On Harmony Search

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Biologically-Inspired Intelligent Systems

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Learning from Musicians & Improv

- Music-inspired metaheuristic
  - Observation: aim of music is to search for perfect state of **harmony**
  - Harmony = finding optimality

- Improvisation process = search process
  - Pleasing perfect harmony determined by audio aesthetic standard

Miles Davis!

Some random musicians?
What did you think engineers do in their free time?

Harmonics and Frequencies

- Aesthetic quality of instrument determined by:
  - Pitch (frequency)
  - Amplitude (loudness)
  - Timbre (sound quality)
    - Largely determined by harmonic content
    - Harmonic content determined by waveforms/modulations of sound signal
    - Harmonics generated depend on pitch or frequency range of instrument

Music, a search process you did not know was a search process all along…

Note Frequency Analysis

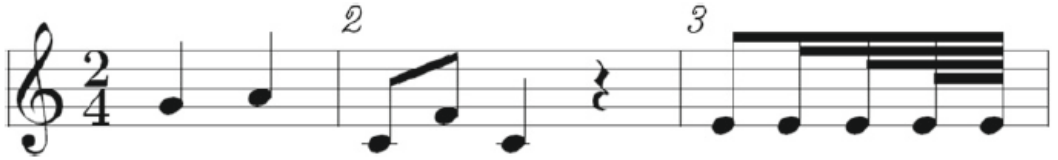


Figure 15.2 Random music notes.

- Different notes have different frequencies
  - Note A4 (above middle C) has fundamental frequency $f_0 = 440$ Hz
  - Speed of sound in dry air $v = 331 \pm 0.6T$ m/s where *T* is temperature (degrees Celsius), @ room temp $T = 20$ °C so A4 has wavelength $\lambda = \frac{v}{f_0} \approx 0.7795$ m

- When we change pitch, we trying to change frequency
- Pitch *p* in Musical Instrument Digital Interface (MID) represented in a linear pitch space via:
  - $p = 69 + 12\log_2(\frac{f}{440\ Hz})$ or $p = 440\ * 2^{(p-69)/12}$
  - A4 has pitch number 69 (octaves = size 12, semitone = size 1),
  - Ratio of note frequencies one octave apart = 2:1, thus, frequency of note is doubled when raised an octave (or halved when lowered one octave)
    - Frequency of A2 is 110 Hz, A5 is 880 Hz

Creating Harmony

- Measurement of harmony when different pitches occur at same time is somewhat subjective (an aesthetic quality)
  - Can use Pythagoras' frequency ratio method to estimate quality
    - Octave w/ 1:2 ratio sounds pleasant when play together, notes w/ 2:3 ratio
    - Random notes put together unlikely to produce pleasant harmony

Figure 15.1 Harmony of two notes with a frequency ratio of 2:3 and their waveform.

Harmony Search Dynamics

Harmony Search

Objective function $f(\boldsymbol{x})$, $\boldsymbol{x} = (x_1, ..., x_d)^T$
Generate initial harmonics (real number arrays)
Define pitch adjusting rate (r_{pa}) and pitch limits
Define harmony memory accepting rate (r_{accept})
while (t <Max number of iterations)
    Generate new harmonics by accepting best harmonics
    Adjust pitch to get new harmonics (solutions)
    if (rand> r_{accept}),
        Choose an existing harmonic randomly
    else if (rand> r_{pa}),
        Adjust the pitch randomly within a bandwidth (15.8)
    else
        Generate new harmonics via randomization (15.9)
    end if
    Accept the new harmonics (solutions) if better
end while
Find the current best estimates

Pseudo code of the Harmony Search algorithm (HSA)

Begin;

Define objective function $f(x)$, $x=(x_1, x_2, \ldots, x_d)^T$

Define Harmony Memory Considering rate (HMCR)

Define Pitch adjusting rate (PAR) and other parameters

Generate Harmony Memory with random harmonies

while (t<max number of iterations)

while (i<=number of variables)

if *(rand*<HMCR*),*

Choose a value from HM for the variable i

if *(rand*<PAR*),*

Adjust the value by adding certain amount

end if

else

Choose a random value

end if

end while

Accept the New Harmony (solution) if better

end while

Find the current best solution

end

/* HM initialization */

for ($i = 1; i \le \mathrm{HMS}; i$++)

  for ($j = 1; j \le n; j$++)

    Randomly initialize x_j^i in HM.

  endfor

endfor

/* End of HM initialization */

Repeat

  /* Construction and evaluation of new solution candidate $\mathbf{x}$ */

  for ($j = 1; j \le n; j$++)

    if (rand(0, 1) < HMCR)

      Let x_j in $\mathbf{x}$ be the jth dimension of a randomly selected HM member.

        if (rand(0, 1) < PAR)

          Apply pitch adjustment distance bw to mutate x_j:

          $x_j = x_j \pm \mathrm{rand}(0, 1) \times \mathrm{bw}$.

        endif

    else

      Let x_j in $\mathbf{x}$ be a random value.

    endif

  endfor

  Evaluate the fitness of $\mathbf{x}$: $f(\mathbf{x})$.

