind Energy Generation: 6.7 kWh

Tariff	Cost	Best	Worst		
Fixed	£ 2.03	£ 2.03	£ 2.03	<input checked="" type="button" value="Selected"/>	<b>Suggested</b>
Variable-C	£ 2.09	£ 1.56	£ 2.50	<input type="button" value="Select"/>	
Variable-B	£ 2.14	£ 1.25	£ 2.81	<input type="button" value="Select"/>	
Variable-A	£ 2.25	£ 0.47	£ 3.59	<input type="button" value="Select"/>	

### Setting

- ☐ Send me an SMS when tariff change is suggested.
- ☒ Automatically select best tariff and send confirmation.
- ☐ Automatically select best tariff without confirmation.

### Budget

**Available:** £19.40 **Spent:** £10.60

[Account Book Details](#)

People preferred medium level of autonomy:  
agent changes, but informs them  
(Alan et al., 2014)

## Agent B

Home Planner Settings FAQ About

Logout

Book New Wash

Book New Wash

Please pick the period you prefer:

	Tuesday (17)	Wednesday (18)	Thursday (19)	Friday (20)	Saturday (21)	Sunday (22)	Monday (23)	Tuesday (24)
060 - 145		From: £2.84	From: £2.82	From: £2.79	From: £2.85	From: £2.81	From: £2.86	From: £2.83
200 - 245		From: £2.86	From: £2.84	From: £2.71	From: £2.84	From: £2.86	From: £2.86	From: £2.86
450 - 545		From: £2.89	From: £2.89	From: £2.72	From: £2.86	From: £2.86	From: £2.86	From: £2.86
600 - 745		From: £2.91	From: £2.86	From: £2.73	From: £2.73	From: £2.86	From: £2.86	From: £2.86
800 - 945	From: £1.31	From: £2.38	From: £2.57	From: £2.78	From: £2.14	From: £2.86	From: £2.86	From: £2.86
1000 - 1145	From: £2.85	From: £2.40	From: £2.59	From: £2.77	From: £2.15	From: £2.86	From: £2.86	
1200 - 1345	From: £1.35	From: £2.42	From: £2.61	From: £2.78	From: £2.18	From: £2.86	From: £2.86	
1400 - 1545	From: £2.85	From: £2.44	From: £2.65	From: £2.81	From: £2.17	From: £2.86	From: £2.86	
1600 - 1745	From: £2.41	From: £2.46	From: £2.66	From: £2.82	From: £2.00	From: £2.86	From: £2.86	
1800 - 1945	From: £2.81	From: £2.48	From: £2.67	From: £2.84	From: £1.76	From: £2.86	From: £2.86	
2000 - 2145	From: £2.32	From: £2.80	From: £2.88	From: £2.80	From: £1.80	From: £2.86	From: £2.86	
2200 - 2345	From: £2.83	From: £2.81	From: £2.89	From: £2.89	From: £1.21	From: £2.86	From: £2.86	

☒ Batt. Prices  
(your price) ☐ Raw Prices  
(for info.)

## Agent B

Home Planner Settings FAQ About

Logout

### Bookings

Next booking

- Wed 14 Jul 11:30

**Price Forecast**

Current battery price: £0.09  
Original battery price: £0.11  
Raw price: £1.63  
Savings: £1.54

### Battery status

not charging

Current charge: 68%

### Budget

available: £39.75 | spent: £10.25

### History

Loads of washing done

- Wed 17 Jul at 08:15
- Fri 19 Jul at 08:55
- Fri 19 Jul at 18:37
- Mon 22 Jul at 18:51
- Mon 22 Jul at 23:27
- Tue 23 Jul at 08:11
- Tue 23 Jul at 20:45

Agent hidden in background behind  
calendar interface  
(Costanza et al., 2014)

# Working with Energy Advisors



- Charity providing support for people in fuel poverty
- Understanding energy advice practices and needs
- Involving advisors in the design process



Advisor workshops



Home visits

# Electric Vehicle Charging

- To meet carbon emission targets, the UK needs to have **5.6 million EVs** on the road by 2020.
- Current infrastructure is highly limited:
  - **Home charging:** Distribution network is not designed for increase in load caused by widespread charging.

Household: ~10 kWh per day



EV Battery: ~25 kWh

- **En-route charging:** Charging takes a significant amount of time, and currently there are few public stations.



Risk of Queues

# Mechanism Design for Home Charging

(Stein et al., 2012)

- How to utilise the charging infrastructure efficiently without exceeding its constraints?
  - **Time of Use Tariff**: may simply shift peak and no guarantee to meet constraints.
  - **Scheduling**: participants can **strategise**.

**Our Approach:** Using *mechanism design*, we define allocation and payment rules that can ensure a range of desirable properties:



