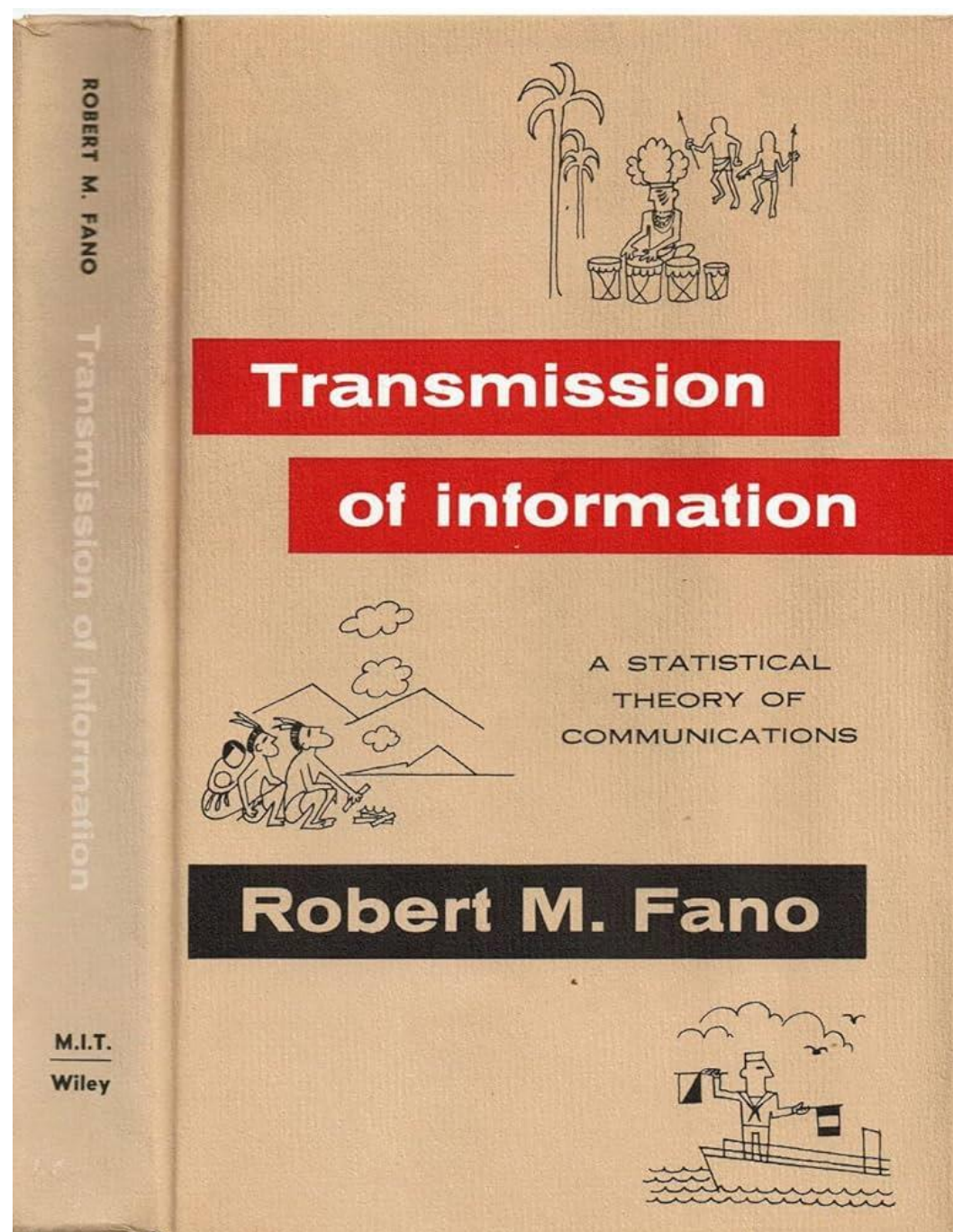


Representation of Information

ECE 598 LV – Lecture 1

Lav R. Varshney

16 January 2024



<https://archive.nytimes.com/opinionator.blogs.nytimes.com/2011/06/23/did-my-brother-invent-e-mail-with-tom-van-vleck-part-five/>



“Shannon himself told me that he believes the most promising new developments in information theory will come from work on very complex machines, especially from research into artificial intelligence.”

[J. Campbell, *Grammatical Man*, 1982]

[L. R. Varshney, “Mathematizing the World,” *Issues in Science and Technology*, vol. 35, no. 2, pp. 93–95, Winter 2019.]

INFORMATION

INTELLIGENCE



CNN

US

Crime + Justice

Energy + Environment

Extreme Weather

Space + Science

A woman bought a vintage dress at an antique store. It had a secret pocket with a mysterious note

By Faith Karimi, CNN

6 minute read · Updated 12:37 PM EST, Mon January 15, 2024



Courtesy Sara Rivers Cofield

The vintage dress is from the 1880s. But despite its age, its delicate embroidery, bronze silk and metallic buttons appeared intact.

Inside a secret pocket tucked under the bustle were two crumpled sheets of paper with seemingly random words and places:

Bismark, omit, leafage, buck, bank

Calgary, Cuba, unguard, confute, duck, Fagan

Notes on the margin of the papers appeared to depict time. A tag stitched into the dress had a handwritten name: Bennett

1130P Bismark mit leafage buck bank

Paul Parity loamy event false new
event

Helena Onus lofo us nail sack

Greenbay nobby piped

1124P Asser Onys league new for bad event

Anton Down

Harry noun Tental causal palm novel
event

Thimble Noun Tammy leafage bear dobbie
ice

Colgarry Cuba Vanguard compute duck fagan
Egypt

Whitby wrongful hugs duck fagan
each

Colgarry noun Signor loamy new ginned
event

Landing Noun Riggins Legacy darck baby
rice

Wayne Chan, who solves codes as a hobby, discovered the coded messages were in fact, a weather report. And they were not encrypted for secrecy but because the code allowed forecasters to shorten detailed weather reports into a few words.

In the era of the telegraph, such shorthand was cheaper than sending a big batch of words and temperature readings. Each word represented meteorological variables such as temperature, wind speed, and barometric pressure at a specific location and time of day.

The line “Bismark omit leafage buck bank” contains surprisingly specific details, from a 19th century telegraphic weather code used by the Army Signal Corps.

- “Bismark” meant it was recorded at Bismarck station in what is now North Dakota
- “omit” meant the air temperature was 56 degrees and the barometric pressure was 0.08 inches of mercury
- “leafage” meant a dew point of 32 degrees observed at 10 pm
- “buck” indicated no precipitation
- “bank” meant a wind velocity of 12 mph and a clear sunset

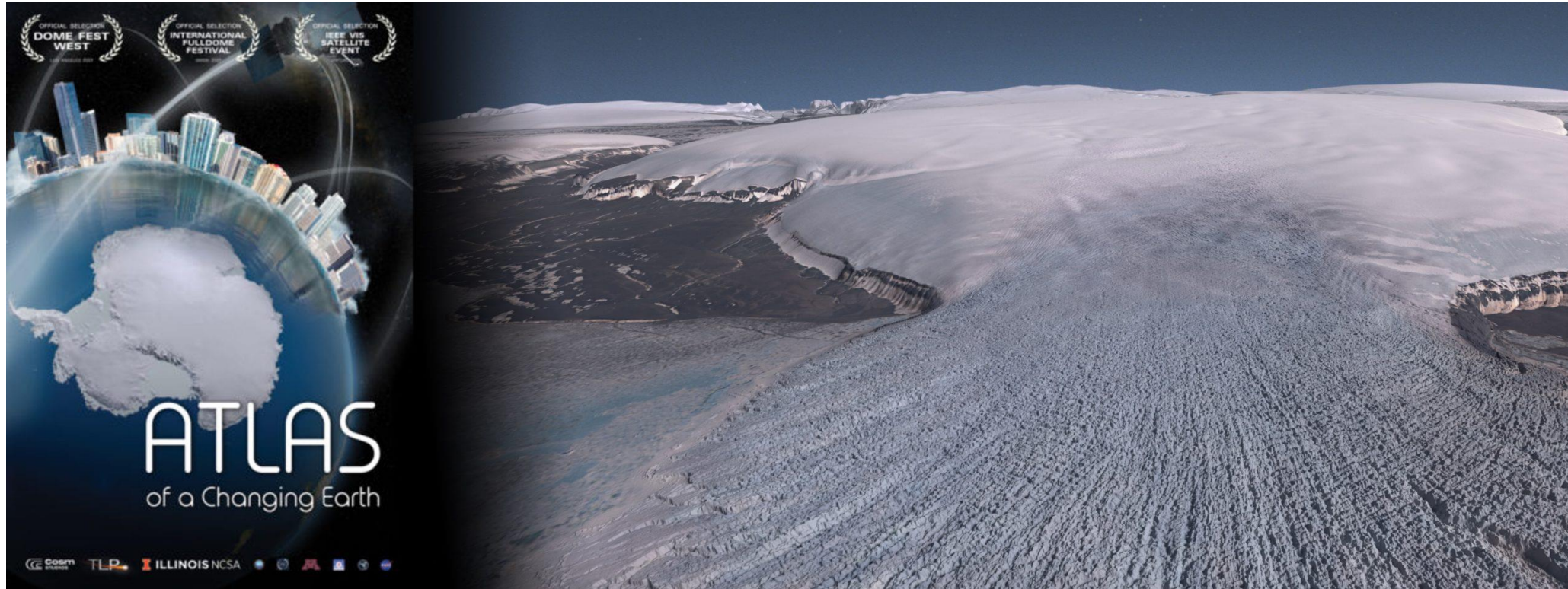
The words were arranged so particular consonant-vowel pairs represented specific numerical values

Previous example was the use of coded representation for the purpose of communicating meteorological data

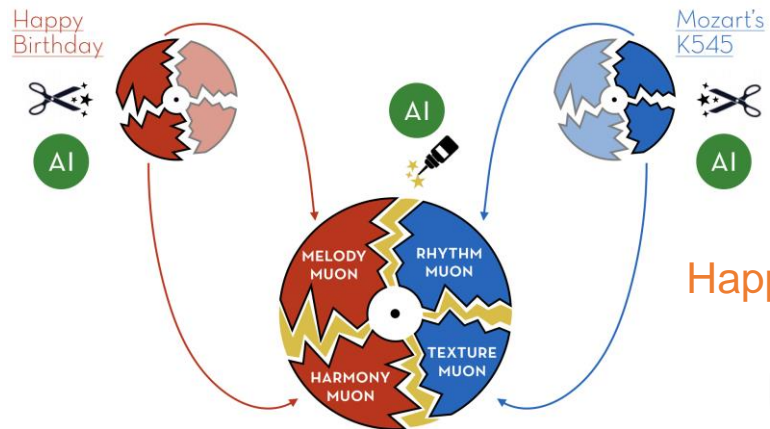
What other purposes can representations of information serve?

What are good (or optimal) representations for such purposes?

Artificial Weather Generators



[A. Jain, D. Oliveira, A. Sharma, L. R. Varshney, C. Watson, K. Weldemariam, D. Wuebbles, and B. Zadrozny, “Toward an AI-based Framework for Accelerated Discovery of Climate Impacts on Agriculture,” presented at *AAAI Fall Symposium on AI Meets Food Security: Intelligent Approaches for Climate-Aware Agriculture*, Nov. 2021.]



Happy Birthday:



I V⁴³ V⁶⁵ I I⁶ IV I⁶ V I

Mozart's K545:



Music Mosaic:



I V⁴³ V⁶⁵ I

I⁶ IV I⁶ V I

M

Tell me how ChatGPT works.



