CARLETON UNIVERSITY

cuACS

Revised Algorithm Design Document

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Contents

1 Introduction

1.1 The Animal-Client Matching (ACM) Algorithm

The Animal-Client Matching (ACM) Algorithm is the main feature of the cuACS system. It is designed to compute the optimal set of matches between clients of the animal shelter and animals that are housed within the shelter. It does this by taking into account both the physical and non-physical traits of the animals in conjunction with the preferences for such traits indicated by the clients to compute which animal will be most compatible with a given client. It also takes into account physical and non-physical traits of the clients themselves so that

matches can be made which suit both the client and the animal instead of just the client. The main feature of the algorithm is that it takes into account the animal's traits to assign it a specific classification to assist in matching the animal with a client depending on that client's living circumstances, traits, and preferences.

This revised design, which has remained largely the same as the original design, now includes improvements to the part of the algorithm which decides how to choose the optimal matches in order to better guarantee that the resulting set of matches is the optimal set of matches. The changes to the algorithm's design are contained in section *4 Operation of the Algorithm*.

1.2 Document Overview

This document will detail the design and rationale for the algorithm. It will begin by detailing which animals are handled by the shelter and the common physical traits and features that each animal has. It will then talk about the common non-physical traits that define the base personality of each type of animal followed by the species-specific traits that are unique to a specific species of animal housed by the shelter. How each of the non-physical traits interact with the algorithm and how they affect the animal's classification will also be detailed.

Following that, the various client traits and preferences will be described in a similar way to the animal traits. Specifically, the interaction between these traits and the profile constructed for the client by the algorithm will be detailed.

The section following that will provide an overview of the basic operation of the algorithm. There will be a diagram giving a basic overview of what the algorithm does to compute the optimal set of matches. Then, a detailed breakdown of the simplified steps will be laid out with accompanying the individual steps of the algorithm can be explained and understood in detail.

Finally, a simple example run-through of the algorithm's matching operation will be performed to match three different clients with four different animals so that the algorithm's operation can be seen in action on a simple, easy to follow sample.

2 Animals

2.1 Overview

The cuACS system is designed to accommodate the animals that the animal shelter is able to hold. The species of animals that the shelter handles are described in this document as common household pets. Each of these animals have common physical and non-physical traits

and also have individual species-specific traits which, together, determine how fit an animal is for a client.

This section will first give a brief overview of the species that the animal shelter houses, it will then detail the classification categories that animals can fall into. Then, it will describe the traits of the animals, first describing the physical traits, then the non-physical traits, and finally the species-specific traits. For each set of traits, a description, set of possible values, and relation to the operation of the algorithm (i.e. how the algorithm uses the trait in computing a match) are given.

2.2 Species of Common Household Pets

The shelter that will be using the cuACS system houses various breeds and types of five species of animal: Dog, Cat, Bird, Lizard, and Rabbit. Each of these different species have common physical and non-physical attributes but they also have specific attributes which are unique to that specific species of animal. This means that the matching algorithm must take all of these differences into account and must handle each type of animal at least partially differently. The algorithm will not attempt to match a client with a species of animal that the client didn't indicate a preference for.

2.3 Traits of the Common Household Pets

2.3.1 Common Physical Traits

Table 1—Physical Traits Common to All of the Species of the Common Household Pets

Trait	**Species**
Description	The species of the animal.
Possible Values	Dog, Cat, Lizard, Bird, Rabbit.
Application to the Algorithm	The clients can choose a specific species of animal that they wish to be matched with.
Trait	**Breed**
Description	The breed or sub-species within the animal's overall species.
Possible Values	Infinite, as the staff members will be able to define their own species. For example, possible values for the breed of lizard can be: Green Iguana, Leopard Gecko, Chameleon, etc.

Application to the Algorithm	The clients can choose a preferred breed or species of animal.
Trait	**Size**
Description	The physical size of the animal.
Possible Values	Teacup, Small, Medium, or Large. These values are relative to the normal expected size of the particular animal's species.
Application to the Algorithm	The clients can choose a preferred size of animal.
Trait	**Age**
Description	The actual or estimated age of the animal in years.
Possible Values	Any integer between 0 and 99.
Application to the Algorithm	The clients can choose a preferred age range that they wish their pet to fall in.
Trait	**Gender**
Description	The biological sex of the animal.
Possible Values	Male or Female.
Application to the Algorithm	The clients can choose a preferred gender that they wish the animal to have.
Trait	**Fur/Scales/Feathers**
Description	The type of fur, scales, or feathers that the animal has. The type of outer coating is determined by the species of the animal.
Possible Values	For dogs, cats, and rabbits possible values are: Hairless, Short, Long. For Lizards, the field will become "Scales" and the possible values are: Spiked, Rough and Smooth. For Birds, the field will become "Feathers" and the possible values are: Yes and No.
Application to the Algorithm	The client can choose a preferred fur, scale, or feather type depending on which species of animal they preferred.
Trait	**Hypoallergenic**

Description	the scale to which the animal is considered hypoallergenic.
Possible Values	Yes or No.
Application to the Algorithm	A client can indicate a preference for a hypoallergenic animal.