**Incentive Compatibility**  
**Efficiency**

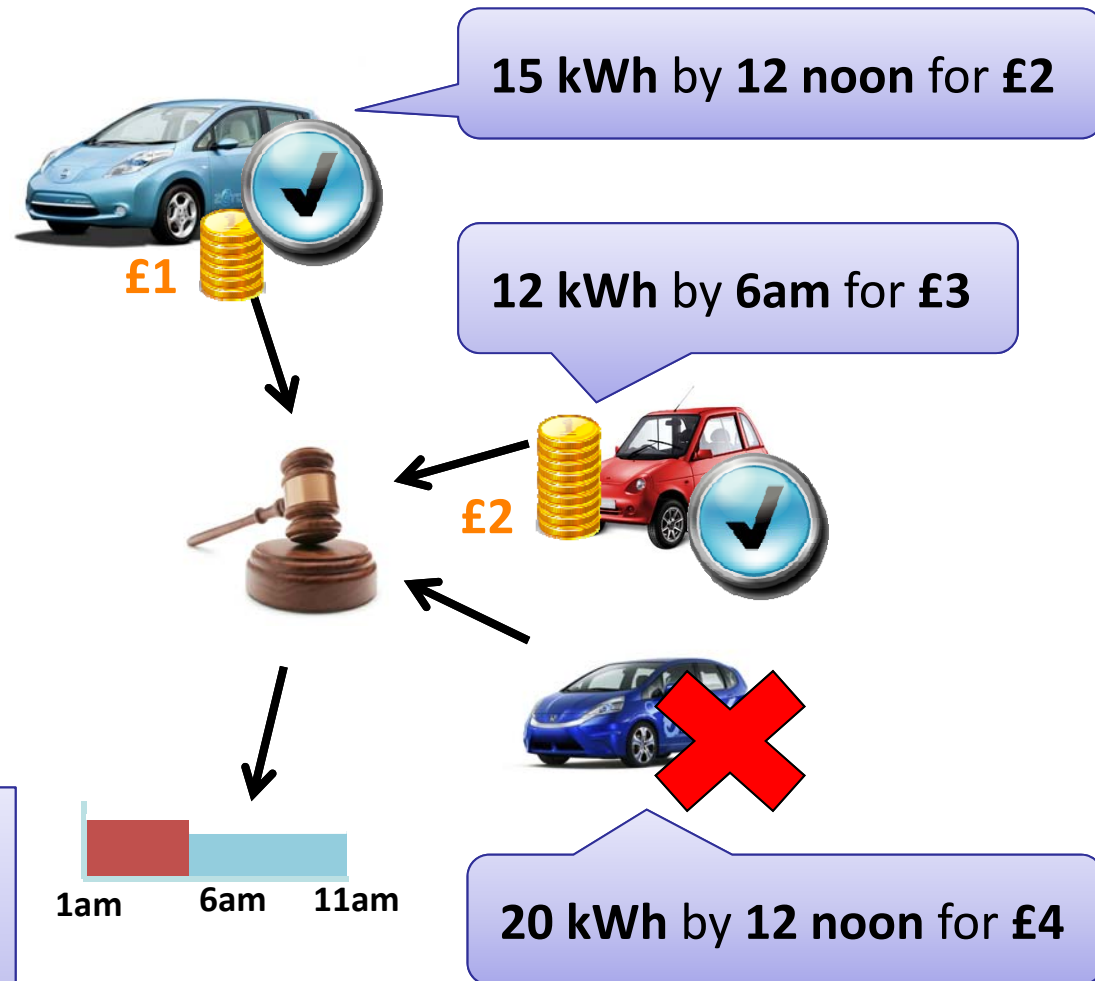
**Individual Rationality**  
**Budget Balance**



# Mechanism Design for Home Charging

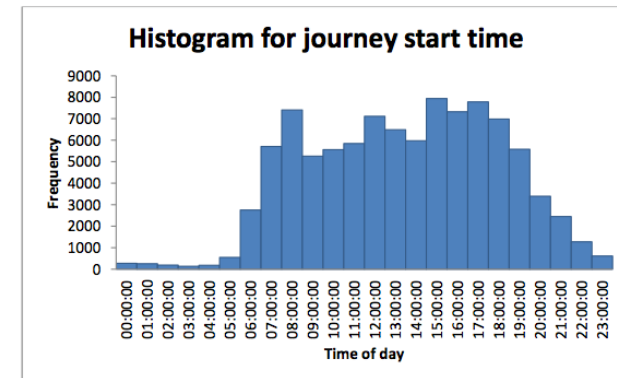
1. **On each arrival:**  
Driver/agent reports charging requirements.
2. **Ongoing:**  
Mechanism schedules charging.
3. **On each departure:**  
Driver pays mechanism, using *critical value payments*.

Our mechanism is **incentive compatible, individually rational** and (weakly) **budget balanced**.