ChatGPT is a large language model that uses deep learning techniques to generate human-like text. It is based on the GPT (Generative Pre-trained Transformer) architecture, which uses a transformer neural network to process and generate text. The model is pre-trained on a massive dataset of text, such as books, articles, and websites, so it can understand the patterns and structure of natural language. When given a prompt or a starting point, the model uses this pre-trained knowledge to generate text that continues the given input in a coherent and natural way.



Links <https://www.cnn.com/2007/09/20/us-president-meets-british-pm>

LONDON, England (CNN) – U.S. President George W. Bush met with British Prime Minister Tony Blair on Monday to discuss the war in Iraq, according to a statement from Blair’s office. \n\nThe meeting was held at 10 Downing Street and lasted about an hour. \n\n”The two leaders discussed Iraq and other international issues of mutual concern,” said Blair. \n\nBush, who is scheduled to meet Wednesday with Russian President Vladimir Putin, will also visit Germany for talks later this week. \n\nIn his statement, Blair said, ”We agreed that we should continue our efforts together to bring peace and stability to Iraq. We both reaffirmed our commitment to working closely together, as well as to continuing to work constructively toward achieving lasting security and prosperity throughout the Middle East region.” \n\nBush’s trip comes after he visited Britain last week where he spoke out against terrorism while visiting Buckingham Palace. \n\nHe has been criticized by some lawmakers over what they say are insufficient military resources being devoted to fighting terrorism.

[N. S. Keskar, B. McCann, L. R. Varshney, C. Xiong, and R. Socher, “CTRL: A Conditional Transformer Language Model for Controllable Generation,” Sept. 2019.]



And Now, From I.B.M., Chef Watson



Robert Caplin for The New York Times

I.B.M. plans to serve a breakfast pastry devised by Watson and the chef James Briscione at its meeting on Thursday.

By STEVE LOHR

Published: February 27, 2013

I.B.M.'s Watson beat "Jeopardy" champions two years ago. But can it whip up something tasty in the kitchen?

More Tech Coverage

News from the technology industry, including start-ups, the Internet, enterprise and gadgets. On Twitter: @nytimesbits.



That is just one of the questions that I.B.M. is asking as it tries to expand its artificial intelligence technology and turn Watson into something that

actually makes commercial sense.

FACEBOOK

TWITTER

GOOGLE+

SAVE

E-MAIL

SHARE

PRINT

REPRINTS

SCIENCE | food | wired magazine

Share 486 Tweet 197 30 Share 35 Pin it

Digital Gastronomy

WHEN AN IBM ALGORITHM COOKS, THINGS GET COMPLICATED—AND TASTY.



Prop styling: Laurie Raab | Justin Fantl

IBM's AI-like computer systems aren't limited to Watson, the *Jeopardy*-winning supercomputer that schooled Ken Jennings on national television. In fact, IBM researchers foresee a not-so-distant future when algorithms will be a replacement for inefficient customer service models, a diagnostic tool for doctors, and believe it or not, chefs.

Researcher Lav Varshney has already built an algorithm that creates recipes from parameters like cuisine type, dietary restrictions, and course. The system determines optimal mixtures based on three things: tens of thousands of recipes taken from sources like the Institute of Culinary Education or the Internet, a database of hedonic psychophysics (what humans like to eat), and food chemistry. Right now, the result is like a pre-Julia Child cookbook, providing chefs, who already know cooking basics, with suggestions for billions of ingredient combinations but no instructions.

To test its skill, we pitted IBM's algorithm against go-to-recipe resource Epicurious (owned by WIRED's parent company, Condé Nast). We searched the site for a Caribbean plantain dessert and found a tasty concoction with rum and coconut sauce. With the same parameters, IBM's computer generated a list of about 50 ingredients, including orange, papaya, and cayenne pepper, from which IBM researcher and professional chef Florian Pinel developed a mind-blowing Caymanian parfait. While the IBM dessert tasted better, it was also insanely elaborate, so we'll call it a draw.

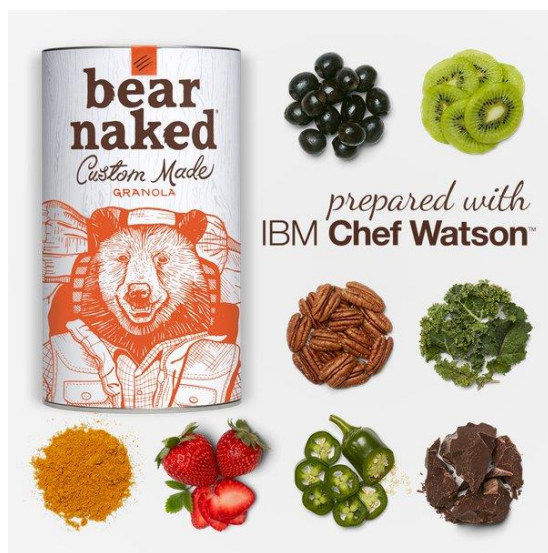
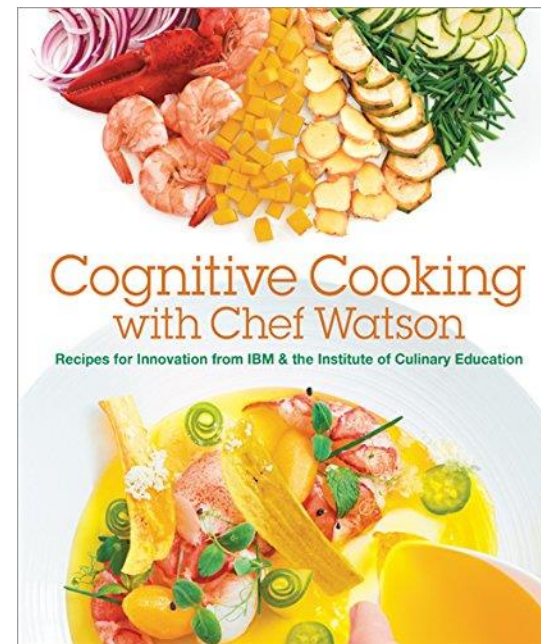
—Allison P. Davis



IBM'S TASTE MASTER

COGNITIVE COMPUTING TAKES ON A NEW FRONTIER: MEAL PLANNING
BY VALERIE ROSS

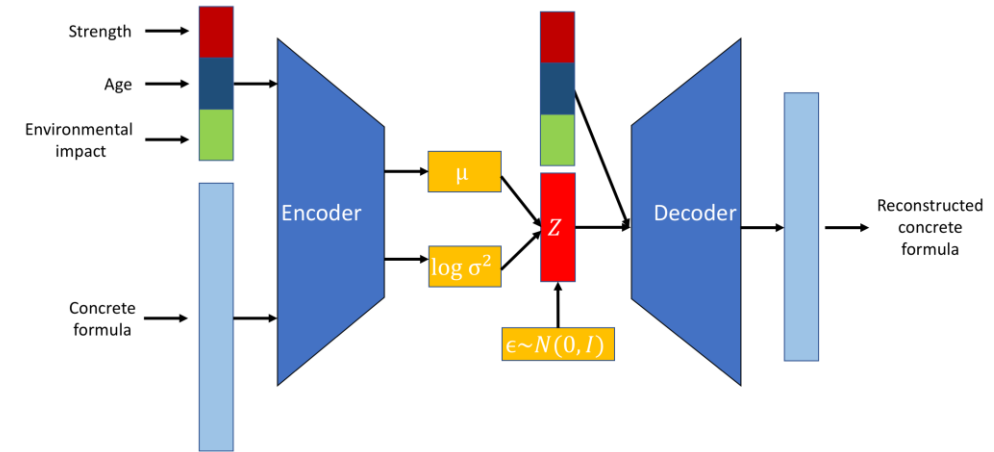
- [The New York Times, 27 Feb. 2013]
- [San Jose Mercury News, 28 Feb. 2013]
- [IEEE Spectrum, 31 May 2013]
- [Wired, 1 Oct. 2013]



Concrete that has half as much embodied carbon and is much stronger

- 8% of worldwide CO₂ emissions caused by cement production
- Reduce environmental impacts of construction materials while complying with product specifications
- UCI ML repository concrete strength dataset + environmental impact evaluated using the Cement Sustainability Initiative's Environmental Product Declaration tool:
 - 1030 instances
 - 8 input variables (composition)
 - 1 (compressive strength)
 - 12 (environmental impact) output variables
- Train a conditional generative neural network model to be able to create novel formulations of concrete

Conditional Variational Autoencoder (CVAE)



Strength	$[0,1]$
Age	$\{0,1\}^6$
Environmental Impact	$[0,1]^{12}$
Concrete formula	$[0,1]^7$

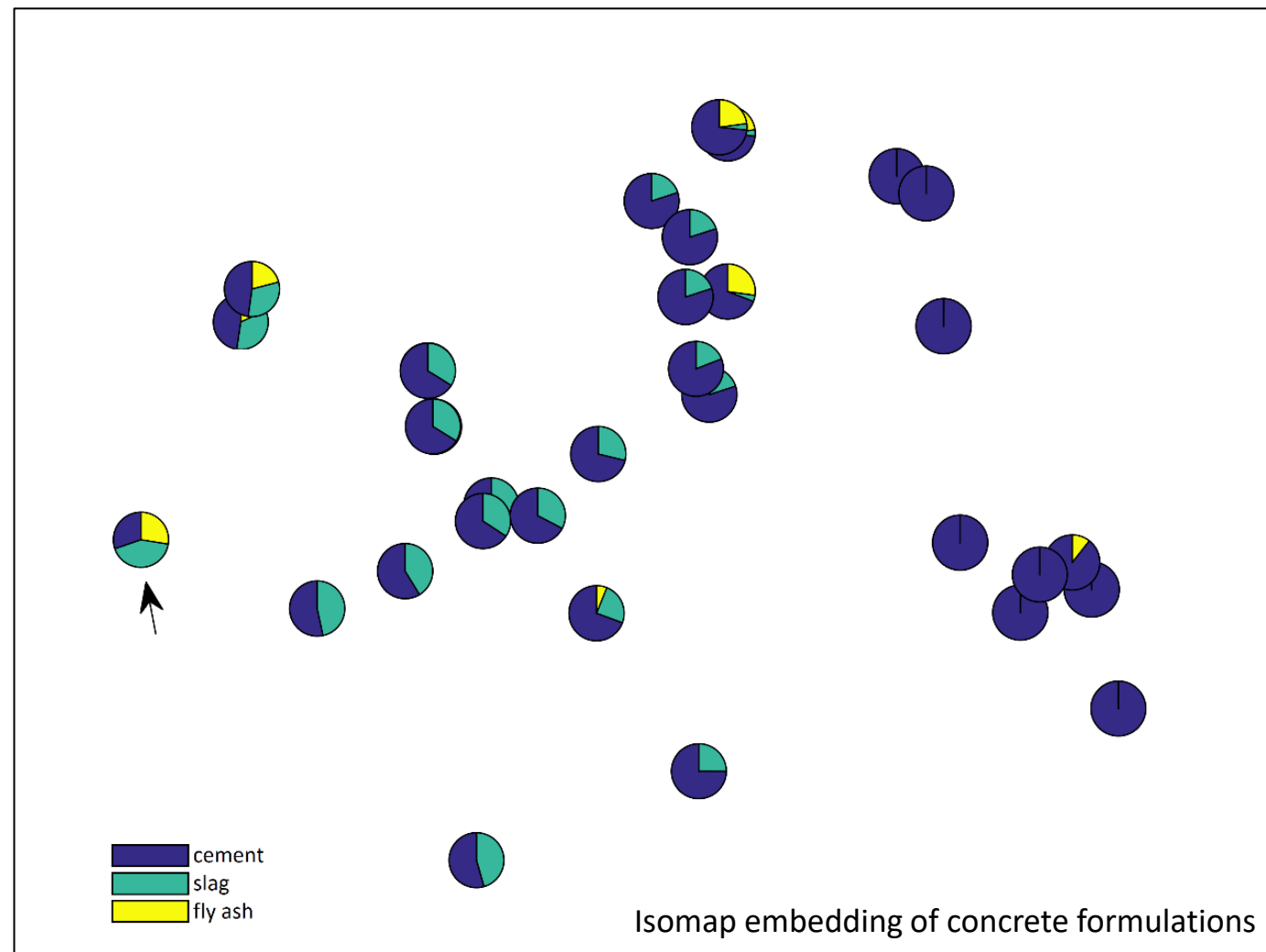
Concrete that has half as much embodied carbon and is much stronger