2.3.2 Common Non-Physical Traits

Table 2—Non-Physical Traits Common to All of the Species of the Common Household Pets

Trait	**Likes Traveling**
Description	This trait indicates the scale to which the animal is a good travel companion. Is it okay on long road trips? Does it handle the stress of travel well?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Good with Children**
Description	This trait indicates the scale to which the animal is good around children. Is the animal gentle around smaller, weaker humans? Is the animal aggressive or twitchy around children?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will take into account whether or not a client has children when making a match even if a client indicates a preference for this trait.
Trait	**Good with Animals**
Description	This trait indicates the scale to which the animal is good around other animals of the same or differing species. Is the animal overly territorial? Is the animal
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will take into account whether or not a client has other

	animals when making a match even if a client indicates a preference for this trait.
Trait	**Good with Strangers**
Description	This trait indicates the scale to which the animal is good around strangers. Does the animal get overly defensive of its owner around others? Is the animal receptive to new people?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Good in Crowds**
Description	This trait indicates the scale to which the animal is good in medium to large crowds of people. Is the animal easily panicked when surrounded? Does the animal become aggressive when surrounded by others?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Good with Loud Noises**
Description	This trait indicates the scale to which the animal handles loud noises like thunderclaps, gunshots, or fireworks well. Does the animal become easily spooked by a loud noise? Does it cower in those cases?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will also take into account the location of a client’s dwelling when computing a match against this trait.
Trait	**Good Home Protector**
Description	This trait indicates how competent the animal is at defending a home and protecting the inhabitants. Does the animal stand a good chance against an intruder like a burglar? Is the animal loyal enough to protect its owners?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5

	indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Lots of Energy**
Description	This trait indicates how much energy an animal has. Does it require frequent walks? Does the animal tire easily?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will also take into account the size of a client’s dwelling when matching against this trait.
Trait	**Is Fearful**
Description	This trait indicates whether or not the animal is easily spooked. Is the animal jumpy? Does it react well to sudden movements?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Is Affectionate**
Description	This trait indicates the level of affection that the animal displays to its owner. Is the animal cuddly? Does the animal tend to give kisses or otherwise readily express affection?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Is Messy**
Description	This trait indicates how messy an animal is. Does the animal tend to cause a mess of household objects and its environment? Does the animal’s living area require a lot of maintenance?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.

Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**History**
Description	Describes the origin of the animal before it was taken in by the shelter.
Possible Values	Given up by owner, Street animal, Rescue, or Unknown.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait.
Trait	**Indoor or Outdoor Type**
Description	Indicates the animal's preference for more outdoor or indoor time.
Possible Values	Indoor, Outdoor, or Both.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will also take into account the client's own activity preferences in order to make an informed match. It will also take into account the location of the client's dwelling.
Trait	**Nocturnal**
Description	Describes the sleeping habits of the animal. Does the majority of the animal's sleeping time occur during the night or day?
Possible Values	Yes or No.
Application to the Algorithm	A client can indicate a preference for the desired value of this trait. The algorithm will also take into account the client's own work schedule in order to match an animal's sleeping schedule with a client's.
Trait	**Length of Time At Shelter**
Description	Describes the length of time that the animal has been present at the shelter in days. This is not a trait that can be entered by a staff member. It is automatically calculated by the system given the date that the animal was first added.
Possible Values	A positive integer, limit of (2^16)-1 days (internally a 2 byte unsigned short).
Application to the Algorithm	Used by the algorithm to break ties or near-ties between matches. If two or more animals are closely matched to a client, the animal with the longest term at the shelter will be chosen first.

2.3.3 Species-Specific Traits

Table 3—Traits Specific to Dogs

Non-Physical	
Trait	**Barks a Lot**
Description	This trait describes the average amount that the dog barks. Is the dog barking at anything and everything all the time? Is the dog relatively silent?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of noise their potential dog makes. The algorithm will take into account the type of dwelling a client has when computing a match against this trait.
Trait	**Follows Commands**
Description	This trait describes the degree to which the dog is trained. Does it easily follow advanced commands? Does it struggle with simple commands like “Sit” or “Stand?”
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of obedience that their potential dog would have.
Trait	**House Trained**
Description	This trait describes whether or not the dog has been house trained? Does it ask to go outside when it needs to relieve itself or does it relieve itself anywhere without a care?
Possible Values	Yes or No
Application to the Algorithm	A client can indicate a preference for whether or not they want their dog to be house trained.

