Tech News

The new molecular gastronomy, or, a gustatory tour of network analysis

The papaya platter was a mistake.

On a hot afternoon in June, my family sat down to sample three dishes. Raspberry and kalamata olive tapenade with lemon zest and balsamic vinegar on crostini with prosciutto; chunks of papaya sprinkled with freshly grated Parmesan cheese and seared with a torch; and Oregon bleu cheese chocolate cake topped with a bleu cheese and cream cheese frosting.

The tapenade was generally agreed to be delicious, the sweet balsamic vinegar complementing the zing of the fruit. But it was a tad too tart for my taste; I found the mixture of raspberry and citrus overpowering. The cake was phenomenal, with the bleu cheese in the frosting complementing the dark chocolate in the warmed cake to produce a delicious, if fleeting, bouquet. It was gone in no time.

And then there was the parmesan papaya. That one was a dud, a goose egg. To me, the combination tasted vaguely of tuna, as in a Niçoise salad. We ate it, but we didn't enjoy it. Mostly, we were trying to figure out exactly what was wrong with it.

Still, two-out-of-three ain't bad, especially considering these recipes weren't pulled off the internet or the Food Network—they came from a systems biology network analysis study published in the journal *Scientific Reports*. A team of researchers—led by Albert-László Barabási, an expert on network analysis at Northeastern University and the Center for Cancer Systems Biology at the Dana-Farber Cancer Institute who, among other things, builds protein-protein interaction networks with geneticist Marc Vidal—applied the computational tools of systems biology to analyze 56,498 recipes pulled from three online databases in an effort to test a hypothesis advanced by chef Heston Blumenthal, among others, “that ingredients sharing flavor compounds are more likely to taste well together than ingredients that do not” (1).

For the study, the team first cross-referenced each recipe's ingredients against *Fenaroli's Handbook of Flavor Ingredients* to create a so-called bipartite network comprising nodes of both ingredients (such as shrimp, olive oil, or parsley) and the chemical compounds that give those ingredients flavor. From that, they constructed a

Science-inspired appetizer: Seared papaya and parmesan cheese. Photo: Robert Perkel

“flavor network” projection in which ingredients, which are represented by nodes (dots), are connected by edges (lines) if the two ingredients have at least one flavor compound in common. 1-penten-3-ol, for instance, is shared by shrimp and parmesan cheese, while alpha-terpineol is found in parsley and tomato. The thickness of the lines indicates the number of compounds the two ingredients share, while the size of the nodes indicates how common the ingredient is in the analyzed recipes.

The result is the sort of map found in interactome and genetic network studies, a multicolored star chart of sorts, except the stars in this case bear labels such as roasted hazelnut, macaroni, and tabasco pepper. Naturally, related foods tend to bunch up in this representation, with constellations for fish and fruits, spices and cheeses. Mushrooms cluster together, but are separate from the main network, as they share no flavor compounds with other ingredients.

Interestingly, when Barabási's team cross-referenced their network against the recipe database they found that North American and Western European recipes do in fact tend to pair ingredients with shared flavor compounds. But East Asian, specifically Korean, recipes do not.

“To our surprise, we found that there seemed to be quite a large regional variation,” says Sebastian Ahnert, Royal Society University Research Fellow at the Cavendish Laboratory, one of the coauthors on the study.

Science versus art

Six months after Barabási's article first appeared in print, it was my wife who kindly created our dinner dishes that afternoon based on his computational analysis. It's not often that one can so readily test the predictions of a network analysis in this way. So, it was with a mixture of pleasure and bemusement that we prepared and tasted our pairings.

Each dish had to include a specific food pairing from the analysis, two ingredients with flavor ingredients in common, in our case, raspberry and olive; papaya and parmesan; or chocolate and bleu cheese—curious, and mostly enjoyable combinations arrived at, in some measure, through scientific analysis. (We opted out of a fourth pairing, strawberries and beer, because it seemed, well, obvious.)

