Optimal IoT control in Smart Homes

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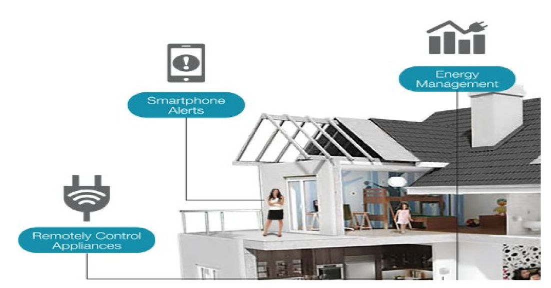
Introduction and Motivation

Goal

- To design an intuitive dishwasher that can be activated at an optimal time during the day via voice command through Amazon Echo Dot.



Smart Home architecture

Negative Prices

- Happens when electricity supply is greater than the demand.
- Customers are actually being paid to use electricity during the negative priced hours

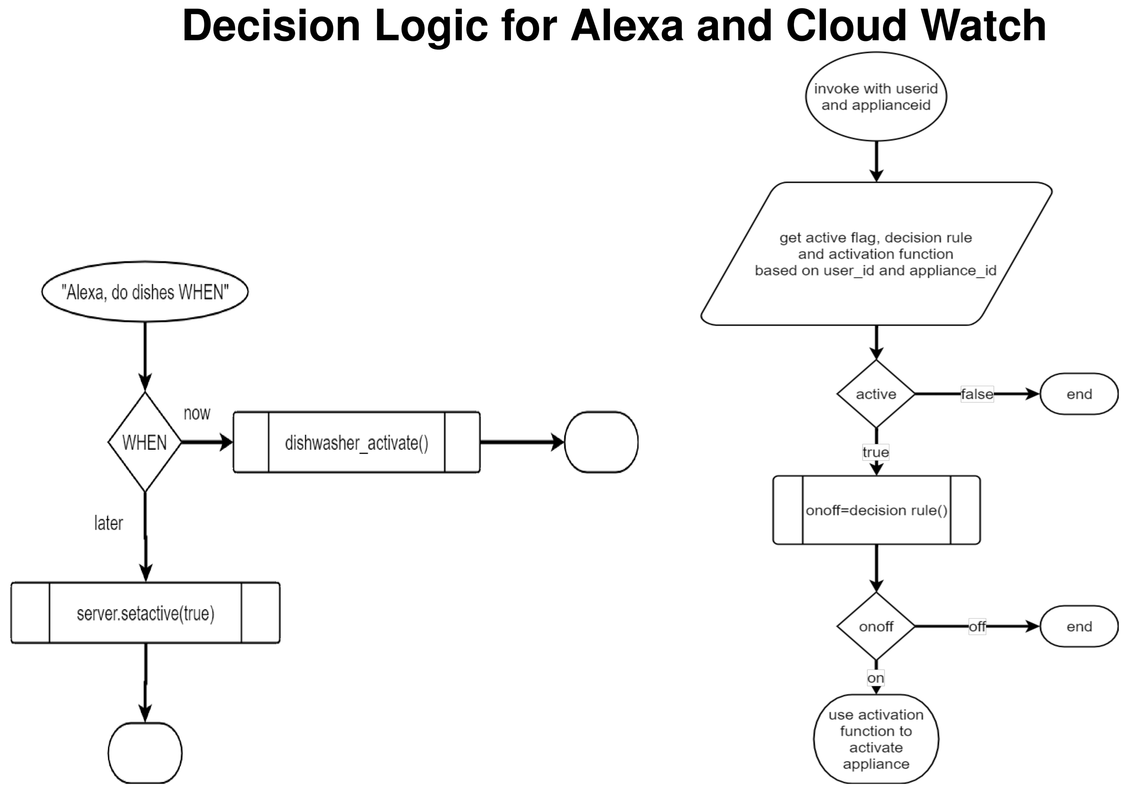
Negative Prices observed May 14, 2017

System Components and Implementation

Setup Components

Amazon Echo Dot | Particle Photon | Dishwasher | Front Panel Connection

Decision Logic for Alexa and Cloud Watch

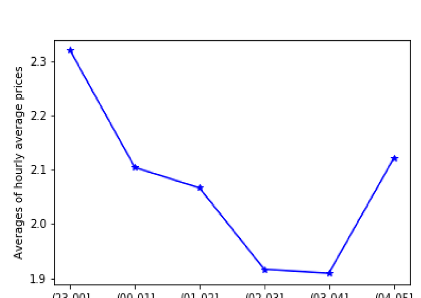


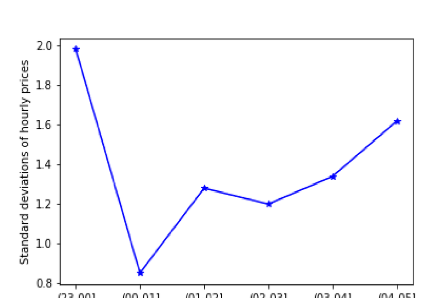
Alexa, Cloud Watch Server architectures resp.

