Dota 2: what should I pick?

Data Mining
Clustering and Association Analysis
732A61

Rasmus Holm

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Introduction

Electronics sports, which will from now on be referred to as esports, are a form of competition using electronic systems, in particular video games, controlled by human players. In recent years the revenue and audience have seen a rapid growth with an estimation of over 300 million viewers in 2016 and over $450 million in global revenue, and it is expected to see a formidable growth in the near future.[1]

The esports industry utilizes many different platforms such as personal computers, x-box, playstation, and since everything is electronic we could potentially utilize all that data that is being generated for various kinds of analyses. That could help organizations/teams find better strategies, improve the viewer experience, and help newcomers getting accustomed to the different games in a short time span.

DOTA 2

Defense of the Ancients (DOTA 2) is a so called multiplayer online battle arena (MOBA) video game developed by Valve Corporation made first available in 2011. The game plays out as two teams of 5 players battle against each other where every player controls a hero, a character with unique abilities. The aim is to destroy the opponents ancient and thus win the game. How that is achieved varies from game to game, from fast paced game that are under 20 minutes to long drawn out game lasting over 60 minutes. It will not be necessary to understand the gameplay to follow this article since the focus is on the draft phase which is explained below.

Draft Phase

The draft phase is the time the two teams pick their heroes, as of June 13, 2017there are 113 unique heroes to select from, that will be played during the gameplay phase. Each team has to pick 5 heroes, ban 5 heroes, and banned heroes are unavailable for either team. The actual order is shown in figure 1.

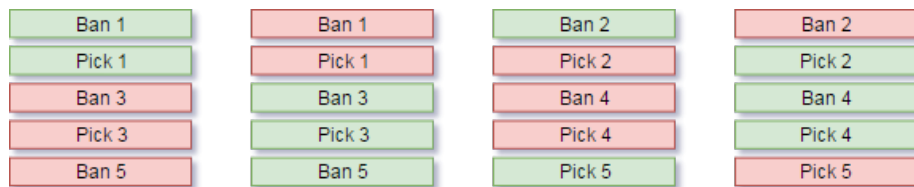| Ban 1 | Ban 1 | Ban 2 | Ban 2 |
Pick 1	Pick 1	Pick 2	Pick 2
Ban 3	Ban 3	Ban 4	Ban 4
Pick 3	Pick 3	Pick 4	Pick 4
Ban 5	Ban 5	Pick 5	Pick 5

Figure 1: The pick and ban orders read from left to right, top to bottom. The colors represent the two teams.

This phase is very tactical and determines a lot how the gameplay will pan out. The reason for that is that heroes have their strengths and weaknesses. The heroes of a team composition fulfill different purposes, very broadly speaking at what time periods they are powerful and weak. Another useful term is the *metagame* that is globally influential on what heroes are being picked. It

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[1]https://newzoo.com/insights/articles/esports-revenues-will-reach-696-million-in-2017/

describes what strategies, heroes, and ideas about the game is currently popular and is heavily influenced by the developers' changes to the game but also as the professional community figures out what works well.

Questions

In this report I am going to use cluster and association analysis in order to figure out if it is possible to find relevant patterns that could help newcomers to watching professional DOTA 2. The questions I have set to explore are mainly based the relationships between heroes. The relationship is either *synergistic*, e.g., hero X works well with hero Y, or *counteractive*, e.g., hero X is strong against hero Y.

- When should I pick hero X?

- Which heroes should I pick along with hero X?

- What are common team compositions overall?

- Do team compositions change between tournaments?

Theory

In this report, I will be using the ROCK clustering algorithm [4] for finding clusters and FP-Growth algorithm [5] for finding association rules. Furthermore, I will be using k-modes clustering algorithm as well which is described below.

k-modes

k-means is one of the oldest and most well known clustering algorithms today. However, it is not well suited for categorical variables that is being used in this report, but k-modes by Zhexue Huang [6] is an exension to k-means for just that purpose.

The k-modes algorithm uses the simple matching dissimilarity measure for categorical objects and is formally

$$d_1(x_i, x_j) = \sum_{k=1}^{m} \mathbb{1}\{x_{i,k} \neq x_{j,k}\},$$

where $\mathbb{1}\{\cdot\}$ is the indicator function and x_i, x_j are vectors of m categorical values.

Let $X = [x_1, x_2, \ldots, x_n]$ be a set of categorical objects describe by categorical attributes $A_1, A_2, \ldots, A_m$. A mode of dataset X is a vector $q = [q_1, q_2, \ldots, q_m]$ that minimizes

$$d(X, q) = \sum_{i=1}^{n} d_1(x_i, q).$$

Let $n_{c_{k,j}}$ be the number of objects having the kth category $c_{k,j}$ in attribute A_j and $f_r(A_j = c_k, j|X) = \frac{n_{c_{k,j}}}{n}$ is the relative frequency of category $c_{k,j}$ in X. The function $d(X, q)$ is minimized by selecting the mode according to $f_r(A_j = q_j|X) >= f_r(A_j = c_{k,j}|X)$ for $q_j \neq c_{k,j}$ for all $j = 1, \ldots, m$.

