Application of Greedy Algorithm in Exodia Deck in Yu-Gi-Oh! Trading Card Game

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Abstract—**Yu-Gi-Oh! Trading Card Game is a battle-based trading card game in which players draw cards from their respective decks and take turns playing cards onto *the field*. The game usually played by two players. The objective of each player is to defeat his/her opponent by reducing their *life points* to zero or by using particular card's effect. Exodia deck is a popular deck in this game. The objective of this deck is to win a game by drawing cards as much as possible until five parts of Exodia cards are in the player hand.**

This paper will cover an analysis of greedy algorithm to choose the right card in each sub-turn, until the objective of this deck is achieved. Even though there are so many variation of Exodia deck, we will only use only one particular deck.

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Index Terms—**Yu-Gi-Oh! Trading Card Game, Exodia, Greedy Algorithm.**

## I. INTRODUCTION

A. Yu-Gi-Oh! Trading Card Game

Yu-Gi-Oh! Trading Card Game is a popular card game developed and published by Konami. This game is based on fictional game created by Kazuki Takahashi in his japanese comic with the same title, Yu-Gi-Oh!. The game usually played by 2 players in *single duel* or 4 players in *tag duel*. The game is a battle-based trading card game in which players draw cards from their respective deck and take turns playing cards onto *the field*. The objective of each player is to defeat his/her opponent(s) by reducing their *life points* to zero using variety of *Monsters*, *Spells* and *Trap* cards, or by using particular card effect. Each player starts with 8000 *life points*. Some games using 2000 or 4000 *life points* instead of 8000 according to players agreement or tournament rules.

The game field is divided into several zones, each zone has special function.

1. *Deck*: The player's deck consisting of 40-60 cards. [1]

2. *Extra Deck*: A side-deck containg up to 15 cards consisting of Fusion, Synchro, and/or Xyz Monster cards, as well as destroyed Pendulum Monster cards. [1]

3. *Graveyard*: A zone in which cards are placed when they are discarded, such as used spell cards or monsters that are destroyed in battle. [1]

4. *Monster Card Zone*: A field of five spaces where Monster cards are placed when successfully summoned. [1]

5. *Spell/Trap Card Zone*: A field of five spaces where Spell and/or Trap cards are placed. [1]

6. *Field Spell Zone*: A designated zone where Field Spell cards are placed. [1]

7. *Banished Zone*: An unmarked zone outside of the play field in which cards that are designated as *Banished* by card effects are placed. [1]

8. *Pendulum Zones*: Two zones in which Pendulum Monsters can be placed for the purpose of Pendulum Summoning. [1]
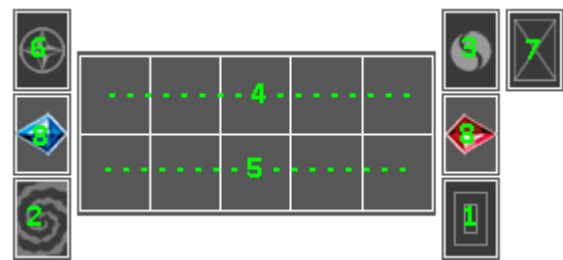
Picture 1.1 - Yu-Gi-Oh! game field

Each player turn, consist of 6 phases. Each phase has some rule about what the player should do or shoudn't do in that phase. The phases has the following order.

1. *Draw Phase*: The turn player draws one card from his/her deck.

2. *Standby Phase*: This phase exists mostly for card effects that activate or resolve during this specific phase.

3. *Main Phase 1*: The turn player may summon a monster, activate cards and effects that they control, change the battle position of a monster, and set cards face-down.

4. *Battle Phase*: The turn player may attack the opponent's monsters, or Life Points if the opponent controls no monsters, once with each monster they control that is in Attack Position, while the opponent may attempt to defend with their own

monsters, Spells, or Traps. If the turn player controls no monsters, or chooses to not attack during the turn, they may skip this phase.

5. *Main Phase 2*: A player may do all the same actions that are available during Main Phase 1, except "normal summon" a monster during this phase if they already did so during Main Phase 1. [1]

6. *End Phase*: much like the standby phase, is mostly used for card effects that activate/resolve during this specific phase. [1]

The game has 3 main card types. Each card type has it's own role in a *duel*. The card types are:

1. *Monster card*: Can be used to attack the opponent to reduce their life points, defense against opponent's monster attack and destroy opponent monster. Some monster also has it's own effect like a Spell card. [1]

2. *Spell card*: Can be played either from the hand, or set on the field for later use. They can either power up monster cards attack/defense, destroy other cards, increase life points, draw cards, increase a monster's level etc. [1]

3. *Trap card*: Cards that are activated in response to certain situations, most often when an opponent activates an effect or attacks. They are set face down on the field and cannot be activated on the turn they were placed down . [1]

B. Exodia Deck

Exodia deck is one of the most popular deck in Yu-Gi-Oh! Trading Card Game. The main cards of this deck is 5 part of *Exodia* card, there are:

1. Exodia the Forbidden One.
2. Right Arm of the Forbidden One.
3. Left Arm of the Forbidden One.
4. Right Leg of the Forbidden One.
5. Left Leg of the Forbidden One.

Picture 1.2 – Five Exodia cards

The text in Exodia the Forbidden One card said that, "When you have "Right Leg of the Forbidden One", "Left Leg of the Forbidden One", "Right Arm of the Forbidden One" and "Left Arm of the Forbidden One" in addition to this card in your hand, you win the Duel". The card's

effect implies that we win the duel when we have all of the card above in the hand. Basically, the objective of this deck, is to draw cards as much as possible until these five cards are in our hand. There are so many variation of Exodia deck out there. One of the popular deck variation is using *Royal Magical Library* card as the main engine. The text in this card said that, "Each time a Spell Card is activated, place 1 Spell Counter on this card (max 3). You can remove 3 Spell Counters from this card to draw 1 card". Basically, every 3 spell cards is activated, we can draw 1 card. This variation usually also using Magical Citadel of Endymion card as the sub-engine. This card can support *Royal Magical Library* by providing additional *Spell Counter* for the card to use the effect.

Picture 1.3 – Royal Magical Library card (left) and Magical Citadel of Endymion card (right)

We will use Exodia deck with this engine in our analysis.

II. THEORIES

A. Greedy Algorithm

Greedy Algorithm is a simple and straightforward algorithm that is used to solve optimization problem. Optimization problem here, can be a maximalization or minimization problem.

The principle of this algorithm is "take what you can get now", that means, it will choose the best option that is available now without considering future consequence.

Greedy Algorithm creating solution step by step. There are many choices that needs to be explored in every step of solution. Therefore, the best choice must be made in every step. Every decicion that have been taken can't be altered in the next step. This algorithm approach is make a decicion that seems will give the best choice, by choosing the *local optimum* in every steps and hoping it will reach the best solution or *global optimum.*

Formally, Greedy algorithm can be stated by the following elements:

1. Candidate set, C
   The candidate set (C) is the set of all the elements that are possibly will be the solutions. An element of this set may be a set as well. At each step in the algorithm, an element is taken from this set and inserted into solution set (S).

2. Solution set, S
   The solution set (S) is the set of elements that are selected throughout the process of algorithm. This set, at the end of the process, will represents the

solution of the problem. As its elements are taken from the candidate set (C), solution set is a subset of candidate set.

3. Selection function

    Selection function are the function that assigns values to solution candidates in the candidate set and selects a candidate that has the best value (in terms of the problem instance, maximum, for example) and removes it from candidate set. The selection function of greedy algorithm can be more than one, depending the problem instance.

4. Feasibility function

    Feasibility function is the function that tests whether the candidate selected by the selection function is feasible to put to the solution set. Being feasible means that when it's combined with other candidates in the solution set, the new candidate does not violate any constraints that exists. A new candidate will be taken from the candidate set by the selection function if the existing candidate is not feasible to put to the solution set. The process are to keep going until no elements are left in the candidate set or until a certain goal or limit is reached by the solution set.

