Artificial Intelligence in Clothing Fashion

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Abstract
"Clothes make the man," said Mark Twain. This article presents a survey of the literature on Artificial Intelligence applications to clothing fashion. An AI-based stylist model is proposed based on fundamental fashion theory and the early work of AI in fashion. This study examines three essential components of a complete styling task as well as previously launched applications and earlier research work. Additionally, the implementation and performance of Neural Networks, Genetic Algorithms, Support Vector Machines and other AI methods used in the fashion domain are discussed in detail. This article explores the focus of previous studies and provides a general overview of the usage of AI techniques in the fashion domain.

Keywords: Artificial Intelligence, Fashion, Clothing Styling.

1. Introduction
There might be a moral argument about whether people should be judged by their apparel. In practice however, few people would consider a person in baggy jeans walking into their first meetings seriously. Dressing properly brings a big ROI (Return of Investment). According to a survey done by OfficeTeam, 93% out of more than 1000 senior managers at companies with 20 or more employees responded that clothing choice affects an employee's chances of promotion (OfficeTeam, 2007). However, keeping track of fashion sense requires significant time and effort, which leads some people to seek help from a professional stylist. Personal stylists can be expensive though and cannot be with clients all the time. This study discusses whether an Artificial Intelligence based computer program could be the new fashion consultant and how it might be executed. There are many benefits associated with using computer programs as future stylists. They could process large amounts of data faster when learning a user's style and memorizing users' feedback. AI stylist programs can also store descriptions of user's items and help users be more organized and efficient.

The goal of this survey study is to explore AI methods in the clothing fashion domain. In the second section, three major components of a full styling task are identified. The third section is a summary of earlier projects and relevant fashion theory. In the methodology section, earlier works in AI implementation and their solutions to each major problem are explored. The last section is a discussion.

2. Related AI-technologies
Every fashion clothing styling task which is completed has 7 steps: picking a theme, deciding on a primary color, mixing and matching clothing pieces, selecting accessories, model or client fitting and finally hair styling and make up.

An AI based computer program focused on modeling centers on solving the following questions:

1. How to represent garments computationally?
2. How to model human stylist behavior?
3. How to detect, track and forecast fashion trends?

Popular AI methods used previously include Fuzzy Logic, Genetic Algorithms, Neural Networks, Decision Trees, Bayesian Networks and Knowledge Based Systems and their variations. This section will briefly outline these AI methods.

A *Bayesian Network* is a probabilistic model that represents variables and their conditional dependencies (Russell & Norvig, 2009). They have been used to infer relationships between previous fashion trends and future trends.

Fuzzy logic is an approach that utilizes uncertainty and approximate reasoning (Eberhart & Shi, 2007). It represents truthfulness and falsehood with degrees and works closer to human brain because it outputs a straightforward like or dislike.

Using *Artificial Neural Networks (ANNs)* is a learning method inspired by animal nervous systems. An ANN maps input to a target output

by adjusting weights (Eberhart & Shi, 2007). This method works well for modeling complex styling tasks with multiple features.

Knowledge-Based Systems are programs that represent knowledge and solve complex problems by reasoning on how knowledge artifacts are related or not related (Eberhart & Shi, 2007). They are used to show the relationships between features in fashion styling.

Decision Trees are tree-structured graphs that represent attributes as internal nodes and outcomes as branches (Kokol, Verlic, & Krizmaric, 2006). They are widely used in human decision-making models.

Genetic Algorithms (GAs) are search techniques that look for approximate or exact solutions to optimization problems. They are guided by a fitness function. Interactive Genetic Algorithms (IGAs) have been used in earlier studies aimed at achieving real-time interaction. The biggest difference between IGAs and regular GAs is that instead of using a fitness function, IGAs assign a fitness value to each individual (Tokumaru, Muranaka, & Imanish, 2003).

3. Contemporary Applications

3.1 Research Design of this Study

In this study, the AI-based fashion applications and articles are classified based on the fundamental definition of fashion. Fashion is a major part of people's daily lives and the fashion market itself is quite large. In the next two sections, current popular computer applications and prior research from the last decade are summarized.

