

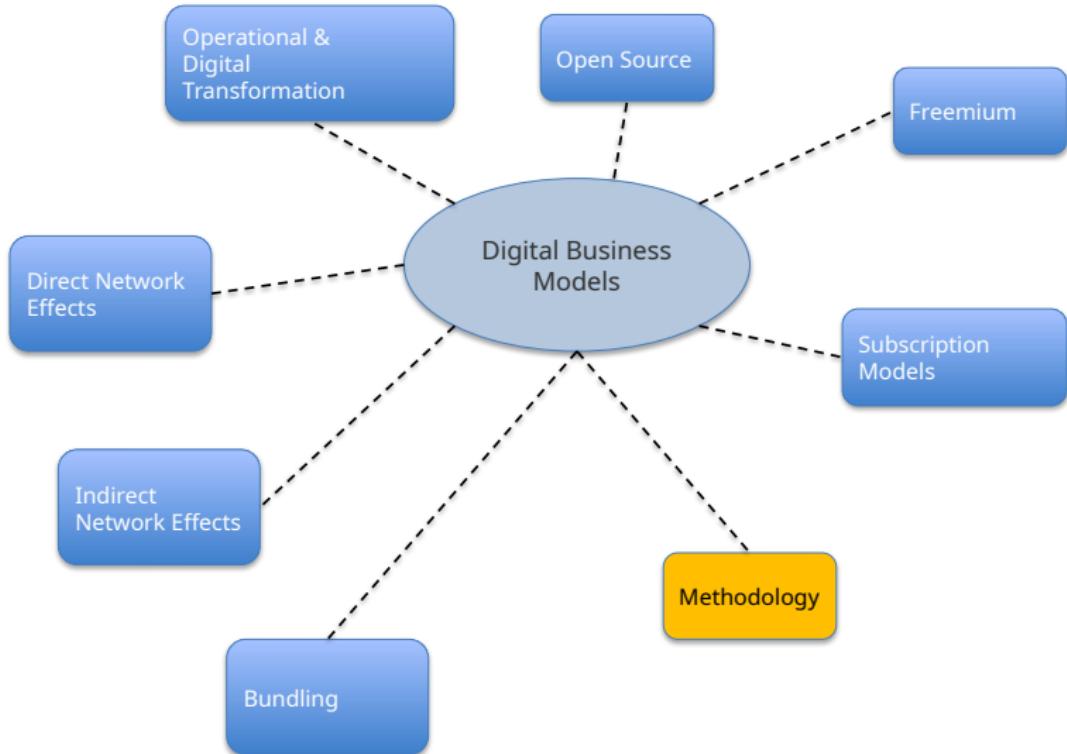
Research Overview

Vineet Kumar

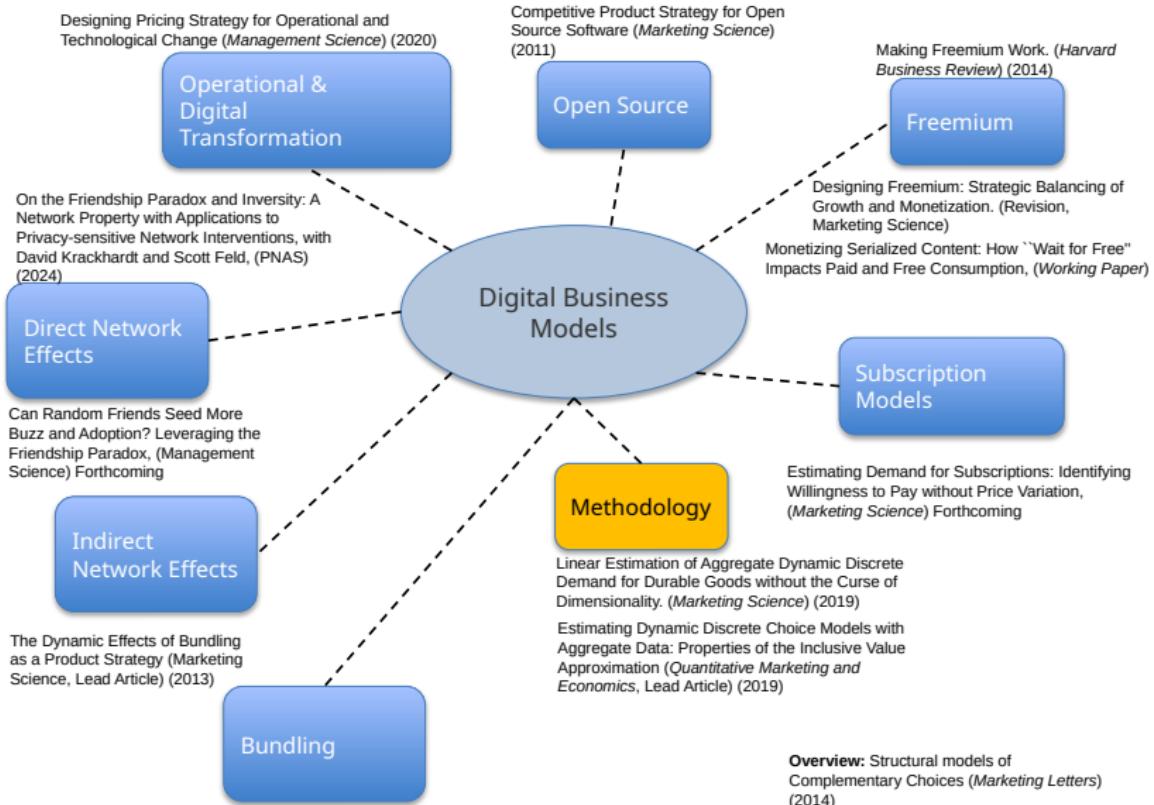
Yale School of Management

Presenting at:
Purdue University
Daniels School of Business
November 2025

Research Overview



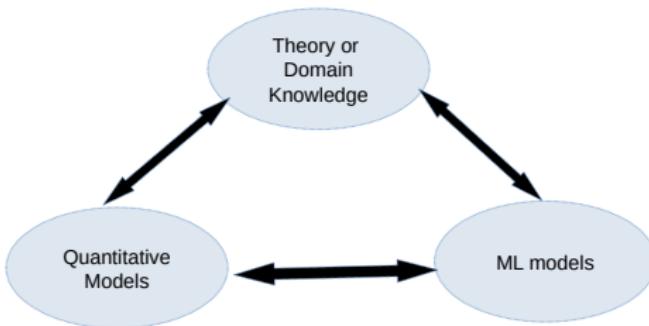
Digital Economy – Business Models



Overview: Structural models of Complementary Choices (*Marketing Letters*) (2014)

Role of Human Knowledge in Research

ML has typically been atheoretical



- One view of ML – advanced form of *statistical pattern matching*
 - Similar model (CNN) used both for detecting lung cancer (medicine) and for detecting stars (astronomy)

My Take

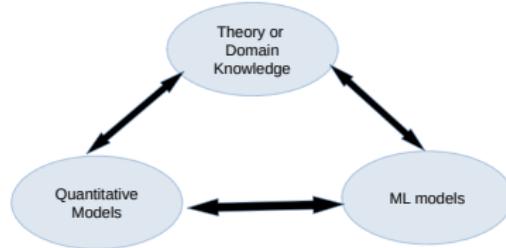
Our **domain knowledge (theory)** has a lot to add

Role of Human Knowledge in Research

ML has typically been atheoretical

Why add domain knowledge?

Can improve predictive *accuracy*, *explainability*, provide *guarantees*



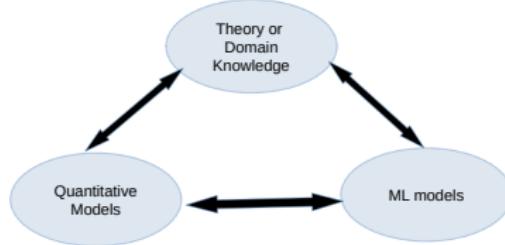
Role of Human Knowledge in Research

ML has typically been atheoretical

Why add domain knowledge?

Can improve predictive *accuracy, explainability, provide guarantees*

- A Theory-Based Explainable Deep Learning Architecture for Music Emotion. *Marketing Science* 44 (1), 196-219



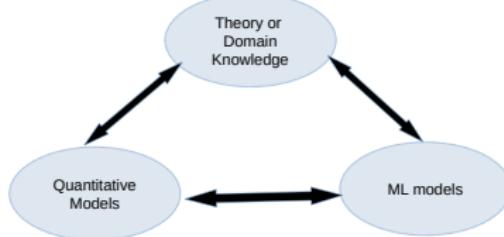
Role of Human Knowledge in Research

ML has typically been atheoretical

Why add domain knowledge?

Can improve predictive *accuracy, explainability, provide guarantees*

- A Theory-Based Explainable Deep Learning Architecture for Music Emotion. *Marketing Science* 44 (1), 196-219
- Generative Interpretable Visual Design: Using Disentanglement for Visual Conjoint Analysis. *Journal of Marketing Research* 62.3 (2025): 405-428

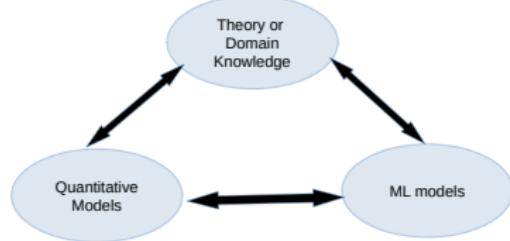


Role of Human Knowledge in Research

ML has typically been atheoretical

Why add domain knowledge?

Can improve predictive *accuracy, explainability, provide guarantees*



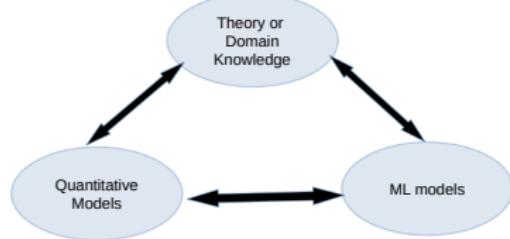
- A Theory-Based Explainable Deep Learning Architecture for Music Emotion. *Marketing Science* 44 (1), 196-219
- Generative Interpretable Visual Design: Using Disentanglement for Visual Conjoint Analysis. *Journal of Marketing Research* 62.3 (2025): 405-428
- Nonparametric Bandits Leveraging Informational Externalities to Learn the Demand Curve. Forthcoming at *Marketing Science*

Role of Human Knowledge in Research

ML has typically been atheoretical

Why add domain knowledge?

Can improve predictive *accuracy, explainability, provide guarantees*



- A Theory-Based Explainable Deep Learning Architecture for Music Emotion. *Marketing Science* 44 (1), 196-219
- Generative Interpretable Visual Design: Using Disentanglement for Visual Conjoint Analysis. *Journal of Marketing Research* 62.3 (2025): 405-428
- Nonparametric Bandits Leveraging Informational Externalities to Learn the Demand Curve. Forthcoming at *Marketing Science*
- Market Structure Mapping with Visual Characteristics. (Research in progress)

Generative Interpretable Visual Design

Sisodia, Burnap and Kumar

Presenting at:
Purdue University
Daniels School of Business
November 2025

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



Cars

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



Cars



Fashion

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



Cars



Fashion



Furniture

... even for mundane categories like yogurt



"We worked hard to get the packaging right ... American yogurt has always been sold in containers with relatively narrow openings. In Europe yogurt containers are wider and squatter, and that's what I wanted for Chobani."

—Hamdi Ulukaya, Founder & CEO, Chobani

Consumer Preferences for Visual Design



Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- **Products are bundles or collections of characteristics**

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- Products are bundles or collections of **characteristics**
- Preferences over products \implies Preferences over characteristics makes this problem feasible.

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- Products are bundles or collections of **characteristics**
- Preferences over products \implies Preferences over characteristics makes this problem feasible.
 - Cereal: (mushy, sugar, fiber, fat)

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- Products are bundles or collections of **characteristics**
- Preferences over products \implies Preferences over characteristics makes this problem feasible.
 - Cereal: (mushy, sugar, fiber, fat)
 - Car: (mpg, horsepower, weight, range) etc.

