A Realistic Dataset for the Smart Home Device Scheduling Problem for DCOPs

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Outline

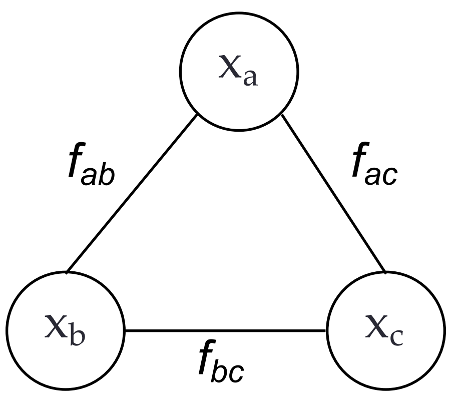
- DCOPs and the need for test cases
- Smart Homes Device Scheduling (SHDS)
- SHDS dataset
- Spam

Distributed Constraint Optimization

Distributed Constraint Optimization

$\langle \mathcal{X}, \mathcal{D}, \mathcal{F}, \mathcal{A}, \alpha \rangle$:

- $\mathcal{X}$: Set of variables.
- $\mathcal{D}$: Set of finite domains for each variable.
- $\mathcal{F}$: Set of constraints between variables.
- $\mathcal{A}$: Set of agents, controlling the variables in $\mathcal{X}$.
- α: Mapping of variables to agents.



Constraint graph

x_a	x_b	cost
0	0	3
0	1	∞
1	0	2
1	1	5

Constraint (cost table)

Distributed Constraint Optimization

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- GOAL: Find a cost minimal assignment.

$$\mathbf{x}^* = \arg\min_{\mathbf{x}} \mathbf{F}(\mathbf{x})$$
$$= \arg\min_{\mathbf{x}} \sum_{f \in \mathcal{F}} f(\mathbf{x}|_{\text{scope}(f)})$$

DCOP: Assumptions

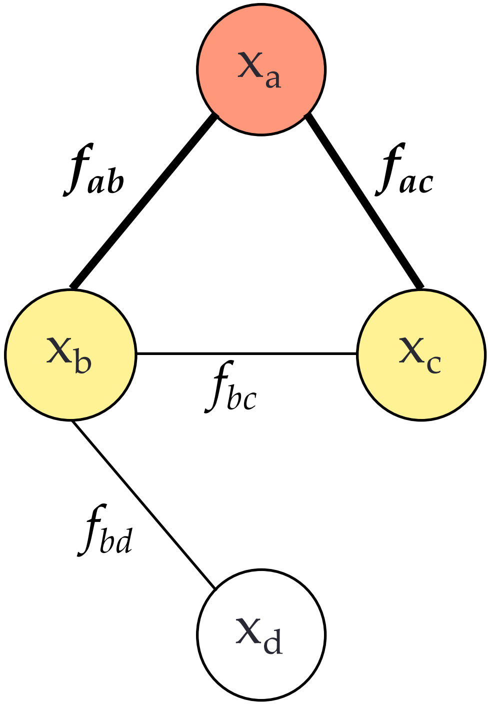
- Agents coordinate an assignment for their variables.
- Agents operate distributedly.

Communication:

- By exchanging messages.
- Restricted to agent's local neighbors.

Knowledge:

- Restricted to agent's sub-problem.

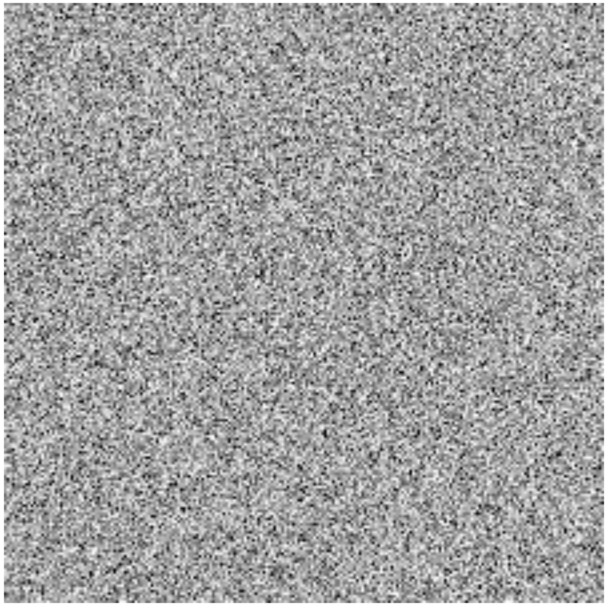


DCOP: Evaluation

- **Metrics**
  - Network load
  - Runtime (or NCCCs)
  - Solution quality

- **Domains**:
  - Mostly random problems

- **Simplifying assumptions**
  - Single variable per agent
  - Binary constraints