The cost function becomes

$$P(W, Q) = \sum_{l=1}^{k} \sum_{i=1}^{n} \sum_{j=1}^{m} w_{l,i} \mathbb{1}\{x_{i,j} \neq q_{l,j}\},$$

where $q_l = [q_{l,1}, q_{l,2}, \ldots, q_{l,m}]$ and $w_{l,i} \in \{0, 1\}$, $\sum_{l=1}^{k} w_{l,i} = 1$, and $0 < \sum_{i=1}^{n} w_{l,i} < n$. This can be minimized iteratively similar to how k-means does it, but instead using the simple matching dissimilarity measure, working with cluster modes, and updating those modes according to the above criteria. Since this algorithm converges to a local optima the initial set of modes are important, therefore I decided to use the initialization method by Cao et al. [1] based on density to do that automatically.

The ordering of the categorical attributes in the dissimilarity measure above matters because it do not make any assumptions about their domains. In the analysis done in this report the domain is the same for all variables so the ordering should not matter in this particular case. So I will also use an alternative dissimilarity measurement defined below.

3

Let x_i and x_j be two vectors of length m, then the dissimilarity measure is defined as

$$d_2(x_i, x_j) = n - \sum_{k=1}^{m} \sum_{l=1}^{m} \mathbb{1}\{x_{i,k} == x_{j,l}\}.$$

Method

As esports is a rather new phenomenon, there have not been much analyses around it in the literature. However, some research have been made in DOTA 2 such as a recommendation engine for picks based on machine learning by Conley and Perry [2]. Summerville et al. [3] have used machine learning to predict picks in the draft phase. In this report it is more of interest to explore patterns in the draft using data mining techniques rather than machine learning which is lacking in the literature.

Dataset

DOTABUFF[2] is a website that contain detailed information and statistics about both competitive and casual matches. The dataset used in this article consists of all the matches from all the Valve major championships until June 13, 2017and all the Internationals from 2012 stored by DOTABUFF. That covers 3028 matches in total.

Evaluation

To evaluate the results from the analyses they have to be analyzed by either players, analysts, or enthusiasts that have a fairly good understanding of the game and the heroes in particular. I decided upon using qualitative analysis based on my own knowledge gained by watching a lot of professional games over the years and therefore heard professional game analysts' opinions about the game.

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[2]https://www.dotabuff.com/

Result

Association Analysis

When should I pick hero X?

To keep the scope realistic I decided to choose two particular heroes, Anti-Mage and Clinkz, to analyze when it should be picked according to patterns in professional matches.

Anti-Mage is usually a niche pick that have specific strengths as his name suggests. A mobile hero that is extra strong against mages so he is usually picked at the end of the drafting phase. The matches analyzed are those where he is picked as a 4th or 5th pick, 153 out of 180 matches, in Valve events as it suggest that he was a counter pick to the opposing teams heroes. The analysis for Anti-Mage was done by select the opposing team composition of the 153 matches and run the FP-Growth algorithm on the matrix, 153x5, and table 1 shows rules that were found.

antecedent	consequent
Razor	Rubick
Ember Spirit	Dark Seer
Sand King	Rubick
Naga Siren	Dark Seer

Table 1: Association rules by FP-Growth algorithm of 153 team compositions against 4th or 5th pick Anti-Mage. The parameters were set to minimum support of 5 and minimum confidence of 0.4.

Clinkz is also a niche pick that is very mobile because he can become invisible and has high single target damage. He his, as Anti-Mage, usually a 4th or 5th pick, 93 out of 102 matches, and so a similar analysis was made which can be seen in table 2.

antecedent	consequent
Dark Seer	Juggernaut
Gyrocopter	Earthshaker
Tiny	Io

Table 2: Association rules by FP-Growth algorithm of 180 team compositions against 4th or 5th pick Clinkz. The parameters were set to minimum support of 5 and minimum confidence of 0.5.

Which hero should I pick along X?

Similar to above, I decided to choose two heroes, Io the Wisp and Magnus. Io is very good at adding mobility and durability to heroes. Io is most commonly picked early in the draft since it can be combined with many heroes depending on the opponent's picks. Magnus is good at buffing melee heroes and initiate engagements

Here I used all the team compositions from 3028 matches, i.e. 6056 team compositions, in which Io occurs 451 times and magnus 165. The rules selected

contained either Io or Magnus in either the antecedent or consequent. Table 3 shows the rules found for Io by FP-Growth

Antecedent	Consequent
Earthshaker, Tiny	Io
Tiny, Beastmater	Io
Tiny, Rubick	Io
Earthshaker, Io	Tiny
Tiny, Queen of Pain	Io
Tiny, Batrider	Io

Table 3: Association rules containing Io by FP-Growth algorithm of 6028 team compositions. The parameters were set to minimum support of 10 and minimum confidence of 0.5.

and table 4 contains the rules that include Magnus.

Antecedent	Consequent
Vengeful Spirit, Magnus	Juggernaut
Templar Assassin, Magnus	Juggernaut
Silencer, Magnus	Juggernaut
Witch Doctor, Magnus	Juggernaut

Table 4: Association rules containing Magnus by FP-Growth algorithm of 6028 team compositions. The parameters were set to minimum support of 5 and minimum confidence of 0.5.

Cluster Analysis

The Manila Major 2016

The Shanghai Major 2016

Discussion

Conclusion

In this paper I have used data mining techniques to find patterns in the drafting phase of DOTA 2 in professional matches by looking at the team compositions.

Future Work

To further improve the evaluation of the techniques used in the analyses is to make it possible for the community to rate it by an online interface. That way it would be possible to gain feedback from people with various degree of knowledge about the game to determine if the results are useful to the targeted demographic.

References

[1] Fuyuan Cao, Jiye Liang, and Liang Bai. A new initialization method for categorical data clustering. *Expert Systems with Applications*, 36(7):10223–10228, 2009.

