Generative Interpretable Visual Design

Application to Visual Conjoint

Ankit Sisodia[1], Alex Burnap[2] and Vineet Kumar[2]

[1]Purdue University

[2]Yale School of Management

Presenting at: ORSI ICBAI 2023

Visual (or aesthetic) design matters across many product categories . . .

Cars

Fashion

Furniture

Visual design matters

"Exterior look/design is the top reason shoppers avoid a particular vehicle (30%), followed by cost (17%)."

—JD Power Avoider Study 2015

What this paper seeks to do

Research Goals

Our research aims to obtain **interpretable** visual characteristics (not surprising / outlier) directly from unstructured product images

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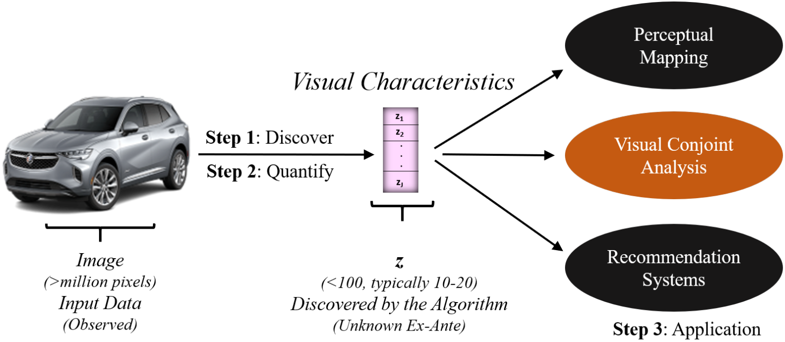
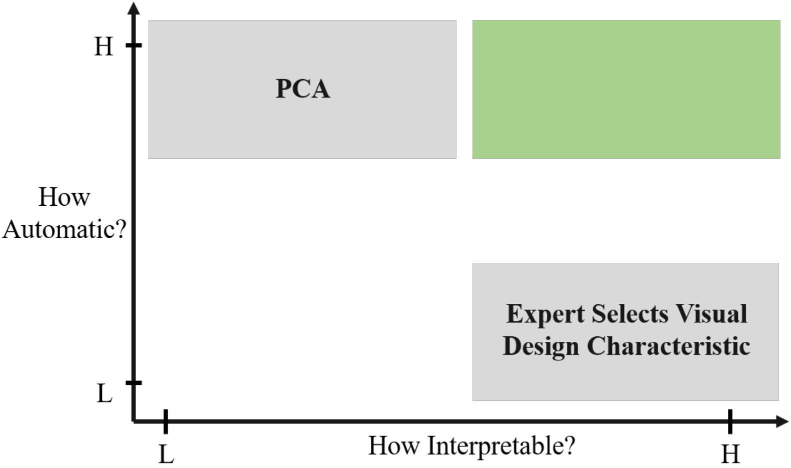
Hyundai: $(3, 8, 5, 9)$ compared to BMW: $(1, 3, 10, 1)$

Why Visual Characteristics?



Modeling Visual Characteristics: A comparison of methods



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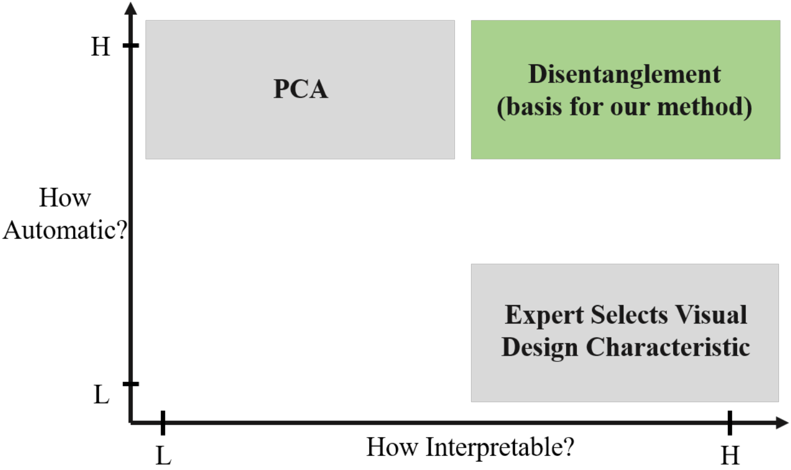