Stronger and more than 50% reduction in carbon emissions



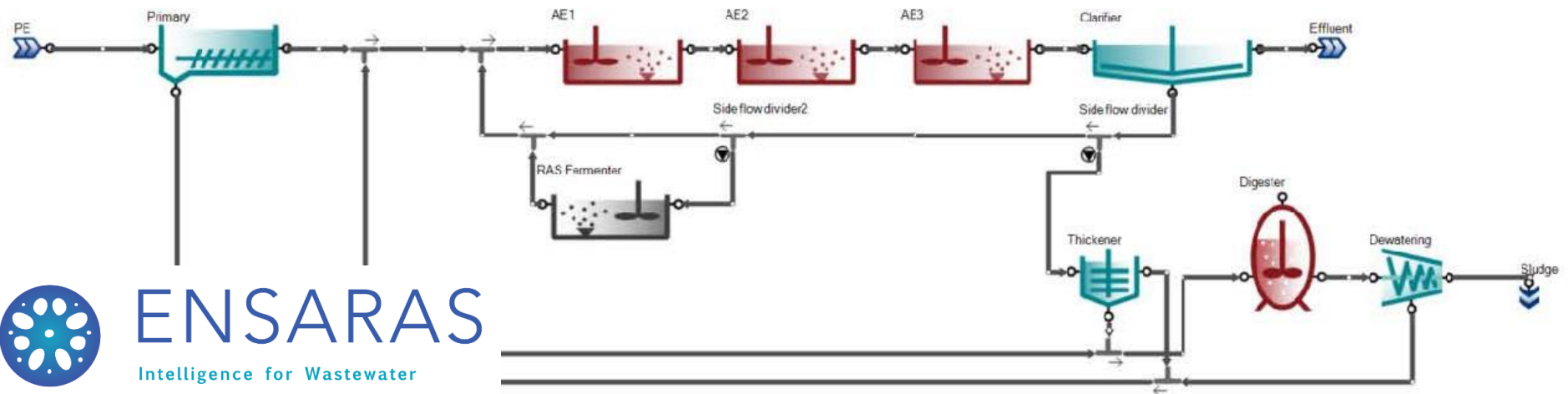
DeKalb data center that has been constructed



Isomap embedding of concrete formulations

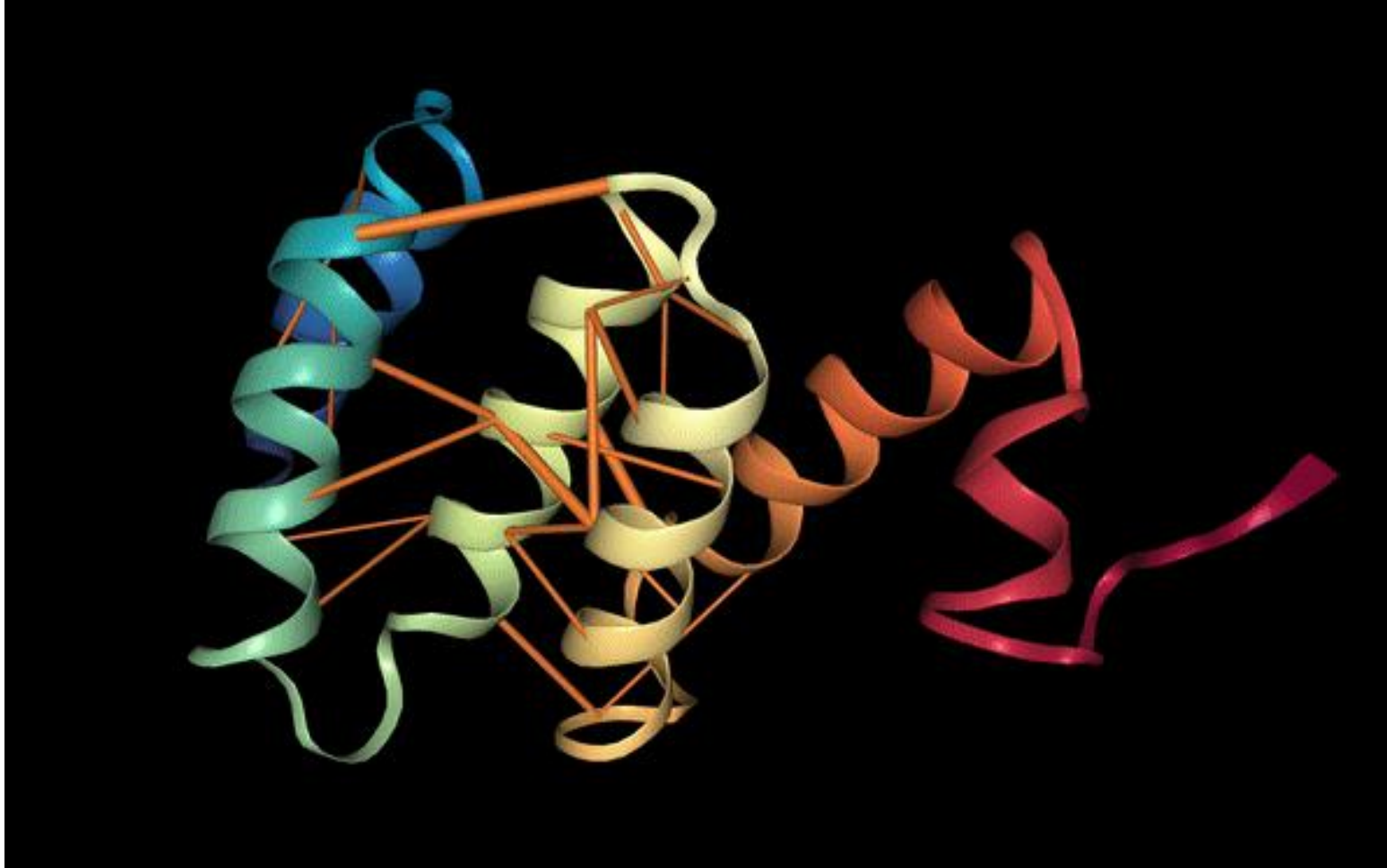


[X. Ge, R. T. Goodwin, H. Yu, P. Romero, O. Abdelrahman, A. Sudhalkar, J. Kusuma, R. Cialdella, N. Garg, and L. R. Varshney, "Accelerated Design and Deployment of Low-Carbon Concrete for Data Centers," in *Proc. 5th ACM SIGCAS Conf. Computing and Sustainable Societies (COMPASS '22)*, Seattle, July 2022.]



ENSARAS
Intelligence for Wastewater

Protein Language Models: Using AI to Generate Proteins

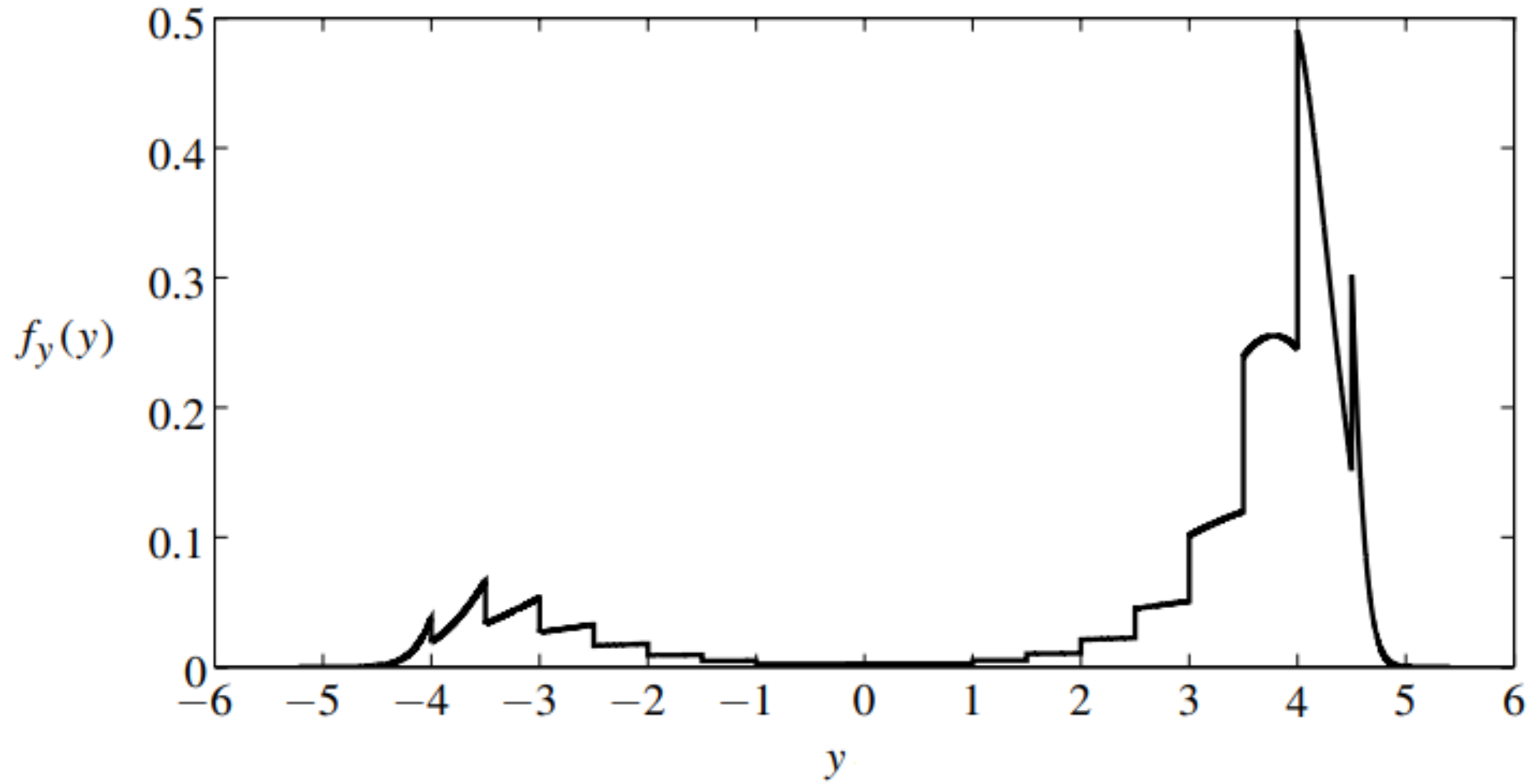


[J. Vig, A. Madani, L. R. Varshney, C. Xiong, R. Socher, and N. F. Rajani, "BERTology Meets Biology: Interpreting Attention in Protein Language Models," in *Proceedings of the 9th International Conference on Learning Representations (ICLR)*, May 2021.]





If I have a bunch of scalar-valued data that is thought to be independent and identically distributed from some source that I want to eventually generate synthetic samples from, what would be a good representation and how should I learn that representation?



