A Preliminary Study on Preference Elicitation in DCOPs for Scheduling Devices in Smart Buildings

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Home Automation

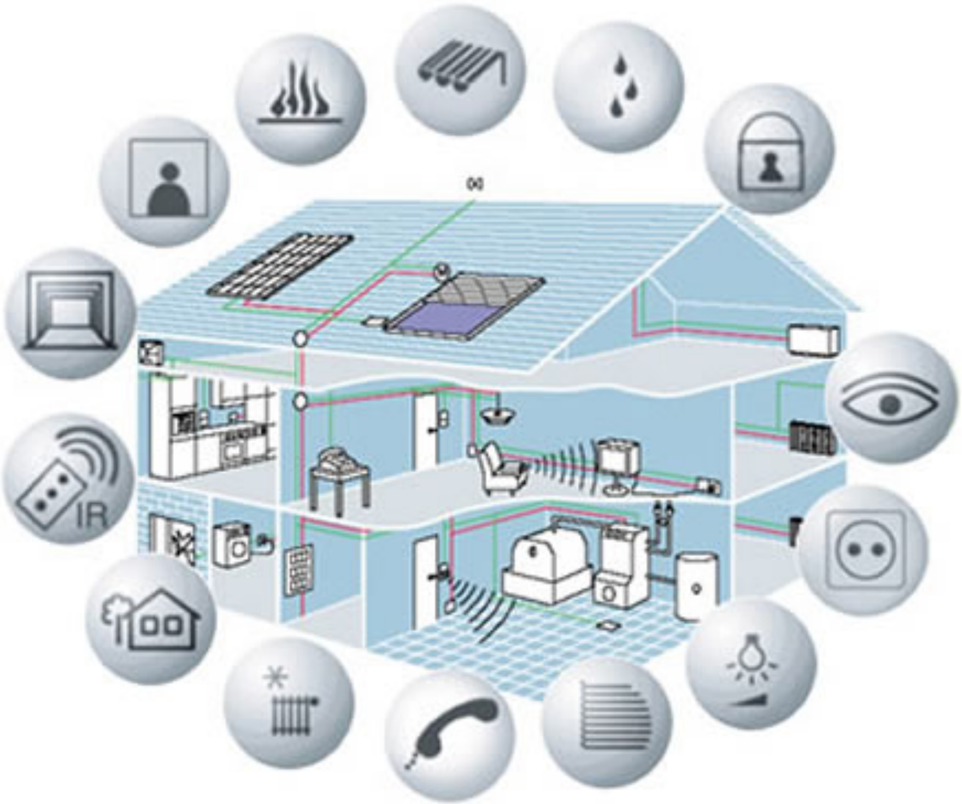


Fig.1

Fig.2

The culture of impatience

Fig.3

Fig.4

Fig.5

Network of smart buildings

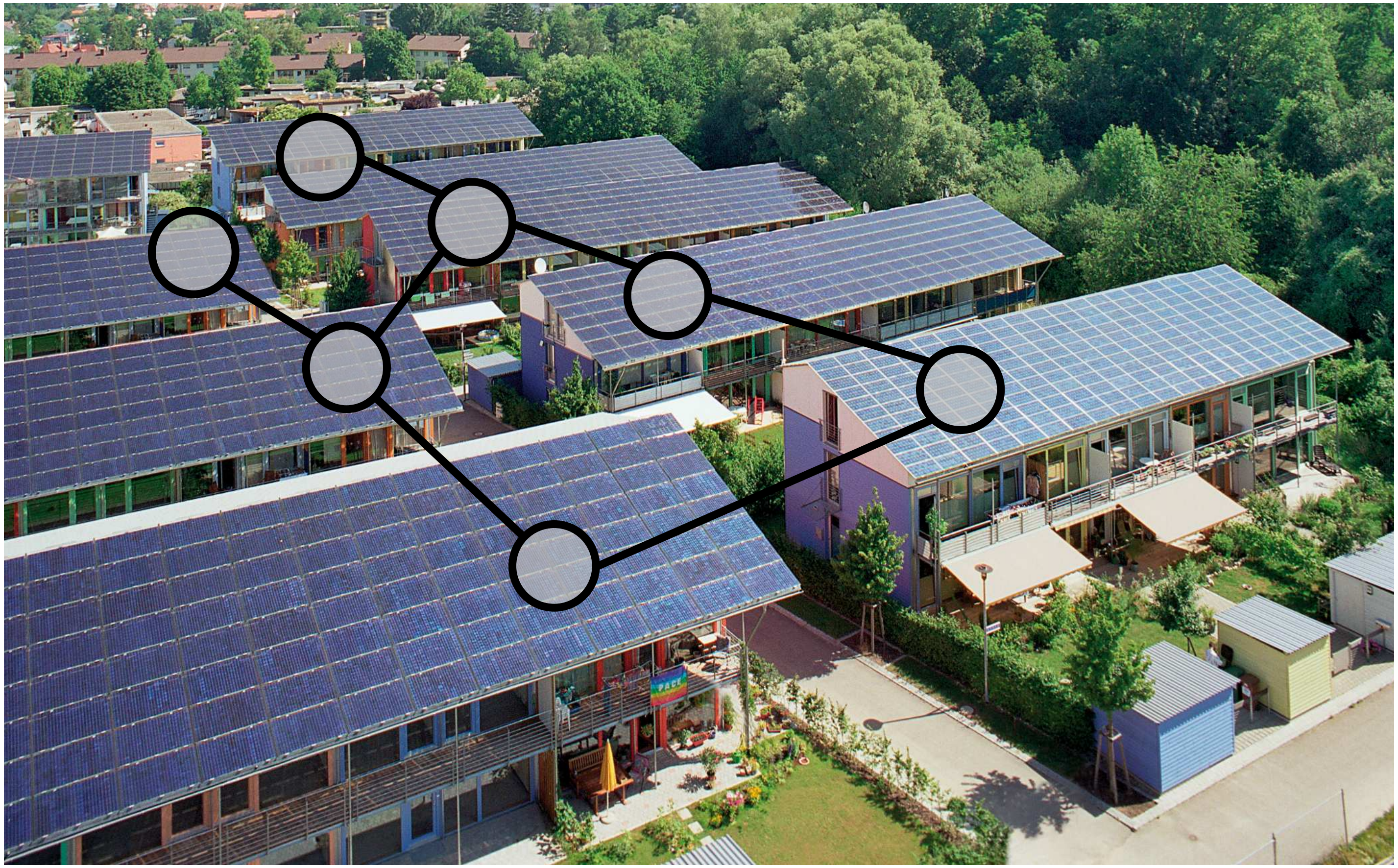


Fig.6

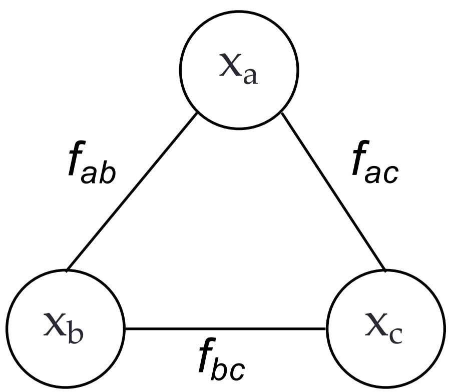
Outline

- Background (DCOPs)
- Smart Building Device Scheduling (SBDS)
- Preference Elicitation in DCOPs
- Preliminary Results
- Conclusions and Future work

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.

$$\begin{aligned} \mathbf{x}^* &= \arg\min_{\mathbf{x}} \mathbf{F}(\mathbf{x}) \\ &= \arg\min_{\mathbf{x}} \sum_{f \in \mathcal{F}} f(\mathbf{x}|_{\mathrm{scope}(f)}) \end{aligned}$$

