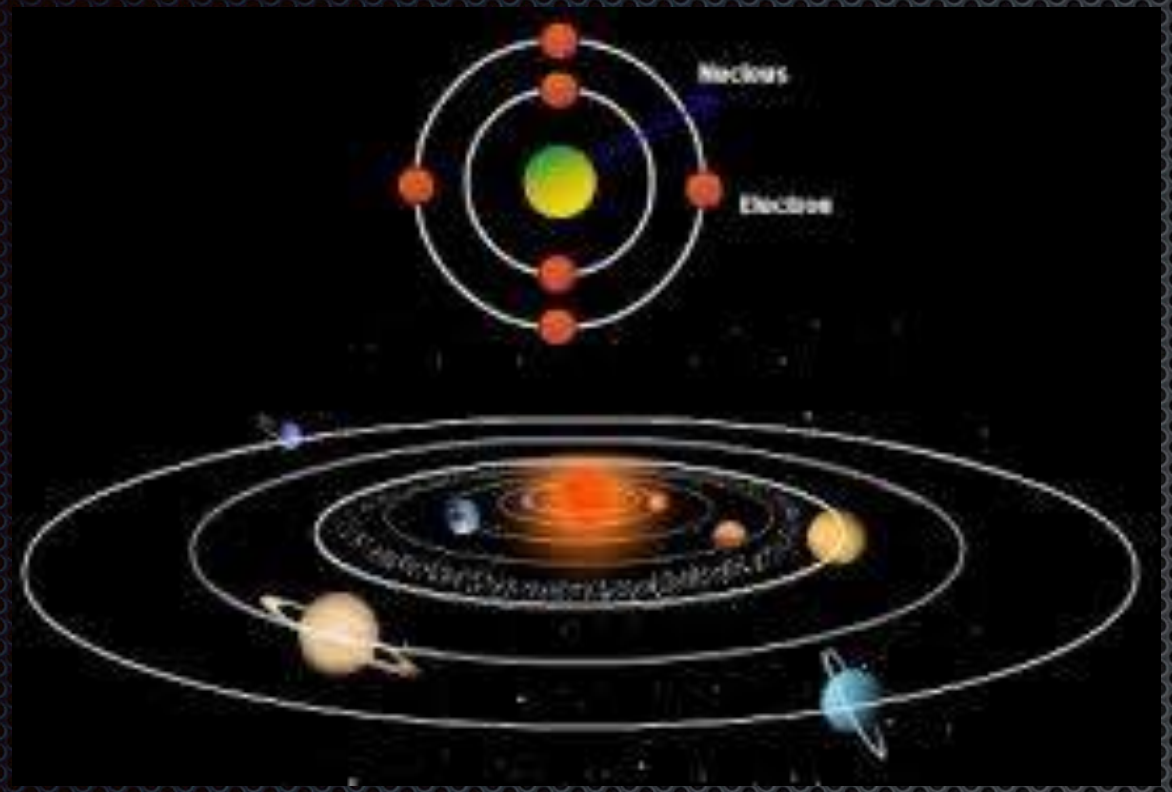
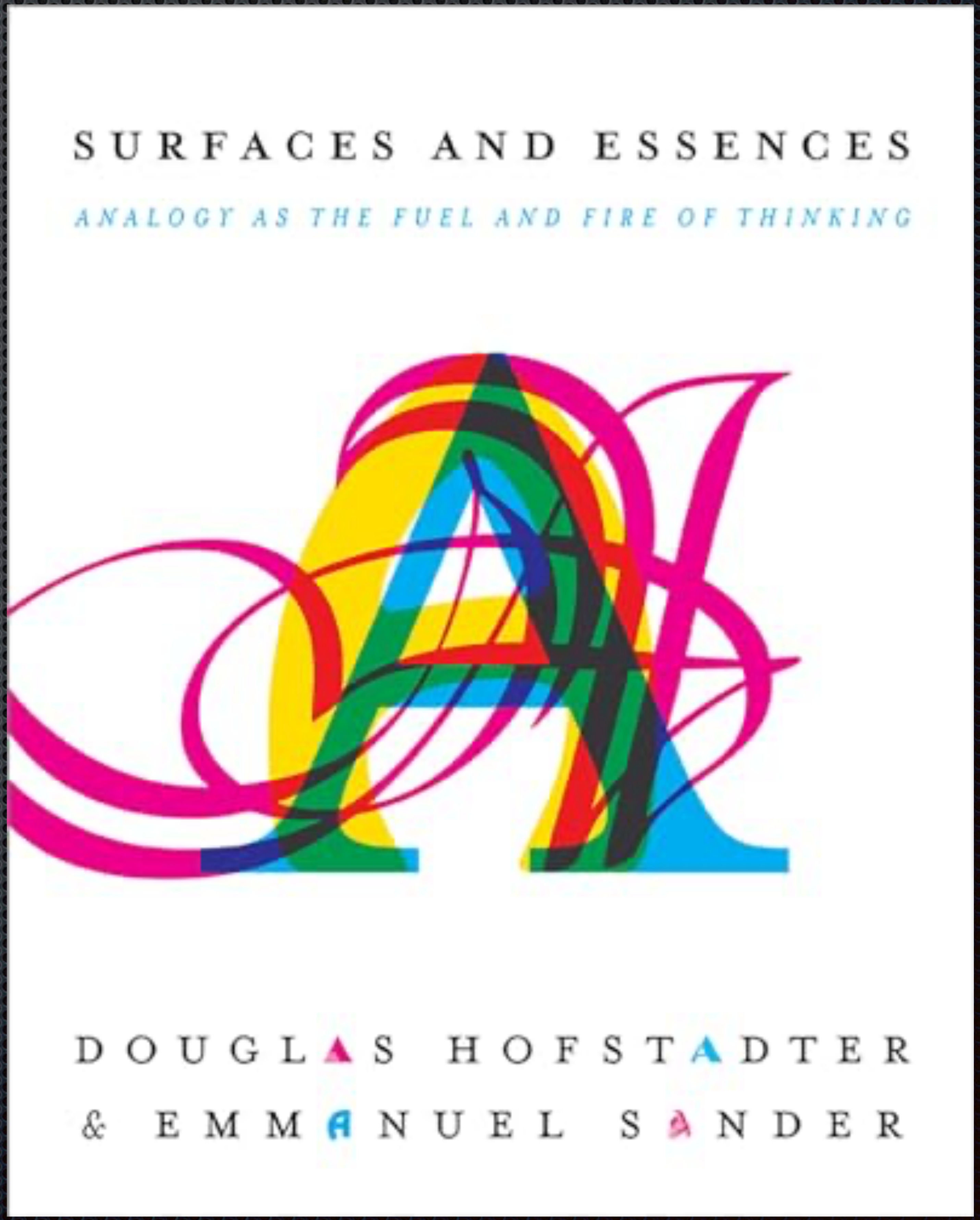
Adjoint Functors and AGI

Sridhar Mahadevan, Adobe Research and U.Mass, Amherst

Analogies and Adjoint Functors

An atom is like a solar system

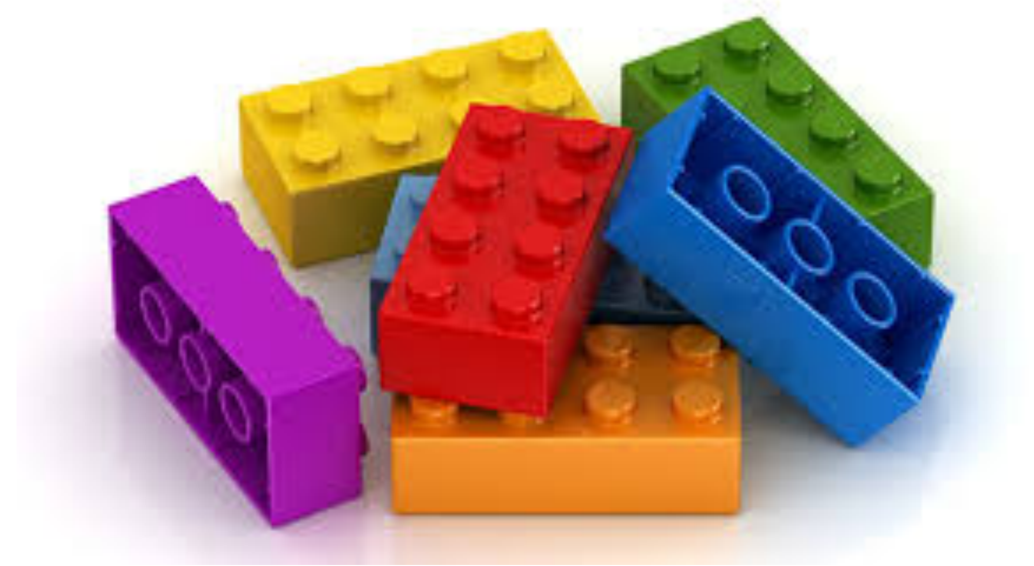




The Universe as a Hologram

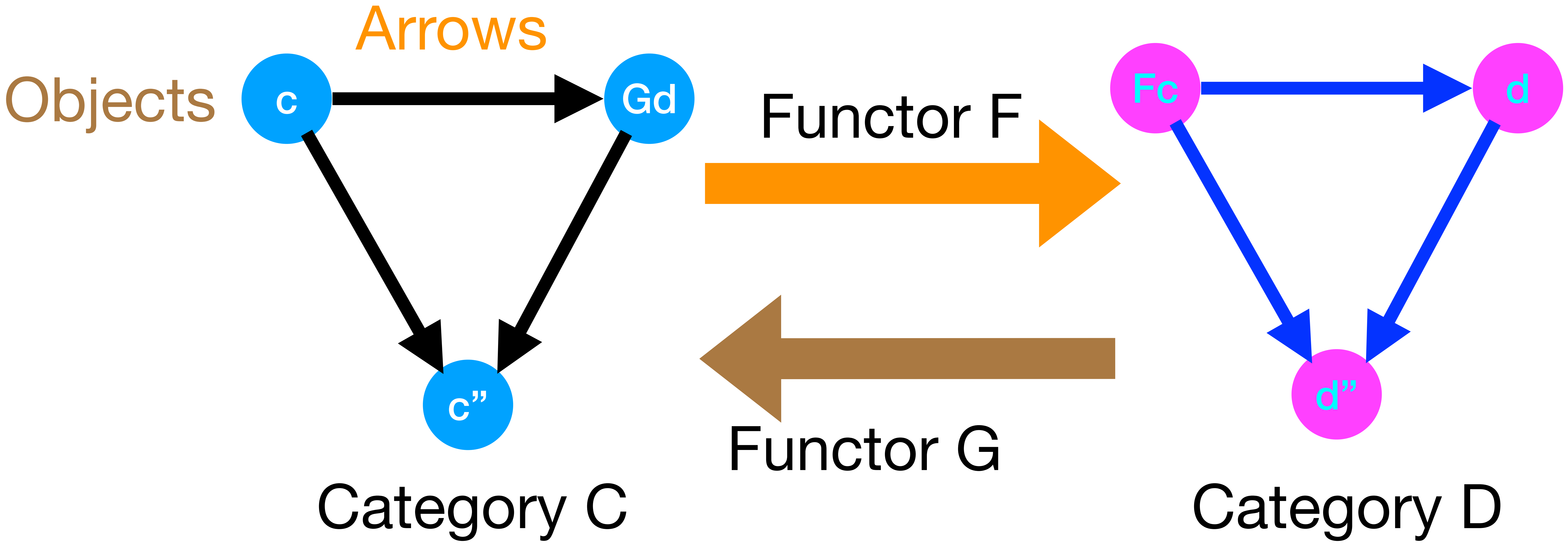
Specifically, Maldacena showed that a five-dimensional theory of a type of imaginary spacetime called anti–de Sitter space (AdS) that included gravity could describe the same system as a lower-dimensional quantum field theory of particles and fields in the absence of gravity, referred to as a conformal field theory (CFT). In other words, he found two different theories that could describe the same physical system, showing that the theories were, in a sense, equivalent—even though they included different numbers of dimensions, and one factored in gravity where the other didn't. Maldacena then surmised that this AdS/CFT duality would hold for other pairs of theories in which one had a single extra dimension, possibly even those describing 4D spacetime akin to ours.

https://www.scientificamerican.com/article/is-our-universe-a-hologram-physicists-debate-famous-idea-on-its-25th-anniversary1/



Adjoint Functors

$C(c, Gd) \sim D(Fc,d)$



Anti deSitter Space

Conformal Field Theory

Free and Forgetful Functors

- A very common style of adjunction is between “free” and “forgetful” functors
  - Sets <-> Abelian Groups
  - Graphs <-> Categories
- Consider the set ice_cream_flavors = {vanilla, chocolate, strawberry}
  - How do we make this set into a vector space?
  - We can choose each flavor as a basis vector
  - New flavor = 3**vanilla* - 1.5**chocolate* + 0.2**strawberry*
- Conversely, we can take any vector space, and look at the set of possible vectors in it
  - That is, we “forget” the fact that it is a vector space, and treat it as if it were a set

Graphs vs Categories

- We can define a pair of “free” and “forgetful” functors between the categories of Graphs and Categories
  - The category Cat of all categories is one where objects are categories and the arrows are functors
  - The category Graph is one where objects are graphs and arrows are edge-preserving homomorphisms
- Left adjoint:
  - F: map a graph X into its “free” category F(X)
  - Intuition: compute the transitive closure of a graph
- Right adjoint:
  - G: map a category C into its “forgetful” graph G(C)
  - Forget which arrows are composite and which arrows are primitive

Adjunctions

Lemma 4.1.3. *Consider a pair of functors* $F\colon \mathsf{C} \rightleftarrows \mathsf{D} \colon G$ *equipped with isomorphisms* $\mathsf{D}(Fc,d) \cong \mathsf{C}(c,Gd)$ *for all* $c \in \mathsf{C}$ *and* $d \in \mathsf{D}$. *Naturality of this collection of isomorphisms is equivalent to the assertion that for any morphisms with domains and codomains as displayed below*

$$\begin{array}{ccc} Fc & \xrightarrow{f^\sharp} & d \\ {\scriptstyle Fh}\downarrow & & \downarrow{\scriptstyle k} \\ Fc' & \xrightarrow[g^\sharp]{} & d' \end{array} \quad\leftrightsquigarrow\quad \begin{array}{ccc} c & \xrightarrow{f^\flat} & Gd \\ {\scriptstyle h}\downarrow & & \downarrow{\scriptstyle Gk} \\ c' & \xrightarrow[g^\flat]{} & Gd' \end{array} \tag{4.1.4}$$

the left-hand square commutes in D *if and only if the right-hand transposed square commutes in* C.

Notation 4.1.5. A turnstyle "$\dashv$" is used to designate that an opposing pair of functors are adjoints: the expressions $F \dashv G$ and $G \vdash F$ and the diagrams

$$\mathsf{C} \underset{G}{\overset{F}{\underset{\perp}{\rightleftarrows}}} \mathsf{D} \qquad \mathsf{C} \underset{F}{\overset{G}{\underset{\top}{\leftrightarrows}}} \mathsf{D} \qquad \mathsf{D} \underset{G}{\overset{F}{\underset{\perp}{\leftrightarrows}}} \mathsf{C} \qquad \mathsf{D} \underset{F}{\overset{G}{\underset{\top}{\rightleftarrows}}} \mathsf{C}$$

all assert that $F\colon \mathsf{C} \to \mathsf{D}$ is left adjoint to $G\colon \mathsf{D} \to \mathsf{C}$.

Figure Source: Emily Riehl, Category Theory in Context

Adjunctions and Naturality

More explicitly, naturality in D says that for any morphism $k\colon d \to d'$, the left-hand diagram displayed below commutes in Set:

$$\begin{array}{ccc} \mathsf{D}(Fc,d) & \xrightarrow{\cong} & \mathsf{C}(c,Gd) \\ {\scriptstyle k_*}\downarrow & & \downarrow{\scriptstyle Gk_*} \\ \mathsf{D}(Fc,d') & \xrightarrow[\cong]{} & \mathsf{C}(c,Gd') \end{array} \qquad \forall Fc \xrightarrow{f^\sharp} d \quad \rightsquigarrow \quad \begin{array}{ccc} c & \xrightarrow{f^\flat} & Gd \\ & {\scriptstyle (k\cdot f^\sharp)^\flat}\searrow & \downarrow{\scriptstyle Gk} \\ & & Gd' \end{array}$$

which amounts to the assertion that for any $f^\sharp\colon Fc \to d$ and $k\colon d \to d'$, the transpose of $k \cdot f^\sharp\colon Fc \to d'$ is equal to the composite of $f^\flat\colon c \to Gd$ with $Gk\colon Gd \to Gd'$.

Dually, naturality in C says that for any morphism $h\colon c' \to c$, the left-hand diagram displayed below commutes in Set:

$$\begin{array}{ccc} \mathsf{D}(Fc,d) & \xrightarrow{\cong} & \mathsf{C}(c,Gd) \\ {\scriptstyle Fh^*}\downarrow & & \downarrow{\scriptstyle h^*} \\ \mathsf{D}(Fc',d) & \xrightarrow[\cong]{} & \mathsf{C}(c',Gd) \end{array} \qquad \forall Fc \xrightarrow{f^\sharp} d \quad \rightsquigarrow \quad \begin{array}{ccc} c' & & \\ {\scriptstyle h}\downarrow & \searrow{\scriptstyle (f^\sharp\cdot Fh)^\flat} & \\ c & \xrightarrow[f^\flat]{} & Gd \end{array}$$

Figure Source: Emily Riehl, Category Theory in Context

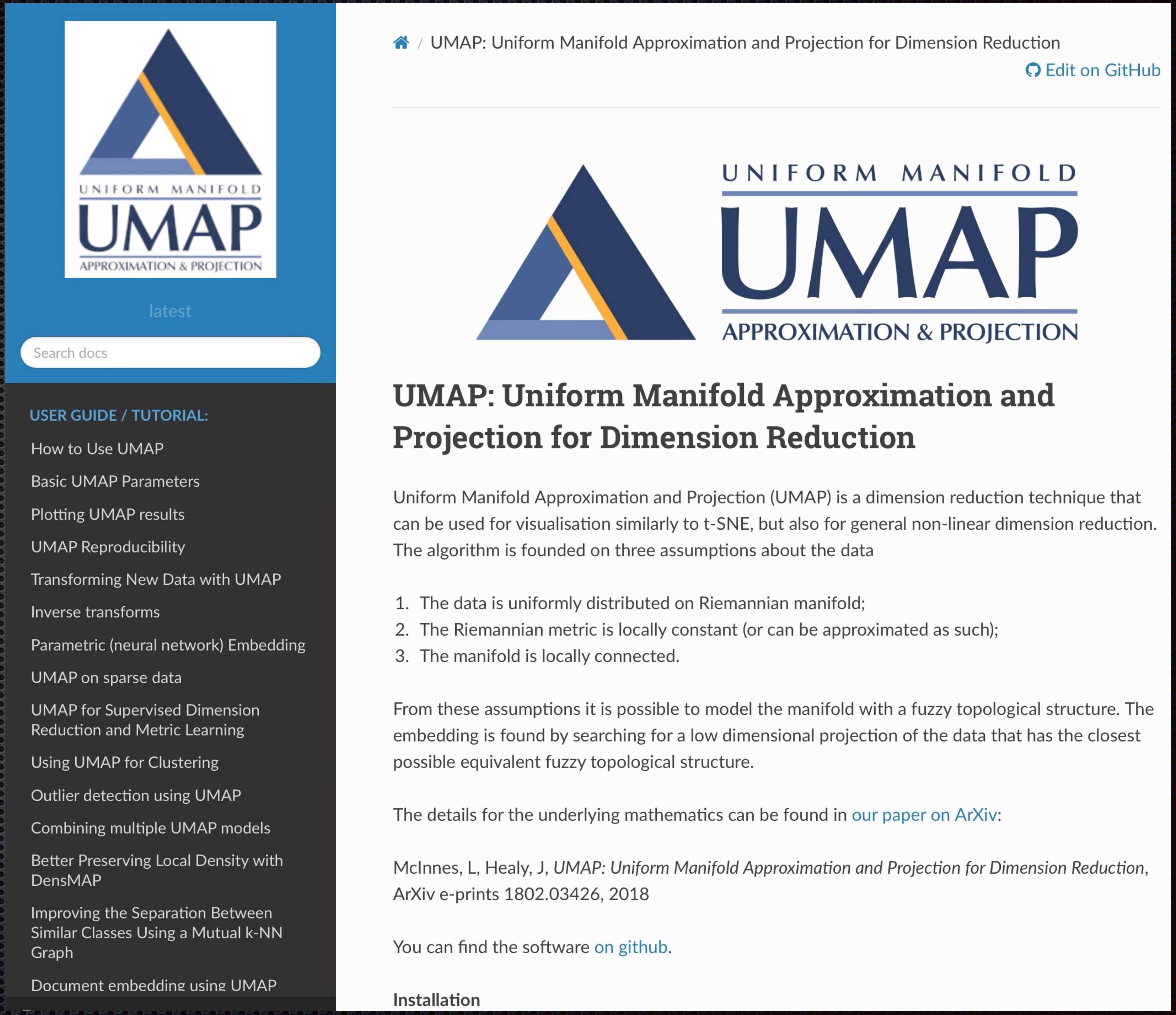
Adjoint Functors are everywhere

Graphs <-> Categories

Causal <-> Statistical

Transfer Learning

Domain adaptation



UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction

Edit on GitHub

latest

Search docs

USER GUIDE / TUTORIAL:

- How to Use UMAP
- Basic UMAP Parameters
- Plotting UMAP results
- UMAP Reproducibility
- Transforming New Data with UMAP
- Inverse transforms
- Parametric (neural network) Embedding
- UMAP on sparse data
- UMAP for Supervised Dimension Reduction and Metric Learning
- Using UMAP for Clustering
- Outlier detection using UMAP
- Combining multiple UMAP models
- Better Preserving Local Density with DensMAP
- Improving the Separation Between Similar Classes Using a Mutual k-NN Graph
- Document embedding using UMAP

UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction

Uniform Manifold Approximation and Projection (UMAP) is a dimension reduction technique that can be used for visualisation similarly to t-SNE, but also for general non-linear dimension reduction. The algorithm is founded on three assumptions about the data

1. The data is uniformly distributed on Riemannian manifold;
2. The Riemannian metric is locally constant (or can be approximated as such);
3. The manifold is locally connected.

From these assumptions it is possible to model the manifold with a fuzzy topological structure. The embedding is found by searching for a low dimensional projection of the data that has the closest possible equivalent fuzzy topological structure.

The details for the underlying mathematics can be found in our paper on ArXiv:

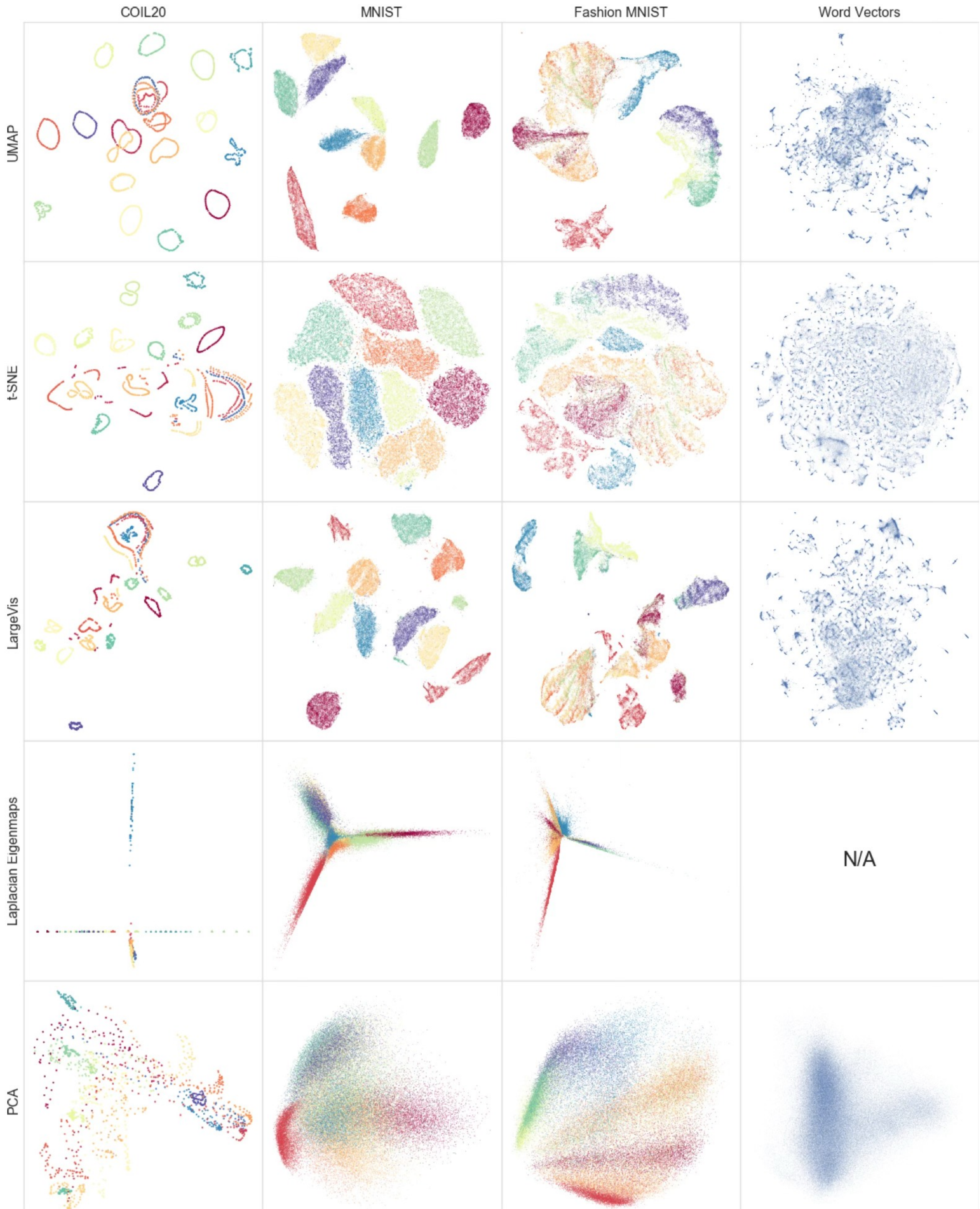
McInnes, L, Healy, J, *UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction*, ArXiv e-prints 1802.03426, 2018

You can find the software on github.

Installation

UMAP

PCA


COIL20
MNIST
Fashion MNIST
Word Vectors
UMAP
t-SNE
LargeVis
Laplacian Eigenmaps
PCA
N/A

UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction

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Abstract

UMAP (Uniform Manifold Approximation and Projection) is a novel manifold learning technique for dimension reduction. UMAP is constructed from a theoretical framework based in Riemannian geometry and algebraic topology. The result is a practical scalable algorithm that is applicable to real world data. The UMAP algorithm is competitive with t-SNE for visualization quality, and arguably preserves more of the global structure with superior run time performance. Furthermore, UMAP has no computational restrictions on embedding dimension, making it viable as a general purpose dimension reduction technique for machine learning.

1 Introduction

Dimension reduction plays an important role in data science, being a fundamental technique in both visualisation and as pre-processing for machine

Definition 1. *The category* $\mathbf{\Delta}$ *has as objects the finite order sets* $[n] = \{1, \ldots, n\}$, *with morphims given by (non-strictly) order-preserving maps.*

Following standard category theoretic notation, $\mathbf{\Delta}^{\text{op}}$ denotes the category with the same objects as $\mathbf{\Delta}$ and morphisms given by the morphisms of $\mathbf{\Delta}$ with the direction (domain and codomain) reversed.

Definition 2. *A* simplicial set *is a functor from* $\mathbf{\Delta}^{op}$ *to* **Sets**, *the category of sets; that is, a contravariant functor from* $\mathbf{\Delta}$ *to* **Sets**.

Given a simplicial set $X : \mathbf{\Delta}^{\text{op}} \to \mathbf{Sets}$, it is common to denote the set $X([n])$ as X_n and refer to the elements of the set as the n-simplices of X. The simplest possible examples of simplicial sets are the *standard simplices* Δ^n, defined as the representable functors $\hom_{\mathbf{\Delta}}(\cdot, [n])$. It follows from the Yoneda lemma that there is a natural correspondence between n-simplices of X and morphisms $\Delta^n \to X$ in the category of simplicial sets, and it is often helpful to think in these terms. Thus for each $x \in X_n$ we have a corresponding morphism $x : \Delta^n \to X$. By the density theorem and employing a minor abuse of notation we then have

$$\operatorname*{colim}_{x \in X_n} \Delta^n \cong X$$

There is a standard covariant functor $|\cdot| : \mathbf{\Delta} \to \mathbf{Top}$ mapping from the category $\mathbf{\Delta}$ to the category of topological spaces that sends $[n]$ to the standard n-simplex $|\Delta^n| \subset \mathbb{R}^{n+1}$ defined as

$$|\Delta^n| \triangleq \left\{ (t_0, \ldots, t_n) \in \mathbb{R}^{n+1} \mid \sum_{i=0}^{n} t_i = 1, t_i \geq 0 \right\}$$

with the standard subspace topology. If $X : \mathbf{\Delta}^{\text{op}} \to \mathbf{Sets}$ is a simplicial set then we can construct the realization of X (denoted $|X|$) as the colimit

$$|X| = \operatorname*{colim}_{x \in X_n} |\Delta^n|$$

Definition 7. *Define the functor* $\mathsf{FinReal}$: **Fin-sFuzz** $\to$ **FinEPMet** *by setting*

$$\mathsf{FinReal}(\Delta^n_{<a}) \triangleq (\{x_1, x_2, \ldots, x_n\}, d_a),$$

where

$$d_a(x_i, x_j) = \begin{cases} -\log(a) & \textit{if } i \neq j, \\ 0 & \textit{otherwise} \end{cases}.$$

and then defining

$$\mathsf{FinReal}(X) \triangleq \operatorname*{colim}_{\Delta^n_{<a} \to X} \mathsf{FinReal}(\Delta^n_{<a}).$$

[McInnes et al., 2020]

Definition 8. *Define the functor* $\mathsf{FinSing} : \mathbf{FinEPMet} \to \mathbf{Fin\text{-}sFuzz}$ *by*

$$\mathsf{FinSing}(Y) : ([n], [0, a)) \mapsto \hom_{\mathbf{FinEPMet}}(\mathsf{FinReal}(\Delta^n_{<a}), Y).$$

We then have the following theorem.

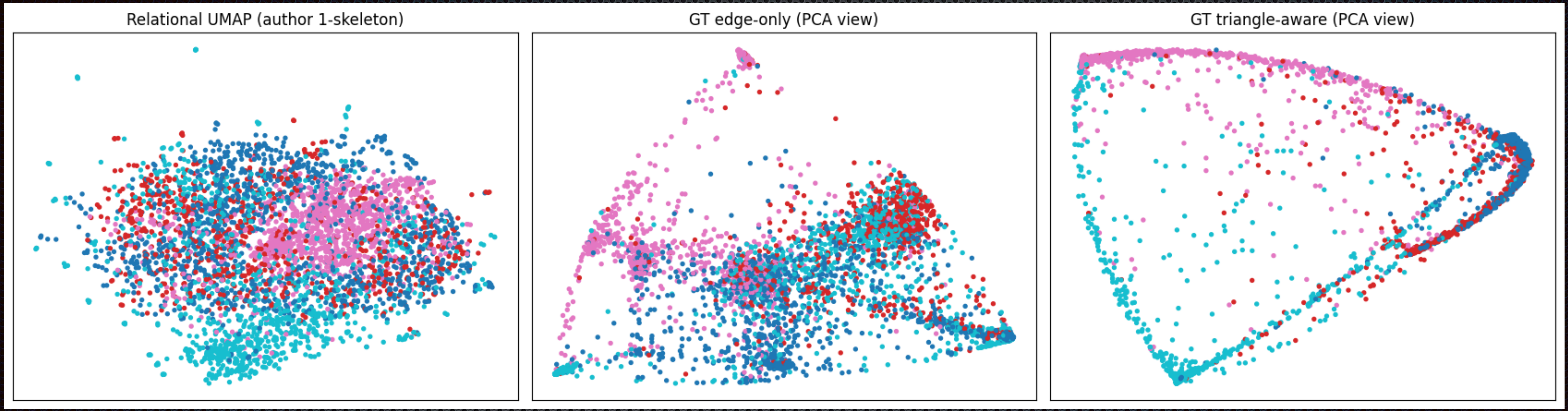
Theorem 1. *The functors* $\mathsf{FinReal} : \mathbf{Fin\text{-}sFuzz} \to \mathbf{FinEPMet}$ *and* $\mathsf{FinSing} : \mathbf{FinEPMet} \to \mathbf{Fin\text{-}sFuzz}$ *form an adjunction with* $\mathsf{FinReal}$ *the left adjoint and* $\mathsf{FinSing}$ *the right adjoint.*

[McInnes et al., 2020]

UMAP vs. DB+GT

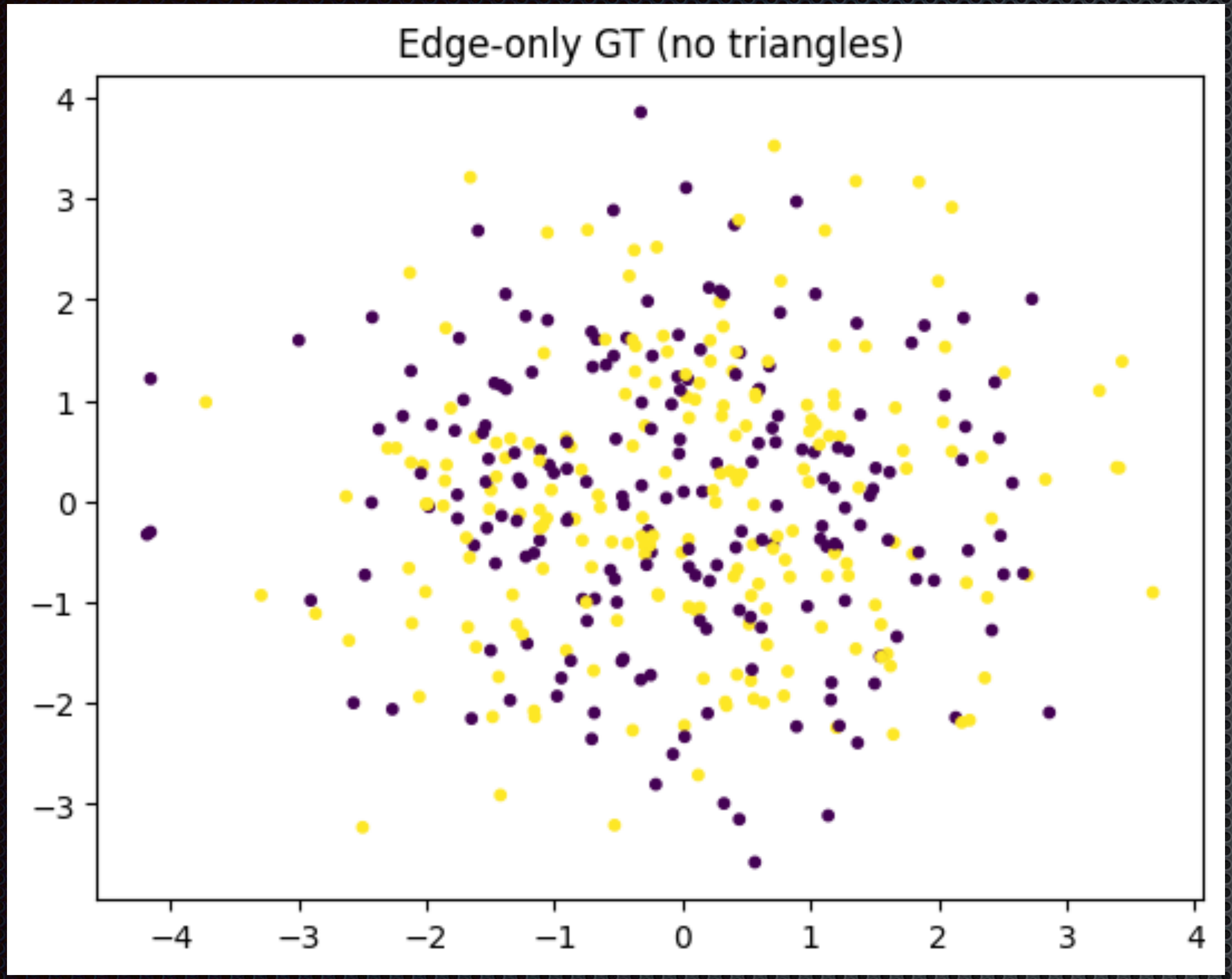
- UMAP is limited to visualizing point cloud datasets
- It only constructs the 1-skeleton (vertices, edges) of the simplicial complex
- Given a relational dataset, UMAP collapses the higher-order structure
- In relational domains, DB+GT work significantly better
  - Causal inference, databases, planning and RL

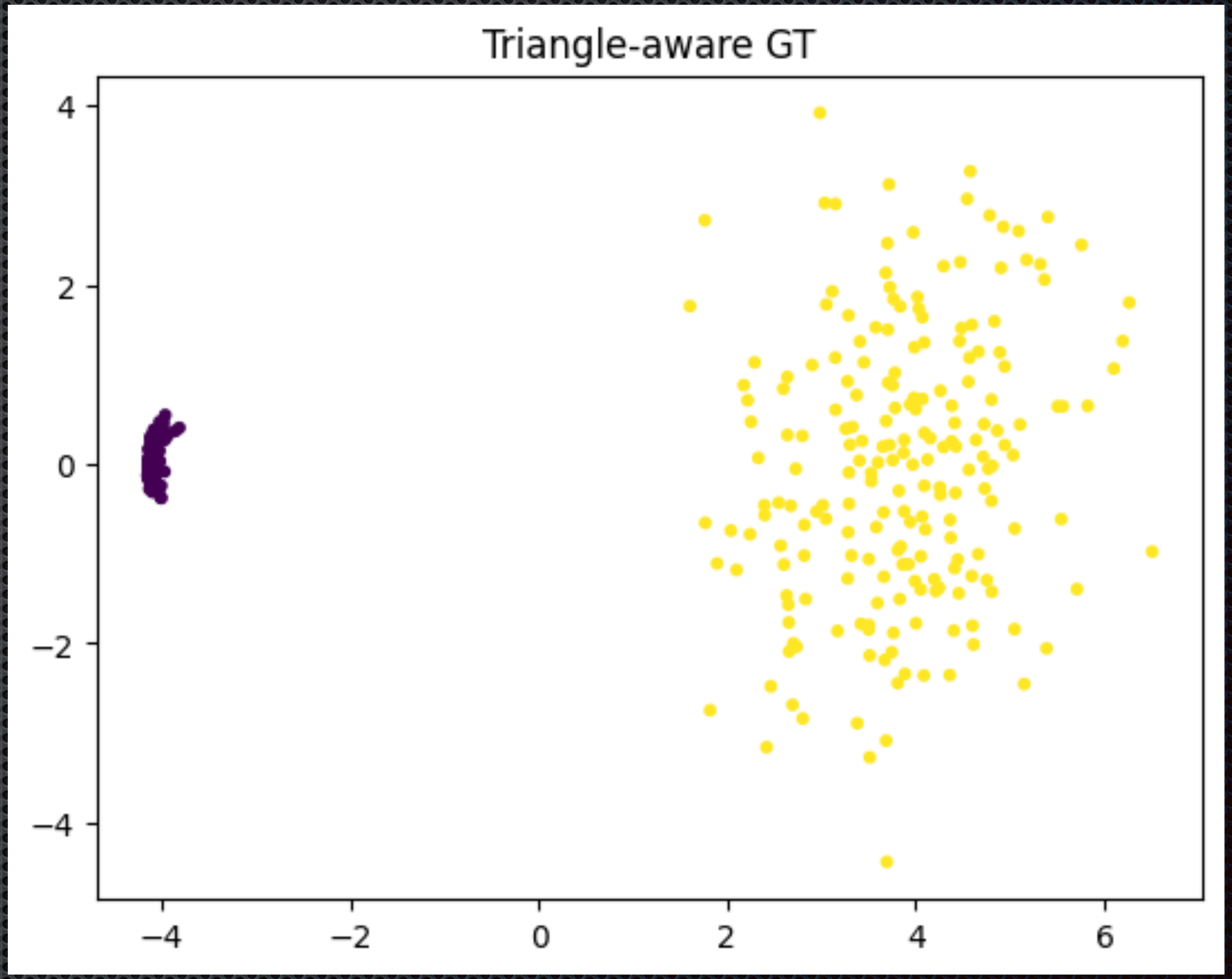
UMAP vs. DB+GT for DBLP dataset



Run the notebook on GitHub repo comparing UMAP with DB+GT

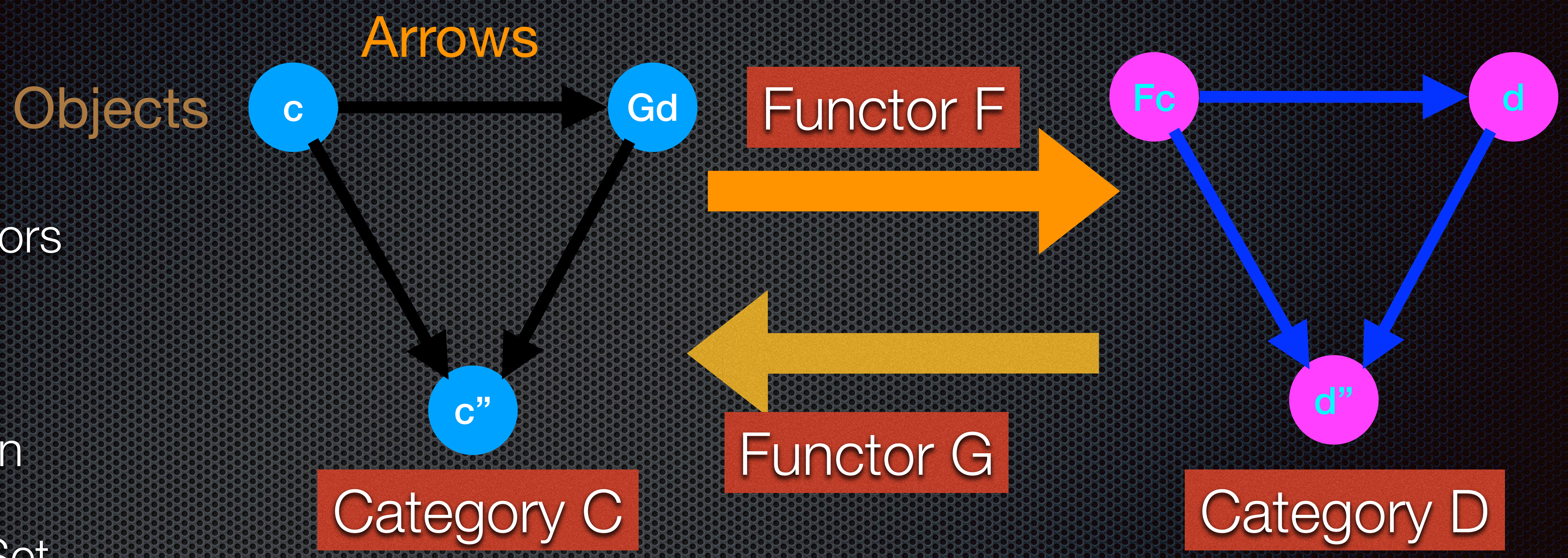
Edge vs. Triangle Embeddings





Run this notebook demo on the GitHub repository

Unit and Counit of Adjunctions



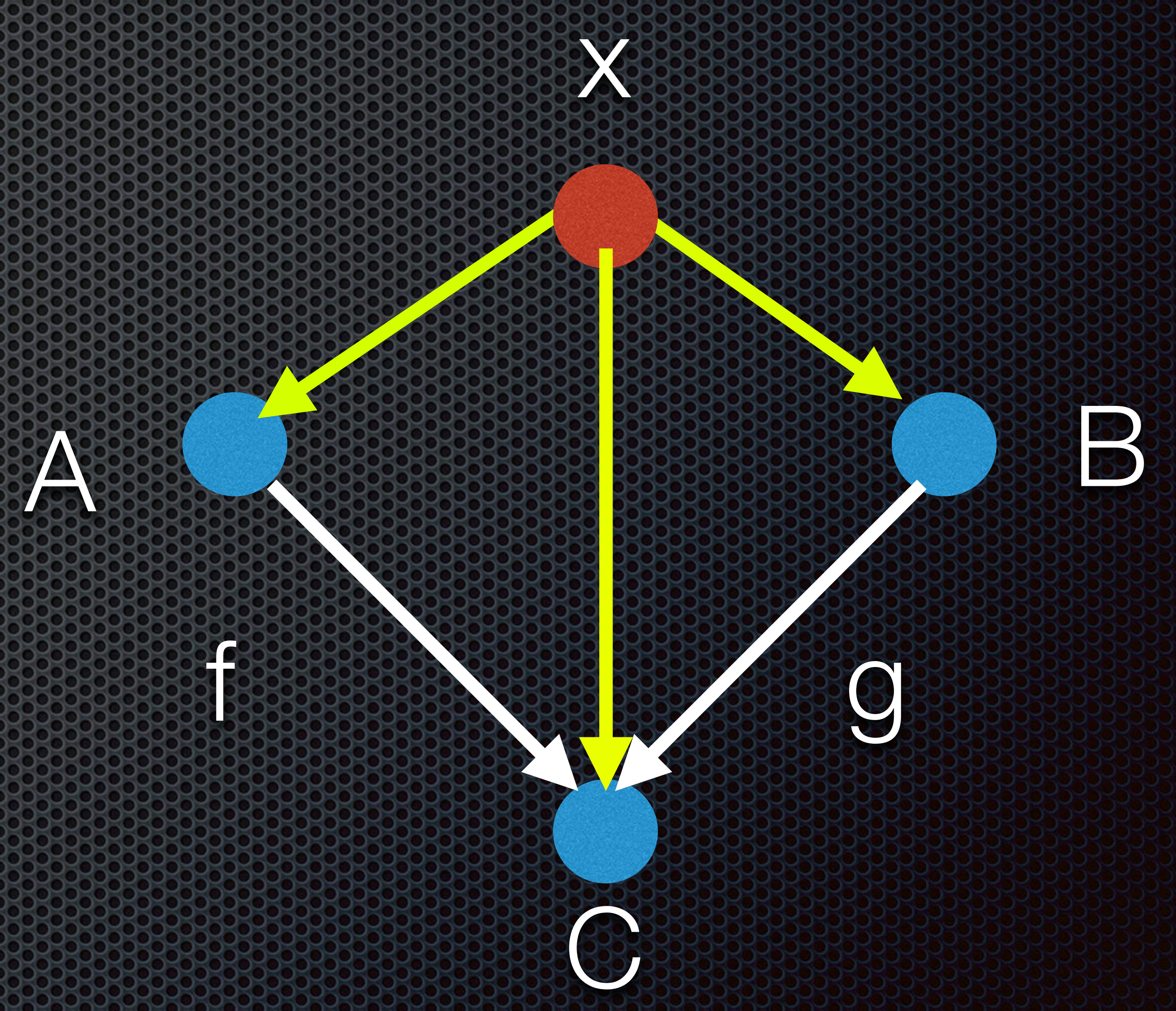
- Given a pair of adjoint functors
  - D(Fc, d) ~ C(c, Gd)
- Yoneda lemma interpretation
  - C(c, G-) ~ D(Fc,-): D -> Set
  - This isomorphism is represented by an element of C(c, GFc)
- Unit: natural transformation $\eta : \mathbf{1}_C \Rightarrow GF$
- Counit: natural transformation $\epsilon : FG \Rightarrow \mathbf{1}_D$

Limits and Cones

A cone over diagram F: J->C with apex x is a natural transformation from the constant functor at x to F

The constant functor at x maps every object in J to x, and every arrow in J to the identity arrow at x

$$\Delta : C \to C^J$$

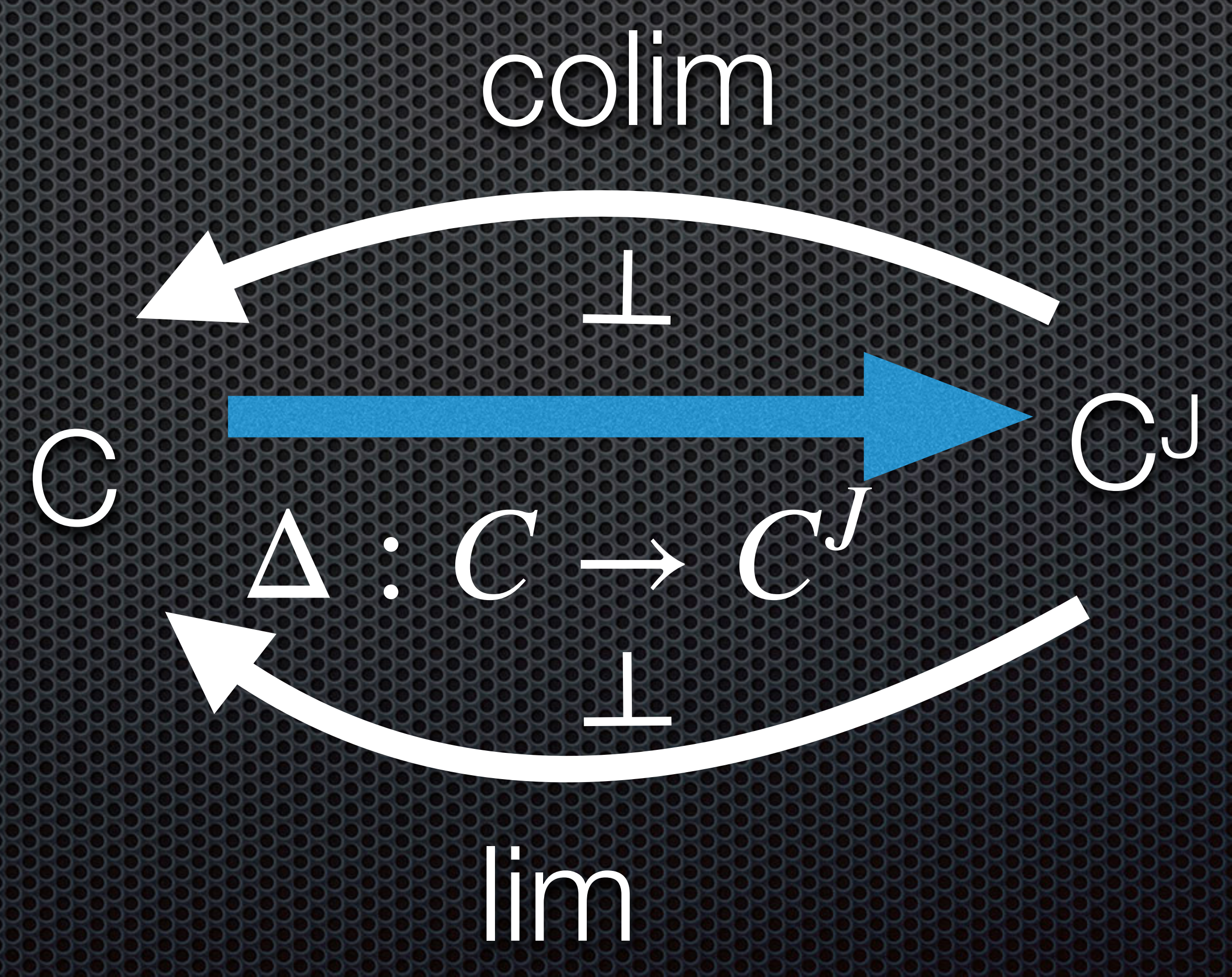


Limits and Colimits: Representable functors using the Yoneda Lemma

- A limit of diagram F is a representation for Cone(-, F)
  - C(-, lim F) ~ Cone(-, F)
- A colimit of diagram F is a representation of Cone(F, -)
  - C(colim F, -) ~ Cone(F, -)

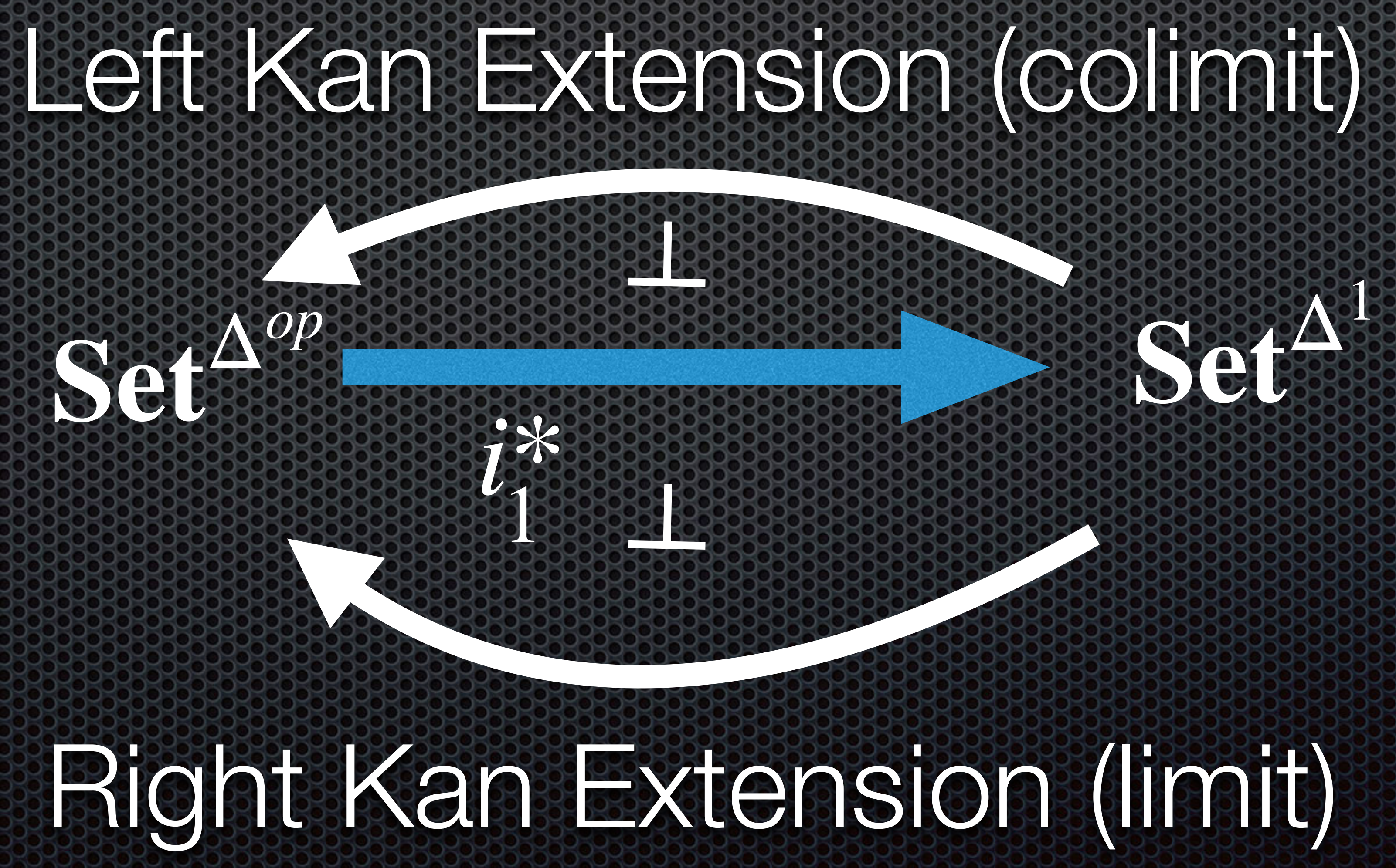
Adjunctions, Limits and Colimits

- Theorem: A category C admits all limits of diagrams indexed by a small category J if and only if the constant diagram functor admits a right adjoint
- Theorem: A category C admits all colimits of J-indexed diagrams if and only if the constant diagram functor admits a left adjoint



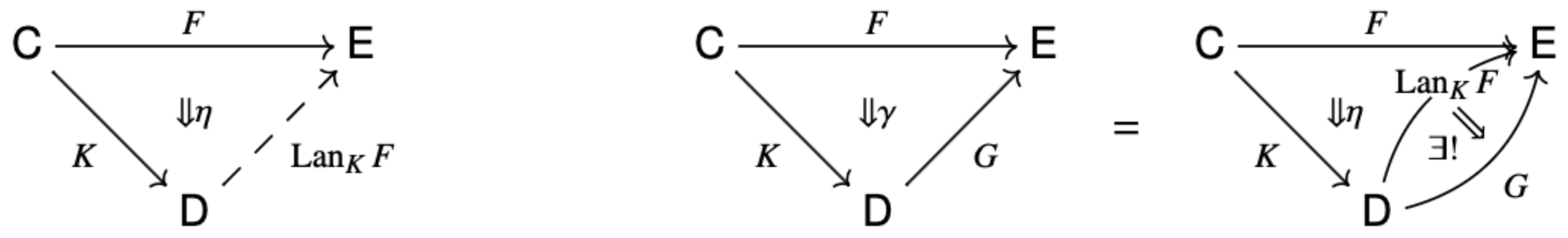
UMAP: 1-truncation of simplicial sets

- We can now formally define the UMAP restriction to 1-skeleton using left and right adjoints of the inclusion functor $i_1 : \Delta_1 \hookrightarrow \Delta$

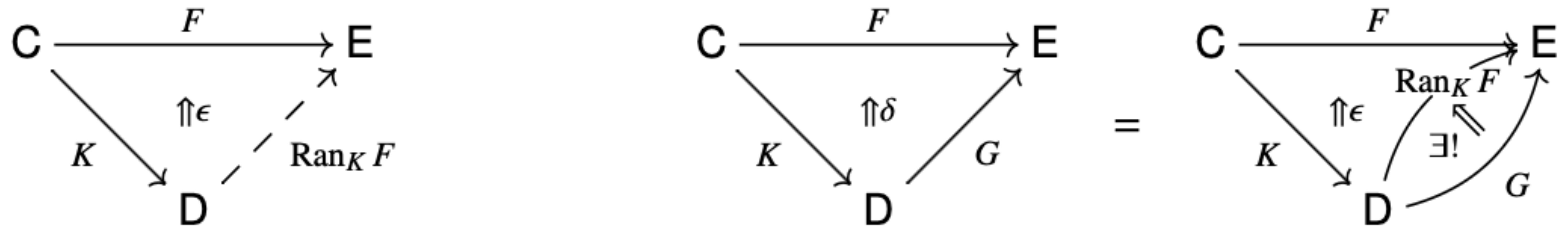


Kan Extensions

Definition 6.1.1. Given functors $F\colon \mathsf{C} \to \mathsf{E}$, $K\colon \mathsf{C} \to \mathsf{D}$, a **left Kan extension** of F along K is a functor $\mathrm{Lan}_K F\colon \mathsf{D} \to \mathsf{E}$ together with a natural transformation $\eta\colon F \Rightarrow \mathrm{Lan}_K F \cdot K$ such that for any other such pair $(G\colon \mathsf{D} \to \mathsf{E}, \gamma\colon F \Rightarrow GK)$, γ factors uniquely through η as illustrated.[1]



Dually, a **right Kan extension** of F along K is a functor $\mathrm{Ran}_K F\colon \mathsf{D} \to \mathsf{E}$ together with a natural transformation $\epsilon\colon \mathrm{Ran}_K F \cdot K \Rightarrow F$ such that for any $(G\colon \mathsf{D} \to \mathsf{E}, \delta\colon GK \Rightarrow F)$, δ factors uniquely through ϵ as illustrated.



Chapter 6

Riehl's textbook

Computing Kan Extensions

THEOREM 6.2.1. *Given functors* $F\colon \mathsf{C} \to \mathsf{E}$ *and* $K\colon \mathsf{C} \to \mathsf{D}$, *if for every* $d \in \mathsf{D}$ *the colimit*

$$\mathrm{Lan}_K F(d) := \mathrm{colim}(K \downarrow d \xrightarrow{\Pi^d} \mathsf{C} \xrightarrow{F} \mathsf{E}) \tag{6.2.2}$$

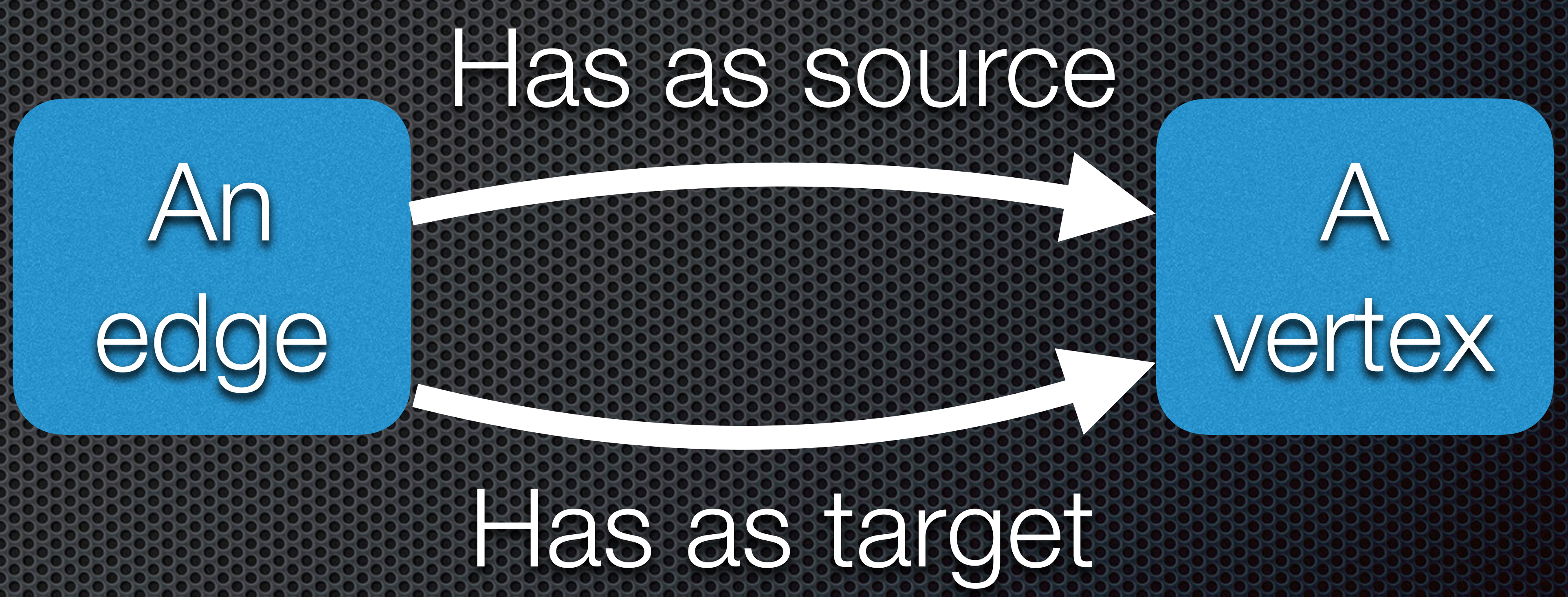
exists, then they define the left Kan extension $\mathrm{Lan}_K F\colon \mathsf{D} \to \mathsf{E}$, *in which case the unit transformation* $\eta\colon F \Rightarrow \mathrm{Lan}_K F \cdot K$ *can be extracted from the colimit cone. Dually, if for every* $d \in \mathsf{D}$ *the limit*

$$\mathrm{Ran}_K F(d) := \lim(d \downarrow K \xrightarrow{\Pi_d} \mathsf{C} \xrightarrow{F} \mathsf{E}) \tag{6.2.3}$$

exists, then they define the right Kan extension $\mathrm{Ran}_K F\colon \mathsf{D} \to \mathsf{E}$, *in which case the counit transformation* $\epsilon\colon \mathrm{Ran}_K F \cdot K \Rightarrow F$ *can be extracted from the limit cone.*

See new chapter on Kan Extension Transformers in my textbook

Database Schemas and instances

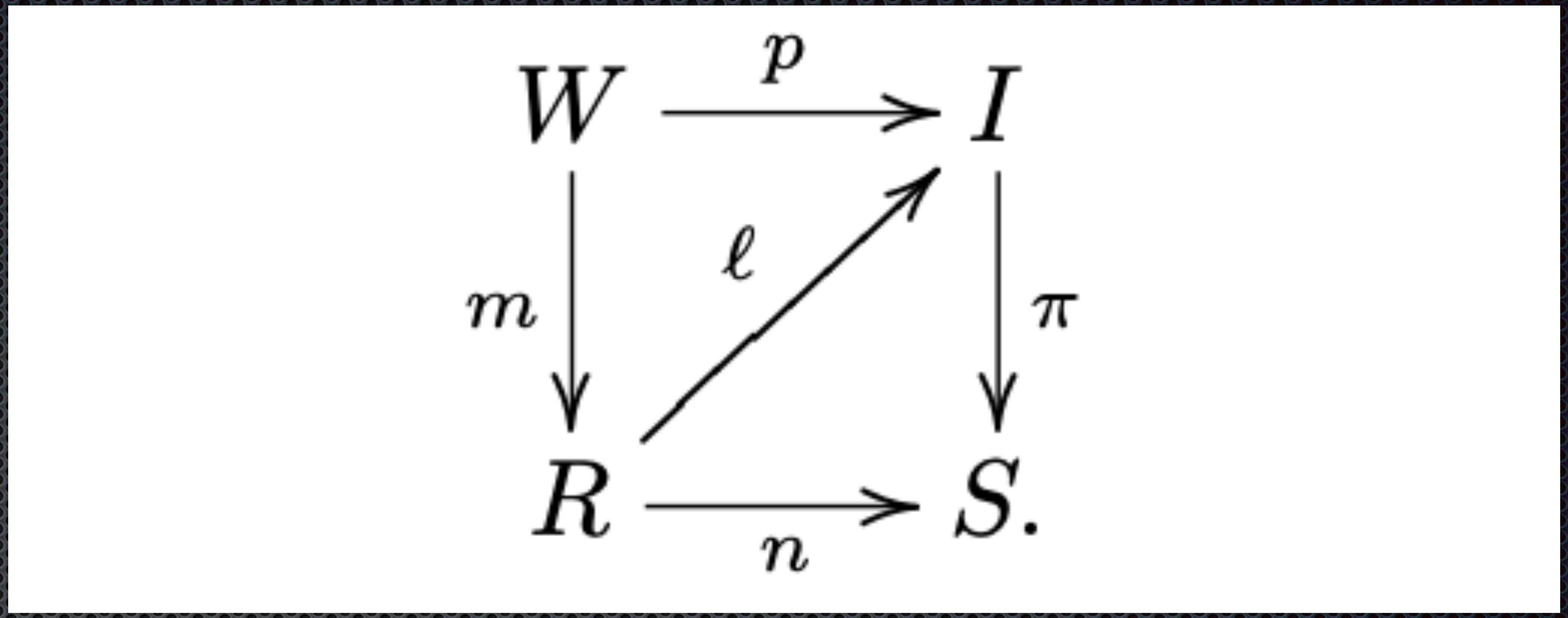


A database schema is a “small” category $\mathscr{C}$

Schemas are like graphs with constraints

A database instance is a functor $F : \mathscr{C} \to$ **Set**

SQL using lifting diagrams



The result of computing an answer using SQL can be viewed as solving a "lifting diagram"

Database instance: $\pi : I \to S$

Queries are functors: $m : W \to R$

Results are lifts: $l : R \to I$

Figure source: [Spivak, Database Queries and Constraints via Lifting Problems]

Adjoint Functors in Databases

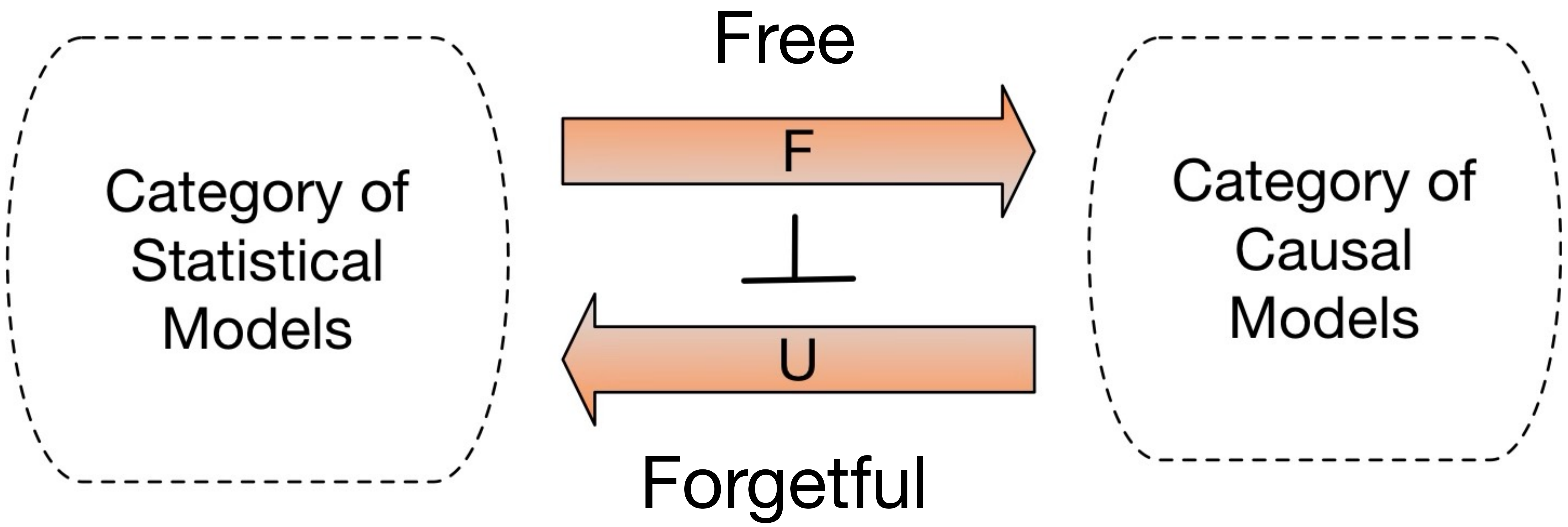
- Given two database schemas, S and T, we can define a functor F: S -> T
- Database migration functors:
  - Pullback: $\Delta_F : T$ **-Set** $\to S$ **-Set**
  - It maps an instance $\delta : T \to \mathbf{Set}$ to the instance $\delta \circ F : S \to \mathbf{Set}$
  - Left adjoint Σ_F: unions and quotients
  - Right adjoint Π_F: products and joins

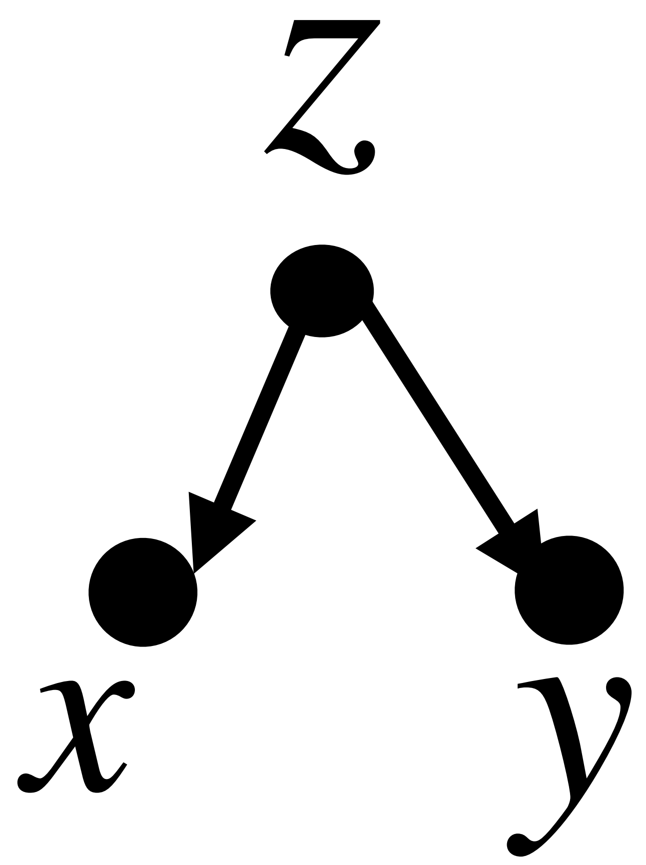
Adjoints in Causal Discovery

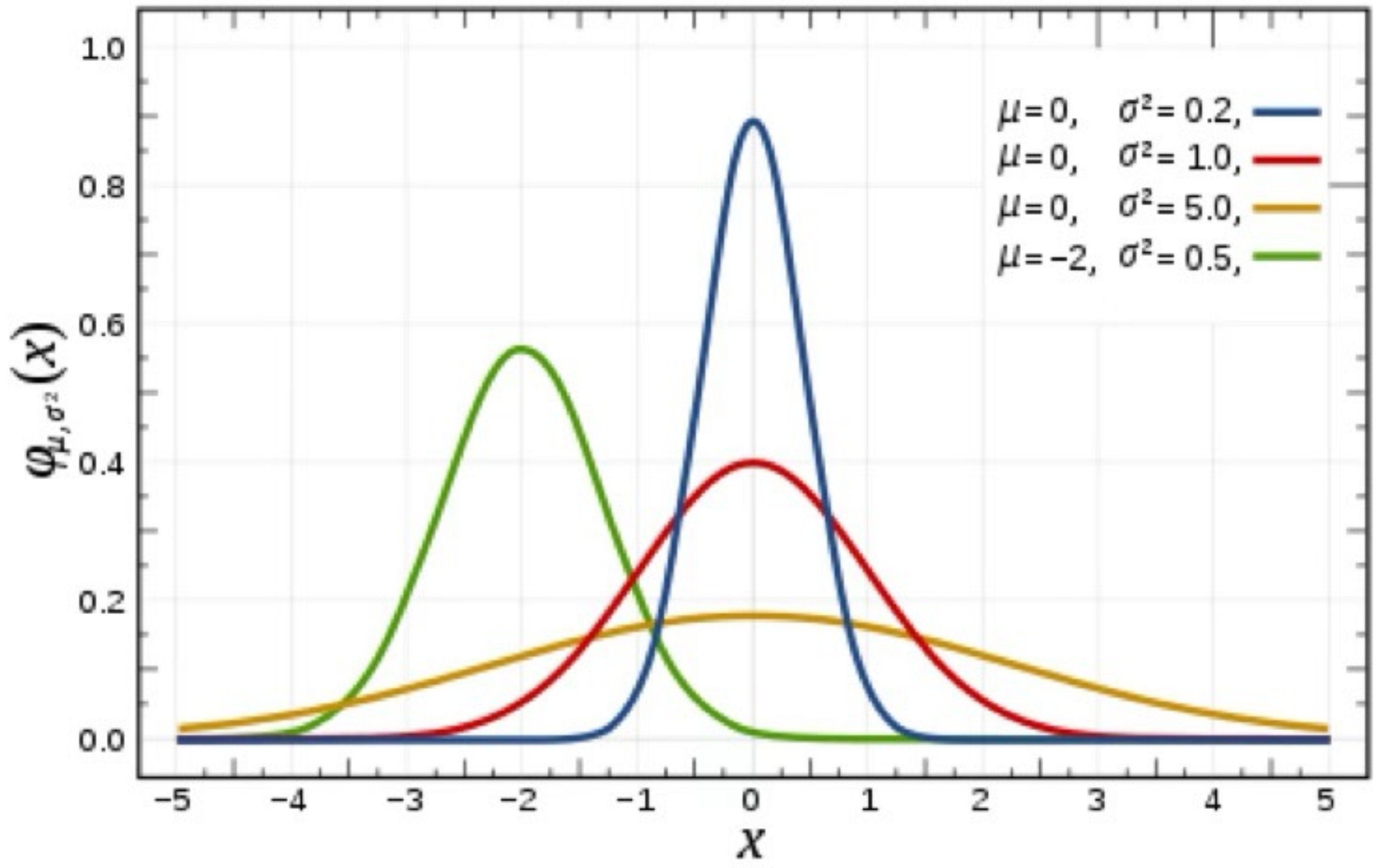
- Causal discovery is finding a directional relationship between variables
  - Does “drinking red wine” lower “blood pressure”?
  - Does “eating dark chocolate” increase “longevity”?
- Directionality is not intrinsic in statistical data processing
  - Correlations and Covariances are symmetric
  - Attention is symmetric

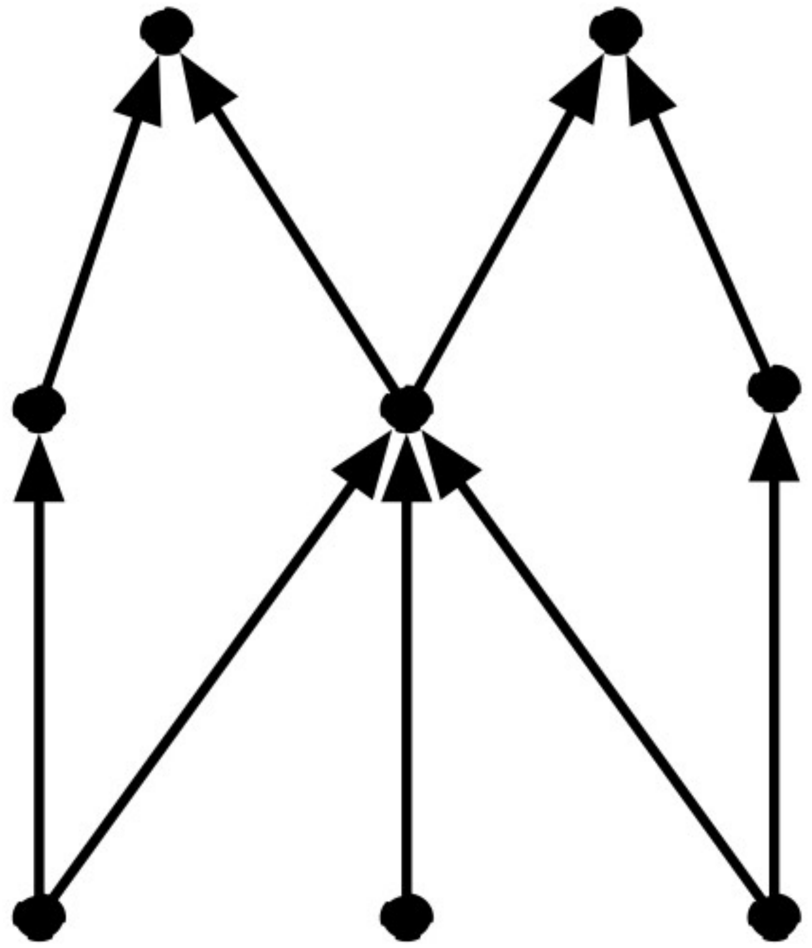
Adjoint Functors

$x \perp y \,|\, z$









DEMOCRITUS: Causality from Language

Category of language <-> Causal Category

[Mahadevan, Large Causal Models from Large Language Models, Arxiv 2025]

The Washington Post
Democracy Dies in Darkness

Science Space Animals Health Environment

When did humanity take its first step? Scientists say they now know.

A new analysis of fossils uncovered in Central Africa offers additional evidence that a human ancestor walked upright 7 million years ago.

January 2, 2026

4 min Summary 289 Make us preferred on Google

A Sahelanthropus tchadensis skull found in Chad. (Philippe Psaila/Science Source)

By Dino Grandoni

More than two decades ago, scientists digging in Central Africa unearthed the 7-million-year-old remains of what may be one of the earliest known human ancestors.

AI Overview

Summary is AI-generated, newsroom-reviewed.

A study published in Science Advances suggests Sahelanthropus tchadensis, a 7-million-year-old ancestor, walked upright, indicating early bipedalism in human evolution. The analysis of limb bones, particularly the femoral tubercle, supports this claim. However, the debate continues as some scientists argue the fossils are too damaged to confirm bipedalism. Further discoveries are needed to resolve the controversy.

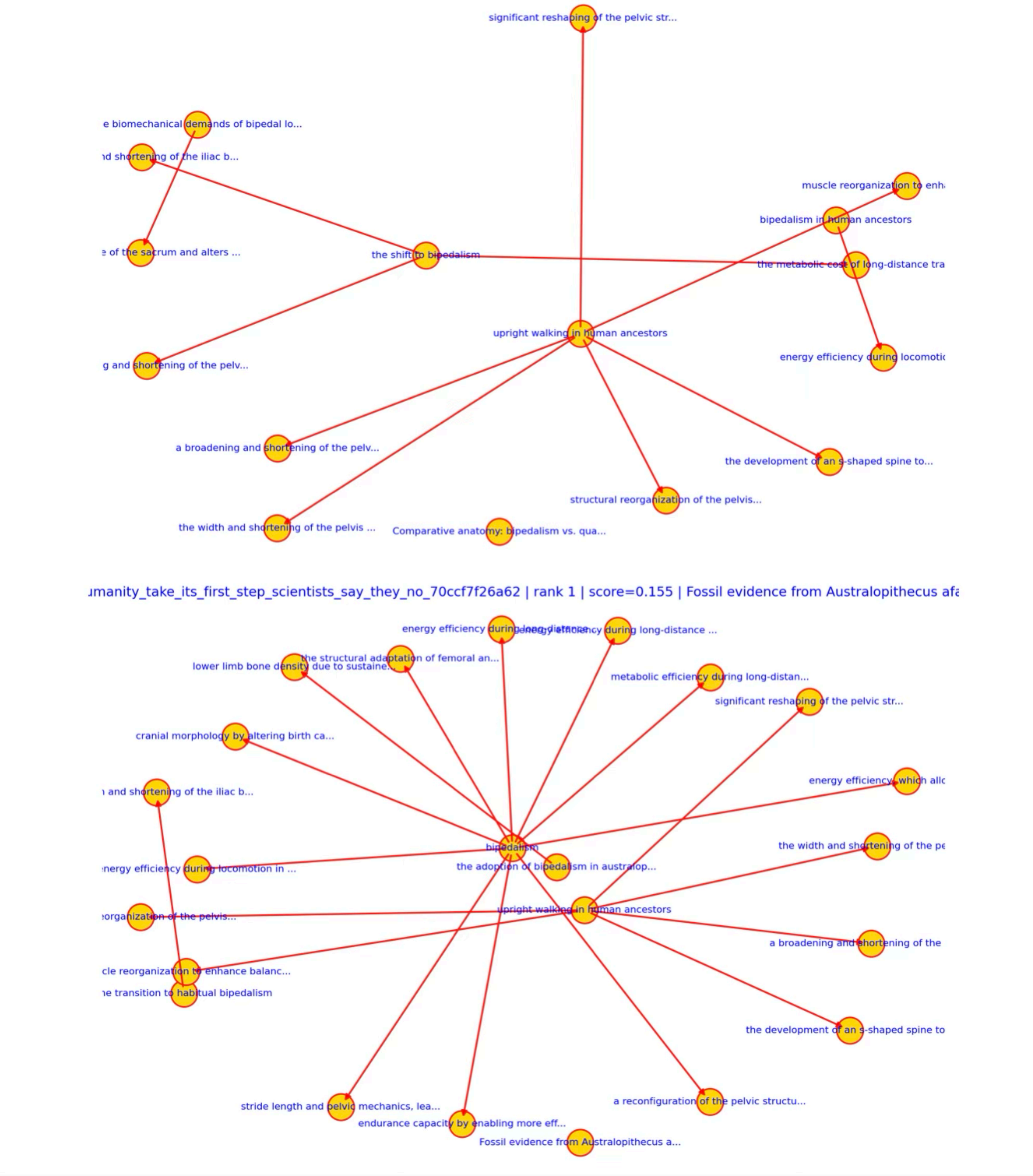
Read the full article for more on:

- The significance of the femoral tubercle in determining bipedalism.
- Why some scientists remain skeptical about the study's conclusions.
- Future plans for fossil hunting in Chad's Djurab Desert.

Did our AI help? Share your thoughts.

LLM summary

DEMOCRITUS



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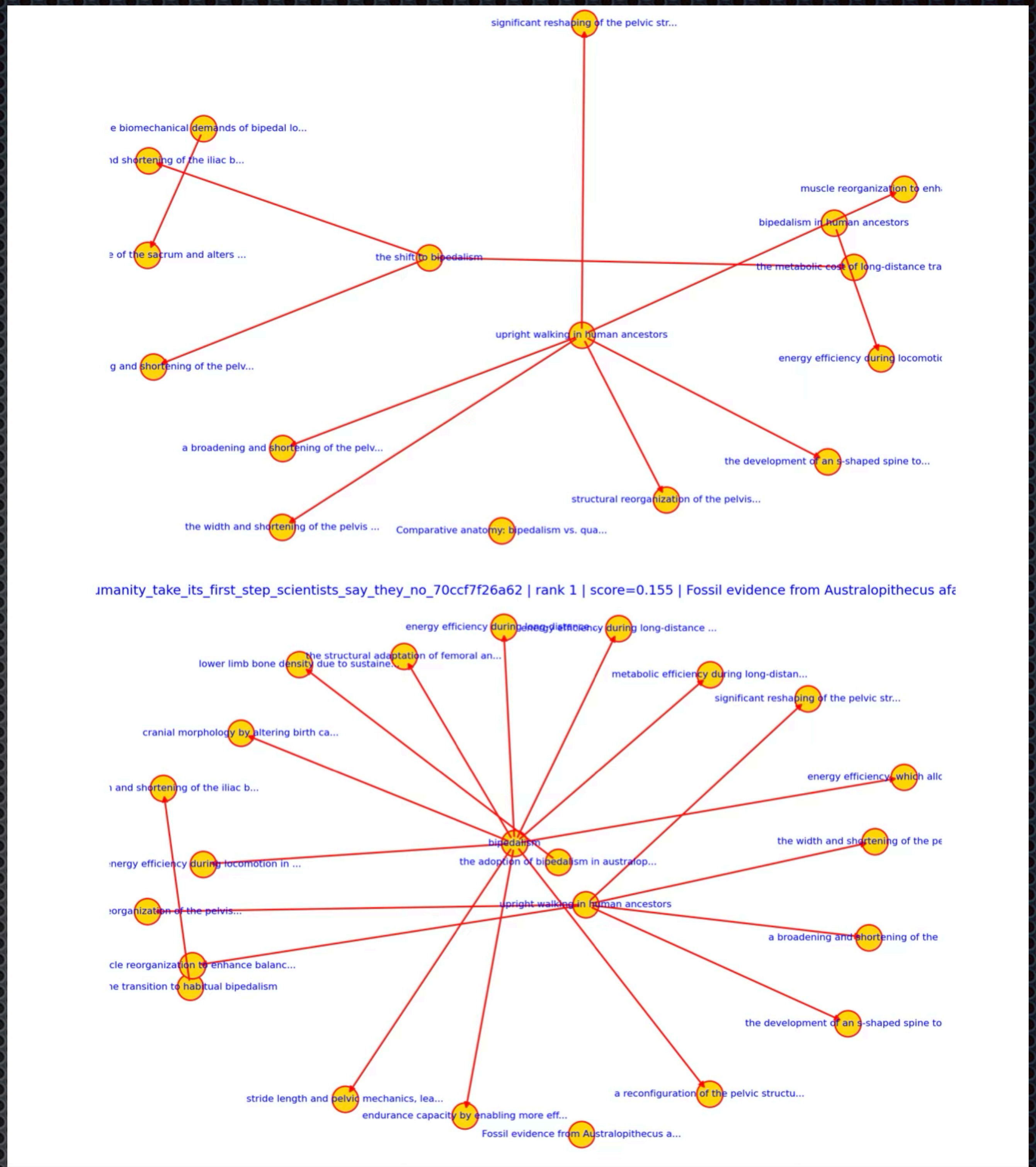


Democritus Atlas Summary (v0)

- Nodes: 501
- Edges (unique): 65
- Edge-support rows: 717
- SCC modules (size>1): 0