Bernard Widrow and István Kollár, *Quantization Noise: Roundoff Error in Digital Computation, Signal Processing, Control, and Communications*, Cambridge University Press, 2008.

Simulation

- A lot of computing software allows you to produce random (or at least pseudorandom) samples according to a uniform $[0,1]$ random variable.
- What if we want to generate random samples from some other random variable?
- Probability integral transformation
 - Applying F^{-1} to a uniform random variable should produce a random variable with cdf F

Simulation

- Let F be a function satisfying the three properties required of a cdf, and let U be uniformly distributed over the interval $[0,1]$
- The problem is to find a function g so that F is the cdf of $g(U)$
- An appropriate function g is given by the inverse function of F ,
$$F^{-1}(u) = \min\{c: F(c) \geq u\}$$

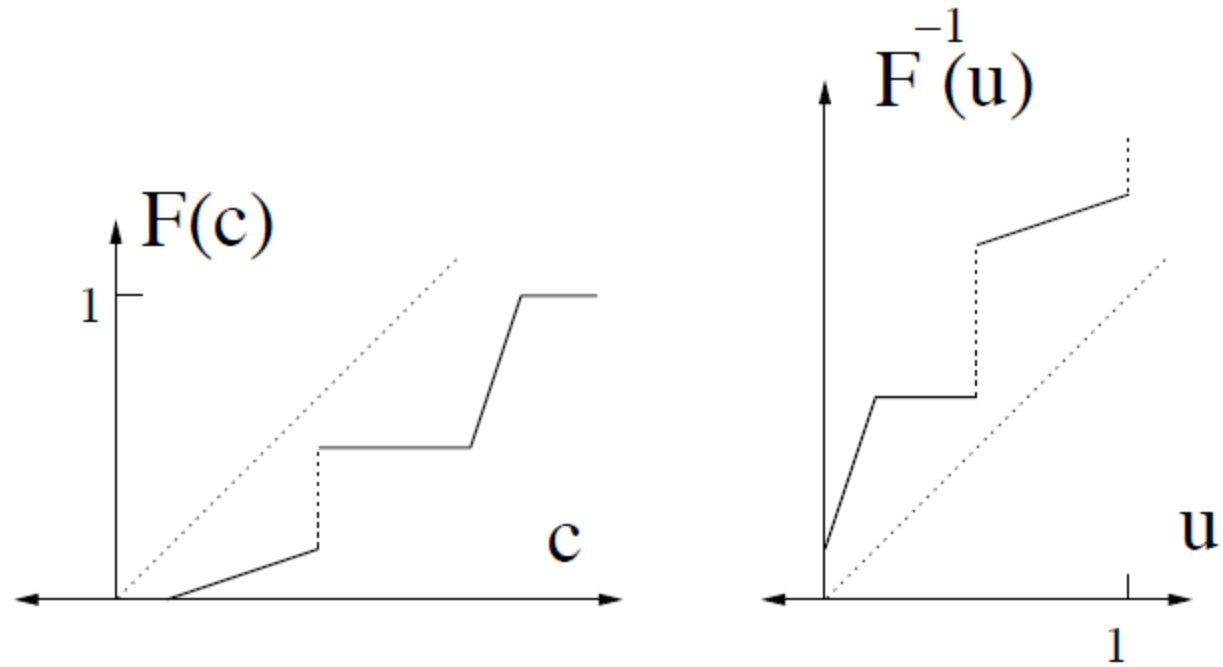
Given any random continuous variable X , define $Y = F_X(X)$.

Then:

$$\begin{aligned} F_Y(y) &= P(Y \leq y) \\ &= P(F_X(X) \leq y) \\ &= P(X \leq F_X^{-1}(y)) \\ &= F_X(F_X^{-1}(y)) \\ &= y \end{aligned}$$

F_Y is just the CDF of a Uniform(0,1) random variable. Thus, Y has a uniform distribution on the interval $[0,1]$.

Simulation



Simulation: Example

- Simulate exponentially distributed random variable with parameter $\lambda = 1$
- $F_X(u) = 1 - e^{-u}$ for $u \geq 0$
- $F_X^{-1}(c) = -\ln(1 - c)$

```
x = rand(1,1000);
```

```
y = -log(1-x);
```

```
hist(y,100);
```

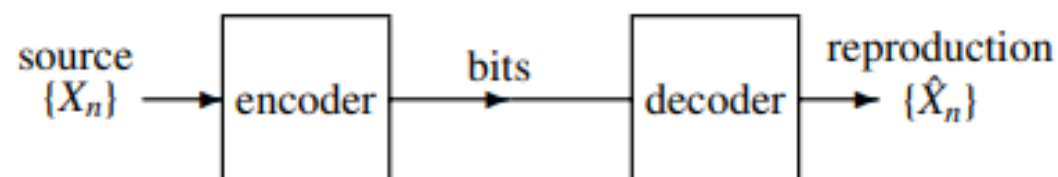
Source Coding and Simulation

XXIX Shannon Lecture, presented at the 2008 IEEE International Symposium on Information Theory, Toronto Canada

Robert M. Gray



Source coding/compression/quantization



Simulation/synthesis/fake process

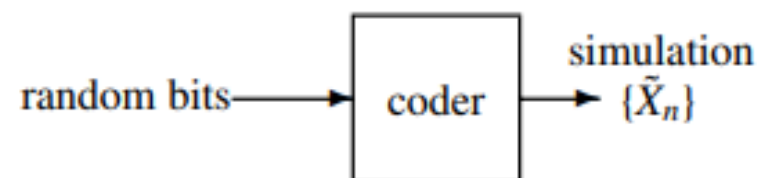
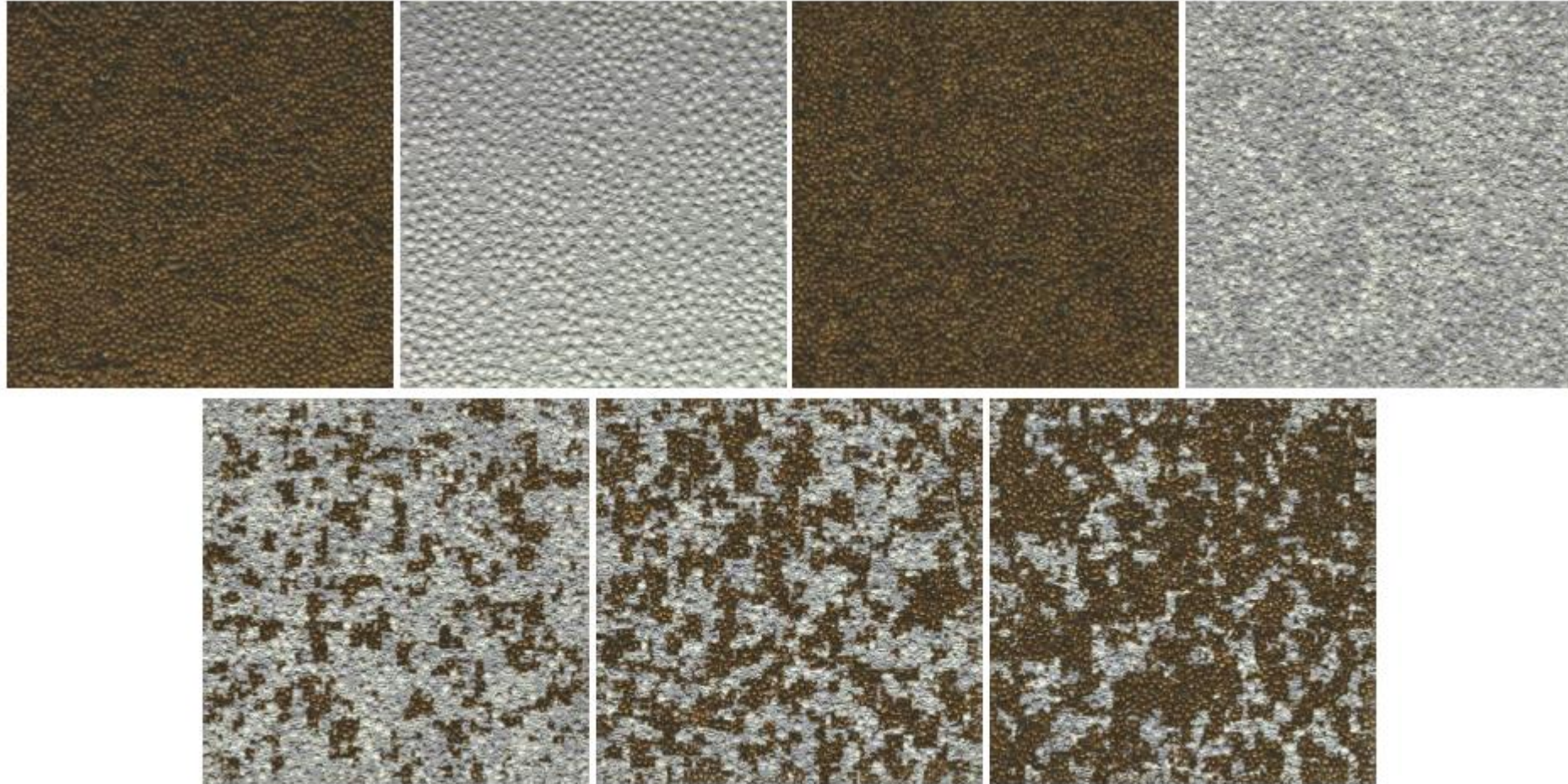


Figure 1: Source coding and simulation.

Learning from samples: Lempel-Ziv



Learning from samples: Lempel-Ziv



High Dimensions

lav varshney - Google Search

https://www.google.com/search?q=lav+varshney&rlz=1C1GCEA_enUS801US824&source=lnms&tbm=isch&sa=X&ved=2ahUKewjWiduyq7v1AhXVHzQIHc46AFAQ...

Google

lav varshney

All News Videos Images Maps More Tools

twitter bio artificial intelligence science festival kush varshney ibm neural computing uiuc urbana champaign illinois coordinated science illinc

The search results are organized into a grid. The first row contains eight image results, each with a small thumbnail and a caption. The second row contains eight video results, each with a video player thumbnail and a caption. The third row contains four larger image results, each with a caption. The results include professional headshots, social media profiles, academic affiliations, and media appearances.

Lav R Varshney | Electrical & Computer ...
ece.illinois.edu

Lav Varshney (@lrvvarshney) / Twitter
mobile.twitter.com

Lav Varshney, PhD, Univer...
midas.umich.edu

Lav Varshney - Center for Health...
chi.healtheng.illinois.edu

Lav Varshney - IMDb
imdb.com

Can AI help fix the food system? - T...
gfi.org

STIR Member :: Lav Varshney
rle.mit.edu

Lav Varshney (@varshney_Jav) / Tw...
twitter.com

First Nerve: Twin Paradox: The Olfacto ...
firstnerve.com

Can AI help fix the food system? - The ...
gfi.org

Illinois ECE Professor Lav Varshney ...
youtube.com

Lav Varshney (@lrvvarsh...
mobile.twitter.com

IBM 5 in 5 2012: Taste | IBM Rese...
ibm.com

Lav Varshney (lvarsh) - ...
pinterest.com

LIDS/ALL 2013
lidsmag.lids.mit.edu

ICLR
BERTology Meets Biology: Interpreting Attention
in Pretrained Language Models
Jesse Vig, Ali Madani, Lav R. Varshney, Gehring Xiong,
Richard Socher, Harrison Edwards

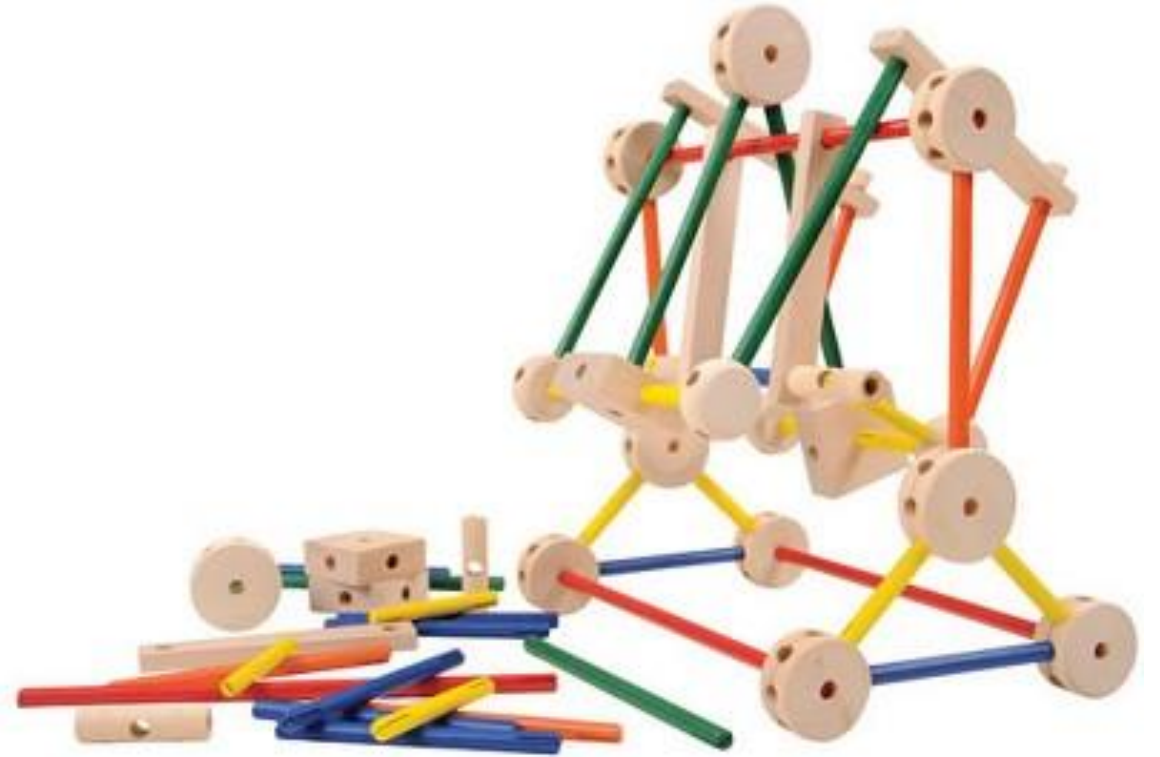
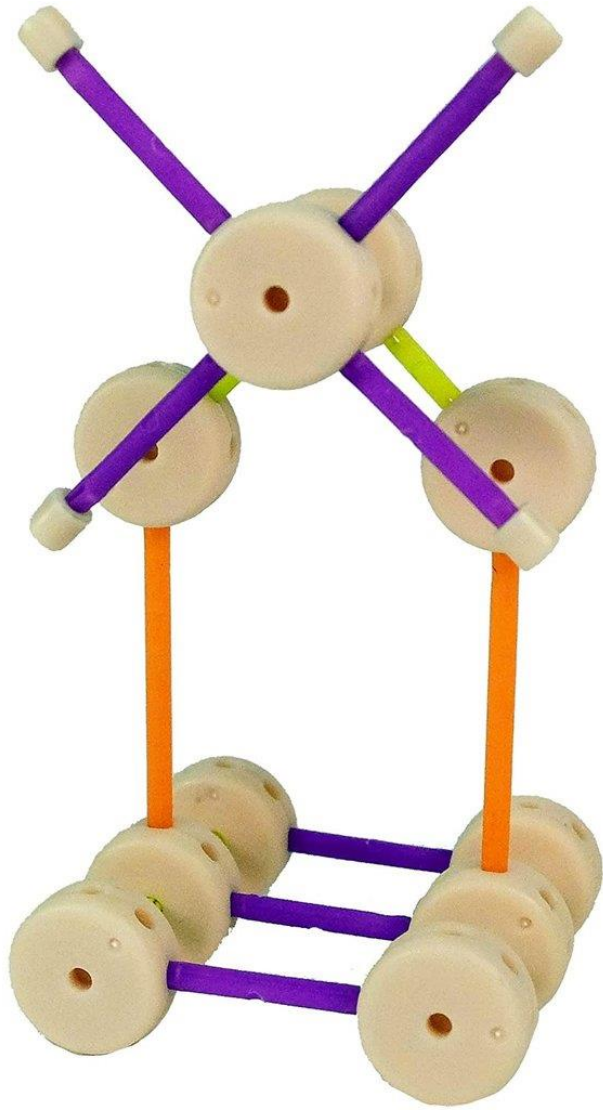
LAV VARSHNEY

ILLINOIS INNOVATORS PODCAST
WITH MIKE KOON

The Idea to Value Podcast
Host: Nick Sallicrú
Guest: Lav Varshney
#024 Prof Lav Varshney - How computers are becoming creative

AI for Good
October 18, 2018

Structured (combinatorial) conceptual spaces



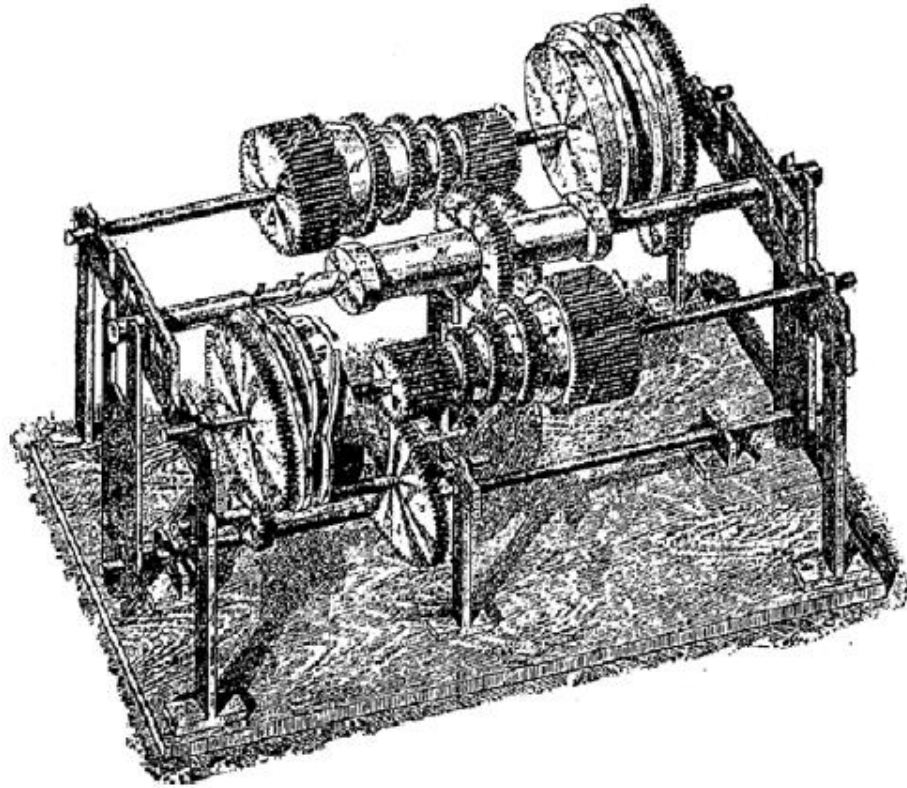
Extrapolation rather than interpolation



Figure 1: Attribute-enhanced generation. The goal of extrapolation (left) is to generate samples whose attribute values exceed that of all training samples, y_τ . We explore target attribute extrapolation for protein sequences (center) and movie reviews (right), where more stable protein sequences and more positives text reviews are generated.

What if I want to represent numbers in such a way that it is easy for computers to perform multiplication operations? What might be a good representation? What about other arithmetic operations?

What if I want to represent numbers in such a way that it is easy for computers to perform multiplication operations? What might be a good representation? What about other arithmetic operations?



Leonardo Torres' endless spindle

Natural Compression for Distributed Deep Learning

Samuel Horváth

SAMUEL.HORVATH@MBZUAI.AC.AE

Mohamed bin Zayed University of Artificial Intelligence (MBZUAI), Abu Dhabi, UAE*

Chen-Yu Ho

CHENYU.HO@KAUST.EDU.SA

King Abdullah University of Science and Technology (KAUST), Thuwal, KSA

L'udovít Horváth

LUDOVIT.HORVATH.94@GMAIL.COM

Dell Technologies[†], Bratislava, Slovakia

Atal Narayan Sahu

ATAL.SAHU@KAUST.EDU.SA

King Abdullah University of Science and Technology (KAUST), Thuwal, KSA

Marco Canini

MARCO@KAUST.EDU.SA

King Abdullah University of Science and Technology (KAUST), Thuwal, KSA

Peter Richtárik

PETER.RICHTARIK@KAUST.EDU.SA



King Abdullah University of Science and Technology (KAUST), Thuwal, KSA

Journal of Mathematical Psychology

Volume 56, Issue 6, December 2012, Pages 495-501



A framework for Bayesian optimality of psychophysical laws

John Z. Sun^a, Grace I. Wang^{a b}, Vivek K Goyal^a, Lav R. Varshney^{a c}  

SYLLABUS



Former IBM Research scientist Lav Varshney presents a demo of an early version of the cognitive cooking technology at IBM Research.