Table 4—Traits Specific to Cats

Physical	
Trait	**Sheds Fur**
Description	This trait describes the level to which the cat sheds its fur. Is it a heavy shedder or a light one?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the amount of shedding they are okay with their potential cat having.
Non-Physical	
Trait	**Is Curious**
Description	This trait describes the level to which the cat is curious about its surroundings? Does it tend to explore or stay within a familiar area?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of curiosity of their potential cat.
Trait	**Is Well Trained**
Description	This trait describes the level of training the cat has received. Is the cat responsive to commands? Would the cat leave dead animals around the client’s dwelling?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of training that their potential cat has.

Table 5—Traits Specific to Birds

Physical	
Trait	**Colour**
Description	This trait describes the overall colour of the bird.
Possible Values	Red, Orange, Yellow, Green, Blue, Pink, Purple, White, Black, Brown, or Gray. For example, if the bird has mostly red feathers with a few accents of white or black then the bird would be classified as “Red.”
Application to the Algorithm	A client can indicate a preference for the colour they would like their potential bird to be.
Non-Physical	
Trait	**Is Loud**
Description	This trait describes the average loudness of the bird. Does the bird tend to squawk? Is the bird a quiet or loud singer?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the loudness of their potential bird. The algorithm will take into account the type of dwelling that the client lives in when matching against this trait.
Trait	**Needs Attention**
Description	This trait describes the degree to which the bird needs attention. Is the bird fairly independent or does it call on it’s owner often?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of attention their potential bird will need.

Table 6—Traits Specific to Lizards

Physical	
Trait	**Colour**
Description	This trait describes the overall colour of the lizard.
Possible Values	Red, Orange, Yellow, Green, Blue, Pink, Purple, White, Black, Brown, or Gray. For example, if the lizard has mostly red scales with a few accents of green or black then the lizard would be classified as “Red.”
Application to the Algorithm	A client can indicate a preference for the colour they would like their potential lizard to be.
Trait	**Needs Strong Heat Lamp**
Description	This trait describes whether or not the lizard requires a stronger than normal heat lamp.
Possible Values	Yes or No.
Application to the Algorithm	A client can indicate a preference for whether or not they wish to support a lizard which needs a strong heat lamp.
Non-Physical	
Trait	**Needs Large Living Space**
Description	This trait describes whether or not the lizard requires a larger-than-normal enclosure independent from their size. Does the lizard require lots of space to hide or hunt?
Possible Values	Yes or No.
Application to the Algorithm	A client can indicate a preference for whether or not they wish to support a lizard which needs a large living space. The algorithm will also take into account the type of the client’s dwelling independent of the client’s preferences when matching against this trait.
Trait	**Preferred Diet**
Description	This trait describes the preferred diet of the lizard.
Possible Values	Crickets, Worms, or Mice.
Application to the Algorithm	A client can indicate a preference for the preferred diet they wish their potential lizard to have.

Trait	Feeding Interval
Description	This trait describes the typical frequency for which the lizard should be fed.
Possible Values	Daily, Weekly, Bi-weekly, Monthly, or > Monthly.
Application to the Algorithm	A client can indicate a preference for the frequency with which their potential lizard should be fed.

Table 7—Traits Specific to Rabbits

Physical	
Trait	**Colour**
Description	This trait describes the overall colour of the rabbit.
Possible Values	Black, Brown, Gray, White, Cream, or Straw. For example, if the rabbit has mostly white fur with spots of black, the rabbit would be classified as “White.”
Application to the Algorithm	A client can indicate a preference for the colour they would like their potential rabbit to be.
Trait	**Pattern**
Description	This trait describes the pattern of the colour(s) on the rabbit.
Possible Values	Solid, Bi-colour, Tortoiseshell, Striped, or Spotted.
Application to the Algorithm	A client can indicate a preference for the pattern they wish their potential rabbit to have.
Non-Physical	
Trait	**Needs Grooming**
Description	This trait describes how much the rabbit needs to be groomed. Will the rabbit shed too much to be manageable by the rabbit on its own?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of grooming their potential rabbit should need.
Trait	**Needs Attention**
Description	This trait describes the degree to which the rabbit needs attention. Is the rabbit fairly independent or does it call on it’s owner often?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Not at all” and 5 indicates “A lot”.
Application to the Algorithm	A client can indicate a preference for the level of attention their potential rabbit will need.

2.4 The Classification of Animals Based on Their Traits

To aid in accurate matching of animals with clients, a system of classification for animals was devised. There are six classifications of animals. Not every animal species will fit into every classification. The classifications, and their most important defining traits, including both animal and client traits, are as follows (client traits are indicated with a "(C)"):

