Energy Aware Consolidation for Dynamic Resource Applications

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Overview

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Introduction

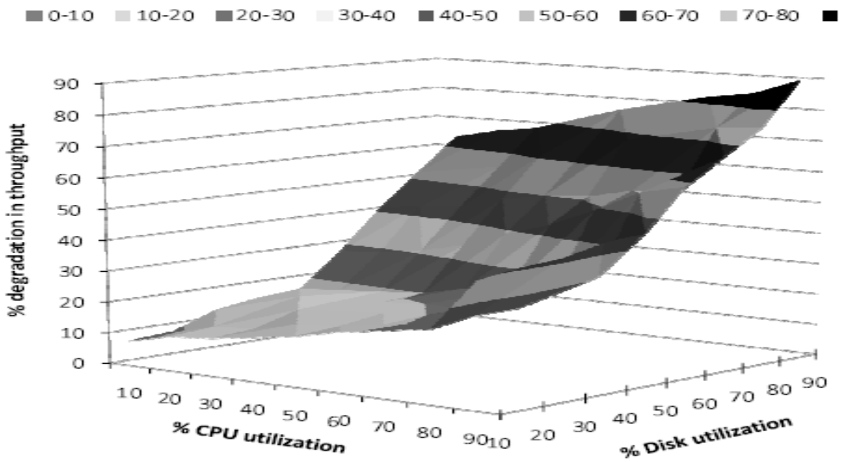
- The goal is to find an method for allocating client applications on a set of common servers in a manner that minimizes energy used.
- The method proposed is an extension of the one described in the original paper *Energy Aware Consolidation in Cloud Computing*
- The original method is limited to allocating applications with static resource utilizations.
- Our extended method is capable of allocating applications with dynamic resource footprint.

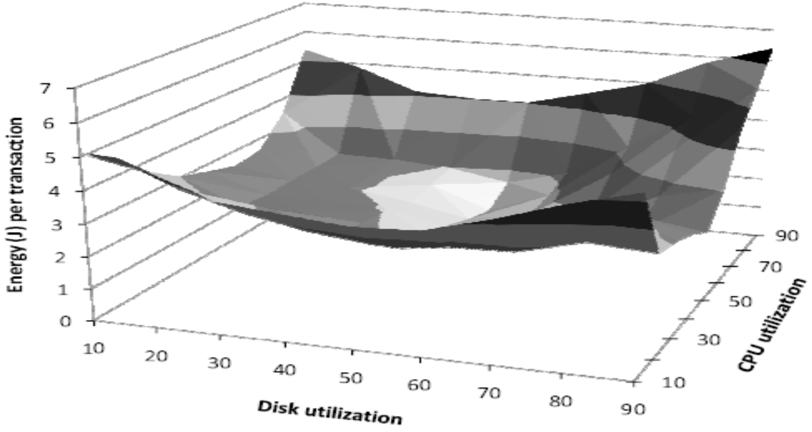
What is Energy Aware Consolidation?

- Running many dissimilar client applications on the same server cluster.
- In other words running multiple data center applications on a common set of servers.
- This allows for the consolidation of application workloads on a smaller number of servers that may be kept better utilized.

Original Paper Review (cont'd)

- Effective consolidation is not as trivial as packing the maximum workload in the smallest number of servers.
- Keeping resources at 100% utilization is not energy efficient.
- Goal is to minimize the energy used per unit service.
- Energy optimal resource point (vector) is 50% hard disk, and 70% cpu utilization.





- The allocation method is almost identical that the method proposed in the original paper, except for the *.

1. For each server type, the server is subjected to various client application workloads in order to obtain Energy consumption data. From this data we obtain:
    a. the Energy vs. resource utilization relationship for the server(s).
    b. the Energy optimal resource point. ex) [70%, 50%]
    c. * the Energy vs. resource usage relationship for the applications.
        i. either tabulated data or function.
2. * Allocate incoming client applications according to the Dynamic Allocation Algorithm.

Notation

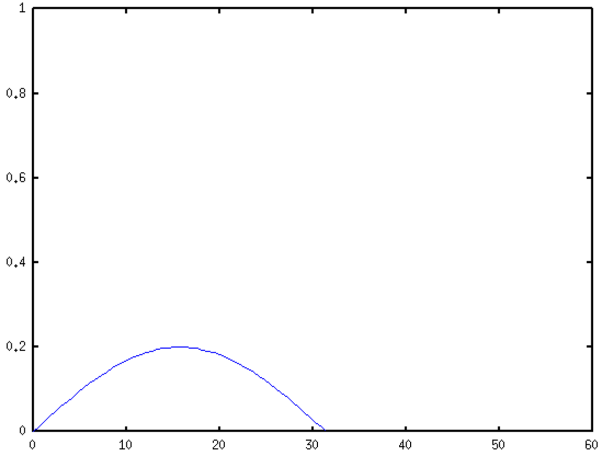
- Resource utilization and consumption by servers and client applications are conveyed with resource vectors.
  - ex) 50% CPU utilization and 50% Hard Disk utilization would be written (0.5,0.5) = **r**
- Distance between two resource points is given by the euclidean distance $\delta_e = \sqrt{(x_1^2 + x_2^2 + .. + x_n^2)}$
  - ex) $\mathbf{r}_1 = (0.3,0.8)$, $\mathbf{r}_2 = (0.7,0.5)$, $\delta_e(\mathbf{r}_2 - \mathbf{r}_1) = \sqrt{((0.7 - 0.3)^2 + (0.5 - 0.8)^2)} = 0.5$
- **r**(t) indicates a resource vector is dependent on time.
- max{ **r**(t) } returns a set of resource vector points that are local maxima.
- **s***=(0.7,0.5) = optimal resource vector for server s.
- | . | , is the cardinality of set, it give the number of elements in the set.

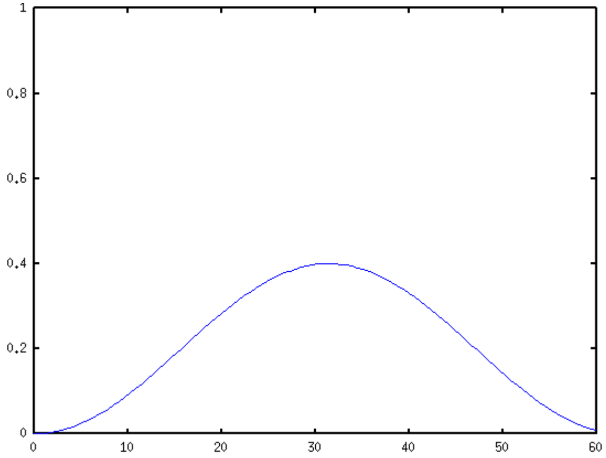
- Consider a workload **W**, and a set of servers **S** the allocated the algorithms as follows.

Dynamic Allocation Algorithm

1. Let score[s] be a map of mean distances of maxima for a server.
2. Foreach client application w in **W**
   a. Foreach server s in **S**
      i. Compute max{s} ∪ max{w} = max_set
      ii. Foreach t in max_set
         1. IF $\mathbf{r}_s(t) + \mathbf{r}_w(t) <= \mathbf{s}^*$ THEN score[s] += $\delta_e(\mathbf{s}^* - (\mathbf{r}_s(t) + \mathbf{r}_w(t)))$
         2. ELSE remove s from score and break.
      iii. score[s] /= |s|
   b. Assign w to the maximum scoring server.

- We have a workload consisting of two applications with resource utilizations of the following form:
  - App 1 has a resource relationship given on the right.
    - The app has a maxima at t = 16 and resource utilization of $\mathbf{r}_1$
  - App 2 has a resource relationship given on the right
    - The app has a maxima at t = 31 and resource utilization of $\mathbf{r}_2$
- The graphs are for both CPU and HD utilization vs. time for each application.





Dynamic Allocation Algorithm Example Part 2

- Assume we have two servers, A and B that are idling at 10% utilization, so $\mathbf{s}_a$ =(0.1,0.1), $\mathbf{s}_b$ =(0.2,0.2).
  - Both servers has optimal resource $\mathbf{s}^*(t)$ =(0.7,0.5)
- First we compute the max_set for $\max\{\mathbf{s}_a\} \cup \max\{\mathbf{r}_1\} = \{t=16\}$
- Now we check if the $\mathbf{r}_1(t=16) + \mathbf{s}_a(t=16) < \mathbf{s}^*(t)$, (0.2,0.2) + (0.1,0.1) < (0.7,0.5)
- Next we add the euclidean distance between the target
  - $\delta_e(\mathbf{s}_a(t) + \mathbf{r}_1(t), \mathbf{s}^*(t)) = \sqrt{(0.3 - 0.7)^2 + (0.3 - 0.5)^2} = 0.447$ -> score[$\mathbf{s}_a$]
  - $\delta_e(\mathbf{s}_b(t) + \mathbf{r}_1(t), \mathbf{s}^*(t)) = \sqrt{(0.4 - 0.7)^2 + (0.4 - 0.5)^2} = 0.316$ -> score[$\mathbf{s}_b$]
- Now we assign the application to the server with largest score, which is $\mathbf{s}_a$.

