Multi-Objective Optimization for Selecting and Scheduling Observations of Agile Earth Observing Satellites

By
Panwadee Tangpattanakul

Directors: Pierre Lopez
Nicolas Jozefowiez
Contents

• About our work
• Multi-Objective Optimization
• Genetic Algorithm for Multi-Objective Optimization
• Implementation and Results
• Conclusions and Future Works
About our work

Agile Earth observing satellites (agile EOS)

• Mission:
  • Acquire photographs on the Earth’s surface, in response to observation requests from several users

• Management problem:
  • Select and schedule a subset of photographs from a set of candidates
    • Maximize profit
    • Minimize the maximum profit difference between users (ensure fairness)
    • Satisfy imperative constraints
      • Time windows
      • No overlapping images
      • Sufficient transition times
      • Each strip is acquired in only 1 direction
      • Stereoscopic constraint
Introduction

- Types of Earth Observing Satellites
  - SPOT 5
    - 3 cameras (Front, Middle, Rear)
  - Agile
    - Single camera
    - 3 degrees of freedom (roll, pitch, yaw)
  - Profit calculation
    - gains
    - partial acquisition
    - piecewise linear function

Ref: Bensana et al. (1999), Lemaître et al. (2002)
Introduction

• Selecting and scheduling of multi-user requests
  • Fairness measurement is the maximum value of profit difference between users
Introduction

- Selecting and scheduling of multi-user requests
  - Fairness measurement is the maximum value of profit difference between users

Requests from

User 1
- P1 = 12
- P2 = 3
- P3 = 6

User 2
- P4 = 8
- P5 = 4

Solution 1: (P1, P2, P3)
- Total profit = 21
- Fairness = 21
Introduction

- Selecting and scheduling of multi-user requests
  - Fairness measurement is the maximum value of profit difference between users

Requests from

User 1
- P1 = 12
- P2 = 3
- P3 = 6

User 2
- P4 = 8
- P5 = 4

Solution 1: (P1,P2,P3)
- Total profit = 21
- Fairness : 21

Solution 2: (P4,P2,P3)
- Total profit = 17
- Fairness : 1
Introduction

• Selecting and scheduling of multi-user requests
  • Fairness measurement is the maximum value of profit difference between users

Requests from

User 1
  P1 = 12
  P2 = 3
  P3 = 6

User 2
  P4 = 8
  P5 = 4

Solution 1 : (P1,P2,P3)
  Total profit = 21
  Fairness : 21

Solution 2 : (P4,P2,P3)
  Total profit = 17
  Fairness : 1

Solution 3 : (P1,P2,P5)
  Total profit = 19
  Fairness : 11
Introduction

• Selecting and scheduling of multi-user requests
  • Fairness measurement is the maximum value of profit difference between users

Requests from

User 1
  P1 = 12
  P2 = 3
  P3 = 6

User 2
  P4 = 8
  P5 = 4

Solution 1: (P1,P2,P3)
  Total profit = 21
  Fairness : 21

Solution 2: (P4,P2,P3)
  Total profit = 17
  Fairness : 1

Solution 3: (P1,P2,P5)
  Total profit = 19
  Fairness : 11

Solution 4: (P4,P2,P5)
  Total profit = 15
  Fairness : 9
Multi-Objective Optimization

- Multi-objective optimization problem

\[(MOP) = \begin{cases} \text{min } F(x) = (f_1(x), f_2(x), \ldots, f_n(x)) \\ \text{s.t. } x \in \Omega \end{cases}\]

with:

- \(n \geq 2\): number of objectives
- \(F = (f_1, f_2, \ldots, f_n)\): vector of functions to optimize
- \(\Omega \subseteq \mathbb{R}^m\): set of feasible solutions
- \(A(\Omega) \subseteq \Omega\): set of feasible solutions visited by an algorithm \(A\)
- \(x = (x_1, x_2, \ldots, x_m) \in \Omega\): a solution
- \(\mathcal{Y} = F(\Omega)\): objective space
- \(y = (y_1, y_2, \ldots, y_n) \in \mathcal{Y}\) with \(y_i = f_i(x)\): point of the objective space
Multi-Objective Optimization

Pareto dominance (maximize $f_1(x)$, minimize $f_2(x)$)

A solution $x$ dominates (denoted $\leq$) a solution $y$ if

$$f_1(x) \geq f_1(y) \text{ and } f_2(x) < f_2(y) \quad \text{or}$$

$$f_2(x) \leq f_2(y) \text{ and } f_1(x) > f_1(y)$$

$f_1(x)$: total profit

$f_2(x)$: maximum profit difference between users
Genetic Algorithm for Multi-Objective Optimization
Biased random-key genetic algorithm (BRKGA)

Evaluation:
- All chromosomes in population
- Calculate fitness value
  - Encoding
  - Decoding

Ref: J.F. Gonçalves et al. (2011)
Biased random-key genetic algorithm (BRKGA)

Elite set:
- Non-dominated solutions

Population in generation $i$

Ref: J.F. Gonçalves et al. (2011)
Biased random-key genetic algorithm (BRKGA)