Table 8—Classifications of Animals

Classification	**Rural Rover**
Description	Rural Rovers include medium to large sized animals which are energetic and require a lot of exercise. They thrive in outdoor settings such as farms and acreages and behave well around other animals.
Most Weighted Traits	Indoor or Outdoor Type, Lots of Energy, Good with Animals, Is Messy, Dwelling Location (C), Dwelling Type (C).
Classification	**Family Pal**
Description	Family Pals are animals which love the affection from their owners—both adults and children. They are animals of any size which thrive in rural or suburban environments. They do not mind the hectic lifestyles of young families.
Most Weighted Traits	Good with Children, Lots of Energy, Good with Loud Noises, Good in Crowds, Likes Traveling, Age, Dwelling Location (C), Dwelling Type (C).
Classification	**Urban Dweller**
Description	Urban Dwellers love the city life. From exciting walks in the park to accompanying owners on brunch dates. They do not mind living the high-rise life and do well with noise and crowds.
Most Weighted Traits	Good in Crowds, Good with Loud Noises, Indoor or Outdoor Type, Is Messy, Lots of Energy, Dwelling Location, Level of Activity (C).
Classification	**Cuddly Companion**
Description	Cuddly Companions are animals which are often more lethargic and therefore do not require as much exercise or space. This makes them perfect for urban environments (although this isn't exclusive).
Most Weighted Traits	Is Affectionate, Lots of Energy, Good with Children, Size.
Classification	**Fierce Convoy**
Description	Fierce Convoys think it is their duty to protect and serve. They are large

	animals (typically dogs) that do best in rural and suburban environments and require lots of exercise.
Most Weighted Traits	Good Home Protector, Lots of Energy, Size, Age, Dwelling Location (C).
Classification	**Experienced Sidekick**
Description	Experienced Sidekicks have seen it all, and are ready to take it easy. These pets are well-suited for any dwelling, do not require as much intense exercise, and are much cleaner than younger animals. These animals pair perfectly with older clients.
Most Weighted Traits	Lots of Energy, Is Affectionate, Is Messy, Indoor or Outdoor Type, Age, Age (C).

3 Clients

3.1 Overview

Every client indicates their matching preferences when they create their profile. These matching preferences are taken into account when matching animals with clients. These matching preferences are used to compute the classification of animal that a client is looking for. Furthermore, the client fills out a small profile indicating several different personal traits. These traits are taken into account when matching against an animal's physical and non-physical attributes so that, for example, a very large dog isn't matched with a client who lives in a very small apartment. This, plus the aforementioned matching preferences, will help ensure not only that an animal is good for a client, but also that a client is good for an animal.

This section will first explain what a client's matching preferences can be, what their options are, and which animal traits they match with. It will then detail the the various client traits that the client fills out as part of the "Personal Information" section of their profiles.

3.2 Client Matching Preferences

When a client first logs into the system, they will be asked to fill out a set of matching preferences. These matching preferences are essentially the exact same as what a staff member would see when they are creating an animal. A client can choose, for example, the amount that their animal "Likes Traveling" or, if the client indicated that their preferred matching species is a lizard, then the client could indicate a preference for the "Scales" of the lizard. Every animal trait, aside from the name of the animal, is used in computing a match

between clients and animals. Therefore, a client can indicate a preference for any of the traits described in section *2 Animals*.

Additionally, a client can choose "No Preference" for any of the traits of an animal. This means that the algorithm will not take into account that trait when matching an animal. The exact mechanics of how this works is discussed in section *4 Operation of the Algorithm*. A client may also indicate a preference for zero or more species such that the algorithm will not try to match a client with any species of animal for which the client did not indicate a preference.

3.3 Client Traits

Similar to the matching preferences, when a client first logs into the system they will be asked to fill out a set of personal information that will be used to better match them with an appropriate animal. The fields that a client will have to fill out are as follows:

Table 9—Personal Traits of Clients

Trait	**Age**
Description	This trait describes the type of dwelling in which the client lives.
Possible Values	An integer between 18 and 120.
Application to the Algorithm	This trait is used by the algorithm when determining if the client is looking for an Experienced Sidekick.
Trait	**Dwelling Type**
Description	This trait describes the type of dwelling in which the client lives.
Possible Values	Small Apartment/Condominium, Large Apartment/Condominium, Townhouse, Detached House, or Farm.
Application to the Algorithm	This trait is used by the algorithm when determining if the client is looking for a Rural Rover or Family Pal. It is also used by the algorithm when matching against an animal's "Lots of Energy" trait, the dog-specific "Barks a Lot" trait, the bird-specific "Is Loud" trait, and the lizard-specific "Needs Large Living Space" trait.
Trait	**Dwelling Location**
Description	This trait describes the general level of development of the location of the client's dwelling.
Possible Values	Urban, Suburban, or Rural.
Application to	The algorithm uses this trait when matching against an animals "Good with

