Graph Theory Application in Species Migration Visualization and Analysis

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***Abstract*—In this world, we human race live along in this earth with a lot of different animals and plants species. All this species including us humans will migrate over different places, islands, and even continents based on our needs, interests, war, disaster, government policies, and many other reasons. Even animals need to migrate for animals such as salmon, different species of birds, etc. To monitor this behaviors, we can use graph theory to help us in visualizing the data needed. Some kind of institution will need these data for certain purposes, either control the migration of one country or to preserve animal migration behavior that crucial for the animal reproduction preventing extinction of certain species. This kind of visualization will provide better illustration to simplify the data that will be used by the experts for certain purposes. This paper will provide how graph theory can be used in visualizing migrations and to analyze them providing further results to be used.**

***Keywords*—Migration, graph, species, analysis.**

I. Introduction

Migrations play a huge part in why we are here in each of our own island, country, with our own family that derived from a certain kind of lineage and specific species, and why that our neighbor have some similarity with us or have too much difference with us. This kind of question needs a lot of data to answer, since a migration doesn't occur in just one day especially humans that take a million years to reach how spread we are now. Of course migrations happens for humans and also for animals.

Efforts done by those who strive in analyzing migrations such as experts from human migration studies and animal biologists and conservationists will always be appreciated since this field of study have so many effects for both humans and animals. And they also help on answering that kind of question, why we are born in this island not that one? Why komodo only exists in one certain area in Indonesia, but we can see snakes and bed bugs in any part in the world (excluding Antarctica).

For humans, unraveling the first migrations of anatomically modern humans out of Africa has invoked great interest among researchers from a wide range of disciplines. Available fossil, archeological, and climatic data offer many hypotheses, and as such genetics, with the advent of genome-wide genotyping and sequencing techniques and an increase in the availability of ancient samples, offers another important tool for testing theories relating to our own history.

Nowadays, migration analysis is used to make policies of each countries, large unions and many other world parties that analyzed the effect of a certain migration. But of course, this work both ways. A larger official can make policies to encourage migration such as European Union that opened their borders and reduce the financial cost for one person to migrate. Others are against migration such as American policy against immigration that came up after a certain effect on their country.

For animals, the case is much simpler. They migrate because of their nature, need to grow and expand their numbers, or human intervention. This activity is most readily observed in birds, but has been documented in many other animals as well, including insects, fish, whales, and other mammals. By knowing how they migrate, scientist can learn a wide range of different species and animals, for the hope to preserve those species for their future.

II. Theoretical Basis

A. Graph

The concept of graph theory was first introduced in 1735 to solve the problems of the Seven Bridge of Köögigberg. Leonhard Euler, a Swiss mathematician, studied this problem and then succeeded in building a solution that gave birth to the concept of the Eulerian Graph. Until now, Euler has been deployed on the basis of graph and is called the Father of Graph Theory.

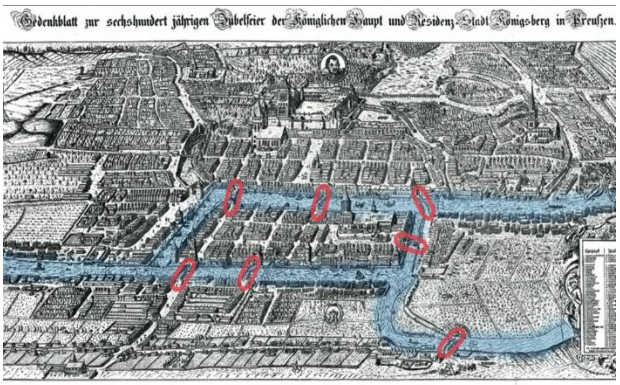
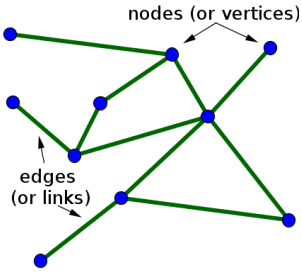


Figure 1. Seven Bridges of Königsberg
Source : http://www.phymath.com/introduction-to-the-seven-bridges-of-konigsberg/

Graph consist of at least one node or vertex (V) or more, and edges or links (E) that can be declared as G = (V,E).