Price Modeling

Trade off

Mean price is low around 4 AM, but the variance is also large at that time.





Some Notations

- $\bar{P}$ - Retroactive averages for any usage in time interval (t-60, t]

$$\bar{P} = \frac{1}{12}\sum_{i=0}^{11} P_{t-5i}$$

- $T_{runtime}$ - Cycle running time for the appliance
- δ - $\frac{1}{12}$ (5 minutes)
- Δ - 24 (a days' worth of time)
- T_{min} = 1, T_{max} = 5 (Activate time between 11 PM and 5 AM)
- $N = \{T_{min}, T_{min}+1 \dots T_{max}\}$
- D_c - No. of days in the past to train policies

Argmin Policy

- Find the most frequented times of least prices from the past.
- d days ago, τ_d was the cheapest time:

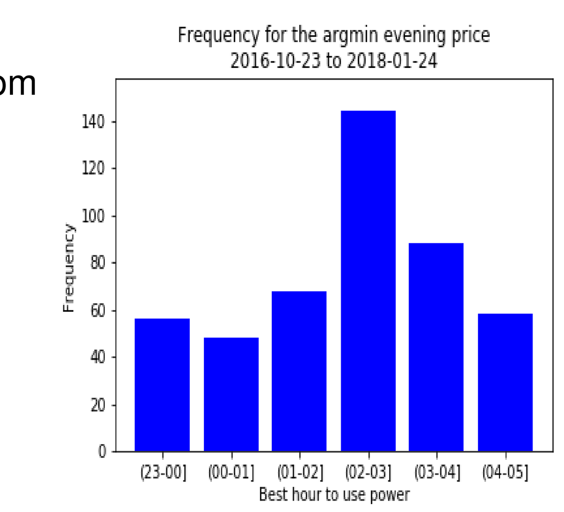
$$\tau_d = argmin\{\bar{P}_{n-\Delta d} : n \in N\}$$

- Frequency count of the τ_d's:

$$F_n = \frac{1}{D_c}\sum_{d=1}^{D_c} 1_{\{\tau_d = n\}}$$

- Activate the appliance if

$$F_n = \max\{F_{n'} : n' \in \{n, n+1 \dots T_{max}\}\}$$



Histogram for the Argmin prices

Hybrid Model

- Optimal time to decide activation = $\delta J_{maxinfo}$ where:

$$J_{maxinfo} = \left\lceil \frac{1 - T_{runtime}}{\delta} \right\rceil - 1$$

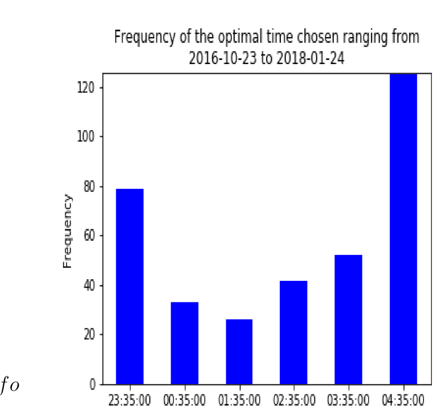
- Decision Interval:

$$D_n = (n - 1 + \delta J_{maxinfo}, n - T_{runtime})$$

- Seasonality using historical averages:

$$\bar{P}_n^H = \frac{1}{D_c}\sum_{d=1}^{D_c} \bar{P}_{n-\Delta d}$$

- Initial Regression:
  - Known spot prices for current hour $\{P_{n-1+j\delta}\}_{1 \le j \le J_{maxinfo}}$
  - Historical averages ($\bar{P}_n^H$)
- Hourly Regression:
  - Prior 5-minute spot price (P_{n-1})
  - Historical averages ($\bar{P}_n^H$)