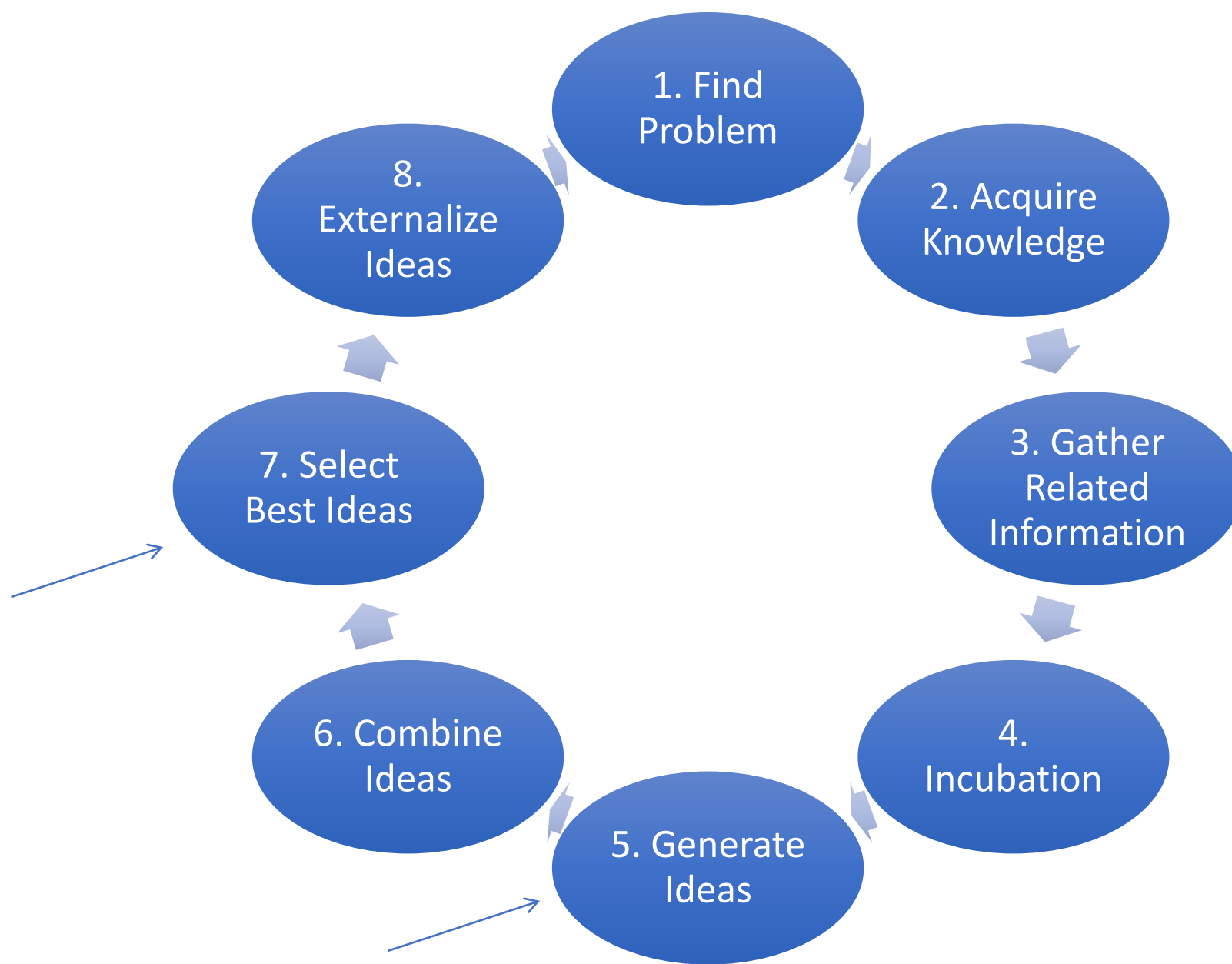
CREDIT: COURTESY IBM

How IBM's Chef Watson Actually Works

[f](#) [t](#) [p](#) [g+](#) [✉](#) [+](#) 47 [Comment](#)

WRITTEN BY ROCHELLE BILOW

[PRINT](#) [RSS](#)



[Sawyer, 2012]



Former IBM Research scientist Lav Varshney presents a demo of an early version of the cognitive cooking technology at IBM Research. CREDIT: COURTESY IBM

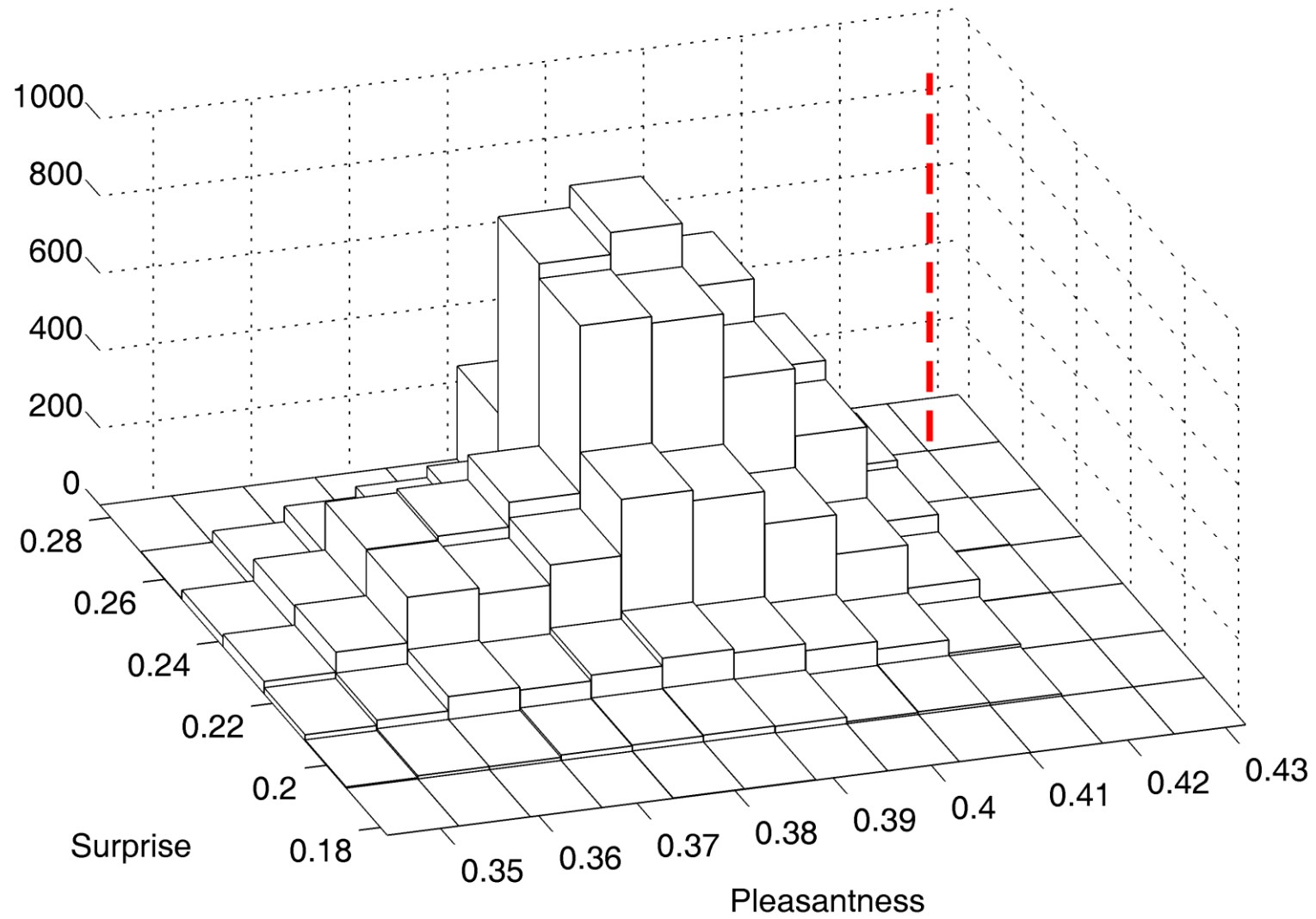
How IBM's Chef Watson Actually Works

 47  Comment

WRITTEN BY ROCHELLE BILOW

 PRINT  RSS

1. Sample from state space, using culturally well-chosen sampling distribution
2. Rank according to psychophysical predictors of novelty and flavor
3. Select either automatically or semi-automatically depending on human-computer interaction model



Joint histogram of surprise and pleasantness for 10000 generated Caymanian Plantain Dessert recipes. Values for the selected/tested recipe indicated with red dashed line.

Data Engineering and Natural Language Processing to Understand the Domain

Chocolate Chip Cookies Edit

Yields: 12-14 servings


Description Edit

Ingredients Edit

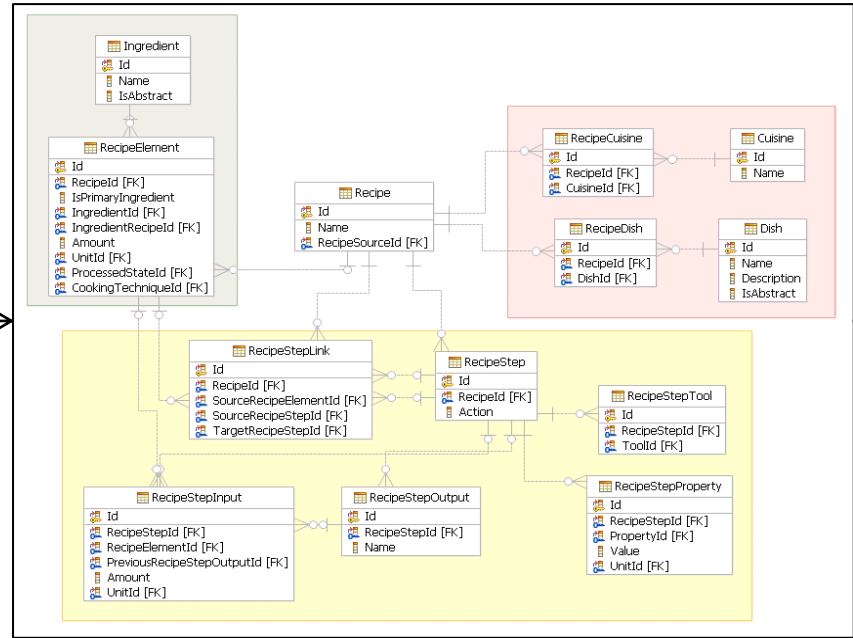
- 1 cup shortening
- 1 cup brown sugar
- 2 tsp vanilla
- 2 cup white flour
- ½ tsp baking powder
- ¼ tsp salt
- ¼ cup water
- 1½ cup chocolate chips

Directions Edit

1. Beat shortening for 30 seconds.
2. Add brown sugar and continue to beat until ingredients are well blended.
3. Add vanilla and mix well.
4. Mix in the baking powder, salt and the flour; beat thoroughly.
5. Add the water, followed by the chocolate chips.
6. Using a teaspoon, mould a teaspoonful of dough and place carefully on a cookie sheet.
7. Bake at 350°F for 10 minutes.
8. Allow cookies to cool on a wire rack.



PARSER



Generative, Selective, and Planning Algorithms to Create the Best New Ideas

NOVEL RECIPE

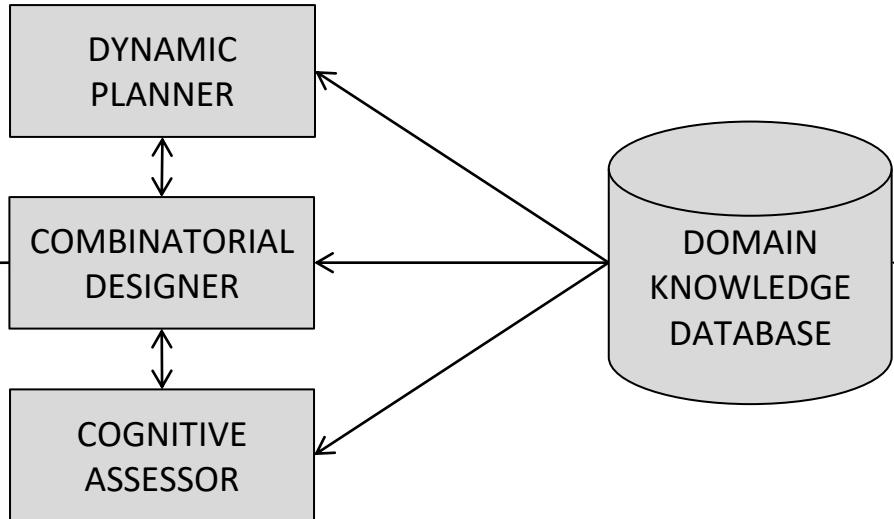
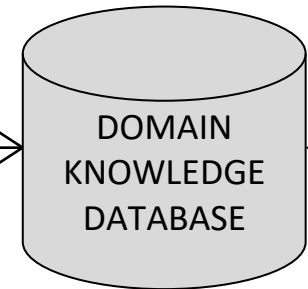


- PLANTAIN CHIPS
- PPRYA AND ORANGE SALAD
- COCONUT MILK AND PASTRY CREAM
- CARAMELIZED BANANAS

DYNAMIC PLANNER

COMBINATORIAL DESIGNER

COGNITIVE ASSESSOR



KEY INGREDIENT: ROOT VEGETABLES

FRIED LOTUS ROOT CHIPS

Yield: Makes a lot

2 lotus roots, peeled

Vegetable oil to fry

Kosher salt to taste

Pinch of cayenne pepper, optional

Thinly slice the lotus root using a mandolin. (If not frying right away, hold the lotus root in water with some vinegar or lemon juice to prevent oxidation.) Heat 2 inches of oil in a heavy pot to 360° F. Pat the sliced lotus root dry with paper towel, and fry in batches until golden brown (they will continue to brown once removed, so cook just to golden). Transfer to a rack over a rimmed sheet pan, and sprinkle with salt (mix in a bit of cayenne pepper to the salt, if a spicier chip is desired).

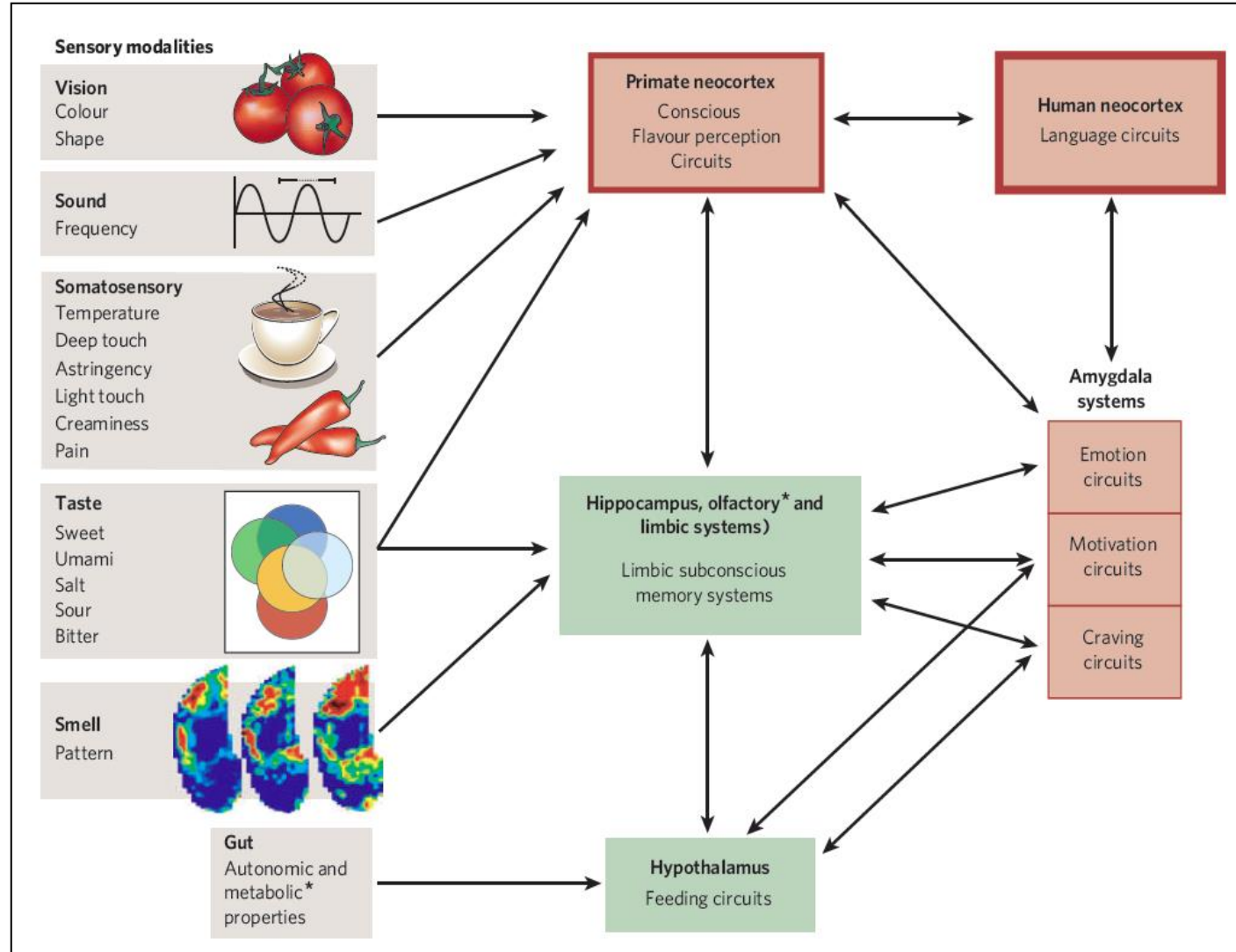
Institute

50

New Yo

www

Neurogastronomy

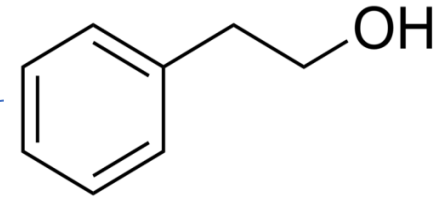


[Shepherd, 2006]

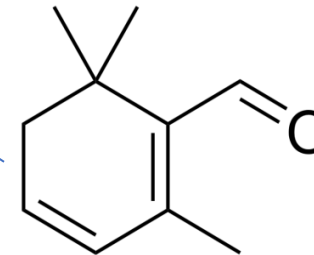
Food Chemistry

Saffron (*Crocus sativus* L.)

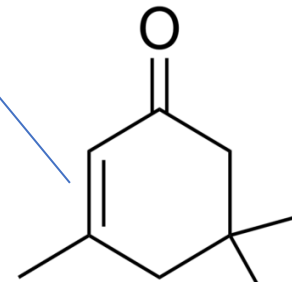
2-phenylethanol (=phenethyl alcohol)
safranal (=2,6,6-trimethyl-1,3-cyclohexadienecarbaldehyde)
3,5,5-trimethyl-2-cyclohexen-1-one (=isophorone)
hexadecanoic acid (=palmitic acid)
2,6,6-trimethyl-2-cyclohexene-1,4-dione
(*Z,Z*)-9,12-octadecadienoic acid (=linoleic acid)
(*Z,Z,Z*)-9,12,15-octadecatrienoic acid (=linolenic acid)
naphthalene
2,4,6-trimethylbenzaldehyde (=mesitylaldehyde)
2,6,6-trimethyl-1,4-cyclohexadienecarbaldehyde
6,6-dimethyl-2-methylene-3-cyclohexenecarbaldehyde
4-hydroxy-2,6,6-trimethyl-1-cyclohexenecarbaldehyde (=4-hydroxysafranal)
3,5,5-trimethyl-3-cyclohexen-1-one
3,3,4,5-tetramethylcyclohexanone
3,5,5-trimethyl-4-methylene-2-cyclohexen-1-one
4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one
2,3-epoxy-4-(hydroxymethylene)-3,5,5-trimethylcyclohexanone
5,5-dimethyl-2-cyclohexene-1,4-dione
2,2,6-trimethylcyclohexane-1,4-dione (=3,5,5-trimethyl-cyclohexane-1,4-dione)
2-hydroxy-3,5,5-trimethyl-2-cyclohexene-1,4-dione
2-hydroxy-4,4,6-trimethyl-2,5-cyclohexadien-1-one
2,6,6-trimethyl-3-oxo-1,4-cyclohexadienecarbaldehyde
4-hydroxy-2,6,6-trimethyl-3-oxo-1,4-cyclohexadienecarbaldehyde
4-hydroxy-2,6,6-trimethyl-3-oxo-1-cyclohexenecarbaldehyde
3-hydroxy-2,6,6-trimethyl-4-oxo-2-cyclohexenecarbaldehyde
4-(2,2,6-trimethyl-1-cyclohexyl)-3-buten-2-one
4-(2,6,6-trimethyl-1-cyclohexen-1-yl)-3-buten-2-one (=β-ionone)
verbenone (=2-pinen-4-one)
octadecanoic acid (=stearic acid)
(*Z*)-9-octadecenoic acid (=oleic acid)
2(5H)-furanone (=crotonolactone, 2-buten-4-olide, 4-hydroxy-2-butenic acid lactone)



phenethyl alcohol

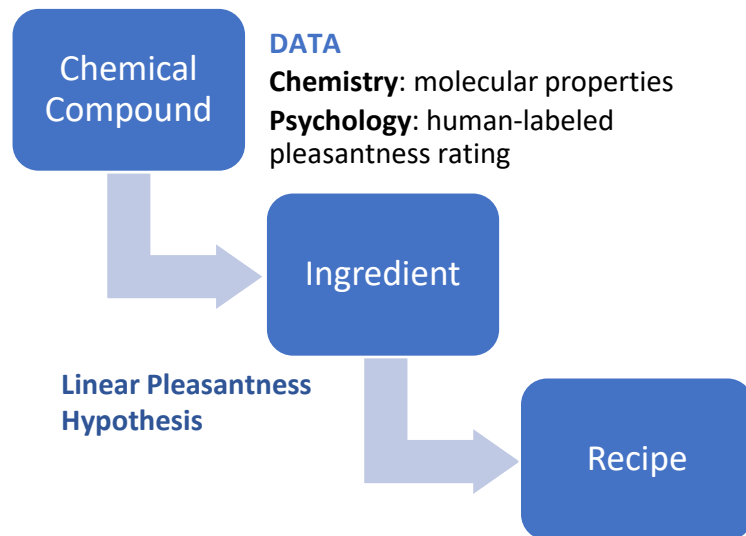
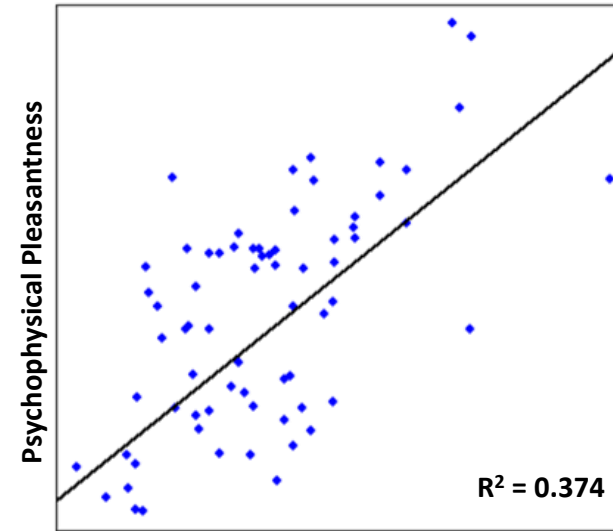
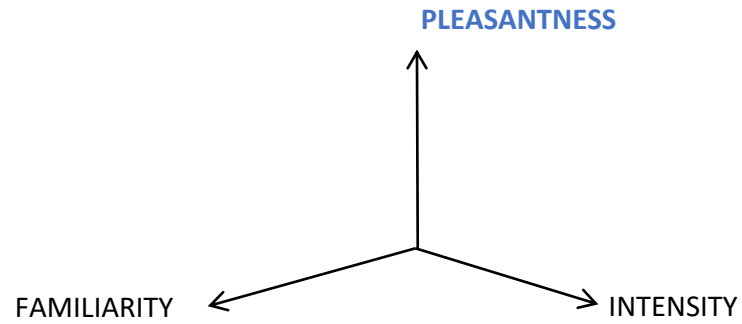


safranal



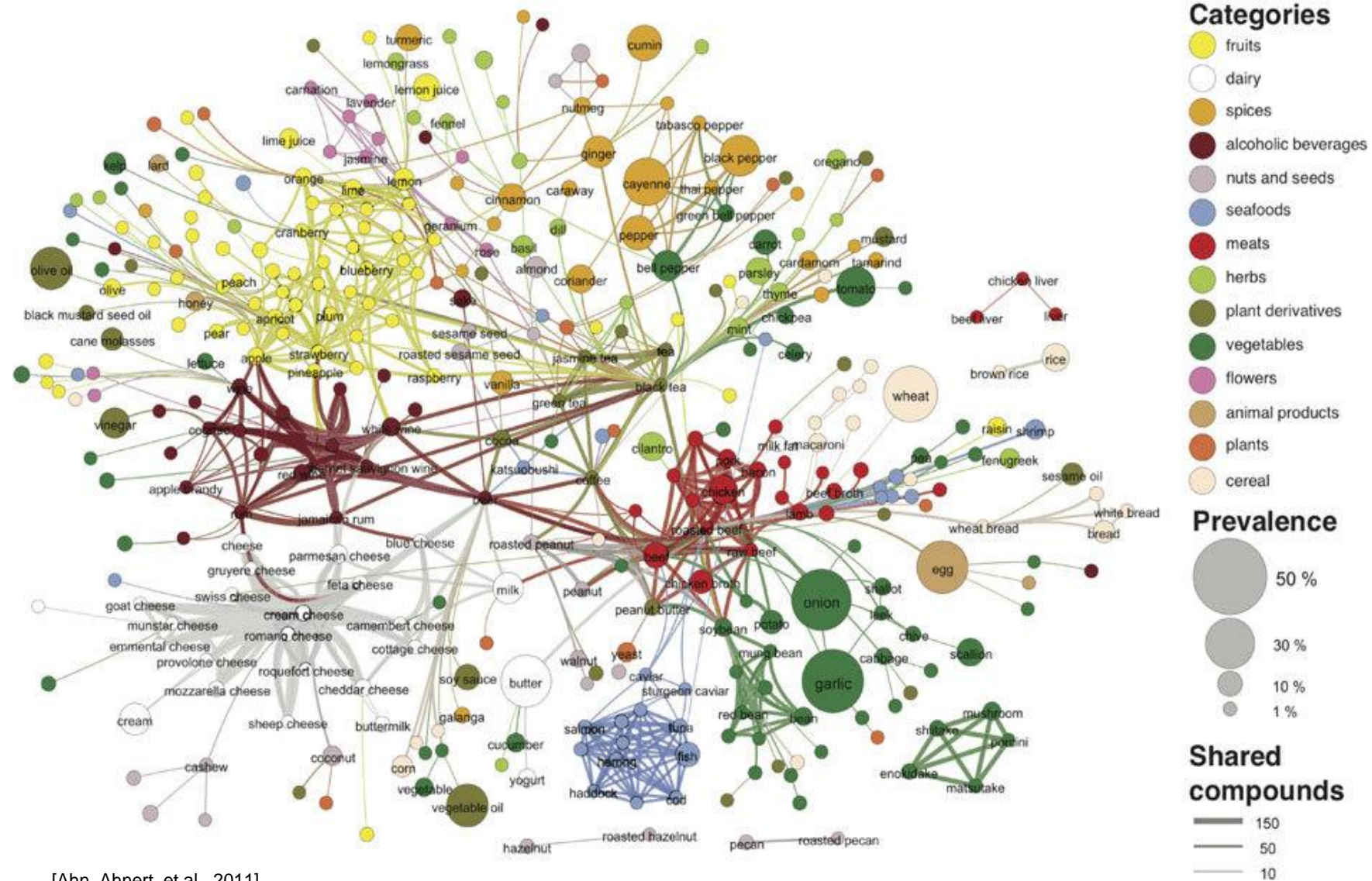
isophorone

Hedonic Psychophysics



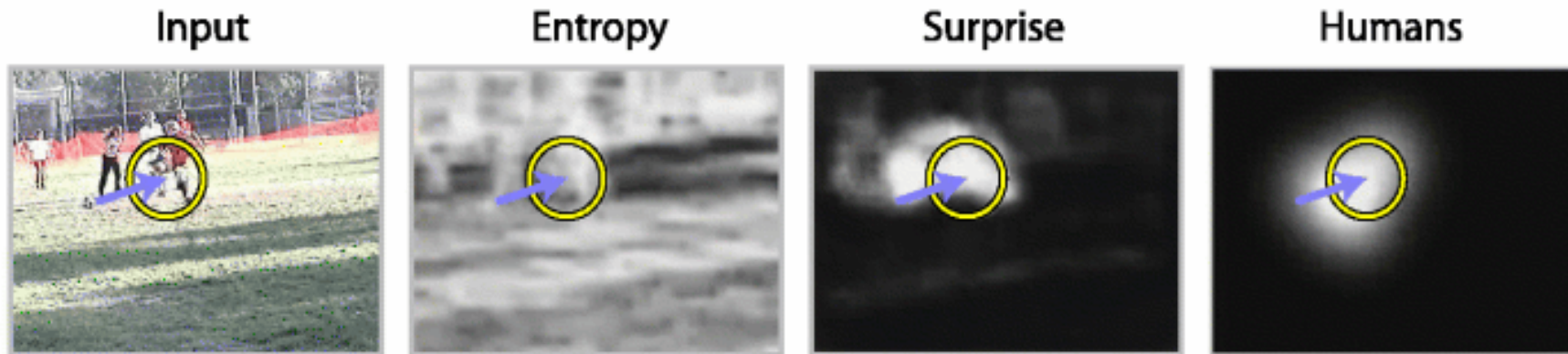
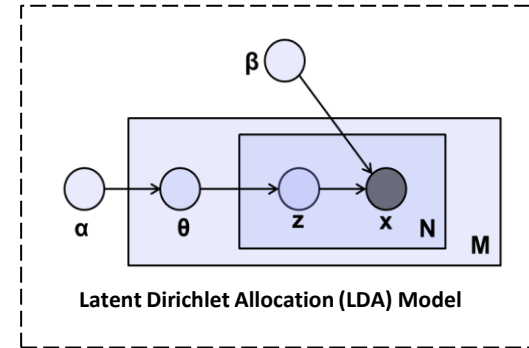
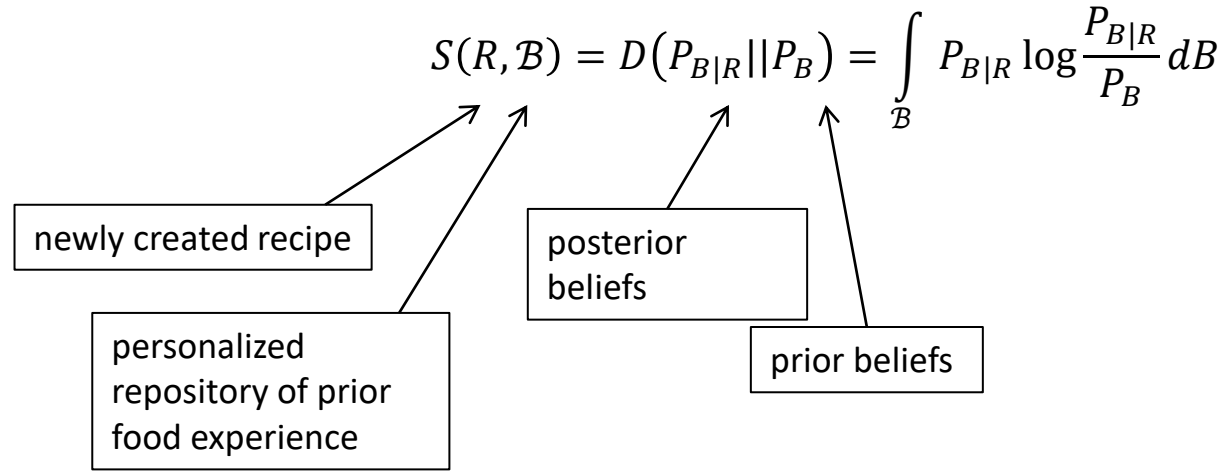
- Black Tea
- Bantu Beer
- Beer
- Strawberry
- White Wine
- Cooked Apple

Flavor Networks

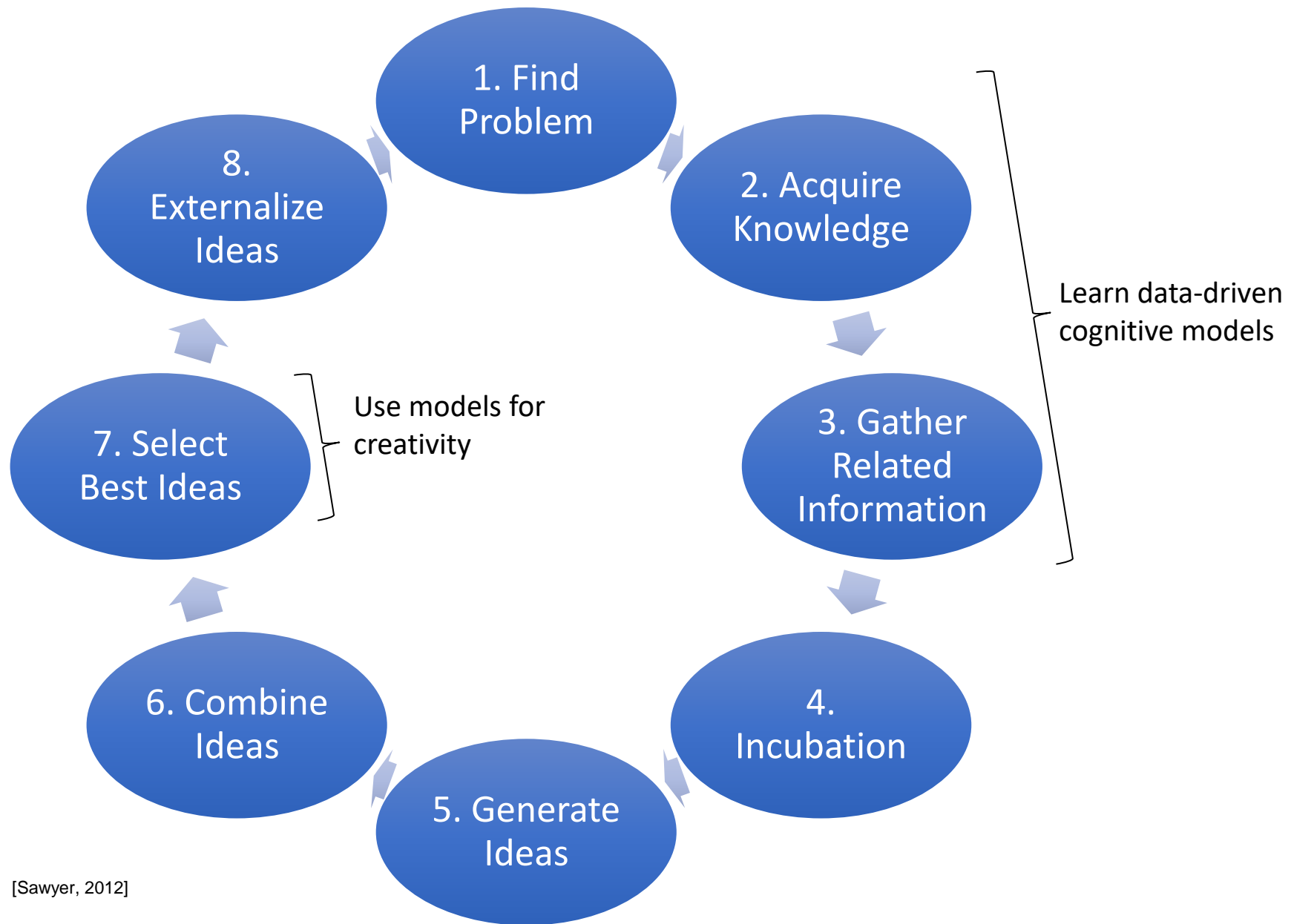


[Ahn, Ahnert, et al., 2011]

Bayesian Surprise and Attention



[Itti and Baldi, 2006]



[Sawyer, 2012]