B. Graph Terminology

1. Adjacent

Two vertices on a non-directional graph G are said to be neighbors when they are connected directly to a side. In other words, u is adjacent to v if (u, v) is a side in graph G.

2. Incident

For any side e = (u, v), the e side is said to be next to the vertices u and n.

3. Degree

The degree to which a node in a non-directional graph is the number of sides adjacent to that node.

4. Path

The length path n of the initial vertex v_o to the destination node v_n in graph G is a sequence of vertices of vertices and sides formed $v_0, e_1, v_1, e_2, v_2, e_3, v_3, ..., v_{n-1}, e_n, v_n$ in such so $e_1 = (v_0, v_1)$, $e_2 = (v_1, v_2)$, ..., $e_n = (v_{n-1}, v_n)$ are the sides of graph G.

5. Empty Graph

The graph whose set of sides is an empty set is called an empty graph and is written as N_n, in which case n is the number of vertices.

6. Circuit

In a graph, a circuit is a path that starts and ends at the same node.

7. Isolated Vertices / Node

A remote node is a node that has no side adjacent to it. Or it can also be stated that the isolated node is a node that neither neighboring the other nodes.

8. Subgraph

Let G = (V, E) be a graph. G1 = (V1, E1) is a subgraph of G if V1 subset of V and E1 subset of E. The complement of subgraph G1 to graph G is graph G2 = (V2, E2) such that E2 = E - E1 and V2 are nodes which the E2 members are side by side with

C. GRAPH TYPES

In this paper, the type of graph we refer to is planar, weighted, non-directional and dual graph.

1. Planar Graph

A graph is said to be planar if the graph can be represented on a plane such that no side intersects.

2. Weighted Graph

A weighted graph is a graph that each side is given a value.

3. Undirected Graph

An undirected graph is a graph that don't have any direction or orientation.

4. Dual Graph

A graph that have vertices for every face in a planar graph G. The dual graph has side if and only if the two faces of G are separated from each other by a side. If the same face is present on both sides of a side, then what is formed is a prop.

D. MIGRATION TYPES

Migration is the large-scale movement of an animal species from one place to another. Migrations are usually tied to seasonal changes in weather and feeding patterns, or mating and breeding patterns. We refer to type of migration that human and animal do.

1. Intercontinental Migration

A migration that occurs from one continent to another. Usually occurs with huge number of people / animals. Such as the migration of early human ancestors from Africa to other continents, or the migration of many bird species.

2. Rural – Urban Migration

This occurs both ways, individuals / species that spread into a more urban areas for new opportunities (expansion for animals).

3. Involuntary Migration

This type of migration usually occurs because of external factor force. Such as government or authorities to force people to migrate because of some reasons, or human that forced to control the migration of some animal species (ex. Wildebeests)

4. Impelled Migration

This also similar to a forced migration, but it's because of some push factors such as war, hunger, plague, limited resources, etc.

5. Seasonal Migration

This happens mostly for animals, such as salmon for breeding and wildebeest searching for rich grasslands.

6. Return Migration

For some humans, after their work in cities to return home. This involves the voluntary return of migrants to their original place after they outlive the reasons for which they left.

III. HUMANS AND ANIMALS MIGRATION ANALYSIS

A. KEY TERMS

1. Migrator

Humans and animals do migrate, either in big or small numbers. Either it's only one species or sometimes also occurs with another species. This will be represented by edges with colors that link a certain location to another with a directed arrow, with the color represent a certain species. (Directed Graph)

2. Migration Locations

This represented by nodes, sometimes can be colored according to the data used. But because of a lot of species can be visualized in a certain graph, we use the color to identify species or how big the migration is rather than to cite locations.

3. Migration Path

Path can be represented in edges, while the weight can be a combination of many factors. These factors are the length, risks, time, and costs from one location to another.