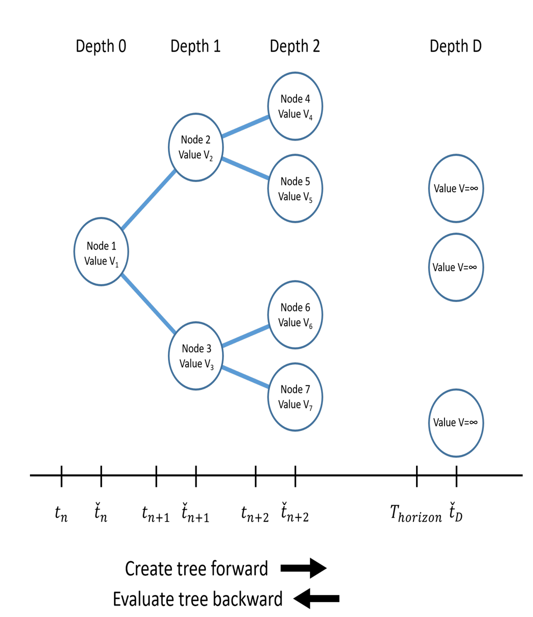


Optimal policy times

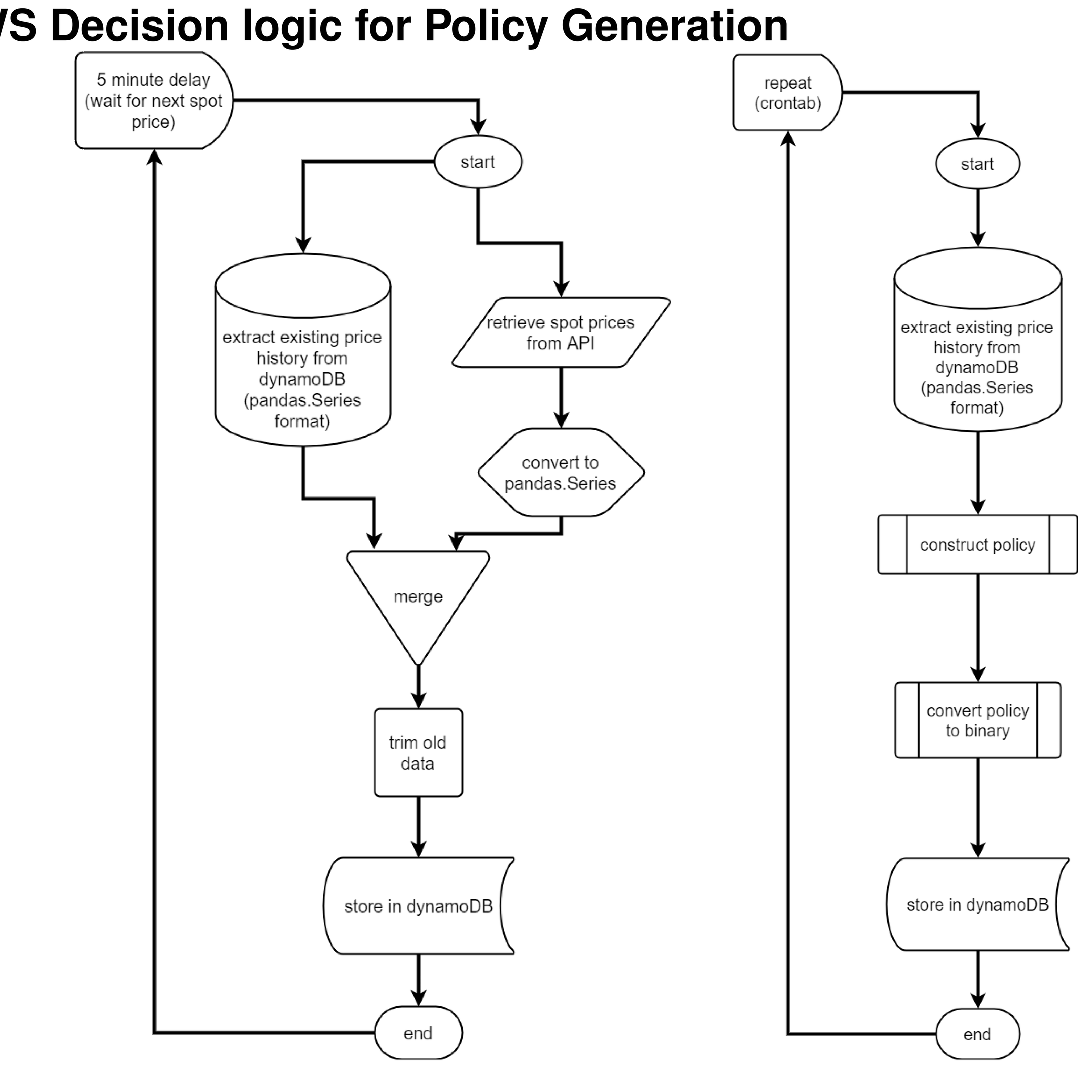
Optimal Stopping Policy

- Constructed: Forward Direction
- Evaluated: Backward Direction.
- The Exercise price ($\bar{P}_n^E$) of consuming energy is computed at each of the future nodes.
- Continuation value (V_n) = ∞ at end node.
- Continuation value $V_n = E[\bar{P}_{n+1}^E \wedge V_{n+1}]$ for $n < T_{max}$.
- Optimal Time: Exercise Price < Continuation Price:

$$\tau^* = Min\{n : \bar{P}_n^E < V_n\} \text{ where } V = E[\bar{P}_{\tau^*}^E]$$



AWS Decision logic for Policy Generation



Data Management and Policy Generation architecture resp.

Project Impact and Results

Economic Impact

- WiFi accessible with inexpensive and fast installation
- Can be extended to any electrical appliance with a switch leading to energy savings
- Can Establish a "Smart Grid" preventing overloading and power outages.
- Particle Photon: $\$19$, Relay Shield: $\$30$, Lifetime Electricity Savings
- Results when back tested on a year's data:

	Mean (average prices)	Mean (policy prices)	Average Savings
Argmin Policy	2.04873	1.86045	9.2 %
Optimal Policy	2.04873	1.83445	10.5 %

Table 1: *Savings from the Argmin and Optimal Stopping policies in a single cycle*

Future Research

Extensions

- Implementation and comparison of Machine Learning models predicting price patterns
- Inclusion of consumer demand and weather conditions as well for the forecast

Acknowledgements

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