the Algorithm	Loud Noises” trait. It is used in determining if the client is looking for any category of animal except Cuddly Companion and Experienced Sidekick.
Trait	**Has Young Children**
Description	This trait indicates whether or not the client has young children present in the dwelling. Young is defined as under 16 years of age.
Possible Values	Yes or No.
Application to the Algorithm	This trait is used by the algorithm when matching against an animal’s “Good with Children” trait. It is used in determining if a client is looking for a Family Pal or Cuddly Companion.
Trait	**Has Other Animals**
Description	This trait indicates whether or not the client has other animals living in the dwelling.
Possible Values	Yes or No.
Application to the Algorithm	This trait is used by the algorithm when matching against an animal’s “Good with Animals” trait. It is used in determining if a client is looking for a Rural Rover.
Trait	**Level of Activity**
Description	This trait describes the typical level of activity of the client? Does the client live a sedentary life? Do they go on daily jogs?
Possible Values	An integer value on a scale from 1 to 5 where 1 indicates “Little” and 5 indicates “A lot”.
Application to the Algorithm	This trait is used by the algorithm when matching against an animal’s “Indoor or Outdoor Type”. It is also used in determining if a client is looking for an Urban Dweller animal. This trait is not heavily weighted in matching.
Trait	**Work Schedule**
Description	This trait describes the client’s typical work schedule.
Possible Values	Typical “9-5”, Afternoon to Late Evening, Varying, Overnight Shifts, or Early Morning to Early Afternoon.
Application to the Algorithm	This trait is matched against an animal’s non-physical Nocturnal trait to determine whether or not the client would have time to interact during the animal’s regular sleep cycle. This trait is not heavily weighted in matching.

4 Operation of the Algorithm

4.1 Overview

The ACM algorithm is a very complex algorithm that must take the preferences and traits of both the clients and the animals into account. It must behave differently based on the species of animal and the preferences indicated by the client. This section will detail the operation of the algorithm. It will begin with a simple diagram detailing the overall operation of the algorithm. It will then detail the individual steps of the algorithm, walking through the operation step-by-step according to the diagram. Then, an example of the semi-final product will be given with a description of what is done to arrive at the final product. Finally, a description of the final product will be given with a small paragraph describing the most major change to the operation of the algorithm in the revised design.