- Not consistent with many (more) realistic applications

Home Automation

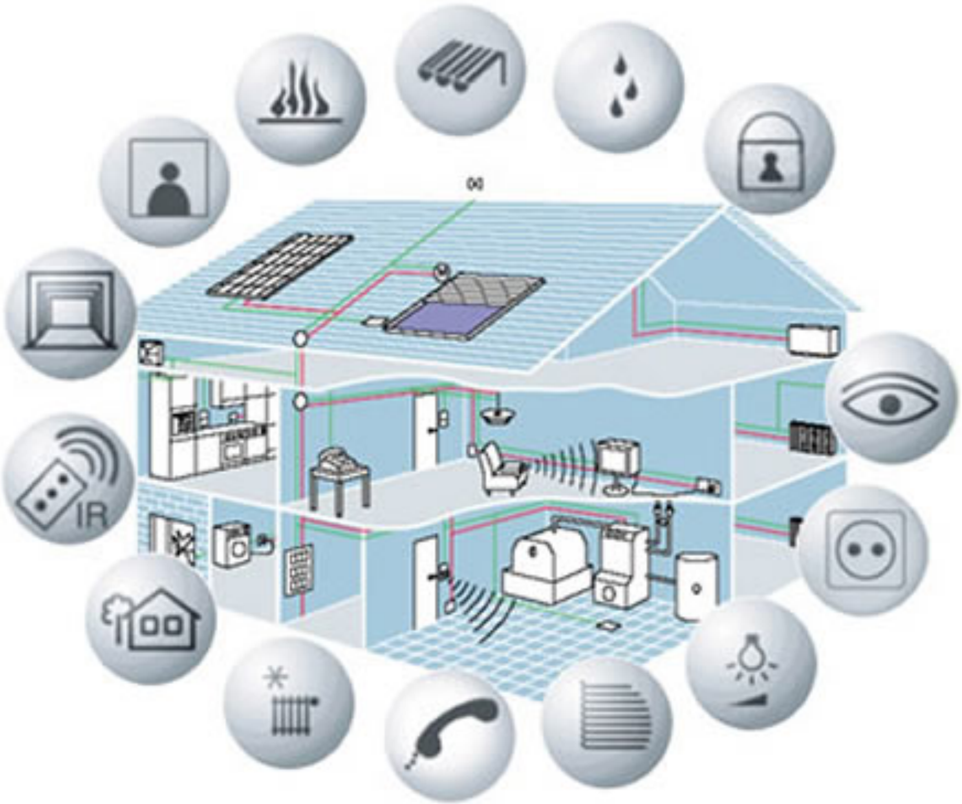