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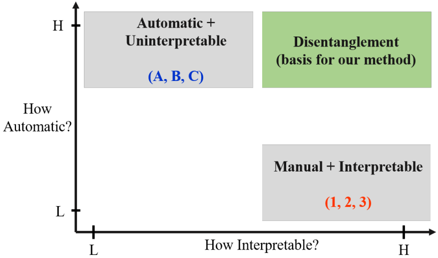

Automatic + Uninterpretable

- A - Bajari, P. L. et al. (2021) : Hedonic prices and quality adjusted price indices powered by AI, *CENMAP working paper*
- B - Law, S., et al. (2019) : Take a look around: using street view and satellite images to estimate house prices. *ACM Transactions on Intelligent Systems and Technology (TIST)*
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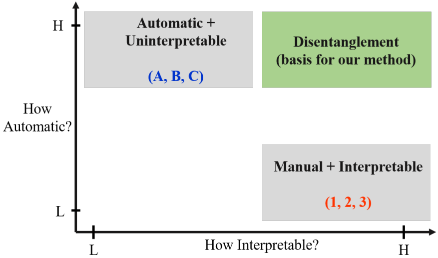

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Manual + Interpretable

- 1 - Zhang, M. et al. (2022) : Can consumer-posted photos serve as a leading indicator of restaurant survival? Evidence from yelp. *Management Science*
- 2 - Liu, Y., et al. (2017) : The effects of products' aesthetic design on demand and marketing-mix effectiveness: The role of segment prototypicality and brand consistency. *Journal of Marketing*
- 3 - Zhang, S., et al. (2021) : What makes a good image? Airbnb demand analytics leveraging interpretable image features. *Management Science*

What is disentanglement?

Bengio et al (2013)

> *"A disentangled representation can be defined as one where* **single latent units** *are sensitive to changes in single generative factors, while being relatively invariant to changes in other factors"*

- Latent Units ($\mathbf{z}$): Dimensions in the model's latent space
- Generative factors ($\mathbf{c}$): Human-interpretable true characteristics

Goal of machine learning process:
Recover latent space and make one-to-one correspondence $\mathbf{c} \longleftrightarrow \mathbf{z}$

Disentangled and Entangled Representations

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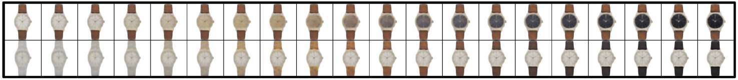
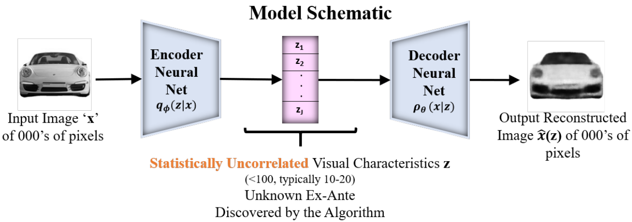
Recover latent space and make one-to-one correspondence $\mathbf{c} \longleftrightarrow \mathbf{z}$