3.2 Popular Applications

There are four major types of applications as shown in Table 1. *Internet Based Human Stylist Consultant Services* put the communication between clients and stylists on the Internet. They improve the flexibility and accessibility of styling work. *Virtual Fitting Systems* fill one of the major gaps between e-commerce and retail stores. The third type of application is *Recommender System Implementations in E-commerce*; for example Amazon recommends new items based on users' browsing histories**.** The last type is *Online Fashion Communities*, such as Polyvore, which provide a platform for people to share, gain and communicate fashion inspiration and shopping information online.

3.3 Earlier Research Projects

Conceptually, fashion can be defined as a two dimensional concept, an object and a behavior process. The form of a "fashion object" can be a

Table 1: Popular Fashion Applications List *All sites listed above were visited on April 15th, 2014

Business Model	Name	Website URL*
Human Stylist Internet-Based Consultant Services		
Recommend new items to mix and match with user's existing items	Topshelf	http://www.topshelfclothes.com/
	MyPrivateStylist	http://www.myprivatestylist.com/
Exclusive, high reputation and experienced stylists offer service to their members	KeatonRow	https://keatonrow.com/
	StyleMeASAP	http://stylemeasap.com/
Human stylists style male customers within clothing collections	TrunkClub	http://www.trunkclub.com/
Virtual fitting system		
Customized virtual avatars for virtual clothes fitting experiences with clothing imagery	Glamstorm	http://glamstorm.com/en
	CovetFashion	http://www.covetfashion.com/
	ChroMirror	(Cheng, et al., 2008)
Recommender system in e-commerce sites		
Recommend items based on user' activities and browsing records	Amazon	http://www.amazon.com/
Recommend new trendy clothing items and search for relevant clothing items based on user's search queries	Google Shopping	http://www.google.com/shopping
Pushes sale information based on user's preferences	Shop It To Me	http://www.shopittome.com/
Online fashion community		
Platforms for users to create, share and look for fashion inspiration	Polyvore	http://www.polyvore.com/cgi/home
	Lyst	http://www.lyst.com/
	StyledOn	http://styledon.com/

specific product or innovative technical features or new membership services. While "fashion process" is a process through which a "fashion object" emerges from its creation to public presentation, trendsetter adapting, majority acceptance/rejection, and replacement of newer object and merge of next trend (Sproles, 1979).

The major focus of this study is to find solutions for the three target problems stated in Section 2. Among the three problems, the first one, garment representation focuses on fashion object. The third one, detection, tracking and forecasting of fashion trend are about fashion process. While the second one, modeling human stylist behavior is a mixture of both.

3.3.1 AI Techniques on "Fashion Objects"

Back in 2000, Genetic Algorithms were used in a fashion design assistant system (Kim & Cho, 2000). Clothing color styling model was proposed in the Virtual Stylist Project in (Tokumaru, Muranaka, & Imanish, 2003). Decision Trees with Genetic Algorithms were used to model individual's clothing in (Kokol, Verlic, & Krizmaric, 2006). Researchers implemented Category Learning and Neural Networks in an intelligent clothing shopping assistant system in 2008 (Cheng & Liu, 2008). Computer Vision techniques with Support Vector Machine (SVM) classifiers were used to discover the semantic correlations between attributes in (Chen, Gallagher, & Girod, 2012).

3.3.2 AI Techniques on "Fashion Process"

Previous studies tried to understand, detect and predict fashion trends and fashion cycles from both the perspectives of theory and application. Two earlier studies focused on predicting clothing color fashion trends. Mello's team developed an expert system that assists the stylist with the proposal of new color trends. Their system implemented a Bayesian Network model stylist proposing process (Mello, Storari, & Valli, 2008). Yu's team compared different AI models for predicting fashion color trends with an expert system (Yu, Hui, & Choi, 2012). There are many interesting models of fashion trends. One model on simplified general fashion cycles was of specific interest. This model has three major factors: base utility, social influence and user boredom (Sarma, Gollapudi, Panigraphy, & Zhang, 2012).