B. KEY CONCEPTS

1. Crime Pattern Theory (CPT)
   This theory consists of four key points :
   a. Complexity of a migration event
   b. Migration isn't random
   c. Migration opportunities isn't random, but sometimes can be derived from a certain random events.
   d. Migration occurs because the needs of one species or because of another external factor
2. Graph Theory
   Which is already explained above.
3. Degree
   How many links of migration of a species to certain locations (vertices).
4. Betweenness
   How many times a node can be linked as a bridge along the shortest path between two nodes. This also indicate that the location is used often as a migration path for a lot of species.
5. Eigenvector
   A measure of a node's influence in a network. In equations, for a given graph G = (V,E) with |V| vertices let A = ($a_{v,t}$) be the adjacency matrix. The relative centrality score of vertex v can be defined as:

$$Xv = \frac{1}{\lambda} \sum_{t \epsilon M(v)} Xt = \frac{1}{\lambda} \sum_{t \epsilon G} Av,t\ Xt$$

Where ***M(v)*** is a set of neighbors of the corresponding vertex and λ is a constant.

C. ANALYSIS

By using graph theory and its terminology, we can indicate many things for migration. How an animal migrates, how dense migration works, where to build a migration analyzing shelter, where our ancestors come from, and the list goes on and on. The real challenge is how we can provide the best visualization for a certain problem / scenario with the right variables to maximize the information gained from our graph. In this paper, we will analyze for both humans and animals kind of migrations, small and big scale, how we can visualize it, simplify it, and gain any kind of information from it.

We can use any graph type to represent the network, which is the most suitable to represent with the data that we have. But because we use migration as our topic, a directed graph is the best one since it also indicates the movement of a certain species to one location and another. And because migration usually comes in a big scale, we can use the world map to help indicates the location of specific migration paths. With the key concepts stated above, we can use it to visualize and represent our migration graph and make it simple.

The first one we will analyze is human migration. For the small scale, we used an example from outer site which draw an example undirected graph of a warzone. This kind of information is of course wanted by many party each with their own gain. The government can use this information to analyze where best to station their troops to defend their citizens, or by the enemy of the country to specify attack location. But what we will discuss for the best of this paper is what route that will provide the best profit for a refugee in a certain location if he want to get to another location such as where the army stationed or refugees aid center ? This kind of question is where the graph application truly shine.

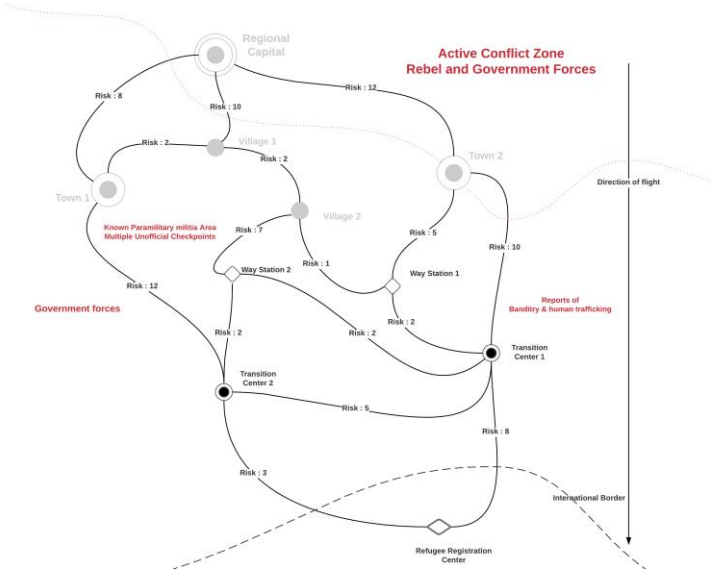


Figure 2. Example of Direction of flight, risk and major migration points of a warzone
Source : https://rstudio-pubs-static.s3.amazonaws.com/

From the figure above, we can see several locations indicated by vertices such as towns, villages, stations, and centers. And we also can see the paths available from one city to another each with their own risks. Example if a refugee needs to travel from Town 2 to the Refugee Registration Center, which path should he/she choose ? From the graph we can conclude from the graph that the refugee should use the path :
Town 2 → Way Station 1 → Transition Center 1 → Way Station 2 → Transition Center 2 → Refugee Registration Center
That way, the refugee can go to the center with minimized risks.