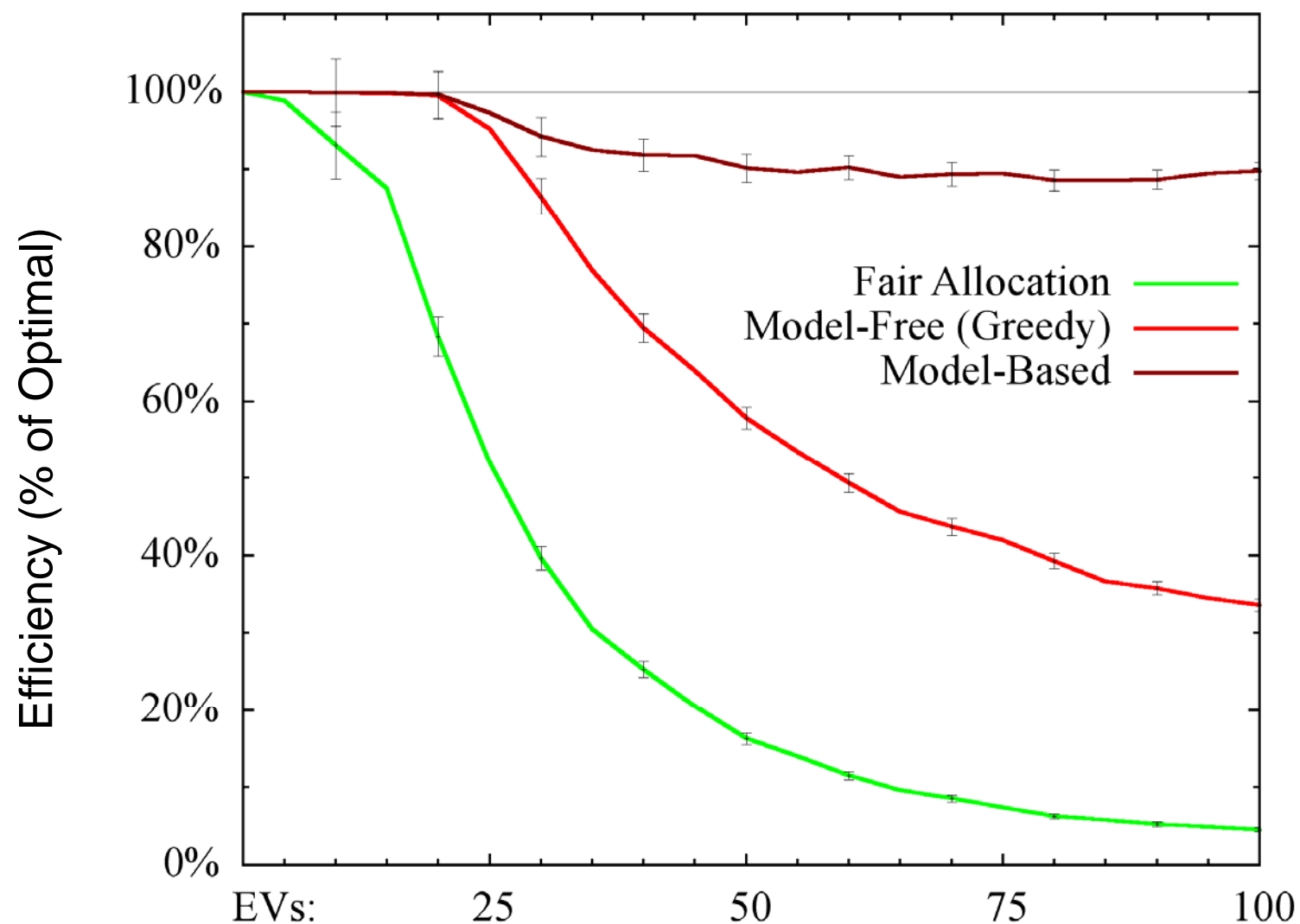


# Evaluation using Real Data

- Based on data from a large-scale trial of EVs in the UK.
  - 110 vehicles over 4 years.
- Driving behaviour sampled from real journey data recorded by GPS.
- Constraints derived from typical household electricity consumption.
- Three mechanisms:
  - Model-free (greedy)
  - Model-based (model of future arrivals)
  - Fair (power is distributed evenly)



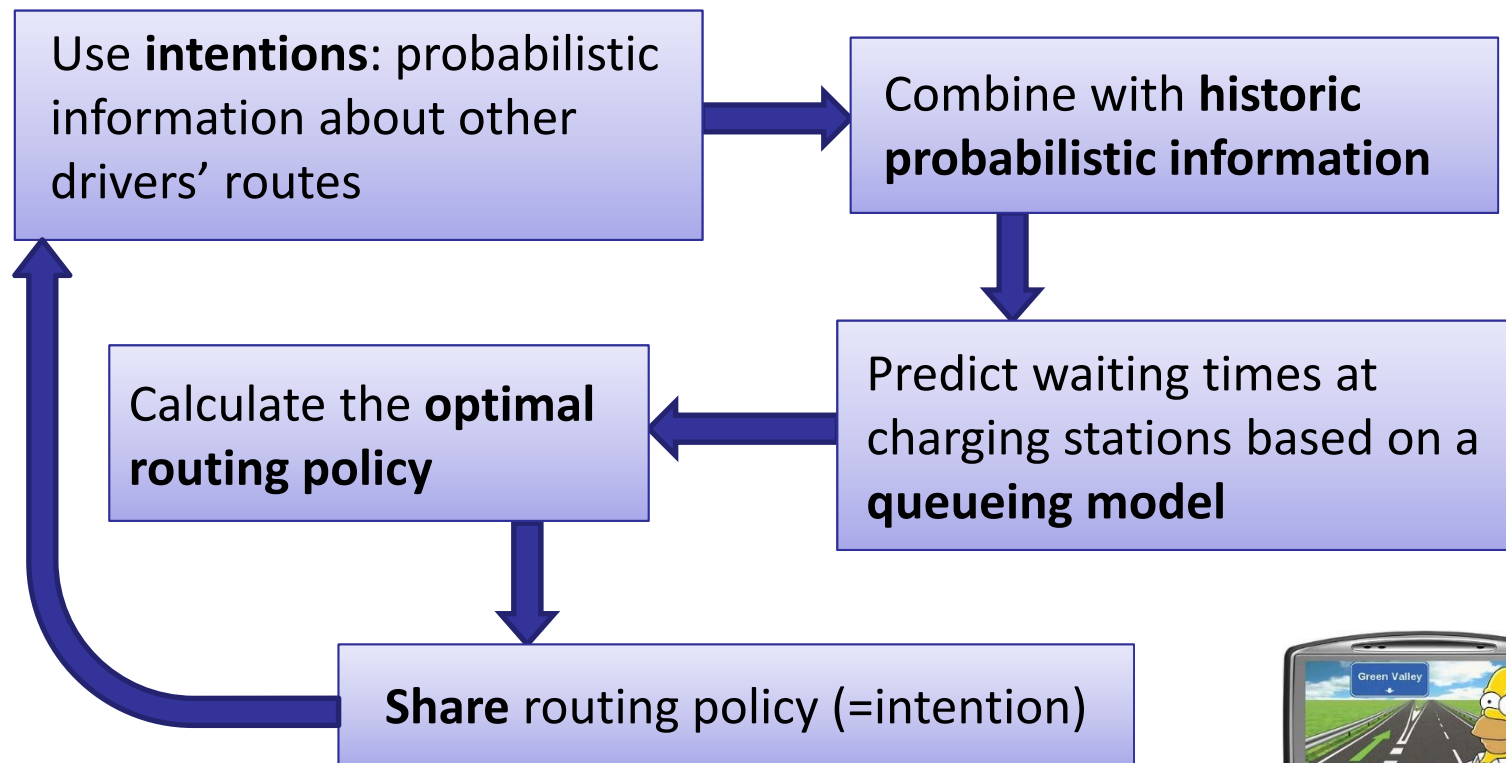
# Results



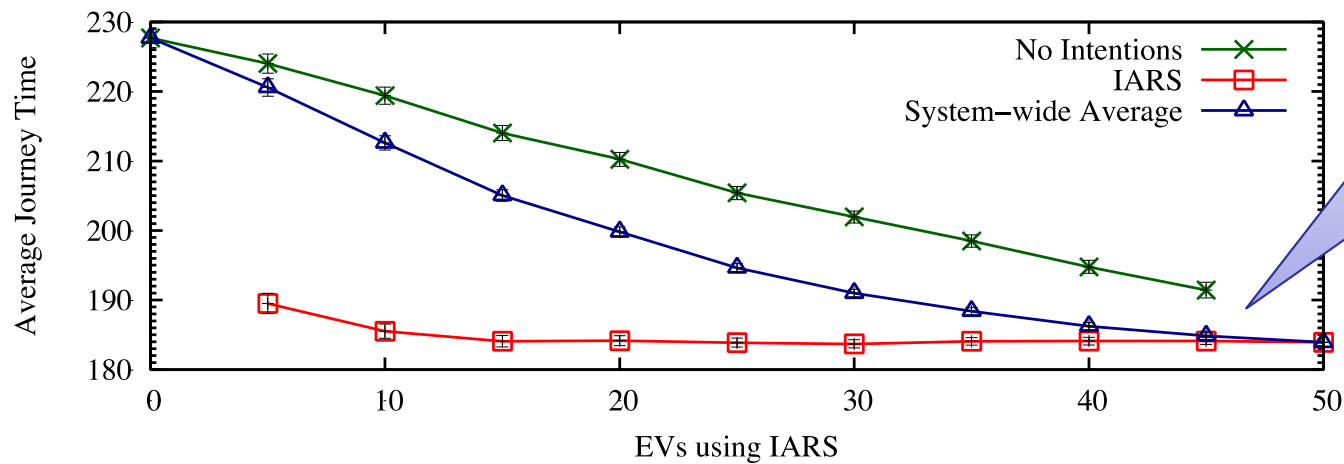
# Coordination for En-Route Charging

(de Weerd et al., 2013)

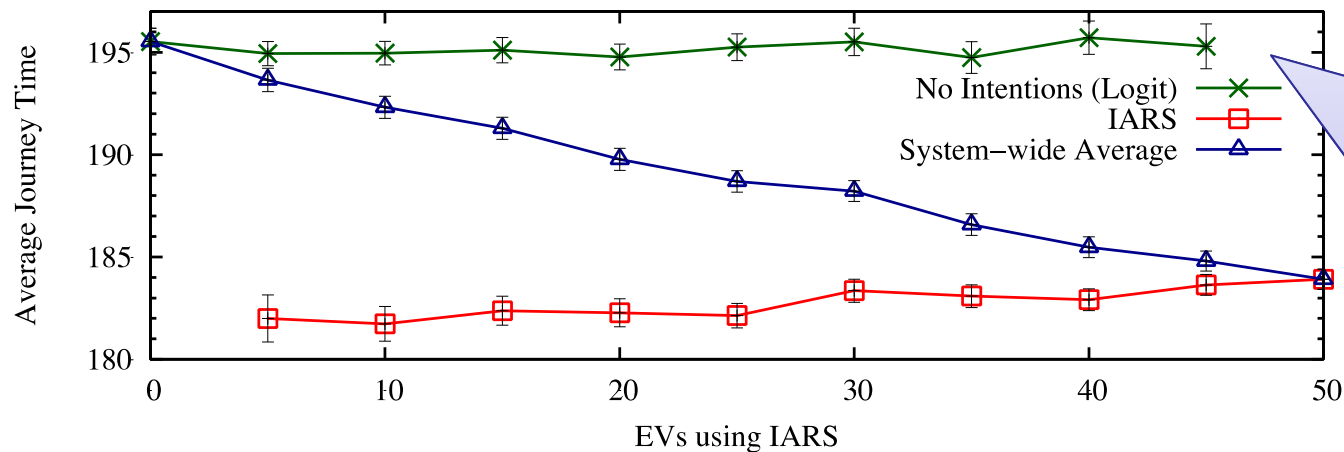
- To deal with the risk of congestion in en-route charging, we designed an **intention-aware routing system** that allows navigation agents to share probabilistic routing information and coordinate.



# Incentives for Drivers to Use IARS



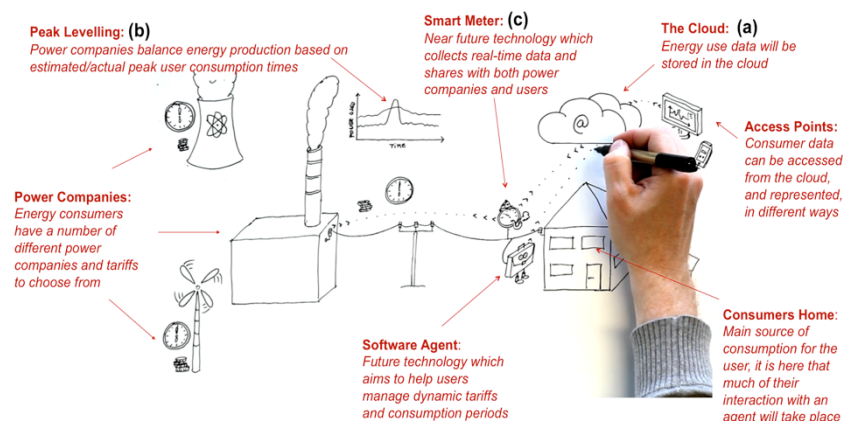
Using intentions is always beneficial, even when few vehicles use IARS.