4. AI Methods in Fashion

4.1 Garment Representation

Table 2: AI in Fashion Projects List

Year	Title	Reference
Garment Representation – Fashion Object		
2000	Application of Interactive Genetic Algorithm to Fashion Design	(Kim & Cho, 2000)
2012	Describing Clothing by Semantic Attributes	(Chen, Gallagher, & Girod, 2012)
Human Stylist Behavior Model – Fashion Objects & Fashion Process		
2003	Virtual Stylist Project – Examination of Adapting Clothing Search System to User's Subjectivity with Interactive Genetic Algorithms	(Tokumaru, Muranaka, & Imanish, 2003)
2006	Modeling Teens Clothing Fashion Preferences using Machine Learning	(Kokol, Verlic, & Krizmaric, 2006)
2008	An Intelligent Clothes Search System Based on Fashion Styles	(Cheng & Liu, 2008)
2008	Mobile Fashion Advisor – A Novel Application in Ubiquitous Society	(Cheng & Liu, 2008)
Fashion Trend Detection, Track and Forecasting- Fashion Process		
2010	Application of Machine Learning Techniques For the Forecasting of Fashion Trends	(Mello, Storari, & Valli, 2008)
2012	An Empirical Study of Intelligent Expert Systems on Forecasting of Fashion Color Trend	(Yu, Hui, & Choi, 2012)
2012	Understanding Cyclic Trends in Social Choices	(Sarma, Gollapudi, Panigraphy, & Zhang, 2012)

Figure 1: Describing garments with attributes *
***Websites are visited on April 30th, 2014**

Garments can be described by a set of features as shown in Figure 1. Different pieces have their own unique features. The most basic features are Color, Shape, Print and Fabric (Material). Computer Vision techniques are able to automatically recognize the first three. Color is initially represented in a RGB (Red, Green and Blue) model and converted into an HSI (Hue, Saturation and Intense) model for further computation (Tokumaru, Muranaka, & Imanish, 2003) (Cheng & Liu, 2008). The Outline can easily be extracted with Computer Vision techniques and the print of a garment can be considered in its loudness. The loudness in this case is the frequency of color changes in the garment and the changes in locality on this garment. Fabric is the trickiest one. Even humans would have difficulties recognizing a fabric just by looking at it.

One possible solution for tricky attributes like "fabric" is inspired by the computer vision research project in 2012. They researched stylistic semantic correlations between clothing attributes. For example, Mark Zuckerberg's dressing style contains attributes like "gray/brown" and "t-shirt/outwear". They applied Support Vector Machine classifiers on single attributes to determine how useful these attributes would be in prediction. Then, the system makes predictions based on inference of different attributes' mutual dependency relations in a Conditional Random Field (Chen, Gallagher, & Girod, 2012). With a similar model, systems could learn correlations between attributes and fill in missing values. For instance, a formal dress has a high possibility of being made of silk. Casual style white t-shirts are likely to be made of cotton.

4.2 Computational Styling Task

4.2.1 Color Harmony Evaluation

Color is the very first step in a fashion styling task. In previous research, Matsuda's Color Coordination (MCC) has been used to evaluate the harmony rate between colors (Tokumaru, Muranaka, & Imanish, 2003; Cheng & Liu, 2008). Yutaka Matsuda who had investigated color schemes of female clothes and dress through a questionnaire for 9 years proposed MCC. In MCC there are 80 color schemes (8 hue types and 10 tone types) and a color scheme is harmonious if there are many samples in the system. Each individual has a unique style preference. An ideal intelligent style system should be able to adapt from a standard color scheme to a specific user's personal preference instantaneously. One working solution is to make static color schemes more dynamic.

In VSP, they added linguistic labels ("neutral, "a little", "slightly", "fairly", "very" and "extremely") on the color scheme and linguistic labels are presented as fuzzy sets respectively. Their system adapts itself to a user's preference during its interaction with the user. They also implemented an Interactive Genetic Algorithm so that the system is able to do so in real time. There are three different types of nodes in their IGA: the parameters of four basic senses, the weight of four senses and fuzzy rules. The system displays some dress patterns based on its knowledge and the user rates the similarity to her clothing sensation from 1 to 5. Highly rated individuals are used to generate the next generation individuals (Tokumaru, Muranaka, & Imanish, 2003). The experimental results confirmed that IGA optimized the system and the system was able to adapt itself to specific user preferences.