By using eigenvector's equation with λ as constant, we can conclude that the Transition Centers are the ones with the densest population of refugee possible, since they are used as a transition from many locations to another. This will indicate where the support of governments should be focused on, and can also be an information for the refugees where to go because of the high probability of big scale refugees are siding at that location overtime. With the help of graph, we can see that in a small scale migration the most effective way to use it is to determine the best path to go from a location to another.

Next, we will analyze how graph can visualize migration in a big scale. Let's travel back in time in thousand years ago and see how our ancestors migrate from one continent to another or the way we call it is Intercontinental Migration. By using the graph below, represented above the world map with directed edge represent the movement, colors to differentiate based on genetic markers are today, and the vertices will be the islands and continents spread throughout the world.

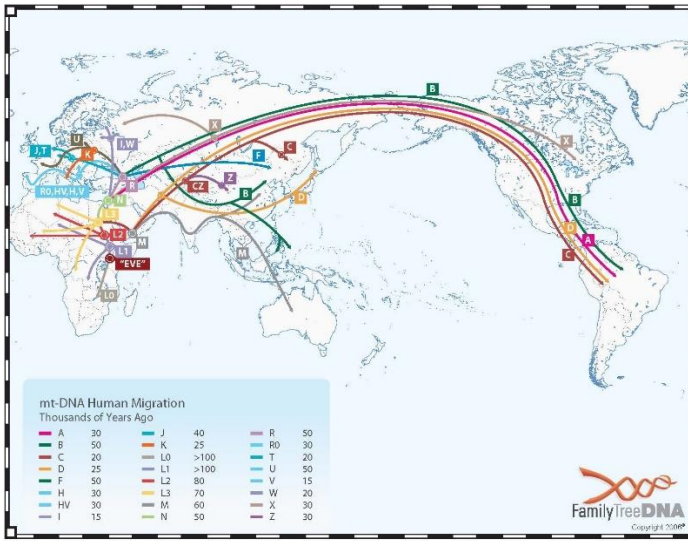


Figure 3. Example of mt-DNA Human Migration Graph
Source :https://www.quora.com/Is-it-possible-to-summarize-the-history-of-large-scale-human-migration

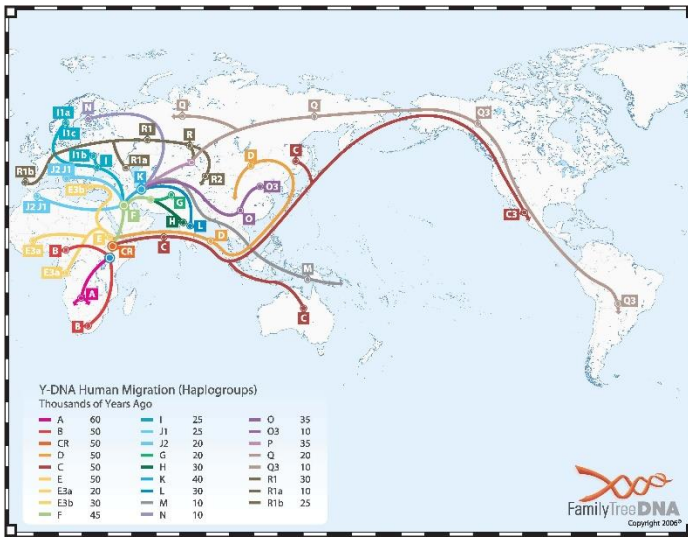


Figure 4. Example of Y-DNA Human Migration Graph
Source : https://www.quora.com/Is-it-possible-to-summarize-the-history-of-large-scale-human-migration

