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Classical Mechanics Optimization for image segmentation

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Abstract. In this work, we focus on image segmentation by simulating the natural phenomenon of the bodies moving through space. For this, a subset of image pixels is regularly selected as planets and the rest as satellites. The attraction force is defined by Newton's third law (gravitational interaction) according to the distance and color similarity. In the first phase of the algorithm, we seek an equilibrium state of the earth-moon system in order to achieve the second phase, in which we search an equilibrium state of the earth-apple system. As a result of these two phases, bodies in space are constructed; they represent segments in the image. The objective of this simulation is to find and then extract the multiple segments from an image.

Keywords: Image segmentation · Combinatorial Optimization ·Artificial Intelligence · Metaheuristic · Classical Mechanics Optimization.

1 Introduction

Segmentation is an important step in the image processing; it extracts segments from images. Each segment represents a set of pixels (each pixel is defined by its coordinates and color).

Image segmentation can be seen as a combinatory optimization problem, because the goal is to find combinations of assigning pixels to segments. To find optimal partitioning in *K* groups of an *n* pixels image, all the possible partitions must be browsed. The number of possible partitions is given by the Stirling numbers of the second kind [1]:

$$S(n,k) = \frac{1}{k!}\sum_{i=1}^{k}(-1)^{k-i}\binom{k}{i}i^{n} \qquad \textit{Where: } \binom{k}{i} = \frac{k!}{i!(k-i)!} \tag{1}$$

If the optimal number of partitions is unknown, Stirling numbers are calculated for $k=1$ to $k=n$. The number of possible partitions is given by Bell number [1]:

$$B(n) = \sum_{k=1}^{n} S(n,k) \quad (2)$$

The Bell number quickly becomes very big (example: *B(10)=115975*). The heuristic approaches for solving a combinatorial problem is to find a good solution in a bounded time among an exponential number of possibilities. So they are based on finding a good compromise between the calculation time and the quality of the best solution found so far.

The objective is to use the state of bodies' equilibrium in the space as a heuristic to tackle the image segmentation problem. We have proposed and implemented an image segmentation method based on a new metaheuristic inspired by the natural phenomenon of the bodies' movement in space. The proposed metaheuristic is based on the impact of the attractive forces between the bodies during their movements.

To simulate this problem as a natural phenomenon of the bodies' movement in space, we need to define the planets, the satellites, and what the attraction force. For this, *m* pixels of the image are uniformly selected. These pixels represent the planets, the remaining pixels represent the satellites and the attraction force is defined by the color similarity and the distance between the planet and the satellite.

The earth-moon system equilibrium is to find a situation, in which every single satellite is in rotation over the planet that applies on it the strongest attraction force. The earth-apple system equilibrium is to find a situation, in which all the bodies are far from colliding on each other, the resulting bodies represent the segments of an image.

2 Metaheuristics inspired from the interaction force

In the universe, attraction forces are divided into two types: Gravity is an attractive force between the bodies, which depends on their masses. The electromagnetic interaction is an attractive force that acts on the elements with electrical charges. Some researchers have proposed metaheuristics based on the forces of attraction between bodies. These forces are generated either from the physical mass or the electric charge. Here are some examples of this type of metaheuristic:

2.1 Gravitational search algorithm (GSA)

The gravitational search algorithm [2] uses Newton's third law to calculate the forces of attraction and Newton's second law to deduce the speed of a body. The diversification of the search in ensured by attraction force; To intensify the search, the gravitational constant is linearly decreased with time. GSA algorithm is combined with Particle Swarm Optimization (PSO) to solve the image segmentation problem [3]; The result algorithm is used in the second phase to search for the optimal threshold estimation used as a search procedure in the first phase.

2.2 Charge Search System (CSS)

The search system based on the electric charge [4] is inspired by the electrostatic; attributing electrical charges to the particles. The algorithm is used as a step of local search to improve the founded solutions in PSO algorithm [5] to solve the image segmentation problem.