Fig.1

Fig.2

Network of smart homes

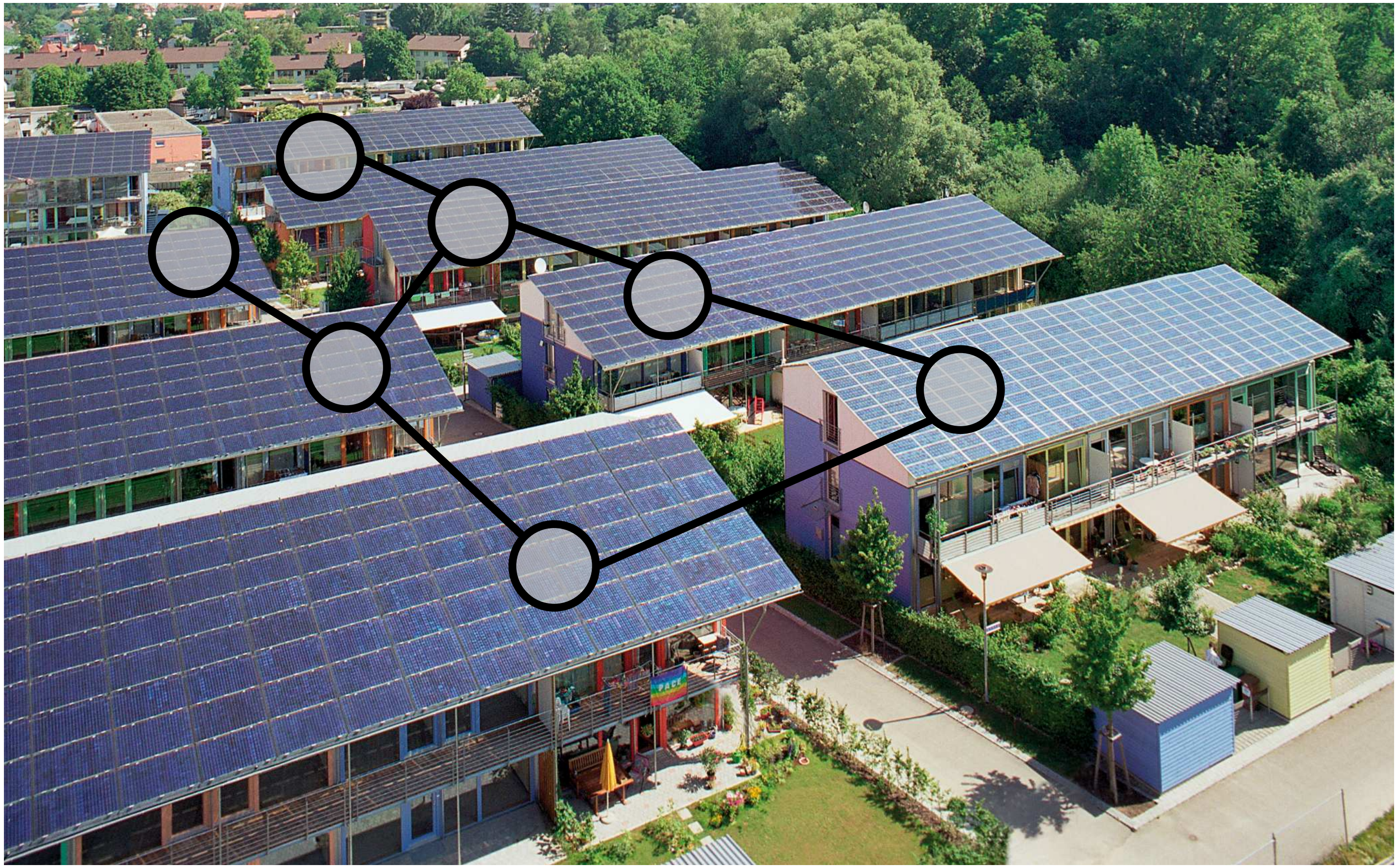
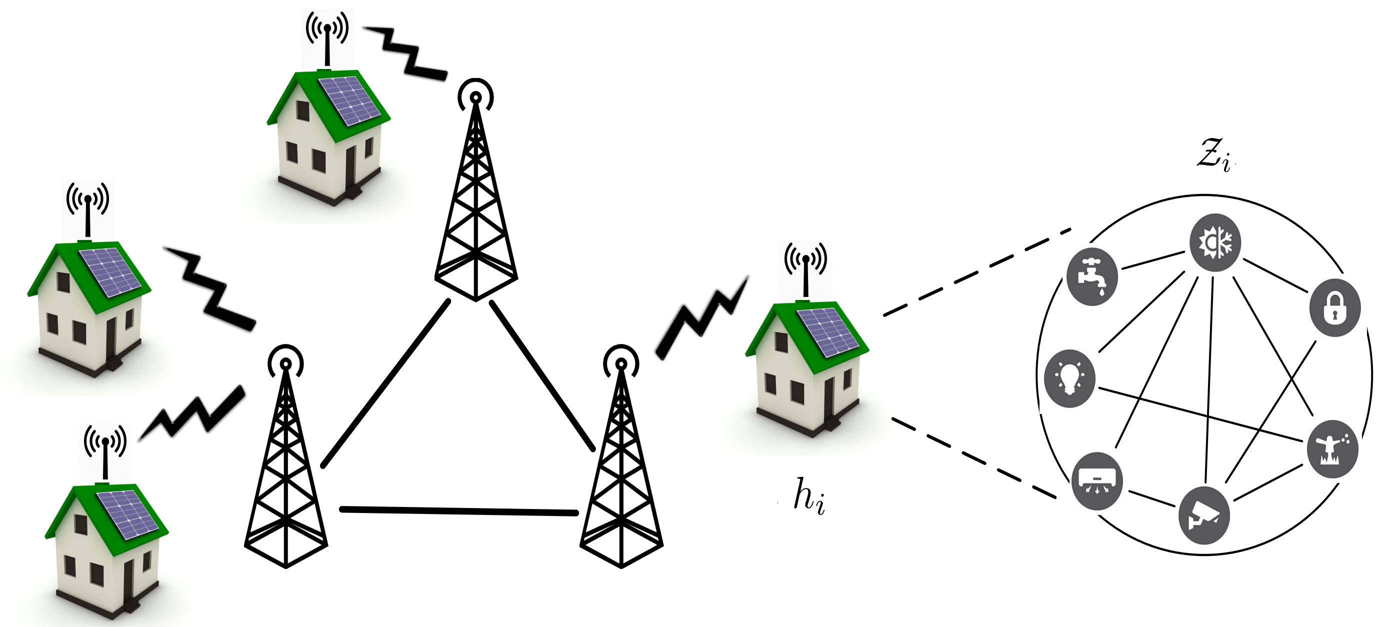