[2] Kevin Conley and Daniel Perry. How does he saw me? a recommendation engine for picking heroes in dota 2. *Np, nd Web*, 7, 2013.

[3] Michael Cook. Draft-analysis of the ancients: Predicting draft picks in dota 2 using machine learning. 2016.

[4] Sudipto Guha, Rajeev Rastogi, and Kyuseok Shim. Rock: A robust clustering algorithm for categorical attributes. *Information systems*, 25(5):345–366, 2000.

[5] Jiawei Han, Jian Pei, and Yiwen Yin. Mining frequent patterns without candidate generation. In *ACM Sigmod Record*, volume 29, pages 1–12. ACM, 2000.

[6] Zhexue Huang. Extensions to the k-means algorithm for clustering large data sets with categorical values. *Data mining and knowledge discovery*, 2(3):283–304, 1998.

Clustering of All Major Events Since 2012

k-modes

Size	Samples
	Clusters
2326	Juggernaut: 268, Timbersaw: 225, Slardar: 300, Rubick: 315, Dazzle: 296 Faceless Void: 179, Invoker: 281, Dazzle: 296, Rubick: 315, Timbersaw: 225
614	Queen of Pain: 195, Disruptor: 193, Dark Seer: 191, Lifestealer: 93, Rubick: 122 Earthshaker: 43, Queen of Pain: 195, Gyrocopter: 61, Disruptor: 193, Dark Seer: 191
486	Io: 203, Earthshaker: 82, Templar Assassin: 97, Witch Doctor: 176, Tiny: 80 Io: 203, Bristleback: 23, Batrider: 48, Tiny: 80, Witch Doctor: 176
462	Slark: 102, Vengeful Spirit: 169, Earth Spirit: 128, Batrider: 131, Dragon Knight: 102 Slark: 102, Vengeful Spirit: 169, Dark Seer: 38, Earth Spirit: 128, Dragon Knight: 102
306	Disruptor: 98, Gyrocopter: 99, Dark Seer: 169, Templar Assassin: 29, Rubick: 33 Disruptor: 98, Night Stalker: 30, Gyrocopter: 99, Dark Seer: 169, Viper: 13
398	Juggernaut: 119, Disruptor: 103, Invoker: 84, Batrider: 140, Enchantress: 53 Juggernaut: 119, Disruptor: 103, Enchantress: 53, Batrider: 140, Beastmaster: 33
372	Tusk: 124, Ember Spirit: 80, Lina: 82, Rubick: 110, Dragon Knight: 78 Queen of Pain: 20, Tusk: 124, Winter Wyvern: 22, Rubick: 110, Dragon Knight: 78
160	Io: 21, Tinker: 58, Sven: 57, Rubick: 35, Clockwerk: 49 Tinker: 58, Sven: 57, Dark Seer: 12, Shadow Shaman: 6, Beastmaster: 16
172	Templar Assassin: 47, Storm Spirit: 67, Lifestealer: 59, Batrider: 31, Rubick: 31 Lifestealer: 59, Elder Titan: 6, Batrider: 31, Rubick: 31, Templar Assassin: 47
109	Io: 31, Juggernaut: 16, Disruptor: 22, Ember Spirit: 76, Bristleback: 21 Io: 31, Juggernaut: 16, Ember Spirit: 76, Bristleback: 21, Lion: 17
69	Tinker: 39, Slark: 21, Dark Seer: 19, Slardar: 21, Witch Doctor: 22 Phoenix: 4, Tinker: 39, Faceless Void: 8, Witch Doctor: 22, Slark: 21
296	Doom: 108, Queen of Pain: 64, Shadow Demon: 74, Dazzle: 85, Weaver: 49 Doom: 108, Shadow Demon: 74, Storm Spirit: 7, Dazzle: 85, Mirana: 42
91	Tinker: 14, Disruptor: 39, Lifestealer: 33, Slardar: 44, Clockwerk: 37 Templar Assassin: 6, Disruptor: 39, Ogre Magi: 6, Lifestealer: 33, Slardar: 44
84	Io: 8, Juggernaut: 20, Anti-Mage: 38, Dazzle: 11, Batrider: 40 Anti-Mage: 38, Ogre Magi: 8, Dazzle: 11, Magnus: 6, Batrider: 40
111	Queen of Pain: 27, Earthshaker: 73, Luna: 21, Rubick: 18, Shadow Fiend: 48 Tusk: 7, Earthshaker: 73, Luna: 21, Rubick: 18, Shadow Fiend: 48

Table 5:

k-modes with modified dissimilarity measure

Clusters	
Size	Samples
1781	Dazzle: 282, Slardar: 301, Timbersaw: 184, Juggernaut: 208, Rubick: 376 Dazzle: 282, Templar Assassin: 56, Slardar: 301, Juggernaut: 208, Rubick: 376
691	Disruptor: 229, Dark Seer: 211, Lifestealer: 107, Queen of Pain: 219, Rubick: 126 Disruptor: 229, Dark Seer: 211, Gyrocopter: 64, Queen of Pain: 219, Earthshaker: 66
519	Earthshaker: 83, Tiny: 68, Witch Doctor: 186, Templar Assassin: 108, Io: 213 Witch Doctor: 186, Bristleback: 33, Tiny: 68, Batrider: 53, Io: 213
465	Vengeful Spirit: 167, Slark: 102, Earth Spirit: 121, Dragon Knight: 103, Batrider: 133 Dark Seer: 36, Slark: 102, Earth Spirit: 121, Dragon Knight: 103, Vengeful Spirit: 167
418	Disruptor: 114, Enchantress: 53, Invoker: 88, Juggernaut: 123, Batrider: 141 Disruptor: 114, Enchantress: 53, Beastmaster: 34, Juggernaut: 123, Batrider: 141
386	Ember Spirit: 80, Tusk: 126, Lina: 80, Dragon Knight: 83, Rubick: 111 Ember Spirit: 80, Tusk: 126, Ancient Apparition: 31, Spirit Breaker: 24, Dragon Knight: 83
283	Dazzle: 102, Tusk: 59, Ember Spirit: 76, Gyrocopter: 82, Lina: 41 Dazzle: 102, Ember Spirit: 76, Gyrocopter: 82, Slardar: 22, Beastmaster: 25
254	Doom: 95, Lina: 23, Lion: 77, Juggernaut: 59, Clockwerk: 41 Doom: 95, Queen of Pain: 24, Night Stalker: 16, Lion: 77, Juggernaut: 59
265	Disruptor: 59, Vengeful Spirit: 75, Morphling: 47, Invoker: 84, Dark Seer: 64 Morphling: 47, Dark Seer: 64, Invoker: 84, Lion: 9, Bounty Hunter: 19
205	Dark Seer: 93, Templar Assassin: 31, Earthshaker: 49, Spectre: 29, Witch Doctor: 37 Gyrocopter: 14, Dark Seer: 93, Templar Assassin: 31, Earthshaker: 49, Ancient Apparition: 7
181	Sven: 34, Storm Spirit: 51, Slardar: 47, Shadow Demon: 53, Bounty Hunter: 28 Storm Spirit: 51, Axe: 14, Shadow Demon: 53, Sand King: 15, Luna: 9
197	Sand King: 36, Razor: 27, Shadow Demon: 73, Mirana: 69, Juggernaut: 65 Ogre Magi: 27, Shadow Demon: 73, Sand King: 36, Mirana: 69, Luna: 29
162	Timbersaw: 33, Shadow Demon: 46, Sand King: 42, Mirana: 73, Shadow Fiend: 26 Naga Siren: 16, Mirana: 73, Shadow Demon: 46, Sand King: 42, Juggernaut: 5
130	Vengeful Spirit: 49, Night Stalker: 19, Gyrocopter: 34, Alchemist: 31, Batrider: 26 Doom: 4, Vengeful Spirit: 49, Gyrocopter: 34, Shadow Fiend: 5, Batrider: 26
119	Slark: 26, Invoker: 43, Beastmaster: 40, Rubick: 19, Winter Wyvern: 19 Invoker: 43, Clinkz: 4, Earth Spirit: 6, Beastmaster: 40, Oracle: 15

Table 6:

Clustering of Manila Major 2016

k-modes

Clusters	
Size	Samples
234	Lion: 60, Dragon Knight: 37, Wraith King: 4, Doom: 52, Batrider: 51 Nature's Prophet: 30, Lion: 60, Batrider: 51, Juggernaut: 27, Enchantress: 27 Lion: 60, Dragon Knight: 37, Nature's Prophet: 30, Doom: 52, Axe: 10 Lion: 60, Alchemist: 18, Io: 31, Doom: 52, Juggernaut: 27 Lion: 60, Dragon Knight: 37, Earth Spirit: 32, Slark: 33, Dark Seer: 24 Lion: 60, Dark Seer: 24, Dragon Knight: 37, Phoenix: 29, Slark: 33 Lion: 60, Dragon Knight: 37, Doom: 52, Lich: 17, Lifestealer: 14 Lion: 60, Dragon Knight: 37, Doom: 52, Tidehunter: 12, Spectre: 14 Lion: 60, Dragon Knight: 37, Juggernaut: 27, Slardar: 24, Enchantress: 27 Lion: 60, Queen of Pain: 18, Doom: 52, Spectre: 14, Nature's Prophet: 30 Dragon Knight: 37, Witch Doctor: 22, Doom: 52, Slark: 33, Nature's Prophet: 30
111	Vengeful Spirit: 41, Beastmaster: 62, Clinkz: 10, Slardar: 33, Queen of Pain: 15 Vengeful Spirit: 41, Beastmaster: 62, Earth Spirit: 16, Slardar: 33, Morphling: 2 Vengeful Spirit: 41, Beastmaster: 62, Lone Druid: 4, Lich: 7, Slardar: 33 Lion: 17, Vengeful Spirit: 41, Beastmaster: 62, Lycan: 7, Invoker: 12 Vengeful Spirit: 41, Beastmaster: 62, Witch Doctor: 18, Juggernaut: 13, Viper: 3
45	Witch Doctor: 31, Windranger: 10, Doom: 10, Phoenix: 10, Slardar: 13 Witch Doctor: 31, Storm Spirit: 1, Doom: 10, Phoenix: 10, Slardar: 13
52	Witch Doctor: 27, Axe: 13, Doom: 21, Lifestealer: 16, Queen of Pain: 12 Witch Doctor: 27, Puck: 10, Doom: 21, Lifestealer: 16, Nature's Prophet: 8
60	Disruptor: 27, Ember Spirit: 4, Lifestealer: 14, Slardar: 9, Bounty Hunter: 25 Broodmother: 1, Disruptor: 27, Puck: 7, Lifestealer: 14, Bounty Hunter: 25 Disruptor: 27, Gyrocopter: 3, Tidehunter: 10, Invoker: 6, Bounty Hunter: 25
39	Vengeful Spirit: 23, Ember Spirit: 11, Doom: 9, Invoker: 12, Dark Seer: 9 Vengeful Spirit: 23, Ember Spirit: 11, Tidehunter: 6, Invoker: 12, Chen: 2
27	Dragon Knight: 8, Disruptor: 17, Doom: 13, Tidehunter: 9, Gyrocopter: 9 Disruptor: 17, Death Prophet: 1, Doom: 13, Gyrocopter: 9, Tidehunter: 9
20	Sven: 6, Alchemist: 8, Disruptor: 8, Beastmaster: 9, Earth Spirit: 9 Alchemist: 8, Beastmaster: 9, Earth Spirit: 9, Lifestealer: 5, Lich: 3
27	Lion: 16, Night Stalker: 8, Juggernaut: 8, Invoker: 4, Enchantress: 6 Lion: 16, Dark Seer: 11, Puck: 6, Lifestealer: 4, Tusk: 3
27	Lion: 6, Invoker: 7, Slardar: 16, Juggernaut: 3, Enchantress: 7 Mirana: 9, Earth Spirit: 3, Witch Doctor: 4, Slardar: 16, Enchantress: 7