4.2.2 Shape, Prints and Fabric styling

Identifying shape, print and fabric is the second step in the fashion styling task. Style principles of these attributes are changing all the time. For instance, one of the standard style rules for prints is to wear only one pattern piece at a time. However, in the 2014 spring season, wearing two patterns with similar shades and detailing became very trendy. Moreover, it heavily depends on individual preference. Women with a classic style will not follow this new trend. Many other features also affect the styling task, such as occasion and cultural background. In this scenario, a stylist looks at a number of features from different categories and tries to classify items based on their experience and fashion sense. A Neural Network model is a good approach for a problem like this. In a previous study, an ALCOVE (Attention Learning Covering map) model based on NN was implemented in a clothing match system (Cheng & Liu, 2008). It converted garment physical attributes into garment sensation space in a fuzzy set (Table 3). Four garment sensations are input

Table 3: Garment Physical Attributes and their garment sensation

Major Physical Attributes	Garment Sensation
Color	Warm / Cold
Print	Cheeriness
Shape	Fitness
Fabric	Softness

nodes of the NN. In Cheng and Liu's project, training data were gathered through a questionnaire designed by a fashion stylist. Clothes were categorized into 10 different styles: Sexy, Modest, Sophisticated, Elegant, Luxuriant, Romantic, Girly, Masculine, Sporty and Casual. During training, the NN adjusted weights based on a given target output Neural Network is a state-of-the-art model to classify items with numerous attributes into different classes. The drawback is that they are less interpretable. For instance, updated style rules would be a great data source to keep track of changes in fashion trends, but it is difficult to extract them out of a NN model.

Decision Trees, on the other hand, are very interpretable. Previous research has used Genetic Algorithms and Vector Decision Trees to model user clothing preferences and generated fashion rules (Kokol, Verlic, & Krizmaric, 2006). They implemented a GA in a tree structure where VDT's genotype and phenotype were the same. This actually sped up the fitness computation. The fitness function has 5 major components: average accuracy over all dimensions, accuracy of the whole vector, average performance of classifiers, the factor minimizing the overall fitness bonus score and a linear penalty to avoid overfitting. They trained the model with 60 initial trees with a mutation rate of 0.5%. The model had an accuracy of 85% after 1273 iterations and it showed that such model is able to handle this highly dynamic task (Kokol, Verlic, & Krizmaric, 2006).

4.3 Fashion Trend Tracker

The ideal intelligent stylist program should be very sensitive to fashion trends. Fashion trend forecasting is the key to success in the fashion industry and always a bigger challenge than prediction of other fields. The biggest variable of it

is human value. In the fashion process as shown in Figure 2, new trends get popular slowly before trendsetter adoption (Phase A), reaches to its peak of fast social majority acceptance (Phase B) and declines dramatically thereafter.

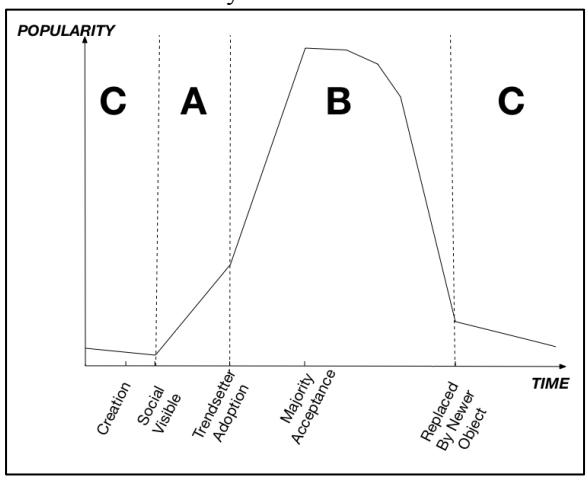

Figure 2: Fashion process or Fashion cycle

Two major reasons for the decline are: 1. Newer trends kick in; 2. People get bored with the trend after the peak. Generally, there are two types of fashion forecasting. The first one focuses on current fashion objects and it does predictions such as fashion color trends. Another type interests in a longer vision, for instance, black and white are never out of date regardless of season or occasion.