Fig.3

Smart Home Device Scheduling (SHDS)

A **SHDS** problem is composed of:

- A neighborhood of smart homes.
- A set of smart electric devices within each home.
- A time horizon for the device scheduling.



Smart Home Device Scheduling (SHDS)

A **SHDS** problem is composed of:

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- A set of smart electric devices within each home.
- A time horizon for the device scheduling.
- A pricing function expressing cost per kWh of energy consumed.

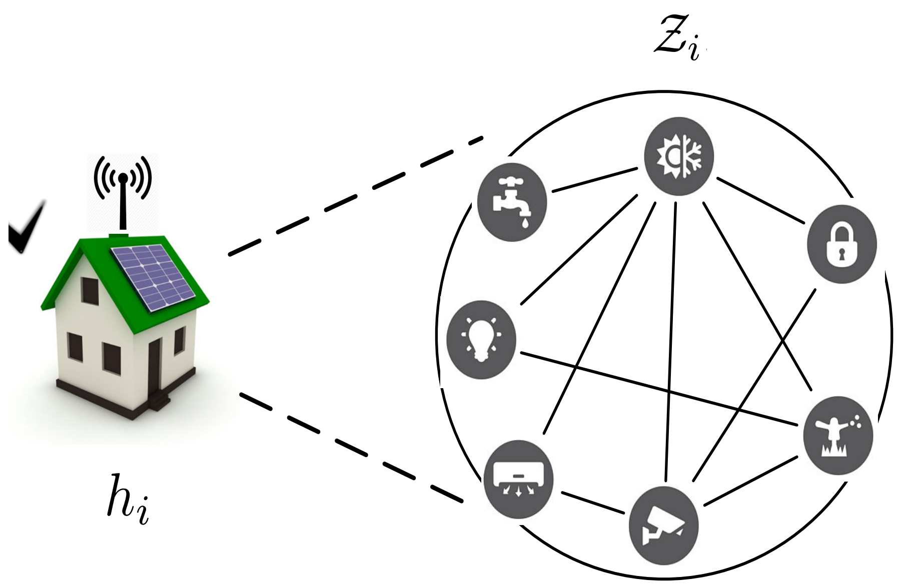
time start	0:00	8:00	12:00	14:00	18:00	22:00
time end	7:59	11:59	13:59	17:59	21:59	23:59
price ($)	0.198	0.225	0.249	0.849	0.225	0.198

Pacific Gas & Electric Co. pricing schema

Smart Home

A smart home has:

- A set of smart devices it can control (e.g, HVAC, roomba)



Smart Home

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- A set of locations (e.g., living room, kitchen)

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- A set of smart devices it can control (e.g, HVAC, roomba)
- A set of locations (e.g., living room, kitchen)
- A set of sensors (e.g., cleanliness, temperature)

Smart Devices (Actuators)

A smart device is defined with a

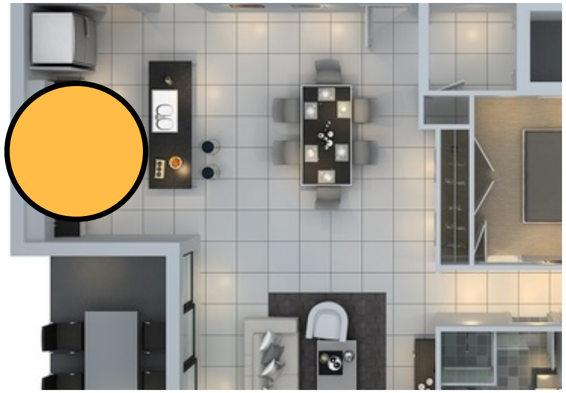
- Location: where the device can act (e.g., living room)
- Actions it can perform (clean, charge, stop) and the power consumption associated to them
- Sensors' states properties it affects (e.g., cleanliness, battery charge)

Action	State property	Power (kW/h)
run	cleanliness, battery charge	0.0
charge	battery charge	0.26
stop		0.0

Smart Devices (Sensors)

- We associate a *predictive model* to each home sensor.
- It describes the transition of a state property from a state s and time t to time t+1, when affected by a set of actuators.

Thermostat



Heater	Oven	Current State	Next State
off	off	12 C	11 C
off	bake	12 C	13.8 C
on	off	12 C	17.5 C
on	bake	12 C	19.3 C

Effect of the environment

Smart Device Schedules

Scheduling Rules

- **Active rules**: specify user-defined objectives on a desired state of the home. E.g.,

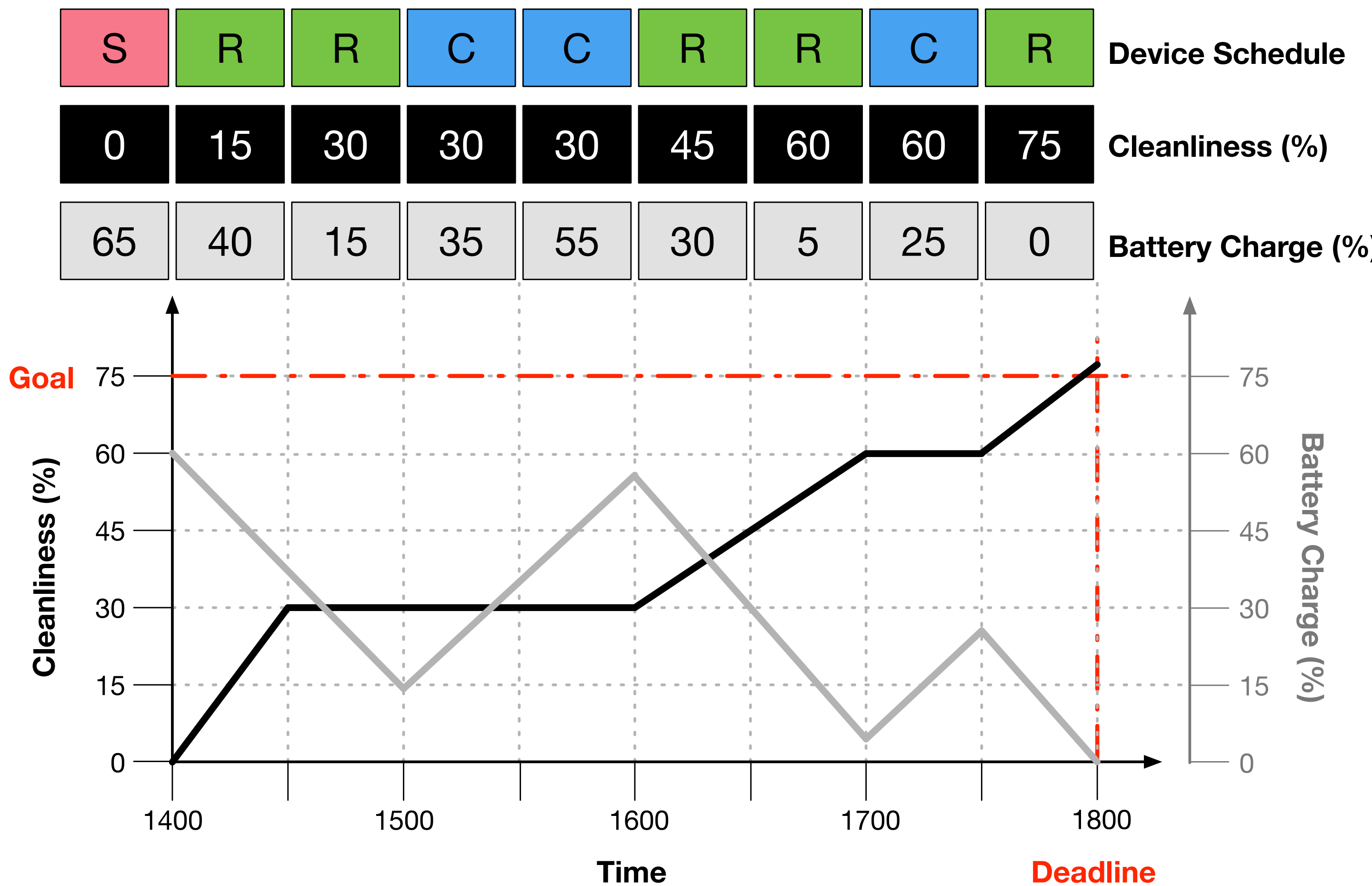
$$\texttt{living\_room cleanliness} \geq \texttt{75 before 1800}$$