Table 7:

k-modes with modified dissimilarity measure

Clusters	
Size	**Samples**
234	Dragon Knight: 48, Wraith King: 4, Doom: 103, Lion: 50, Batrider: 49 Dragon Knight: 48, Doom: 103, Lich: 19, Lion: 50, Lifestealer: 23 Dragon Knight: 48, Doom: 103, Nature's Prophet: 26, Lion: 50, Axe: 16 Dragon Knight: 48, Doom: 103, Lion: 50, Tidehunter: 14, Spectre: 14 Dragon Knight: 48, Nature's Prophet: 26, Doom: 103, Witch Doctor: 26, Slark: 17 Queen of Pain: 21, Doom: 103, Lion: 50, Dark Seer: 21, Lifestealer: 23 Lion: 50, Juggernaut: 25, Doom: 103, Io: 24, Alchemist: 13 Dragon Knight: 48, Queen of Pain: 21, Doom: 103, Crystal Maiden: 15, Phoenix: 28 Queen of Pain: 21, Doom: 103, Nature's Prophet: 26, Lion: 50, Spectre: 14 Dragon Knight: 48, Lich: 19, Doom: 103, Witch Doctor: 26, Slark: 17 Dragon Knight: 48, Doom: 103, Lion: 50, Weaver: 5, Abaddon: 6
118	Clinkz: 9, Beastmaster: 71, Queen of Pain: 15, Vengeful Spirit: 39, Slardar: 33 Earth Spirit: 16, Slardar: 33, Morphling: 2, Vengeful Spirit: 39, Beastmaster: 71 Slardar: 33, Beastmaster: 71, Lone Druid: 4, Lich: 7, Vengeful Spirit: 39 Beastmaster: 71, Lycan: 6, Lion: 18, Vengeful Spirit: 39, Invoker: 14 Beastmaster: 71, Witch Doctor: 20, Juggernaut: 13, Viper: 3, Vengeful Spirit: 39
88	Slardar: 48, Witch Doctor: 40, Batrider: 16, Lifestealer: 12, Vengeful Spirit: 18 Slardar: 48, Witch Doctor: 40, Earth Spirit: 11, Invoker: 13, Gyrocopter: 10 Slardar: 48, Witch Doctor: 40, Lich: 5, Ember Spirit: 13, Batrider: 16 Slardar: 48, Witch Doctor: 40, Earth Spirit: 11, Invoker: 13, Sven: 6
57	Earthshaker: 5, Puck: 15, Slark: 13, Enchantress: 27, Disruptor: 25 Faceless Void: 11, Disruptor: 25, Chaos Knight: 1, Enchantress: 27, Puck: 15
36	Alchemist: 4, Queen of Pain: 9, Lifestealer: 9, Lion: 6, Bounty Hunter: 21 Lifestealer: 9, Queen of Pain: 9, Witch Doctor: 8, Broodmother: 1, Bounty Hunter: 21
32	Death Prophet: 10, Slardar: 5, Slark: 9, Earth Spirit: 13, Disruptor: 6 Dragon Knight: 4, Slark: 9, Earth Spirit: 13, Lion: 5, Dark Seer: 5
24	Bounty Hunter: 2, Ember Spirit: 7, Lion: 14, Dark Seer: 13, Spectre: 5 Dark Seer: 13, Invoker: 5, Lion: 14, Winter Wyvern: 1, Lifestealer: 7
20	Medusa: 5, Puck: 7, Witch Doctor: 7, Nature's Prophet: 5, Vengeful Spirit: 6 Medusa: 5, Beastmaster: 7, Witch Doctor: 7, Phoenix: 4, Puck: 7
22	Night Stalker: 5, Medusa: 1, Lion: 12, Dark Seer: 5, Invoker: 7 Juggernaut: 3, Queen of Pain: 1, Night Stalker: 5, Lion: 12, Phoenix: 6
11	Bane: 2, Faceless Void: 2, Enigma: 3, Invoker: 2, Phantom Lancer: 4 Bane: 2, Slardar: 1, Enigma: 3, Io: 4, Alchemist: 3

Table 8:

ROCK

Clusters	
Size	Samples
21	Queen of Pain: 11, Dark Seer: 12, Lifestealer: 9, Doom: 10, Lion: 9 Earth Spirit: 6, Dark Seer: 12, Queen of Pain: 11, Lifestealer: 9, Lion: 9
16	Lifestealer: 6, Lich: 4, Doom: 13, Dragon Knight: 7, Lion: 9 Spectre: 1, Tidehunter: 3, Doom: 13, Dragon Knight: 7, Lion: 9
13	Dark Seer: 5, Gyrocopter: 3, Vengeful Spirit: 13, Doom: 11, Queen of Pain: 2 Vengeful Spirit: 13, Dark Seer: 5, Puck: 4, Doom: 11, Lifestealer: 1
12	Batrider: 10, Slark: 2, Puck: 6, Doom: 4, Crystal Maiden: 6 Morphling: 2, Batrider: 10, Puck: 6, Doom: 4, Crystal Maiden: 6
13	Tidehunter: 6, Mirana: 6, Doom: 10, Disruptor: 12, Queen of Pain: 1 Slardar: 2, Disruptor: 12, Doom: 10, Mirana: 6, Gyrocopter: 4
12	Beastmaster: 8, Juggernaut: 8, Vengeful Spirit: 7, Mirana: 5, Enigma: 2 Earth Spirit: 4, Beastmaster: 8, Vengeful Spirit: 7, Invoker: 3, Juggernaut: 8
20	Slardar: 6, Puck: 10, Witch Doctor: 17, Nature's Prophet: 7, Lifestealer: 10 Lifestealer: 10, Puck: 10, Doom: 5, Nature's Prophet: 7, Witch Doctor: 17
11	Slardar: 10, Dark Seer: 6, Doom: 4, Templar Assassin: 5, Witch Doctor: 6 Slardar: 10, Dark Seer: 6, Witch Doctor: 6, Templar Assassin: 5, Bane: 1
16	Earth Spirit: 9, Dark Seer: 16, Slark: 5, Dragon Knight: 5, Lion: 10 Earth Spirit: 9, Dark Seer: 16, Invoker: 2, Spectre: 6, Lion: 10
23	Slardar: 20, Earth Spirit: 6, Gyrocopter: 6, Invoker: 7, Witch Doctor: 19 Slardar: 20, Earth Spirit: 6, Sven: 5, Invoker: 7, Witch Doctor: 19
11	Slardar: 9, Morphling: 1, Beastmaster: 8, Vengeful Spirit: 9, Earth Spirit: 6 Slardar: 9, Beastmaster: 8, Vengeful Spirit: 9, Clinkz: 1, Queen of Pain: 3
10	Slardar: 7, Phoenix: 3, Dragon Knight: 9, Disruptor: 4, Lifestealer: 4 Slardar: 7, Phoenix: 3, Vengeful Spirit: 5, Dragon Knight: 9, Lone Druid: 1
12	Dazzle: 10, Tidehunter: 5, Lycan: 5, Invoker: 4, Earth Spirit: 7 Dazzle: 10, Earth Spirit: 7, Batrider: 4, Lycan: 5, Timbersaw: 2
15	Slardar: 8, Morphling: 5, Beastmaster: 5, Lion: 12, Lich: 6 Morphling: 5, Beastmaster: 5, Elder Titan: 4, Mirana: 7, Lion: 12
12	Puck: 4, Beastmaster: 9, Lifestealer: 7, Enchantress: 4, Lion: 8 Beastmaster: 9, Lion: 8, Tinker: 4, Disruptor: 3, Lifestealer: 7
34	Puck: 10, Juggernaut: 19, Faceless Void: 12, Enchantress: 19, Lion: 20 Slardar: 5, Invoker: 8, Juggernaut: 19, Enchantress: 19, Lion: 20

Table 9:

Clustering of Shanghai Major 2016

k-modes

Clusters	
Size	Samples
221	Vengeful Spirit: 37, Witch Doctor: 57, Juggernaut: 12, Invoker: 40, Nature's Prophet: 30 Witch Doctor: 57, Batrider: 20, Lone Druid: 26, Earth Spirit: 28, Death Prophet: 23 Witch Doctor: 57, Faceless Void: 14, Ember Spirit: 14, Earth Spirit: 28, Invoker: 40 Spirit Breaker: 18, Bounty Hunter: 15, Witch Doctor: 57, Invoker: 40, Death Prophet: 23 Faceless Void: 14, Witch Doctor: 57, Spectre: 10, Invoker: 40, Enchantress: 26 Sven: 14, Io: 23, Witch Doctor: 57, Tiny: 17, Dark Seer: 31 Vengeful Spirit: 37, Bristleback: 7, Witch Doctor: 57, Spectre: 10, Nature's Prophet: 30 Spirit Breaker: 18, Doom: 7, Witch Doctor: 57, Outworld Devourer: 18, Invoker: 40 Dark Seer: 31, Witch Doctor: 57, Outworld Devourer: 18, Tiny: 17, Bounty Hunter: 15 Io: 23, Beastmaster: 23, Witch Doctor: 57, Tiny: 17, Queen of Pain: 17 Faceless Void: 14, Witch Doctor: 57, Oracle: 19, Invoker: 40, Viper: 6
76	Juggernaut: 12, Slardar: 8, Bane: 19, Tusk: 34, Invoker: 24 Ancient Apparition: 6, Ember Spirit: 7, Tusk: 34, Invoker: 24, Dark Seer: 13 Legion Commander: 1, Beastmaster: 7, Tusk: 34, Invoker: 24, Gyrocopter: 13
76	Vengeful Spirit: 38, Disruptor: 20, Drow Ranger: 6, Gyrocopter: 31, Nyx Assassin: 13 Vengeful Spirit: 38, Disruptor: 20, Drow Ranger: 6, Gyrocopter: 31, Nature's Prophet: 7 Vengeful Spirit: 38, Disruptor: 20, Gyrocopter: 31, Sand King: 1, Queen of Pain: 8
44	Sven: 13, Vengeful Spirit: 25, Slardar: 4, Chen: 14, Invoker: 10 Sven: 13, Dark Seer: 7, Batrider: 6, Doom: 2, Vengeful Spirit: 25
40	Spirit Breaker: 12, Dragon Knight: 2, Gyrocopter: 21, Oracle: 13, Zeus: 6 Spirit Breaker: 12, Abaddon: 4, Puck: 1, Gyrocopter: 21, Oracle: 13
40	Lion: 20, Ember Spirit: 8, Beastmaster: 15, Clinkz: 3, Nature's Prophet: 15 Lion: 20, Ursa: 4, Beastmaster: 15, Razor: 1, Nature's Prophet: 15
38	Puck: 10, Faceless Void: 27, Witch Doctor: 10, Gyrocopter: 19, Pudge: 1 Faceless Void: 27, Witch Doctor: 10, Gyrocopter: 19, Templar Assassin: 3, Enchantress: 8
23	Juggernaut: 11, Disruptor: 6, Tusk: 9, Invoker: 10, Nature's Prophet: 11 Death Prophet: 3, Witch Doctor: 4, Tusk: 9, Juggernaut: 11, Nature's Prophet: 11
23	Juggernaut: 10, Chen: 4, Tusk: 15, Invoker: 9, Tidehunter: 6 Lion: 1, Juggernaut: 10, Tusk: 15, Invoker: 9, Tidehunter: 6
17	Batrider: 5, Bane: 13, Terrorblade: 1, Invoker: 8, Chen: 5 Doom: 2, Bane: 13, Juggernaut: 3, Invoker: 8, Chen: 5

Table 10:

k-modes with modified dissimilarity measure

Clusters	
Size	Samples
205	Vengeful Spirit: 42, Witch Doctor: 54, Nature's Prophet: 33, Invoker: 66, Juggernaut: 28
	Death Prophet: 22, Spirit Breaker: 17, Witch Doctor: 54, Invoker: 66, Bounty Hunter: 13
	Vengeful Spirit: 42, Slark: 12, Nature's Prophet: 33, Invoker: 66, Disruptor: 18
	Tusk: 22, Juggernaut: 28, Nature's Prophet: 33, Invoker: 66, Disruptor: 18
	Faceless Void: 21, Witch Doctor: 54, Invoker: 66, Enchantress: 17, Spectre: 6
	Vengeful Spirit: 42, Pugna: 4, Nature's Prophet: 33, Invoker: 66, Dazzle: 19
	Spirit Breaker: 17, Dazzle: 19, Nature's Prophet: 33, Invoker: 66, Juggernaut: 28
	Oracle: 13, Faceless Void: 21, Witch Doctor: 54, Invoker: 66, Viper: 8
	Beastmaster: 15, Vengeful Spirit: 42, Night Stalker: 17, Invoker: 66, Gyrocopter: 20
	Spirit Breaker: 17, Witch Doctor: 54, Invoker: 66, Doom: 8, Outworld Devourer: 14
94	Bane: 22, Juggernaut: 16, Slardar: 9, Tusk: 42, Invoker: 34
	Ancient Apparition: 6, Ember Spirit: 8, Tusk: 42, Dark Seer: 16, Invoker: 34
	Gyrocopter: 17, Treant Protector: 2, Nature's Prophet: 10, Invoker: 34, Tusk: 42
	Beastmaster: 8, Legion Commander: 1, Tusk: 42, Gyrocopter: 17, Invoker: 34
82	Drow Ranger: 6, Vengeful Spirit: 40, Disruptor: 20, Nyx Assassin: 14, Gyrocopter: 35
	Drow Ranger: 6, Vengeful Spirit: 40, Disruptor: 20, Nature's Prophet: 8, Gyrocopter: 35
	Undying: 9, Vengeful Spirit: 40, Nature's Prophet: 8, Zeus: 13, Gyrocopter: 35
	Sand King: 1, Vengeful Spirit: 40, Queen of Pain: 8, Disruptor: 20, Gyrocopter: 35
48	Clinkz: 3, Beastmaster: 17, Ember Spirit: 9, Nature's Prophet: 17, Lion: 21
	Ursa: 4, Beastmaster: 17, Nature's Prophet: 17, Lion: 21, Razor: 1
45	Medusa: 6, Faceless Void: 23, Witch Doctor: 9, Zeus: 11, Vengeful Spirit: 15
	Death Prophet: 9, Faceless Void: 23, Witch Doctor: 9, Enchantress: 9, Outworld Devourer: 8
32	Earthshaker: 4, Dazzle: 4, Lone Druid: 10, Earth Spirit: 17, Anti-Mage: 8
	Ursa: 4, Crystal Maiden: 6, Lone Druid: 10, Death Prophet: 3, Earth Spirit: 17
33	Oracle: 12, Gyrocopter: 18, Dragon Knight: 5, Zeus: 3, Spirit Breaker: 11
	Oracle: 12, Gyrocopter: 18, Puck: 1, Abaddon: 5, Spirit Breaker: 11
19	Beastmaster: 5, Tiny: 8, Io: 15, Enchantress: 4, Batrider: 4
	Tiny: 8, Nature's Prophet: 1, Io: 15, Lich: 1, Beastmaster: 5
23	Witch Doctor: 11, Spectre: 5, Juggernaut: 4, Enchantress: 9, Disruptor: 5
	Treant Protector: 1, Witch Doctor: 11, Zeus: 2, Enchantress: 9, Sven: 4
17	Chen: 6, Skywrath Mage: 2, Tusk: 6, Spectre: 3, Zeus: 6
	Earthshaker: 2, Chen: 6, Outworld Devourer: 4, Tusk: 6, Queen of Pain: 3