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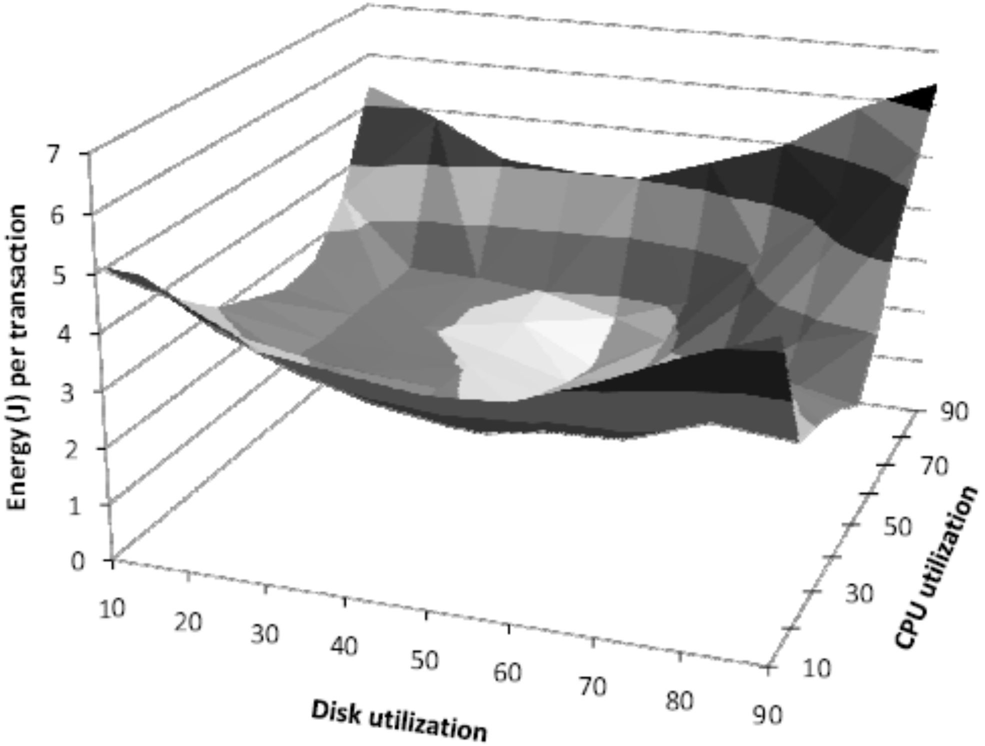
- In order to validate the algorithm, a simulation of the original experimental conditions was constructed.
- The simulation consists of four servers processing a workload of 8 client applications.
- The Power vs. resource utilization for the simulated servers was obtained from the Energy per transaction graph shown below.



Obtaining Power vs. Resource

- We want **Power** as a function of cpu and hard disk utilization.
- The original experiment gives data for the total energy used over a 60second period for constant utilizations.
- We use the thermodynamic relationship **Power** * **Time** = **Work**, and make the approximation that **Power** is dependent only on the utilization rates. This approx. is only true for small time intervals.
  - c = CPU utilization rate, and h = Hard Disk utilization rate.
- E(c,h) / N is given, and we know that P(c,h) * 60 = E(c,h)/N.
  Solving for P(c,h) yields P(c,h) = E(c,h) / (N * 60).
- The **Power** as a function of resource utilizations is critical for the simulation, since P(c,h) * dt = Energy used for the small time interval dt.

- Assumption:
  - Profiling data has already been obtained for all client applications.
  - All servers are homogenous with identical **Power** vs. resource relationship.
  - All servers are awake.
- Simulation Description:
  - Processing a workload consisting of dummy applications with variable resource utilizations.
  - At simulation start, the allocation algorithm begins delegating applications to each of the servers.
  - Server processing takes place in discrete time steps ~0.1 (ms).
    - The energy used during each timestep is calculated using
      - P(c,h) * (timestep), and added to the total.
  - The simulation concludes when the workload has been processed.

- The simulation was run for three allocation algorithms using a workloads of varying utilization functions.
  - Dynamic algorithm - algorithm for allocating applications with dynamic resource utilizations.
  - Original Algorithm - algorithm for allocating applications with static resource utilizations.
  - Optimal Algorithm - algorithm that allocates applications according to a aprior calculated ordering that is optimal. This is algorithm is used for validation only.

Simulation Results (cont'd)

- For a workload mix with a constant utilization of 180% CPU and 180% HD.
  - Original Algorithm ~ 4.12 [J/Op]
  - Dynamic Algorithm ~ 4.12 [J/Op]
  - Optimal Algorithm ~ 4.1 [J/Op]
- For a workload with mix of constant and sinusoidal utilizations.
  - Original Algorithm ~ 6.18 [J/Op]
  - Dynamic Algorithm ~ 4.5 [J/Op]

References

- Srikantaiah S et al. (2008). Energy aware consolidation for cloud computing. In: Proc of HotPower

Questions?