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- Products are bundles or collections of **characteristics**
- Preferences over products \implies Preferences over characteristics makes this problem feasible.
 - Cereal: (mushy, sugar, fiber, fat)
 - Car: (mpg, horsepower, weight, range) etc.

Demand Estimation: Big Picture

Goal:

Obtain consumer preferences for visual design (conjoint or market data)

Demand Estimation for Products in Differentiated Product Markets in Economics and Marketing

- Builds on foundation of Lancaster (1966), Kotler (1967)
- Products are bundles or collections of **characteristics**
- Preferences over products \implies Preferences over characteristics makes this problem feasible.
 - Cereal: (mushy, sugar, fiber, fat)
 - Car: (mpg, horsepower, weight, range) etc.

What about preferences in visual space?

Cannot do this because characteristics for visual design are unknown!

What this research seeks to do

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover and extract characteristics for products*

What this research seeks to do

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover* and extract characteristics for products
- *quantify* these characteristics

What this research seeks to do

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover* and extract characteristics for products
- *quantify* these characteristics
- *generate visual designs that span the space of visual characteristics*

What this research seeks to do

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover* and extract characteristics for products
- *quantify* these characteristics
- *generate* visual designs that span the space of visual characteristics

What this research seeks to do

Research Goals

Obtain **human-interpretable** visual characteristics (not outliers) directly from unstructured product image data:

- *automatically discover* and extract characteristics for products
- *quantify* these characteristics
- *generate* visual designs that span the space of visual characteristics



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

Research Goals

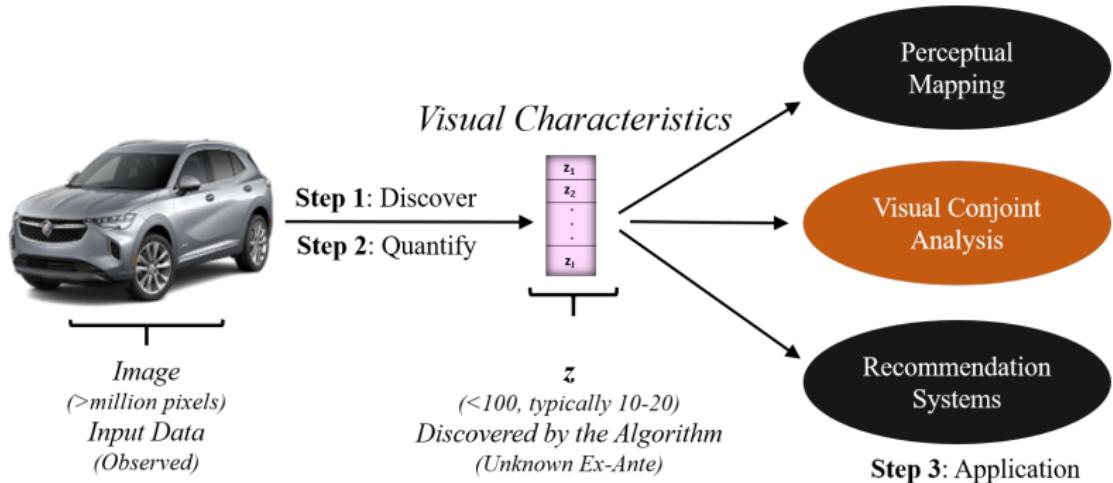


Hyundai: (3, 8, 5, 9) compared to BMW: (1, 3, 10, 1)

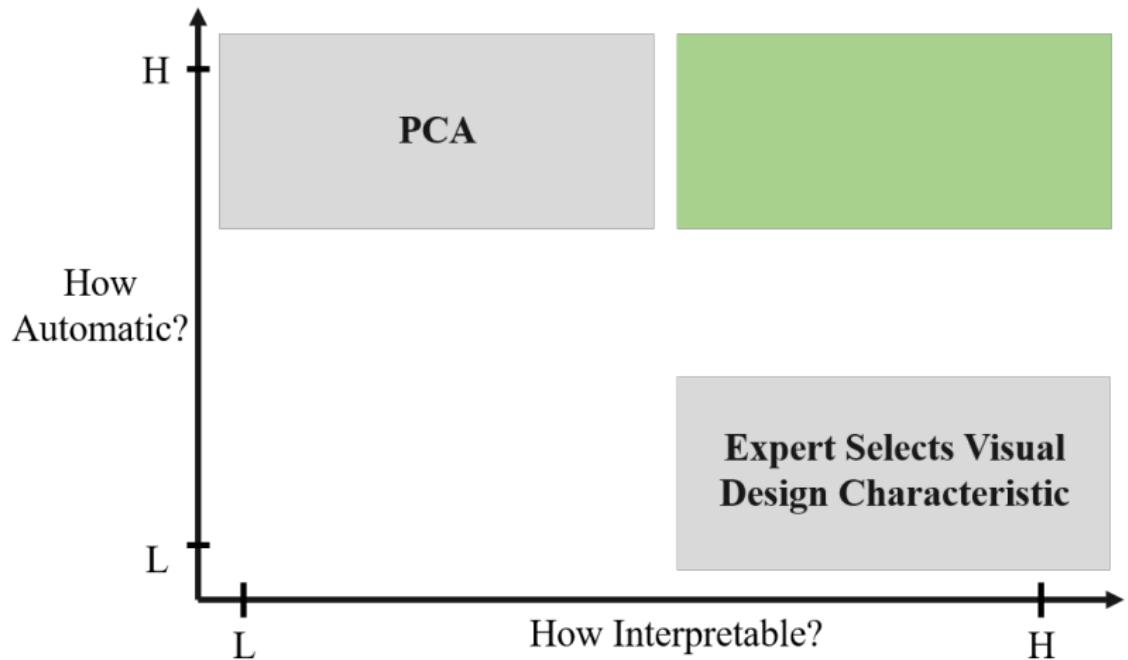
Several questions come to mind:

- What does the first number represent? Does 3 mean something different from 1?
- Can humans interpret these numeric values?
- What domain knowledge does the model need to have?

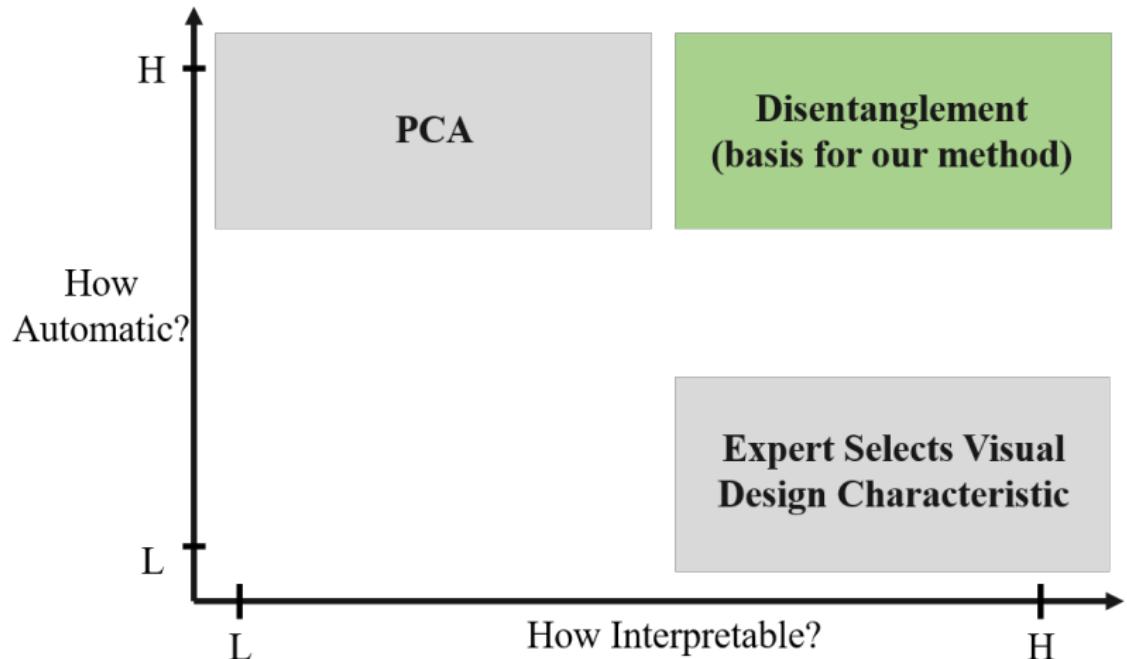
Why Visual Characteristics?



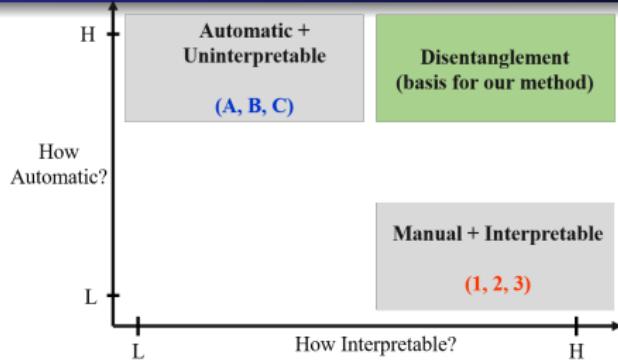
Modeling Visual Characteristics: A comparison of methods



Modeling Visual Characteristics: A comparison of methods



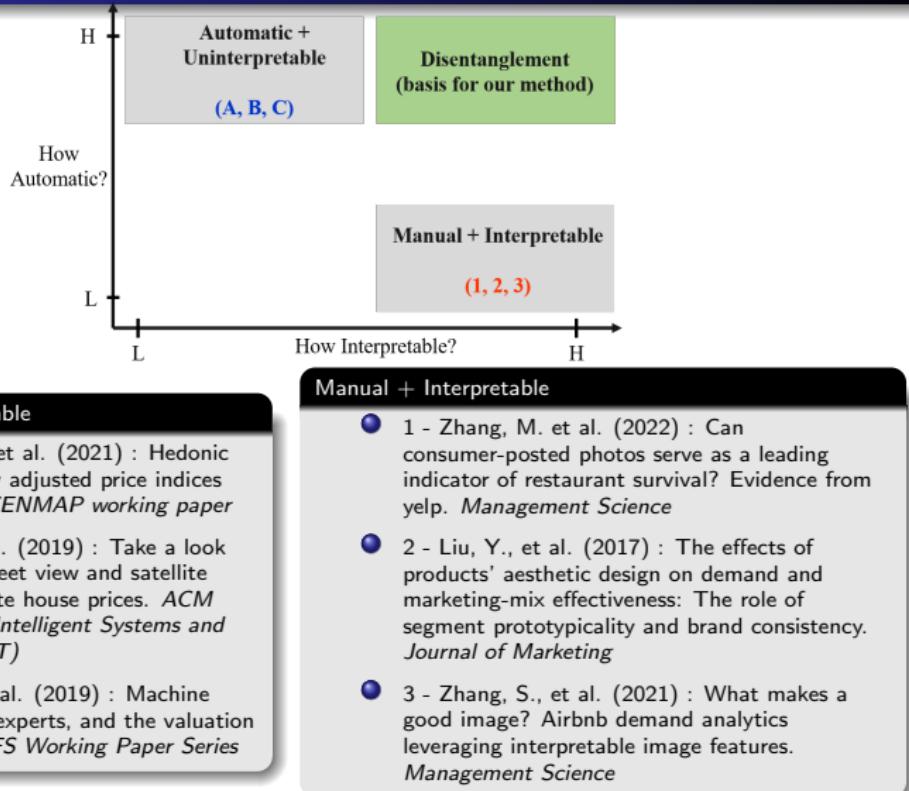
Modeling Visual Characteristics: A comparison of methods



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)*
- C - Aubry, S., et al. (2019) : Machine learning, human experts, and the valuation of real assets. *CFS Working Paper Series*

Modeling Visual Characteristics: A comparison of methods



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"*

What is disentanglement?