Another different approach of a graph theory is presented from Figure 3. From this figure we can see the migration of our ancestors based on mt-DNA and Y-DNA, two of the base genetic markers today. mt-DNA stands for mitochondrial DNA that only can be derived from mothers, and Y-DNA from fathers. We can see how dense the migration of human is in Africa, Europe and Asia. And we can see the similarity of history which indicates that American ancestors are the Europeans, derived from the data of the graph. Brought by Family Tree DNA, this graph really explains why we are who we are now, from many different races and tribes, to be where we at now. Such as the author who is an Indonesian, the possible ancestors are the early African who populated Asia. By the same data we can also use it to test our ancestry and genealogy provided that the probability of correctness is not 100%, but from the graph at least we can understand how and how to explain to other people the reason of why humans are spread like this nowadays. We can also identify the push and pull factors of why our ancestors move, such as Europeans move to America to obtain new lands, high resources, and to establish colonialism, and they move to Asia to expand their own knowledge, religions, and open a global-sized trade center.

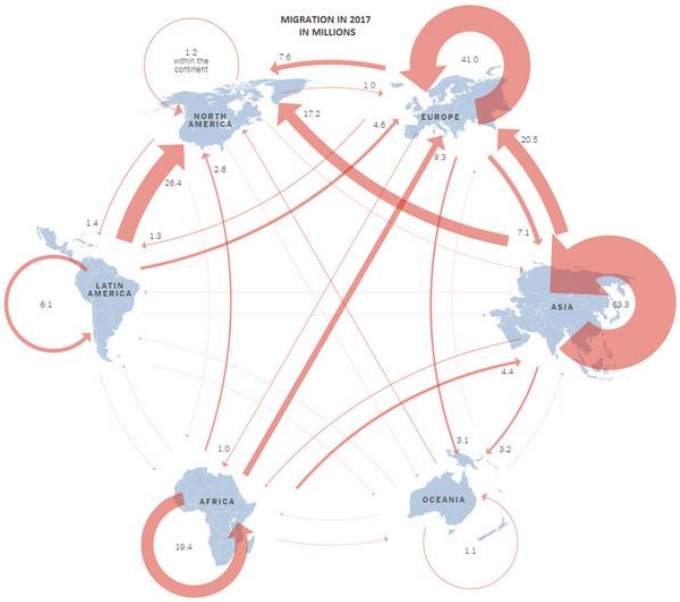


Figure 5. Immigration Flow 2017 in Millions
Source :
https://www.nytimes.com/2018/09/11/learning/whats-going-on-in-this-graph-sept-12-2018.html

And now, let's talk about today migration. From Figure 5 we can see the flow of immigration occurred in 2017 in millions. This directed graph with edges represent how many people migrate from one continent to another, weight as in how many people travel from one country, and the loop represents how many people migrate on the same continent. We can conclude that people around Asia tends to migrate inside Asia the most, and people from Latin America migrate to North America as the largest Intercontinental migration in 2017. From this graph, we can derive many things, such as we can conclude why there is a lot of Asian Tourist compared to other tourist in a certain country at one time, and why Oceania has the least dense population compared to other continents ? These conclusion sometimes can be related to a certain events. Such as Brexit, which is a famous headline for some time in the European Continent, or because of the war in middle eastern countries make many refugees travel from one place to another. This explains why immigration policies is one of the difficult to come up with, and also why it really related by a certain kind of event.

Governments or other political parties from many countries will try to control the flow of these immigration by their own policies based on immigration graphs. Such as to control migrators, cost of airplanes and fuels is increased just to prevent people to travel across to another location. But if those kind of policies are already implemented without any change in the

flow, then government will try to direct the flow to another location / country.

Now is the time to analyze the migration of animals. There are few sights as majestic as the mass migrations of animals. To humans, thousands of monarch butterflies roosting in trees or scores of wildebeests surging across the African plains are beautiful and impressive to witness.