Example of *Entangled* Visual Characteristics

Example of *Disentangled* Visual Characteristics

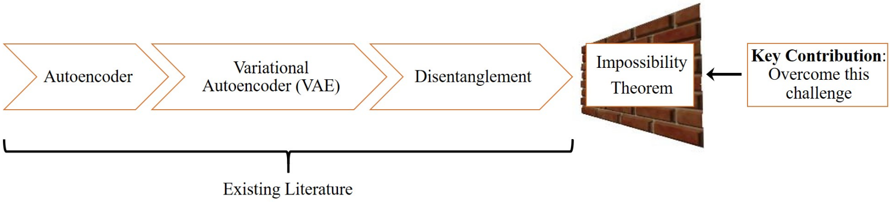


Models in Existing Literature

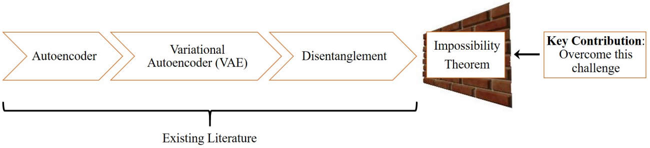


Model	Goal
Autoencoder (AE)	Reconstruction accuracy
Variational Autoencoder (VAE)	...+ structured latent space
Disentanglement	...+ ...+ statistically independent latent space

Roadmap of Our Approach



Impossibility Theorem



Impossibility Theorem

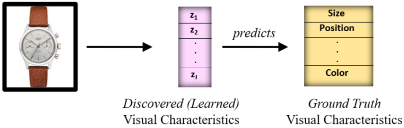
Unsupervised (*i.e. only images*) learning of disentangled representations is *fundamentally impossible* except under certain restrictive conditions.[a]

[a] Locatello, Francesco, et al. "Challenging common assumptions in the unsupervised learning of disentangled representations." ICML. PMLR, 2019.

Implication: Every disentangled representation can have other *infinite* equivalent entangled representations.

Impossibility Theorem – Implications

Common approach to ground truth in ML is to get humans to label[1]



What's the Problem?

- Ground truth on visual characteristics is *unknown*.

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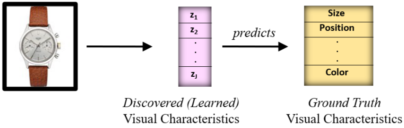

What's the Problem?

- Ground truth on visual characteristics is *unknown*.
- In fact, these are precisely what we want to find.

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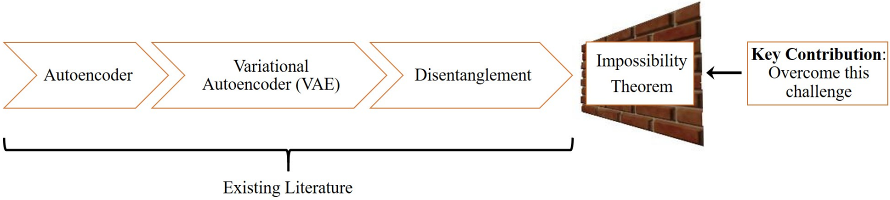
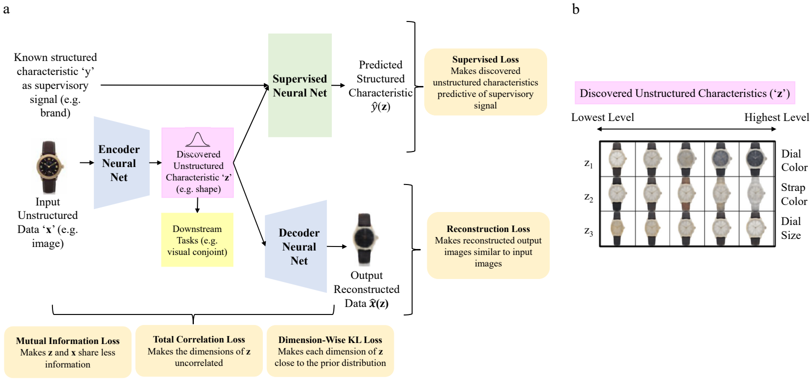
Roadmap of Our Approach



Contribution

We aim to overcome this impossibility theorem without ground truth by using structured product characteristics.