Bengio et al (2013)

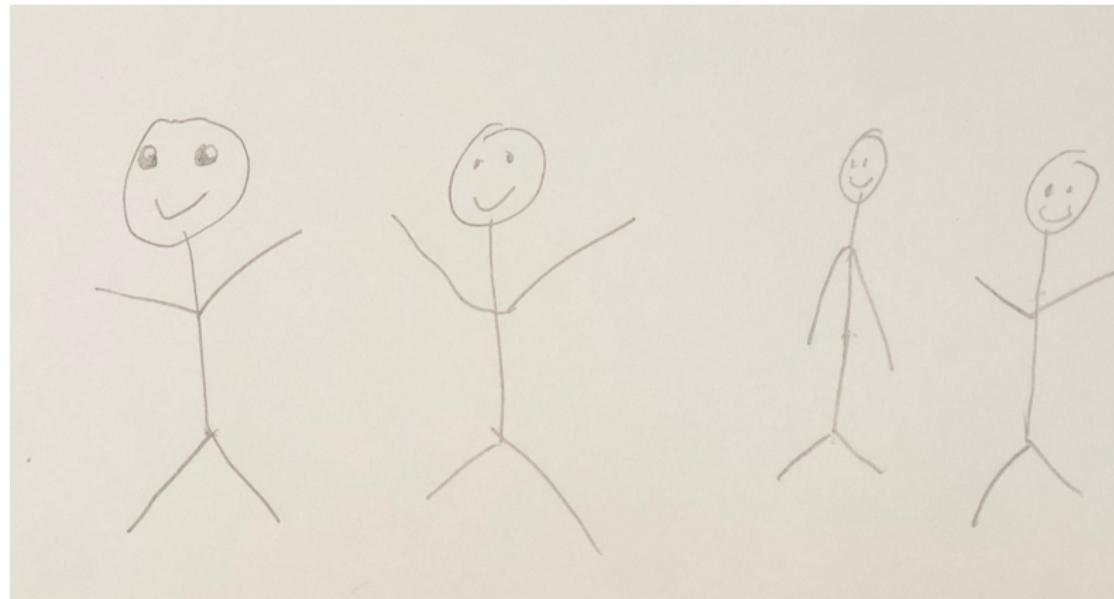
*"A disentangled representation can be defined as one where **single latent units** are sensitive to changes in **single generative factors**, while being relatively invariant to changes in other factors"*

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

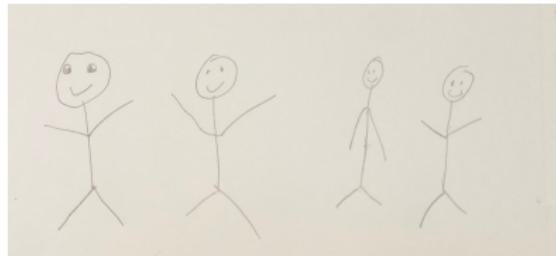
Idea: Reality or Data generating process is compositional based on generative factors.

What is disentanglement?

Stick



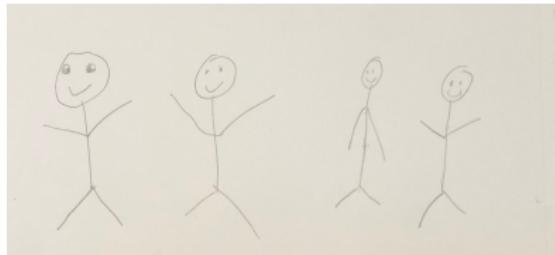
What is disentanglement?



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"*

What is disentanglement?

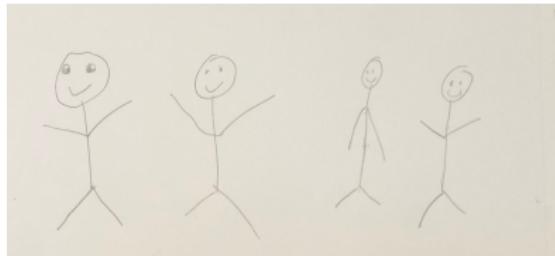


Bengio et al (2013)

*"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}): What algorithm discovers – dimensions in the model's latent space
- Generative factors (\mathbf{c}): Human-interpretable

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 (z): What algorithm discovers – dimensions in the model's latent space
- Generative factors (c): Human-interpretable

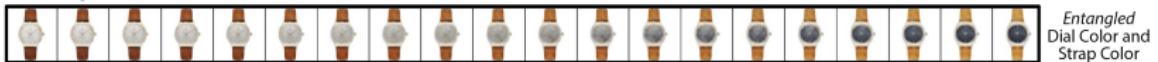
Goal: One to one mapping between $z \Leftrightarrow c$

Product Images and Parts of Watch



Disentangled and Entangled Representations

Example of *Entangled* Visual Characteristics



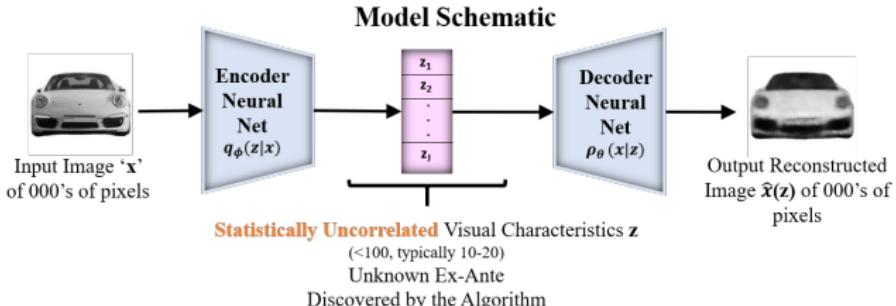
Entangled
Dial Color and
Strap Color

Example of *Disentangled* Visual Characteristics



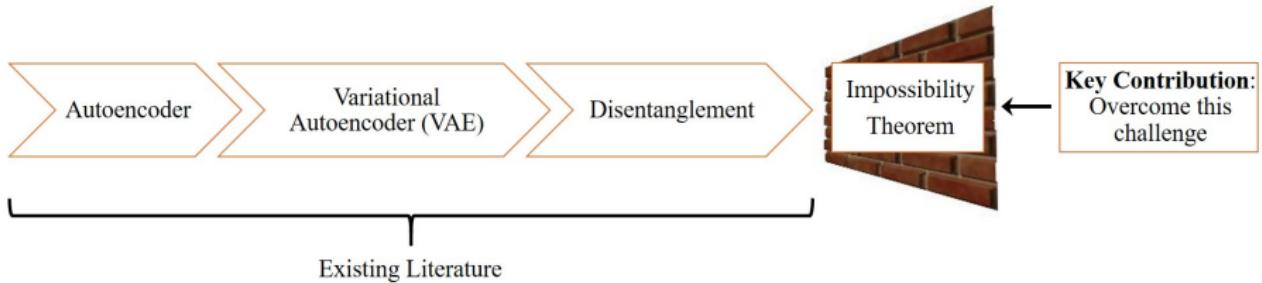
Dial Color
Strap Color

Models in Existing Literature



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

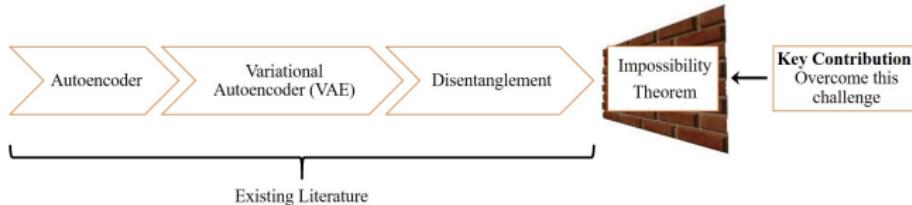
Roadmap of Our Research Approach



Contribution

We aim to overcome this impossibility theorem with a simple approach of using structured product characteristics.

Impossibility Theorem



Impossibility Theorem

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

^aLocatello, 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.

ML Approach to Impossibility Theorem

Impossibility: Without Supervision, every disentangled representation can have other *infinite* equivalent entangled representations.

- ML researchers recognize the challenge of impossibility

ML Approach to Impossibility Theorem

Impossibility: Without Supervision, every disentangled representation can have other *infinite* equivalent entangled representations.

- ML researchers recognize the challenge of impossibility
- Need a supervisory signal

ML Approach to Impossibility Theorem

Impossibility: Without Supervision, every disentangled representation can have other *infinite* equivalent entangled representations.

- ML researchers recognize the challenge of impossibility
- Need a supervisory signal
- ML methods assume that ground truth is known by researchers

ML Approach to Impossibility Theorem

Impossibility: Without Supervision, every disentangled representation can have other *infinite* equivalent entangled representations.

- ML researchers recognize the challenge of impossibility
- Need a supervisory signal
- ML methods assume that ground truth is known by researchers
 - Human labeling

ML Approach to Impossibility Theorem

Impossibility: Without Supervision, every disentangled representation can have other *infinite* equivalent entangled representations.

- ML researchers recognize the challenge of impossibility
- Need a supervisory signal
- ML methods assume that ground truth is known by researchers
 - Human labeling
- Can we use this approach to discover visual characteristics?

Impossibility Theorem – Implications



predicts

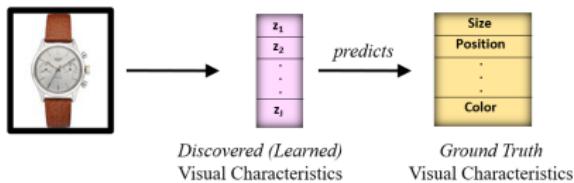
A horizontal black arrow pointing from right to left, indicating a flow or relationship between the learned features and the ground truth characteristics.

Discovered (Learned)
Visual Characteristics

Ground Truth
Visual Characteristics

Impossibility Theorem – Implications

Common approach to ground truth in ML is to get humans to label¹



What's the Problem?

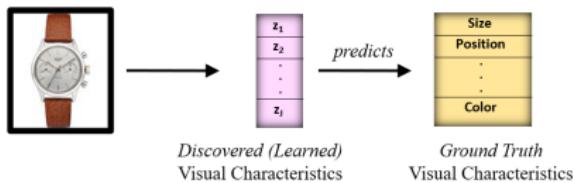
- Ground truth on visual characteristics is *unknown*.

¹

Locatello, Francesco, et al. "Disentangling factors of variation using few labels." ICLR. 2020.

Impossibility Theorem – Implications

Common approach to ground truth in ML is to get humans to label¹



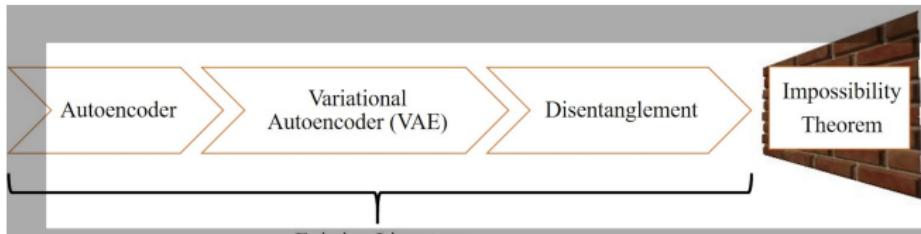
What's the Problem?

- Ground truth on visual characteristics is *unknown*.
- Need to ensure humans understand what these labels are and *how to quantify them* for each image

¹

Locatello, Francesco, et al. "Disentangling factors of variation using few labels." ICLR. 2020.

Contribution



- **Solution** without ground truth on visual characteristics:
- Leverage **structured product characteristics** to provide a supervisory signal for disentanglement

Model

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

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

Model

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

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbb{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

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: Reconstruction Loss

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

$$E_{q_\phi(z|x)}[\log p_\theta(x|z)]$$

- Given latent representation z , can decoder accurately obtain the x in the data?
- $p_\theta(x|z)$ high probability if reconstruction is good
- Encoder produces z probabilistically, so need to take expectations $E_{q_\phi(z|x)}$
- Both encoder and decoder are learning here

Model: Mutual Information Loss

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

$$I_q(X; Z) = \mathbb{E}_{q(x,z)} \left[\log \left(\frac{q(x,z)}{q(x)q(z)} \right) \right]$$

- Each input x produces a distinct z , retains lot of information

Model

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

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

Model

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

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbb{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

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

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

- Supervised Loss is used to predict signal from latent representation z : $s = f(z)$

Model – Role of Supervised Loss

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

- Supervised Loss is used to predict signal from latent representation z : $s = f(z)$
- Can use structured product characteristics as signals: brand, price, material etc.

Model – Role of Supervised Loss

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

- Supervised Loss is used to predict signal from latent representation z : $s = f(z)$
- Can use structured product characteristics as signals: brand, price, material etc.