  /* End of construction and evaluation of new solution candidate $\mathbf{x}$ */

  /* HM update */

  if ($f(\mathbf{x})$ is better than the fitness of the worst HM member)

    Replace the worst HM member with $\mathbf{x}$.

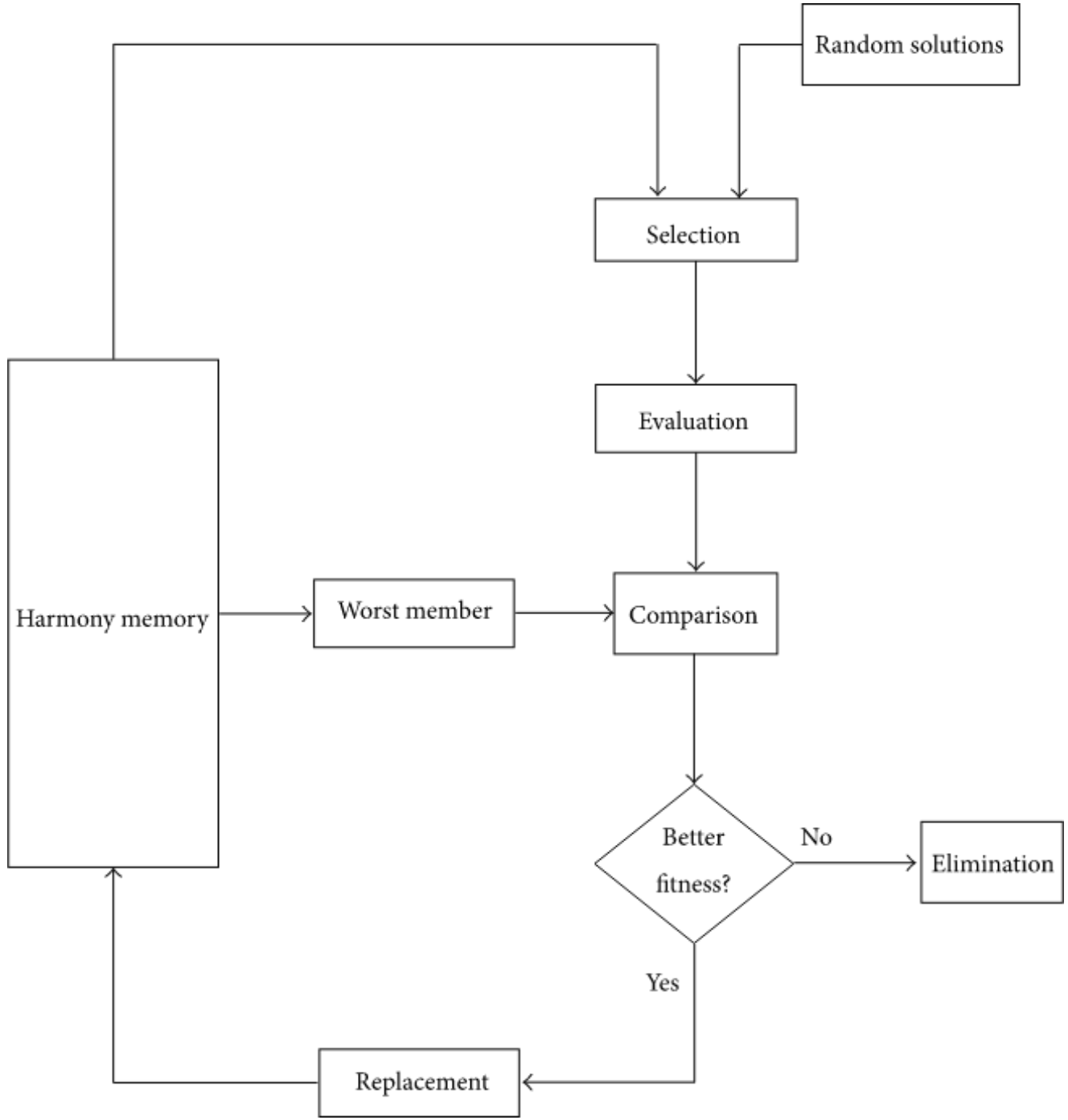
  else

    Disregard $\mathbf{x}$.

  endif

  /* End of HM update */

Until a preset termination criterion is met.