Schematic of Proposed Approach



Model

- Learn model parameters by minimizing loss $L(\theta, \phi; \mathbf{x}, \mathbf{z})$ of integrated model
- θ and ϕ are encoder and decoder parameters; $\mathbf{x}$ are images

$$\underbrace{L(\theta, \phi, \mathbf{w}); \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})}\left[\log p_\theta(\mathbf{x}|\mathbf{z})\right]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL\left[q(\mathbf{z}) || \prod_{j=1}^{J} q(z_j)\right]}_{\text{Total Correlation Loss}}$$

$$+ \gamma \underbrace{\sum_{j=1}^{J} KL\left[q(z_j) || p(z_j)\right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

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Loss Term	Why is this term included?
Reconstruction	Promotes accurate reconstruction of images
Mutual Information	Minimizes redundant information
Total Correlation	Promotes statistical independence between visual characteristics
Dimension-Wise KL	Penalizes deviations from a prior
Supervised	Provides a signal to address the impossibility theorem

Model – Role of Supervised Loss

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Key Idea

If the supervisory signal is sufficiently correlated with visual characteristics, then it can help obtain the unique (true) disentangled representation

Human Interpretable Characteristics?

- Are these discoveredt visual characteristics human interpretable?
  - Without any domain knowledge about the product category?

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Starting from the image on the left, **what part of the watch changes the <u>most</u>** as you go from left to right? Carefully check both large and small visual aspects. Go through each part of the watch one by one before selecting any option. Refer to the above image to see parts of the watch.

Note: Images are low-quality on purpose

- ○ Bezel
- ○ Crown
- ○ Date Window
- ○ Dial
- ○ Hands
- ○ Hour Marker
- ○ Lug
- ○ Strap

How is that part of the watch changing?

Visual Characteristics: Quantification?

Interpretability and Quantification

Visual characteristic	Interpretability Survey	Quantification Survey
Dial Size	76%	83%
Dial Color	80%	92%
Strap Color	88%	92%
Rim (Bezel) Color	79%	88%
Dial Shape	87%	68%
Knob (Crown) Size	70%	85%

Discovered Visual characteristics

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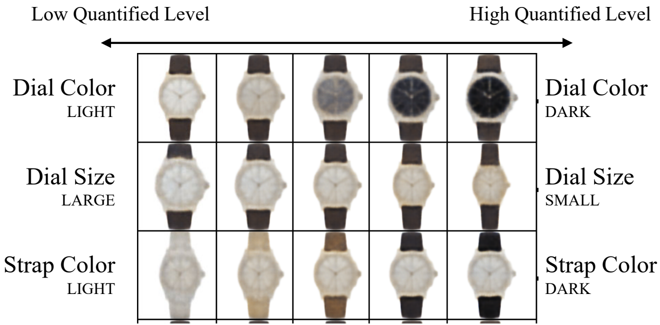

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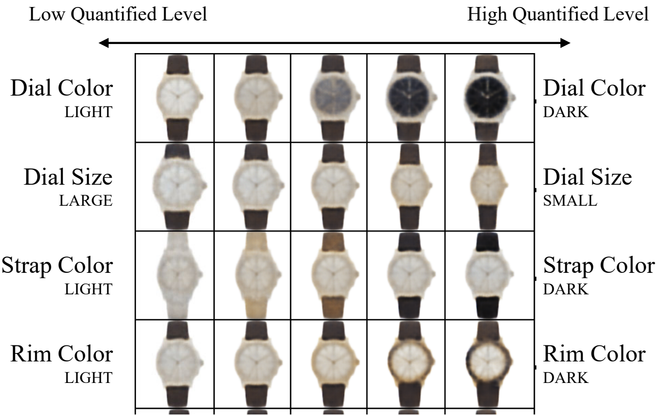