Table 11:

ROCK

Clusters	
Size	**Samples**
11	Death Prophet: 5, Earth Spirit: 4, Dark Seer: 4, Juggernaut: 5, Oracle: 7 Earth Spirit: 4, Juggernaut: 5, Oracle: 7, Nature's Prophet: 5, Outworld Devourer: 3
11	Undying: 5, Gyrocopter: 3, Vengeful Spirit: 11, Zeus: 6, Nature's Prophet: 7 Ember Spirit: 4, Vengeful Spirit: 11, Undying: 5, Nature's Prophet: 7, Ursa: 1
29	Io: 21, Beastmaster: 13, Tiny: 17, Witch Doctor: 9, Queen of Pain: 3 Io: 21, Dark Seer: 9, Sven: 7, Tiny: 17, Witch Doctor: 9
27	Invoker: 6, Gyrocopter: 23, Oracle: 4, Dark Seer: 16, Rubick: 9 Invoker: 6, Gyrocopter: 23, Oracle: 4, Dark Seer: 16, Bane: 8
22	Tidehunter: 5, Chen: 12, Juggernaut: 13, Invoker: 8, Tusk: 12 Chen: 12, Juggernaut: 13, Invoker: 8, Earthshaker: 5, Disruptor: 9
29	Invoker: 19, Slark: 5, Vengeful Spirit: 20, Disruptor: 7, Nature's Prophet: 11 Vengeful Spirit: 20, Drow Ranger: 8, Invoker: 19, Nature's Prophet: 11, Viper: 2
16	Death Prophet: 7, Juggernaut: 7, Witch Doctor: 14, Nature's Prophet: 7, Tusk: 5 Death Prophet: 7, Slardar: 1, Juggernaut: 7, Witch Doctor: 14, Tusk: 5
23	Invoker: 14, Faceless Void: 13, Enchantress: 8, Witch Doctor: 11, Spectre: 4 Earth Spirit: 5, Faceless Void: 13, Invoker: 14, Witch Doctor: 11, Ember Spirit: 2
15	Batrider: 3, Zeus: 8, Faceless Void: 8, Witch Doctor: 9, Gyrocopter: 5 Zeus: 8, Faceless Void: 8, Vengeful Spirit: 3, Witch Doctor: 9, Medusa: 3
13	Morphling: 7, Vengeful Spirit: 5, Dark Seer: 9, Invoker: 2, Disruptor: 5 Morphling: 7, Dark Seer: 9, Tiny: 4, Disruptor: 5, Bane: 3
11	Death Prophet: 6, Lone Druid: 4, Vengeful Spirit: 9, Tusk: 6, Dazzle: 4 Death Prophet: 6, Chen: 5, Wraith King: 1, Vengeful Spirit: 9, Tusk: 6
14	Zeus: 8, Chen: 4, Gyrocopter: 11, Dragon Knight: 2, Tusk: 8 Zeus: 8, Juggernaut: 1, Oracle: 4, Tusk: 8, Gyrocopter: 11
11	Vengeful Spirit: 6, Clinkz: 5, Enigma: 6, Invoker: 3, Tidehunter: 9 Tidehunter: 9, Razor: 3, Vengeful Spirit: 6, Clinkz: 5, Lion: 6
11	Night Stalker: 3, Invoker: 5, Ember Spirit: 8, Nature's Prophet: 7, Lion: 4 Ember Spirit: 8, Outworld Devourer: 1, Witch Doctor: 4, Nature's Prophet: 7, Lion: 4
10	Earth Spirit: 5, Beastmaster: 5, Invoker: 6, Slark: 3, Lion: 4 Ancient Apparition: 5, Earth Spirit: 5, Dark Seer: 2, Invoker: 6, Slark: 3
19	Phoenix: 7, Gyrocopter: 8, Faceless Void: 4, Invoker: 6, Tusk: 16 Gyrocopter: 8, Enchantress: 4, Tusk: 16, Nature's Prophet: 6, Viper: 4
10	Juggernaut: 5, Razor: 5, Night Stalker: 8, Vengeful Spirit: 3, Disruptor: 3 Ancient Apparition: 2, Juggernaut: 5, Razor: 5, Night Stalker: 8, Clockwerk: 4
11	Earth Spirit: 3, Batrider: 8, Zeus: 5, Anti-Mage: 6, Undying: 3 Batrider: 8, Slark: 3, Vengeful Spirit: 5, Zeus: 5, Undying: 3
16	Faceless Void: 5, Enigma: 2, Vengeful Spirit: 10, Drow Ranger: 6, Outworld Devourer: 10 Vengeful Spirit: 10, Outworld Devourer: 10, Enchantress: 4, Ember Spirit: 3, Mirana: 5

Table 12: