Flavor network and the principles of food pairing

Yong-Yeol Ahn, Sebastian E. Ahnert, James P. Bagrow and Albert-Laszlo Barabasi

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- Question: Are there any quantifiable and reproducible principles behind our choice of certain ingredient combinations and avoidance of others?
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- Factors affecting food sensation: flavor compounds of ingredients (taste, odor, freshness), color, texture, temperature, mode of preparation, sound, ...
- Network-based approach to explore the impact of flavor compounds on ingredient combinations
- Analyze 1021 flavor compounds of 381 ingredients from 57 K recipes across 5 cuisines (North \& Latin American, West \& South European, East Asian)
- Note: proportions of flavor compounds in ingredients ignored


## Bipartite graph: Ingredients vs flavor compounds

A


Flavor compounds
1-penten-3-0
2-isobutyl thiazole 2,3-diethylpyrazine 2,4-nonadienal 3-hexen-1-ol 4-hydroxy-5-methyl.. 4-methylpentanoic acid acetylpyrazine allyl 2-furoate alpha-terpineol beta-cyclodextrin cis-3-hexenal dihydroxyacetone dimethyl succinate ethyl propionate hexyl alcohol isoamyl alcohol isobutyl acetate isobutyl alcohol lauric acid limonene (d-, l-, and dl-) I-malic acid methyl butyrate methyl hexanoate methyl propyl trisulfide nonanoic acid phenethyl alcohol propenyl propyl disulfide propionaldehyde propyl disulfide p-mentha-1,3-diene p-menth-1-ene-9-al terpinyl acetate tetrahydrofurfuryl alcohol trans, trans-2,4-hexadienal

## Flavor network


weight $=$ number of shared components

Number of ingredients per recipe


Frequency of ingredients in recipes


## Backbone of flavor network

- several flavor compounds are shared by a large number of ingredients
- Flavor network is too dense for direct visualization (average degree $\approx 214$ )
- Backbone extraction method: statistically significant links for each ingredient


## Backbone of flavor network


$\equiv$

## Shared compounds

A Many shared compounds


B Few shared compounds


## Food pairing hypothesis

- Ingredients sharing flavor compounds are more likely to taste well together than ingredients that do not

$$
\begin{gathered}
N_{s}(R)=\frac{2}{n_{R}\left(n_{R}-1\right)} \sum_{i, j \in R, i \neq j}\left|C_{i} \cap C_{j}\right| \\
\Delta N_{s}=N_{s}^{\mathrm{real}}-N_{s}^{\mathrm{rand}}
\end{gathered}
$$

- Note: Random model (null model) different for cuisines (to control for the frequency of a particular ingredient in a cuisine)


## Food pairing hypothesis



## Distribution of $N_{s}$ for random recipes



## Measuring ingredient contributions to shared compounds

- $\chi_{i}$ measures how much does an ingredient affect $\Delta N_{s}$.
- Are there frequently used ingredients that affect food pairing?


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## Flavor principle

- Flavor principle: the differences between regional cuisines can be reduced to a few key ingredients with specific flavors
- e.g. soy sauce leads to oriental taste
- Measuring authenticity:

$$
\begin{gathered}
P_{i}^{c}=n_{i}^{c} / N_{c} \\
p_{i}^{c}=P_{i}^{c}-\left\langle P_{i}^{c^{\prime}}\right\rangle_{c^{\prime} \neq c}
\end{gathered}
$$

- Create flavor pyramids with 6 most authentic ingredients, ingredient pairs and ingredient triplets

A North American


Note: co-occurring compounds share more compounds


Note: co-occurring compounds share less compounds

## Measuring similarity between cuisines

## C Co-occurrence in recipes



Select the six most authentic ingredients in each regional cuisine

Thank you!


WEVE DECIDED TO DROP THE CS DEPARTMENT FROM OUR WEEKLY DINNER PARTY HOSTNG ROTATON.

Image source: http://xkcd.com/720/