2.3 Gravitational Interactions Optimization (GIO)

Optimization by gravitational interactions [6] called particle swarm optimization with gravitational interactions. Each body stores its current position and its best position. The interactions of bodies follow the Newton's third law and move each body to a new location so that the whole population tends to reach the optimum. This method uses the Newton's second law to calculate the speed of a body. To intensify the search, authors use a mass unit placed in space to exert forces on other bodies to move them. When the bodies are close to each other, the resulting forces are strong, and there are many displacements..

2.4 Fusion-Fission metaheuristic

The fusion-fission metaheuristic [7] is inspired from nuclear physics. It is applied on the graph partitioning problem, the clustering of documents and image segmentation. The atom is formed of electrons with a negative charge and nucleons which form the atomic core. There are two kinds of Nucleons: protons, positively charged and neutrons, neutrally charged. The cohesion of the atomic core is ensured by their strong interactions. During the fission of an atom, the core divides into two fragments, along with several ejected neutrons. An atom can split either spontaneously if its core is too heavy, or because of being hit by a neutron. To merge, atoms must have sufficiently high speeds. He considers a cloud of nucleons. It is subjected to high temperature and pressure, so that the nucleons have great chances of collision. It is the fusion of these nucleons together that forms the resulting atoms, which will help achieve an equilibrium state of the system. Fission is used to explode the biggest or non stable atoms.

3 Classical Mechanics Optimization (CMO)

As mentioned earlier, metaheuristics based on the gravitational interaction are hybridized with other metaheuristics, such as GSA algorithm with simulated annealing, and GIO algorithm that is hybridized with the particle swarm optimization. The proposed method is independent; it relies on applying the laws of classical mechanics.

The CMO simulates the natural phenomenon of the bodies' movement in a space by considering the pixels as bodies. m of these pixels are selected as planets and the n remaining are considered satellites, the attraction force is defined by Newton's third law (gravitational interaction).

After the simulation of the problem as a system of bodies in space, we execute the algorithm in two main phases: The first phase is to find an equilibrium of the rotating satellites around planets by applying the earth-moon system. The second phase is to group the segments formed in the first phase by applying the earth-apple system.

3.1 Transformation of the problem into a system of bodies in space

The planets represent a subset *S* of the set *E* (*E* is the global set that contain all pixels of image), and satellites represent the subset *N* representing the complement of *S* in *E*. Rules (3) and (4) are to calculate the number of planets and the number of satellites:

$$m = PixelNbr \times \frac{PlanetNbr}{PlanetNbr + SatelliteNbr} \quad (3)$$

$$n = PixelNbr - m \quad (4)$$

The following figure shows the image to segment, the black pixels represent the planets, the remaining are satellites.

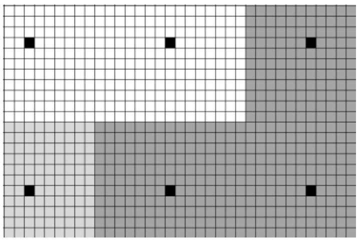

Fig. 1. Planets selection.

The number of pixels of each segment defines their mass:

$$ClassMass = UnitMass \times ClassPixelNbr \quad (5)$$

$$\text{Where: } UnitMass = \frac{SystemMass}{PixelNbr}$$

Newton's third law (gravitational interaction) is used to define the attraction force.

$$F_{ab} = g\frac{m_a m_b}{d_{ab}^{2}} \quad (6)$$

Where m_a, m_b represent masses and d_{ab} represents distance between pixels *a* and *b*.