4.2 Diagram of Operation

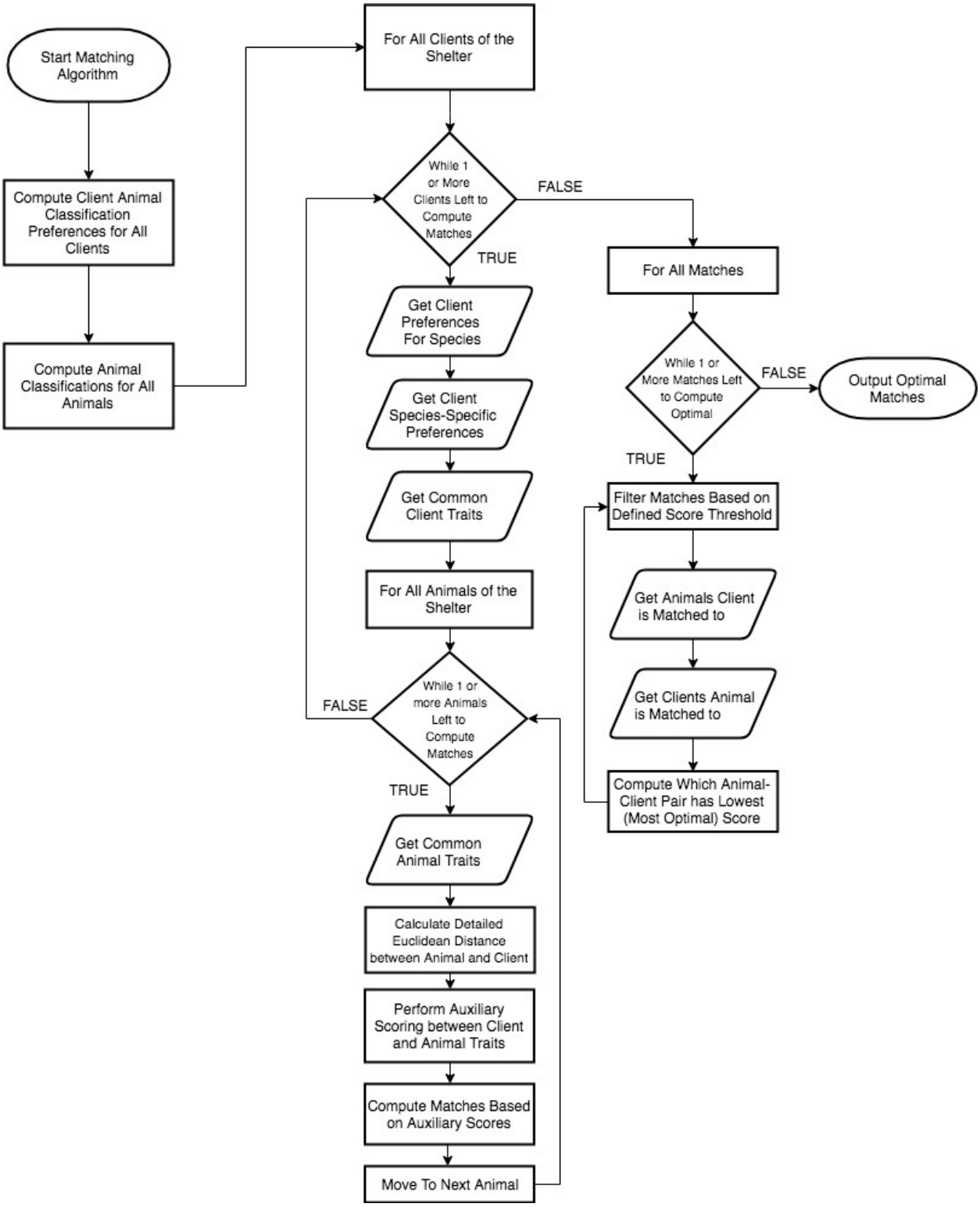

Figure 1— Flow Chart of the Operation of the Algorithm

4.3 Individual Steps of the Matching Algorithm

This subsection goes into further detail about the actions performed for each step that the matching algorithm performs.

4.3.1 Compute Client Animal Classification Preferences for All Clients

The algorithm begins by taking a client's matching preferences and traits and computing the complex attribute of what classification of animal the client seems to want. The classifications described in section *2.4 The Classification of Animals Based on Their Traits* are all represented internally as vectors where each trait is assigned a value inside the vector. The same is true of clients and animals. Therefore, to compute the classifications of animal that the client is looking for, the Euclidean distance formula can be used. This formula, along with examples showing which matches are deemed optimal and which are deemed non-optimal is described in *Appendix A The Euclidean Distance Formula*.

The formula is used to compute the distance or similarity between the classification vector and a vector made up of the relevant preferences and traits which apply to each classification from the client profiles. A client matches the classification for which they have the lowest score.

Traits which are not defined explicitly on a 1-to-5 scale must have their possible values translated into numerical values in order to work with the Euclidean Distance Formula. The closer the values are made to each other, the less a different value affects the total final distance. For example, if a Yes/No trait has a numeric value of "1, 2", then the value of that trait will affect the total distance less than if it was "1, 5". The following table describes such a translation:

Table 10—Translation of Non-Numeric Animal Traits to Numeric Values

Trait	Possible Values	Numeric Translation
Age	0-3, 4-7, 8-11, 12-15, 15+	1, 2, 3, 4, 5
Size	Teacup, Small, Medium, Large	1, 2, 3, 4
Gender	Male, Female	1, 5
Fur	Hairless, Short, Long	1, 3, 5
Scales	Spiked, Rough, Smooth	1, 3, 5
Feathers	Yes, No	1, 5
History	Given up by owner, street animal, rescue, unknown	1, 2, 3, 4

Indoor or Outdoor Type	Indoor, Both, Outdoor	1, 3, 5
Nocturnal	Yes, No	1, 5
Dog – House Trained	Yes, No	1, 5
Lizard – Needs Strong Heat Lamp	Yes, No	1, 2
Lizard – Needs Large Living Space	Yes, No	1, 2
Lizard – Preferred Diet	Crickets, Worms, Mice	1, 2, 3
Rabbit – Patterns	Solid, Bi-colour, Tortoiseshell, Striped, Spotted	1, 2, 3, 4, 5

Table 11—Translation of Non-Numeric Client Traits to Numeric Values

Trait	Possible Values	Numeric Translation
Age	18-25, 26-35, 36-50, 51-65, 65+	1, 2, 3, 4, 5
Dwelling Type	Small Apartment/Condominium, Large Apartment/Condominium, Townhouse, Detached House, Farm	1, 2, 3, 4, 5
Dwelling Location	Urban, Suburban, Rural	1, 3, 5
Has Young Children	Yes, No	1, 5
Has Other Animals	Yes, No	1, 5
Work Schedule	Typical “9-5”, Afternoon to Late Evening, Varying, Overnight Shifts, Early Morning to Early Afternoon	1, 2, 3, 4, 5

Given the above enumerations and all of the traits necessary to match against a specific classification, the vectors that define the classifications can be seen below:

Rural Rover = {Indoor or Outdoor Type, Lots of Energy, Good with Animals, Is Messy, Dwelling Location, Dwelling Type}

Family Pal = {Good with Children, Lots of Energy, Good with Loud Noises, Good in Crowds, Likes Traveling, Age, Dwelling Location, Dwelling Type}

Urban Dweller = {Good in Crowds, Good with Loud Noises, Indoor or Outdoor Type, Is Messy, Lots of Energy, Dwelling Location, Level of Activity}

Cuddly Companion = {Is Affectionate, Lots of Energy, Good with Children, Size}

Fierce Convoy = {Good Home Protector, Lots of Energy, Size, Age, Dwelling Location}

Experienced Sidekick = {Lots of Energy, Is Affectionate, Is Messy, Indoor or Outdoor Type, Age, Age (Client)}

The values assigned to these vectors which are matched against the corresponding client preferences and traits are as follows:

Rural Rover = {5, 4, 4, 3, 5, 5}
Family Pal = {5, 4, 4, 3, 3, 2, 3, 3}
Urban Dweller = {4, 5, 1, 2, 2, 1, 3}
Cuddly Companion = {5, 4, 4, 2}
Fierce Convoy = {4, 4, 3, 2, 3}
Experienced Sidekick = {2, 4, 2, 2, 4, 4}

4.3.2 Compute Animal Classifications for All Animals

The exact same thing that was performed to categorize client matching preferences with classifications of animals is done again except this time comparing the relevant traits of the animals themselves to the relevant traits of each classification to determine how closely the animal matches each classification. An animal is said to match a classification for which they have the lowest score.