Some recent and relatively successful studies have attempted to predict fashion color trends with AI techniques. Dr. Mello and her team have implemented Knowledge Base Systems and Bayesian Networks (Mello, Storari, & Valli, 2008). They modeled a human stylist's new color trend proposal process with a Bayesian Network. Based on the knowledge of past and current color trends, BN classifiers classified color into binary target values, proposed or not proposed based on their probability. The human stylist then confirmed their application performance. In another study, researchers compared the performance of 5 models in fashion color prediction (Yu, Hui, & Choi, 2012) .The 5 models are the statistical models ARIMA (Autoregressive Integrated Moving Average), GM, GNNM (Grey Neural Network Model), Improved GM, ANN, ELM (Extreme Learning Machine). After the comparison, they proposed a hybrid GRA (Grey Relational Analysis)-ELM that achieved high accuracy and was less time consuming.

Researchers proposed a simplified fashion trend model taking three major factors into account: Base Utility, Boredom and Influence (Figure3).

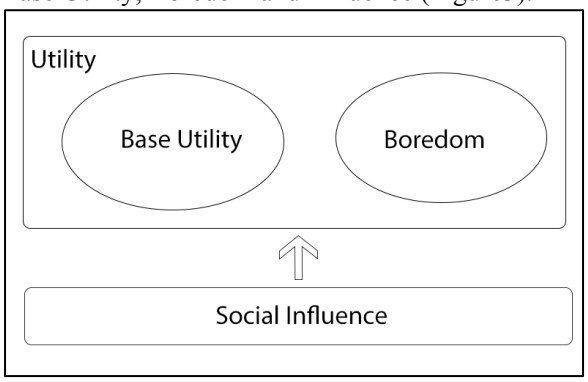

Figure 3: Simplified fashion process model

They modeled individual boredom as a "memory" factor of an object and the parameter of "memory" as the number of times using it in the past. With more times of use, more memories, higher boredom and less utility are left. The goal is to explore how to maximize the user's overall utility of an item. The fashion process is continuous and a solution to this problem is to compute the consumption cycle at a regular time (Sarma, Gollapudi, Panigraphy, & Zhang, 2012). They considered the fashion cycle as an NP-Hard problem and validated it with both a greedy algorithm and double greedy algorithm. In their experiment, they collected data including music, events and the boredom factors from Google Trend. Their experiment showed that a double greedy algorithm has better performance than a greedy algorithm in this model.

5. Concluding Remarks

AI based Stylist programs should consider the following three major components: (1) Visual Garment Representation, (2) Computational Styling and (3) Fashion Trend Tracking. This study has presented various ways to use AI techniques in a fashion stylist computational model.

For the first task, earlier works show that computer vision techniques can extract attribute information from an image and AI techniques such as semantic mapping give the program the ability to deal with tricky attributes, such as fabric. For cloth-piece styling, earlier researchers started off using Color Harmony Evaluation (Tokumaru, Muranaka, & Imanish, 2003) between garment pieces and then taking four basic attributes - color, outline, print and fabric - into consideration. Neural Networks

with category learning techniques have been applied successfully (Cheng & Liu, 2008). However, a completed styling task requires more attributes, such as event, clothes, shoes, accessories, makeup and hairstyling. A stylist is also very personal. Earlier work used GAs and Decision Trees to model fashion personal preferences (Kokol, Verlic, & Krizmaric, 2006). Even though their study is not focused on a completed styling task, their model is a good example of a fashion personal preference model. Change is also central to fashion. Computers have the ability to deal with large amounts of data and the ability to deal with large amounts of data and would be a good assistant for human stylists. Two research projects applied Bayesian Network Neural Networks and Knowledge Base Systems to fashion trend prediction (Mello, Storari, & Valli, 2008) (Yu, Hui, & Choi, 2012). Their experiments indicate that hybrid models and Bayesian Networks both have good performance on predicting color trends in the next season.

Earlier work has shown that AI-based programs have the ability to execute a fashion styling task and fashion can be modeled with a simplified model. However, there is still much work to be done on AI based styling. Models in earlier studies are not comprehensive. For instance, styling task requires more features than color, fabric, shape and outline. Also fashion changes among different cultures and times. For instance, Asian fashion style is different from Parisian.

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