Model – Role of Supervised Loss

$$\underbrace{L(\theta, \phi, \mathbf{w}; \mathbf{x}, \mathbf{z})}_{\text{Total Loss}} = \underbrace{\mathbf{E}_{q_\phi(\mathbf{z}|\mathbf{x})} [\log p_\theta(\mathbf{x}|\mathbf{z})]}_{\text{Reconstruction Loss}} + \alpha \underbrace{I_q(\mathbf{z}, \mathbf{x})}_{\text{Mutual Information Loss}} + \beta \underbrace{KL \left[q(\mathbf{z}) || \prod_{j=1}^J q(z_j) \right]}_{\text{Total Correlation Loss}} \\ + \gamma \underbrace{\sum_{j=1}^J KL \left[q(z_j) || p(z_j) \right]}_{\text{Dimension-Wise KL Divergence Loss}} + \delta \underbrace{P(\hat{\mathbf{y}}(\mathbf{z}), \mathbf{y})}_{\text{Supervised Loss}}$$

- Supervised Loss is used to predict signal from latent representation z : $s = f(z)$
- Can use structured product characteristics as signals: brand, price, material etc.

Idea to Overcome Impossibility Theorem

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

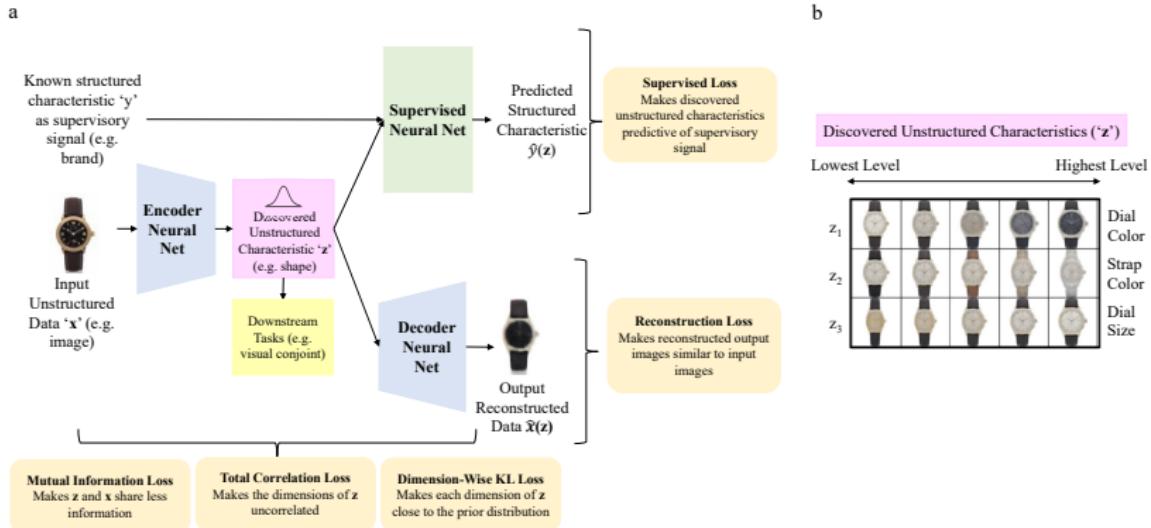
Why might brand aid the disentanglement model?



Brand as a Supervisory Signal

Idea: Brands have a specific “look” that can be correlated with visual appearance (and therefore visual characteristics)

Schematic of Proposed Approach



Evaluating Visual Characteristics

Visual Characteristics: Human Interpretable?

- Are these visual characteristics human interpretable?

Visual Characteristics: Human Interpretable?

- Are these visual characteristics human interpretable?



Starting from the image on the left, **what part of the watch changes the most** 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

- | | |
|-----------------------------------|-----------------------------------|
| <input type="radio"/> Bezel | <input type="radio"/> Hands |
| <input type="radio"/> Crown | <input type="radio"/> Hour Marker |
| <input type="radio"/> Date Window | <input type="radio"/> Lug |
| <input type="radio"/> Dial | <input type="radio"/> Strap |

How is that part of the watch changing?

Visual Characteristics: Quantification?

Interpretability and Quantification

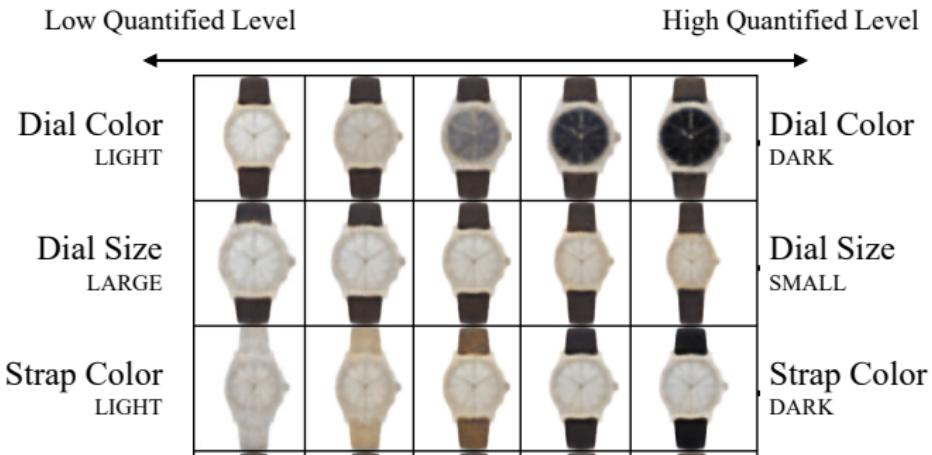
Visual characteristic	Interpretability Survey	Quantification Survey
Dial Size	76%	83%
Dial Color	80%	92%
Strap Color	88%	92%
Rim (Bezel) Color	79%	88%
Dial Shape	87%	68%
Knob (Crown) Size	70%	85%

Discovered Visual characteristics

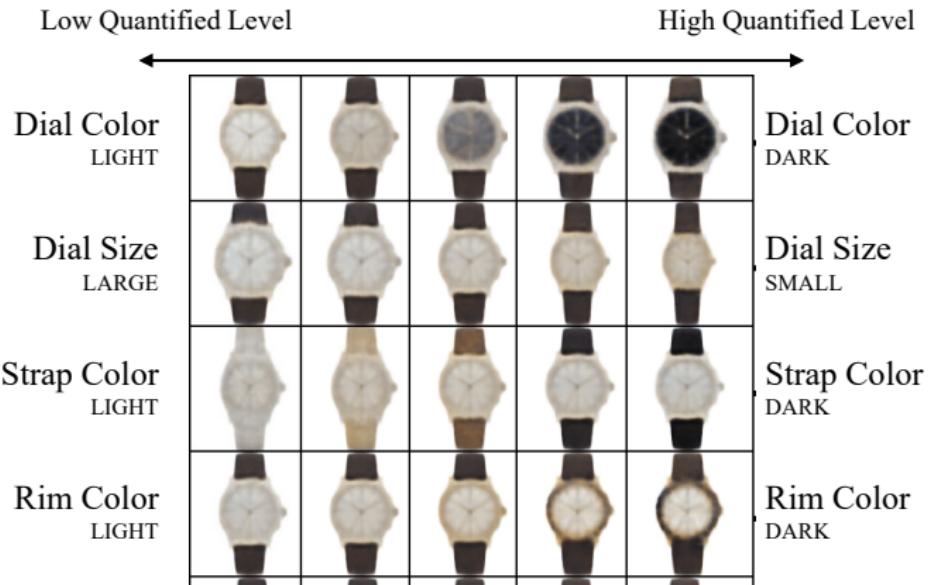
Discovered Visual characteristics



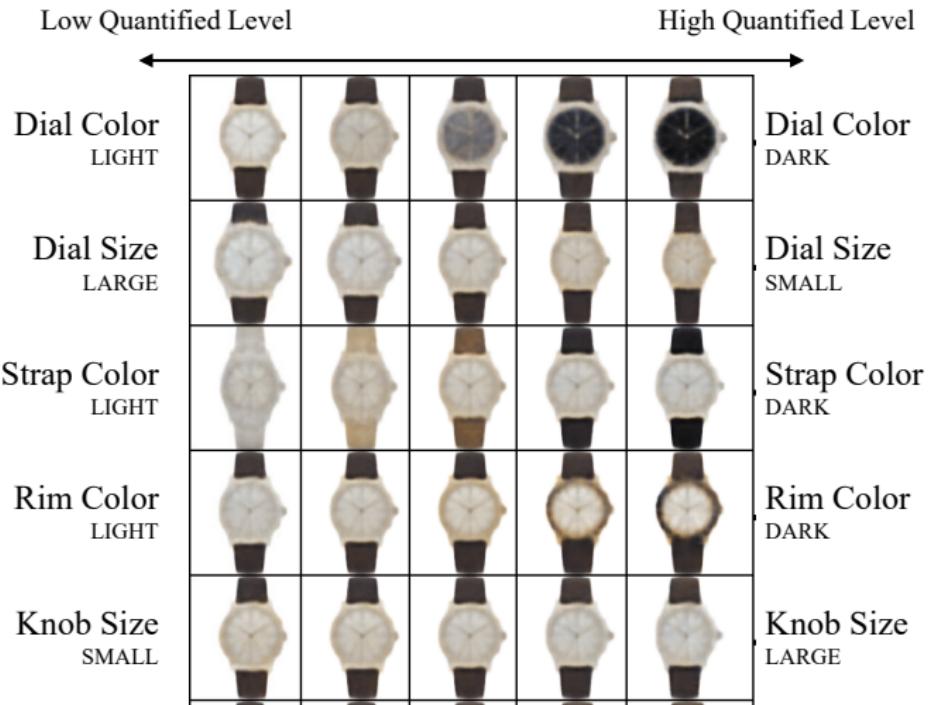
Discovered Visual characteristics



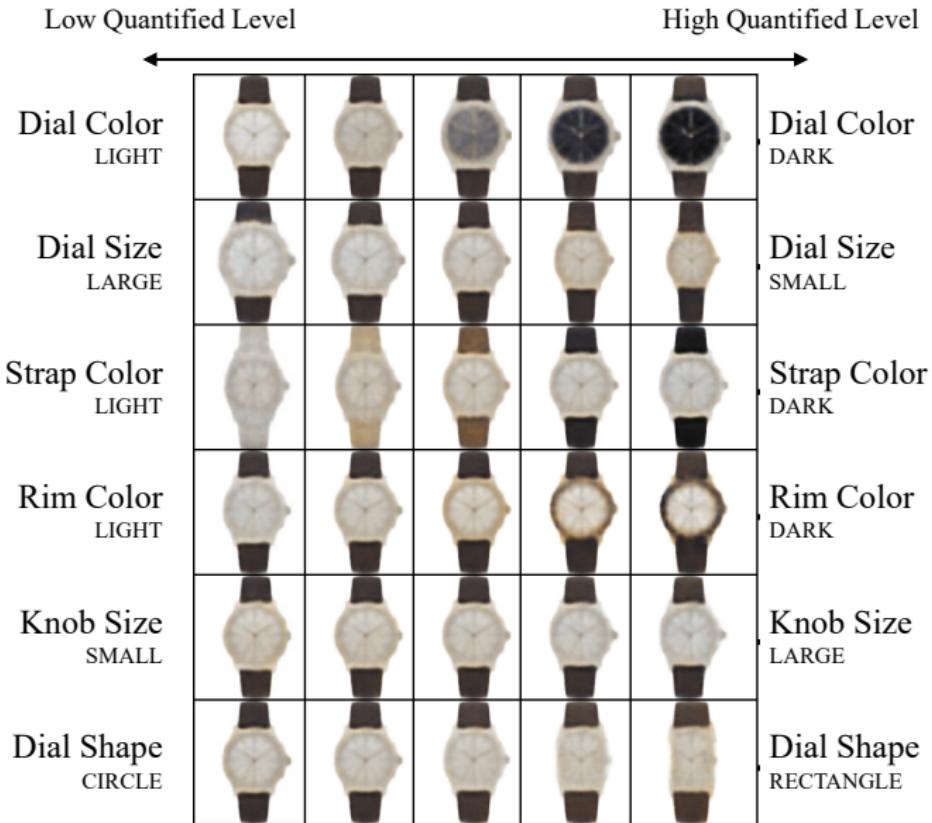
Discovered Visual characteristics



Discovered Visual characteristics



Discovered Visual characteristics



Market Structure Mapping with Interpretable Visual Characteristics

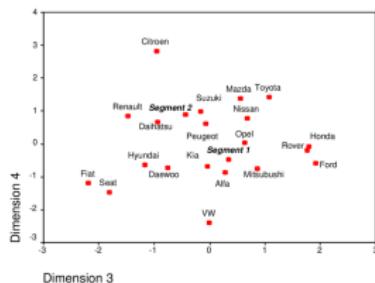
Sisodia and Kumar

Presenting at:
Purdue University
Daniels School of Business
November 2025

What is a Market Structure Map?

A common element of market structure analysis is the derivation of a **market structure map**, that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)

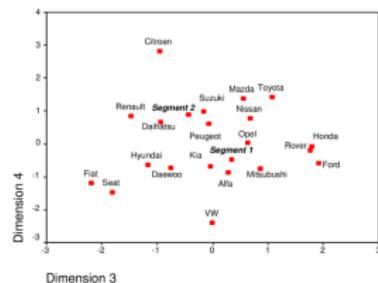
- Graphical representations of product positioning (e.g. Multidimensional Scaling)



What is a Market Structure Map?

A common element of market structure analysis is the derivation of a **market structure map**, that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)

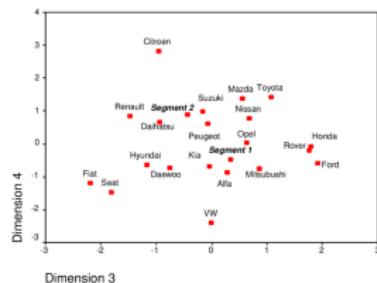
- Graphical representations of product positioning (e.g. Multidimensional Scaling)
- Strategic tool for understanding competitive landscape that enable us to:



What is a Market Structure Map?

A common element of market structure analysis is the derivation of a **market structure map**, that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)

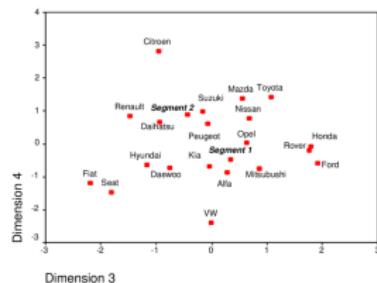
- Graphical representations of product positioning (e.g. Multidimensional Scaling)
- Strategic tool for understanding competitive landscape that enable us to:
 - Identify market gaps



What is a Market Structure Map?

A common element of market structure analysis is the derivation of a **market structure map**, that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)

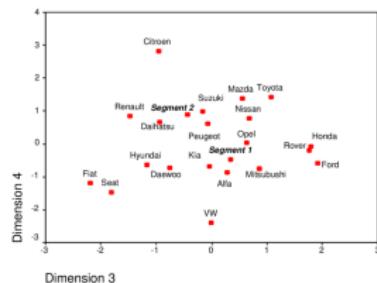
- Graphical representations of product positioning (e.g. Multidimensional Scaling)
- Strategic tool for understanding competitive landscape that enable us to:
 - Identify market gaps
 - Spot new opportunities



What is a Market Structure Map?

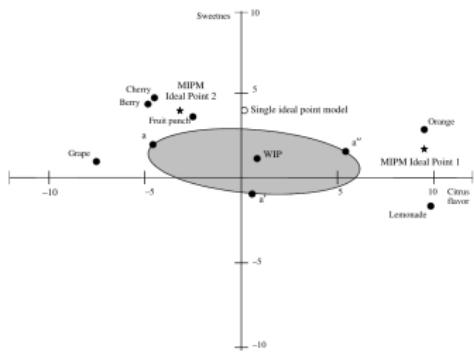
A common element of market structure analysis is the derivation of a **market structure map**, that is, a spatial representation of firms' competitive positions relative to one another based on some measure of their competitive relationships (DeSarbo et al. 1993)

- Graphical representations of product positioning (e.g. Multidimensional Scaling)
- Strategic tool for understanding competitive landscape that enable us to:
 - Identify market gaps
 - Spot new opportunities
 - **Identify competitors and evaluate positioning**

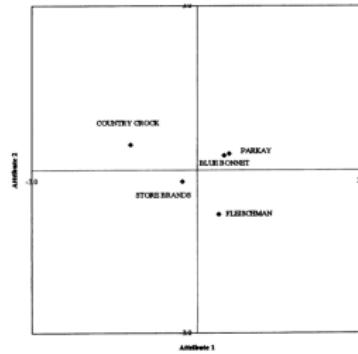


Market Structure Map: Examples

Compositional (Left) & Decompositional (Right)



Lee, Sudhir and Steckel (2002), *Journal of Marketing Research*



Erdem (1996), *Marketing Science*

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices
- Sales data (cross-elasticity of demand)

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices
- Sales data (cross-elasticity of demand)
- **User comments and reviews**

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices
- Sales data (cross-elasticity of demand)
- User comments and reviews
- Search Co-occurrence

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices
- Sales data (cross-elasticity of demand)
- User comments and reviews
- Search Co-occurrence

Market Structure Mapping

Sources of Data

Compositional (Building up)

- Product characteristics – functional, psychological

Decompositional (Breaking down)

- Survey data by asking 1st and 2nd choices
- Sales data (cross-elasticity of demand)
- User comments and reviews
- Search Co-occurrence

What's common?

Neither of these approaches have considered visual characteristics.



Are these cars close substitutes?

First, consider *functional* product characteristics:

(A)

\$179,000-\$243,000, 553 HP,
16-23 MPG

(B)

From \$242,700, 542-650 HP,
14-22 MPG

Are these cars close substitutes?

First, consider *functional* product characteristics:

(A)

\$179,000-\$243,000, 553 HP,
16-23 MPG

Ferrari California



(B)

From \$242,700, 542-650 HP,
14-22 MPG

Bentley Continental GT



Importance of Visual Design

Functional characteristics alone are *not sufficient* to even place the car in an appropriate segment (submarket)

Visual design matters *a lot* for cars



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

—JD Power Avoider Study 2015

Challenges in using visual images for market structure mapping

Three Challenges:

- ① Inputs from Raw Images: Backgrounds, lighting, and camera angles overshadow actual product design, causing mis-clusters.

Challenges in using visual images for market structure mapping

Three Challenges:

- ① Inputs from Raw Images: Backgrounds, lighting, and camera angles overshadow actual product design, causing mis-clusters.
- ② Scalability: Need to work with hundreds or thousands of product models / images, so challenging to have human intervention

Challenges in using visual images for market structure mapping

Three Challenges:

- ① Inputs from Raw Images: Backgrounds, lighting, and camera angles overshadow actual product design, causing mis-clusters.
- ② Scalability: Need to work with hundreds or thousands of product models / images, so challenging to have human intervention
- ③ Black-Box (Un)interpretable Embeddings: Pretrained networks may focus on brand logos or color, complicating interpretation of true style.

Challenges in using visual images for market structure mapping

Three Challenges:

- ① Inputs from Raw Images: Backgrounds, lighting, and camera angles overshadow actual product design, causing mis-clusters.
- ② Scalability: Need to work with hundreds or thousands of product models / images, so challenging to have human intervention
- ③ Black-Box (Un)interpretable Embeddings: Pretrained networks may focus on brand logos or color, complicating interpretation of true style.
 - We need to be able to choose what visual characteristics matter for market structure

Challenges in using visual images for market structure mapping

Three Challenges:

- ① Inputs from Raw Images: Backgrounds, lighting, and camera angles overshadow actual product design, causing mis-clusters.
- ② Scalability: Need to work with hundreds or thousands of product models / images, so challenging to have human intervention
- ③ Black-Box (Un)interpretable Embeddings: Pretrained networks may focus on brand logos or color, complicating interpretation of true style.
 - We need to be able to choose what visual characteristics matter for market structure
 - Does color matter? Does angle matter?

Should Color be included in Visual Characteristics Maps?

- Should a red Ferrari California be close substitute to a red Toyota Corolla?

- **UK Automobile Market**
 - 2,439 make-model-year observations from 2008 to 2017
 - 379 unique models from 49 unique makes
- **Sales and Auto Characteristics:**
 - Characteristics (price, MPG, horsepower, weight, dimensions, etc.) from Parker's
 - Sales from DVM-CAR²
- **Images:**
 - Front-facing automobile images from DVM-CAR
 - Converted from color to grayscale to *focus on shape* rather than color.
 - (very) Low-resolution: 128×128 pixels

²

Huang, Jingmin, et al. (2022), *IEEE International Conference on Big Data*

Segments in the UK automobile market

Segment	Description				
A	Minicars		Seg A (Minicar)		
B	Subcompact		Seg B (Subcompact)		
C	Compact		Seg C (Compact)		
D	Mid-size		Seg D (Mid-Sized)		
E	Mid-size Luxury		Seg E (Mid-Sized Luxury)		
J	SUV		Seg J (SUV)		
M	MPV		Seg M (MPV)		

Summary Statistics of the 2013 UK Auto Market

Variable	Mean	St. Dev.	Min.	Max.
Total Quantity Sold	8,074.834	13,714.100	1	113,390
Price (in £000 units)	26.333	14.668	7.868	108.624
MPG (tens of miles per gallon)	4.999	1.058	2.250	7.200
Weight (in 10 lbs)	327.704	2.444	324.506	332.106
HP/Wt (in HP per 10 lbs.)	0.461	0.169	0.060	1.347
Length (in 1000 inches)	1.724	0.178	1.062	2.054
Width (in 1000 inches)	0.756	0.063	0.580	0.899
Height (in 1000 inches)	0.616	0.054	0.537	0.780
Wheelbase (in 1000 inches)	1.046	0.081	0.735	1.266
Space (length × width)	1.310	0.215	0.697	1.759
Vehicle Segment (Proportion):				
Segment A (Minicars)	0.112	0.316	0	1
Segment B (Subcompact)	0.120	0.326	0	1
Segment C (Compact)	0.162	0.369	0	1
Segment D (Mid-Size)	0.129	0.335	0	1
Segment E (Mid-Size Luxury)	0.071	0.257	0	1
Segment J (SUV)	0.241	0.428	0	1
Segment M (MPV)	0.166	0.373	0	1
Country of Origin (Proportion):				
France	0.108	0.311	0	1
Germany	0.241	0.428	0	1
Japan	0.220	0.415	0	1
South Korea	0.091	0.289	0	1
UK	0.108	0.311	0	1
USA	0.058	0.234	0	1

Match each model with front-facing image

Is this sufficient?

"Market research studies have shown that 70% of consumers identify and judge automobiles by the appearance of headlights and grille located on the face of the automobile."

– *The Wall Street Journal*
2006



Loss Function & Supervisory Signals

$$\underbrace{L(\theta, \phi; \mathbf{m}, \mathbf{v})}_{\text{Disentanglement Loss}} = \underbrace{-\mathbb{E}_{q_\phi(\mathbf{v}|\mathbf{m})} [\log p_\theta(\mathbf{m}|\mathbf{v})]}_{\text{Reconstruction Loss}} + \underbrace{I_q(\mathbf{v}, \mathbf{m})}_{\text{Mutual Information Loss}} \\
 + \lambda_1 \underbrace{KL \left[q(\mathbf{v}) || \prod_{j=1}^J q(v_j) \right]}_{\text{Total Correlation Loss}} + \underbrace{\sum_{j=1}^J KL [q(v_j) || p(v_j)]}_{\text{Dimension-Wise KL Divergence Loss}} + \lambda_2 \underbrace{P(\widehat{\mathbf{y}(\mathbf{v})}, \mathbf{y})}_{\text{Supervised Loss}}$$
(1)

Number of Signals	Supervisory Signals	λ_1	λ_2	UDR
3	Wheelbase, Width, Height	50	10	0.739
3	HP/Weight, MPG, Space	50	30	0.710
1	Price	50	30	0.708
1	Weight	50	40	0.708
1	Wheelbase	50	30	0.690
1	Width	50	5	0.689
3	Length, Width, Height	50	40	0.678
1	Length	50	40	0.666
0	Unsupervised β -TCVAE	50	0	0.658
1	Height	30	20	0.378
1	Country of Origin	10	10	0.139
1	Segment	10	10	0.134
1	Unsupervised VAE	1	0	0.073
1	Unsupervised AE	0	0	0.074
1	Make	1	1	0.072

$$\lambda_1 \in [1, 5, 10, 20, 30, 40, 50] \text{ and } \lambda_2 \in [0, 1, 5, 10, 20, 30, 40, 50].$$

Visual Characteristic 1: Body Shape



Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Body Shape	0.30	0.33	0.39	-0.28	0.25	-0.42

- Hatchback-like profiles → taller, narrower and lighter
- Sedan-like profiles → larger wheelbase, lower length, and heavier

Visual Characteristic 2: Boxiness



Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Boxiness	0.05	-0.07	0.14	-0.59	0.02	-0.49

- Higher degree of boxiness → Taller and upfront from the front
- Lower degree of boxiness → Flatter and sleeker
- Boxiness captures cabin “uprightness” (not related to length or wheelbase)

Visual Characteristic 3: Grille Height



Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Grille Height	0.04	0.02	0.05	-0.04	0.03	-0.05

- Reflects stylistic design choices
- Unrelated to size-related factors

Visual Characteristic 4: Grille Width



Correlation Between Discovered Visual Dimensions and Physical Vehicle Measures

	Wheelbase	Weight	Length	Height	Width	Height/Width Ratio
Grille Width	0.12	0.08	0.12	0.03	0.15	-0.09

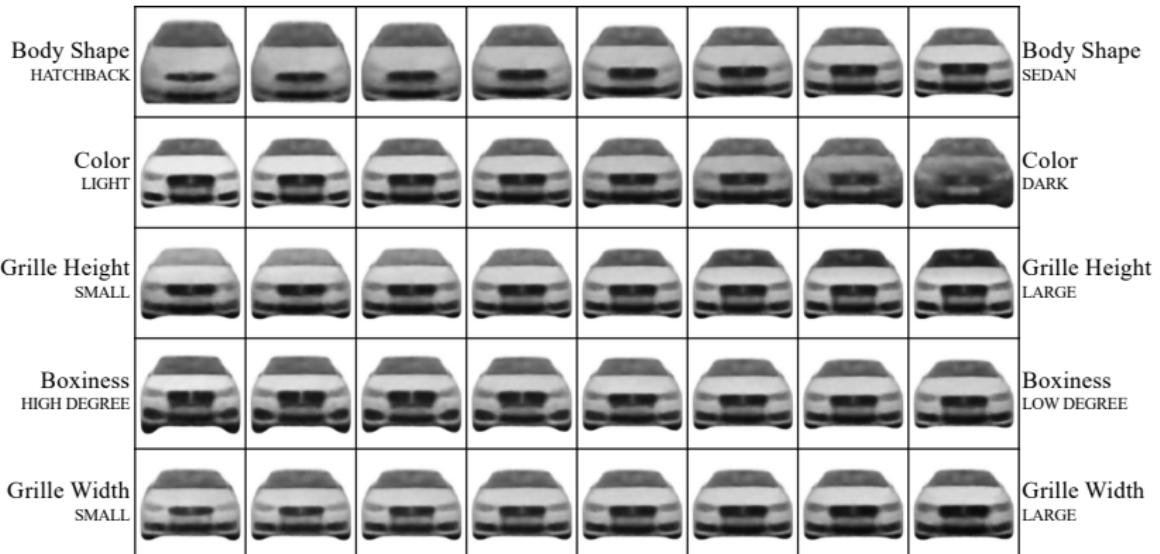
- Reflects stylistic design choices
- Unrelated to size-related factors

Visual Characteristic 5: Color



- We find the visual characteristic of *Color*.
- Color should not impact market structure because a car is available in many colors.
- We, therefore, exclude it when we create market structure maps.
- This is only possible because of disentanglement.

Disentanglement obtains four interpretable visual characteristics



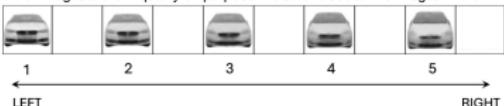
Human Understanding of Visual Characteristics

- Showed respondents sequence of car images

Q1/4: Look at the below image to see the various parts of a car.



Now, carefully examine each car image below from 1 to 5, going from left to right.
Note: Images are low-quality on purpose. Be sure to see all the images 1 to 5.



How does the car change the most as you go from image 1 to 5? Go through each part of the car one by one before deciding your response. Write it in a few words.

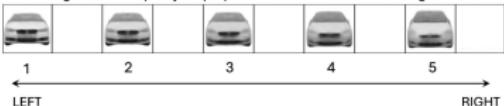
Human Understanding of Visual Characteristics

- Showed respondents sequence of car images
- Asked respondents open-ended questions about visual changes

Q1/4: Look at the below image to see the various parts of a car.



Now, carefully examine each car image below from 1 to 5, going from left to right.
Note: Images are low-quality on purpose. Be sure to see all the images 1 to 5.



How does the car change the most as you go from image 1 to 5? Go through each part of the car one by one before deciding your response. Write it in a few words.

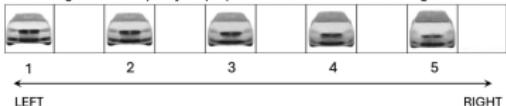
Human Understanding of Visual Characteristics

- Showed respondents sequence of car images
- Asked respondents open-ended questions about visual changes
- Used LLMs (GPT-4, Claude) to identify *common themes* in respondent responses

Q1/4: Look at the below image to see the various parts of a car.



Now, carefully examine each car image below from 1 to 5, going from left to right.
Note: Images are low-quality on purpose. Be sure to see all the images 1 to 5.



How does the car change the most as you go from image 1 to 5? Go through each part of the car one by one before deciding your response. Write it in a few words.

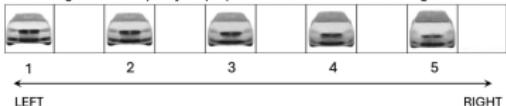
Human Understanding of Visual Characteristics

- Showed respondents sequence of car images
- Asked respondents open-ended questions about visual changes
- Used LLMs (GPT-4, Claude) to identify *common themes* in respondent responses
- Example: LLM summarizes that respondents are saying that cars becoming lower, flatter, and wider can be thought of as boxiness

Q1/4: Look at the below image to see the various parts of a car.



Now, carefully examine each car image below from 1 to 5, going from left to right.
Note: Images are low-quality on purpose. Be sure to see all the images 1 to 5.



How does the car change the most as you go from image 1 to 5? Go through each part of the car one by one before deciding your response. Write it in a few words.

Quantification Validation Survey Question

Which pair of cars in your judgment are visually more similar? Carefully check both large and small visual aspects. Do not consider any non-visual features like brand or price.



Left Pair



Right Pair



Correlation Between Different Characteristics

	Price	Functional Characteristics			Boxiness	Visual Characteristics		Grille Width
		MPG	HP/Weight	Space		Body Shape	Grille Height	
Price	1.00							
MPG	-0.60	1.00						
HP/Weight	0.74	-0.48	1.00					
Space	0.67	-0.47	0.36	1.00				
Boxiness	0.06	0.04	0.29	0.09	1.00			
Body Shape	0.50	-0.25	0.54	0.36	0.13	1.00		
Grille Height	0.11	0.03	0.12	0.05	0.04	-0.02	1.00	
Grille Width	0.07	-0.05	0.04	0.15	0.01	-0.12	-0.05	1.00

Does Form Follow Function?

Insight 1: Products close in functional space are differentiated visually

- *Operationalization:* Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment

Does Form Follow Function?

Insight 1: Products close in functional space are differentiated visually

- *Operationalization:* Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment
- *Result:* Low correlation between functional and visual similarity

Does Form Follow Function?

Insight 1: Products close in functional space are differentiated visually

- *Operationalization:* Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment
- *Result:* Low correlation between functional and visual similarity
- *Implication:* Visual can create distinctiveness

Does Form Follow Function?

Insight 1: Products close in functional space are differentiated visually

- *Operationalization:* Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment
- *Result:* Low correlation between functional and visual similarity
- *Implication:* Visual can create distinctiveness

Does Form Follow Function?

Insight 1: Products close in functional space are differentiated visually

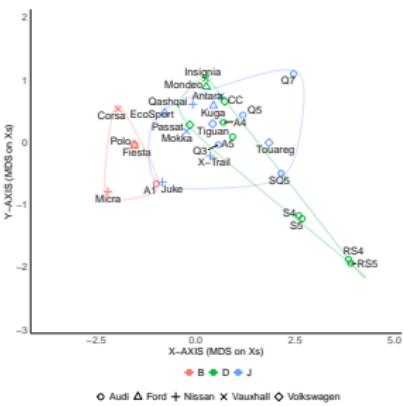
- *Operationalization:* Calculate correlation between distances in functional product characteristics and visual product characteristics for each pair of make-models within each segment
- *Result:* Low correlation between functional and visual similarity
- *Implication:* Visual can create distinctiveness

Segment	Correlation	Std. Error
A (Minicars)	-0.08	0.05
B (Subcompact)	-0.05	0.05
C (Compact)	-0.05	0.04
D (Mid-size)	0.02	0.04
E (Mid-size Luxury)	0.13	0.10
J (SUV)	0.09	0.03
M (MPV)	0.11	0.04

Market Structure Maps

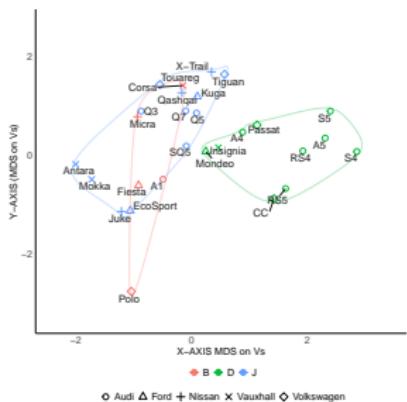
Market Structure Map using only functional characteristics

Segment	Description
B	Subcompact
D	Mid-size
J	SUV



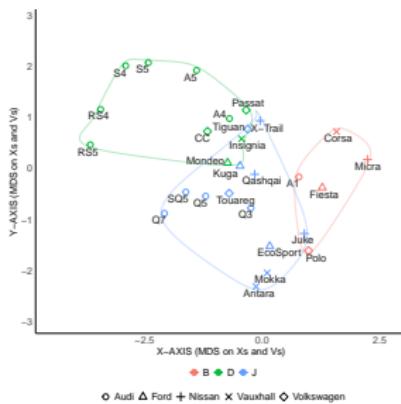
Market Structure Map using only visual characteristics

Segment	Description
B	Subcompact
D	Mid-size
J	SUV



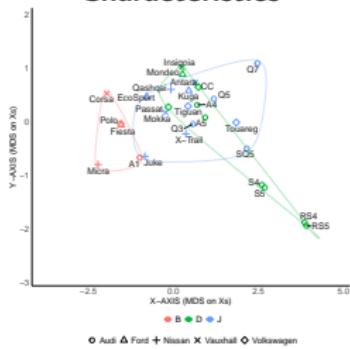
Market Structure Map using both type of characteristics

Segment	Description
B	Subcompact
D	Mid-size
J	SUV

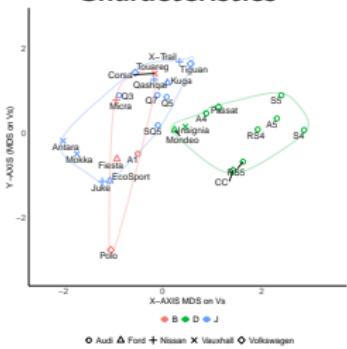


Insight 2: Visual increases differentiation and helps separate segments

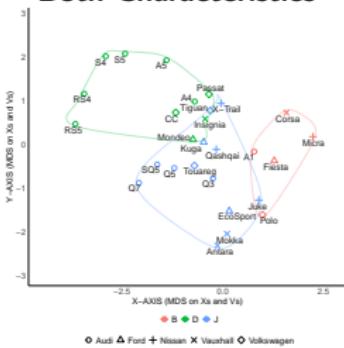
Only Functional
Characteristics



Only Visual
Characteristics



Both Characteristics

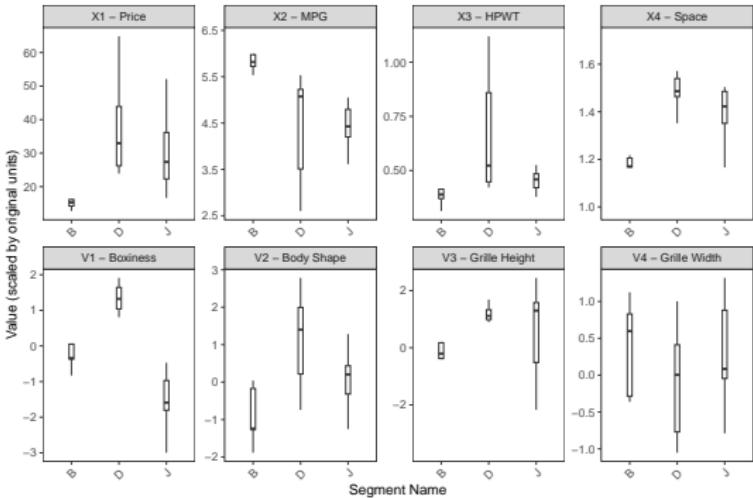


8.3% segment overlap

Does Disentanglement Provide Further Insights?