Random solutions
Selection
Evaluation
Harmony memory
Worst member
Comparison
Better fitness?
No
Elimination
Yes
Replacement

Harmony Search in Action

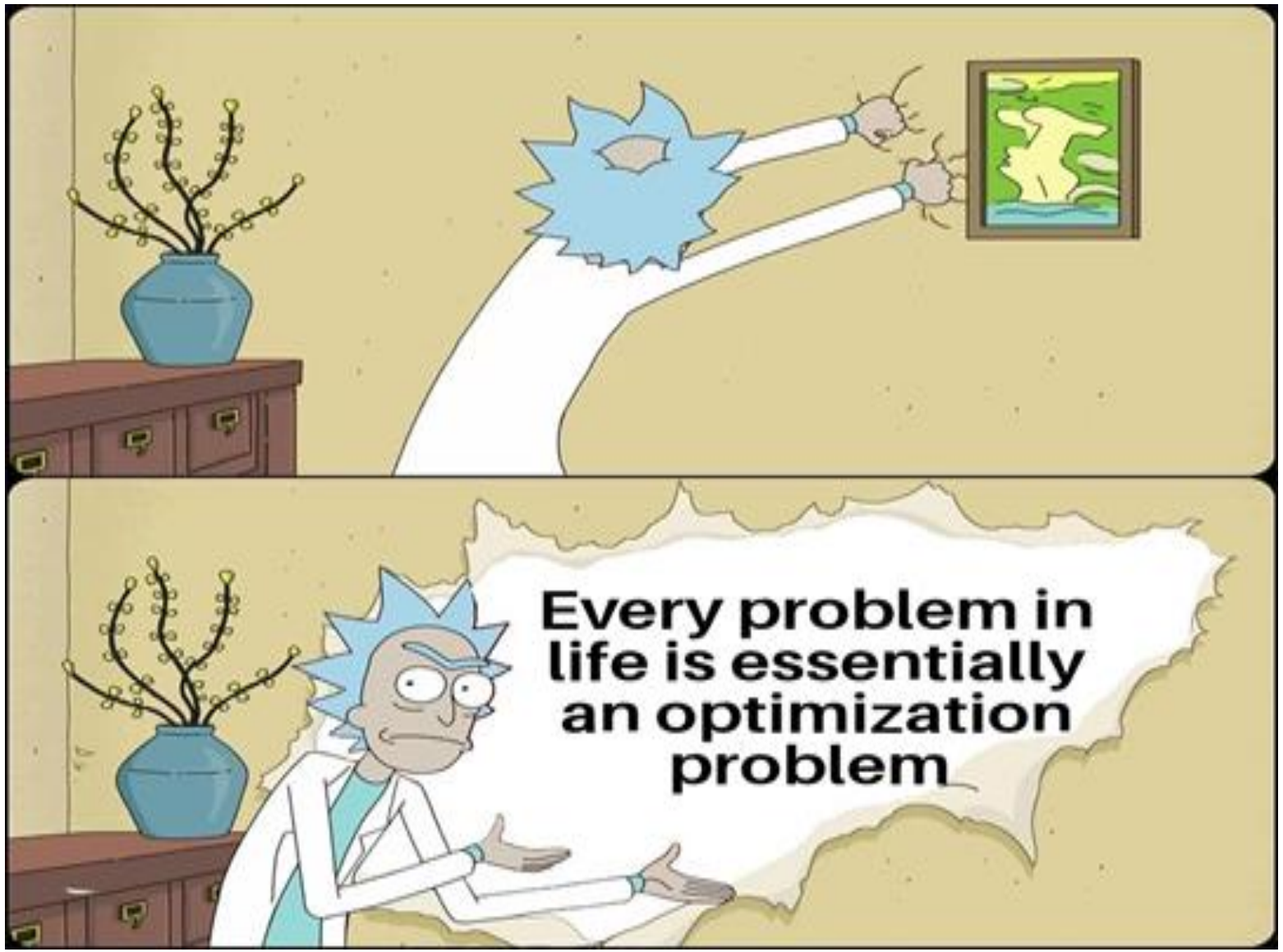
- https://www.youtube.com/watch?v=4UqALf9mGas

Applications

- Water distribution network optimization
- Groundwater modeling
- Energy-saving dispatch optimization
- Structural design modeling
- Vehicle routing

- Often combined with genetic algorithms and/or particle swarm optimization

Questions?


Every problem in life is essentially an optimization problem