The distance d_{ab} is calculated by Euclidean distance, after the simulation of the spatial distance from a triangular rule:

GreatestPixelDistance(GPD)→*GreatestBodiesDistance(GBD)*

PixelDistance(PD) → *BodiesDistance(BD)*

So the distance ratio becomes:

$$\text{Distance Ratio} = \text{GBD/GPD} \quad (7)$$

The image is composed by a matrix of pixels; each pixel is defined by its coordinates and its color. After experimentation, the equation of attraction is improved as follows:

$$F_{ab} = \frac{m_a m_b}{d_{ab} e^{\sqrt{|c_a - c_b|}}} \tag{8}$$

Where c_a and c_b represent the color of the pixel *a* and the pixel *b*.
The gravitational fields earth-moon system GF_{em} and earth-apple system GF_{ea} are derived from the mechanic laws in rule (9) and rule (10) respectively:

$$GF_{em} = 1.068 \times mass \times 10^{-21} \tag{9}$$

$$GF_{ea} = G\mathrm{F_{em}} / 200 \tag{10}$$

3.2 Finding a body equilibrium by applying the earth-moon system

We look in space for an equilibrium of the bodies, to stabilize the movement of satellites around planets. The movement of the satellites is caused by the gravitational attraction exerted by the planets.

A body *a* is rotating around the body *b* with a force F_{ab}. If there is a body *c* where: $F_{ac} > F_{ab}$, then the body *a* leave its path around *b* and follows a new path around *c*.

For each combination, we calculate the attraction force for planets. The gravity center becomes the center of all satellites around this planet.

We repeat the two previous steps until the system equilibrium is verified. The algorithm of this step is described as follows:

```
Algorithm 1 Find the system equilibrium {Earth-Moon sys-
tem}
  var    E: array [1..z,1..w] of real; {E is the image
             where z and w are the dimensions}
         Planet: array [1..m,1..n] of integer; {Each
            row of this matrix represents the satellites
            turned around the corresponding planet Since
            Planet(j, 1) represents the center of
            gravity of the same line}
         Satellite: array [1..n] of integer; {Each case i
            represents the corresponding planet of
            satellite i}
         m, n : integer; {m is planet number and n is
            satellite number }

  begin
    Calculate(m); Calculate(n);
    Initialize(Planet, Satellite);
```

```
    repeat
      For i = 1 to n
        For j = 1 to m
          If Earth-Moon gravitational field (Planet(j))
              > Distance (Planet(j),Satellite(i)) then
            If Force (Planet (j,1), Satellite(i)) > Force
               (Planet (Satellite (i),1),Satellite (i))
            then
              Move (Satellite(i), j);{Is to release the
                satellite i from his planet and assign it
                to the planet j}
            end;
          end;
        end;
      end;
    Until system stabilization
end.
```

The following figure shows a stable distribution of the satellites around the planets.

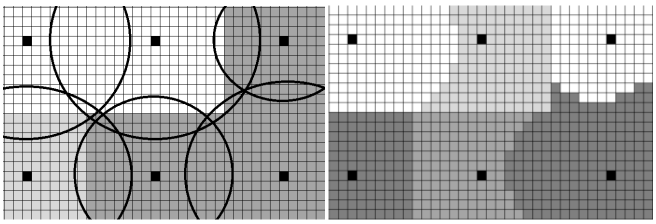

Fig. 2. System equilibrium for earth-moon system and grouping of bodies.

3.3 Construction of segments by applying the Earth-apple system

After the stabilization of satellites around planets, each planet-moon system is considered as one body. Then the gravitational fields of bodies (earth-apple system) is calculated. Each body situated in the gravitational field of another body falls (fusion of two segments) and the two bodies are considered as a single body. After the fusion, we repeat the previous two steps until the overall system is stable (all the found segments are too far to be fused). The algorithm of this phase is as follows:

```
Algorithm 2 Research earth-apple system equilibrium
  use Result of Algorithm 1
  begin
    repeat
      For i = 1 to n
        For j = 1 to m
          If Gravitational field earth-apple(Planet(i))
```

```
               > Distance(Planet(i), Planet(j)) then
             Move (Planet(j), i); {move all pixels of the
               body j to the body i, recalculate the new
               center of gravity and  remove the line j
               from the Planet Matrix}
             m := m-1;
           end;
         end;
       end;
     Until system stabilization
   end.
```

The following figure shows the bodies gravitational fields and fusion (earth-apple system).