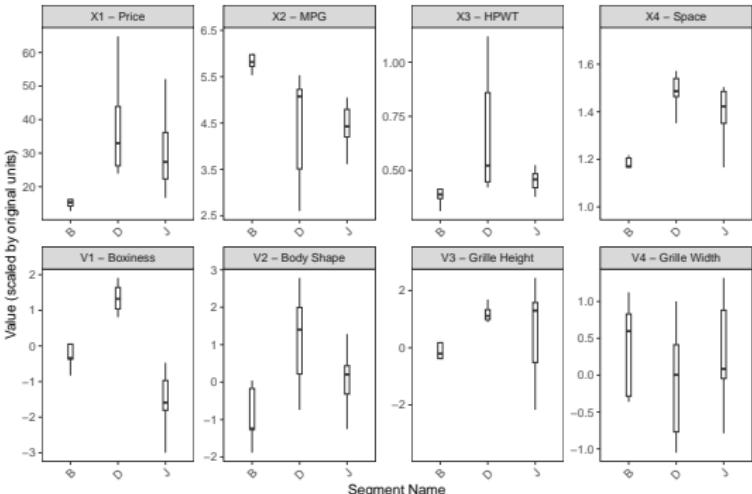
Insight 2D: Which visual characteristics increase differentiation?

- Disentanglement identifies interpretable characteristics contributing to differentiation



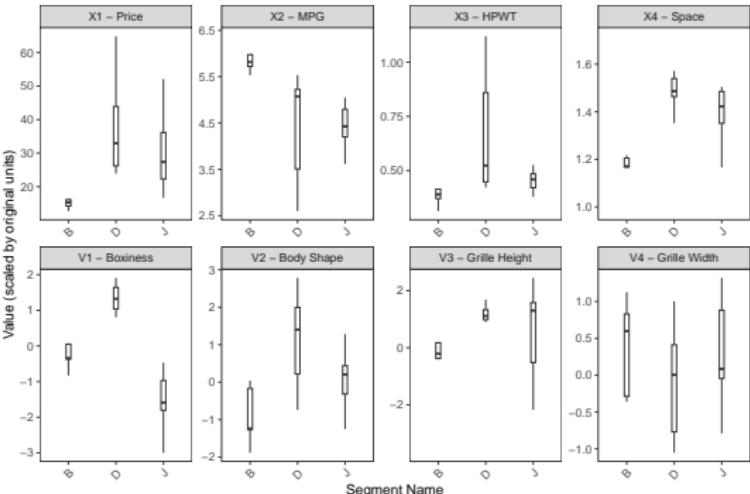
Insight 2D: Which visual characteristics increase differentiation?

- Disentanglement identifies interpretable characteristics contributing to differentiation
- Seg D & J overlap on most of the functional characteristics but Seg B is different



Insight 2D: Which visual characteristics increase differentiation?

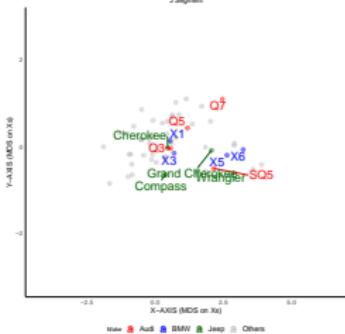
- Disentanglement identifies interpretable characteristics contributing to differentiation
- Seg D & J overlap on most of the functional characteristics but Seg B is different
- Seg D & J different in boxiness and grille



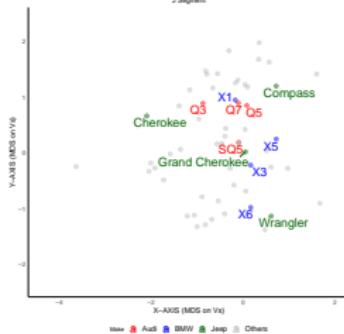
Insight 3: Different Visual Strategy Across Brands

Segment J – SUVs

**Only Functional
Characteristics**

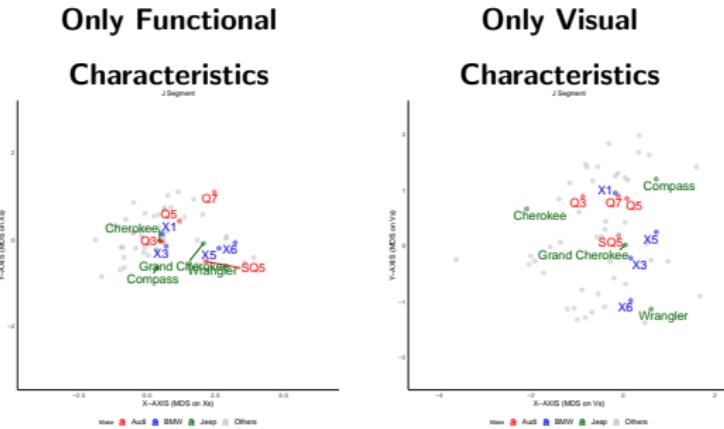


**Only Visual
Characteristics**



Insight 3: Different Visual Strategy Across Brands

Segment J – SUVs



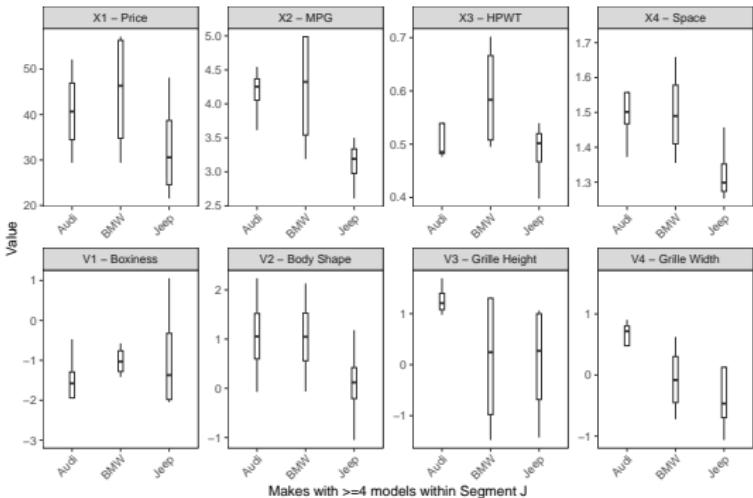
Area Share of a Make in Functional Space & Visual Space (Segment J: SUVs)

Make	Models	Area Share (Functional)	Area Share (Visual)	Ratio
Audi	4	17.90%	2.96%	6.05
BMW	4	6.35%	6.48%	0.98
Jeep	4	9.38%	28.42%	0.33

Insight 3D: Different Visual Strategy Across Brands

Disentanglement identifies interpretable characteristics

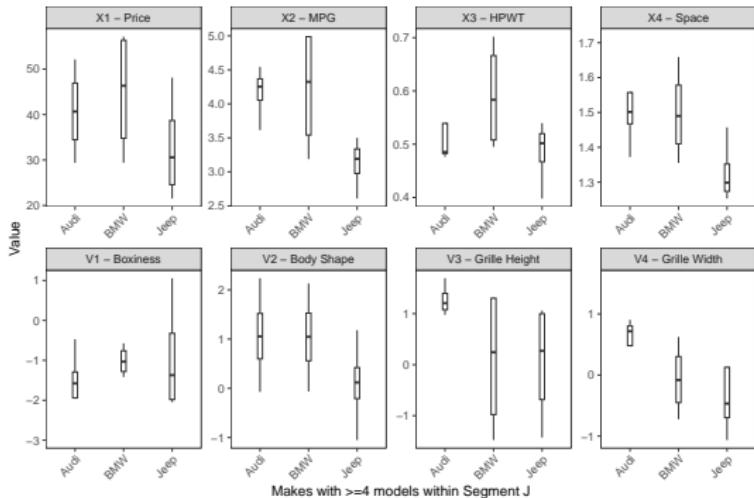
- Audi is very tight on some visual characteristics, notably, grille height and grille width \implies distinctive look



Insight 3D: Different Visual Strategy Across Brands

Disentanglement identifies interpretable characteristics

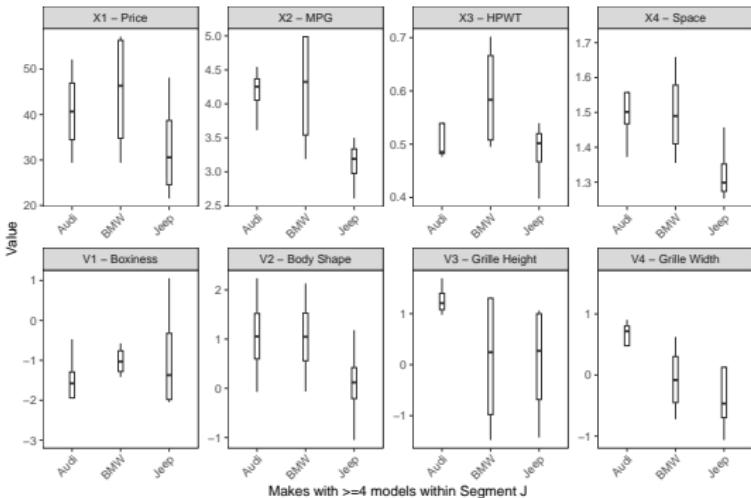
- Audi is very tight on some visual characteristics, notably, grille height and grille width \implies *distinctive look*
- BMW is typically a more “boxy” look



Insight 3D: Different Visual Strategy Across Brands

Disentanglement identifies interpretable characteristics

- Audi is very tight on some visual characteristics, notably, grille height and grille width \implies *distinctive look*
- BMW is typically a more “boxy” look
- Jeep varies on most visual characteristics



Insight 3: Different Visual Strategy Across Brands

Audi Q3



Audi Q5



Audi Q7



Audi SQ5



BMW X1



BMW X3



BMW X5



BMW X6



Jeep Cherokee



Jeep Compass



Jeep Grand
Cherokee

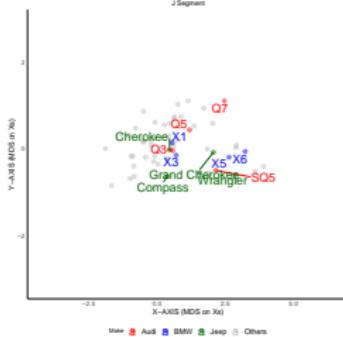


Jeep Wrangler

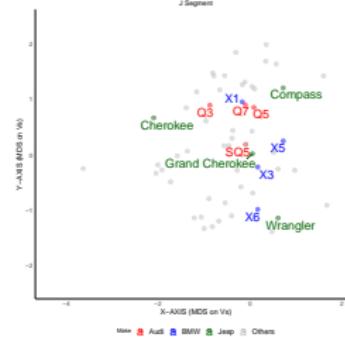


Insight 4: Product-Level

Only Functional Characteristics



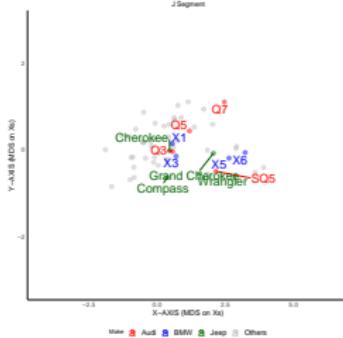
Only Visual Characteristics



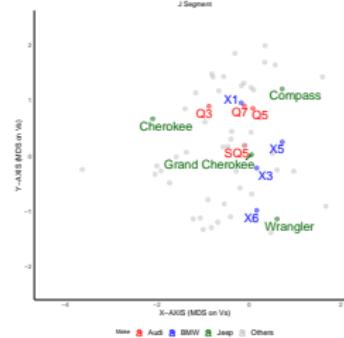
- Looking only at functional characteristics, BMW seems to be positioning X5 and X6 too close (cannibalization risk)