A logit-based approach outperforms shortest-path, but IARS is consistently better.



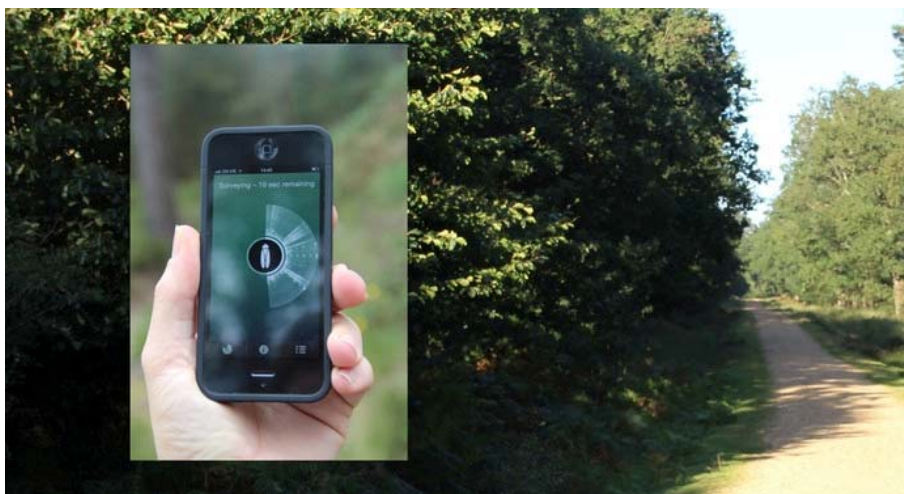
# Application Areas



## Smart Energy Systems



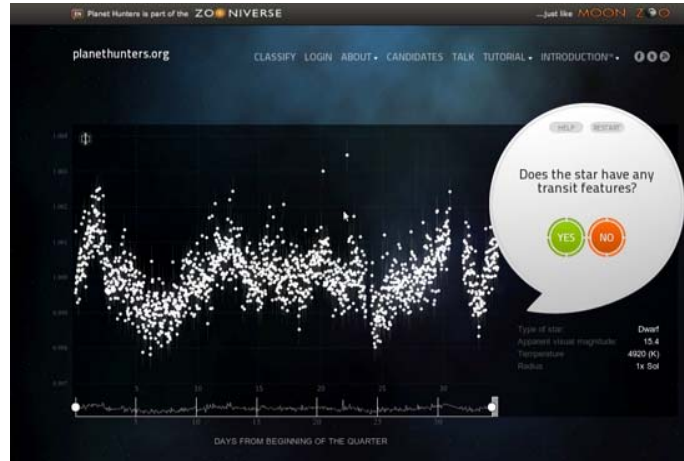
## Disaster Response



## Citizen Science



# HACs in Citizen Science



**Classifying  
Galaxies**

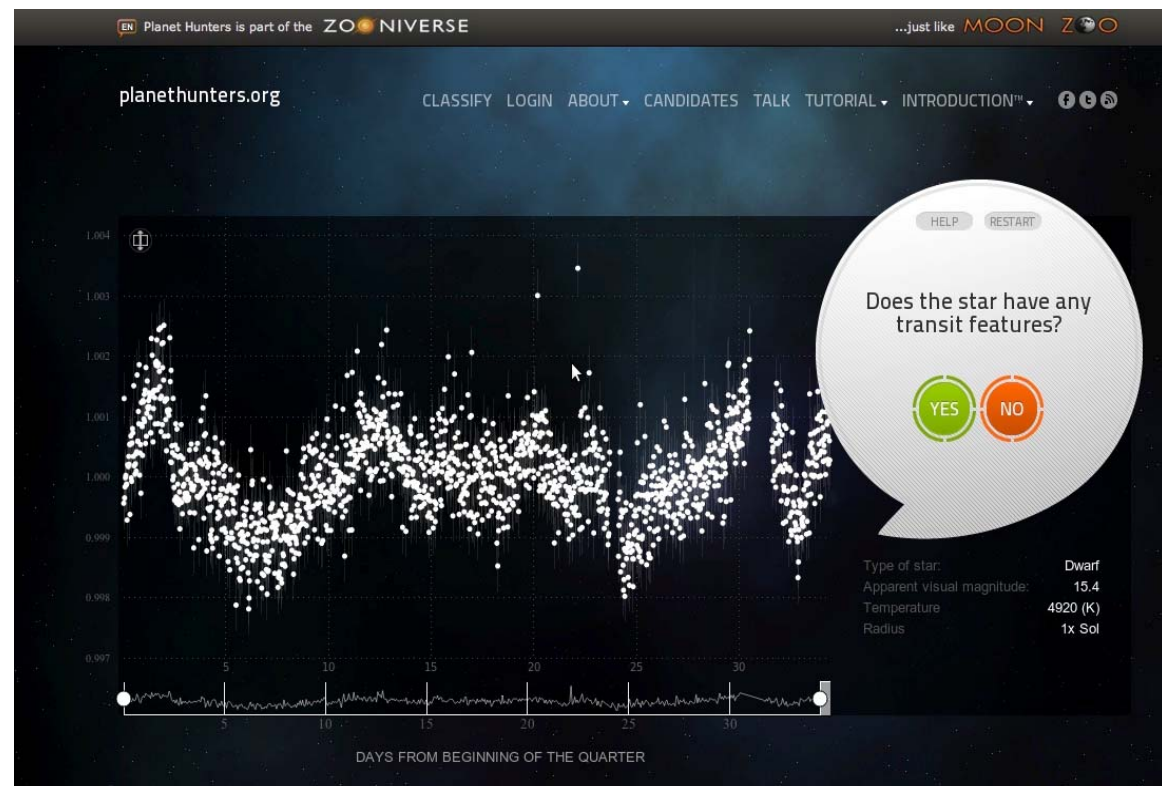


**Hunting for  
Endangered  
Species**

# Classifying Galaxies

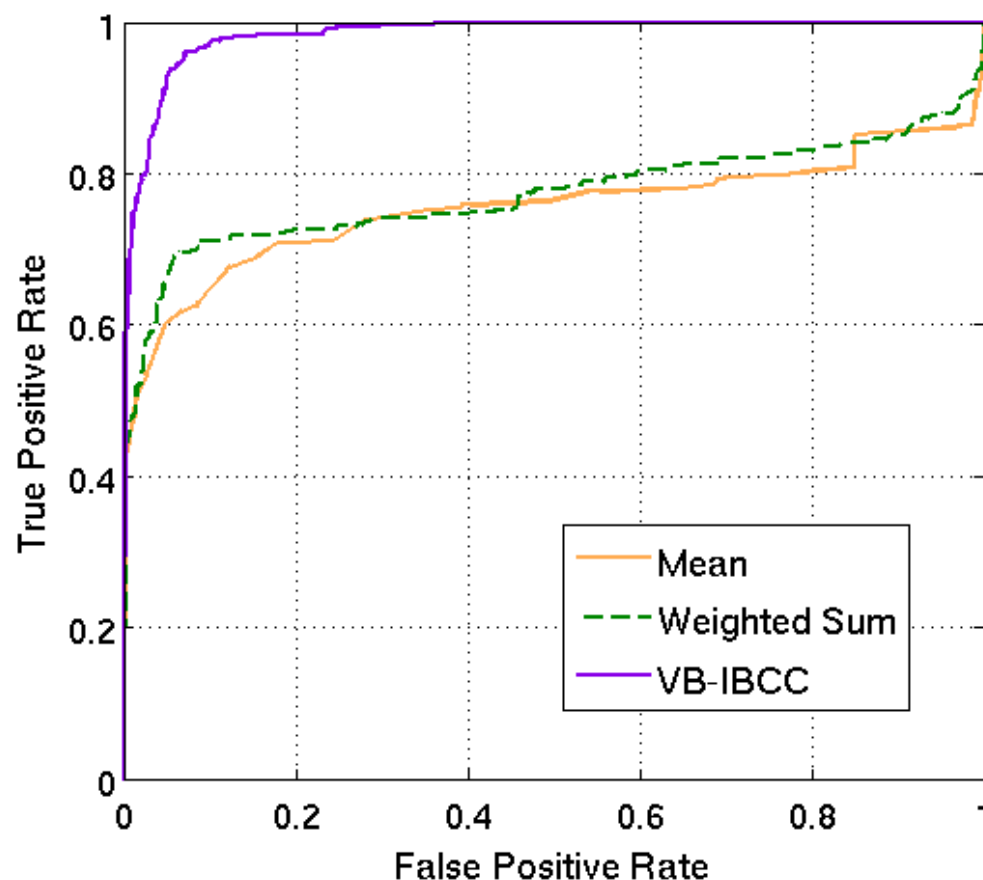