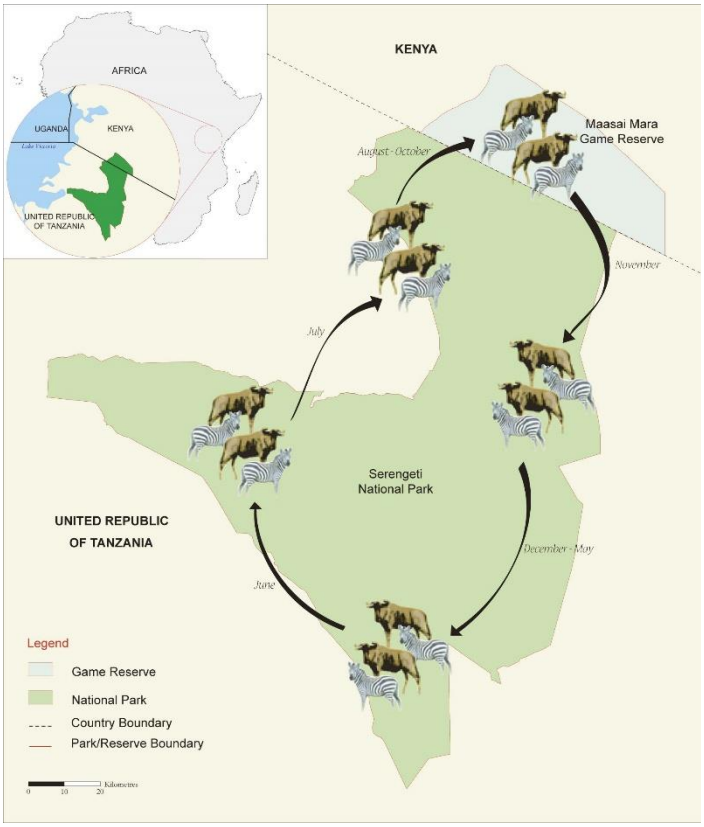


Figure 6. Mara-Serengeti Migration
Source : [5]

As represented from the graph above, we can see the path wildebeests and zebras take in a certain part of United Republic of Tanzania. With the animal picture as nodes, and the directed edges show their circular movement which they do frequently in their lives, and we can also color the nodes to represent which part of country they belong to (Kenya, Uganda and United Republic of Tanzania). With this graph, the zoo conservationists can monitor the flow of migration in their own habitat and prevent further external cause if someday will happen because of poachers, predatory causes, roadblocks of country war, or any other external causes that can cause misshapen in a zoo with this graph.

From these two analysis done on human migration and animal migration, we can conclude that visualizing them with graph really help to efficiently provide the information needed for further uses. Such as how to prevent some migration to happens, conclude the causes from a certain migration, try to analyze the profits and negative impact from migration, and represent them in a simplified graph to further help our research. With this paper, the author represent how graph application can be used in visualizing and representation of migration, and how to conclude and gain information from one kind of graph.

IV. Conclusion

A detailed analysis on migration is needed for every public experts and biologist also animal conservationists to help further with their efforts. With graph as the representation, we can help them by providing further detailed analysis that can be made simple, whilst not reducing many information gained with it.

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Pernyataan

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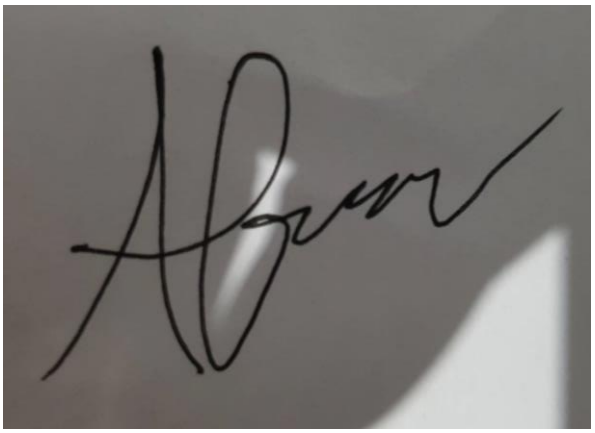

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