DCOP: Assumptions

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

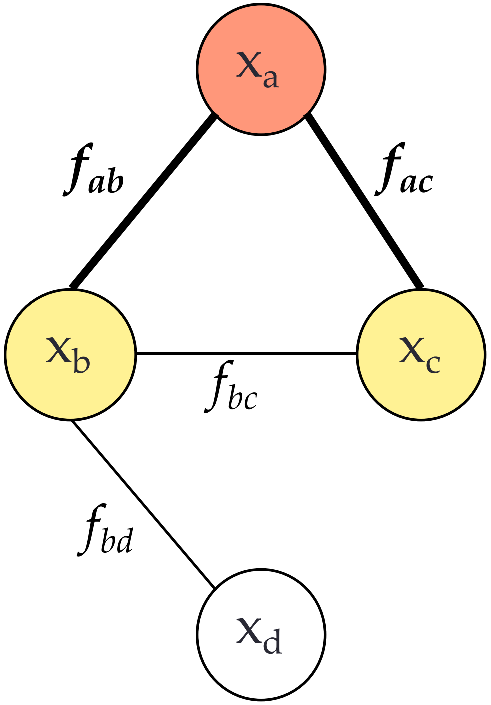
Communication:

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

Knowledge:

- Restricted to agent's sub-problem.

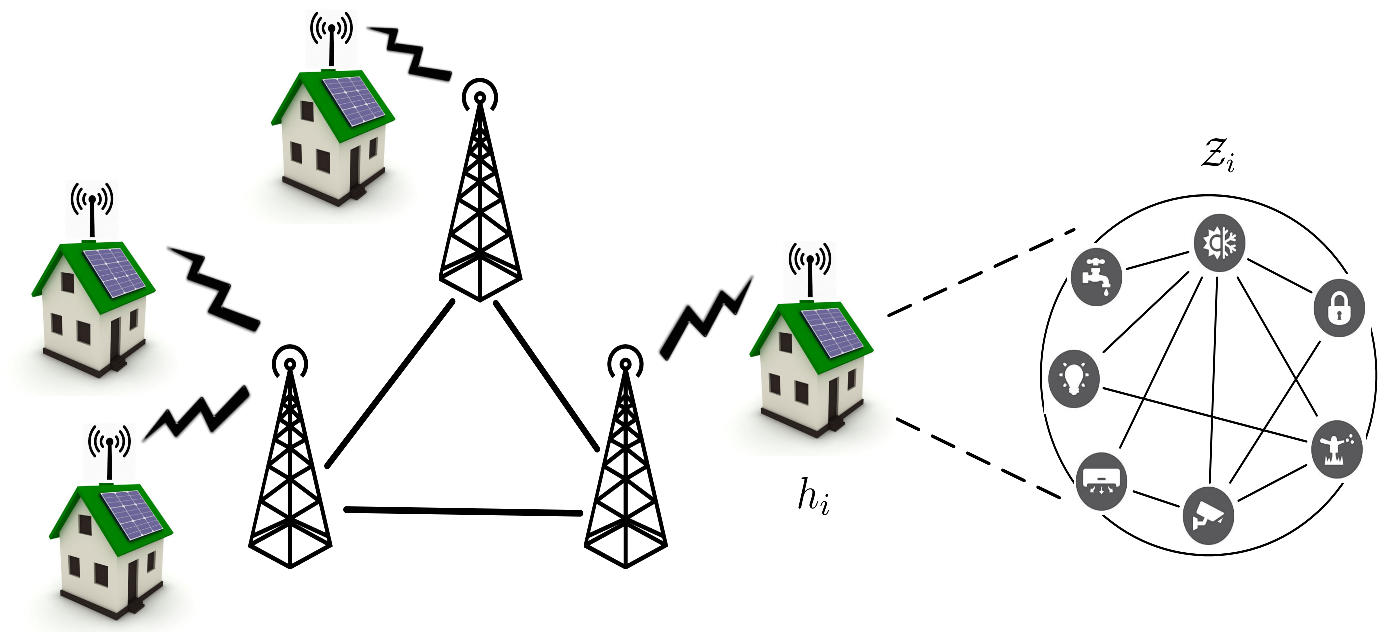
- Privacy preserving.



Smart Building Device Scheduling (SBDS)

A **SBDS** problem is composed of:

- $\mathcal{H}$: A neighborhood of smart buildings.
- $\mathcal{Z}_i$: A set of smart electric devices within each building h_i.
- H: A time horizon for the device scheduling.