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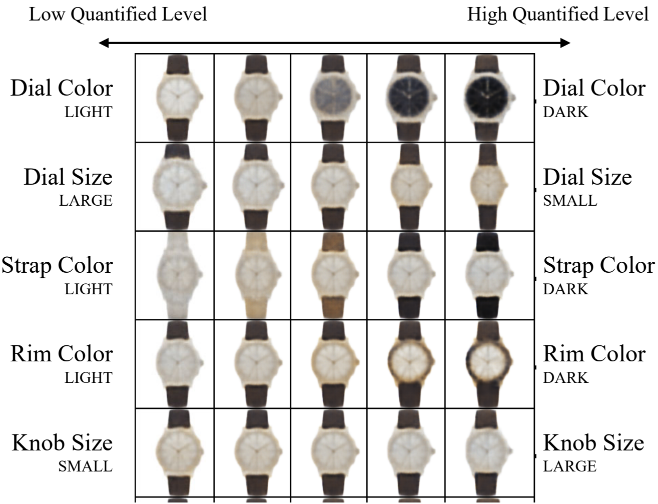

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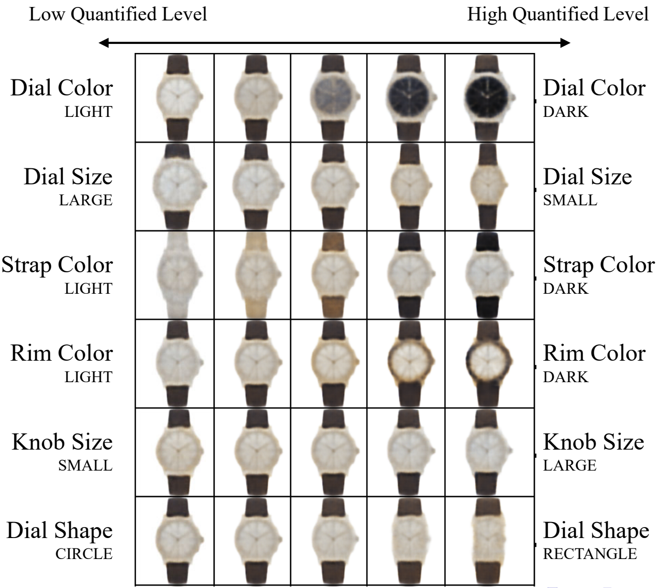
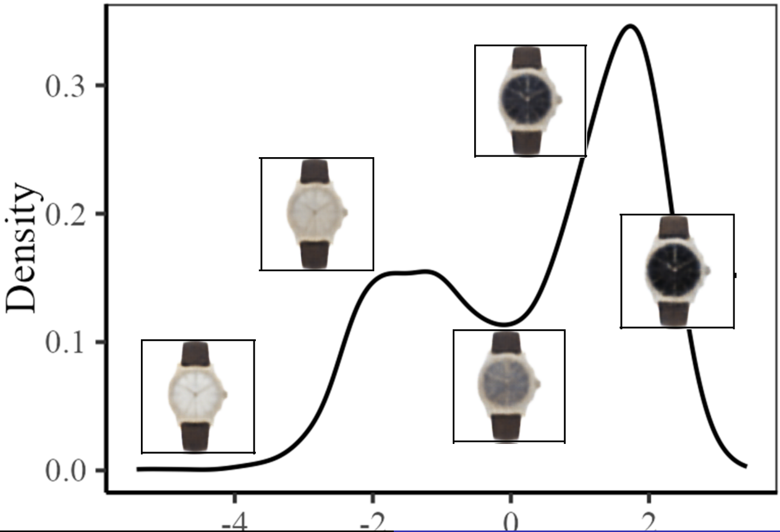


Density of Discovered Visual characteristics (from 'Brand+Material' Signal)