Of course, the Barabási study has obvious limitations. Its recipe index is

necessarily incomplete, as is the data source on flavor compound ingredients. It makes no predictions, such as of pairings that, some groups might find repugnant. Most significantly, the team's analysis ignores variables such as how much of any chemical is present in the ingredient and in the dish (that is, is it detectable to the palate), what form of the ingredient is used in any given recipe, and how the food is prepared.

But those criticisms are beside the point. Analyses like these are essays in the craft of computational analysis. Online recipes represent massive, easily accessible, and unstructured data sources. Wouldn't it be fun to download them, parse them, and see what shakes out? Indeed, at least two other research teams have published network analyses of online recipes: Lada Adamic at the University of Michigan and Ronaldo Menezes at the Florida Institute of Technology, who combed these resources looking for patterns of recipe substitutions (such as apple sauce for olive oil) and cultural influences, respectively.

"To be extremely honest with you, we did it initially just for fun," says Menezes.

Yet these studies are intriguing, if for no other reason than they demonstrate the application of systems biology (and social networking) approaches to very non-biological datasets.

"I think it's an interesting exercise," says Marcia Pelchat, a neuroscientist and Associate Member of the Monell Chemical Senses Center in Philadelphia, of the Barabási paper. "It shows how far we've come in our ability to analyze the flavor components of food."

Robert Wolke, a professor emeritus of chemistry at the University of Pittsburgh, is the author of several books on the science of food, including *What Einstein Kept Under His Hat: Secrets of Science in the Kitchen*. A former nuclear chemist, Wolke spent 10 years writing a food-science column for the *Washington Post* in which he answered readers' questions and debunked many food myths that permeate American kitchens. Over the years, Wolke has tackled such questions as why some hams can be stored at room temperature (Answer: Because they're cured), and why a woman's Dutch oven exploded (Answer: alcohol vapor, meet heating element).

While Wolke wasn't intimately familiar with network analysis in general, or Barabási's work in particular, he sees promise in such approaches. "It sounds like a very interesting start on organizing food and flavors, which is an incredibly complex, wide-ranging field." He allowed

The flavor network that inspired our meal. Ingredients are listed in dots (nodes) and are connected by lines (edges) if they have one or more flavor compounds in common. Source: Y.Y. Ahn et al., *Scientific Reports*, 1:196, 2011

that: "When it matures—and I don't think anybody would claim it's mature now—it can be very useful."

In many ways, understanding the chemistry (and physics and biology) behind cuisine is at the heart of a scientific discipline known as "molecular gastronomy." Coined by French chemist Hervé This and English physicist Nicholas Kurti, molecular gastronomy looks at the mechanisms underlying certain kitchen phenomena.

This has applied approaches including fluorescence spectroscopy, NMR, and GC-MS, to questions such as why carrot stock turns brown (it can't be the carotenoids, they are not soluble in water) and why a chemical found in tarragon is toxic on its own, but not in tarragon leaves themselves. He works with chef Pierre Gagnier to put some of his observations to the test.

But when it comes to the Barabási study, This was unimpressed. On the technical side he questioned the team's methods, asking, for instance, just what exactly constitutes a "Western European" or "North American" diet. "People in Germany don't eat [the same] as people in England. And people in England don't eat as people in Provence."

More importantly, he says, trying to apply mathematical formulas to cuisine is pointless, as cuisine is more art than science. "A good artist can make any mix, it will always be good," he says, just as a world-class musician can do more with seemingly dissonant notes than the average atonal neophyte. On the Food Network program, *Chopped*, for instance, chefs must pair bizarre, seemingly impossible ingredients, and make them work. (One recent episode required contestants to fashion appetizers from pancake mix,

strawberry papaya, blue foot mushrooms... and precooked chicken feet.)

"It's not a question of technique, it's a question of art," says This. "And [for] the question of art, there are no rules, by definition."