Ref: J.F. Gonçalves et al. (2011)
Biased random-key genetic algorithm (BRKGA)

Mutant set:
- Randomly generated
- (the same method with initial population)

Ref: J.F. Gonçalves et al. (2011)
Biased random-key genetic algorithm (BRKGA)

Ref: J.F. Gonçalves et al. (2011)
Biased random-key genetic algorithm (BRKGA)

Population for new generation
- Selection
- Crossover
- Mutation

Stopping criteria :
- A fixed number of generations since the generation of the last solution total profit improvement

Ref: J.F. Gonçalves et al. (2011)
Genetic Algorithm for Multi-Objective Optimization

• BRKGA with our problem
  • Encoding
    • One chromosome for one solution
    • Number of genes is two times the number of strips
    • Each gene represents one strip acquisition
    • By real values randomly generated in the interval (0,1]

• Example : 2 strips (strip 0 and strip 1)
  • Each chromosome in population

<table>
<thead>
<tr>
<th>Stp0 Dir0 Index 0</th>
<th>Stp0 Dir1 Index 1</th>
<th>Stp1 Dir0 Index 2</th>
<th>Stp1 Dir1 Index 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
</tbody>
</table>
Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding

<table>
<thead>
<tr>
<th>Stp0 Dir0 Index 0</th>
<th>Stp0 Dir1 Index 1</th>
<th>Stp1 Dir0 Index 2</th>
<th>Stp1 Dir1 Index 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
</tbody>
</table>

- Chromosome
Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding

<table>
<thead>
<tr>
<th></th>
<th>Stp0 Dir0 Index 0</th>
<th>Stp0 Dir1 Index 1</th>
<th>Stp1 Dir0 Index 2</th>
<th>Stp1 Dir1 Index 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromosome</td>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
</tbody>
</table>

Scheduling sequence 1
Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding

<table>
<thead>
<tr>
<th></th>
<th>Stp0 Dir0</th>
<th>Stp0 Dir1</th>
<th>Stp1 Dir0</th>
<th>Stp1 Dir1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 0</td>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
<tr>
<td>Index 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chromosome

Scheduling sequence 1
Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding

<table>
<thead>
<tr>
<th></th>
<th>Stp0 Dir0</th>
<th>Stp0 Dir1</th>
<th>Stp1 Dir0</th>
<th>Stp1 Dir1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 0</td>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
<tr>
<td>Index 1</td>
<td>0.6885</td>
<td>0.2509</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index 2</td>
<td>0.2509</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Chromosome

Scheduling sequence: 1 2

Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding

<table>
<thead>
<tr>
<th>Stp0 Dir0</th>
<th>Stp0 Dir1</th>
<th>Stp1 Dir0</th>
<th>Stp1 Dir1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 0</td>
<td>Index 1</td>
<td>Index 2</td>
<td>Index 3</td>
</tr>
<tr>
<td>0.6984</td>
<td>0.9939</td>
<td>0.6885</td>
<td>0.2509</td>
</tr>
</tbody>
</table>

- Chromosome

Scheduling sequence: 1 2
Genetic Algorithm for Multi-Objective Optimization

- BRKGA with our problem
  - Decoding
    
    | Stp0 Dir0 Index 0 | Stp0 Dir1 Index 1 | Stp1 Dir0 Index 2 | Stp1 Dir1 Index 3 |
    |------------------|------------------|------------------|------------------|
    | 0.6984           | 0.9939           | 0.6885           | 0.2509           |

- Chromosome

Scheduling sequence 1 2

Total profit 1.04234 x 10^7

Maximum difference profit between users 5.21172 x 10^6
Implementation and Results

Multi-objective scheduling of required photographs to be assigned to agile EOS:

- 4-users modified ROADEF 2003 challenge instances (Subset A)
- Parameters setting:
  - Number of strips $n$
  - Size of population $(p) = 2n$
  - Size of elite set $(p_e) \leq 0.15p$
  - Size of mutant set $(p_m) = 0.3p$
  - Probability of elite element inheritance $(\rho_e) = 0.6$
  - Stopping value $= 50$
- C++ language
Implementation and Results

Modified instance 2_9_170 : 12 requests (2 stereos) from 4 users, 25 strips

Computation time : 3 minutes 47 seconds
Conclusions and Future works

• Conclusions
  • Earth observing satellite
    • Obtain the requests to satisfy users requirement
  • Multi-objective optimization
    • Efficient for real problems
  • Objective functions
    • Maximize : total profit
    • Minimize : maximum profit difference between users
      (Ensure fairness)
  • Instances
    • Modified instances of ROADEF 2003
  • BRKGA
    • Good performance but computation time is quite high
Conclusions and Future works

• Future works
  • BRKGA
    • Decoding
      • The other decoding methods
    • Hypervolume concept
  • Evolutionary Algorithm
    • Indicator-Based Evolutionary Algorithm (IBEA)
  • Local search
    • Indicator-Based Multi-Objective Local Search (IBMOLS)
Thank you for your attention.

Questions and suggestions?