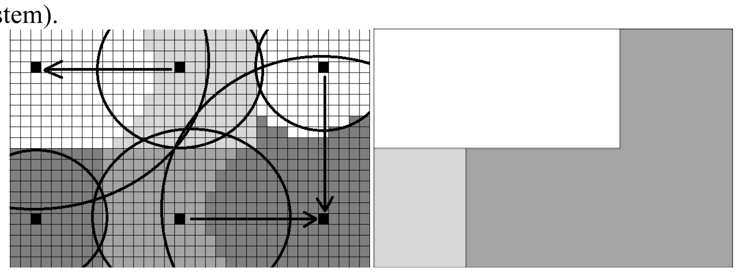

Fig. 3. Bodies gravitational fields and fusion (earth-apple system).

3.4 Tests and results

We applied the CMO approach on real images by simulating the solar system. The number of pixels planets *m* is calculated as follows:

*m = the number of pixels in the image*8 / (167 + 8)*

Because in the solar system there are one hundred and sixty seven (167) satellites and eight (08) planets. The results of the segmentation are:

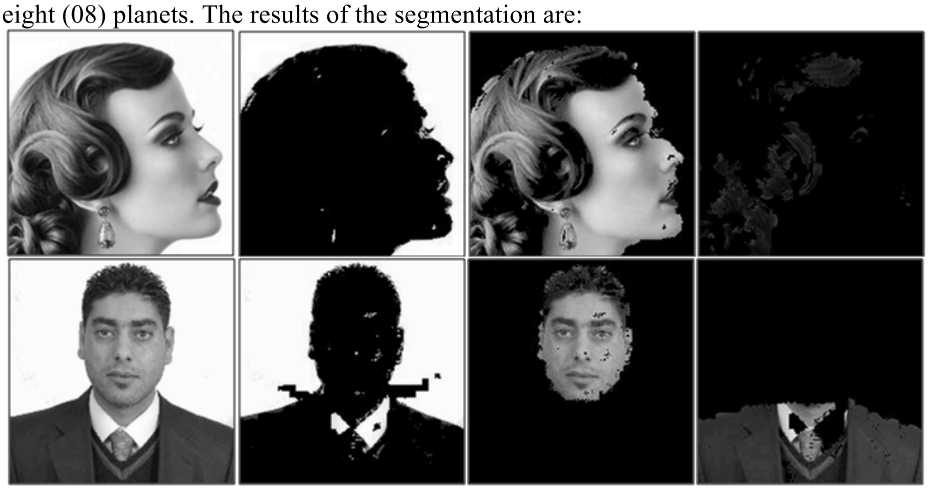

Fig. 4. Image segmentation results by using CMO.

The segmentation of the two images provides three segments that represent the objects of each image, that the dice coefficient of the approach is 88,65. There are small segments that are not displayed, it is the influence of light or stains. This is positive because these pixels or smaller segments can be treated isolated segments which are used to solve other problems such as the detection of tumors in medical imaging.

4 Conclusion

In this work, we developed an image segmentation method based on the simulation of the natural phenomenon of bodies' movement in space, called Classical Mechanics Optimization. It consisted on two phases. As a first step, we seek an equilibrium of the bodies in the earth-moon system (satellites assignment to the planets that apply more attraction force). The second step is to group the most similar segments, applying an earth-apple system.

The simulation is made by the extraction of a pixels subset as planets and the remaining pixels represent the satellites. The attraction force equation is defined by the rule (8) that represents Newton's third law according to the pixels' color, considering the importance of color in image segmentation.

In CMO, intensification and diversification are provided by the distance ratio that transforms the distance between pixels in the spatial distance. When it is small, the algorithm becomes more intensive because the gravitational field increases. However, if the distance ratio is very small, all the bodies may fall into a black hole which represents a segment that includes all pixels. Otherwise, if it is very large, grouping objects is not assured, because of the decrease in the gravitational field.

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