4.3.3 Calculate Detailed Euclidean Distance Between Client and Animal

Now that there is a set of animals which all have an assigned classification. The algorithm loops through all clients and for each client it loops through all animals. For each animal, if the animal is of the species that the client has a preference for (or of any species if the client has no preference), the Euclidean distance is calculated on the complete vectors of both the client and the animal. That is to say, one vector containing all of the current client's matching preferences, and one vector containing all of the current animal's traits are compared using the Euclidean distance formula. The distance value is added to a matrix, represented internally as a two-

dimensional array, containing all of the clients and all of the animals, as the element $value_{client,animal}$. If the animal fails the above check regarding species and classifications, the element at $value_{client,animal}$ is set to negative one. These values are known as match scores.

4.3.4 Perform Auxiliary Scoring

Auxiliary scoring is performed for every animal-client match, based on predefined rules to add or remove a fixed amount to or from a match score. The rules are as follows:

Breed: If the client's preferred breed matches the animal's breed, remove 2 from the score.

Colour: If the client's preferred colour matches the animal's colour, remove 2 from the score.

Hypoallergenic: If the client indicated they wanted a hypoallergenic animal and the animal is not hypoallergenic, add 5 to the score.

Good with Children: If the animal has a "Good with Children" score of 1 or 2, and the client has indicated that they have children, add 1 to the score.

Good with Animals: If the animal has a "Good with Animals" score of 1 or 2, and the client has indicated that they have other animals, add 1 to the score.

Dog – Barks a Lot: If the dog has a "Barks a Lot" score of 4 or 5, and the client lives in an apartment/condominium, add 2 to the score.

Lizard – Needs Large Living Space: If the lizard needs a large living space and the client lives in a small apartment/condominium, add 2 to the score.

Bird – Is Loud: If the bird has an "Is Loud" score of 4 or 5, and the client lives in an apartment/condominium, add 2 to the score.

It is important to note that the values of the matrix must remain positive. Therefore, if the value reaches 0.00, a further subtraction will cause the score to remain at 0.00. The score of 0.00 is considered a "perfect match".

4.3.5 Compute Optimal Matches From Set of Animals Matched

From the previous steps, there now exists a matrix, represented internally as a map of client IDs mapped to a vector containing all of the potential matches that that client can make with animals. The lower the number, the better the match. If the number is negative one then the match is not considered when determining the optimal matches as this indicates that the client was not looking for that species of animal.

This is an example of what one such matrix might look like:

	Animal0	Animal1	Animal2	Animal3
Client0	5.67	14.5	11.23	2.34
Client1	1.26	4.11	3.33	8.19
Client2	13.41	-1.00	8.23	8.21

Illustration 1—Example Matrix of Final Matching Values

The final thing to determine is which animal will get matched with which client. The algorithm computes this by first counting the number of viable, good matches that each client has. The threshold for a match to be considered viable is when it's score is less than 4.00. In *Illustration 1—Example Matrix of Final Matching Values*, Client0 has one good match, Client1 has three good matches, and Client2 has, initially, no good matches. As matches are made, animals and clients are removed from contention.

The algorithm then assigns animals starting with clients who only have one good match. The algorithm will then look at the set of clients with only one match at the current threshold and if two or more clients have only one match and this one match is the same animal, then the animal-client match with the lowest score is the one that is selected as the optimal match. If there are no clients with only one good match, it will begin matching clients with more than one good match.

It does this by taking the first client in the collection of clients with viable matches and finding the best match (the match with the lowest score) for that client. Then the algorithm will apply logic similar to matching clients with only one good match where it will look through the rest of the clients with viable matches at the current threshold and, for the other clients which also matched with the same animal, the animal-client match with the lowest score for that match then that is the match that will be made. The process then repeats from the top looking for clients with only one match because since a match was just made, a client and an animal was removed from contention which may lead one or more clients to now have only one good match.

The process is repeated until there are either no more clients left or there are clients with no viable matches under the current threshold. In the latter case, the threshold is increased by a value of 1.00 and the whole process is repeated. The threshold value can increase up to a maximum value of 10.00. Anything beyond that and the match is considered to be too poor to be viable, being ideal for neither the client nor the animal. Clients who do not have any corresponding animal with a match score less than 10.00 do not get matched with an animal.

The values for the thresholds of good matches, increments, and auxiliary rule scores have been decided upon based upon the average maximum score possible for matches (not including auxiliary rules) of 14.97.