Top stable bonds (by support_docs, then score_sum)

rank	support_docs	support_lcms	score_sum	controversy	rel_type	src	dst
1	1	15	1.462	0.000	INFLUENCES	`bipedalism`	`metabolic efficiency during long-distance travel by optimizing stride mechanics and muscle utilization`
2	1	13	1.328	0.000	INCREASES	`bipedalism`	`energy efficiency during locomotion in early hominins by reducing the metabolic cost of walking over long distances`
3	1	13	1.264	0.000	INCREASES	`bipedalism`	`energy efficiency during long-distance locomotion by reducing the metabolic cost of walking compared to quadrupedal gaits`
4	1	13	1.256	0.000	INFLUENCES	`bipedalism`	`endurance capacity by enabling more effective heat dissipation and sustained pacing over extended distances`
5	1	12	1.209	0.000	INCREASES	`bipedalism`	`energy efficiency which allows for greater metabolic resources to be allocated to brain development`
6	1	11	1.201	0.000	INFLUENCES	`bipedalism`	`structural adaptation of femoral and tibial bones by altering stress distribution patterns over evolutionary time`
7	1	11	1.103	0.000	INFLUENCES	`bipedalism`	`stride length and pelvic mechanics leading to more sustained and efficient terrestrial movement`
8	1	6	0.464	0.000	INFLUENCES	`reduced forest cover`	`selection for upright walking by favoring energy-efficient movement over long distances`
9	1	4	0.403	0.000	INCREASES	`changes in environmental conditions that favored energy-efficient locomotion over long distances`	`likelihood of bipedalism in early hominins`
10	1	6	0.156	0.000	INFLUENCES	`abnormal femoral tubercle position`	`knee joint alignment during locomotion by altering the line of pull on the patellar tendon`
11	1	2	0.136	0.000	INFLUENCES	`fossil structure of ardipithecus`	`emergence of efficient terrestrial walking in early hominins by demonstrating adaptations in the pelvis and foot that support bipedal locomotion`
12	1	6	0.129	0.000	CAUSES	`abnormal femoral tubercle position`	`increased postoperative patellar instability after tibial tubercle osteotomy`
13	1	2	0.128	0.000	INCREASES	`muscle reorganization for balance and propulsion in bipedalism`	`efficiency of upright walking in human ancestors`
14	1	6	0.081	0.000	CAUSES	`larger brain size in primates`	`enhanced problem-solving abilities by enabling greater neural complexity and cognitive flexibility`
15	1	4	0.076	0.000	INCREASES	`lateral displacement of the femoral tubercle`	`patellar maltracking leading to altered patellofemoral alignment`

Conditional independence

- A fundamental tool in causal discovery is the use of conditional independence relationships
  - I(X, Z, Y): means that X is conditionally independent of Y given Z
- Axioms of conditional independence:
  - Symmetry: I(X, Z, Y) => I(Y, Z, X)
  - Decomposition: I(X, Z, Y + W) => I(X, Z, Y) and I(X, Z, W)
  - Weak union: I(X, Z, Y + W) => I(X, Z + W, Y)

Category of CI vs. Causal Models

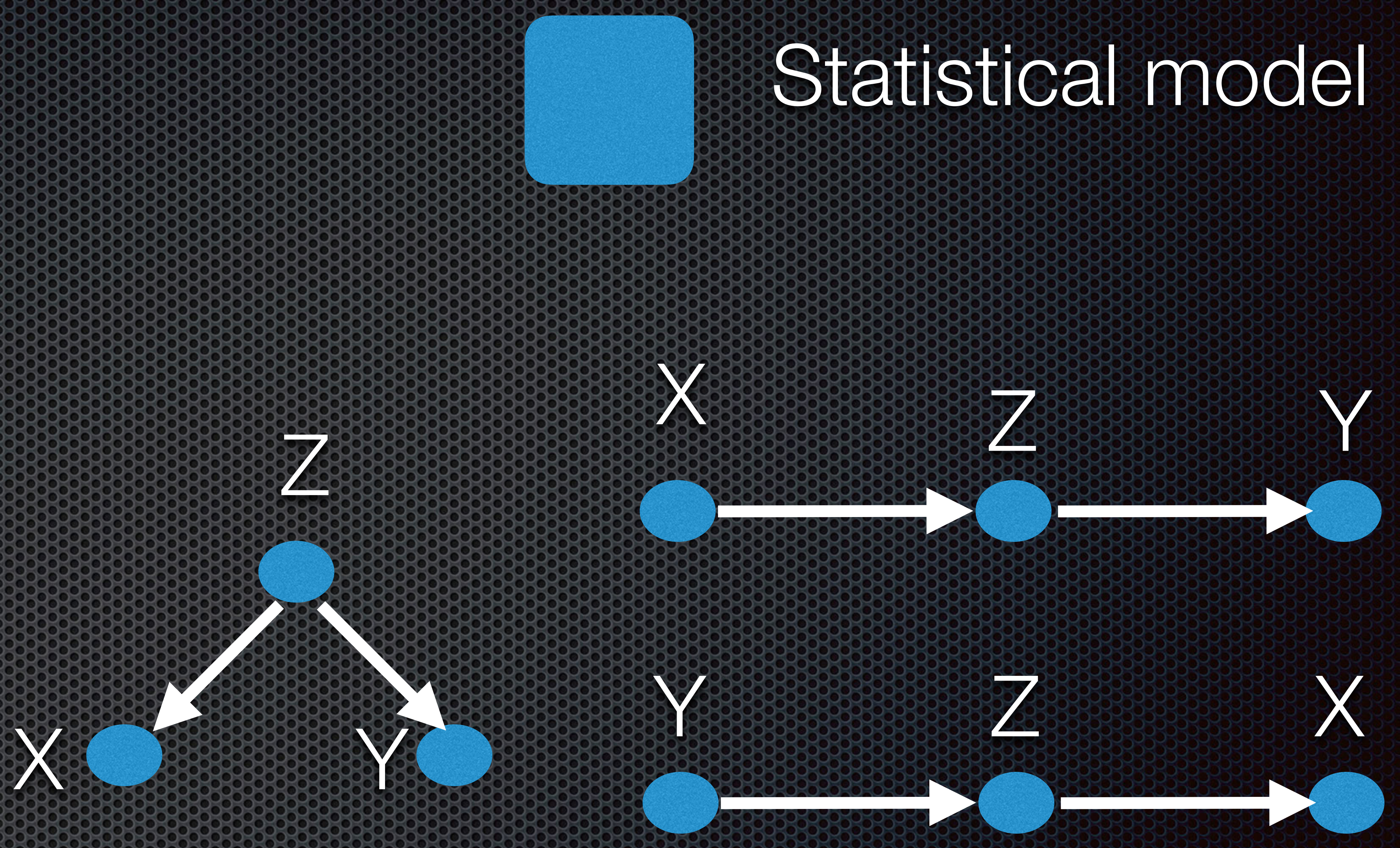
- We can define a category where each object is a set of conditional independence properties
  - These objects can be abstractly viewed as statistical models
- We can also define a category of causal models, where each object is a casual model
  - Each object can be a directed acyclic graph (DAG)

Causality as a “free” object

Given a CI object such as I(X,Z,Y)

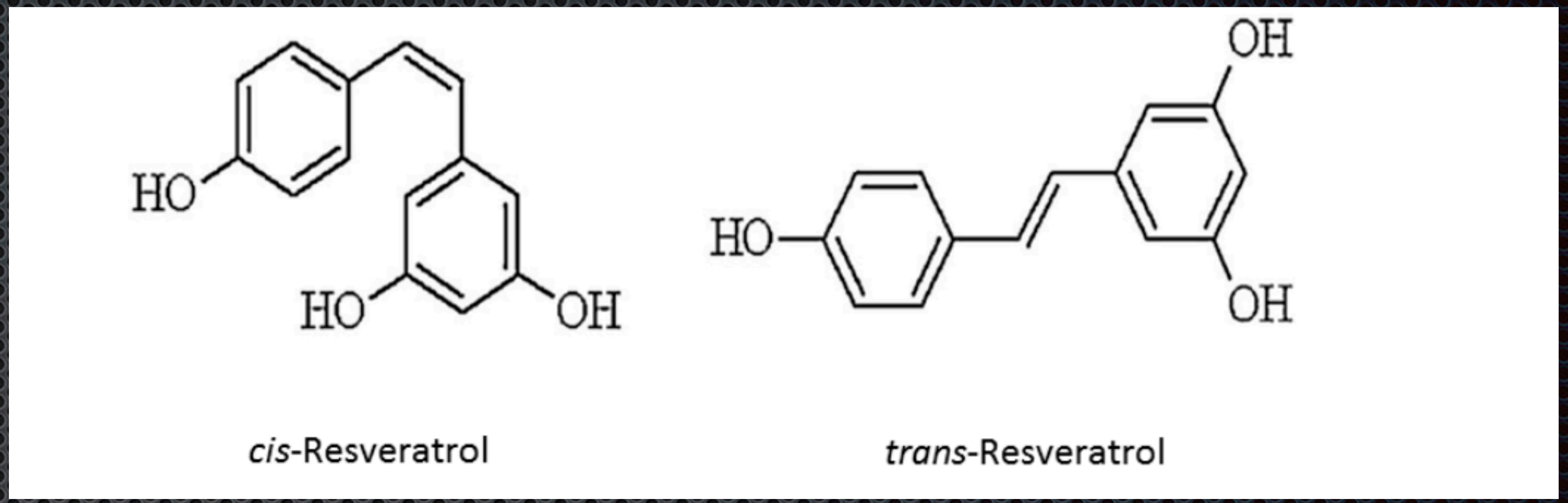
There can be multiple causal objects associated with it

I(X,Z,Y)



“Free” causal models

Does drinking red wine make you healthier?



Red wine contains reseveratol

It is an antioxidant

It has anti-tumor properties

molecules

MDPI

Review

Red Wine Consumption and Cardiovascular Health

Luigi Castaldo [1,2], Alfonso Narváez [1], Luana Izzo [1], Giulia Graziani [1], Anna Gaspari [1], Giovanni Di Minno [2] and Alberto Ritieni [1,*]

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Abstract: Wine is a popular alcoholic beverage that has been consumed for hundreds of years. Benefits from moderate alcohol consumption have been widely supported by the scientific literature and, in this line, red wine intake has been related to a lesser risk for coronary heart disease (CHD). Experimental studies and meta-analyses have mainly attributed this outcome to the presence in red wine of a great variety of polyphenolic compounds such as resveratrol, catechin, epicatechin, quercetin, and anthocyanin. Resveratrol is considered the most effective wine compound with respect to the prevention of CHD because of its antioxidant properties. The mechanisms responsible for its putative cardioprotective effects would include changes in lipid profiles, reduction of insulin resistance, and decrease in oxidative stress of low-density lipoprotein cholesterol (LDL-C). The aim of this review is to summarize the accumulated evidence correlating moderate red wine consumption with prevention of CHD by focusing on the different mechanisms underlying this relationship. Furthermore, the chemistry of wine as well as chemical factors that influence the composition of the bioactive components of red wine are also discussed.

Keywords: red wine; resveratrol; polyphenols; alcohol; cardioprotective; antioxidants

1. Introduction

Coronary heart disease (CHD) and stroke are the leading causes of mortality, disability

biomedicines

MDPI

Review

Resveratrol: A Double-Edged Sword in Health Benefits

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Abstract: Resveratrol (3,5,4′-trihydroxy-trans-stilbene) belongs to polyphenols' stilbenoids group, possessing two phenol rings linked to each other by an ethylene bridge. This natural polyphenol has been detected in more than 70 plant species, especially in grapes' skin and seeds, and was found in discrete amounts in red wines and various human foods. It is a phytoalexin that acts against pathogens, including bacteria and fungi. As a natural food ingredient, numerous studies have demonstrated that resveratrol possesses a very high antioxidant potential. Resveratrol also exhibit antitumor activity, and is considered a potential candidate for prevention and treatment of several types of cancer. Indeed, resveratrol anticancer properties have been confirmed by many in vitro and in vivo studies, which shows that resveratrol is able to inhibit all carcinogenesis stages (e.g., initiation, promotion and progression). Even more, other bioactive effects, namely as anti-inflammatory, anticarcinogenic, cardioprotective, vasorelaxant, phytoestrogenic and neuroprotective have also been reported. Nonetheless, resveratrol application is still being a major challenge for pharmaceutical industry, due to its poor solubility and bioavailability, as well as adverse effects. In this sense, this review summarized current data on resveratrol pharmacological effects.

Keywords: resveratrol; physiological effects; pharmacological activity; antioxidant;

Summary and Further Reading

- Chapter 4: Emily Riehl, Category Theory in Context
- Adjunctions chapter in Categories for AGI
- Suggested exercises
  - Construct examples of adjoint functors