Volunteers presented with data and images of galaxies, possible moons etc.

- Answer questions to classify objects
- Many volunteers classify each object



# Intelligent Aggregation of Volunteer Votes

(Simpson et al., 2011)



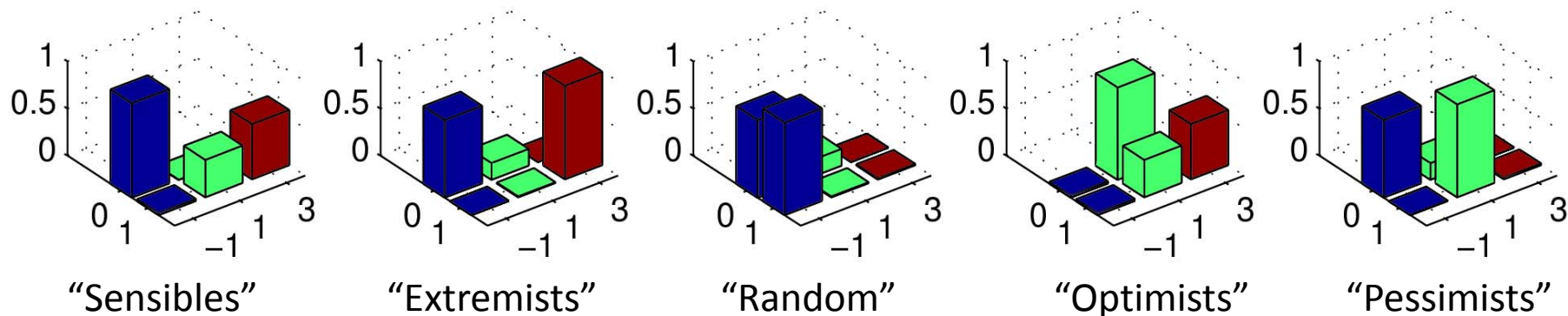
Method	AUC
Mean of Scores	0.7543
Weighted Sum	0.7722
Simple Majority Voting	0.7809
Weighted Majority Voting	0.7378
Gibbs-IBCC	0.9127
VB-IBCC	0.9840

## Independent Bayesian Classifier Combination (IBCC)

Principled approach to combine vote of volunteers within GalaxyZoo.

