Introduction to Harmony Search Algorithm (HSA)

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Research Domain: Energy Management in Smart Grid
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Introduction

• Essential relationship between music and mathematics in ancient times
• An interesting connection found between optimization techniques and music in recent times
• Term harmony refers to sound result caused from two or more instruments play at the same time
• Harmony evaluates relationship between two or more sound waves
• Music inspired harmony based optimization algorithm
  • Harmony search algorithm (HSA) based on improvisation process of a skilled musician
• Proposed by Zong Woo Geem in 2001. [1]
• Music band improves rehearsal after rehearsal, HSA improves iteration after iteration

Introduction

- Pitch of each musical instrument determines the aesthetic quality
- Fitness function value determines the quality of the decision variables
- Music improvisation process
  - Musicians sound pitches within possible range
- If all pitches make a good harmony
  - Each musician store harmony in his memory
  - possibility of making a good harmony is increased next time
- In optimization
  - Initial solution generated randomly from decision variables is good
  - Possibility of good solution is increased next time
In the HSA, each musician (= decision variable) plays (= generates) a note (= a value) for finding a best harmony (= global optimum) all together.

<table>
<thead>
<tr>
<th>Comparison factor</th>
<th>Harmony improvisation</th>
<th>Optimization process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targets</td>
<td>Aesthetic standard</td>
<td>Objective function</td>
</tr>
<tr>
<td>Best states</td>
<td>Fantastic harmony</td>
<td>Global optimum</td>
</tr>
<tr>
<td>Components</td>
<td>Pitches of instruments</td>
<td>Values of variables</td>
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<tr>
<td>Process unit</td>
<td>Each practice</td>
<td>Each iteration</td>
</tr>
</tbody>
</table>
Musical improvisation

• Playing a note from the harmony memory
• Playing a note which is close to another one stored in memory
• Playing a random note from the possible range

Optimization

• New variable values are selected from the harmony memory
• Replaced new values with other values close to current values
• New variable values are randomly selected from the possible range
HSA Procedure

Basic steps: [2]

- **STEP 1**: parameter initialization
- **STEP 2**: initialize Harmony memory (HM)
- **STEP 3**: improvise new harmony
- **STEP 4**: update the HM
- **STEP 5**: repeat step 2-3 until a termination criteria reached.

HSA Steps (2/4)

• **Step 1: initialize the problem and algorithm parameters**
  • Harmony memory size (HMS): the number of solution vectors in the HM
  • Harmony memory considering rate (HMCR)
  • Pitch adjusting rate (PAR)
  • Stopping criteria

• **Step 2: initialize the HM**
  • The initial population HM contains of HMS vectors is generated randomly as follows:
    \[ X_{i,j} = l_j + \text{rand}() \cdot (U_j - l_j) \]
  • HM structure:
    \[
    HM = \begin{bmatrix}
    x_1^1, x_2^1, \ldots, x_n^1 \\
    x_1^2, x_2^2, \ldots, x_n^2 \\
    \vdots \\
    x_1^\text{HMS}, x_2^\text{HMS}, \ldots, x_n^\text{HMS}
    \end{bmatrix}
    \]
• **Step 3: improvise a new harmony:**
  - Involves three steps
    - **Memory consideration**
      - choosing any value from HM
      - Value of HMCR specify the probability of choosing value from historic values stored in HM
      - Typical values of HMCR are from 70% to 95%

---

```
for each \( i \in (1, N) \) do
  if \( \text{rand}(0,1) \leq \text{HMCR} \) then
    \( x'_i = x_q \) (\( j = 1, 2, ..., \text{HMS} \)) % memory consideration
    if \( \text{rand}(0,1) \leq \text{PAR} \) then
      \( x'_i = x'_i \pm \text{rand}(0,1) \times \text{bw} \) % pitch adjustment
    end if
  else
    \( x'_i = L_B_i + \text{rand}(0,1) \times (U_B_i - L_B_i) \) % random selection
  end if
end
```
HSA Steps (3/4)

Step 3: improvise a new harmony:

- Pitch adjustment
  - Every component of the new harmony chosen from HM, is likely to be pitch-adjusted.
  - similar to Mutation procedure in genetic algorithm
- Random selection
  - select a totally random value from the possible value range
  - Increase the diversity of the solutions