- **Passive rules**: define implicit constraints on devices. E.g.,

$$z_v \; \texttt{battery\_charge} \geq \texttt{0 always}$$
$$z_v \; \texttt{battery\_charge} \leq \texttt{100 always}$$

Smart Device Schedules

Schedule: A sequence of actions for the home devices.



Smart Home Device Scheduling (SBDS)

- SHDS objective:

$$\min_{\xi_{\mathbf{z}_i}^{[0\to H]}} \quad \alpha_c \cdot \overbrace{C^{\text{sum}}}^{\text{Aggregated monetary cost of the homes schedules}} + \alpha_e \cdot \underbrace{E^{\text{diff}}}_{\text{Energy consumption peaks across all homes}}$$

Homes' devices schedules

subject to:

$$\forall h_i \in \mathbf{H}, R_p^{[t_a \to t_b]} \in \mathbf{R}_i : \quad \xi_{\Phi_p}^{[t_a \to t_b]} \models R_p^{[t_a \to t_b]}$$

All device scheduling rules must be satisfied

DCOP mapping

SBDS	**DCOP**
A home $h_i \in \mathcal{H}$.	Agent $a_i \in \mathcal{A}$
A device z_j (in building h_i)	Variable $x_i \in \mathcal{X}$ (controlled by a_i)
Action j for device z_j.	j-th value in domain D_i of variable x_i
Schedule costs for a device z_j	Local soft constraint
Device scheduling feasibility	Local hard constraint
Energy peak consumption	Global soft constraint

Physical Models

- House structural parameters
- Smart Devices
  - Sensors
  - Actuators
- Battery models
- Air Temperature Model
- Water temperature model
- Cleanliness model
- …

Physical Model (homes)

FIG. 2: Floor plans for a small (left), medium (center), and large (right) house.