# Characterising Volunteer Behaviour

- Volunteers can be grouped according to behaviour patterns
- Communities evolve over time
- Informs design of tasks and training
  - Train “pessimists” when to give high scores
  - Use “sensible” group as teachers



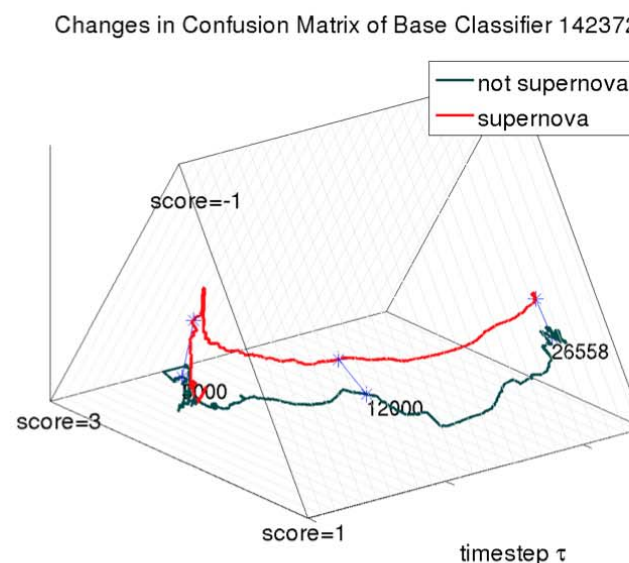
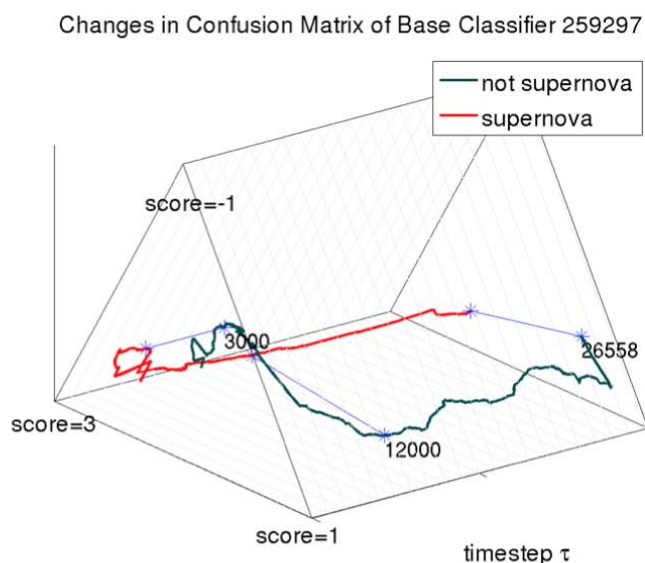
**Ground truth:** 0 = not supernova, 1 = supernova

**Assessment:** -1 = not supernova, 1 = possible supernova, 3 = likely supernova<sub>48</sub>



# Tracking Changing Volunteer Behaviour

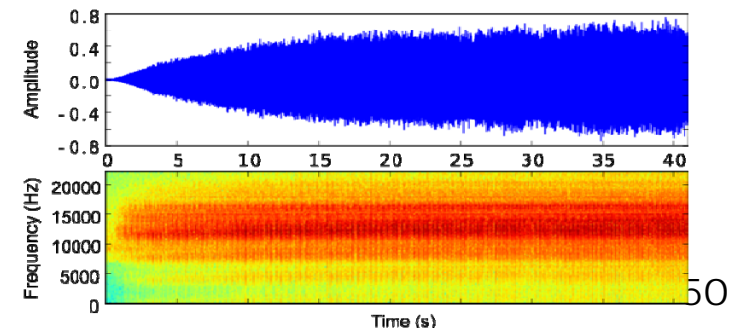
- Volunteer behaviour changes over time as they gain experience, learn and possibly become bored.
- Can we exploit changes to improve performance in long term?



# Hunting for Endangered Species

[www.newforestcicada.info](http://www.newforestcicada.info)

- New Forest cicada
  - Only native cicada to the UK
  - Known since 1812 in New Forest
  - Last confirmed sighting in 1992
- UK Priority Species
  - Survey for new breeding sites
    - Area of 600 km<sup>2</sup>
- Characteristic song at 14.5kHz
  - Difficult for adults to hear
  - Easy for smart phones to hear

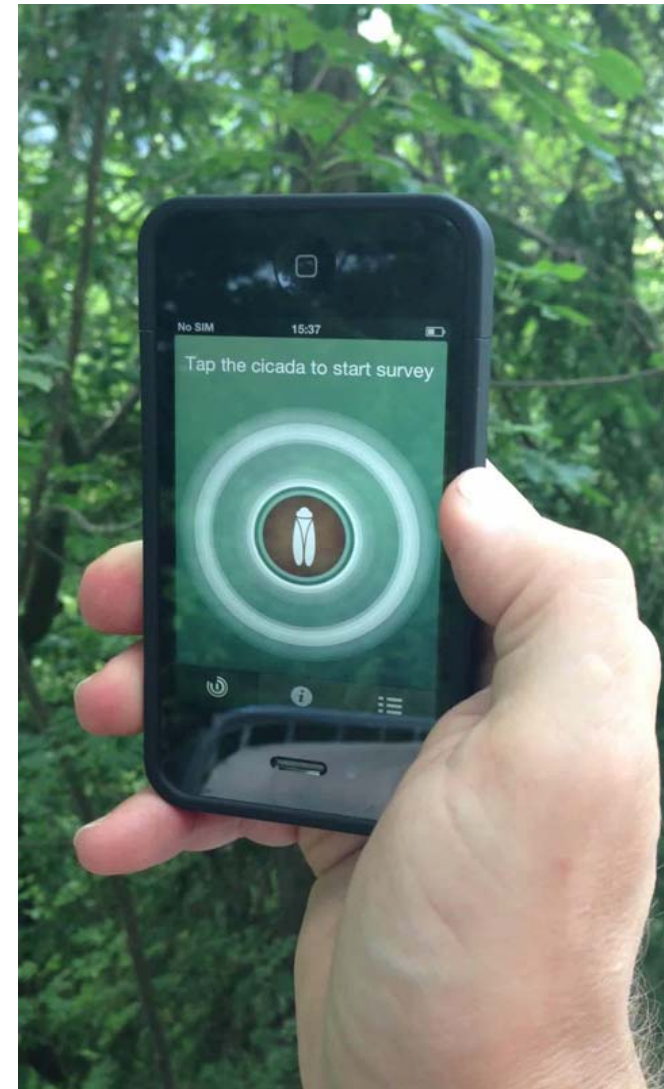


# 'Cicada Hunt' App

[www.newforestcicada.info](http://www.newforestcicada.info)