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Device	Power (kWh)	Duration (min.)
dish washer	0.75	120
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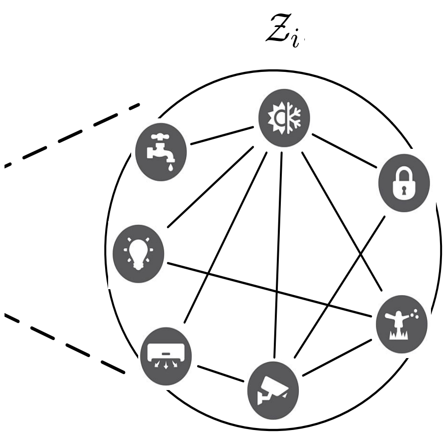
desktop computer	0.30	180
vacuum cleaner	1.20	30
fridge	0.30	360
electrical vehicle	3.50	180



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- H: A time horizon for the device scheduling.
- θ : A pricing function expressing cost per kWh of energy consumed.

Time (min.)	[0-60]	[60-120]	[120-180]	[180-240]	[240-300]	[300-360]
RTP ($/kWh)	0.172	0.161	0.191	0.145	0.149	0.174

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- H: A time horizon for the device scheduling.
- θ : A pricing function expressing cost per kWh of energy consumed.

Preferences:
users express their discomfort for scheduling a device at a given time.

Smart Building Device Scheduling (SBDS)

- SBDS objective:

$$\textbf{minimize} \quad \sum_{t \in \mathbf{T}} \sum_{h_i \in \mathcal{H}} \alpha_c \cdot \overbrace{C_i^t}^{\text{monetary cost of } h_i \text{ schedule at time t}} + \alpha_u \cdot \underbrace{U_i^t}_{\text{discomfort for the } h_i \text{ schedule at time t}}$$

subject to:

$$1 \leq s_{z_j} \leq T - \delta_{z_j} \qquad \forall h_i \in \mathcal{H}, z_j \in \mathcal{Z}_i$$

$$\sum_{t \in \mathbf{T}} \phi_{z_j}^t = \delta_{z_j} \qquad \forall h_i \in \mathcal{H}, z_j \in \mathcal{Z}_i$$

$$\sum_{h_i \in \mathcal{H}} P_i^t \leq \ell^t \qquad \forall t \in \mathbf{T}$$

Smart Building Device Scheduling (SBDS)

- SBDS objective:

$$\textbf{minimize} \sum_{t \in \mathbf{T}} \sum_{h_i \in \mathcal{H}} \alpha_c \cdot C_i^t + \alpha_u \cdot U_i^t$$

subject to:

start time

duration

$$1 \leq s_{z_j} \leq T - \delta_{z_j} \qquad \forall h_i \in \mathcal{H}, z_j \in \mathcal{Z}_i$$

$$\sum_{t \in \mathbf{T}} \phi_{z_j}^t = \delta_{z_j} \qquad \forall h_i \in \mathcal{H}, z_j \in \mathcal{Z}_i$$

Device scheduling feasibility

$$\sum_{h_i \in \mathcal{H}} P_i^t \leq \ell^t \qquad \forall t \in \mathbf{T}$$

Maximum total load limit

h_i load at time t

DCOP mapping

SBDS	DCOP
A building $h_i \in \mathcal{H}$.	Agent $a_i \in \mathcal{A}$
Start time s_{zj} for a device z_j (in building h_i)	Variable $x_i \in \mathcal{X}$ (controlled by a_i) with domain $D_i = \{1,..,H\}$
Schedule costs for a device z_j	Local soft constraint
Schedule preferences for z_j	Local soft constraint
Device scheduling feasibility	Local hard constraint
Maximum total power limit	Global hard constraint

Preference Elicitation in DCOPs

- DCOP assumption: Cost tables are known a priori.
- Unrealistic assumption in SBDS!
- User populated cost tables expressing preferences for each device schedule.
- Lots of devices!

Preference Elicitation in DCOPs

How to effectively elicit user's preferences asking a few questions?

- Ask for the user's input.
- Use historical data.