5. Objective function.

    The objective function is the function that become the goal of the solution of the problem. Typically, objective function can't be expressed in the code, but rather become the global goal of the code itself. It makes the best global solution (maximum or minimum). [2]

Every greedy algorithm has the same general scheme. Generally, the scheme of greedy algorithm is:

1. Create an empty set as a solution set (S). [2]
2. Choose a candidate (by using selection function) from candidate set C [2]
3. Substract C with the choosen candidate from the second step. [2]
4. Check using feasibility function whenever the solution set is feasible. If feasible add the candidate into solution set. [2]
5. Check using objective function whenever the solution set is complete If not complete, repeat from the second step. [2]

From the description above, the pseudo code for greedy algorithm generally:

```
function greedy (input C:candidate_set)
himpunan_kandidat
{ Return the solution of greedy optimization
problem
input: candidate set C
output: solution set S with th same type as the
candidate set}
Declaration:
        x : candidate
        S : solution_set
Algorithm:
    S {} { initialize S with empty set }
    while (not SOLUTION(S)) and (C {} ) do
        x SELEKSI(C)
        {choose a candidate from C}
        C C - {x}
        { remove that candidate from candidate set}
        if FEASIBLE(S {x}) then
            S S {x}
        endif
    endwhile
    { SOLUTION(S) or C = {} }
    if SOLUTION (S) then
        return S
    else
        write('no solution')
    endif
```

III. PROBLEM ANALYSIS

Yu-Gi-Oh! Trading Card Game is a complex game with many variation in the term of gameplay or the card itself. To simplify this, we choose an Exodia deck as the main focus of our analysis. The Exodia deck itself has so many variation. As we said before we will even more focused our analysis in Exodia deck with *Royal Magical Library* card as the main engine. The deck is consist of the following cards.

Monster cards:
- 5 cards of Exodia parts
- 3 Royal Magical Library

Spell cards:
- 3 Magical Citadel of Endymion (Field spell card)
- 1 One Day of Peace
- 3 Upstart Goblin
- 3 Terraforming
- 3 Broken Bamboo Sword
- 3 Golden Bamboo Sword
- 3 Dark World Dealings
- 3 Magical Mallet
- 3 Reload
- 3 Toon Table of Contens
- 1 Toon World
- 1 Pot of Duality
- 2 Spell Power Grasp

Picture 3.1 The complete deck list

To simplify our analysis we only consider all card's effect that has an effect on increasing or reducing the number of cards in the hand or the deck. So, any card effect like "increase your life points by 1000","destroy opponent card" and something similar will not be considered. The card effect of all cards in the deck are:

- Royal Magical Library
  - +1 *counter* for each activated spell card
  - Remove 3 counter, draw 1 card
- Magical Citadel of Endymion
  - +1 *counter* for each activated spell card
  - Once per turn if Royal Magical Library on the Monster Zone, remove 3 counter, draw 1 card
- One Day of Peace; Upstart Goblin
  - Draw 1 card
- Terraforming
  - Add Magical Citadel of Endymion from deck to the hand
- Golden Bamboo Sword
  - If Broken Bamboo Sword on the spell card zone Draw 2 cards
- Dark World Dealings
  - Draw 1 card, remove 1 card from hand
- Magical Mallet; Reload
  - Shuffle all card from hand, and draw the same amount
- Toon Table of Content
  - Add Toon Table of Content or Toon World from deck to the hand
- Pot of duality
  - Draw 3 cards, return 2 to the deck.
- Spell Power Grasp
  - +1 counter to 1 card on the field

Some important aspect to remember:
- All spell cards except Magical Citadel of Endymion can only be activated once each card, after that that it sent to graveyard.
- The effect of Royal Magical library can be activated many times as long as it has 3 *counters*.
- Royal Magical Library can only be summoned once per turn, due the rule of Yu-Gi-Oh! Trading Card Game.

To even more simplify our problem, we use an assumption that opponent act will not affect our cards, so, we can say that we play a game without opponent.

We will use the following term in our analysis:
- Turn: Turn is a player turn, in Yu-Gi-Oh! Trading Card Game, 1 turn is from the draw phase until the end phase.
- Sub-turn: Sub turn is every state after the activation of card effect.

The greedy strategy we use here, is to choose the card with the highest priority in each sub-turn so we hope that we can get all Exodia cards with as few turns as possible. The priority of each card is determined by the card functionality.