(Zilli et al., 2013)

- Live detection algorithm operating on phone:
  - Goertzel algorithm generates features from frequency spectrum
  - Hidden Markov model performs classification of other insects
    - New Forest cicada
    - Roesel's Bush-cricket
    - Dark Bush-cricket
- iOS and Android versions using Cordova framework with native audio plugins to perform live detection

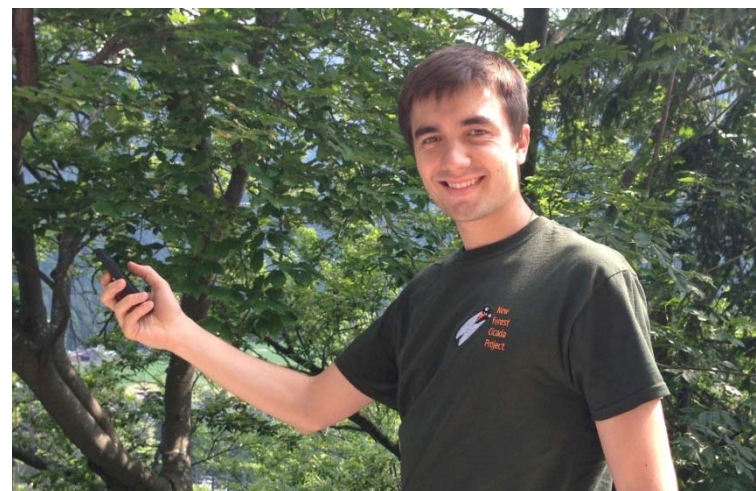




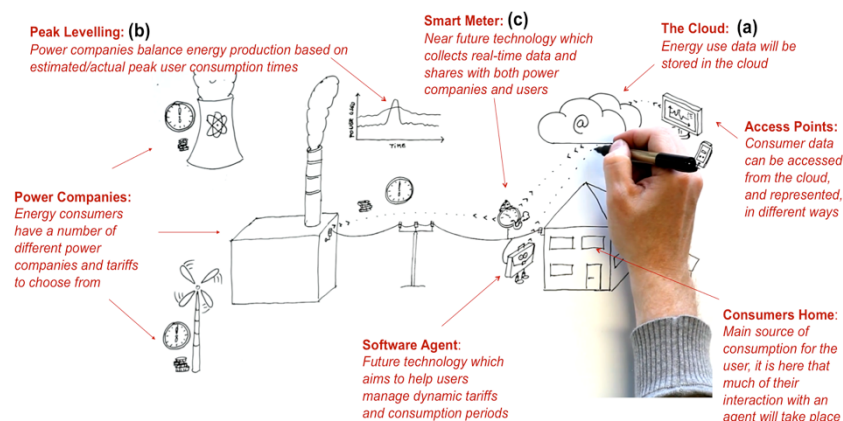
# 'Cicada Hunt' App

[www.newforestcicada.info](http://www.newforestcicada.info)

- Launched at New Forest BioBlitz on 8<sup>th</sup> June 2013
  - Over 2,000 downloads, 6,000 reports (1700 from the New Forest).
  - Supplied to Forestry Commission (FC) entomologists conducting NFC search.
  - No cicada found to date.
- Supplied audio recording plugins to Centre for Ecology and Hydrology (CEH) and UK Biological Records Centre (BRC) for a UK Orthoptera reporting app.



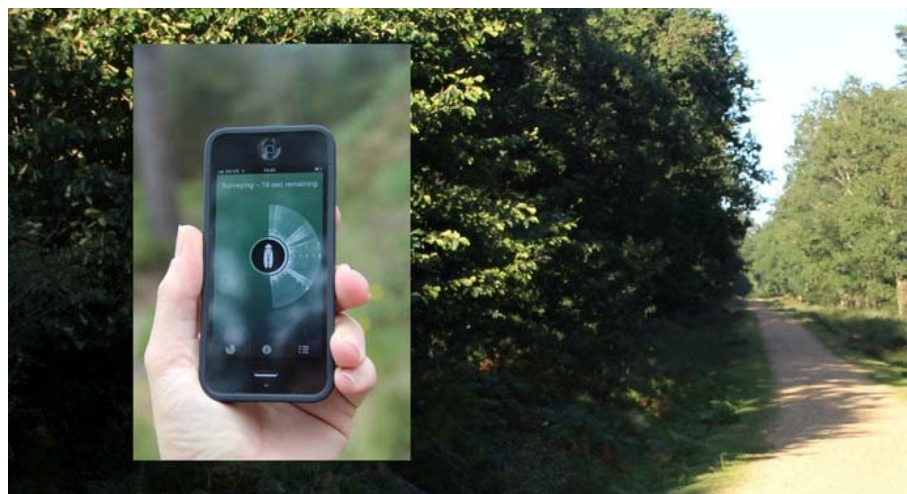
# Application Areas



## Smart Energy Systems



## Disaster Response



## Citizen Science





# SUMMARY

# Conclusions

- Ambitious and challenging research agenda
  - Fundamental scientific challenges at interfaces of AI, HCI, agent-based computing, crowd sourcing, participatory systems and ubiquitous computing.
  - Development of applications for key societal challenges.
- Number of “in the wild” deployments
  - Have shown number of fragments of HAC vision
- Work needed on joining fragments together into over-arching whole

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