Preference Elicitation in DCOPs

If we could ask only k questions,

which k cost tables should be asked for user elicitation?

Preference Elicitation in DCOPs

- Uncertain DCOP: $\hat{\mathcal{P}} = \langle \mathcal{X}, \mathcal{D}, \hat{\mathcal{F}}, \mathcal{A}, \alpha \rangle$

where: $\hat{\mathcal{F}} = \overbrace{\mathcal{F}_r}^{\text{revealed cost tables (by the user)}} \cup \underbrace{\mathcal{F}_u}_{\text{uncertain cost tables (estimated from historical data)}}$

revealed cost tables (by the user)

uncertain cost tables (estimated from historical data)

x_a	x_b	cost
0	0	3
0	1	1
1	0	2
1	1	5

Scalars

x_a	x_b	cost
0	0	$\mathcal{N}(\mu_0, \sigma^2_0)$
0	1	$\mathcal{N}(\mu_1, \sigma^2_1)$
1	0	$\mathcal{N}(\mu_2, \sigma^2_2)$
1	1	$\mathcal{N}(\mu_3, \sigma^2_3)$

Random variables

Preference Elicitation in DCOPs

- Oracle DCOP: $\mathcal{P} = \langle \mathcal{X}, \mathcal{D}, \mathcal{F}, \mathcal{A}, \alpha \rangle$
  - $\mathcal{F}$ = accurate cost tables.
  - Costs are sampled from the corresponding distributions of the uncertain tables.

x_a	x_b	cost		cost
0	0	3	←	$\mathcal{N}(\mu_0, \sigma^2{}_0)$
0	1	1	←	$\mathcal{N}(\mu_1, \sigma^2{}_1)$
1	0	2	←	$\mathcal{N}(\mu_2, \sigma^2{}_2)$
1	1	5	←	$\mathcal{N}(\mu_3, \sigma^2{}_3)$

samples

Random variables

Preference Elicitation in DCOPs

- Given an oracle DCOP P and a value $k \in \mathbb{N}$, construct an uncertain DCOP $\hat{\mathcal{P}}$ that reveals exactly k constraints per agent, minimizing the error:

$$\epsilon_{\hat{\mathcal{P}}} = \mathbb{E}\left[\left|\mathbf{F}_{\hat{\mathcal{P}}}(\underbrace{\hat{\mathbf{x}}^*}_{\text{optimal solution for a realization of } \hat{\mathcal{P}}}) - \mathbf{F}_{\mathcal{P}}(\overbrace{\mathbf{x}^*}^{\text{optimal solution for the oracle DCOP } \mathcal{P}})\right|\right]$$

Preference Elicitation in DCOPs

- Given an oracle DCOP P and a value $k \in \mathbb{N}$, construct an uncertain DCOP $\hat{\mathcal{P}}$ that reveals exactly k cost tables per agent, minimizing the error:

$$\epsilon_{\hat{\mathcal{P}}} = \mathbb{E}\left[\left|\mathbf{F}_{\hat{\mathcal{P}}}\underbrace{(\hat{\mathbf{x}}^*)}_{\text{optimal solution for a realization of } \hat{\mathcal{P}}} - \mathbf{F}_{\mathcal{P}}\overbrace{(\mathbf{x}^*)}^{\text{optimal solution for the oracle DCOP } \mathcal{P}}\right|\right]$$

- Challenge: there are $\binom{|\mathcal{F}|}{k\cdot|\mathbf{A}|}$ possible uncertain DCOPs.
- Solving each DCOP is NP-hard.
- We propose 5 heuristics to construct an uncertain DCOP.