Insight 4: Product-Level

Only Functional Characteristics



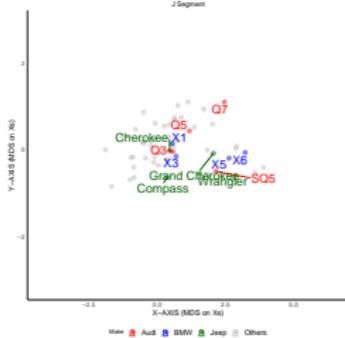
Only Visual Characteristics



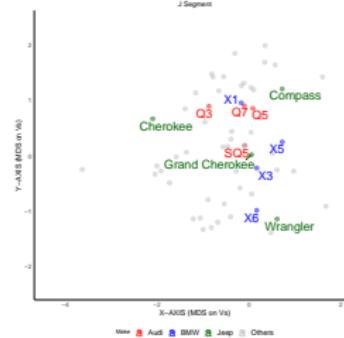
- Looking only at functional characteristics, BMW seems to be positioning X5 and X6 too close (cannibalization risk)
 - Looking at visual, we can see that they are now separated more

Insight 4: Product-Level

Only Functional
Characteristics



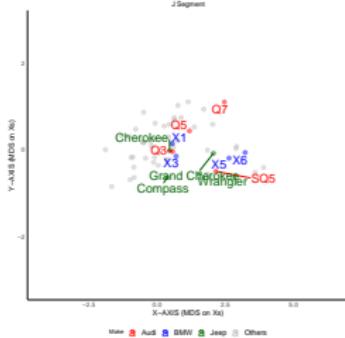
Only Visual
Characteristics



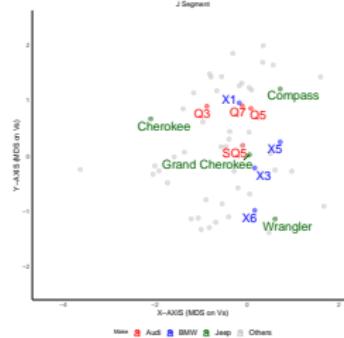
- Looking only at functional characteristics, BMW seems to be positioning X5 and X6 too close (cannibalization risk)
 - Looking at visual, we can see that they are now separated more
- Positioning BMW X3: Should I focus on Cherokee (which is what functional map suggests)?

Insight 4: Product-Level

Only Functional
Characteristics



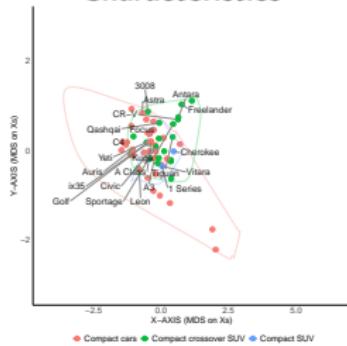
Only Visual
Characteristics



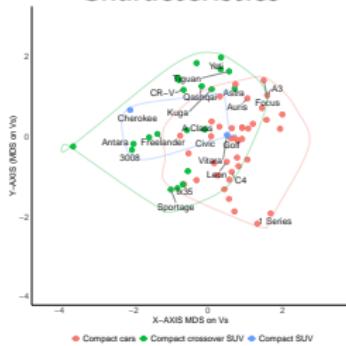
- Looking only at functional characteristics, BMW seems to be positioning X5 and X6 too close (cannibalization risk)
 - Looking at visual, we can see that they are now separated more
- Positioning BMW X3: Should I focus on Cherokee (which is what functional map suggests)?
 - Visual map suggests the Grand Cherokee is closer instead

Insight 5: Leaping to Another Category

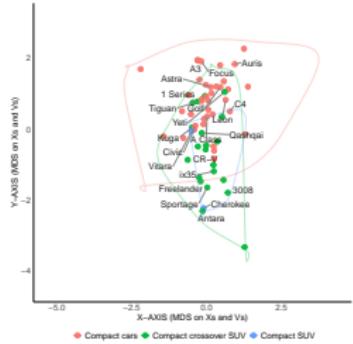
**Only Functional
Characteristics**



**Only Visual
Characteristics**

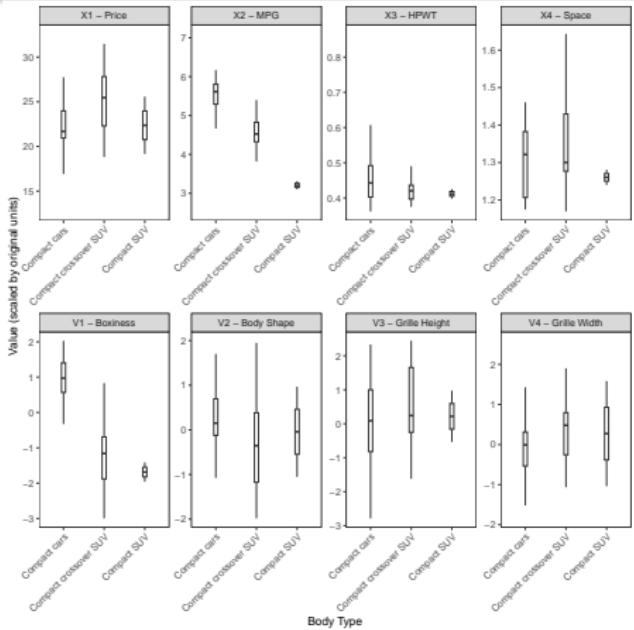


Both Characteristics



Insight 5D: Leaping to Another Category

- Compact cars and compact crossover SUVs differ in boxiness
- Compact cars and compact crossover SUVs overlap across most functional characteristics
- Compact crossover SUVs and compact SUVs are similar in visual characteristics
- Compact crossover SUVs and compact SUVs differ in some



Connecting Consumer Search to Market Structure Maps

Consumer Search \iff Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for “Honda Civic” and “Toyota Corolla” more likely to be comparing

$$\log_{10}(Y_{AB} + 1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

³Raw Google Trend values are scaled by each pair's segment sales share

Consumer Search \iff Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for “Honda Civic” and “Toyota Corolla” more likely to be comparing
- Models likely in consideration set

$$\log_{10}(Y_{AB} + 1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

³Raw Google Trend values are scaled by each pair's segment sales share

Consumer Search \iff Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for “Honda Civic” and “Toyota Corolla” more likely to be comparing
- Models likely in consideration set

$$\log_{10}(Y_{AB} + 1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

- $\log_{10}(Y_{AB} + 1)$ is the log-transformed normalized Google Trends score for the pair (model A, model B) belonging to the same segment³

³Raw Google Trend values are scaled by each pair's segment sales share

Consumer Search \iff Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for “Honda Civic” and “Toyota Corolla” more likely to be comparing
- Models likely in consideration set

$$\log_{10}(Y_{AB} + 1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

- $\log_{10}(Y_{AB} + 1)$ is the log-transformed normalized Google Trends score for the pair (model A, model B) belonging to the same segment³
- (X_A, X_B) are standardized functional characteristics

³Raw Google Trend values are scaled by each pair's segment sales share

Consumer Search \iff Market structure maps?

We use Google Trends to look for consumers searching pairs of models

- Consumer searching for “Honda Civic” and “Toyota Corolla” more likely to be comparing
- Models likely in consideration set

$$\log_{10}(Y_{AB} + 1) = \beta_0 + \beta_1(|X_A - X_B|) + \beta_2(|V_A - V_B|) + \epsilon_{AB}$$

- $\log_{10}(Y_{AB} + 1)$ is the log-transformed normalized Google Trends score for the pair (model A, model B) belonging to the same segment³
- (X_A, X_B) are standardized functional characteristics
- (V_A, V_B) are standardized visual characteristics

³Raw Google Trend values are scaled by each pair's segment sales share

Consumer Search \iff Market structure maps?

	(1)	(2)	(3)	(4)
Constant	2.778*** (0.205)	9.509*** (1.425)	2.974*** (0.291)	8.871*** (1.479)
Δ HP/Weight	-2.395 (1.691)	-3.761** (1.460)	-2.886* (1.638)	-4.021*** (1.453)
Δ Space	-1.685 (1.068)	1.200 (0.851)	-1.444 (1.031)	1.431* (0.853)
Δ MPG	-0.601*** (0.199)	-0.407** (0.163)	-0.599*** (0.196)	-0.432*** (0.165)
Δ Price	-0.214*** (0.037)	-0.188*** (0.031)	-0.203*** (0.036)	-0.194*** (0.032)
Δ Boxiness			-0.263 (0.161)	0.249 (0.154)
Δ Bodyshape			0.149 (0.108)	-0.361** (0.144)
Δ Grille Height			-0.284*** (0.072)	-0.007 (0.065)
Δ Grille Width			0.324** (0.138)	-0.001 (0.145)
Make Fixed Effects	No	Yes	No	Yes
Observations	306	306	306	306
R ²	0.168	0.590	0.247	0.602
Adjusted R ²	0.157	0.559	0.227	0.566

Note: * p<0.1; ** p<0.05; *** p<0.01

Consumers search for visually similar cars even after accounting for functional similarity

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)
 - Obtain consumer preference parameters for visual design

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)
 - Obtain consumer preference parameters for visual design
- Focus: How do market outcomes change as visual design varies in a competitive market?

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)
 - Obtain consumer preference parameters for visual design
- Focus: How do market outcomes change as visual design varies in a competitive market?
 - With / without changing functional characteristics(?)

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)
 - Obtain consumer preference parameters for visual design
- Focus: How do market outcomes change as visual design varies in a competitive market?
 - With / without changing functional characteristics(?)
 - **What is the economic impact of rebadging? Platform sharing while maintaining brand identity.**

Next: Economic Value of Visual Design

- Typically model consumers having preferences over functional characteristics (BLP+):
- $u_{ijt} = X_{jt}\beta + \alpha p_{jt} + \xi_{jt} + \epsilon_{ijt}$
 - Can incorporate interpretable visual characteristics (Augment X with V visual characteristics)
 - Obtain consumer preference parameters for visual design
- Focus: How do market outcomes change as visual design varies in a competitive market?
 - With / without changing functional characteristics(?)
 - What is the economic impact of rebadging? Platform sharing while maintaining brand identity.
 - (Method) **What is the impact of ignoring visual design (just letting ξ_{jt} pick it up)**

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- **Visual design increases differentiation across segments**

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- Visual design increases differentiation across segments
- **Different visual strategy across brands**

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- Visual design increases differentiation across segments
- Different visual strategy across brands
 - Brand consistency (e.g. Audi)

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- Visual design increases differentiation across segments
- Different visual strategy across brands
 - Brand consistency (e.g. Audi)
 - Within-brand differentiation (e.g. Jeep) in design

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- Visual design increases differentiation across segments
- Different visual strategy across brands
 - Brand consistency (e.g. Audi)
 - Within-brand differentiation (e.g. Jeep) in design
- Product close in functional space often differentiated visually and the other way around

Conclusion and Takeaways

- We quantify human-interpretable visual design characteristics and obtain market structure maps
 - Method allows us to select only *relevant* visual characteristics
- (Interpretable) Visual characteristics can provide an entirely new set of insights at segment (submarket) level, brand level and product level
- Visual design increases differentiation across segments
- Different visual strategy across brands
 - Brand consistency (e.g. Audi)
 - Within-brand differentiation (e.g. Jeep) in design
- Product close in functional space often differentiated visually and the other way around
- Consumers search for visually similar cars even after accounting for functional similarity