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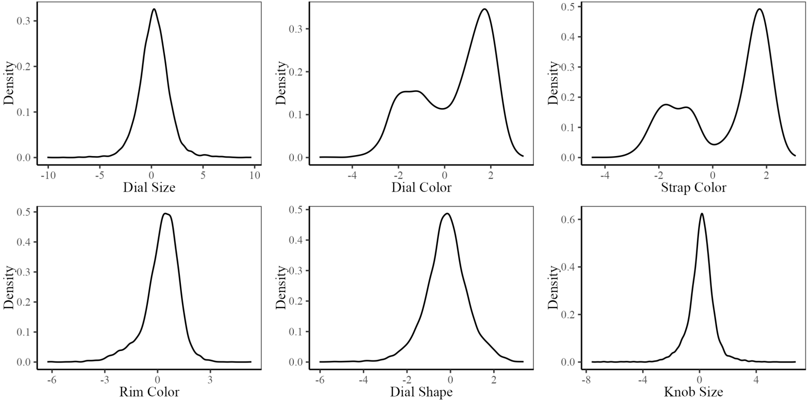
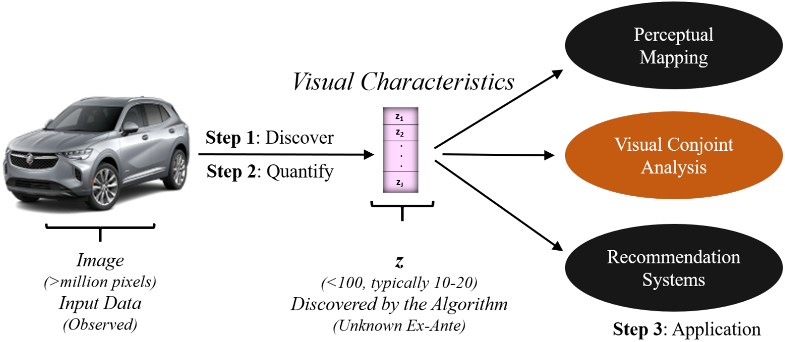
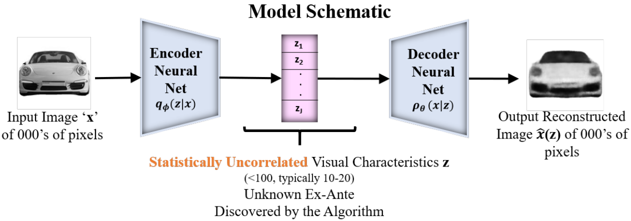


Research Goals



Visual Conjoint Analysis: Background



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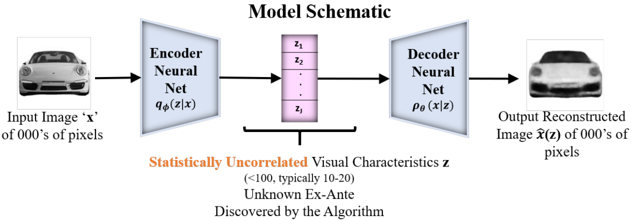

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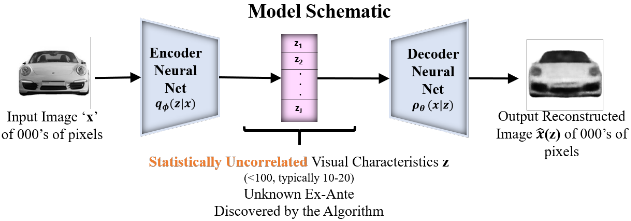

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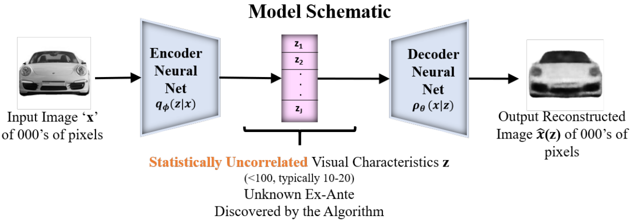

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- Designs have always been manually generated by product designers (prototypes)
- Our approach generates new never-seen visual designs (counterfactual)
- Can span the entire space of visual designs *without being bound by the correlations in the data.*

Conclusion

We obtain interpretable visual characteristics directly from unstructured product images

- *automatically discover* (extract) characteristics
- *quantify* these characteristics
- *generate* visual design that span the space of visual characteristics

Applications

We then used the model to:

- generate new counterfactual designs to obtain consumer preferences over visual characteristics.
- obtain ideal point visual designs corresponding to different consumer segments