Preference Elicitation Heuristics

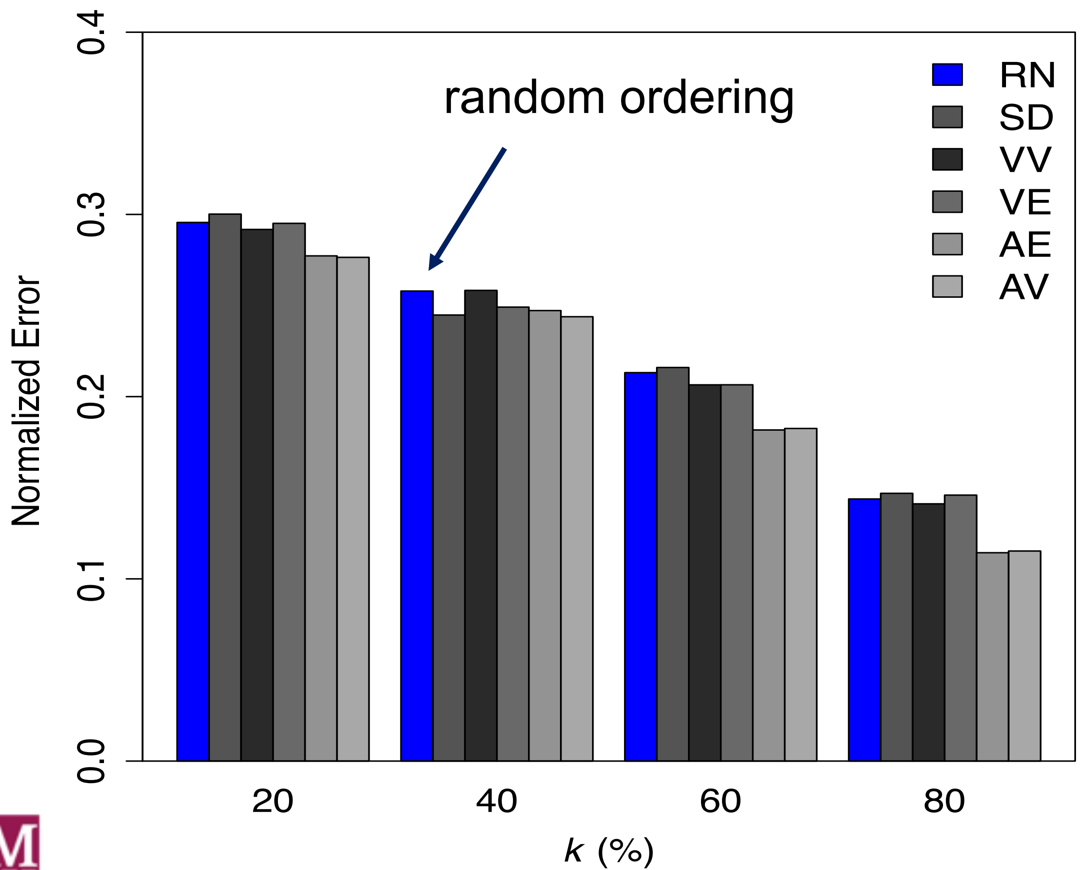
Goal: Elicit the first k cost tables, according to an ordering $\succeq_\circ$.

Heuristics to enforce an **ordering over cost tables**:

- $\geq_{[AE]}$ Average of the expected costs of the uncertain constraints.
- $\geq_{[AV]}$ Average of the variance of the uncertain constraints.
- $\geq_{[VE]}$ Variance of the expected costs of the uncertain constraints.
- $\geq_{[VV]}$ Variance of the variance of the uncertain constraints.
- $\geq_{[SD]}$ Second-order stochastic dominance: Takes into account the notion of the risk.

Evaluation

- Analysis of $\epsilon_{\hat{\mathcal{P}}}$ at the increasing of the cost tables to elicit *(k)*.
- 50 realizations of the uncertain DCOP.
- Results are averaged over 50 oracle DCOPs.



Settings:

- $|\mathcal{H}| = 10$
- $|\mathcal{Z}\_i| = 10$
- H = 12 (step = 30 min)
- Preferences sampled from $\mathcal{N}(\hat{\mu}, \hat{\sigma}^2)$

$\hat{\mu}$ sampled in [1, 100]
$\hat{\sigma}^2$ sampled in $[1, \frac{\sqrt{\hat{\mu}}}{2}]$