Harmony Search Improvisation

for each \( i \in (1,N) \) do

if \( \text{rand}(0,1) \leq \text{HMCR} \) then

\[ x_i' = x_i \quad (j=1,2,...,\text{HMS}) \quad \text{% memory consideration} \]

if \( \text{rand}(0,1) \leq \text{PAR} \) then

\[ x_i' = x_i \pm \text{rand}(0,1) \times \text{bw} \quad \text{% pitch adjustment} \]

end if

else

\[ x_i' = L_{B_i} + \text{rand}(0,1) \times (U_{B_i} - L_{B_i}) \quad \text{% random selection} \]

end if

end
Step 4: Update HM

- If new harmony vector is better than worst harmony, replace the worst harmony in the HM
  
  \[
  \text{If } (x_{\text{new}} < x_{\text{worst}}) \text{ then} \\
  \quad \text{Update the HM as } x_{\text{worst}} = x_{\text{new}} \\
  \text{End if}
  \]

Step 5: Termination

- If stopping criteria is satisfied, computation is terminated.
- Otherwise, repeat step 3 and 4
HSA Applications for Real_World Problems

• Engineering optimization problems
• Nurse scheduling problem
• Travelling salesman problem
• School bus routing problem
• University timetabling
• Power and energy [3]

Pricing schemes

- TOU pricing scheme [4]
  - Prices set for on peak and off peak hours
  - Hours are divided into blocks
  - Each block has fixed price
- IBR pricing scheme [5]
  - Prices are divided into several blocks
  - First block is at the lowest electricity price
  - With the increment in electricity consumption price also increased


[5]: http://www.prepayment.eskom.co.za/IBT.asp
Pricing schemes

- Real time Pricing scheme (RTP)
  - Rates are based on hourly consumption of electricity
  - Utility regulates RTP into two parts
  1. Base bill: It depends on customer’s base load (CBL)
  2. Hourly prices: Hourly prices are applied according to customer’s usage (difference between actual and CBL)

\[
\text{RTP} = \begin{cases} 
\text{Price}^\text{Unit} & \text{if Load} \leq \text{Limit} \\
\text{Price}^\text{Unit} + \text{Extra changes} & \text{if Load} > \text{Limit}
\end{cases}
\]
Pricing schemes

- Variable Peak Pricing (VPP)

\[ VPP_{total} = VPP_{off\_peak\_hour} + VPP_{on\_peak\_hour} \]

\[ VPP_{off\_peak\_hour} = \text{TOU} \]

\[ VPP_{on\_peak\_hour} = \text{RTP} \]

- Critical Peak Pricing (CPP)
  - During power system emergency conditions
  - Usually occurs in hot summer week days
## Energy Optimization by HSA (4/14)

### Parameter initialization

<table>
<thead>
<tr>
<th>HSA parameters</th>
<th>HEMS parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMS</td>
<td>Number of homes</td>
</tr>
<tr>
<td>HMCR</td>
<td>Number of appliances</td>
</tr>
<tr>
<td>PAmin</td>
<td>Pricing signal</td>
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<tr>
<td>PAmx</td>
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<tr>
<td>MaxItr</td>
<td></td>
</tr>
</tbody>
</table>
## Energy Optimization by HSA (5/14)

### Appliances

<table>
<thead>
<tr>
<th>Group</th>
<th>Appliances</th>
<th>Power rating (KWh)</th>
<th>Daily usage (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interruptible burst load</strong></td>
<td>Vacuum cleaner</td>
<td>0.7</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Water heater</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Water pump</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Dish washer</td>
<td>1.8</td>
<td>10</td>
</tr>
<tr>
<td><strong>Base load</strong></td>
<td>Refrigerator</td>
<td>0.225</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>1.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Oven</td>
<td>2.15</td>
<td>10</td>
</tr>
<tr>
<td><strong>Non-interruptible load</strong></td>
<td>Washing machine</td>
<td>0.7</td>
<td>5</td>
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<tr>
<td></td>
<td>Cloth dryer</td>
<td>5</td>
<td>4</td>
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</tbody>
</table>
Energy Optimization by HSA (6/14)

HSA terms corresponding to HEM

<table>
<thead>
<tr>
<th>HSA Parameters</th>
<th>HEMS parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmony</td>
<td>Array of on/off states of appliances in binary</td>
</tr>
<tr>
<td>Harmony memory size</td>
<td>Population size</td>
</tr>
<tr>
<td>Fantastic harmony</td>
<td>Global optimum / best solution</td>
</tr>
<tr>
<td>Aesthetic standard</td>
<td>Objective function</td>
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<tr>
<td>Each practice</td>
<td>Each iteration</td>
</tr>
<tr>
<td>Number of instruments</td>
<td>Number of appliances</td>
</tr>
<tr>
<td>Pitches of instruments</td>
<td>Appliance states</td>
</tr>
</tbody>
</table>
Generate initial population

for i=1:HMS
    for j=1:NVAR
        HM(i,j) = xl + rand(1)*(xu-xl);
    end
end

HM1=HM;

for i=1:HMS
    for j=1:NVAR
        if HM1(i,j)>0.5*std(unscheduledload) % rand(1) means 1*1 matrix
            HM1(i,j)=1;
        else
            HM1(i,j)=0;
        end
    end
end