Following this process and using the example above, the following matches (shown in green) can be made:

	Animal0	Animal1	Animal2	Animal3
Client0	5.67	14.21	11.23	2.34
Client1	1.26	4.11	3.33	8.19
Client2	13.42	null	8.23	8.21

Illustration 2—Animal-Client Matches From the Example Matrix

It is important to note that Animal1 has not been matched. Outcomes like this are expected from the algorithm since one client may be matched with only one animal. It is also an expected and permitted outcome if there are many matches which are too poor for adoption to be considered and are therefore not made.

This revised algorithm design should now guarantee optimal matches between clients and animals when compared to the previous design. This is because the previous design, which only matched clients with more than two viable matches by looking at the animal that they matched the best, didn't take into account whether other clients matched better with that animal. Now, because, for clients with more than one viable match, the algorithm operates similarly to when clients have only one viable match, the final outcome is a guaranteed optimal set of matches.

Appendix A The Euclidean Distance Formula

The Euclidean distance is the vertical distance between two vectors of n-dimension, in n-space, where n is the number of components in the vector.

For example, vector $\vec{V}=\begin{bmatrix}2\\3\\5\end{bmatrix}$ is a 3-dimensional vector and is in 3-space. Each of the components in the vector determine the distance starting from the origin (the point *(0,0,0)*), on a Cartesian plane, and the tip of the vector lying on the point *(2,3,5)* The distance between two vectors is calculated using the Pythagorean Theorem, in n-space. In basic terms, it calculates the difference of each of the vector's i^{th} elements, squares them then sums them up. Once summed, the square-root of this value is the Euclidean distance. The formula for calculating the Euclidean distance is:

Illustration 3—Euclidean Distance Equation

Example 1: given two vectors **S** and **T**, where $\vec{S}=\begin{bmatrix}2\\3\\5\end{bmatrix}\wedge\vec{T}=\begin{bmatrix}4\\2\\1\end{bmatrix}$, the Euclidean distance is calculated as the following:

$$d(\vec{S},\vec{T})=\sqrt{(2-4)^2+(3-2)^2+(5-1)^2}$$
$$d(\vec{S},\vec{T})=\sqrt{2^2+1^2+4^2}$$
$$d(\vec{S},\vec{T})=\sqrt{21}$$
$$d(\vec{S},\vec{T})\approx 4.58$$

Illustration 4—Example of the Euclidean Distance Equation

Two vectors (**S** and **T**), in any n-space, are said to be close when their Euclidean distance is close to 0. If $\vec{S}=\begin{bmatrix}1\\2\\1\end{bmatrix}\wedge\vec{T}=\begin{bmatrix}1\\2\\2\end{bmatrix}$, their Euclidean distance is 1. They lie in the same x-plane, the same y-plane, and only differentiate 1 unit in their z-plane.

In the cuACS matching algorithm, one of the components to determine how good a match, between a client and an animal is, is the Euclidean distance. Using the Euclidean distance, the algorithm calculates how far apart the two vectors lie, and uses the resulting figure, along with a number of other calculations and variables, to determine if it's a good match.

As an example, each animal has a value for their attributes and each client has their own attribute values, both can be stored in a vector. In the cuACS algorithm, vectors using 14 or more elements are used in calculating the perfect match. For simplicity's sake, let's say there is an animal with 5 traits and a client with preferences for those 5 traits: *Is Affectionate*; *Is Fearful*; *Lots of Energy*; *Good with Crowds* and; *Is Messy*. Each attribute is based off a 5-point scale, 1 being low and 5 being high. The resulting 5-dimensional vector would lie in 5-space and would lie on 5 Cartesian planes. Here are the vectors for the animal **A** and client **C**.

$$\vec{A} = \begin{bmatrix} 5 \\ 4 \\ 1 \\ 1 \\ 5 \end{bmatrix} \wedge \vec{C} = \begin{bmatrix} 5 \\ 5 \\ 1 \\ 2 \\ 2 \end{bmatrix}$$

The resulting Euclidean Distance is approximately 3.317 and suggests the animal-client pairing is a good match.

$$\vec{A} = \begin{bmatrix} 5 \\ 4 \\ 5 \\ 4 \\ 5 \end{bmatrix} \wedge \vec{C} = \begin{bmatrix} 3 \\ 1 \\ 1 \\ 2 \\ 1 \end{bmatrix}$$

The resulting Euclidean Distance is approximately 7.000 and suggests the animal-client pairing is a **not** good match.

The perfect animal-client match would result in a Euclidean Distance of 0.000. This is the case when all the elements of 2 vectors are identical, regardless of the dimension size. Using the above 5-dimensional vector, with values ranging from 1 to 5 for each vector element, the worst-case match would have a Euclidean Distance of approximately 8.944, it's vectors are shown below.

$$\vec{A} = \begin{bmatrix} 5 \\ 5 \\ 5 \\ 5 \\ 5 \end{bmatrix} \wedge \vec{C} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

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