Structural Parameters	small	medium	large	Structural Parameters	small	medium	large
house size (m)	6×8	8×12	12×15	U_{roof} (W/(m^2 °C))	1.1	1.1	1.1
walls area (m^2)	67.2	96	129.6	lights energy density (W/m^3)	9.69	9.69	9.69
window area (m^2)	7.2	10	16	background load (kW)	0.166	0.166	0.166
U_{walls} (W/(m^2 °C))	3.9	3.9	3.9	background heat gain (W)	50	50	50
U_{windows} (W/(m^2 °C))	2.8	2.8	2.8	people heat gain (Btu/h)	400	400	400

Battery Models

	Tesla Model S			iRobot Roomba 880
	Slow Charge	Regular Charge	Super Charger	
V_b	240	240	240	120
E_b	354 Ah	354 Ah	354 Ah	3 Ah
C^+	48 A	72 A	500 A	1.25 A
C^-	60 A	60 A	60 A	0.75 A
b_α^+	7 hr 22 min	5 hr	43 min	2 hr 24 min
b_α^-	6 hr	6 hr	6 hr	4 hr

Dataset

- 624 instances of increasing difficulty.
- Homes of 3 sizes (small, medium, large)

City	Density (km^2)
Dos Moines, IA	718
Boston, MA	1357
San Francisco	3766

Parameters	
Homes	[7, 7523]
Coalitions	[1, 1024]
Devices per home	[4, 20]
Rules	> above
Horizon	12

- We provide our instance generator! Allows different horizons.

Dataset

$\langle location \rangle$	$\langle state\ property \rangle$	$\langle relation \rangle$	$\langle goal\ state \rangle$	$\langle time \rangle$
Room	*air temperature*	$r \in \{>, \geq\}$	$g_1 \in [17, 24]$	$\langle time \rangle$
Room	*floor cleanliness*	$r \in \{>, \geq\}$	$g_2 \in [50, 99]$	$\langle time \rangle$
Electric Vehicle	*charge*	$r \in \{>, \geq\}$	$g_3 \in [50, 99]$	$\langle time \rangle$
Water heater	*temperature*	$r \in \{>, \geq\}$	$g_4 \in [15, 40]$	$\langle time \rangle$
Clothes Washer	*laundry wash*	$r \in \{\geq\}$	$g_5 \in \{45, 60\}$	$\langle time \rangle$
Clothes Dryer	*laundry dry*	$r \in \{\geq\}$	$g_6 \in \{45, 60\}$	$\langle time \rangle$
Oven	*bake*	$r \in \{=\}$	$g_7 \in \{60, 75, 120, 150\}$	$\langle time \rangle$
Dishwasher	*dish cleanliness*	$r \in \{\geq\}$	$g_8 \in \{45, 60\}$	$\langle time \rangle$

TABLE 6: Scheduling (active) rules

$\langle location \rangle$	$\langle state\ property \rangle$	$\langle relation \rangle$	$\langle goal\ state \rangle$	$\langle location \rangle$	$\langle state\ property \rangle$	$\langle relation \rangle$	$\langle goal\ state \rangle$
Room	*air temperature*	$\geq$	0	*EV*	*charge*	$\leq$	100
Room	*air temperature*	$\leq$	33	*Water heater*	*temperature*	$\geq$	10
Room	*floor cleanliness*	$\geq$	0	*Water heater*	*temperature*	$\leq$	55
Room	*floor cleanliness*	$\leq$	100	*Clothes Washer*	*laundry wash*	$\leq$	g_5
Roomba	*charge*	$\geq$	0	*Clothes Dryer*	*laundry dry*	$\leq$	g_6
Roomba	*charge*	$\leq$	100	*Oven*	*bake*	$\leq$	g_7
EV	*charge*	$\geq$	0	*Dishwasher*	*dish cleanliness*	$\leq$	g_8

TABLE 7: Scheduling (passive) rules

Dataset

- Upper bounds for all the instances released.
- Uncoordinated approach.
- Communication and coordination of the MAS is implemented via the JADE framework.
- Each agent uses an internal CP solver (JaCoP) to solve its local scheduling problem.
- More on this on Thursday - Session 4D

14:30-16:10 Novel Applications in Smart Grids and Mobility

Smart devices

A Raspberry PI with a dangle

Conclusions

- Distributed Constraint Optimization – great potential, very exciting era.
- Review DCOP assumptions – need for realistic benchmark.
- Smart Home Device Scheduling Problem as a DCOP.
- New dataset for SHDS problems – available to the community

https://github.com/nandofioretto/SHDS_dataset

References:

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Fig. 2: goo.gl/dqwUz2
Fig. 3: goo.gl/WFzMhv

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Thank You!

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