Pelchat basically agrees. Many food ingredients, she says, are like cloth fabrics laced with different colored pinstripes: They can be paired with a wide range of things.

But that's only part of the story, she says. Food isn't just about chemicals; there's also visual appearance, aroma, and texture. "People in our culture like contrast as well," she notes. Like the classic BLT, with the warm bacon and cold tomato, the soft bread and the crunchy lettuce.

Genomics in the kitchen

Of course, there's also the possibility that the West-vs-East pairing differences Barabási and colleagues uncovered really do have an actual biological basis, some genetic quirk that influences how different subpopulations perceive food combinations? In other words, could the differences be traced back to variations in odor or taste receptors?

It certainly wouldn't be unprecedented. The ability to detect that characteristic sulfur-like odor in urine following ingestion of asparagus? There's a SNP for that (2).

Donald Katz, associate professor of psychology and neuroscience at Brandeis University, studies neural networks underlying taste, and authored a 2006 review on the gustatory processing (3). One figure in that review details the presumptive

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Hervé This, who coined the term “molecular gastronomy,” says cuisine is more art than science. Courtesy Hervé This

circuitry underlying how humans taste and see. The visual system is displayed as a highly interconnected, dizzying circuit diagram. The taste system appears a bit sparser by comparison (taste, he says, is “the red-headed stepchild of the sensory systems”). But neither representation even comes close to the complexity of the actual neural circuitry involved, says Katz.

Fundamentally, humans taste because chemicals in food interact with receptors on sensory neurons in the tongue, producing electrical signals that transduce the chemicals into brain activity. “But that’s a little bit like saying, how does a TV work? Well, you plug it in,” notes Katz.

Recently Charles Zuker of Columbia University and colleagues took a stab at the problem, using in vivo two-photon calcium imaging to produce what they call a “gustotopic map” of the mouse brain, in which sweet, bitter, umami, and salty tastes are wired to neurons in discrete “cortical folds” in the gustatory cortex (4).

Zuker’s findings, says Katz, are controversial. “No one else, using any other technique, has ever seen what looks like a gustatopic map in cortex,” he says. (Zuker could not be reached for comment.) Indeed, it is likely that taste is “hideously complex,” involving as it does more than just taste receptors, but also smell, touch, and vision.

But in any event, the Barabási results are “almost certainly” more cultural than biological, he says. Why? Well, rodents told him so—more or less.

Katz is looking for something of a 30,000-foot overview on taste in rats, observing their behavior and recording their neural activity in response to different foods. Rats, it seems, do not much care for cocoa. But, if they smell the flavor on another animal’s breath, they will readily eat it.

In one experiment, his team forced one rat—Katz calls him “Ralphie”—to eat cocoa-laced chow. They then allowed that rat to interact with another animal—“Don”—and watched what happened. “Even if he’s never had it before—and mind you, it’s a bitter, bitter taste—when [Don] gets his first chance to taste [cocoa], he won’t reject it. He’ll actually like it,” says Katz. If Katz records Don’s brain activity before and after this experience, he can detect changes from one associated with an unpleasant taste, to one linked to something like sugar.

And that, says Katz, suggests that taste preference is essentially a cultural phenomenon, rather than a biological one. After all, people tend to eat what others around them eat, as well. “When you’re sitting in a high chair and your parents are enjoying a certain kind of food, that actually has a strong impact on you,” he notes. Conversely, when humans see someone getting sick on a certain food—or if they themselves get ill—that forms a psychological association that is likewise hard to break.

“It is so easy, from a social and cultural perspective, to cause differences in taste profiles, that it strikes me as a little lame to go running to the genome and saying, there’s got to be a genetic difference that explains it,” says Katz. “You don’t need to go to the genome. It’s the easiest thing in the world to provide a half-hour experience and change what an animal likes and doesn’t like.”

That’s probably true. But I’m still not going to like that papaya.

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