Formally, our problem can be stated as:
1. Candidate set
   The candidate set in our problem is a set of all card effect that can be activated during this sub-turn.
2. Solution set
   The set of all activated cards effects until all Exodia cards in the hand.
3. Selection function
   Choose the card effect with the highest priority, the priority itself is determined by the card functionality and the state of cards on the field.
4. Feasibility function
   Check whenever the card effect can be activated.
5. Objective function
   The number of turn spent is minimum

IV. APPLICATION

Firstly, we implements the selection function, the selection function must determine each card priority by considering it's card effect. We use the following rules in determining cards priority:

1. The lowest priority is cards with no effect of drawing or adding card from the deck. In our case, is Broken Bamboo Sword card and Toon World card.
2. The second lowest priority is card with the effect of adding the other card from the deck to the hand
3. The next priority is cards effect with the effect of replacing card(s) in the with card(s) from the deck. The cards is, Reload, Magical Mallet and Dark World dealings.
4. The second highest priority is a card with the effect of drawing card. In our case, is Upstart Goblin card, One Day of Peace card, Golden Bamboo Sword and Royal Magical Library drawing effect.
5. The highest priority is the main engine of the deck. First one is normal summoning Royal Magical Library and placing Magical Citadel of Endymion on the field card zone.

The pseudo code for the selection function is:

```
function select (input C:candidate_set)
himpunan_kandidat
{ Return the candidate with highest priority from
candidate set C
input: candidate set C
output: a candidate
}
Declaration:
Algorithm:
    for each (candidate c in C)
        if(c.effect = NO_EFFECT)
            c.priority = 1;
        else if(c.effect = ADD)
            c.priority = 2;
        else if(c.effect = REPLACE)
            c.priority = 3;
        else if(c.effect = DRAW)
            c.priority = 4;
        else {c.effect = MAIN}
            c.priority = 5;
        endif
    end for
    return (candidate with highest priority)
```

After that, we implements the feasibility function, the function is quite simple as it follow the rule of the game and card effect limitation The rules are:

1. Normal summon can only be invoked once per turn.
2. Royal Magical Library drawing effect can only be activated after it summoned on the monster card zone and when it has 3 counters
3. Magical Citadel of Endymion draw effect can only be activated when there is Royal Magical Library on the monster card zone.
4. Golden Bamboo Sword card's effect can only be activated when there is Broken Bamboo Sword on the spell card zone.
5. Cards with the effect of adding other card from the deck can only be activated when the card to be added still exist in the deck.

The pseudo code for feasibility function is:

```
function feasible (input c:candidate, f: field)
himpunan_kandidat
{ Return whenever the candidate is feasible or not
input :a candidate
output    :true, if the candidate set is feasible
          false, if the candidate set not feasible
}
Declaration:
```

```
Algorithm:
    if(c.effect = NORMAL_SUMMON)
        if(fied.isAlreadyNormalSummon())
            return false
        else
            return true
        endif
    else if(c.effect = DRAW)
        if(c.card = RoyalMagicalLibrary)
            if(c.has3Counter and c.isOnMonsterZone)
                return true
            else
                return false
            endif
        elseif(c.card = MagicalCitadelofEndymion)
            if(c.has3Counter and f.monsterZone.
isExist(RoyalMagicalLibrary))
                return true
            else
                return false
            endif
        else if(c.card = GoldenBambooSword)
            if(f.spellZone.isExist(BrokenBambooSwo
rd))
                return true
            else
                return false
            endif
        else return false
        endif
    else {c.effect = ADD}
        if(f.deck.isExist(c.effect.card))
            return true
        else
            return false
        endif
    endif
```

The main greedy function will be much alike the general greedy function we described before. With the difference, when no candidate is feasible, that's not means there are no solution, but, we go to the next turn, draw 1 card, and repeat all the step with addition of 1 card. This process stopped when all Exodia cards in the player hand.

V. CONCLUSION

Exodia deck is one of the popular deck in Yu-Gi-Oh! Trading Card Games. This deck objective is to win a duel using Exodia cards effect.

Greedy algorithm can be used in this kind of deck to minimize the number of turn spent in a game using this deck. By choosing local maximum we can draw as much as possible card from the deck until all five cards of Exodia part collected. The solution of this problem using greedy algorithm is not the best solution if we can see the card sequence in the deck. But, because in the real game we can't see card sequence in the deck, the solution can

be the best solution depends on the selection function we describe.

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PERNYATAAN

Dengan ini saya menyatakan bahwa makalah yang saya tulis ini adalah tulisan saya sendiri, bukan saduran, atau terjemahan dari makalah orang lain, dan bukan plagiasi.

Bandung, 19 Mei 2014

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