Vacuum cleaner Water heater Water pump Dish washer Washing machine Cloth dryer refrigerator AC oven

0 0 1 1 0 0 1 1 0

1 0 1 1 1 0 1 1 0

1 1 1 0 1 0 0 0 1

0 1 0 0 0 1 1 1 1

0 0 1 1 0 1 1 1 0
calculate initial fitness based on fitness criteria

- \( \text{min(cost)} \)
- \( F = (\text{electricity cost} \times HM1') \)

<table>
<thead>
<tr>
<th></th>
<th>Vacuum cleaner</th>
<th>Water heater</th>
<th>Water pump</th>
<th>Dish washer</th>
<th>Washing machine</th>
<th>Cloth dryer</th>
<th>Refrigerator</th>
<th>AC</th>
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<th>fitness</th>
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<td>12</td>
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</tbody>
</table>
Energy Optimization by HSA (9/14)

Improvise new harmony vector

• Memory consideration

\[ v_{i,j} = \begin{cases} x_{\text{randj}} & \text{if } \text{rand()} < \text{HMCR} \\ 1_j + \text{rand}.(U_j - 1_j) & \text{otherwise} \end{cases} \]

• Pitch adjustment

\[ v_{i,j} = \begin{cases} v_{i,j} + \text{rand}.b_wj & \text{if } \text{rand()} < \text{PAR} \\ v_{i,j} & \text{otherwise} \end{cases} \]
improvise new harmony vector

for i =1:NVAR
    ran = rand(1);
    if( ran < HMCR ) % memory consideration
        index = randint(1,HMS);
        NCHV(i) = HM(index,i);
    end
    pvbRan = rand(1);
    if( pvbRan < PA) % pitch adjusting
        pvbRan1 = rand(1);
        if( pvbRan1 < 0.5)
            result = result+ rand(1) * BW(i);
            NCHV(i) = result;
        else
            result = result- rand(1) * BW(i);
            NCHV(i) = result;
        end
    else
        NCHV(i) = xl+rand(1)*(xu-xl); % random selection
    end
end
new_h= NCHV;

Memmory consideration
- New harmony vector $X^{\text{new}}$
- Evaluate fitness of new vector

<p>|</p>
<table>
<thead>
<tr>
<th>$f (X^{\text{new}})$</th>
</tr>
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<tbody>
<tr>
<td>10</td>
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</tbody>
</table>

Pitch adjustment

Random selection
Energy Optimization by HSA (11/14)

Update population
If ($x^{\text{new}} < x^{\text{worst}}$) then
Update the HM as $x^{\text{worst}} = x^{\text{new}}$
End if

<table>
<thead>
<tr>
<th>Cost</th>
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<tbody>
<tr>
<td>25</td>
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<tr>
<td>15</td>
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</table>

[worst worst_index]= max(F);
if (new<worst)&&
new_h1*p'>min(unscheduledload)
HM(worst_index,:)=new_h;
F(worst_index)= new;
end

<table>
<thead>
<tr>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(X^{\text{new}})$ = 10</td>
</tr>
</tbody>
</table>
Energy Optimization by HSA (12/14)

Update population

If \(x^{\text{new}} < x^{\text{worst}}\) then

Update the HM as  \(x^{\text{worst}} = x^{\text{new}}\)

End if

<table>
<thead>
<tr>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
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<table>
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<tr>
<th>cost</th>
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<tbody>
<tr>
<td>(f(X^{\text{new}}) = 10)</td>
</tr>
</tbody>
</table>

10 < 25  condition true
Energy Optimization by HSA (13/14)

Updated population

<table>
<thead>
<tr>
<th>Vacuum cleaner</th>
<th>Water heater</th>
<th>Water pump</th>
<th>Dishwasher</th>
<th>Washing machine</th>
<th>Clothes dryer</th>
<th>Refrigerator</th>
<th>AC</th>
<th>Oven</th>
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1 1 0 1 0 1 1 0 1
### Energy Optimization by HSA (14/14)

**Updated population**

<table>
<thead>
<tr>
<th>Vacuum cleaner</th>
<th>Water heater</th>
<th>Water pump</th>
<th>Dish washer</th>
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</table>

Updated population: 1101011101
Thank You

Any Question