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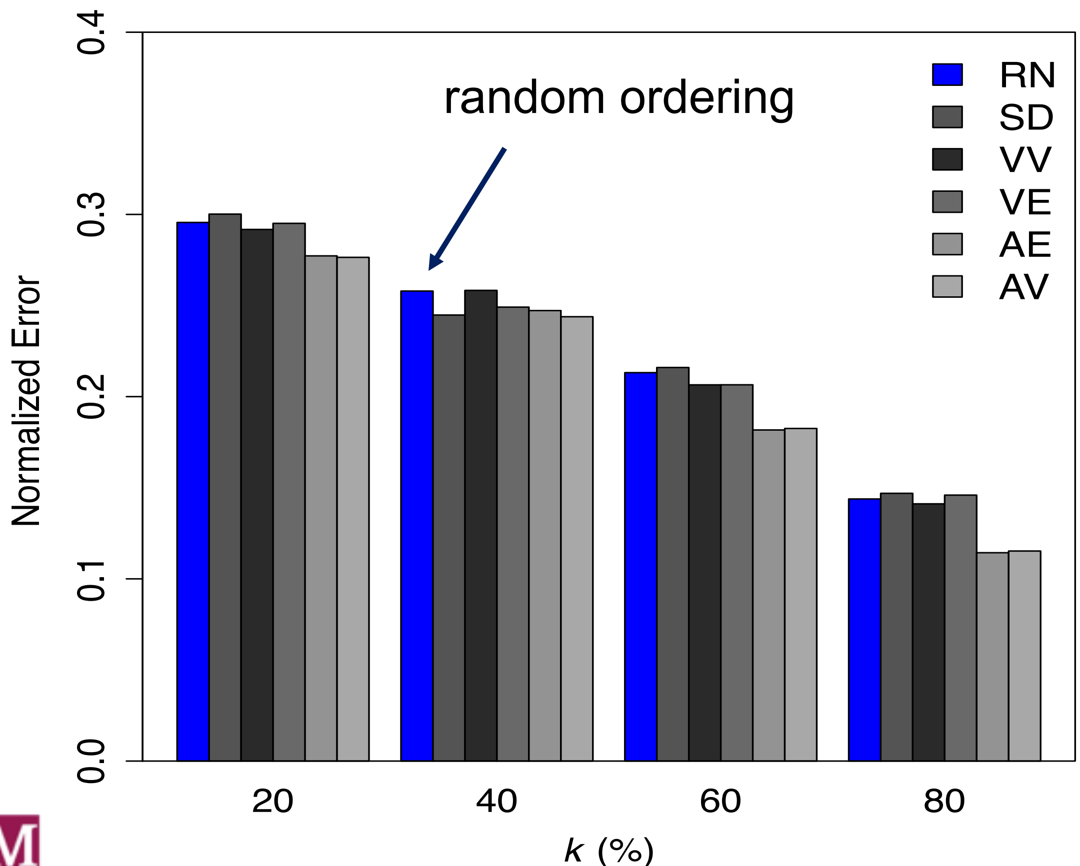

Main Results:

1. The error decreases as the k increases.

2. AE and AV outperform other heuristics.

Conclusions and Future Work

- We studied the effect of preference elicitation in scheduling smart appliances within a network of interconnected buildings.
- We propose the SBDS problem and cast it as a DCOP.
- We propose 5 heuristics to select a subset of cost tables to elicit.
- Preliminary results:
  - Our best heuristics are more accurate than a baseline method.
- Future work:
  - More extensive analysis of our methods.
  - More realistic setting for the SBDS agents.

Thank You!

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References:

Fig. 1: http://goo.gl/5znqip
Fig. 2: goo.gl/dqwUz2
Fig. 3: goo.gl/daWjOP
Fig. 4: goo.gl/CeWvSn
Fig. 5: goo.gl/afyUXV
Fig. 6: goo.gl/WFzMhv

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Preference Elicitation Heuristics (extra)

- $\geq_{[SD]}$ Second-order stochastic dominance:

$f_i \geq_{[SD]} f_j$ *iff:*

$$\sum_{m=1}^{|\Sigma_{\mathbf{x}}^{f_i}|} (f_i(m) - f_j(m)) \geq 0$$

where $f_i(m)$ is the expected cost of the m-th value assignment for the variables in the scope of f_i.

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